National Park Service
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Natural Resource Stewardship and Science

Appalachian National Scenic Trail Forest Health Monitoring Protocol

Natural Resource Report NPS/NETN/NRR—2018/1804

ON THE COVER
A hiker walks along the Appalachian National Scenic Trail between Hughes Gap and Iron Mountain Gap in Tennessee.
Photograph by: Brenda Wiley

Appalachian National Scenic Trail Forest Health Monitoring Protocol

Natural Resource Report NPS/NETN/NRR—2018/1804

Fred Dieffenbach

National Park Service
Northeast Temperate Network
54 Elm Street
Woodstock, VT 05091

November 2018

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

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Please cite this publication as:

Dieffenbach, F. 2018. Appalachian National Scenic Trail forest health monitoring protocol. Natural Resource Report NPS/NETN/NRR—2018/1804. National Park Service, Fort Collins, Colorado.

NPS 962/149418, November 2018

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Revision History

Version numbers will be incremented by a whole number (e.g., Version 1.3 to 2.0) 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
1.00	October 2018	Fred Dieffenbach	First draft	–
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Executive Summary

Knowing the condition of natural resources is fundamental to the National Park Service's mission to manage park resources "unimpaired for the enjoyment of future generations." Park managers are confronted with increasingly complex and challenging issues that require a broad-based understanding of the status and trends of park resources. Specifically, forest health was selected for monitoring because forests are the dominant ecological communities associated with the Appalachian National Scenic Trail (APPA).

The large, but narrow configuration of APPA makes a ground-based plot monitoring program logistically and financially infeasible for the National Park Service to implement. In light of that challenge, the Northeast Temperate Network (NETN) developed a data acquisition protocol to track the overall condition of forest resources along the Appalachian Trail using plot-based data collected by the US Forest Service's Forest Inventory and Analysis Program (FIA). The primary objectives of this protocol are to monitor the status and trends in forest composition and structure based on available FIA data. Data acquired from FIA are summarized within an area surrounding the APPA corridor (HUC10 Shell) and further into distinct ecoregional subsection intersecting the APPA.

This protocol, along with the associated standard operating procedures (SOPs), provides the framework and guidance for monitoring and assessing forest resource condition at APPA over time. Data collected as a part of this protocol are stored locally in databases and uploaded to national databases maintained by NPS on an annual basis. Reporting on these data occurs at regular intervals defined in part by the revisit of FIA plots within the HUC10 Shell and has multiple applications for management decision-making, park planning, research, education, and promoting public understanding of park resources.

List of Acronyms

APPA: Appalachian National Scenic Trail

ATC: Appalachian Trail Conservancy

DQS: Data Quality Standards

FIA: Forest Inventory Analysis Program

HUC10: 10-digit Hydrologic Unit Code

I&M: Inventory and Monitoring Program

NASA: National Aeronautics and Space Administration

NETN: Northeast Temperate Network

NPS: National Park Service

QAP: Quality Assurance Plan

SOP: Standard Operating Procedures

USDA: U.S. Department of Agriculture

USGS: U.S. Geological Survey

Introduction

Background

In an effort to provide a broad understanding of baseline conditions as well as the status and trends of ecosystems within national parks, the Natural Resource Inventory and Monitoring Program (I&M) was established by congressional mandate in 1998 through the Natural Resource Challenge. This program was initiated, in part, to help National Park Service (NPS) managers gain a better understanding of the status and trends in natural resources they are charged with protecting and conserving now and into the future. The Northeast Temperate Network (NETN) serves 13 Park Service units in the northeast region.

The temperate deciduous forests that dominate the Appalachian National Scenic Trail (APPA) region are characterized by broadleaf trees, including oak, hickory, maple, beech, and birch, often mixed with conifers such as hemlock, spruce, fir, and pine on drier or higher elevation sites. Other terrestrial habitats include alpine vegetation, rocky outcrop woodlands, and old-field successional habitats and plantations. A variety of wetland, riparian, and aquatic habitats are present within these forests, including forested and shrub swamps, marshes, wet meadows, fens and bogs, lakes, rivers, ponds, and vernal pools.

Worldwide, temperate deciduous forests have been highly altered and possess the highest index of human disturbance of any major biome (Hannah et al. 1995) and high indices of fragmentation (Ritters et al. 2000). The eastern United States is no exception, where temperate deciduous forests have been heavily used for timber, cleared for agriculture, or converted into towns and cities. The region through which APPA passes is predominantly forested, but also includes many open fields and exposed rocky areas. Key stressors of these forest resources include land use change and habitat fragmentation on lands adjacent to the APPA corridor, nonnative species, visitor usage, wet and dry atmospheric deposition (Sulphur, Nitrogen, and other pollutants), and climate change. The scoping process that advocated for long term monitoring of forest resources along APPA and a description of the stressors affecting these forest resources, is described in the APPA Vital Signs Monitoring Plan (Dieffenbach 2011).

This protocol was adapted from the APPA plot-based forest monitoring protocol (Tierney et al. 2013), which was developed to support the Forest Health component of a National Aeronautics and Space Administration (NASA) decision support system (DSS) enhancement project1. Due to logistical difficulties and lack of funding for NPS to implement a plot-based monitoring program along a 2,100 mile long resource, publically available plot-based data that are collected and maintained by the U.S. Forest Service (USFS) Forest Inventory and Analysis Program (FIA) were chosen as a better option to assess forest resource condition over time along APPA.

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[1] The Appalachian Trail (A.T.) Decision Support System (DSS) is an Internet-based data analysis and dissemination utility that, when finished, will improve decision support by giving users access to remote sensing and geospatial data. http://www.edc.uri.edu/ATMT-DSS/default.html

Justification for monitoring forest resources along APPA

APPA is a public footpath that traverses more than 2,100 miles of the Appalachian Mountains and valleys between Mount Katahdin, Maine and Springer Mountain, Georgia. The APPA trail corridor links extensive forest landscapes and a large variety of aquatic and terrestrial habitats. The diverse array of habitats include subalpine forests, open balds, rocky outcrops, and lowland forests, each consisting of a diverse mix of hardwood and softwood species that provide critical habitat for abundant flora and fauna including many regional and globally rare species. NPS works in partnership with the Appalachian Trail Conservancy, U.S. Forest Service, states, local communities, and volunteer-based trail maintaining clubs to manage and preserve the trail which spans 14 states, 88 counties, 164 townships and municipalities, 8 national forests, 6 national park units, 2 national wildlife refuges, 24 wilderness areas, 8 national natural landmarks, 3 national historic landmarks, and dozens of state protected areas.

In October 2004, NETN and APPA staff convened a meeting of park staff and managers, government scientists, and other stakeholders to identify key "Vital Signs" or indicators of ecological condition for APPA, with forest health being among the 12 vital signs identified for monitoring within APPA.

The 2004 meeting, which resulted in the report entitled: Appalachian Trail Vital Signs (Shriver et al 2005), laid the foundation for the 2006 workshop (Welcome to the A.T. MEGA-Transect, Dufour and Crisfield 2008) and the APPA vital signs monitoring plan (Dieffenbach 2011).

During the 2004 meeting, a conceptual model of APPA terrestrial resources was developed. Key stressors of APPA forest resources identified in the model include land use change and habitat fragmentation on lands adjacent to the APPA corridor, nonnative species, visitor usage, ozone, wet and dry deposition, and climate change (Dieffenbach 2011).

Subsequent to the 2004 meeting, NETN, APPA, and the Appalachian Trail Conservancy (ATC) co-hosted a workshop in 2006 to explore the possibility of using the Appalachian Trail corridor as an ecological monitoring bellwether. The workshop led to the launch of the A.T. MEGA-Transect program that aimed to promote the Appalachian Trail corridor to professional researchers and citizen scientists for ecological research and monitoring. In response to the launch of the A.T. MEGA-Transect project a number of projects were proposed, one of which was a Deposition Effects study by USGS (Lawrence et al. 2015).

NPS and partners greatly value the character and function of APPA's forests. In addition to NETN, Shenandoah National Park, Great Smoky Mountain National Park and other NPS units and programs conduct forest monitoring along or near the APPA. Data from this protocol will be used to supplement and complement data from these programs and should be especially valuable to our patterns and other NPS programs in areas where plot-based sampling is logistically challenging and unaffordable. Additionally, products from this protocol will be derived from a standardized regional data source, meaning that summaries of forest conditions can be evaluated and compared along APPA at multiple spatial scales. This will enable partners to address local to regional issues affecting forest health and should assist in making future decisions to protect APPA's valuable forested resources.

Objectives

Monitoring programs must balance the need to monitor current natural resource issues against the need to detect future, perhaps unforeseen, threats to park ecosystems, as outlined by Fancy et al. (2009). During development of the long-term forest monitoring program on APPA, NETN evaluated a plot-based protocol (Tierney et al 2013), but after a short test period, NETN and APPA declined to implement this approach due to the extreme cost and complexity associated with coordinating field data collection.

An alternative to NPS implementing plot-based sampling to monitor APPA's forest resources is to rely on data collected by other programs. The USFS FIA program has established an extensive network of plots across the USA in order to "report on status and trends in forest area and location; in the species, size, and health of trees; in total tree growth, mortality, and removals by harvest; in wood production and utilization rates by various products; and in forest land ownership". FIA protocols have undergone extensive development by the USFS, with academic and other government agency partners, similar to other NPS Inventory and Monitoring protocols (USFS 2005, FIA Field Guides, Methods and Procedures page), and have been used to develop a substantial and ongoing database that tracks regional trends in forest resources and health across the country (FIA Data and Tools page). The data are routinely summarized to identify regional trends in forest resources and health at multiple spatial scales and analyzed by researchers nation-wide to address scientific questions relevant to forest ecology, forest health, and carbon sequestration.

The objectives of this protocol are to monitor the status and trends in the composition and structure of forest species along the APPA corridor using methodologies and data collected by the USFS FIA program. FIA data will be used to address the specific monitoring objectives listed in Table 1 and summarized to generate an ecological integrity rating.

Table 1. Appalachian National Scenic Trail Forest Monitoring Protocol objectives*. All objectives will evaluate variation in metrics across plots and ecoregional subsections of the Appalachian NST within the HUC10 Shell.

Category	Metric	Monitoring Objectives
Stand structure	Stand structural class	Estimate forest structure (e.g., pole, mature, late successional)
	Snag abundance	Estimate snags/ha and proportion of snags to live trees
	Live basal area	Estimate live basal area
	Coarse woody debris (CWD)	Estimate coarse woody debris volume to live tree volume.
Composition and health	Tree mortality and growth rates	Estimate mortality and growth rates of 10 most abundant canopy tree species.
	Tree composition	Estimate composition of 10 most abundance canopy species
	Tree condition	Estimate for the top 10 most common species in each subsection the percentage of individuals with reported foliage damage >50%

*All metrics presented in Table 1 relate to conditions present along APPA within 20 ecoregional subsections contained within the HUC10 Shell. These conditions are compared across ecoregional subsections, thereby making it possible to assess condition of resources along APPA.

Table 1 (continued). Appalachian National Scenic Trail Forest Monitoring Protocol objectives*. All objectives will evaluate variation in metrics across plots and ecoregional subsections of the Appalachian NST within the HUC10 Shell.

Category	Metric	Monitoring Objectives
Composition and health (continued)	Tree regeneration	Estimate seedling abundance and associated regeneration indices for all species
	Invasive species	Identify the presence of high priority invasive plant species

*All metrics presented in Table 1 relate to conditions present along APPA within 20 ecoregional subsections contained within the HUC10 Shell. These conditions are compared across ecoregional subsections, thereby making it possible to assess condition of resources along APPA.

The list of metrics is based on the list identified in NETN's forest vegetation monitoring protocol (Tierney 2013), and on the availability of data needed to calculate the metrics. 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). Data will be analyzed to evaluate patterns in forest health among plots and across ecoregional subsection, and eventually to assess the importance of land use patterns, climate change, deposition of atmospheric pollutants, and land development on forest structure and dynamics.

Sampling Design

Approach and Rationale

This protocol is specifically designed to acquire and summarize plot-based data from the FIA program that is representative of APPA resources. The FIA program uses permanent plots located throughout the conterminous United States to track status and trends in forest area, timber volume, and forest health and has made important contributions to our understanding of eastern forests (Woodall et al. 2011). Plots are located on properties managed by federal and state governments and private landowners and are sampled following a rotating panel design (4- or 5-year cycle, with one panel of plots sampled each year). Information is available from the USFS on the following:

- Sampling: https://www.fia.fs.fed.us/library/sampling/index.php (accessed June 2018) and https://www.fs.usda.gov/treesearch/pubs/20376 (accessed June 2018)
- Field methods: https://www.fia.fs.fed.us/library/field-guides-methods-proc/index.php (accessed June 2018)
- Available data: https://apps.fs.usda.gov/fia/datamart/datamart_access.html (accessed June 2018).

To complete analyses, all publicly available swapped and fuzzed FIA Phase 1 and Phase 2 data from within the HUC10 Shell will be obtained. USFS describes Phase 1 to include *"…the traditional aerial photography and/or remote sensing activity used to characterize the acreage of forest and non-forest land in the US…"* Phase 2 *"…are the traditional FIA ground plots that focus on forest and tree information as it relates to timber but not exclusively…"* Data relevant to APPA will be obtained once available and refreshed following FIA's revisit schedule.

Ecologically Relevant Areas of Analysis

Forest vegetation data relevant to APPA will be accessed at the broadest scale within the HUC10 Shell (described below) and then summarized at the ecoregional scale. This area of acquisition (HUC10 Shell) will permit summarization of forest health data at scales relevant to management and also permit comparisons of trends and status in forest resources among ecoregions.

HUC 10 Shell

The HUC10 Shell (Figure 1 and Appendix A) was created to define an area of interest that is in close proximity to APPA and represents the resources found along APPA. The shell is a buffer surrounding the APPA land area that is based on hydrologic units defined by the USGS at the watershed level (USGS 2017).

Watersheds are defined at the fifth level of the Hydrologic Unit Code system, with each being given a discrete 10-digit code (HUC10). Though they are termed watersheds, Omernik (2003) explains that hydrologic units are not always true watersheds and that some hydrologic elements contained within a HUC10 unit may not include all upstream components of a true watershed.

Figure 1. Appalachian National Scenic Trail HUC10 Shell.

We selected the HUC10 scale because it incorporates all areas of immediate interest to APPA resource managers as well as areas that are more distant but ecologically similar. Coarser (i.e., regional scale) levels of categorization incorporate areas that are far beyond the spatial "zone" of interest, while finer (i.e., parcel- or stand-scale) levels of categorization omit areas that are of interest to APPA resource managers. Ultimately, the HUC10 Shell provides a standardized area for data analysis and reporting that is ecologically relevant and meaningful to resource management.

Ecoregional Subsections

While the HUC10 Shell defines a singular area of interest around the APPA (Figures 1), stratifying data using ecologically similar areas makes it possible to summarize data at a scale that may be more useful to APPA resource managers and APPA partners (Figure 2). One way of doing this is to associate data within ecoregions or subsections using the system developed by Bailey (1980) and Bailey et al. (1994) (Figure 2). Other ecoregional classification systems exist, but the Bailey system is widely used and is already integrated into the FIA database (every record in the FIA dataset is assigned to a Bailey ecoregion).

Figure 2. Ecoregional subsections that intersect the Appalachian National Scenic Trail (APPA) land area (blue), and subsections that do not intersect the APPA land area (red).

The ecoregion system developed by Bailey (1980) is hierarchical, and the level of the hierarchy used for data analysis in this protocol will be the subsection scale. Subsections are areas defined by similar environmental characteristics, such as climate and vegetation, and thus are discrete, ecologically relevant areas for summarizing FIA data. Within the HUC10 Shell, 20 ecoregional subsections intersect the land managed as part of the APPA and we have limited our analysis to these 20 ecoregional subsections.

Data Management

Data management is coordinated and overseen by the NETN AT Environmental Coordinator. Protocol methods are thoroughly documented in a series of Standard Operating Procedures (SOPs). The SOPs capture a workflow that consists of three general steps: (1) source data acquisition and pre-processing; (2) calculation of summary statistics; and, (3) reporting results. In general, FIA data will be summarized to calculate the metrics listed in Table 1 and the associated ecological integrity index (SOP 3).

Data Acquisition

Acquiring FIA data is the foundation of this protocol and objectives set by the APPA Environmental Monitoring Program. While these data are publicly available, they are also spatially swapped and fuzzed. Swapping, as defined by the FIA program (O'Connell et. al. 2016) below.

> *…consists of exchanging the plot coordinates for a small number of similar plots within the same county. Swapping only occurs on private forested plots and depends on the region of the country. Between 0 and 10 percent of the forested plots are randomly selected for swapping with plots from the remaining data for a total swapping of between 0 and 25 percent. The primary criterion for swapping is based on a measure of ecological similarity. Plots with the smallest ecological difference are swapped. The variables for swapping (e.g., x and y coordinates, forest type group, and stand size) vary by region. This induces enough uncertainty as to the actual property owner to satisfy the legal requirements without introducing an unacceptable amount of error in the population estimates computed for analyses…"* Fuzzing, also defined by the FIA program, *"…consists of randomly relocating most plot latitude and longitude coordinates within one-half mile of their actual coordinates, with the remainder relocated up to 1 mile. This means that the actual plot location is generally masked within a 500-acre area…*

Despite this known uncertainty about the collection location of the FIA data used to represent APPA, data are believed to be sufficiently relevant for the intended purpose and work well with the intended archiving and reporting schedule. Swapped and fuzzed FIA data can be analyzed and reported upon without prior USFS approval, and there are no distribution restrictions. FIA data based on actual coordinates cannot be analyzed or reported upon without prior USFS approval, and there are distribution and long-term storage limitations that would make disseminating results to resource managers and other stakeholders difficult.

The FIA program refreshes their data on a state-by-state basis; however, not all states are refreshed at the same time. The FIA program publishes the Most recent FIA data by State and Collection Yea page. When new data are available for the entire 14-state region through which APPA passes, which is typically every few years but this may vary by state and in the future due to appropriated funding, they are downloaded from the USFS FIA Data Mart page into a Microsoft Access database (accdb format) (SOP 1).

Data Processing

Data from the 14-state download are subsequently associated with the HUC10 Shell, records from within the shell are identified, and a new APPA-specific dataset is created that contains only FIA plots found within the HUC10 Shell (see SOP 1). The Ecoregional Subsection with which the data are associated is already assigned by FIA, so no additional steps are needed to associate the acquired FIA data with each subsection prior to analysis. Analyses within the HUC10 Shell are restricted to the 20 subsections that intersect the APPA corridor. The number of plots within these 20 subsections ranges from 35 – 574 (4,076 total) (Table 2).

Table 2. Number of FIA plots per ecoregional subsection within HUC10 Shell surrounding Appalachian National Scenic Trail.

Subsection	Abbreviation	No. of Plots
Kittatinny-Shawangunk Ridges	221Bd	35
Sunapee Uplands	M211Bc	62
Connecticut Lakes	M211Af	64
Southern Piedmont	1Bb	82
Berkshire-Vermont Upland	M211Cc	113
Hudson Limestone Valley	221Ba	121
Taconic Mountains	M211Cb	121
Northern Piedmont	221De	131
Southern Green Mountain	M211Cd	155
Mahoosic Rangely Lakes	M211Ae	204
Northern Great Valley	M221Ad	218
Northern Ridge and Valley	M221Ac	219
Hudson Highlands	221Ae	226
Maine Central Mountains	M211Ac	255
White Mountains	M211Ad	266
Northern Blue Ridge Mountains	M221Da	271
Ridge and Valley	M221Aa	304
Great Valley of Virginia	M221Ab	325
Metasedimentary Mountains	M221Dd	330
Southern Blue Ridge Mountains	M221Dc	574

Data Storage

Data acquired from FIA for the 14-state APPA region are maintained in MS Access database format (accdb) and are processed with an Access User Interface to create a new APPA-specific dataset (SOP 1) that is also in MS Access format. An interim step in the process relies on a MySQL database that temporarily stores the combined contents of all 14 statewide FIA Access datasets. The new dataset uses the same schema developed by the FIA program and is stored on NETN computers. A copy of the new dataset developed under the procedures described in SOP 1, and the User Interface (UI) used to generate the APPA specific database, are posted annually to the NPS Data Store.

Quality Assurance and Quality Control (QA/QC)

The quality of the data acquired is covered entirely under the USFS FIA program's Quality Assurance Plan (QAP) which is set by the USFS Forest Survey Handbook (U.S. Forest Service 2008). NETN performs no QA/QC efforts on the acquired raw data beyond any that are completed by the USFS FIA program. All elements of the FIA's quality assurance plan include

> *…quality assurance operational techniques designed to assure and improve the quality of FIA data. These include: planning, method documentation, training for data collectors, checks of data quality, evaluation of uncertainty in survey data, peer review of analysis products, and continuous feedback to ensure that the data collection and processing system improves over time.*

A review of the FIA QAP PDF provides a discussion of the quality assurance procedures for the northeast region are summarized in Gormanson et al. (2017).

After the data are downloaded from FIA, a series of procedures are followed (see SOPs 2 and 3) to ensure data have been selected from the correct time period, ensure that data from all states have been downloaded correctly, determine whether new plots have been appended to the database since the last download, which may occur as a consequence of acquiring data from swapped and fuzzed plot locations, spatially associate data with the areas of analysis (HUC10 Shell), and add new fields to assist with data filtering to support specific analyses. Prior to analyses, data are evaluated for completeness and to determine whether there are enough data for analysis. Data are then filtered following the criteria for calculating each metric (e.g., by size class, species, etc). An overview of these procedures is described in the SOPs, and associated data standards are detailed in the accompanying Data Quality Standards document.

Analysis and Reporting

Forest plot data from within the HUC10 Shell are compiled and summarized at the scale of the ecoregional subsection to determine:

1) Stand structural class (proportion of plots classified as late successional, mature, and pole)
2) Snag abundance (snags/ha and as a proportion of live tree density)
3) Live basal area (m2/ha) of live trees
4) Coarse woody debris volume (m3/ha and as a proportion of live tree volume)
5) Tree mortality (percent of stems dead per year) calculated from repeat observations of canopy tree species
6) Tree growth (percent change in the diameter at breast height) calculated from repeat observations of canopy tree species
7) Composition (percent occupancy) of the 10 most abundant canopy tree species
8) Tree condition (percentage of individuals for each of the 10 most abundant species with > 50% of canopy damaged)
9) Tree regeneration (seedlings/ ha and ratio of tall (30-200cm) to short seedlings (<30 cm) following Sweetapple and Nugent (2004)) total and by species
10) Presence of noxious invasive weeds (Number of invasive species detected per plot by subsection)

The above metrics are then used to assess "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). 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.

In order to identify aspects of forest composition, structure, and function most relevant to the assessment of ecological integrity, NETN developed a conceptual ecological model for terrestrial systems for APPA (Dieffenbach 2011). This model highlights linkages between APPA terrestrial ecosystems, known stressors and agents of change, and key attributes and ecological processes of these systems, and defined a suite of metrics that will be used as the basis for assessing ecological integrity of APPA forests (SOP 3).

Data, models, and expert opinion from the scientific literature were used to establish assessment points for each metric, that distinguish expected or acceptable conditions from those 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 recognizing the inherent natural variation in ecosystems across space, time, and stages of ecological succession (Landres et al. 1999). The interpretation of ecological integrity is a useful, but developing conservation application and ratings will be reviewed and updated as new information becomes available.

Assessing and reporting the ecological integrity of park resources is a major goal of the APPA environmental monitoring program. Ultimately, a vital sign is useful only if it provides information that guides management decisions or quantifies the successes or limitations of past decisions. Ecological integrity must be assessed from data and presented in a format (e.g., resource briefs or visualization) that can be clearly understood by managers, scientists, policy makers, and the public.

Reporting Schedule

Reporting the condition of forest resources based on existing data is entirely dependent on the availability of new data from the USFS. In general, data summary will be completed at the ecoregional subsection scale when appropriate data are available to do so. An analysis across the entire APPA may occur once every decade or so. USFS posts data following QAQC, but not all states' data are posted at the same time. The current status of FIA data by state and collection year is available on the Most recent FIA data by State and Collection Yea page.

In general, analysis and reporting is automated. Data from FIA are processed by a database that performs calculations to address the protocol objectives (Table 1). Summary tables and figures are then compiled into either a web-based resource review or a technical document which summarize the FIA data under each protocol objective heading (e.g., snag abundance, mortality, etc). Once longer periods of data are collected within each subsection (limited data collection began in 2004), trend analyses will be conducted. Web-based resource reviews resulting from analysis of recent FIA data are written for a general audience and provide the reader with information (e.g., graphics and charts) that enables them to make their own interpretation of the summary data. We use this approach to generate individual resource reviews at a subsection scale. More in-depth reports, such as those reporting trends or other analyses (spatial and temporal), will provide a more detailed evaluation of patterns in forest health among ecoregional subsections and eventually will assess the importance of land use, climate change, deposition, and other stressors on forest structure and dynamics.

Reports will be prepared to document the current status and trend in the condition of APPA forest resources when enough plots have been resampled to justify updates to the analyses, and new reports and reporting systems will be introduced as newer technology is adopted.

Personnel and Operational Requirements

Annual Workload

Just one person is needed to download and process all data associated with the protocol. NETN personnel will compile and internally review the results prior to dissemination to ensure accuracy of the information (reference SOPs or DQS).

Operating Budget

- No funds are needed for the acquisition of new data. Funds equivalent to approximately 4-weeks (~0.2 FTE) of staff time are needed to cover the time of NETN personnel.
- Equipment is limited to a computer with GIS, Microsoft Office, and MySQL software.
- Estimated annual operating costs for implementation of the APPA forest vegetation monitoring protocol (FY18 dollars):
    - Environmental Monitoring Coordinator – 0.2 FTE, GS 12 step 9: $18,588. This includes data downloading, processing, analysis, and reporting.
    - NETN program manager - 0.05 FTE, GS 13 Step 2: $4,500. To review summary data and reports.
    - Plant Ecologist - 0.05 FTE, GS 11 Step 7: $3,670. To review summary data and reports.
    - Computer equipment: $3,000
    - Total: $29,758

Data are maintained on NPS program computers and uploaded to NPS DataStore annually.

Safety

Implementation of this protocol has minimal risks as all activities take place in an office setting. Protocol implementation staff will follow the general guidelines set forth in the NPS Occupational Safety and Health Program (Directors Order #50B, September 2008). These procedures are generally outlined as follows:

- Adhere to established occupational safety and health procedures, including those contained within Reference Manual 50B.
- Work collaboratively with supervisors to develop and use JHAs or equivalent for all routine tasks, and help develop and use site-specific safety plans for non-routine, complex, multi-phase jobs.
- Properly use and maintain required clothing and/or personal protective equipment.
- Maintain a level of personal wellness and fitness as needed for assigned work tasks.
- Identify and, where appropriate, correct unsafe conditions and work practices.
- Report unsafe/unhealthful conditions and/or operations to his or her immediate supervisor or the appropriate chain of command.
- Report mishaps, including minor accidents and "near-hits," to a supervisor as soon as possible, but in no case later than the end of the work shift.
- Participate in establishing a safe working culture, and practice safe work procedures, even when working alone.

Literature Cited

Bailey, R. G., P. E. Avers, T. King, W. H. McNab, eds. 1994. Ecoregions and subregions of the United States (map). Washington, DC: U.S. Geological Survey. Scale 1:7,500,000. Colored. Accompanied by a supplementary table of map unit descriptions compiled and edited by McNab, W.H. and Bailey, R.G. Prepared for the USDA Forest Service.

Bailey, R. G. 1980. Ecoregions of the United States. Miscellaneous Publication No. 1391, USDA Forest Service, Washington, DC.

Bennetts R. E, J. E. Gross, K. Cahill, and others. 2007. Linking monitoring to management and planning: assessment points as a generalized approach. The George Wright Forum 24:59–77.

Dieffenbach, F. 2011. Appalachian National Scenic Trail vital signs monitoring plan. Natural Resource Report NPS/NETN/NRR—2011/389. National Park Service, Fort Collins, Colorado.

Dufour, C., and E. Crisfield, eds. 2008. The Appalachian Trail MEGA–Transect: Appalachian Trail Conservancy, 31 p. Available at: http://www.edc.uri.edu/atmt-dss/News_References/ATMEGATransectReport.pdf (accessed 10 October 2018).

Fancy, S. G., J. E. Gross, and S. L. Carter. 2009. Monitoring the condition of natural resources in US national parks. Environmental Monitoring and Assessment 151:161–174.

Gormanson, D. D., S. A. Pugh, C. J. Barnett, P. D. Miles, R. S. Morin, P. A. Sowers, J. A. Westfall. 2017. Statistics and quality assurance for the Northern Research Station Forest Inventory and Analysis Program, 2016. Gen. Tech. Rep. NRS-166. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 23 p. https://doi.org/10.2737/NRS-GTR-166.

Hannah, L., J. L. Carr, and A. Lankeerani. 1995. Human disturbance and natural habitat: a biome level analysis of a global data set. Biodiversity and Conservation 4:128–155.

Karr J. R., and D. R. Dudley. 1981. Ecological perspective on water-quality goals. Environmental Management 5:55–68.

Karr, J. R., and E. W. Chu. 1999. Restoring life in running waters: Better biological monitoring. Island Press, Washington, D.C.

Landres, P. B., P. Morgan, and F. J. Swanson. 1999. Overview of the use of natural variability concepts in managing ecological systems. Ecological Applications 9:1179–1188.

Lawrence, G. B., T. J. Sullivan, D. A. Burns, S. W. Bailey, B. J. Cosby, M. Dovciak, H. A. Ewing, T. C. McDonnell, R. Minocha, R. Riemann, J. Quant , K. C. Rice, J. Siemion, and K. Weathers. 2015. Acidic deposition along the Appalachian Trail corridor and its effects on acid-sensitive terrestrial and aquatic resources: Results of the Appalachian Trail MEGA-transect atmospheric deposition effects study. Natural Resource Report NPS/NRSS/ARD/NRR—2015/996. National Park Service, Fort Collins, Colorado.

O'Connell, B. M., B. L. Conkling, A. M. Wilson, M. Andrea, E. A. Burrill, J. A. Turner, S. A Pugh, G. Christiansen, T. Ridley, J. Menlove. 2016. The Forest Inventory and Analysis Database: Database description and user guide version 6.1 for Phase 2. U.S. Department of Agriculture, Forest Service. 892 p. [Online]. Available at: http://www.fia.fs.fed.us/library/database-documentation/ (accessed 10 October 2018).

Parrish, J. D., D. P. Braun, and R. S. Unnasch. 2003. Are we conserving what we say we are? Measuring ecological integrity within protected areas. Bioscience 53: 851–860.

Ritters, K., J. Wickham, R. O'Neill, B. Jones, and E. Smith. 2000. Global-scale patterns of forest fragmentation. Conservation Ecology [online] 4(2):3. Available at http://www.consecol.org/vol4/iss2/art3

Shriver, G., T. Maniero, K. Schwarzkopf, D. Lambert, F. Dieffenbach, D. Owen, Y. Q. Wang, J. Nugranad-Marzilli, G. Tierney, C. Reese, T. Moore. November 2005. Appalachian Trail Vital Signs. Technical Report NPS/NER/NRTR--2005/026. National Park Service. Boston, MA.

Sweetapple, P. J., and G. Nugent. 2004. Seedling ratios: a simple method for assessing ungulate impacts on forest understories. Wildlife Society Bulletin 32(1):137–147.

Tierney, G., F. Dieffenbach, B. Mitchell, and K. Miller. 2013. Appalachian National Scenic Trail plot-based forest monitoring protocol. Natural Resource Report NPS/NETN/NRR—2013/633. National Park Service, Fort Collins, Colorado.

Tierney, G., B. Mitchell, K. Miller, J. Comiskey, A. Kozlowski, and D. Faber-Langendoen. 2016. Northeast Temperate Network long-term forest monitoring protocol: 2016 revision. Natural Resource Report NPS/NETN/NRR—2016/1184. National Park Service, Fort Collins, Colorado.

U.S. Forest Service. 2008. Accuracy standards. In: Forest Survey Handbook. FSH 4809.11, chapter 10. Washington, DC: U.S. Department of Agriculture, Forest Service.

US Forest Service. 2015. Forest inventory and analysis national core field guide, volume 1: field data collection procedures for Phase 2 plots. Version 7.0. USDA Forest Service, Washington, D.C., USA. Available at: https://www.fia.fs.fed.us/library/database-documentation/current/ver70/FIADB%20User%20Guide%20P2_7-0_ntc.final.pdf (accessed 10 October 2018).

U.S. Geological Survey (USGS). 2017. Hydrologic Unit Maps website. Available at: https://water.usgs.gov/GIS/huc.html (accessed 10 October 2018).

Woodall, C. W., M. C. Amacher, W. A. Bechtold, J. W. Coulston, S. Jovan, C. H. Perry, K. C. Randolph, B. K. Schulz, G. C. Smith, B. Tkacz, and S. Will-Wolf. 2011. Status and future of the forest health indicators program of the USA. Environmental Monitoring and Assessment 177:419–436.

Appendix A. HUC10 Shell: What is it, why we created it, and how is it used?

Background

The HUC10 shell (Figure A1), or the general frame of reference used to establish an area of interest around the Appalachian National Scenic Trail (APPA), is the "outer" boundary of all HUC10 hydrologic units that are in close proximity to the APPA land base that is used to identify data that are representative of APPA managed lands. The HUC10 shell is based on units defined by the USGS at the fifth level of the Hydrologic Unit Code (HUC) system, with each being given a discrete 10-digit code (HUC10).

Figure A1. HUC10 Shell (black outline) and APPA footpath (blue).

Hydrologic Unit System

USGS defines a hydrologic unit to be "…a drainage area delineated to nest in a multi-level, hierarchical drainage system. Its boundaries are defined by hydrographic and topographic criteria that delineate an area of land upstream from a specific point on a river, stream or similar surface waters. A hydrologic unit can accept surface water directly from upstream drainage areas, and indirectly from associated surface areas such as remnant, non-contributing, and diversions to form a drainage area with single or multiple outlet points…"

Hydrologic Units Are Not Watersheds

Though hydrologic units are sometimes referred to as watersheds, this is not always true because hydrologic units do not always include all upstream components of a true watershed (Omernik 2003; Figure A2). This is acknowledged by USGS in the following statement: "…Hydrologic units are only synonymous with classic watersheds when their boundaries include all the source area contributing surface water to a single defined outlet point…"

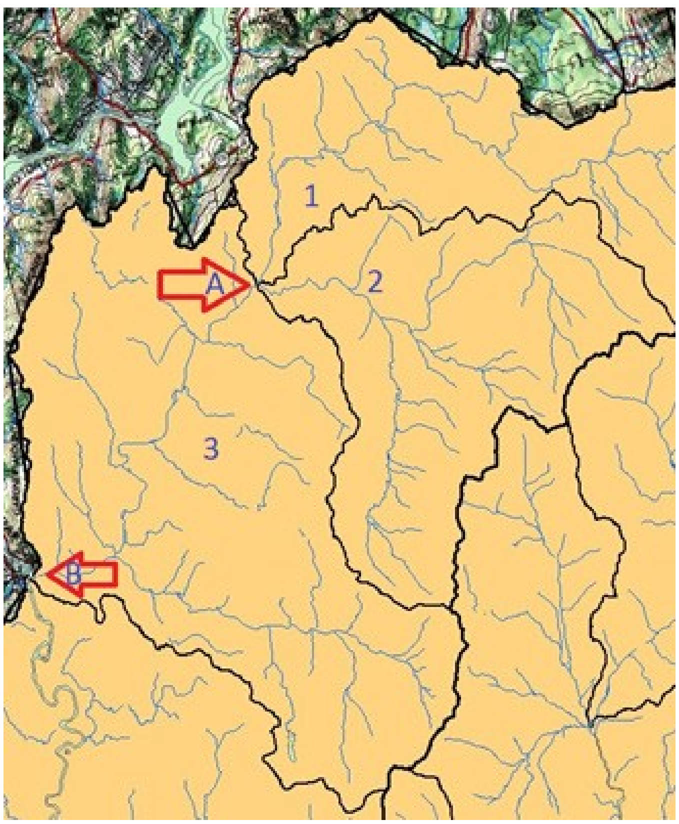

Figure A2. HUC10 units. Hydrologic units 1 (not fully visible) and 2 are true watersheds, and converge with one another at point "A." Hydrologic unit 3, which terminates at point "B," is not a true watershed because it does not include all upstream surface components. To be considered a true watershed, hydrologic unit 3 would need to be combined with hydrologic units 1 and 2.

Why use HUC10?

Even though hydrologic units, like watersheds, are based on surface water patterns, hydrologic units must also remain within a specified size range. At the HUC10 scale, the size ranges from 40,000 -

250,000 acres, or 16,187 to 101,171 hectares (NRCS 2008). Units that exceed the specified size range are truncated. While this occurs with great frequency throughout the HUC system, it is somewhat less likely to happen in the HUC10 shell for three reasons:

1) HUC's that originate at the 'top' of a 'classic' watershed are watersheds themselves, up to the point that the HUC size criteria are reached (Figure A2, watersheds 1 and 2). Subsequent HUC's, those that do not originate at the top of a classic watershed, are not considered to be watersheds themselves because not all upstream elements are included in the subsequent HUC's (Figure A1, watershed 3).
2) The midline of the shell, where the APPA is generally located, marks the divide between watersheds that flow in opposite directions (i.e., HUC's that originate at the midline of the HUC10 shell are watersheds). There is typically only one hydrologic unit between the midline and the outer boundary of the HUC10 shell.
3) While units inside the HUC10 shell are generally complete watersheds (Figure A2, watersheds 1 and 2), the HUC10 shell does contain some 10-digit HUC units that illustrate the caution raised by Omernik (2003), Figure A2, watershed 3. The inclusion of units that are not true watersheds does not diminish the value of the HUC10 shell, however, because the utility of the HUC10 shell is not dependent on each element actually being a true watershed. Rather, the HUC10 shell is based on the proximity of hydrologic units, as defined by USGS, to the Appalachian National Scenic Trail. Thus, any HUC10 element within the prescribed distance of the APPA land area (see below) was used to create the HUC10 shell, regardless of whether the unit was, or was not, a true watershed.

What Defines the HUC10 Shell?

The HUC10 shell is the distal boundary of all HUC10 units that are within 5 miles (8 km)of the APPA land area, and was originally developed to - identify water resource data needed to describe the condition of water resources on APPA (Argue et. al. 2011). Following this initial application, the shell was quickly expanded for other purposes, including the acquisition of forest health data. We did consider other levels of the HUC system and found that a boundary based on HUC08 units was too expansive (Figure A3), while an area of interest based on HUC12 units was too small (Figure A4). A boundary that is too large incorporates more data, but much of those data originate far from the APPA and at some point cease to be representative of resources found on APPA. Conversely, a smaller area of interest might ensure that the available data are more representative of APPA resources, but the volume of available data rapidly decreases. The latter is the case for a shell based on HUC12 units.

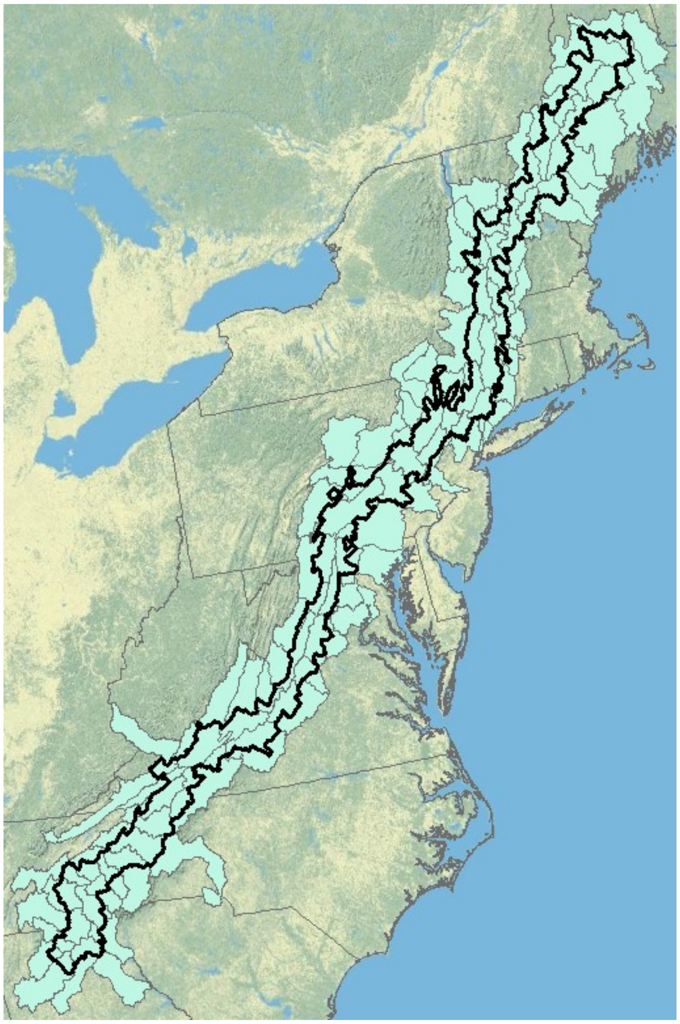

Figure A3. HUC08 units with outline of HUC10 shell.

Selection Method

Creating buffers around the APPA land area has historically supported a variety of needs, ranging from determining the population within a specified distance from APPA to identifying scientific data. Typically, such buffers were established around the APPA using uniform distances like, 5, 10, or 15-miles. While relatively easy to construct, buffers based on distance alone are arbitrary and tend to miss important ecological features. Creating an area of interest around APPA based on hydrologic units is advantageous because hydrologic units are derived from natural landscape features.

The term 'area of interest' is preferred over buffer because it more accurately describes the purpose of the shell, which is to identify an area from which data are drawn and used to make inferences about the condition of APPA's ecological resources on APPA itself are found. This is a key point because unlike other parks, we rely on existing data to describe the resources on APPA, thereby avoiding the great cost and difficulty associated with collecting 'new' APPA data. For example, annually collecting forest health data on APPA lands would be prohibitively expensive and logistically challenging, whereas data collected by the U.S. Forest Service (USFS) Forest Inventory Analysis (FIA) program are freely available.

Figure A4. HUC12 units with outline of HUC10 shell.

In defining an area of interest around APPA, we believe the HUC10 Shell balances two fundamental requirements. First, the HUC10 shell is large enough to ensure ample data availability, and second, the shell describes a boundary that maintains relevance to the resources that characterize the APPA itself. The other two boundaries we considered, HUC08 and HUC12, were not able to simultaneously fulfill both requirements.

It is important to understand that the HUC10 shell is a starting point. There is no guarantee that the HUC10 shell includes all items of interest related to APPA, or that it excludes all items that are not of interest. For some projects, a larger or smaller area of interest may be needed, but the HUC10 shell is a good starting point, is adequate for most applications, and encourages consistency between otherwise disparate projects.

Beyond a Boundary

The utility of the HUC10 shell has expanded beyond just establishing an outer boundary of an area of interest. The HUC10 shell can be partitioned by the internal HUC elements themselves, by state boundaries, by elements of the Bailey (1994) ecoregional system, or by any other system that is pertinent to the analysis being performed. Finding an appropriate balance when dividing the HUC10 Shell into discrete units depends on the project in question. One approach that has been successful is to divide the HUC10 shell using units appropriate for the given analysis, but then only analyze that portion of the elements that intersect the APPA land area (Table A1, Figure A5). We have done this to analyze forest health data using ecoregional subsections. The subsection scale is particularly useful for forest health analysis because there are sufficient FIA plots within each subsection, and when the FIA plots are sampled, the USFS associates all plot data to subsection. Despite the clear advantages of the subsection approach, to analyze all 50 subsections that are within the HUC10 shell would be a large task. We overcame this problem by limiting the analysis to only those subsections that directly intersect the land administered by the APPA, which reduces the number of subsections to 20 (Table A1, Figure A5).

Table A1. Example units of division for the HUC10 shell.

Unit of Division	Intersects APPA	Do Not Intersect APPA	Total
HUC08	62	7	69
HUC10	176	60	236
HUC12	430	787	1,217
Province	3	2	5
Section	7	12	19
Subsection	20	30	50

Figure A5. Ecoregional subsections that intersect the Appalachian National Scenic Trail (APPA) land area (blue), and subsections that do not intersect the APPA land area (red).

Another consideration is the spatial area appropriate for the analysis being conducted. The USFS, the agency responsible for the FIA program, states that "…there is one forest plot approximately every 6,000 acres…" and that "…FIA data are statistically useful from the National scale down to areas of about 200,000 acres…" Given that, our forest health analysis based on FIA data within the 20 intersecting subsections is well within the specified 200,000 acre threshold, but attempting to do a similar analysis based on individual HUC10 units would not be advisable because the average size of units associated with the HUC10 shell is 113,300 acres (Table A2) – well below the 200,000 acre limit recommended by USFS. Maintaining a minimum size is another justification for filtering subsections, or any other approach to dividing the HUC10 shell, to only those elements that intersect the land area. Of the 30 subsections that do not intersect APPA (Table A1), most are generally small, ranging from 9.86 to 558,885 acres with a mean ($\bar{x}$) of 158,869 acres and a median of 129,236 acres. Had the non-intersecting subsections been included in our forest health analysis, our ability to make meaningful inferences about the condition of resources in several of the smaller subsections would have been questionable. Other data analysis projects are likely to have similar constraints that will dictate the aerial thresholds that must be observed.

Table A2. Units of division, range, average, and standard deviation of different land area divisions inside the HUC10 shell.

Unit of Division	Acres (Hectares)			
	Min. Range	Max. Range	Average (x̄)	SD
HUC08	68,069 (27,547)	1,152,013 (466,203)	387,517 (156,823)	212,527 (86,007)
HUC10	39,630 (16,038)	347,817 (140,757)	113,300 (45,851)	46,822 (18,948)
HUC12	1,720 (696)	210,564 (85,212)	21,971 (8,891)	10,607 (4,293)
Provinces	700,908 (283,647)	12,612,851 (5,104,240)	5,347,636 (2,164,111)	4,912,720 (1,988,107)
Section	3,563 (1,442)	6,215,016 (2,515,128)	1,407,273 (569,503)	1,977,362 (800,210)
Subsection	<10 (<4)	2,637,737 (1,067,455)	534,764 (216,411)	622,213 (251,801)

Sampling Pack

To go along with the HUC10 shell, we have developed a series of spatially balanced data sets that are designed to help researchers develop sampling strategies within the HUC10 shell. These datasets, known collectively as the Appalachian Trail GIS sampling pack, rely on the GRTS (Generalized Random Tessellation Stratified) design methodology.

IstheHUC10ShellRepresentative?

We developed the HUC10 shell to help identify data that are representative of resources on APPA. If sufficient data were available from APPA managed lands we would not need to look for representative data, but after a thorough data mining effort we determined that using data from outside the APPA land area was the only affordable way to characterize the resources on APPA. The FIA data set provides a good example of APPA specific data scarcity. Out of 23,710 FIA forest plots (swapped and fuzzed) within the HUC10 shell, only 235 are on APPA lands. Other datasets, such as water resources, exhibit the same pattern where there is an abundance of data available from within the HUC10 shell but relatively few data from the APPA land area.

With this strategy, we assume that resources within the HUC10 shell, but not within the land area managed by APPA, are substantially the same as the resources found on the APPA. In making this assumption, we recognize that it is unrealistic that the entire HUC10 shell can be treated as a single unit in all instances, which is why we advocate dividing the HUC10 by ecoregions or some other division to create smaller units to mitigate this limitation.

In one respect, we know that at the 'whole' HUC10 scale, the two zones (On APPA vs. Off of APPA) do differ. Because the HUC10 shell is based on hydrologic units, with the trail generally following the ridge line that longitudinally bisects the shell, it is reasonable to assume that ground elevations will generally decrease as you move away from the trail centerline. This is perhaps the single instance where the conclusions reached at the scale of the entire HUC10 are not transferable to smaller scales. Following a comparison of the elevation of land areas On vs. Off APPA we have found that the median elevation of lands Off APPA is significantly lower than the median elevation of lands on APPA (Figure A6.a).

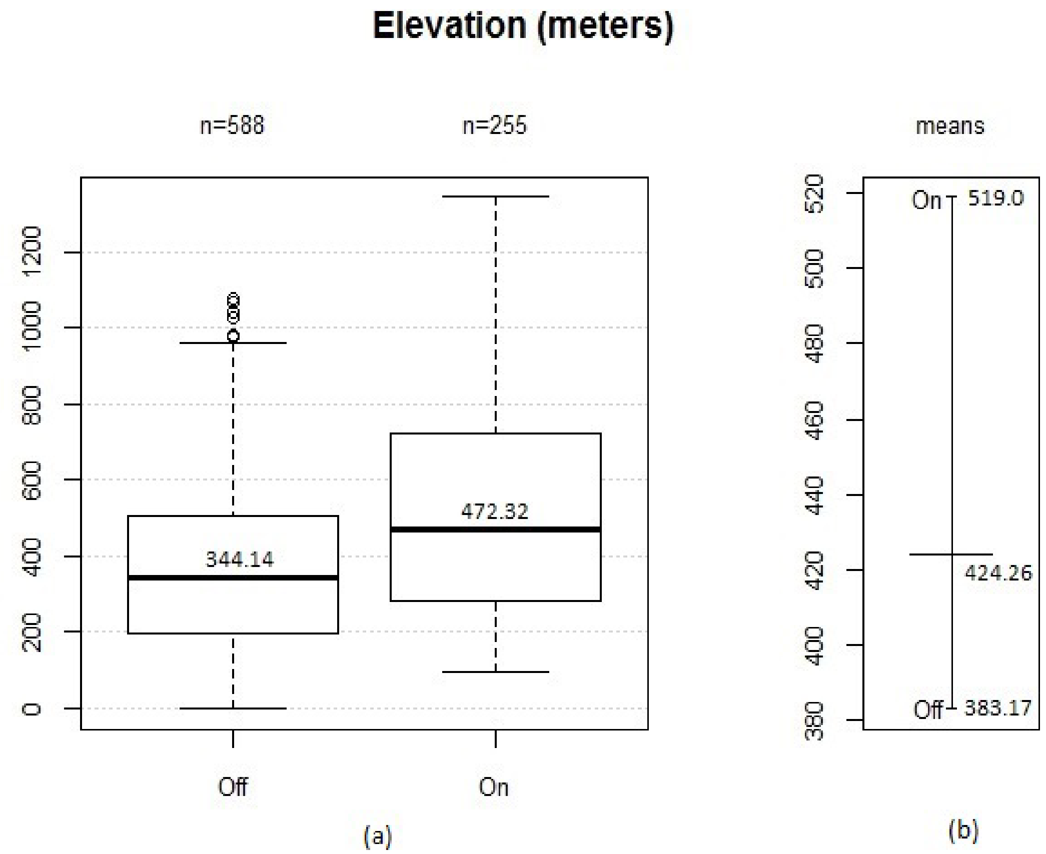

Figure A6. a. Comparison of the median elevation from 'Off' APPA to 'On' APPA (p <0.0001); b. Comparison of mean (x̄) elevations (m) 'On' APPA vs. 'Off' APPA, and overall mean (x̄).

Other Considerations

The process we followed to generate the HUC10 shell may have a rational basis, but it isn't perfect. When looking at the HUC10 shell, some users express concern that some areas that extend too far from APPA are nonetheless included. While there are examples of small extensions from APPA, that is not true of the HUC10 Shell boundary in general. It is also important to recognize that the boundary is the result of a process that was free of arbitrary manipulation, and while it might seem advantageous to simply remove extensions that have no apparent relationship with the APPA, that would introduce an arbitrary element into the process and thereby violate one of the most important tenets upon which we relied to create the shell. Consequently, NETN has avoided tampering with the original conformation of the HUC10 shell by retaining all outer boundary components, regardless of how far they might extend from the footpath.

Literature Cited

Argue, D. M., J. P. Pope, and F. Dieffenbach. 2011. Characterization of the water quality of headwater streams along the Appalachian National Scenic Trail and within adjacent watersheds, Maine to Georgia: U.S. Geological Survey Scientific Investigations Report 2011-5151, 63 p., plus CD-ROM. Available at https://pubs.usgs.gov/sir/2011/5151/ (accessed 10 October 2018).

Bailey, R. G., P. E. Avers, T. King, W. H. McNab, eds. 1994. Ecoregions and subregions of the United States (map). Washington, DC: U.S. Geological Survey. Scale 1:7,500,000. Colored. Accompanied by a supplementary table of map unit descriptions compiled and edited by W. H. McNab, and R. G. Bailey. Prepared for the USDA Forest Service.

Natural Resource Conservation Service (NRCS). 2008. Delineation of 10- and 12-Digit Hydrologic Unit (HU) Boundaries. SD-FS-54. Available at: www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs141p2_036230.doc (accessed 10 October 2018).

Omernik, J. M. 2003. The Misuse of Hydrologic Unit Maps for Extrapolation, Reporting, and Ecosystem management Journal of the American Water Resources Association. (JAWRA) 39(3):563-573.

NPS 962/149418, November 2018

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

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