National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Natural Resource Condition Assessment

Great Smoky Mountains National Park

Natural Resource Report NPS/GRSM/NRR—2018/1626

ON THE COVER

View from Clingmans Dome looking south into Great Smoky Mountains National Park and points beyond in western North Carolina. Photo courtesy of Jim Renfro (2004).

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Executive Summary

This Natural Resource Condition Assessment (NRCA) describes the state of the natural resources in Great Smoky Mountains National Park (GRSM). The primary goals of the NRCA were to (1) document the current conditions and trends for important park natural resources, (2) list important data and knowledge gaps, and (3) identify some of the factors that are influencing park natural resource conditions. The information delivered in this NRCA can be used to communicate current resource condition status to park stakeholders. It will also be used by park staff to support the implementation of their integrated approach to the management of park resources.

In 2011, GRSM staff identified and prioritized critical natural resource issues as part of their long-term ecological monitoring program. The 2011 monitoring plan lays out the park's Vital Signs, which are a subset of physical, chemical, and biological elements and processes that represent the overall health or condition of park resources. Park staff identified six top Vital Signs that would be most indicative of the park's overall health. These are (1) Water Chemistry, (2) Atmospheric Deposition, (3) Soil Quality, (4) Vegetation Communities, (5) Freshwater Communities and (6) Climate Change. For this assessment, we considered the park's monitoring plan and then grouped resources into six broad general categories: Air and Climate, Geology and Soils, Water, Biological Integrity, Human Use, and Landscape Patterns and Processes. Each of these general categories, referred to as Level 1, was further subdivided into Level 2 and Level 3 categories. As the categories move from Level 1 to Level 3, the resolution of the data involved also increases. This NRCA conducted assessments of 52 Level 3 resources.

Since the primary purpose of the NRCA is to provide a snapshot of current conditions, we focused largely on the most recent data available. However, temporal trends are important when assessing current conditions for most metrics and were evaluated where possible. Relevant inventory and monitoring data were analyzed quantitatively and applied directly to the assessment of resource condition. Where data were lacking, we conducted a review and synthesis from existing assessment reports, and we relied heavily on input from GRSM staff and resource specialists.

This NRCA identified four resource areas of particular importance in terms of management and monitoring that are critical to the park's mission. These are (1) air quality, (2) water quality, (3) non-native plants, animals, and diseases, and (4) biodiversity, particularly as reflected in rare plants and animals. These resource areas largely overlap with the top vital signs identified by park staff as most indicative of the park's overall health.

GRSM experiences some of the highest measured air pollution of any national park in the U.S. Acid deposition has been shown to cause measureable effects on ecosystem structure and function, and the high levels of sulfate and nitrate wet deposition recorded in GRSM easily exceed ecological thresholds. Other aspects of air quality that are measured and evaluated include mercury deposition, ozone, particulates, and haze. While most air quality indicators have improved in recent years (with the exception of wet nitrogen deposition) all indicators still exceed ecological and national standards and are of significant concern.

Stream water acidification resulting from the atmospheric deposition of sulfur and nitrogen likely poses the most significant threat to water quality and aquatic biota within the park. High-elevation watersheds are subjected to high atmospheric deposition of nitrate and sulfate, and therefore exhibit lower pH values (higher acidity) than lower elevation stream reaches. These areas are particularly sensitive to atmospheric deposition due to the low natural buffering capacity of the soil and water. Neither nitrate nor sulfate concentrations have significantly declined over the monitoring period. This lack of improved water quality is likely due to biogeochemical processes operating within upland soils and suggests that it will take decades for watersheds to recover from acidic deposition.

Approximately 380, or 20%, of the vascular plant species found in the park are non-native, and 53 of these are documented as displacing native plant communities, hybridizing with native plants, and/or interfering with cultural landscapes. The vectors by which non-native invasive plants enter the park are numerous and varied, and although past and current efforts have successfully managed or even eliminated some invasive populations, the need to monitor and treat these species will continue indefinitely. There are many exotic animal species documented in the Smokies but only a few are considered invasive. Considerable effort has been expended in recent decades in managing feral hogs, rainbow trout, and brown trout.

Non-native insects and diseases introduced from Europe and Asia are having devastating impacts on several keystone species within the park. Perhaps most notable are the chestnut blight, balsam woolly adelgid, and hemlock woolly adelgid. These have largely eliminated American chestnut from the forest overstory throughout the park, and caused significant declines in Fraser fir and hemlock. Numerous other non-native insect and disease pests, such as dogwood anthracnose, gypsy moth, emerald ash borer, and thousand cankers disease will continue to threaten the park’s forests. To date, there are few effective treatments to combat widespread infestations, leaving continuous monitoring and aggressive containment and elimination as the best strategy for preventing future outbreaks.

Some diseases in mammals, such as rabies, pseudorabies, hantavirus, and epizootic hemorrhagic disease, have been relatively well-documented in the park and are episodic. White-nose syndrome (WNS) is much more worrisome, and has been documented as causing serious losses in several rare bat species in the park. On-going studies in the park are a critical part of nationwide research and monitoring efforts, hopefully leading to eventual recovery from WNS. The park’s amphibian fauna, especially salamanders, are reported to have undergone a significant loss in the past few decades, perhaps due to various infections including ranavirus, chytrid fungus, or Bd (bacteria). The situation is unclear at present but is concerning to the park.

GRSM is characterized as one of the richest centers of biodiversity in the eastern U.S., due in part to its complex geology, topographic relief, varied microclimates, and abundant rainfall. Understanding and protecting this biodiversity is a critical park management objective. Among the vast number of species in the park, a number of rare and/or listed species occur, and the park is considered a particularly important refuge for them. Park staff actively monitor populations of 36 rare plant species, which were selected based on potential or documented disturbances, federal and state listing, and park rarity. Among park animals, about 39 vertebrates and at least 53 invertebrates – species groups like mollusks, aquatic insects, crustaceans, moths, and bees – are listed by North Carolina, Tennessee, and the U.S. Fish and Wildlife Service as threatened or endangered, or have been designated by NatureServe as G1 (critically imperiled globally) or G2 (imperiled globally). Many of these species are endemic to the region, if not the park itself. While the park has actively restored a few rare vertebrates like peregrine falcons, river otters, and several fishes, other species are in need of similar efforts.

Overall, resource conditions in the park are stable, but significant concern and declining trends exist for some categories. When examining the condition and trends of all 52 Level 3 resources presented in this NRCA, half (26) have a current condition that warrants significant concern. Factors that influence these conditions include past land use (forest clearing, fire suppression), atmospheric deposition, non-native invasive species (plants, animals, diseases), direct human-caused disturbances (poaching, trampling), regional trends (LULC changes, development), and climate change. Also, the level of confidence in assessments generally is high, but significant data gaps occur. Information provided in this assessment will help identify future data needs that could help park management plan for and focus future sampling efforts, which will further enhance existing knowledge of the park's natural reosurces.

Acknowledgements

We acknowledge the Great Smoky Mountains National Park staff for their tireless efforts in providing assistance and technical review throughout all phases of this report. We are particularly indebted to Tom Remaley, Jim Renfro, Kristine Johnson, Becky Nichols, Matt Kulp, Bill Stiver, Janet Rock, Troy Evans, Glenn Taylor, Rob Klein, Tom Colson, and Paul Super. We are also grateful for contributions by Western Carolina University research technicians James Rogers and Anja Nothdurft Collette. Gabriella Hovis provided invaluable assistance in formatting and editing this document. Finally, thank you to Dale McPherson for his counsel and logistical support throughout the entire NRCA process.

Chapter 1. NRCA Background Information

Natural Resource Condition Assessments (NRCAs) evaluate current conditions for a subset of natural resources and resource indicators in national park units, hereafter "parks." NRCAs also report on trends in resource condition (when possible), identify critical data gaps, and characterize a general level of confidence for study findings. The resources and indicators emphasized in a given project depend on the park's resource setting, status of resource stewardship planning and science in identifying high-priority indicators, and availability of data and expertise to assess current conditions for a variety of potential study resources and indicators.

NRCAs Strive to Provide…

- *Credible condition reporting for a subset of important park natural resources and indicators*
- *Useful condition summaries by broader resource categories or topics, and by park areas*

NRCAs represent a relatively new approach to assessing and reporting on park resource conditions. They are meant to complement—not replace—traditional issue-and threat-based resource assessments. As distinguishing characteristics, all NRCAs:

- Are multi-disciplinary in scope;[1]
- Employ hierarchical indicator frameworks;[2]
- Identify or develop reference conditions/values for comparison against current conditions;[3]
- Emphasize spatial evaluation of conditions and GIS (map) products; [4]
- Summarize key findings by park areas; and [5]
- Follow national NRCA guidelines and standards for study design and reporting products.

Although the primary objective of NRCAs is to report on current conditions relative to logical forms of reference conditions and values, NRCAs also report on trends, when appropriate (i.e., when the underlying data and methods support such reporting), as well as influences on resource conditions. These influences may include past activities or conditions that provide a helpful context for

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[1] The breadth of natural resources and number/type of indicators evaluated will vary by park.

[2] Frameworks help guide a multi-disciplinary selection of indicators and subsequent "roll up" and reporting of data for measures ⇨ conditions for indicators ⇨ condition summaries by broader topics and park areas

[3] NRCAs must consider ecologically-based reference conditions, must also consider applicable legal and regulatory standards, and can consider other management-specified condition objectives or targets; each study indicator can be evaluated against one or more types of logical reference conditions. Reference values can be expressed in qualitative to quantitative terms, as a single value or range of values; they represent desirable resource conditions or, alternatively, condition states that we wish to avoid or that require a follow-up response (e.g., ecological thresholds or management "triggers").

[4] As possible and appropriate, NRCAs describe condition gradients or differences across a park for important natural resources and study indicators through a set of GIS coverages and map products.

[5] In addition to reporting on indicator-level conditions, investigators are asked to take a bigger picture (more holistic) view and summarize overall findings and provide suggestions to managers on an area-by-area basis: 1) by park ecosystem/habitat types or watersheds, and 2) for other park areas as requested.

understanding current conditions, and/or present-day threats and stressors that are best interpreted at park, watershed, or landscape scales (though NRCAs do not report on condition status for land areas and natural resources beyond park boundaries). Intensive cause-and-effect analyses of threats and stressors, and development of detailed treatment options, are outside the scope of NRCAs.

Due to their modest funding, relatively quick timeframe for completion, and reliance on existing data and information, NRCAs are not intended to be exhaustive. Their methodology typically involves an informal synthesis of scientific data and information from multiple and diverse sources. Level of rigor and statistical repeatability will vary by resource or indicator, reflecting differences in existing data and knowledge bases across the varied study components.

The credibility of NRCA results is derived from the data, methods, and reference values used in the project work, which are designed to be appropriate for the stated purpose of the project, as well as adequately documented. For each study indicator for which current condition or trend is reported, we will identify critical data gaps and describe the level of confidence in at least qualitative terms. Involvement of park staff and National Park Service (NPS) subject-matter experts at critical points during the project timeline is also important. These staff will be asked to assist with the selection of study indicators; recommend data sets, methods, and reference conditions and values; and help provide a multi-disciplinary review of draft study findings and products.

NRCAs can yield new insights about current park resource conditions, but, in many cases, their greatest value may be the development of useful documentation regarding known or suspected resource conditions within parks. Reporting products can help park managers as they think about near-term workload priorities, frame data and study needs for important park resources, and communicate messages about current park resource conditions to various audiences. A successful NRCA delivers science-based information that is both credible and has practical uses for a variety of park decision making, planning, and partnership activities.

Important NRCA Success Factors

- *Obtaining good input from park staff and other NPS subject-matter experts at critical points in the project timeline*
- *Using study frameworks that accommodate meaningful condition reporting at multiple levels (measures ⇨ indicators ⇨ broader resource topics and park areas)*
- *Building credibility by clearly documenting the data and methods used, critical data gaps, and level of confidence for indicator-level condition findings*

However, it is important to note that NRCAs do not establish management targets for study indicators. That process must occur through park planning and management activities. What an NRCA can do is deliver science-based information that will assist park managers in their ongoing, long-term efforts to describe and quantify a park's desired resource conditions and management targets. In the near term, NRCA findings assist strategic park resource planning[6] and help parks to report on government accountability measures.[7] In addition, although in-depth analysis of the effects of climate change on park natural resources is outside the scope of NRCAs, the condition analyses and data sets developed for NRCAs will be useful for park-level climate-change studies and planning efforts.

NRCAs also provide a useful complement to rigorous NPS science support programs, such as the NPS Natural Resources Inventory & Monitoring (I&M) Program.[8] For example, NRCAs can provide current condition estimates and help establish reference conditions, or baseline values, for some of a park's vital signs monitoring indicators. They can also draw upon non-NPS data to help evaluate current conditions for those same vital signs. In some cases, I&M data sets are incorporated into NRCA analyses and reporting products.

NRCA Reporting Products…

Provide a credible, snapshot-in-time evaluation for a subset of important park natural resources and indicators, to help park managers:

- *Direct limited staff and funding resources to park areas and natural resources that represent high need and/or high opportunity situations* ***(near-term operational planning and management)***
- *Improve understanding and quantification for desired conditions for the park's "fundamental" and "other important" natural resources and values* ***(longer-term strategic planning)***
- *Communicate succinct messages regarding current resource conditions to government program managers, to Congress, and to the general public* ***("resource condition status" reporting)***

Over the next several years, the NPS plans to fund an NRCA project for each of the approximately 270 parks served by the NPS I&M Program. For more information visit the NRCA Program website.

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[6] An NRCA can be useful during the development of a park's Resource Stewardship Strategy (RSS) and can also be tailored to act as a post-RSS project.

[7] While accountability reporting measures are subject to change, the spatial and reference-based condition data provided by NRCAs will be useful for most forms of "resource condition status" reporting as may be required by the NPS, the Department of the Interior, or the Office of Management and Budget.

[8] The I&M program consists of 32 networks nationwide that are implementing "vital signs" monitoring in order to assess the condition of park ecosystems and develop a stronger scientific basis for stewardship and management of natural resources across the National Park System. "Vital signs" are a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values.

Chapter 2. Introduction and Resource Setting

2.1. Introduction

2.1.1. Park History and Enabling Legislation

The area that now encompasses Great Smoky Mountains National Park (GRSM or 'the park') has a long human history going back thousands of years. Beginning approximately 8,000 years ago, Native Americans used the land primarily for hunting and gathering as evidenced through archaeological records. As farming techniques developed and were refined over the centuries, natives moved into the lower reaches of the park, established villages, and used fire to clear land, encourage game-rich grounds, and cultivate fields. The first white settlers reached the park in the late 1700s. Following the forced removal of the Cherokee in the 1830s, the early European settlers expanded farther and wider into the area. By the mid-1850s settlers including those in Cataloochee and Cades Cove had established permanent homesteads and developed self-sustaining livelihoods. Early European settlers differed little from their Cherokee predecessors; they still hunted wildlife, gathered plants, nuts, and berries, but also cleared land for livestock grazing and farming. In the early 1900s large lumber companies entered the region and began extracting timber on a wide scale (Fig. 2.1.1.1).

Figure 2.1.1.1. A steam-powered loader uses tongs to place logs onto a railroad flat car in the Smokies in the early 1900s.

The local population took jobs with the companies and by the 1920s most of the area residents, who previously lived in a self-sufficient economy, became reliant on manufactured items, store bought food, and cash. In 20 years, approximately 80% of the Smokies had been selectively logged or clearcut. Clearcutting, building roads, railroads, and using streams for log transport had significant impacts on soils and streams. The resulting ecological damage prompted a call to action among conservationists, politicians, and the general public to preserve what remained of the forests and waterways and recover what was lost due to the high-impact logging practices. Great Smoky Mountains National Park was authorized by the U.S. Congress in 1926. Through funds committed from the states of Tennessee and North Carolina, and philanthropists including John D. Rockefeller, the federal government began buying land from timber companies and from small landowners; this included more than 6,000 tracts in all. This seemingly monumental task was achieved through land acquisitions from willing landowners, and also from uncooperative landowners through the implementation of eminent domain. Older land owners were allowed to live out their lives in the park through mutually agreed upon lifetime leases. Eight years after authorization, the park was established in 1934 and officially dedicated in 1940.

Park Statistics at a Glance (NPS 2015)

- Great Smoky Mountains National Park lies in two states: 111,832 ha (276,344 ac) in North Carolina and 99,044 ha (244,742 ac) in Tennessee.
- The park had 10.7 million recreational visitors in 2015 - the highest visitation of any of the 58 national parks and an all-time record for the park.
- The park generates over $734 million per year (in 2013) for surrounding communities.
- In fiscal year 2014 the park had a base budget of $18.5 million.
- The park hosted 225,000 overnight campers in 2013 at its nine campgrounds. There are more than 100 backcountry sites which see more than 77,000 overnight visits per year.
- There are 11 picnic areas in the park, with a total of 1,050 sites.
- Over 400,000 hikers annually traverse over 1,280 km (800 mi) of maintained trails; 113 km (70 mi) of the Appalachian Trail runs through the park.
- There are 342 structures maintained in the park, including 78 historic structures in five historic districts.
- The park was designated an International Biosphere Reserve in 1976 and a World Heritage Site in 1983.

2.1.2. Geographic Setting

GRSM comprises approximately 2,000 km^2 (772 mi^2) of almost entirely forested land in the southern Appalachian Mountains (Fig. 2.1.2.1). Divided almost equally between the states of North Carolina and Tennessee, the park is characterized by rugged terrain, large elevation gradients, and highly varied aspects. The park has an elevation range from 267 to 2,025 m (876 to 6,643 ft). This combined with some of the highest precipitation levels in North America have helped create one of the most biodiverse regions in the world. Three Tennessee and two North Carolina counties border the park, and also, a large part of the Eastern Band of Cherokee Indians (EBCI) tribal lands borders the southeastern portion of the park in North Carolina. The Blue Ridge Parkway's southern terminus enters the park through these tribal lands. The Nantahala and Pisgah National Forests border the park in areas on the North Carolina side, and a small portion of the Cherokee National Forest in Tennessee is situated near the western edge of the park (Fig. 2.1.2.2.). There are three major gateway communities adjacent to GRSM with several other smaller communities that are important to the economies of Tennessee and North Carolina.

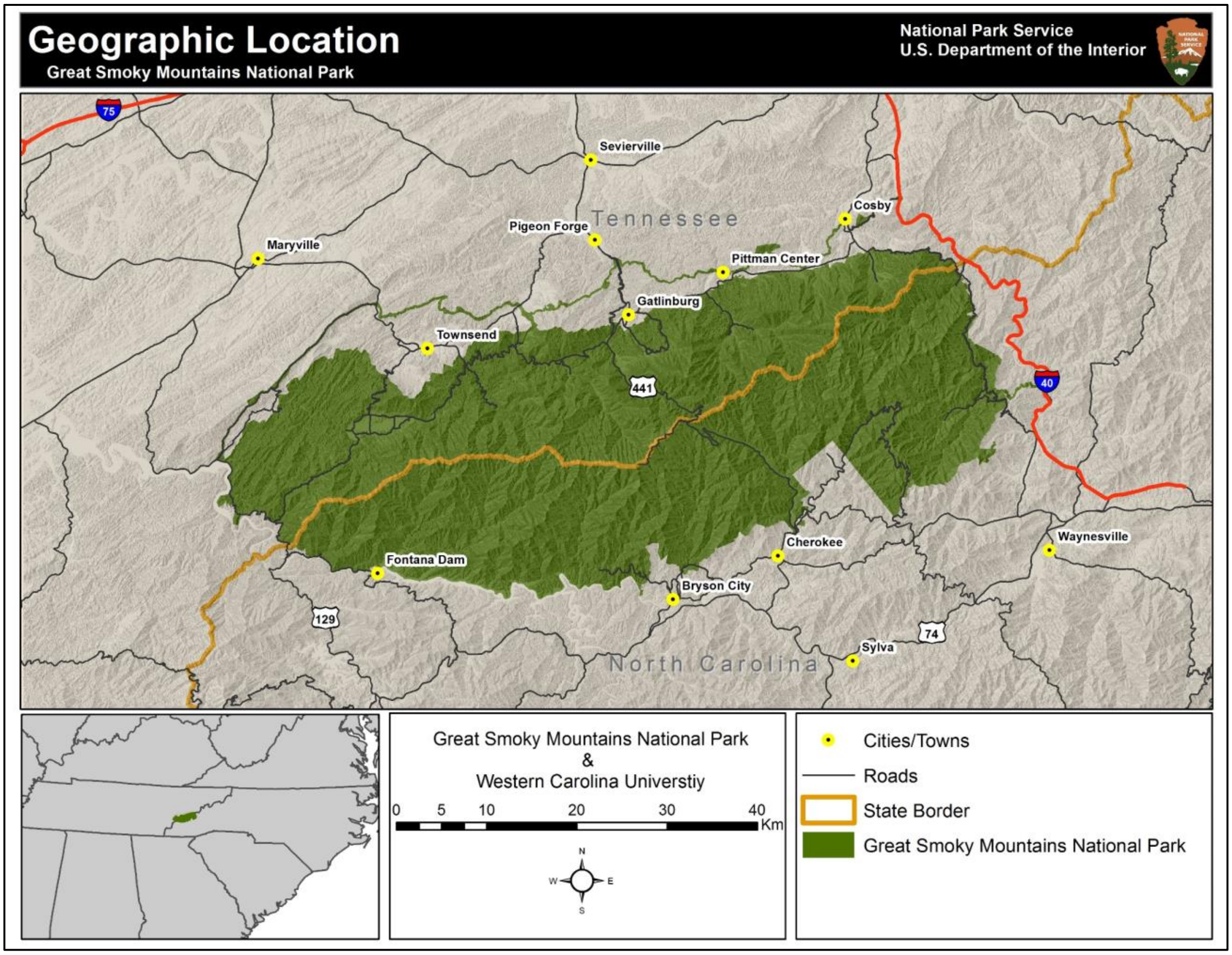

Figure 2.1.2.1. Great Smoky Mountains National Park lies at the southern terminus of the Appalachian Mountains and is equally distributed between Tennessee and North Carolina. Source: GRSM 2012.

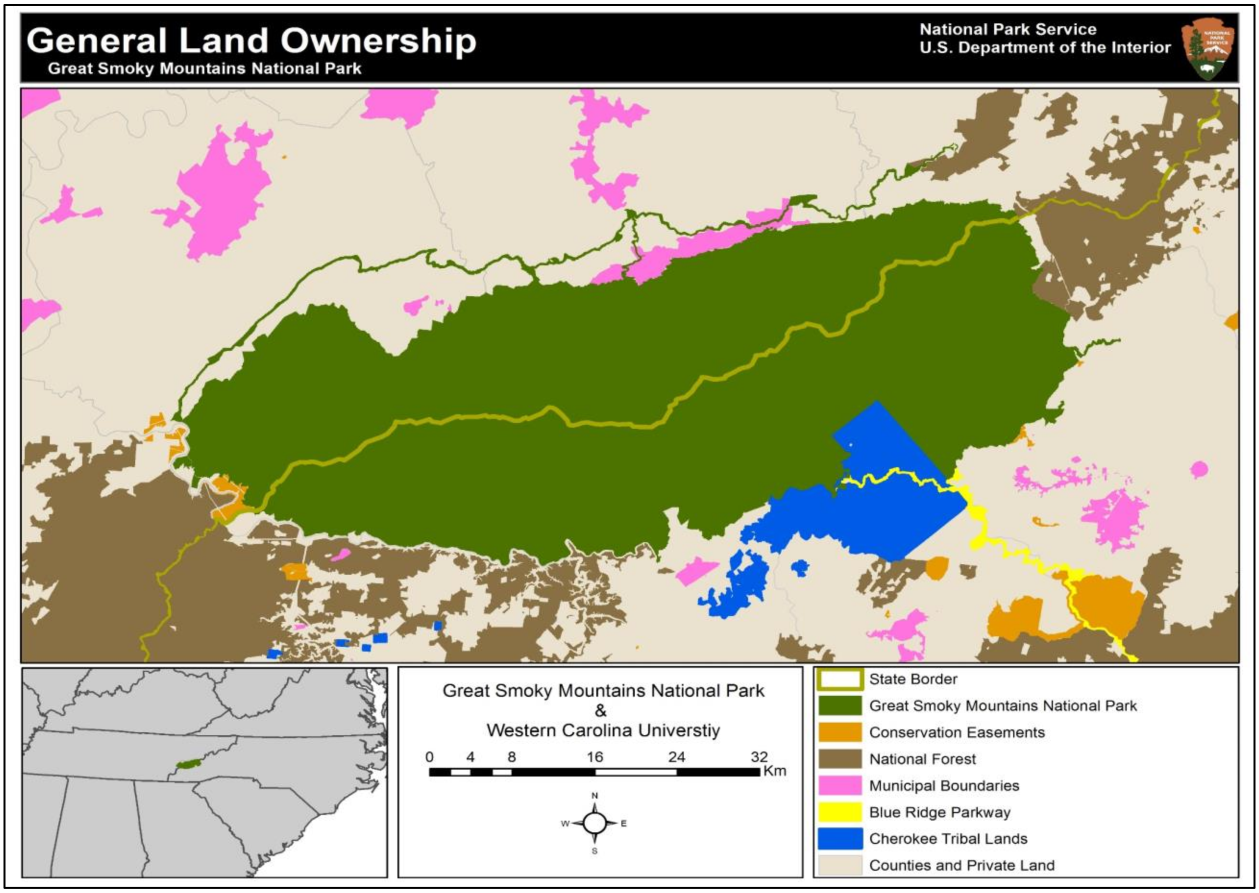

Figure 2.1.2.2. General land ownership adjacent to GRSM. Source: GRSM 2012.

Weather and Climate

GRSM is located within a region known for having a humid subtropical climate characterized by hot, humid summers with frequent thunderstorms, and cool winters. However, in this mountainous terrain the climate is dynamic and constantly changing, and varies greatly as a result of steep moisture and temperature gradients. Precipitation is somewhat evenly distributed throughout the year, and is mainly in the form of rainfall, although snowfall does occur in the area, mainly at higher elevations (NOAA 2015, Renfro 2015). July is typically the wettest month and October is the driest (Fig. 2.1.2.3), with an annual average precipitation range of 140 cm (55 in) in the valleys to more than 215 cm (85 in) at the higher elevations. During anomalously wet years, more than 2 m (6.6 ft) of rain can fall along the ridges and peaks (NPS 2008). Average temperatures range from -2.8 to -3.3 °C (27 to38 °F) in January to 15 to 22.4 °C (59 to 72 °F) in July (NOAA 2015) (Fig. 2.1.2.4), again depending on elevation. Winds vary greatly in both speed and direction depending on the specific location within the overall complex mountainous terrain of the park (Renfro 2015).

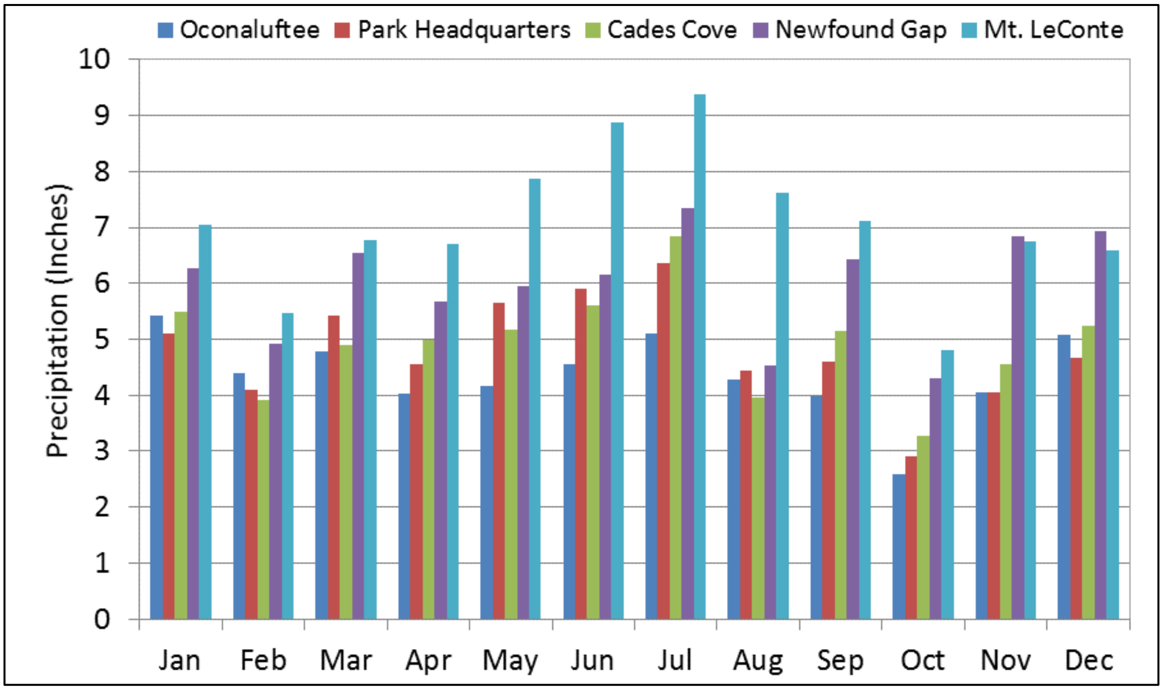

Figure 2.1.2.3. Monthly mean precipitation reported from five NWS COOP weather stations in GRSM, 1988-2014. Source: J. Renfro; NWS/NCDC.

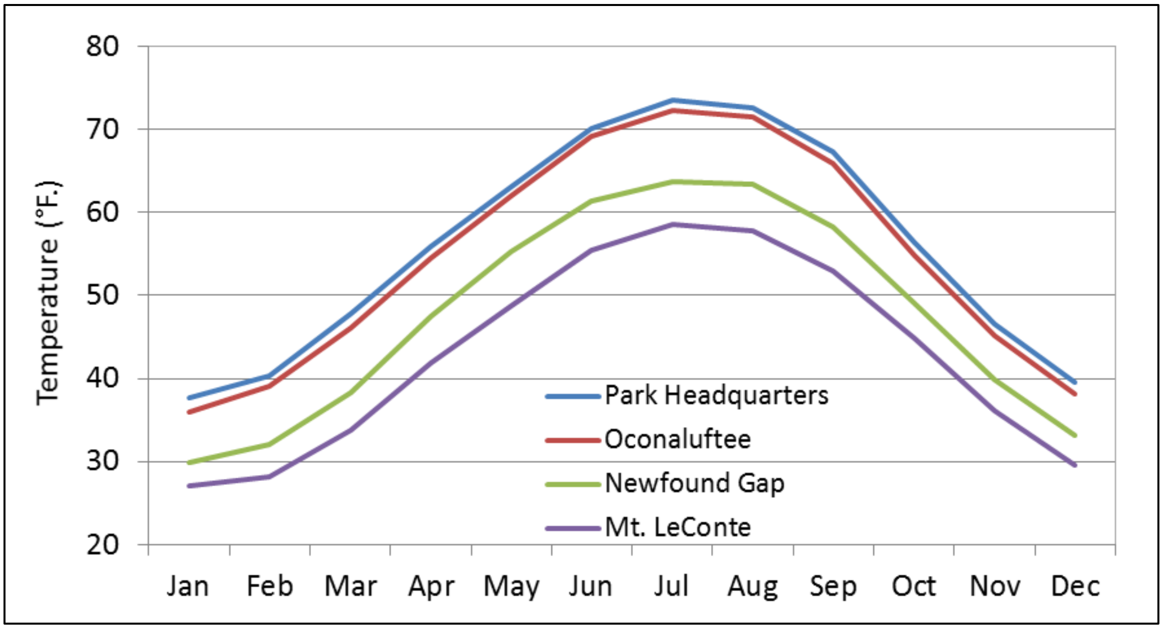

Figure 2.1.2.4. Monthly mean temperature reported from four weather stations in GRSM, 1988-2014. Source: J. Renfro; NWS/NCDC.

2.1.3. Visitation Statistics

Visitors come to the park for a wide array of activities. Backcountry camping and hiking, fishing, auto touring, fall color viewing, horseback riding, picnicking, wildlife viewing, historical research, and waterfall and vista viewing are just a few of the reasons tourists come to the Smokies. Great Smoky Mountains National Park is the most visited national park in the National Park System (NPS 2015). The high rate of visitation is likely due in large part to the park's proximity to one-third of the American population - within 885 km (550 mi) of its boundaries. Additionally, towns such as Pigeon Forge and Gatlinburg, both of which are close to the park, attract large numbers of tourists seeking shopping opportunities and other attractions. The park is an economic hub generating over $734 million per year for surrounding communities (NPS 2015). Visitation has increased steadily since the park's establishment (Fig. 2.1.3.1). In 2015, it attracted an all-time record high of over 10,700,000 visitors. Average park visitation for the past two decades (since 1995) has been approximately 9,550,000 per year. Monthly statistics, which have been recorded since 1979, show that visitation has ranked highest during the month of July, accounting for 16% of visitors during the year, while the month of January sees the least number of visitors, or less than 1%. October is the second busiest month due to fall foliage interest.

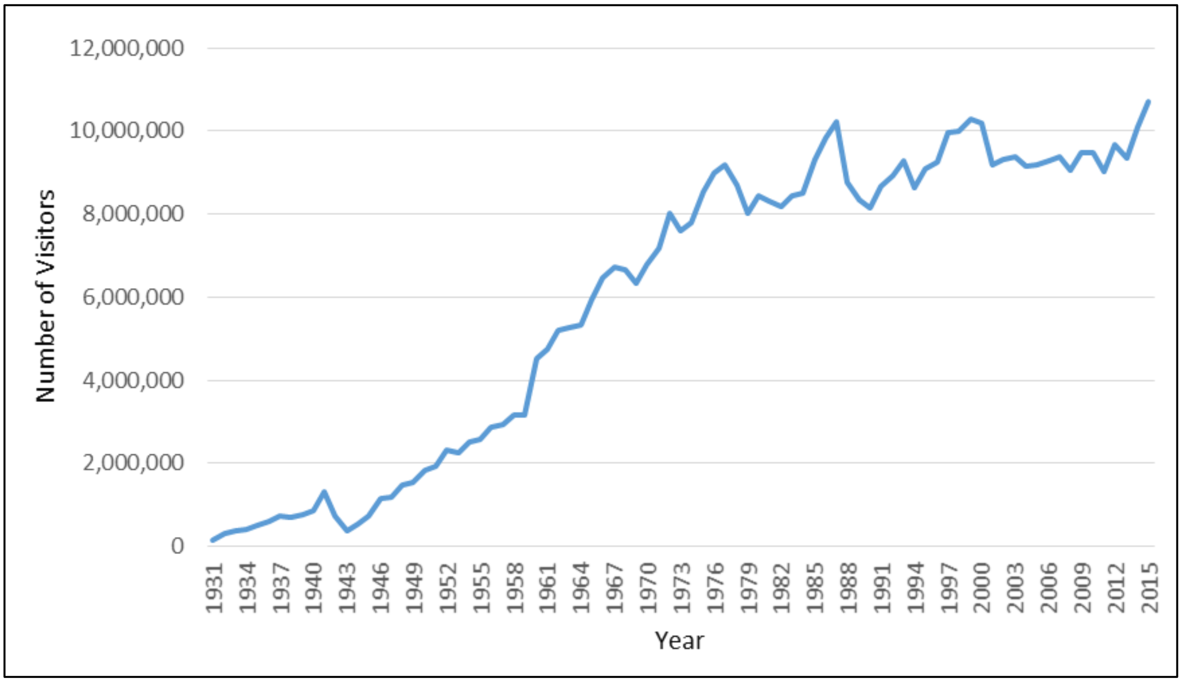

Figure 2.1.3.1. Number of visitors to GRSM from 1931 – 2015. Source: NPS 2015.

2.2. Natural Resources

2.2.1. Ecological Units and Watersheds

In 1995, the Environmental Protection Agency (EPA) collaborated with other federal agencies, state agencies, and groups from neighboring nations to develop a hierarchical spatial framework in which ecoregions are defined by ecosystems that are similar in character. The general purpose of these frameworks is to "…structure the research, assessment, monitoring, and ultimately the management of environmental resources (Griffith et al. 2002)."

The park lies in the southern Appalachian Mountains within the Level III Blue Ridge ecoregion (Fig. 2.2.1.1 inset) and the southern portion is characterized as "one of the richest centers of biodiversity in the eastern U.S.," with its large elevation gradients, varied aspects, and abundant annual precipitation totals. Appalachian oak forests, northern hardwoods, spruce-fir forests, shrub, grass, and heath balds, hemlock, cove hardwoods, and oak-pine communities are all significant vegetation communities (EPA 2013a).

On a finer scale, four separate Level IV ecoregions are represented within the park's boundaries (Fig. 2.2.1.1). The following Level IV ecoregions are listed in order of total area represented in the park starting with the largest:

- **Southern Metasedimentary Mountains** are characterized by steeply dissected mountains with geologic materials dating mostly to the late Precambrian period. The mountains are densely forested with Appalachian oak forests and, at higher elevations, northern hardwoods with a variety of oaks and pines, as well as silverbell (*Halesia tetraptera*), hemlock (*Tsuga canadensis*), tulip poplar (*Liriodendron tulipifera*), basswood (*Tilia americana*), yellow buckeye (*Aesculus flava*), yellow birch (*Betula alleghaniensis*), and American beech (*Fagus grandifolia*). The region supports complex and numerous plant communities and a great diversity of plant species.
- **The High Mountains** generally occur above 1,370 m (4,500 ft) and have a more boreal-like climate than the lower regions. Wind, ice, and frigid soils influence the vegetation, which includes red spruce (*Picea rubens*) and Fraser fir (*Abies fraseri*). Heath balds composed of evergreen rhododendron (*Rhododendron maximum*) and mountain laurel (*Kalmia latifolia),* and grassy balds of mountain oat grass and other herbaceous and shrub species are found on slopes and ridgetops. Other forests common in this ecoregion include red oak and northern hardwood forests.
- **The Limestone Valley and Coves** region is represented in small but distinct lowlands of the park. This region was formed about 450 million years ago when older Blue Ridge rocks were forced up and over younger rocks. In portions of the region, including the park, the Precambrian rocks have eroded through to Cambrian limestones, giving rise to fertile soils.
- **The Cades Cove area**, a historically significant settlement in the Smokies, lies in this subecoregion.
- **The Southern Sedimentary Ridges** region is represented in portions of the Foothills Parkway and generally occurs between 460 and 1,500 m (1,500 and 4,900 ft). Slopes tend to be steep and rocks are primarily Cambrian-age sedimentary. Soils are mostly friable loams and fine sandy loams and support mostly mixed oak and oak-pine forests.

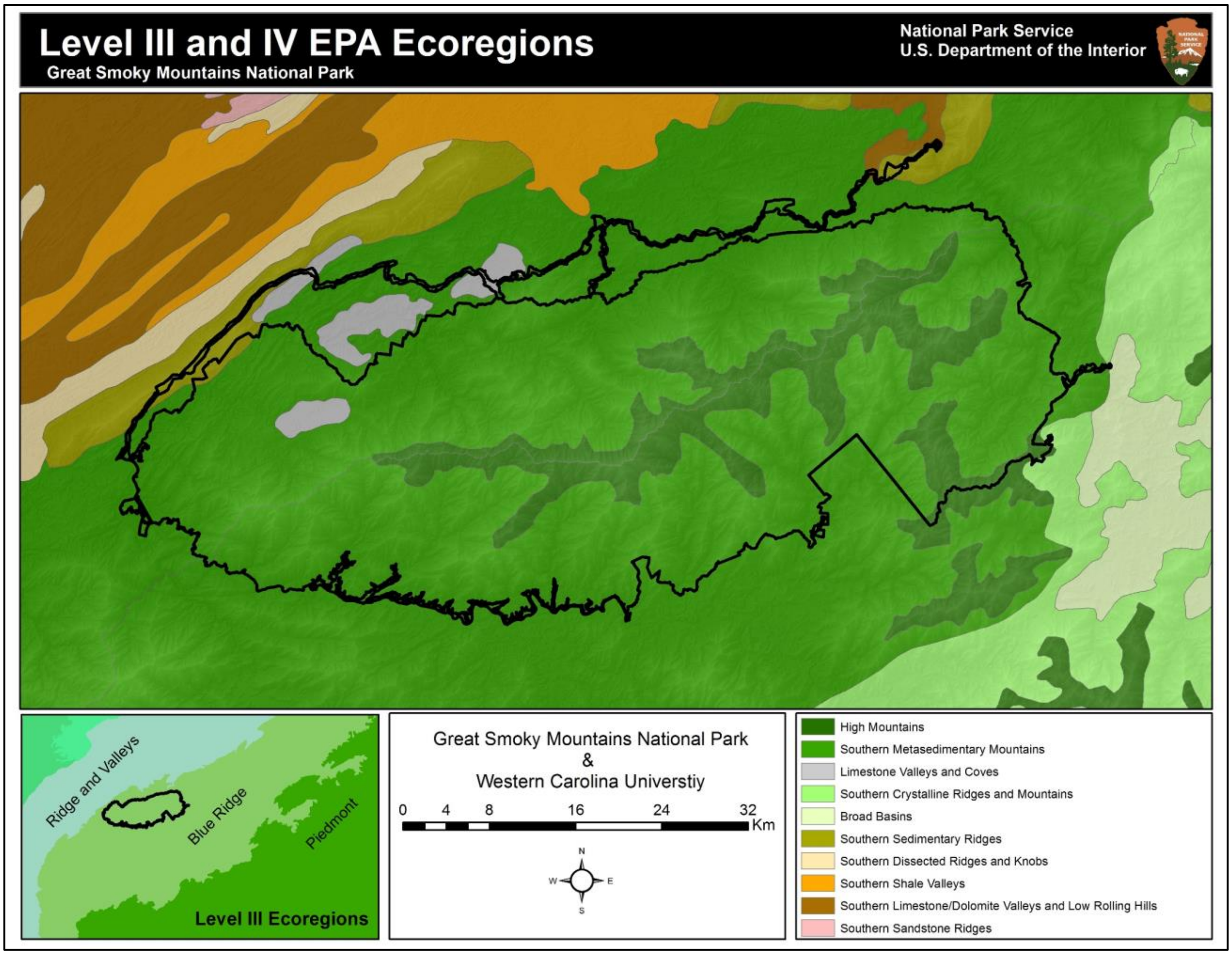

Figure 2.2.1.1. GRSM lies within the Level III Blue Ridge ecoregion and within four distinct Level IV ecoregions. Source: EPA 2013a.

Hydrology and Surface Water Dynamics

Great Smoky Mountains National Park possesses a total drainage area of approximately 14,000 km^2 (5,405 mi^2) in eastern Tennessee and western North Carolina, and is part of the Tennessee River basin. Contained within this area, there are more than 4,667 km (2,900 mi) of permanent streams, the majority of which are small, first order channels that head within the park (Fig. 2.2.1.2). Five of these streams (Abrams Creek, Little River, West Prong Little Pigeon River, Middle Prong Little Pigeon River, and Cataloochee Creek) have been designated as Outstanding Natural Resource Waters, by the TN Department of Environment and Conservation and the NC Department of Environmental Quality, whereas 12 have been listed on the 303d list by the EPA as impaired due to acidic conditions. Watersheds have been delineated within the park in different ways, depending on the purpose of the classification. Parker and Pipes (1990) subdivided the area into 45 distinct watersheds for management purposes, where the mouth of each watershed was defined on the basis of where its axial stream crossed the park boundary or where it encountered the normal pool levels of a Tennessee Valley Authority (TVA) reservoir to which it flowed. Many state and federal agencies utilize the U.S. Geological Survey (USGS) hierarchal hydrologic unit code (HUC) classification system. Using this approach, there are six HUC 8-digit sub-basins and 46 HUC 12-digit sub-watersheds within GRSM (Fig. 2.2.1.3).

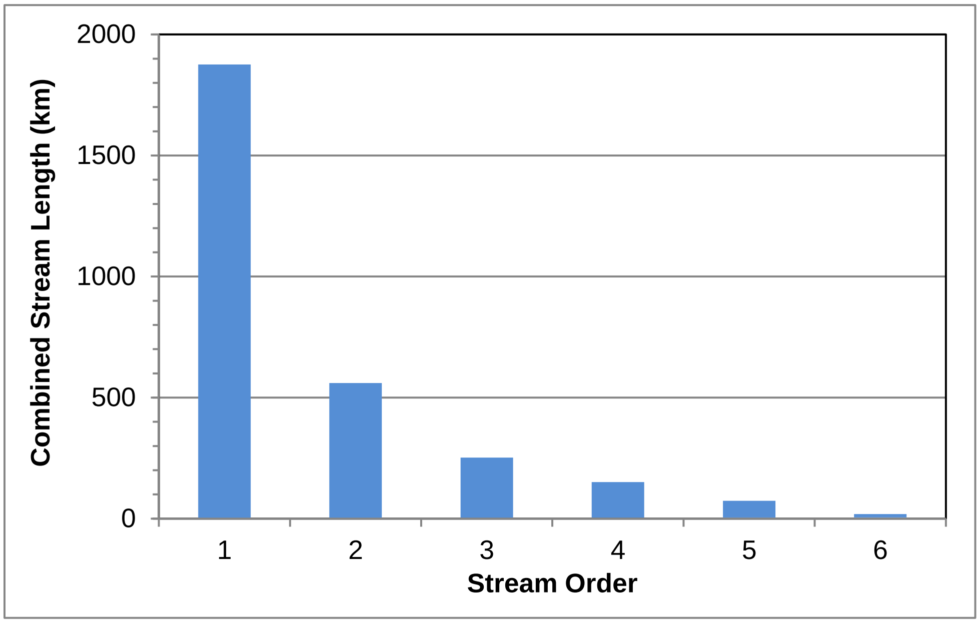

Figure 2.2.1.2. Combined lengths of streams of a given order within GRSM. Source: Nichols and Kulp 2015.

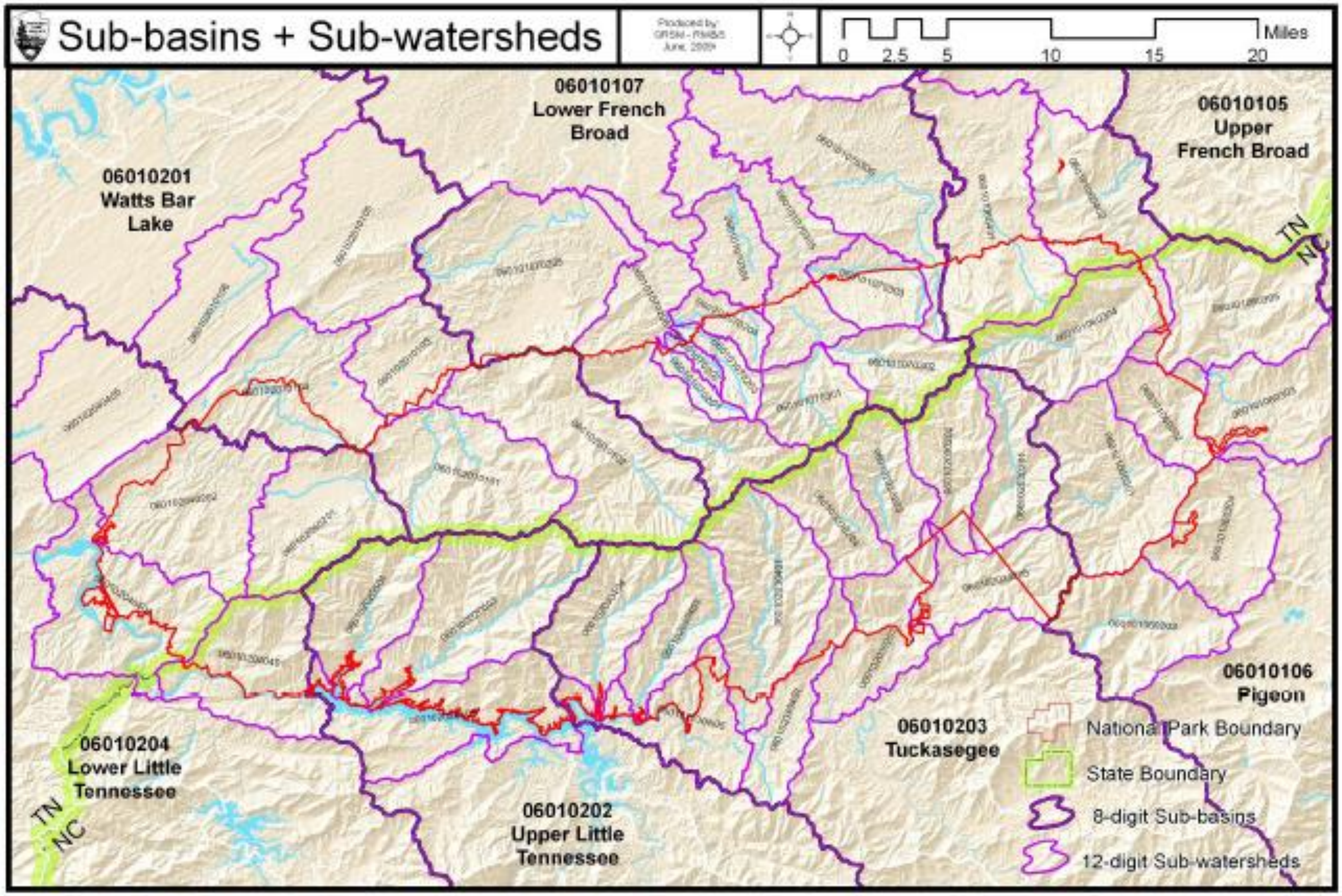

Figure 2.2.1.3. Locations of 8- and 12-digit HUC sub-basins and sub-watersheds within GRSM. Source: NPS ARD 2010.

As a result of high rainfall and snow pack accumulation, streams and rivers are subject to significant variations in flow. Seasonal variations in runoff are characterized by peak monthly flows occurring in late winter and early spring (February – March) and low flows occurring in late summer (July-August) (Fig. 2.2.1.4). Superimposed on these seasonal trends are significant variations related to short-term storm events. Many of these storms are associated with intense but local summer thunderstorms as well as larger-scale disturbances associated with the movement of tropical cyclones out of the gulf and across the southeastern U.S. (e.g., hurricanes Frances and Ivan in 2004 produced about 41 cm [16 in] of precipitation at the higher elevations of the Blue Ridge). Other floods are associated with rain on snow events.

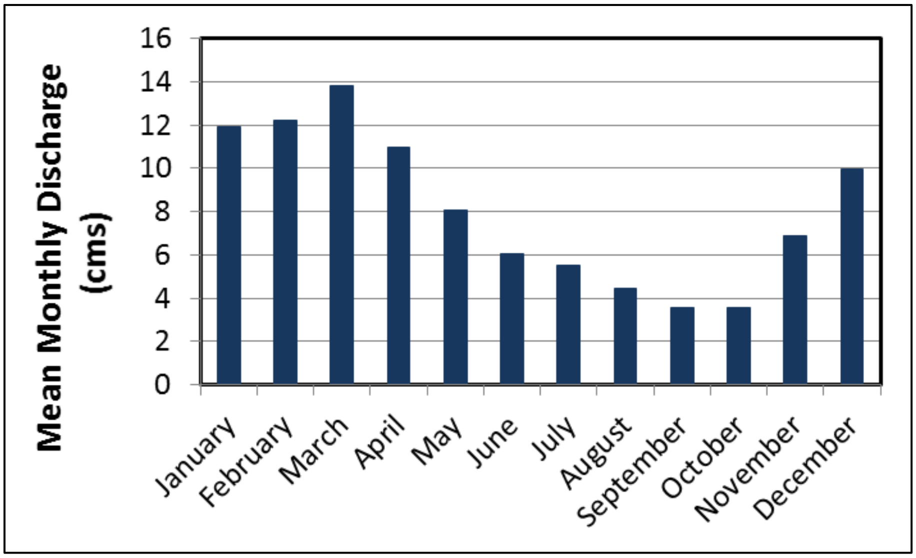

Figure 2.2.1.4. Mean monthly discharge (in cubic meters per second) calculated using data collected by USGS at the Little River gauging station above Townsend, TN, between October 1963 and October 2014.

During most storms, streams are fed primarily by a combination of interflow (i.e., the movement of water through the shallow subsurface), enhanced groundwater flow, and/or return flow. In spite of the dominance of these subsurface flow paths during most events, flood flows tend to be highly flashy in nature, producing dynamic stream systems characterized by high-gradient gravel bed channels.

Streams and rivers within the park are accompanied by many small wetlands which include bogs and vernal pools at lower elevations and springs and seeps at higher elevations (Emmott et al. 2005). Park staff have begun to inventory and characterize these wetlands - a task that has proven difficult as most wetlands are too small to be identified using remote sensing techniques. Existing data show that the hydrology as well as the structure and composition of wetland vegetation is highly variable from site to site, but most are characterized by open canopies and shallow waters. Vernal pools are particularly rare, but serve as important breeding habitats for many amphibians (Emmott et al. 2005). Several natural ponds also exist within the park, the majority of which are associated with meander cut-offs (oxbow lakes) or are related to sinkholes created by limestone solution (Langdon 2011).

Groundwater systems within the park have received very little attention to date. Early work by McMaster and Hubbard (1970) revealed that water yield is primarily controlled by the degree to which the bedrock is fractured and the thickness of the overlying regolith, both of which are concentrated along valley floors. With the exception of Cades Cove, water yielding fractures appear to occur above a depth of 91 m (300 ft). More recent studies by Mesko (1999) and Swain et al. (2004) have attempted to characterize water yield in the region in terms of hydrogeologic terrains (i.e., the nature of the bedrock). GRSM is predominantly located within the schist-sandstone geologic terrain, which is generally characterized by a water yield of 38 to 231 l (10 to 61 gal) per minute.

2.2.2. Resource Descriptions

Geology

Geology is a physical resource that influences much of the visitor experience, from landforms including waterways and knobs, to ecological and physical processes. The park identified the following issues as significant for geologic resources management:

- **Erosion and slope processes:** The wet climate and steep slopes make the Smokies susceptible to slides and slumps.
- **Abandoned mines:** Waste from mines abandoned years ago pose an environmental and human safety threat.
- **Biodiversity and geology:** The park's famous biodiversity is a direct result of geology and climate. Locating and managing species and understanding relationships between geology and biology are key management issue for the park.
- **Historical landscapes:** Geology influenced and shaped settlement patterns and attracted mining activities; it also can compromise historic architecture through weathering and erosion.

The Great Smoky Mountains are among the oldest in the world. The interaction of mountains, glaciers, and climate is a primary factor behind the park's rich biodiversity. The core of the Smoky Mountains was formed at least 1 billion years ago and consists of metamorphosed sedimentary and igneous rocks. The sedimentary rocks that were deposited over the older rocks were formed approximately 800 to 450 million years ago, as soils, silt, and gravel accumulated. Approximately 450 million years ago the rocks were metamorphosed by heat and pressure, and the last phase of Appalachian mountain building occurred 200 to 300 million years ago when the North American and African plates collided. This process uplifted the entire Appalachian Mountain chain from Canada to Georgia (USGS 2013). These series of geologic events have produced a highly complex lithology.

The park lies within the Blue Ridge physiographic province, formed largely during the Paleozoic era by tectonic shifting and faulting when the Blue Ridge was thrust to the northwest over the Ridge and Valley province (Fig. 2.2.2.1. inset). Although the park lies within the Blue Ridge province, its geology combines several aspects of the Piedmont and Valley & Ridge provinces which run parallel to the north and south of the park. For this reason, it is considered a geologically distinct subdivision as it represents a transition between that of the crystalline Appalachian provinces (Piedmont and Blue Ridge), and the sedimentary Appalachian Valley & Ridge and Cumberland Plateau (Thornberry-Ehrlich 2008) (Fig. 2.2.2.1). Although no glaciation occurred in the southern Appalachians, glaciers influenced the park's climate and produced alpine conditions in the upper elevations. Today periglacial features, including large boulder deposits, are present in the park.

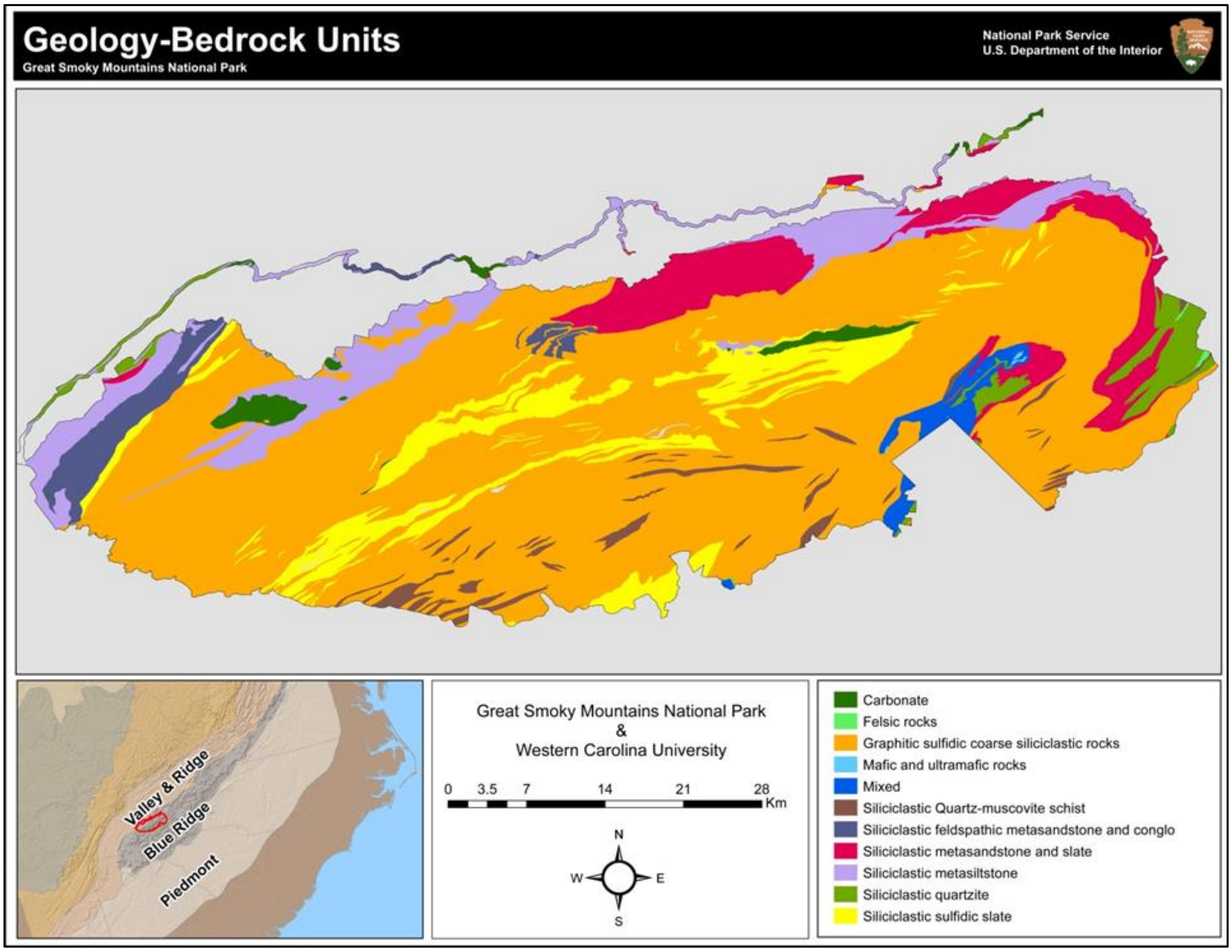

Figure 2.2.2.1. Geology-bedrock units of GRSM. Source: Southworth et al. 2005.

The exposed and near-surface bedrock and surficial material provide the foundation on which unique habitats and ecosystems exist in the park. The complex distribution of bedrock and surficial deposits, with accompanying geochemically diverse parent materials, are believed to strongly control some species distributions (Langdon et al. 2011). The park's bedrock units have been classified based on their chemical and residual units. The units comprise three major lithologic groups: (1) sedimentary and metasedimentary, (2) metamorphosed igneous rocks, and (3) unconsolidated surficial deposits. These bedrock units influence soil type, acid neutralization capacity of streams, and are potentially useful for better understanding plant and animal distributions (McNab 1996, Southworth 2001). The park's bedrock is diverse, consisting of metamorphosed sandstones, carbonate rocks, mineralized acidic slates, and small areas of metamorphosed igneous rocks (Southworth et al. 2005).

Within the park, surficial deposits (i.e., those deposits consisting of unconsolidated sediments) result from three primary agents and processes: running water, chemical and physical weathering, and gravity on slopes (Southworth et al. 2005). Seven generalized surficial units have been mapped in the Smokies and are classified as alluvium, terrace deposits, sinkholes, residuum, colluvium, debris flows, and debris fans.

Caves and Karst

Jennings (1985) defined karst as a “terrain with distinct landforms and drainage arising from greater rock solubility in natural water than is found elsewhere.” Inherent in this definition is the fact that karst is produced by solution processes that enlarge voids and fractures within the rock, thereby allowing large amounts of water to be funneled into the underground drainage system (Ritter et al. 2011). The diversion of water subsurface tends to enhance the solution processes, and in doing so develops a distinctive terrain that, within GRSM, is characterized by depressions (e.g., dolines/sinkholes, uvalas, etc.). Although karst may develop in any rock type given enough time and water, it is most often associated with carbonate rocks, particularly rocks that contain at least 50% carbonate minerals (mainly limestone and, to a lesser degree, dolomite).

The majority of GRSM is dominated by metamorphic rocks of Precambrian age (i.e., rocks of the Ocoee Supergroup, the Snowbird Group [Metcalf phyllite], and Great Smoky Group [Cades sandstone]). However, during formation of the Appalachian Mountains, these rocks were thrust up and over younger carbonate rocks of the Cambrian and Ordovician periods (which are about 450-500 million years old), including Jonesboro limestone (which actually contains some dolomite minerals) and Shady dolomite. Both Jonesboro limestone and Shady dolomite have been locally exposed by erosion of the older, overlying metamorphic rocks within and adjacent to the western portion of the park in Tennessee (Southworth et al. 2005). These exposed areas of carbonates form flat, often grassy valleys with steep sides that are referred to as ‘fensters’ or ‘windows.’ It is within these windows (floored by limestones and dolomites) that the karstic landforms have developed. There are five primary karst areas within the park, depending on how one defines them, including Cades Cove, Rich Mountain, Big Springs Cove, White Oak Sink, and Calderwood karst areas (Nolfi 2011, Soto 2013). In addition, the park manages a strip of terrain known as the Foothills Parkway (Fig. 2.2.2.2) which traverses several areas characterized by karst including the Walland, Wear Cove, Cosby, and Pigeon River karst areas (Nolfi 2011). The Cades Cove karst area, which encompasses approximately 13 km^2 (5 mi^2), is the largest area of karst within the park, and the most popular. In total, carbonate rocks that may be subjected to karstification cover an areas of about 18.5 km^2 (7 mi^2), or about 1% of the park (Langdon 2015).

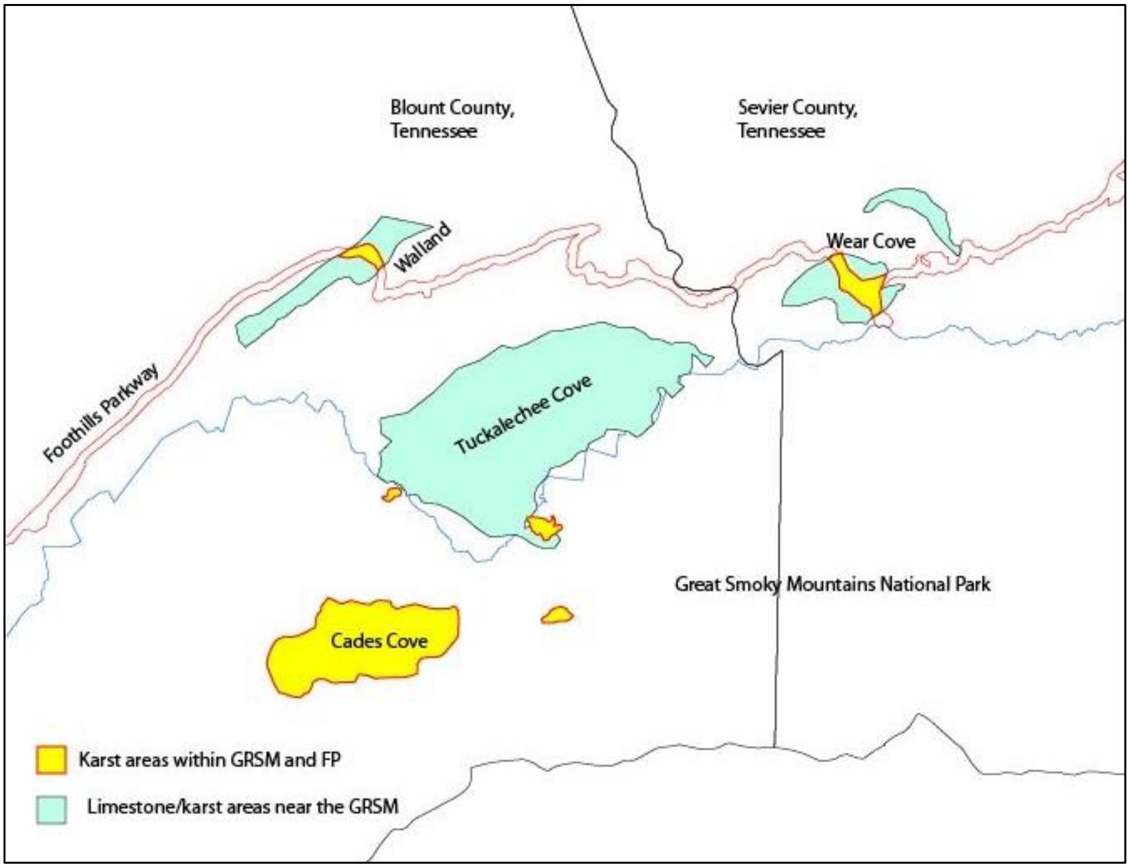

Figure 2.2.2.2. Locations of karst areas within GRSM, including the Foothills Parkway. Source: Kulp and Carmichael 2013.

The predominant landforms associated with karst areas within and adjacent to the park are closed, circular, or elliptical shaped depressions called sinkholes. Sinkholes are created by two distinct processes (although most are formed by a combination of the two processes). Solution sinkholes are formed by the progressive dissolution of the underlying rock along joints and fissures in the rock. A funnel-shaped sinkhole is formed because the solution process is most rapid near the ground surface and decreases with depth. Collapse sinkholes form as the 'roof' of a solution cavity within the rock fails and the overlying materials drop suddenly into the opening. Both types of sinkholes (solution and collapse) have been reported within GRSM. As sinkholes represent distinct avenues of inflow to the groundwater system, they represent important components of the subsurface drainage system.

In a recent study, Langdon (2015) developed a database of sinkholes within the park using a combination of field reconnaissance and LiDAR images. Eighty-four sinkholes were identified from nine different areas, and all but one was in either the Jonesboro limestone or the Shady dolomite (it is questionable whether the last sinkhole is of karstic origins). Sinkholes within the area generally range in diameter from about 2 m (6.5 ft) to as much as 305 m (1,000 ft), and Langdon (2015) found that about half of the known sinkholes exhibited a maximum depth of 2 m (6.5 ft). At least nine of the sinkholes are seasonally flooded, creating wetlands or ponds.

Other karst landforms included uvalas (typically formed by the coalescence of multiple sinkholes) and poljes (relatively large flat-floored depressions with steep sides). Springs are also abundant in some areas, such as the vicinity of Cades Cove.

To date, 16 solution caves have been identified within GRSM (including the Foothills Parkway), 12 of which are in the Cades Cove area. As subsurface features, they are technically not part of karst topography; however, they serve as an integral part of the drainage network, are formed by solution processes, and often lead to the formation of karst landforms. Thus, they are typically included in discussion of karst terrain.

Many of the caves in the region form along inclined bedding planes within the carbonate rock units or along thrust faults that occur within or between the units (e.g., the Great Smokies fault). Given the relief in the area, caves may descend significant distances before reaching base level (saturated conditions), typically set by the elevation of the predominant axial river channel. As a result, some of the deepest caves in the U.S. are found within the park. For example, the Bull Cave system, located near the crest of Rich Mountain at an elevation of about 579 m (1,900 ft) is characterized by a 43 m (140 ft) deep opening that leads to a 152 m (500 ft) deep shaft Its total known depth is 282 m (925 ft), making it the third deepest cave in the eastern U.S. and the 20th deepest cave in the U.S. (Nolfi 2011). While it is likely that most caves within and adjacent to the park have been identified and mapped, other types of physical and biological information on caves is limited, in part because cave access is difficult and restricted (Kulp et al. 2013).

Although karst and caves are limited within the park, they represent an important ecological resource. Biologically, about 270 organisms are associated with caves and karstic areas in GRSM, including salamanders, amphibians, and a variety of invertebrate cavernicoles, such as the endemic amphipod *Stygobromus fecundus*. Caves also serve as important hibernating areas for bats, including the federally endangered Indiana bat (*Myotis sodalis*).

Draft cave and karst management plans have been developed for the park in 1979, 1989, and the latest by Nolfi (2011). However, none of the plans were finalized because of an insufficient characterization and understanding of kart features and processes in the area. Efforts are currently underway to remedy this data gap, in part because there is significant concern that karst resources could be impacted by ongoing activities in the karst areas immediately adjacent to the park (and vice versa). Of particular concern is significant development in the Tuckaleechee Cove and Wear Cove areas (Fig. 2.2.2.2), as well in the Wears Valley section of the Foothills Parkway construction. Much of the development is occurring in areas lacking municipal sewer systems and domestic water supplies, and as a result, numerous groundwater wells are being developed in the karsted (limestone) aquifer adjacent to the park. In fact, TDEC reported that more than 7,000 wells were installed in Blount and Sevier counties. It is possible that the increased number of wells in the area may lead to lower groundwater levels and a reduction in the movement of water through the caves. The latter is essential to cave biota and cave formations (speleothems). Moreover, groundwater wells in the Cades Cove area serve as the water supply for the 2 million people who visit the area annually.

Contamination of the karst aquifer(s) by the widespread use of septic systems, the future development of oil shales, and other forms of anthropogenic pollution adjacent to the park is also of concern. The movement of water and contaminants through fractures and enlarged openings in the rock, including sinkholes, make these limestone aquifers particularly susceptible to widespread contamination.

Soils

In addition to serving as a medium for plant growth, soils play a critical role in maintaining ecological health. Natural biodiversity, plant productivity, carbon sequestration, and the ability to buffer acids and store toxins are largely dependent on soil properties (NPS 2011b). Soils reflect how the geologic or organic materials in which they formed have been modified by climate, topography, and biological organisms over time. Less than 1% of soils in the park formed in organic materials scattered throughout the higher elevations. The remaining soils formed in geologic formations dominated by Precambrian sandstone, but also include areas of acidic Anakeesta formations (rich in pyrite) and a few areas of Ordovician limestones (Southworth et al. 2005). Relief in the park varies greatly, and influences drainage, surface runoff, temperature, and the extent of geologic erosion, thus influencing soil formation and soil type.

The climate in the park varies greatly in relation to landscape position and elevation, and the interaction of time (age) and temperature contribute to the formation of variable soil profiles. The higher precipitation and colder temperatures in high elevations produce medium-textured brown soils high in organic matter in the surface layer. Lower portions of the park with milder microclimates produce redder soils resulting from more clay in the subsoil. Plants and animals are the primary source of organic material in the soils, and in the Smokies, soils formed under a hardwood forest below 1,280 m (4,200 ft) and under a mixed hardwood and coniferous forest above 1,280 m (4,200 ft). The differing natures of the forest types influence the soil with different types of organic matter inputs.

The 2009 soil survey for the park identified 64 unique soil series in the park that were grouped into 15 general soils units (Fig. 2.2.2.3) (USDA NRCS 2009). Each of these general map units and the landscapes where they are found are discussed below.

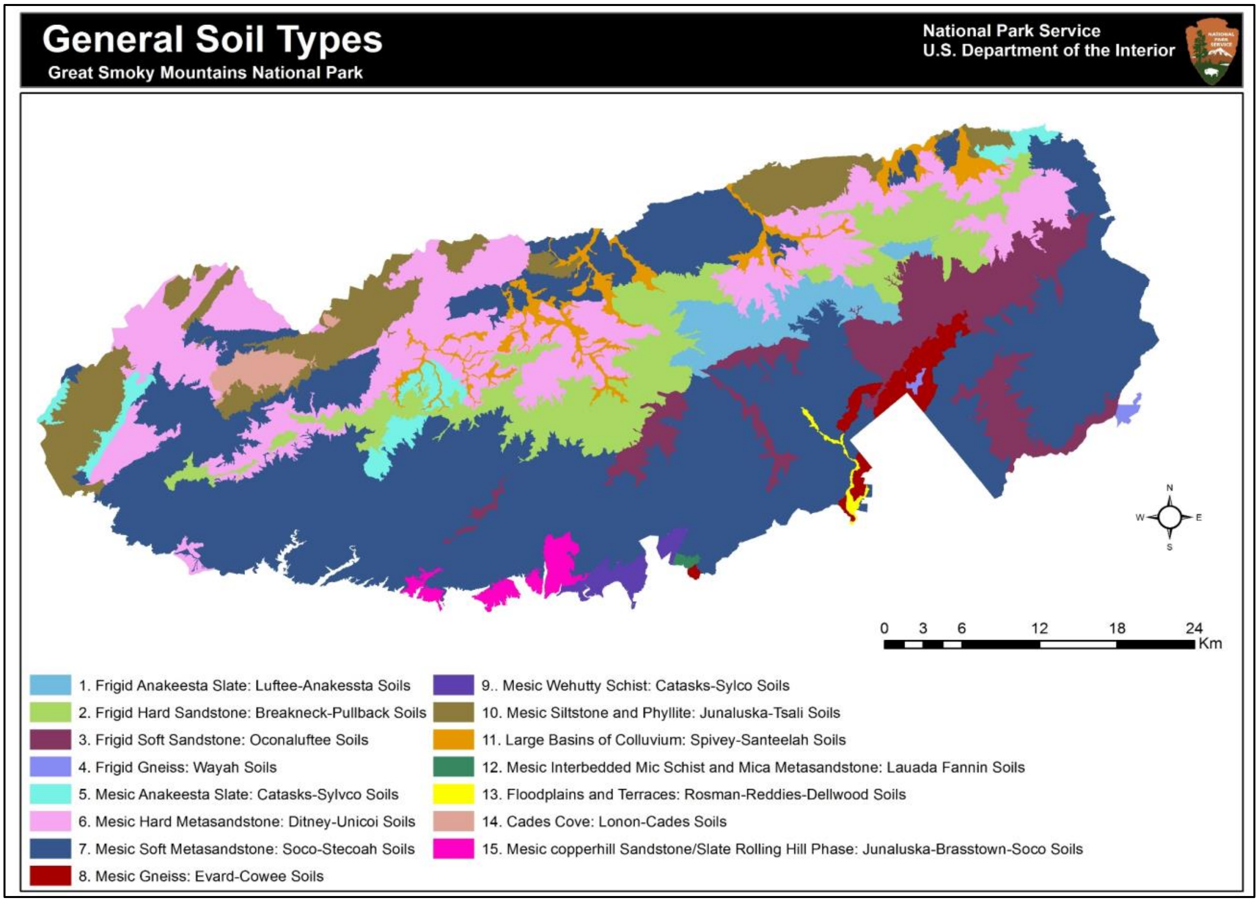

Figure 2.2.2.3. General soil types found within GRSM. Source: NPS 2009.

Frigid Anakeesta Slate: Luftee-Anakeesta Soils

This general soil map unit consists of black slates (Anakeesta; Fig. 2.2.2.4) in areas at elevations of more than 1,280 m (4,200 ft) in watersheds draining north to east and in areas at elevations of more than 1,402 m (4,600 ft) in watersheds draining south to west. It is associated with black slate which is interbedded with some massive metasandstone. It also includes the chloritoid slate found on Mount LeConte. This unit is commonly covered with red spruce and Fraser fir. Some areas are covered in northern hardwoods, such as northern red oak (*Quercus rubra*), yellow birch, sweet birch (*Betula lenta*), American beech, and sugar maple (*Acer saccharum*). Understory plants are commonly sparse under pure northern hardwoods. Laurel and rhododendron commonly dominate and form heath balds.

Figure 2.2.2.4. An exposure of the Anakeesta slate formation as viewed from the Alum Cave Bluff trail in GRSM. Source: NRCS 2009.

Soils in this general soil map unit are very low in plant macro-nutrients. This landscape has very low vigor and productivity. Upland soils, landslides, and heath balds comprise more than 99% of the landscape, and the colluvial soils less than 1%. For the most part, upland soils range from deep to moderately deep. The risk of exposing pyrite to the environment is high, the risk of stream acidification is high, and the risk of landslides is high.

Frigid Hard Sandstone: Breakneck-Pullback Soils

This general soil map unit consists of hard metasandstone (Thunderhead) in areas with elevations of more than 1,280 m (4,200 ft) in watersheds draining north to east and in areas at elevations of more than 1,402 m (4,600 ft) in watersheds draining south to west. It is associated with massive metasandstone which is interbedded with some black slate. There is some pyrite in the metasandstone, but most is associated with the black slate. This unit is most commonly covered with red spruce and Fraser fir on the ridges and side slopes, and the understory is often sparse. Incorporated in this unit are heath balds, and the colluvial part of this landscape is covered with northern hardwoods, such as northern red oak, yellow birch, sweet birch, beech, and sugar maple.

Soils in this general soil map unit are very low in plant macro-nutrients. Plant vigor and productivity are moderate or low. Upland soils, rock outcrops, and heath balds comprise more than 95% of the landscape and the colluvial soils less than 5%. Upland soils range from moderately deep to shallow for the most part. The risk of exposing pyrite to the environment is moderate, the risk of stream acidification is moderate, and the risk of landslides is moderate.

Frigid Soft Sandstone: Oconaluftee Soils

This general soil map unit consists of soft metasandstone (Copperhill, Roaring Fork, and Elkmont) in areas at elevations of more than 1,280 m (4,200 ft) in watersheds draining north to east and in areas at elevations of more than 1,402 m (4,600 ft) in watersheds draining south to west. It is associated with soft metasandstone with varying amounts of black slate. Northern hardwoods are the most common cover and include northern red oak, yellow birch, sweet birch, beech, maple, black cherry (*Prunus serotina*), yellow buckeye (*Aesculus flava*), and serviceberry (*Amelanchier* spp.). Red spruce and Fraser fir cover does occur, but there are commonly mixed stands of spruce/fir and northern hardwoods. Heath balds are common and are generally confined to windswept ridgetops.

Soils in this general soil map unit are low in plant macro-nutrients. Except for the windswept areas, this landscape has moderate or high vigor and productivity. Upland soils, rock outcrops, and heath balds comprise more than 85% of the landscape, and the colluvial soils less than 15%. Upland soils range from very deep to moderately deep for the most part. The risk of exposing pyrite to the environment is low, the risk of stream acidification is moderate, and the risk of landslides is low.

Frigid Gneiss: Wayah Soils

This general soil map unit consists of gneiss (biotite granitic gneiss) in areas at elevations of more than 1,402 m (4,600 ft) in watersheds draining south to west. It is associated with biotite granite gneiss. It is interlayered with biotite gneiss, amphibolite, and calc-silicate granofels. Climax vegetation is generally northern hardwoods, such as northern red oak, yellow birch, sweet birch, beech, maple, black cherry, buckeye, and serviceberry. There are some mixed stands of spruce/fir and northern hardwoods, and rhododendron and red spruce cover is found in some hanging coves. Heath balds are extremely rare.

Soils in this general soil map unit have a moderate amount of plant macro-nutrients. Except for the part that is windswept, the landscape has moderate or high vigor and productivity. Upland soils comprise more than 85% of the landscape, and the colluvial soils less than 15%. Upland soils range from very deep to moderately deep for the most part. There is no risk of exposing pyrite to the environment, and there is no risk of stream acidification. The risk of landslides is low.

Mesic Anakeesta Slate: Cataska-Sylco Soils

This general soil map unit consists of black slates (Anakeesta) areas at elevations of less than 1,280 m (4,200 ft) in watersheds draining north to east and in areas at elevations of less than 1,402 m (4,600 ft) in watersheds draining south to west. It is most commonly associated with black slates. This landscape is most commonly covered with oak-hickory-yellow pine on the ridges and side slopes. Various other species may occur or dominate at any given spot on the uplands, such as white pine (*Pinus strobus*), laurel, black locust (*Robinia pseudoacacia*), red maple (*Acer rubrum*), and sourwood (*Oxydendrum arboreum*). Various other species may occur or dominate at any given spot in the colluvium, such as northern red oak, sweet birch, black cherry, and white pine. Understory plants are often sparse. Laurel and rhododendron often dominate and form heath balds.

Soils in this general soil map unit are very low in plant macro-nutrients. Plant vigor and productivity are very low. Upland soils, landslides, and heath bald comprise more than 98% of the landscape, and the colluvial soils less than 2%. Upland soils range from moderately deep to shallow for the most part. The risk of exposing pyrite to the environment is high, the risk of stream acidification is high, and the risk of landslides is high.

Mesic Hard Metasandstone: Ditney-Unicoi Soils

This general soil map unit consists of hard metasandstone (Thunderhead) in areas at elevations of less than 1,280 m (4,200 ft) in watersheds draining north to east. It is associated with hard massive metasandstone which is interbedded with black slate. This landscape is most commonly covered with oak-hickory-yellow pine on the ridges and side slopes. The main exception is on the east- to north-facing, very steep-sided slopes where a cover of northern hardwoods and hemlock-white pine-rhododendron dominates. Various other species may occur or dominate at any given spot on the uplands, such as white pine, laurel, black locust, red maple, and sourwood. The colluvial part of this landscape is most often covered in tulip poplar. Various other species may occur or dominate at any given spot in the colluvium, such as northern red oak, sweet birch, black cherry, hemlock, black locust, Fraser magnolia (*Magnolia fraseri*), beech, white pine, and silverbell.

Soils in this general soil map unit are very low in plant macro-nutrients. Plant vigor and productivity are moderate or low. Upland soils and rock outcrops comprise more than 80% of the landscape, and the colluvial and shaded head slopes soils less than 20%. Upland soils range from moderately deep to shallow for the most part. The risk of exposing pyrite to the environment is moderate, the risk of stream acidification is moderate, and the risk of landslides is moderate.

Mesic Soft Metasandstone: Soco-Stecoah Soils

This general soil map unit consists of soft metasandstone (Copperhill, Roaring Fork, Elkmont, Wading Branch, Longarm, and Wehutty) areas at elevations of less than 1,280 m (4,200 ft) in watersheds draining north to east and in areas at elevations of less than 1,402 m (4,600 ft) in watersheds draining south to west. It is associated with soft metasandstone with varying amounts of black slate. This landscape is most commonly covered with oak-hickory-yellow pine on the hot ridges and side slopes. The main exception is on the east- to north-facing, very steep-sided slopes where a cover of northern hardwoods and hemlock-white pine-rhododendron dominates. Various other species may occur or dominate at any given spot on the hot uplands, such as white pine, laurel, black locust, red maple, and sourwood. The colluvial and shaded head slope areas are most often covered in tulip poplar. Various other species may occur or dominate at any given spot in the colluvium and on shaded head slopes, such as northern red oak, sweet birch, black cherry, hemlock, basswood, black locust, Fraser magnolia, beech, white pine, white ash (*Fraxinus americana*), silverbell, and black walnut (*Juglans nigra*). Heath balds are common and are generally confined to windswept ridgetops.

Soils in this general soil map unit are very low in plant macro-nutrients. This landscape has high vigor and productivity. Warmer upland soils, heath balds, and rock outcrops comprise more than 75% of the landscape, and the colluvial and shaded head slope soils less than 25%. Upland soils are deep and moderately deep for the most part. The risk of exposing pyrite to the environment is low, the risk of stream acidification is moderate, and the risk of landslides is low.

Mesic Gneiss: Evard-Cowee Soils

This general soil map unit consists of gneiss (biotite granitic gneiss) in areas at elevations of less than 1,280 m (4,200 ft) in watersheds draining south to west. It is associated with biotite granite gneiss and is interlayered with biotite gneiss, amphibolite, and calc-silicate granofels. This landscape is most commonly covered with oak-hickory-yellow pine on the ridges and side slopes. The main exception is on the east- to north-facing, very steep-sided slopes where a cover of northern hardwoods and hemlock-white pine-rhododendron dominates. Various other species may occur or dominate at any given spot on the warm uplands, such as white pine, laurel, black locust, red maple, and sourwood. The colluvial and shaded side slope areas are most often covered in tulip poplar. This is a rare/unique habitat in the park where plant vigor and productivity are high. Various other species may occur or dominate at any given spot on the colluvium and shaded side slopes, such as northern red oak, sweet birch, black cherry, hemlock, basswood, black locust, Fraser magnolia, beech, white pine, silverbell, and black walnut. Rhododendron and white pine or hemlock cover is found in some hanging coves.

Soils in this general soil map unit have a moderate amount of plant macro-nutrients. The majority of this landscape has moderate plant vigor and productivity; however, shaded side slopes and colluvium have some of the highest plant vigor and productivity measured in the park. Hot upland soils comprise more than 70% of this landscape, and the shaded side slopes and colluvial soils less than 30%. Hot upland soils range from very deep to moderately deep for the most part. There is no risk of exposing pyrite to the environment, and there is no risk of stream acidification. The risk of landslides is low.

Mesic Wehutty Schist: Cataska-Sylco Soils

This general soil map unit consists of black schist (Wehutty) in areas at elevations of less than 1,402 m (4,600 ft) in North Carolina. It is mostly associated with black graphitic, sulfidic schist. This landscape is most commonly covered with oak-hickory-yellow pine on the ridges and side slopes. Various other species may occur or dominate at any given spot on the uplands, such as white pine, laurel, black locust, red maple, and sourwood; understory plants are often sparse. Laurel and rhododendron may dominate and form heath balds, and the colluvial part of this landscape is most often covered in tulip poplar. Various other species may occur or dominate at any given spot in the colluvium, such as northern red oak, sweet birch, black cherry, and white pine

Soils in this general soil map unit are very low in plant macro-nutrients. Plant vigor and productivity are very low; only the colluvial part of landscape has good vigor and productivity. Upland, residual soils dominate this landscape, and range from moderately deep to shallow for the most part. The risk of exposing pyrite to the environment is moderate, the risk of stream acidification is moderate, and the risk of landslides is moderate.

Mesic Siltstone and Phyllite: Junaluska-Tsali Soils

This general soil map unit consists of siltstone and phyllite (Pigeon siltstone and Metcalf phyllite) in areas at elevations of less than 1,280 m (4,200 ft) in Tennessee. It is most commonly associated with siltstone and phyllite but could be applied to any thinly bedded rock with little or no pyrite, such as argillites and slate. This landscape is most commonly covered with oak-hickory-yellow pine on the ridges and side slopes. The main exception is on the east- to north-facing, very steep-sided slopes, where a cover of northern hardwoods and hemlock-white pine- rhododendron dominates. Various other species may occur or dominate at any given spot on the uplands, such as white pine, laurel, black locust, red maple, and sourwood. The colluvial and shaded head slope areas are most often covered in tulip poplar. Various other species may occur or dominate at any given spot on the colluvium and shaded head slopes, such as northern red oak, sweet birch, black cherry, hemlock, basswood, black locust, Fraser magnolia, beech, white pine, silverbell, and black walnut. Laurel and rhododendron dominate and form heath balds.

Soils in this general soil map unit are low in plant macro-nutrients. This landscape has low vigor and productivity; only the shaded head slopes and colluvial areas of the landscape have good vigor and productivity. Hot upland soils comprise more than 90% of the landscape, and the shaded head slope and colluvial soils less than 10%. Hot upland soils range from deep to shallow and comprise more than 85% of the upland, and the shallow soils less than 15%. The risk of exposing pyrite to the environment is low, the risk of stream acidification is low, and the risk of landslides is moderate.

Large Basins of Colluvium: Spivey-Santeetlah Soils

This general soil map unit consists of large basins of colluvium in areas at elevations of less than 1,280 m (4,200 ft) in Tennessee. It is associated largely with colluvium from hard metasandstone (Thunderhead) but has varying amounts of colluvium from any of the following formations: Roaring Fork, Elkmont, Wading Branch, Longarm, Pigeon siltstone, and Metcalf phyllite. This landscape is most commonly covered in tulip poplar. Various other species may occur or dominate at any given spot, such as northern red oak, white oak, hickory (*Carya* spp.), sweet birch, black cherry, hemlock, basswood, black locust, Fraser magnolia, beech, white pine, silverbell, and black walnut. Rhododendron can form small thickets.

This landscape has old farmstead sites and has very high vigor and productivity. Spivey and Santeetlah soils are mapped in a complex and are the dominant soils in this general soil map unit. On slopes of less than 15%, Nowhere soils comprise up to 15% of the unit and are added to the Spivey-Santeetlah complex. Water tables range from a depth of 30 cm (12 in) to more than 152 cm (60 in). There is no risk of exposing pyrite to the environment, and there is no risk of stream acidification. The risk of landslides is none.

Mesic Interbedded Mica Schist and Mica Metasandstone: Lauada-Fannin Soils

This general soil map unit consists of interbedded schist and micaceous metasandstone in areas at an elevation of less than 1,402 m (4,600 ft) in North Carolina. It is most commonly associated with interbedded schist and micaceous metasandstone. This unit is adjacent to the biotite granitic gneiss unit. This landscape is most commonly covered with oak-hickory-yellow pine on the ridges and side slopes. Various other species may occur or dominate at any given spot on the uplands, such as white pine, laurel, black locust, red maple, and sourwood. The colluvial part of this landscape is most often covered in tulip poplar. Various other species may occur or dominate at any given spot on the colluvium, such as northern red oak, sweet birch, black cherry, hemlock, basswood, black locust, Fraser magnolia, beech, white pine, silverbell, and black walnut. Laurel and rhododendron may dominate and form heath balds.

Soils in this general soil map unit are low in plant macro-nutrients. This landscape has low vigor and productivity; only the colluvial part of the landscape has good vigor and productivity. Warm upland soils comprise more than 90% of the landscape, and the shaded head slope and colluvial soils less than 10%. Hot upland soils range from very deep to moderately deep. The risk of exposing pyrite to the environment is low, the risk of stream acidification is low, and the risk of landslides is moderate.

Floodplains and Terraces: Rosman-Reddies- Dellwood Soils

This general soil map unit consists of floodplains and terraces in areas at elevations ranging from about 366 to 975 m (1,200 to 3,000 ft) (Fig. 2.2.2.5). Some of the floodplains and stream terraces are in tall fescue that is used as forage for wildlife or hay for livestock, or have been revegetated with trees. Stream terraces have many old farmstead sites, which commonly had apple, peach, cherry, plum, and pear trees. Wooded areas are most commonly covered in tulip poplar, and various other species may occur or dominate at any given spot, such as northern red oak, white oak, hickory, sweet birch, black cherry, hemlock, basswood, black locust, Fraser magnolia, beech, shortleaf pine (*Pinus echinata*), white pine, silverbell, sweetgum (*Liquidambar styraciflua*), and black walnut. Rhododendron can form small thickets. Some areas that have American sycamore (*Platanus occidentalis*) and river birch (*Betula nigra*) occur along streams.

Figure 2.2.2.5. A floodplain and stream terrace landscape near the Oconaluftee Visitor Center in GRSM. Source: NRCS 2009.

The floodplain areas have different soils depending on the depth of the fine-earth material over the gravel/cobble beds and the drainage class. There are three soils mapped where the fine-earth material is less than 51 cm (20 in) over the gravel/cobble beds: Dellwood, Smokemont, and Wesser. There are three soils mapped where fine-earth material is 51 to 102 cm (20 to 40 in) over the gravel/cobble beds: Cullowhee, Ela, and Reddies. There are two soils mapped where the fine-earth material is more than 102 cm (40 in) over the gravel/cobble beds: Biltmore and Rosman. Statler soils are mapped on the low stream terraces, which are elevated areas along present-day floodplains and are directly associated with modern-day stream systems. Plant vigor and productivity is very high. There is no risk of exposing pyrite to the environment, there is no risk of stream acidification, and there is no risk of landslides.

Cades Cove: Lonon-Cades Soils

This general soil map unit includes Cades Cove and Whiteoak Sink and is in areas at elevations of 518 to 610 m (1,700 to 2,000 ft) in Tennessee. The vegetation has been totally manipulated; the majority of the cove is in tall fescue that was used as pasture for livestock, although some areas are being managed for warm-season grasses. This landscape has old farmstead sites which commonly had apple, peach, cherry, plum, and pear trees. Wooded areas are dominated by oak-hickory-yellow pine, and some areas of sycamore and tulip poplar occur along the drainageways.

In this general soil map unit, the highest level above the floodplain is dominated by Lonon soils and is mainly an example of remnants of an old stream terrace system. The next lower level is a colluvial fan deposit that is dominated by Cades soils. The level just above the floodplain, which does not flood, is a series of stream terrace deposits that occur along the current drainageways, and the dominant soils are Allegheny and Cotaco. The floodplain is discontinuous in places, with Dellwood, Smokemont, Rosman, and Toxaway soils being found here. This area does flood for very brief duration in winter and during episodes of very intense rainfall. Plant vigor and productivity are very high. There is no risk of exposing pyrite to the environment, there is no risk of stream acidification, and there is no risk of landslides.

Mesic Copperhill Sandstone/Slate Rolling HillPhase: Junaluska-Brasstown-Soco Soils; Sandstone Portion of the Unit

This general soil map unit consists of soft sandstone (Copperhill) in areas at elevations of less than 793 m (2,600 ft) in North Carolina. It is associated with soft metasandstone with varying amounts of black slate. This landscape is most commonly covered with oak-hickory-yellow pine on the ridges and side slopes. The main exception is in the east- to north-facing gorges, where a cover of hemlock-white pine-rhododendron dominates. Various other species may occur or dominate at any given spot on the uplands, such as white pine, laurel, black locust, red maple, and sourwood. The colluvial part of this landscape is most often covered with tulip poplar, and various other species may occur or dominate at any given spot, such as northern red oak, sweet birch, black cherry, hemlock, basswood, black locust, Fraser magnolia, beech, white pine, silverbell, and black walnut.

Soils in this general soil map unit are very low in plant macro-nutrients. This landscape has low vigor and productivity; only the colluvial part of landscape has good vigor and productivity. Upland soils comprise more than 90% of the landscape, and the colluvial soils less than 10%. Upland soils range from deep to shallow. The risk of exposing pyrite to the environment is low, the risk of stream acidification is moderate, and the risk of landslides is low.

Mesic Copperhill Sandstone/Slate Rolling Hill Phase: Junaluska-Brasstown-Soco Soils; Slate Portion of the Unit

This general soil map unit consists of black slate (Copperhill) in areas at elevations of less than 793 m (2,600 ft) in North Carolina. It is mostly associated with black graphitic, sulfidic slate. This landscape is most commonly covered with oak-hickory-yellow pine on the ridges and side slopes. The main exception is in the east- to north-facing gorges, where a cover of hemlock-white pine-rhododendron dominates. Various other species may occur or dominate at any given spot on the uplands, such as white pine, laurel, black locust, red maple, and sourwood; understory plants are often sparse. The colluvial part of this landscape is most often covered in tulip poplar, and various other species may occur or dominate at any given spot, such as northern red oak, sweet birch, black cherry, and white pine.

Soils in this general soil map unit are very low in plant macro-nutrients. Plant vigor and productivity are very low; only the colluvial part of the landscape has good vigor and productivity. Upland soils comprise more than 95% of the landscape, and the colluvial soils less than 5%. Upland soils range from moderately deep to shallow for the most part. The risk of exposing pyrite to the environment is moderate, the risk of stream acidification is moderate, and the risk of landslides is moderate.

Flora and Fauna

Great Smoky Mountains National Park is known for its diversity, especially in the more charismatic groups such as vascular plants, salamanders, and birds. Efforts are currently underway to inventory every species from every taxa group that exists in the park. This project, referred to as an All Taxa Biodiversity Inventory (ATBI), began in 1998 and has resulted in nearly doubling the number of known species in the park. To date, there are 19,308 species known from park, of which 979 are new to science, and 9,135 are new records. Prior to the ATBI, the park knew of 9,194 species (ATBI 2016). Scientists estimate that there are 70,000 to 80,000 species of living organisms in the park. While most of the species are likely invertebrates, fungi, and unicellular organisms, they nonetheless provide a broader insight into ecological interactions and species' roles in an ecological context (White and Langdon 2006). Additionally, the Smokies contain several federally endangered and threatened species (Table 2.2.2.1).

The Smokies contain 68 mammal species, 249 birds, 72 native fish, and more than 80 species of reptiles and amphibians (NPS 2013a). The park's most recognizable and iconic mammal, the American black bear (*Ursus americanus*), can be found in wooded areas and dense brushlands at all elevations. There are approximately 1,500 black bears living inside park boundaries, all of which are black-colored and can reach 1.8 m (6 ft) in length and ~1 m (3 ft) in height at the shoulder. During summer months, male bears typically weigh approximately 113 kg (250 lbs) while females weigh slightly over 45 kg (100 lbs), although bears weighing over 270 kg (600 lbs) have been documented in the park. Life expectancy ranges between 12 and 15 yrs or more. During the colder months, bears in the Smokies den in hollowed out trees and may leave the den for short periods of time if disturbed or during periods of warmer temperatures (NPS 2013b).

Table 2.2.2.1. Park species listed as federally endangered or threatened. Source: NPS 2013f.

Major Group	Common Name	Scientific Name	Endangered (E) or Threatened (T)
Mammals	Carolina northern flying squirrel	*Glaucomys sabrinus coloratus*	E
	Northern long-eared bat	*Myotis septentrionalis*	T
	Indiana bat	*Myotis sodalis*	E
Fish	Citico darter	*Etheostoma sitikuense*	E
	Smoky madtom	*Noturus baileyi*	E
	Yellowfin madtom	*Noturus flavipinnis*	T
Arthropods	Spruce-fir moss spider	*Microhexura montivaga*	E
Plants	Spreading avens	*Geum radiatum*	E
	Virginia spiraea	*Spiraea virginiana*	T
Lichen	Rock gnome lichen	*Gymnoderma lineare*	E

Some of the other mammal species in the park include elk (*Cervus elaphus*), which were successfully reintroduced into the Cataloochee Valley in 2001 after a roughly 150-year absence from the park, white-tailed deer (*Odocoileus virginianus*), bobcat (*Lynx rufus*), red and gray foxes (*Vulpes vulpes* and *Urocyon cinereoargenteus*), coyotes (*Canis latrans*), raccoons (*Procyon lotor*), woodchucks (*Marmota monax*), 12 species of bats, and numerous other species. Of the 249 birds, 121 species breed in the park, including 52 species from the neo-tropics (NPS 2013c). Many other species use the park as a stopover and foraging area during their semiannual migrations. The park lists seven bird species as federal species of concern.

Over 1,600 vascular plant species have been identified in the park (of which less than a quarter are non-native), including 100 native tree species and over 100 native shrub species. Eighty-six of these vascular plant species are endemic to the southern Appalachians. The park contains over 80 state-listed plants, one federally endangered plant (spreading avens [*Geum radiatum*]), and one federally threatened plant (Virginia spiraea [*Spiraea virginiana*]). Federal species of concern include Fraser fir, Cain's reed-bent grass (*Calamagrostis cainii)*, mountain bittercress (*Cardamine clematitis*), Smoky Mountain manna grass (*Glyceria nubigena*), and Blue Ridge catchfly (*Silene ovata*) (NPS 2013f). The park also contains one of the largest tracts of primary forest in eastern North America. Additionally, the park is a global center for non-flowering plants including over 450 bryophytes (mosses, liverworts, and hornworts), and over 60 ferns and fern allies. There are 833 species of lichens currently known in the park, and one of these is a federally endangered species (rock gnome lichen [*Gymnoderma lineare*]).

The park's forest communities vary with respect to elevation and moisture, and moisture gradients are influenced by relief, slope degree, slope position, slope aspect, geology, soils, hydrology, and local and prevailing wind patterns. In combination, these two gradients generally influence forest community locations within the park where some communities overlap and other communities are disjunct on the gradient axes (Fig. 2.2.2.6). These complex ecological gradients combine to enable a diverse mosaic of plant communities in the park, making GRSM one of the most species-rich parks in the U.S.

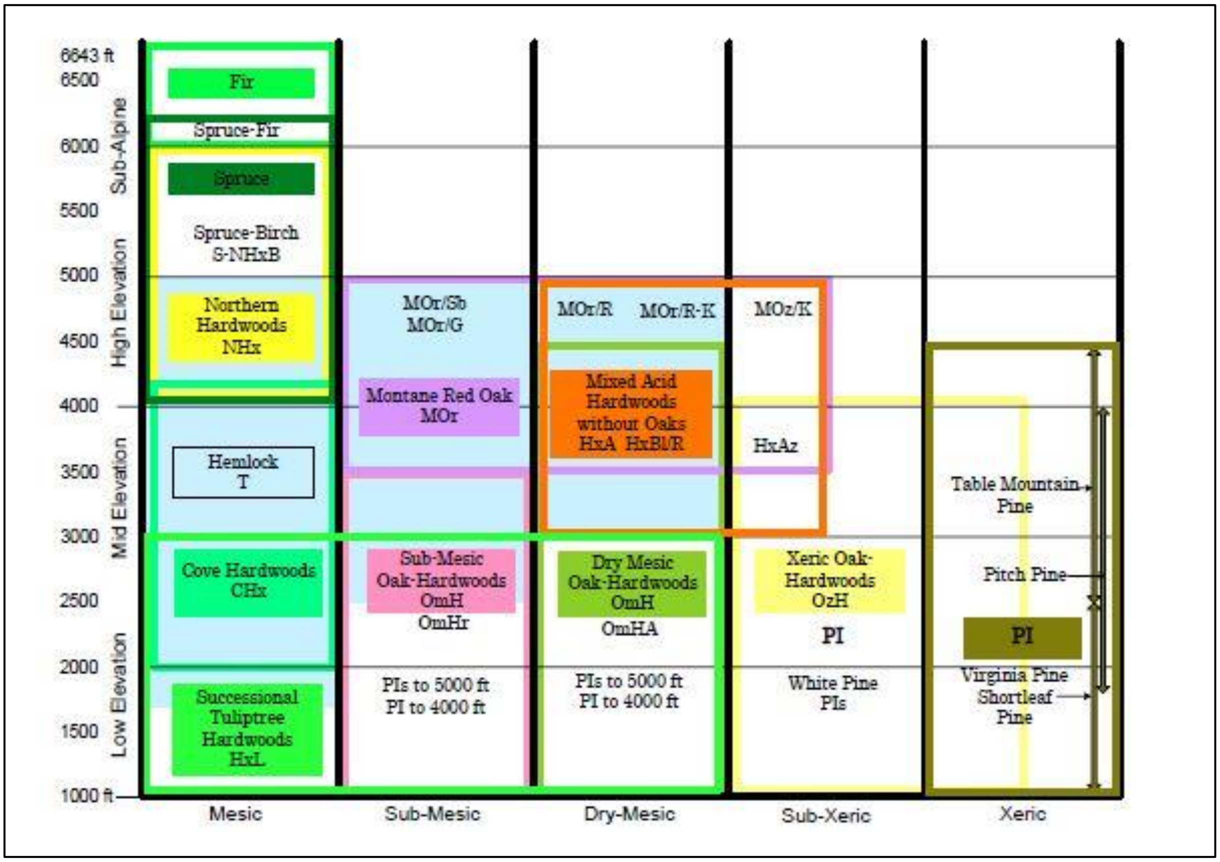

Figure 2.2.2.6. The park's highly variable physical characteristics give rise to a diverse assemblage of plant species. Forest communities are influenced by elevation and moisture gradients (x and y axis, respectively). Source: Used with permission from Madden et al. 2004.

Abbreviations for Figure 2.2.2.6 (Source: Madden et al., 2004 Attachment C, Digital Vegetation Maps for Great Smoky Mountains National Park):

S-NHxB: Red Spruce-Birch (Northern Hardwood)/Shrub/Herbaceous (4500-6000 ft)

NHx: Southern Appalachians Northern Hardwoods (4000-5500/6000 ft)

T: Eastern Hemlock/Rhododendron (1700-5000 ft)

CHx: Southern Appalachian Cove Hardwood Forests (2000-4000/4500 ft)

HxL: Tuliptree-Red Maple-Sweet Birch-(Black Locust)

MOr/Sb: Northern Red Oak/Deciduous Shrub-Herbaceous

MOr/G: Northern Red Oak/Graminoid-Herbaceous

MOr: Montane Northern Red Oak (3500-5000 ft)

OmH: Submesic to Mesic Oak/Hardwoods (1000-3500/4000 ft)

OmHr: Red Oak-(White Oak, Chestnut Oak, Scarlet Oak)-Hardwoods/Herbaceous, Rich Type (1800-3800 ft)

PIs: Eastern White Pine Successional

PI: Southern yellow pine species in xeric woodlands

MOr/R: Northern Red Oak/Rhododendron

MOr/R-K: Northern Red Oak/Rhododendron-Kalmia

HxA: Red Maple-Sweet Birch

HxBl/R: Southern Appalachian Sweet Birch/Rhododendron (2500-5000 ft)

OmHA: White Oak-(Red Oak-Chestnut Oak)-Hickory

MOz/K: Montane Xeric Northern Red Oak-Chestnut Oak-(White Oak)/Kalmia Woodland

HxAZ: Southern Appalachian Xeric Mixed Hardwoods, Acidic Red Maple-Sweet Birch-Fraser Magnolia-Black gum-Sourwood/Kalmia (HxAz at 2500-3500+ ft)

OzH: Chestnut Oak-Red Maple-Scarlet Oak/Mountain Laurel Xeric Ridge/Slope Woodland (below 4000 ft)

Within the park, 79 vegetation associations, which are defined as “a plant community of definite floristic composition, uniform habitat conditions, and uniform physiognomy” (Flahault and Schroter 1910, in Moravec 1993), have been identified for the purposes of describing, classifying, and ranking specific ecological community types (White et al. 2003). Of these 79 associations, approximately 25 are ranked as either G1 or G2 on a global scale of 1 through 5. A G1 ranking generally means that there are either five or fewer occurrences of the association, and/or very few remaining hectares (acres), or the association is very vulnerable to elimination throughout its range. Jenkins (2007) generalized the 79 vegetation communities into eight forested and three non-forested type communities based on similar species composition. Park staff further modified the communities by including wetlands and combining pine and oak forest types (Table 2.2.2.2). Overstory vegetation classes were developed by the Center for Geospatial Research, Department of Geography, University of Georgia (Fig. 2.2.2.7).

Table 2.2.2.2. Generalized vegetation communities and their stressors. Source: Jenkins 2007, Langdon et al. 2007.

General Vegetation Communities	Percent of Park Area	Dominant Species	Stressors
Oak/Pine Forests	47	*Quercus* spp., *Pinus* spp.	Fire exclusion, southern pine beetle, American chestnut loss
High-elevation Hardwood Forests	17	Yellow birch, American beech, northern red oak	Beech bark disease, hog damage, ozone, acid deposition
Cove Hardwood Forests	12	Sugar maple, yellow buckeye, American basswood, silverbell, eastern hemlock, tulip poplar, sweet birch, red maple	Ozone
High-elevation Spruce-Fir Forests	8	Fraser fir, red spruce	Balsam woolly adelgid, acid deposition, ozone, climatic stress
Early Successional Forests	5	Tulip poplar, black locust, Virginia pine	Ozone, southern pine beetle
Hemlock Forests	2	Eastern and Carolina hemlock	Hemlock woolly adelgid

Table 2.2.2.2 (continued). Generalized vegetation communities and their stressors. Source: Jenkins 2007, Langdon et al. 2007.

General Vegetation Communities	Percent of Park Area	Dominant Species	Stressors
Montane Alluvial Forests	1.3	American sycamore, tulip poplar, white ash	Development, emerald ash borer
Heath Balds	1	Ericaceous shrubs including catawba rhododendron	Stable but may be susceptible to landslides
Grasslands/Grassy Balds	<1	Variable composition	Invasive non-native plants and hogs
Wetlands	N/A	N/A	Non-native plants, hogs

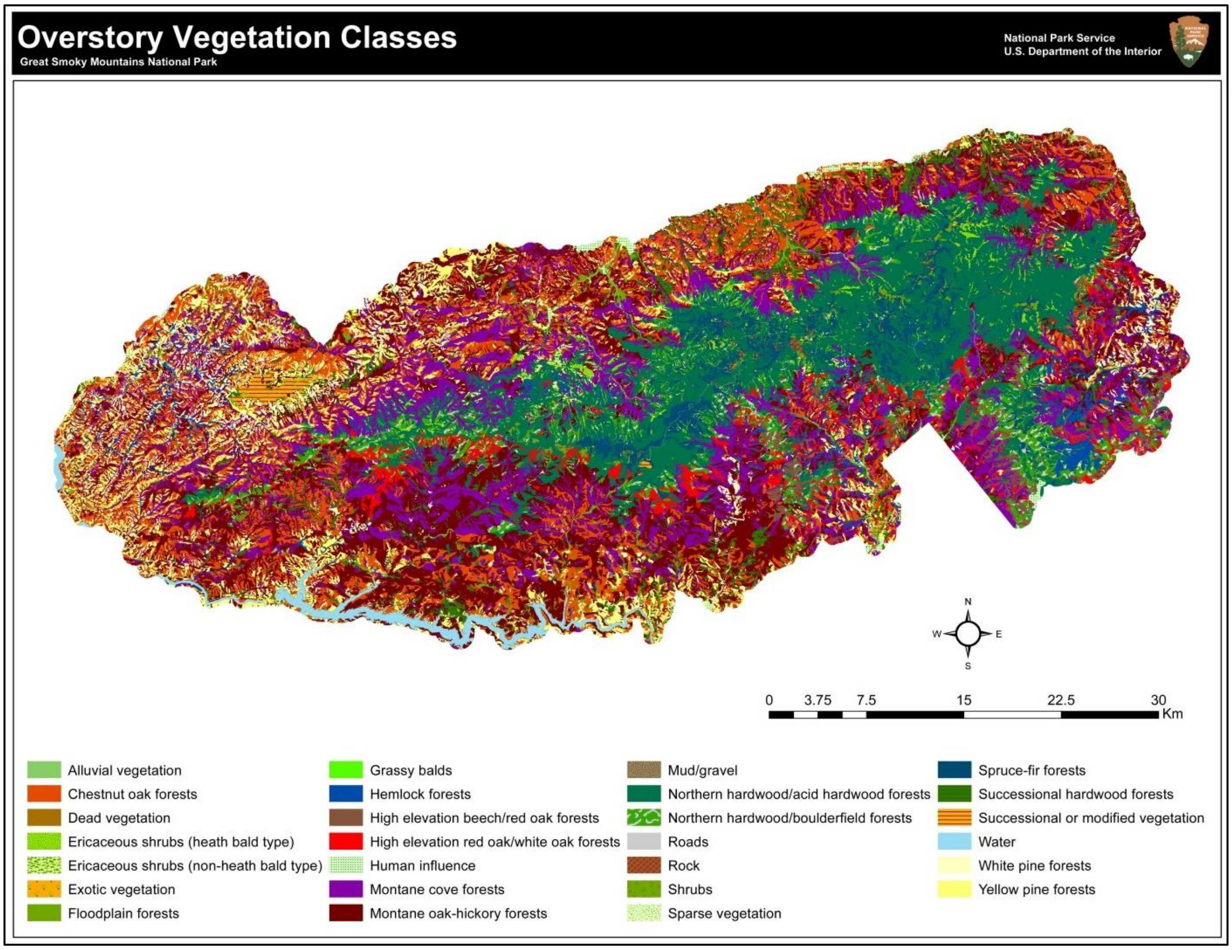

Figure 2.2.2.7. Overstory vegetation types that can be found in GRSM. Source: Center for Geospatial Research, Department of Geography, University of Georgia

2.2.3. Resource Issues Overview

Air Quality

Air pollution can significantly affect visitor enjoyment, public health, park resources, and ecological processes, from individual species to the ecosystem level. Specifically, air pollution can adversely impact water quality and soil pH, reduce tree productivity, growth, and species distribution, deteriorate cultural features, and impair visibility and human health (NPS 2011a). Great Smoky Mountains National Park experiences some of the highest measured air pollution of any national park in the U.S. (NPS 2013d). This is likely because the park is located downwind of many sources of air pollution; some of these sources are nearby, while others are more distant (e.g., industrial cities of the Southeast and Midwest).

Sources of pollution affecting air quality in GRSM include fossil fuel burning power plants, industry, and automobiles. The NPS has identified deposition of nitrogen (N), sulfur (S), and mercury (Hg), and concentrations of ozone and particulate matter, and their impacts on visibility, as air quality concerns for GRSM.

> *Air pollution from acid deposition has been shown to cause measureable effects on ecosystem structure and function (Likens and Bormann 1974); sulfate and nitrate wet deposition values recorded at monitors in GRSM indicate high levels, easily exceeding the ecological threshold and warranting significant concern for the park. Similarly, total mercury wet deposition in GRSM has been well above natural background levels since monitoring began in 2002, and it has been shown that atmospheric deposition of mercury can lead to contamination of aquatic systems, which can result in human health issues. Ozone has been recognized as the most widespread air pollutant in eastern North America, causing impacts to human health (EPA 1999), and although ozone levels are above suggested reference conditions, long-term trends suggest that they are improving. Particulate pollution is one of the most widespread human health threats, and is possibly a greater threat than ozone because it can occur at any time of the year (EPA 2013b). Most recent measurements are below the ecological threshold, but there is insufficient long-term data to suggest that this is the trend; therefore, particulate levels still warrant significant concern. Haze is a general term for one of the most basic forms of air pollution that degrades visibility across the landscape. Haze is particularly an issue in the eastern U.S., and the eastern Tennessee and western North Carolina regions in which GRSM is located has consistently experienced values well in excess of estimated natural conditions.*

Non-native plants and animals

Non-native, or exotic, animal and plant species threaten the park’s natural resources. Over 380 exotic plants have been documented in the Smokies, of which over 50 species offer some threat to native species and communities. The park has a history of past and current land use in the form of human settlement, logging operations, road and trail development, and recreational use. All of these activities have made the park vulnerable to invasive plant species. Common plant species such as kudzu (*Pueraria lobata*), mimosa (*Albizzia julibrissin*), and oriental bittersweet (*Celastrus orbiculatus*) are aggressive exotic invasives that quickly spread and outcompete native plants. The park focuses its efforts on eradicating those species that are an immediate threat to resources by using a system of integrated pest management - a combination of hand pulling and selective use of NPS-approved herbicides. See Section 4.4, Invasive Species, for further discussion.

Non-native insects and diseases

Since the park's inception, Eurasian forest insects and diseases have caused some of the greatest forest losses in the park's history. One example is the loss of the American chestnut in the early 20th Century (see Section 4.5.2, Oak-Hickory Forests). By the 1940s essentially all mature chestnut trees had succumbed to the chestnut blight caused by the bark-inhabiting fungus *Cryphonectria parasitica*. Today, chestnuts are only a minor component of the understory and may reach 20 to 25 cm (8 to 10 in) in diameter before succumbing to the blight.

Other insects and diseases that are affecting the Smoky Mountain forests today include beech bark disease (see Section 4.5.4, High-elevation Hardwood Forests), emerald ash borer, Dutch elm disease, butternut canker (see Section 4.5.5 Cove Hardwood Forests), balsam woolly adelgid (see Section 4.5.6, High-elevation Spruce-Fir Forests), thousand cankers disease (see Section 4.5.7, Early Successional Forests), and hemlock woolly adelgid (see Section 4.5.8, Hemlock Forests). Currently, the park's eastern hemlocks are suffering massive mortality from the hemlock woolly adelgid. These insects and diseases are monitored and treated, where treatment can be effective.

Climate Change

Climate is a dominant factor affecting natural and cultural resources in national parks. Climate constantly changes, but we may see changes of unprecedented magnitude in the near future. The Intergovernmental Panel on Climate Change (IPCC 2014) reviewed all global circulation models and concluded that warming over most land areas, with fewer cold days and more warm days, is virtually certain for the rest of the 21st century. There is uncertainty in model projections of the magnitude and timing of the warming trend, but there is agreement on the direction of the trend (IPCC 2014). In addition to temperature increases, climate change may bring unexpected and increased variations in local weather (IPCC 2014). Models predict more frequent occurrences of extreme weather events and these could alter the park's forest communities, stream flows, and fire regimes, and challenge the ability of park managers to preserve and protect natural and cultural resources (IPCC 2014).

There is concern about increased warming and the response of natural communities in the park. A number of taxa could be lost as communities follow their thermal requirements and/or hosts by moving into the increasingly smaller areas upslope, or as they fail to adapt and die. Initial analysis of data from the GRSM All Taxa Biodiversity Inventory (ATBI) indicates that for some groups of arthropods, which are by far the most species-rich group of multi-cellular life, population size increases with elevation (N. Sanders, pers. comm.). This means that a larger percentage of the park's species is more vulnerable than previously thought, as high-elevation micro-climates disappear. A number of endemic plant species could also be at risk, since the number of endemic species seems to increase with elevation as well. Currently we do not know to what degree climate change will affect the park's species and the ecological processes that sustain them. However, it is clear that changes are occurring.

Fridley (2009) has developed a temperature model of the park, which has been synchronized to the park's climate monitoring stations that have been operating since the 1930s, allowing backcasting as well as forecasting. Preliminary modeling shows that a rise in regional temperature may only slightly increase temperatures at the highest elevations in the park, due to increased orographic moisture (i.e., moisture from clouds that develop in response to being forced upwards over mountainous topography) cooling the landscape. If this hypothesis is correct, the temperature gradient will increase, and the greatest displacement of organisms may occur at lower elevations.

Like many areas in the U.S., GRSM is subject to strong environmental changes on an annual, multi-year, or decadal scale. There are many overlapping influences, indirect effects, and cycles, making the assignment of what is a natural driver and what is a human-induced stressor very difficult and controversial. Anthropogenic changes may also amplify or dampen natural cycles, obscuring what may be an important influence (Diffenbaugh et al. 2005). At the local level, these changes could alter many park ecosystem functions and natural attributes, including plant primary productivity, air quality, soil and water chemistry, vernalization, animal migration, sensitive habitat types, dates of first and last frost, increased drought occurrences, and increased storm/flooding severity and frequency. These changes may also alter natural ecosystem disturbance regimes (including fire and landslides), and can facilitate exotic species invasions, among many other potential impacts (Dale et al. 2001). In addition, changing climate attributes may cause indirect stresses on resources. For example, a plant with high moisture requirements may continue to receive the same amount of precipitation in its habitat, but if it warms, additional moisture will be required to compensate for increased evapotranspiration rates (Ibanez et al. 2007).

Night Skies

The loss of dark night skies has obvious impacts to star-gazing, but influences on nocturnal wildlife behavior (Longcore and Rich 2004) and adverse effects on human health (Bogard 2013) have also been documented. Two-thirds of Americans can’t see the Milky Way from their backyard, and 99% of Americans live in areas considered to be light polluted (Cinzano et al. 2001). At the rate light pollution is currently increasing, there will be almost no unimpaired night skies in the contiguous U.S. by 2025 (McFarland, pers. comm. 2016). Ecological impacts on wildlife include changes in: habitat quality for birds, terrestrial and marine mammals, fish, and sea turtles; nocturnal wildlife activity and behavior; migration patterns; and predator-prey interactions (Longcore and Rich 2004). Physiological impacts on the human body include sleep disorders, disruption of circadian rhythms, and disruption of melatonin production (Bogard 2013). Regulations that limit the intensity of night light are necessary in order to minimize the negative effects of artificial lighting on park resources and ecosystems.

Natural dark skies are a valued resource within the NPS, as reflected in NPS management policies (NPS 2006) which highlight the importance of a natural photic environment to ecosystem function, and the importance of the natural lightscape for aesthetics. The reference condition for natural sky brightness is necessary to maintain natural and cultural components of the special places harbored within national parks. When considering the entire sky, measurements obtained from both Cades Cove and Clingmans Dome indicate that the night sky is significantly brighter than average natural conditions. Little sense of naturalness remains in the night sky; the landscape is clearly shadowed or illuminated, and the horizon may appear aglow with anthropogenic light. According to Cinzano et al. (2001), night light pollution, particularly across the eastern U.S., is projected to increase, which can most likely be attributed to population growth and subsequent urban development.

Soundscapes

The soundscape of a national park is defined as the total ambient sound level of that park, which includes both natural ambient sound and human-made sounds (NPS 2000). The mission of the NPS is to preserve the natural resources associated with national park units, including the natural soundscape. According to the NPS, many visitors come to national parks to equally enjoy both the natural scenery and the natural soundscape, and undesirable sounds detract from their overall park experience (Gramann 1999).

Visitors to national parks often indicate that an important reason for visiting the parks is to enjoy the relative quiet that parks can offer. In a 1998 survey of the American public, 72% of respondents identified opportunities to experience natural quiet and the sounds of nature as an important reason for having national parks (Haas and Wakefield 1998). Additionally, 91% of NPS visitors consider enjoyment of natural quiet and the sounds of nature as compelling reasons for visiting national parks (McDonald et al. 1995). Despite this desire for quiet environments, anthropogenic noise continues to intrude upon natural areas and has become a source of concern in national parks (Lynch et al. 2011).

The reference condition for a soundscape in any national park is that of an area free from human-made sounds (e.g., vehicles, trains, air traffic, and other human uses), and consisting solely of natural sounds such as wind, water, and animal sounds (Ambrose and Burson 2004). Soundscape protocols have been developed by the NPS (2000), and as part of this protocol, selected locations have been identified for each park to help determine the soundscape status over a period of 1-10 years. The protocol also includes various metrics of natural ambient sound levels, natural sound frequencies, and sources of sounds. Additionally, the protocol addresses soundscape changes in the face of increasing visitor numbers and surrounding development. Ambient sound level data and data regarding the distribution of non-natural sounds have been collected in GRSM at seven locations to date. These data indicate that the acoustic impact level at the park is low, meaning that the condition of the acoustic environment is good. However, long-term projected increases in ground-based (U.S. DOT FHA 2016) and aircraft traffic (FAA 2016) indicate a deteriorating trend in the quality of acoustic resources at GRSM.

Fire management

Fire has long been a part of the Great Smoky Mountains National Park landscape. The legacy of fire is evident in the fossil pollen record, in charcoal dating, in tree-ring scars, and in written accounts (Fesenmyer and Christensen 2010, Underwood 2013, Aldrich et al. 2014). Perhaps the most compelling evidence of past fires is the contemporary vegetation of the park, which exhibits traits that have evolved over millions of years with naturally occurring fire. Adaptations to fire such as sprouting, cone serotiny, thick bark, pyrogenic foliage, and nitrogen fixation are features of species found on dry, exposed ridges and slopes throughout the park. Soil charcoal and tree-ring data suggest that natural communities dominated by pine and oak have been maintained on the landscape for thousands of years by a regime of frequent, low- to moderate-intensity fire. Fire is recognized as a vital natural process in several of the park’s forest types, most notably in the Xeric Ridge Pine/Oak Woodland, Dry-Mesic Oak Forest, and in the Montane Red Oak Forest. Fire has also played a role in the creation or maintenance of several rare communities that occur within the park, most notably native-grass meadows, canebrakes, and heath balds.

The establishment of Great Smoky Mountains National Park in 1934 coincided directly with the onset of the U.S. Forest Service's "10 a.m." policy for wildfire suppression. This policy stated that the goal of the service was to put all wildfires out by 10 a.m. the day after they were spotted. This policy, coupled with the fact that there had been numerous large and destructive wildfires in the Smoky Mountains following corporate logging during the 1920s, led to a policy of full fire suppression and exclusion in the newly formed park that would last until the publication of the park's first Fire Management Plan in 1996.

The suppression and exclusion of fires in GRSM since the 1930s constitutes a substantial departure from the fire regime that likely exerted an overriding influence on vegetation dynamics over nearly one-third of the park's landscape for thousands of years. Research shows that this long-term exclusion of fire from GRSM forests has been a major factor driving changes in forest structure, function, and composition, particularly among forest types dominated by yellow pines (shortleaf, pitch [*Pinus rigida*], table mountain [*Pinus pungens*], and Virginia pine [*P. virginiana*]) and oaks. Just as importantly, the long absence of fire has contributed to a buildup of wildland fuels (especially duff, dead wood, and evergreen shrubs) that exacerbates fire control problems and poses a threat to forest health. Partially as a result of competitive stress on mature pines, the loss of ridgetop yellow pine forests and buildup of forest fuels has been accelerated by large-scale outbreaks of southern pine beetle (*Dendroctonus frontalis*) during the last 20-30 years. In the short term, these alterations to the fire regime can lead to increased risk of wildfires that are very resistant to control, especially on sites with large accumulations of beetle-killed pine fuel and/or heavy growth of evergreen shrubs. When these forests eventually burn, they can burn with undesirable intensity and/or severity, resulting in negative consequences such as loss of old trees, soil erosion, and invasion by exotic plants.

In the longer term, with continued lack of fire, succession to a closed forest canopy will result in continued declines in plant and animal diversity, and lead to dominance by species that are poorly adapted to drought, fire, and changing climatic conditions. These changes over such a substantial portion of the park's land base are believed to pose a serious threat to the park's ability to achieve its goal for preservation of a diverse, resilient, and naturally functioning ecosystem. The GRSM Fire Management Plan (FMP) of 1996 was developed as a response to direction in the park's General Management Plan, Resource Management Plan, and National Park Service policy to take action in order to prevent these losses. The 2010 FMP provides the most current update to NPS policy and park direction for the management of fire. Aside from the primary objective to protect human life and property from the adverse effects of wildfire, the major objectives of the FMP pertain to protection, restoration, and maintenance of the park's natural resources. The FMP identifies the following strategies that can be used to achieve these objectives:

- Manage human-caused wildfires within existing guidelines to minimize resource damage and degradation
- Manage natural ignitions to the greatest extent possible to achieve resource management goals for vegetation and fuels

- Utilize prescribed burning to the greatest extent possible to achieve resource management goals for vegetation and fuels; the long-term prescribed fire strategy is further addressed in section 4.3.2 of the FMP
- Utilize monitoring data to evaluate potential impacts of wildfires, prioritize prescribed-fire treatments, communicate findings, and continually improve the effectiveness of fire management operations.

Fire must play its critical role as an ecological process in order to achieve the fundamental conservation goals of GRSM and NPS. A large percentage of the park is covered by dynamic forests that are most reliably maintained by a disturbance regime of fire. In the absence of fire, these forests are undergoing dramatic changes that are accompanied by losses in species diversity and overall ecosystem resilience. For nearly 40 years, lessons from GRSM have contributed to our understanding of eastern fire ecology and management, and over the past 17 years, GRSM staff has made tremendous strides in learning how to manage fire and effectively reintroduce fire onto the southern Appalachian landscape.

2.3. Resource Stewardship

2.3.1. Management Directives and Planning Guidance

As a unit in the National Park System, Great Smoky Mountains National Park is responsible for the management and conservation of its natural and cultural resources. This primary mandate is supported by the National Park Service Organic Act of 1916, which directs the Park Service to:

> *Conserve the scenery and natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such a manner and by such means as will leave them unimpaired for the enjoyment of future generations.*

The GRSM General Management Plan (GMP) was written in 1983 and contains sections on the park purpose, management objectives, the environment, management zoning, resources management, visitor use and services, and general development. Since 1983, one amendment - the Elkmont Historic Final Environmental Impact Statement - has been added to the GMP. As of 2004, there were no plans for the development of a new GMP.

GRSM staff identified and prioritized critical natural resource issues as part of its long-term ecological monitoring program. This plan lays out the park’s Vital Signs, which are a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, effects of stressors, or elements that have important human values (Langdon et al. 2011). Out of 24 Inventory & Monitoring categories at the park, staff used a prioritized ranking system to identify the top six Vital Signs that would be most indicative of the park’s overall health: (1) water chemistry, (2) atmospheric deposition, (3) soil quality, (4) vegetation communities, (5) freshwater communities, and (6) climate changes. By identifying these vital signs, the park will be able to focus resources and provide the minimum infrastructure needed to track the overall condition of its natural resources.

2.3.2. Status of Supporting Science

Due in large part to the park's long history, popularity, and renowned biodiversity, there is a wealth of research on the park's resources. Numerous books, book chapters, theses, dissertations, and research papers have been published covering wide ranging topics over the years. Several park resources and issues have been monitored and studied consistently over the past 20 or 30 years, including vegetation communities and water resources, and the effects of atmospheric deposition, ozone levels, aerosols, and invasive species, on those communities. Additionally, past and on-going research projects cover topics on land use history, plant-specific studies, entomological studies, and visitor use impact studies among a myriad other research topics too numerous to list here. Inventory and monitoring projects provide the base on which many research studies are conducted.

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Chapter 3. Study Scoping and Design

3.1. Preliminary Scoping

Project scoping was initially discussed during a conference call in November, 2011, between the GRSM NRCA project manager, WCU project PI, NPS SE Region NRCA coordinator, and GRSM Resource Management and Science Division Chief. The purpose of the call was to define the scope of the NRCA and discuss how the report could best serve the needs of the park. An initial GRSM site visit and scoping meeting was held in March, 2012, where the majority of the discussions focused on the overall purpose and depth of the NRCA and the availability of inventory and monitoring data from the park. Internal discussions at GRSM produced an extensive list of potential assessment metrics by May, 2012.

3.2. Study Design

3.2.1. Indicator Framework

The ranking framework used for this natural resource condition assessment was modified from the 2005 NPS ecological monitoring framework (Fancy et al.2009). The NPS framework divides monitoring into six general categories: air and climate, geology and soils, water, biological integrity, human use, and landscape pattern and processes. Each of these general categories, referred to as level 1, are further subdivided into level 2 and level 3 categories, with each park vital sign most closely associated with the fine-scale level 3 division. Biological integrity, a level 1 category for example, is divided into four level 2 categories: invasive species, infestations and disease, focal species or communities, and at-risk biota. Invasive species, in turn, includes two level 3 categories: invasive/exotic plants and invasive/exotic animals. As the categories move from level 1 to level 3, the resolution of the data involved also increases. The ranking framework and the main sources of data used for the assessment, summarized by category, are presented in Tables 3.2.1.1 and 3.2.1.2.

Reference conditions have largely been identified based upon the GRSM Vital Signs monitoring plan, which reflects both state and federal standards (where available) or target conditions identified by GRSM managers. Where reference or target conditions were not yet established, values may have been determined specifically for this NRCA, or this effort was able to provide baseline information for future planning. To date, extensive geospatial data, inventory and monitoring data, and/or numerous related synthesis reports have been provided by GRSM. The assessment framework tables do not list all data provided but only those sources most directly supporting the proposed analyses.

3.2.2. Reporting Areas

To the extent possible, metrics assessed in this NRCA will be summarized and reported park-wide so that a more holistic view of current conditions can be provided. Specific data analysis methods, however, vary based upon the spatial and temporal scale and resolution of available data. For example, air quality and climate conditions are monitored at locations within the park but also regionally and thus, a comparison of GRSM-specific conditions with regional conditions is necessary. Other measures such as water quality and soil properties are specific to where data were collected and are reported for individual sampling locations, streams, or watersheds. Species inventory and monitoring data are collected at varying degrees of intensity from individual sample locations but reporting of their trends may be most useful when considering specific forest community types, adjacent land use/land cover (LULC) changes, or watershed specific measures.

Table 3.2.1.1. Monitoring framework for the GRSM NRCA.

Level 1 Category	Level 2 Category	Level 3 Category	Specific Resource/Area of Interest
Air and Climate	Air quality	Sulfur deposition	Sulfur from sulfate
	Air quality	Nitrate deposition	Nitrogen from nitrate and ammonium
	Air quality	Ozone	Concentrations of ground level ozone
	Air quality	Mercury deposition	Mercury deposition
	Air quality	Particulate matter	Particulate matter <2.5 µm in diameter
	Air quality	Visibility	Haze index
Geology and Soils	Soil quality	Organic layer	Percentage by weight
	Soil quality	Water holding capacity	Volume of water from 0 to 150 cm
	Soil quality	pH	Hydrogen ions
	Soil quality	Acid neutralizing capacity	Difference between cations and anions
	Soil quality	Cation exchange capacity	Exchangeable cations per dry weight that a soil is capable of holding
	Soil quality	Soil carbon	Mass per volume
	Soil quality	C:N (Carbon:Nitrogen)	Concentration ratio
	Soil quality	Ca:Al (Calcium: Aluminum)	Concentration ratio
	Soil quality	Base saturation	Percent
Water	Water quality	pH	Hydrogen ions
	Water quality	Acid neutralizing capacity	Difference between proton acceptors and proton donors (µeq/l)
	Water quality	Sulfate	Concentration of sulfate
	Water quality	Nitrate	Concentration of nitrate
	Water quality	Temperature	Stream water (°C)
	Water quality	Specific conductance	Microsiemens per centimeter
	Water quality	Organic acids	Concentration
	Water quality	Dissolved organic carbon	Concentration
	Water quality	Toxics	Metals, emerging pollutants
Biological Integrity	Invasive species	Invasive/exotic plants	Exotic species identified in the GRSM 2014 exotic plant briefing statement, didymo
	Invasive species	Invasive/exotic animals	Wild hogs, green tree frogs; Asian jumping earthworms, New Zealand mud snail, zebra/quagga mussels
	Focal species or communities	Oak-Hickory Forests	Community health: insect pests, plant diseases, air pollution, climate change, anthropogenic disturbance

Table 3.2.1.1 (continued). Monitoring framework for the GRSM NRCA.

Level 1 Category	Level 2 Category	Level 3 Category	Specific Resource/Area of Interest
Biological Integrity (continued)	Focal species or communities	Pine-Oak Forests	Community health: insect pests, plant diseases, air pollution, climate change, anthropogenic disturbance
	Focal species or communities	Cove Hardwood Forests	Community health insect pests, plant diseases, air pollution, climate change, anthropogenic disturbance
	Focal species or communities	High elevation Spruce-Fir Forests	Community health: insect pests, plant diseases, air pollution, climate change, anthropogenic disturbance
	Focal species or communities	Early Successional Forests	Community health: insect pests, plant diseases, air pollution, climate change, anthropogenic disturbance
	Focal species or communities	Hemlock Forests	Community health: insect pests, plant diseases, air pollution, climate change, anthropogenic disturbance
	Focal species or communities	Montane Alluvial Forests	Community health: insect pests, plant diseases, air pollution, climate change, anthropogenic disturbance
	Focal species or communities	Heath balds	Community health: insect pests, plant diseases, air pollution, climate change, anthropogenic disturbance
	Focal species or communities	Grassy balds	Community health: insect pests, plant diseases, air pollution, climate change, anthropogenic disturbance
	Focal species or communities	Wetlands	Community health: insect pests, plant diseases, air pollution, climate change, anthropogenic disturbance
	Focal species or communities	Freshwater invertebrates	Benthic macroinvertebrates
	Focal species or communities	Terrestrial invertebrates	Pollinators, habitat specialists
	Focal species or communities	Fish	High-elevation fish, lower elevation fish, extirpated and reintroduced species
	Focal species or communities	Amphibians and reptiles	Amphibians and reptiles, ranavirus, chytrid

Table 3.2.1.1 (continued). Monitoring framework for the GRSM NRCA.

Level 1 Category	**Level 2 Category**	**Level 3 Category**	**Specific Resource/Area of Interest**
Biological Integrity (continued)	Focal species or communities	Birds	Birds
	Focal species or communities	Mammals	Mammals; Reintroductions: red wolf, river otter, peregrine falcon; Diseases: West Nile virus, tick and mosquito borne, WNS, rabies, pseudorabies, EHD, leptosprirosus
	Focal species or communities	Rare communities	Rare communities
	At-risk biota	T&E plants	T&E plants
	At-risk biota	T&E animals	T&E animals
Human Uses	Consumptive use	Exploitable plants	American ginseng, ramps and other exploited plants
Landscape Patterns and Processes	Fire and fuel dynamics	Fire policy and management	Fire policy and management
	Landscape dynamics	Landscape pattern, fragmentation, land use, and disturbance	Landscape pattern, fragmentation, land use, historic disturbance of soils
	Extreme disturbance events	Extreme disturbance events	Wind and wind throw
	Soundscape	Acoustic environment	Natural ambient sound levels vs existing ambient sound levels
	Viewscape	Night sky	Night sky brightness

Table 3.2.1.2. Summary of ecological attributes, assessment measures, and data sources used in the NRCA for GRSM. Citations and additional data sources are found in the appropriate sections of Chapter 4.

Attribute	Assessment Measure	Data Source	Data Description	Data Period
Air Quality	Wet deposition of nitrogen from nitrate and ammonium, and sulfur from sulfate	National Atmospheric Deposition Program (NADP)	Nitrate, ammonium, and sulfate wet deposition (in kg/ha/yr) based on data from NADP network monitors (Site TN11) at Elkmont	1981-2013
	Dry deposition of nitrogen from nitric acid, nitrate, and ammonium, and sulfur from sulfur dioxide and sulfate	Clean Air Status and Trends Network (CASTNET)	Nitric acid, nitrate, ammonium, sulfur dioxide, and sulfate (in kg/ha/yr) based on data from CASTNET network monitors (GRS420) at Look Rock	1999-2013
	Total nitrogen and sulfur deposition from throughfall and wet precipitation	University of Tennessee (UT), from Noland Divide watershed; J. Renfro, NPS	Wet, dry, and cloud deposition of nitrate and sulfate (in kg/ha/yr) based on data from UT, from Noland Divide watershed near Clingmans Dome	1992-2013
	Total mercury wet deposition and annual mercury concentrations in precipitation	Mercury Deposition Network (MDN)	Mercury wet deposition (in µg/m3) and concentrations in precipitation (in µg/l) based on data from MDN network monitor (Site TN11) at Elkmont	2002-2013

Table 3.2.1.2 (continued). Summary of ecological attributes, assessment measures, and data sources used in the NRCA for GRSM. Citations and additional data sources are found in the appropriate sections of Chapter 4.

Attribute	Assessment Measure	Data Source	Data Description	Data Period
Air Quality (continued)	Annual ozone concentrations	NPS park monitors in GRSM; J. Renfro	4th highest 8-hour ozone concentrations (in ppb) and 3-year average of 4th highest 8-hour ozone concentrations (in ppb) based on data from five monitors located in the park at Look Rock, Cove Mountain, Clingmans Dome, and Cades Cove in TN and Purchase Knob in NC; W126 exposure values (in ppm-hours)	1990-2013
	Annual and 24-hour fine particulate matter (PM2.5) concentrations	U.S. EPA Air Quality System (AQS) and Interagency Monitoring of Protected Visual Environments (IMPROVE); J. Renfro	3-year rolling averages of annual PM2.5 concentrations and 24-hour PM2.5 concentrations (in µg/m3) based on data from eight AQS/IMPROVE regional monitors (one in the park at Look Rock)	1999-2013
	Visibility/haze	Interagency Monitoring of Protected Visual Environments (IMPROVE); J. Renfro	Haze index values (in deciviews, or dv) based on data from IMPROVE monitor in the park at Look Rock	1990- 2013
Soil Quality	Soil pH	Taylor 2008, Cai et al. 2010, Grell 2010, Cai et al. 2011a, Cai et al. 2011b, Neff et al. 2013	Compilation and comparison of soil pH from soil surface horizons, including both a single study site and from multiple watersheds	2008-2013

Table 3.2.1.2 (continued). Summary of ecological attributes, assessment measures, and data sources used in the NRCA for GRSM. Citations and additional data sources are found in the appropriate sections of Chapter 4.

Attribute	Assessment Measure	Data Source	Data Description	Data Period
Soil Quality (continued)	Soil acid neutralizing capacity	Cook et al. 1994, Nodvin et al. 1995, Driscoll et al. 2001, Cai et al. 2010, Grell 2010	Various sources of ANC data	1994-2010
	Soil cation exchange capacity	Taylor 2008, Bardhan et al. 2012, Cai et al. 2012, Neff et al. 2013	Various sources of CEC data	2008-2013
	Soil base saturation	Fenn et al. 2011, Cai et al. 2012	Very little data found for GRSM	2011-2012
	Soil Ca:Al	Bryant et al. 1997, Bintz and Butcher 2007, Cai et al. 2010, Rosenberg and Butcher 2010, Bardhan et al. 2012, Wilson and Butcher 2012	Various sources of Soil Ca:Al data and included studies with both foliar Ca:Al and soil Ca:Al	1997-2012
Water Quality	pH, acid neutralizing capacity, sulfates, nitrates, dissolved oxygen, temperature, specific conductivity	Integrated Forest Study	Noland Divide watershed (data from throughflow, soil water, two stream monitoring sites); data available on NPSTORET	1991-present
	pH, acid neutralizing capacity, sulfates, nitrates, dissolved oxygen, temperature, specific conductivity	GRSM Inventory & Monitoring (I&M) Program	Park-wide monitoring; number of sites and frequency has varied; 357 sites total; 43 current sites; see Chapter 4 for specifics; data available on NPSTORET	1993–present
	Organic acids, dissolved organic carbon	NPS 1995	Various sites within and adjacent to the park	Prior to 1993
	Organic acids, dissolved organic carbon	Deyton et al. 2009	Data on organic acids and DOC during base- and storm-flows from three basins	Jan.–March, 2007

Table 3.2.1.2 (continued). Summary of ecological attributes, assessment measures, and data sources used in the NRCA for GRSM. Citations and additional data sources are found in the appropriate sections of Chapter 4.

Attribute	Assessment Measure	Data Source	Data Description	Data Period
Water Quality (continued)	Organic acids, dissolved organic carbon	Cook et al. 1994	DOC data from six basins during base- and storm-flows	Jan.–June 1984; Jan.–Feb. 1986
	Organic acids, dissolved organic carbon	Neff 2010	DOC from eight basins	May 2008–April 2009
	Metals	GRSM Inventory & Monitoring (I&M) Program	Park-wide monitoring of Al, Cu, Fe, Mn, Zn; number of sites and frequency has varied; 357 sites total; 43 current sites; data available on NPSTORET	1993-present for Al; 2003-present for Cu, Fe, Mn, Zn
	Metals	NPS 1995 - Baseline Water Quality Data Inventory and Analysis Project	Various sites and frequencies of monitoring for As, Cd, Cr, Fe, Pb, Mn, Hg, Ni, Ag, Zn	1967-1994, depending on metal
	Emerging pollutants	Data from GRSM unavailable. See Chapter 4 for additional data collected for specific studies	–	–
Invasive Species	Invasive plants	Tennessee Exotic Pest Plant Council	List of plant species that are invasive or may become invasive and cause damage to native plant communities	2009
	Invasive animals	Pivorun et al. 2009	Mammals of GRSM	2009
	Invasive animals	GRSM fish distribution	Point layer showing trout distribution for each stream segment in GRSM	2016

Table 3.2.1.2 (continued). Summary of ecological attributes, assessment measures, and data sources used in the NRCA for GRSM. Citations and additional data sources are found in the appropriate sections of Chapter 4.

Attribute	Assessment Measure	Data Source	Data Description	Data Period
Invasive Species (continued)	Invasive animals	GRSM biodiversity database	Describes locations in which species have been found	Ongoing
	Invasive animals	EIS for Foothills Parkway section 8-D	Environmental impact statement for the Foothills Parkway	1995
	Invasive animals	Asper 2015	Investigation of a management program for the introduced green tree frog	2015
Focal Species or Communities	Vegetation communities; current and reference conditions	White et al. 2003	Vegetation community descriptions for GRSM	2003
	Vegetation communities; current and reference conditions	Jenkins 2007	Vegetation community descriptions for GRSM	2007
	Vegetation communities; current and reference conditions	Madden et al. 2004	Vegetation community maps for GRSM	2004
	Vegetation communities; current and reference conditions	Schafale 2012	Classification of vegetation communities of North Carolina	2012
	Vegetation communities; current and reference conditions	TNC 2016	LANDFIRE vegetation community descriptions	2016

Table 3.2.1.2 (continued). Summary of ecological attributes, assessment measures, and data sources used in the NRCA for GRSM. Citations and additional data sources are found in the appropriate sections of Chapter 4.

Attribute	Assessment Measure	Data Source	Data Description	Data Period
Focal Species or Communities (continued)	Climate change impacts	Climate Change Atlas (U.S. Forest Service 2016)	Estimates of species migration in response to varying climate emission scenarios	2016
	High elevation fish	Schwartz et al. 2014, narrative summaries from annual administrative reports, and Nichols and Kulp 2014	Brook trout density and biomass estimates for 298 stream sites from 1990 to 2010, and 129 sites between 2011 and 2015, plus 11 sites on eight Vital Signs streams in 2014	1990-2015
	Low elevation fish	Annual administrative reports, Lennon and Parker 1959, and Nichols and Kulp 2014	Species richness, brook trout density and biomass, IBI scores (recent)	1990-2015
	Extirpated and reintroduced fish	Shute et al. 2005, Gibbs et al. 2014, and annual administrative reports	Numbers of reintroduced species, and snorkel surveys	1986-2014
	Aquatic macroinvertebrates	Nichols 2012a, Nichols 2012b, Schwartz et al. 2014, and Nichols and Kulp 2014	Taxa richness and/or bio classification scores (NCBI) from approximately 420 sites	1990-2015
	Terrestrial invertebrates	ATBI	Describes and documents locations in which species have been found	Ongoing
	Reptiles	ATBI, Cash 2004	Describes and documents locations in which species have been found	2004; ongoing
	Amphibians	Hairston et al. 1992, Dodd 2003	Long running amphibian monitoring project. Multiyear intensive study of amphibians in GRSM	1970s-present; 1998-2002

Table 3.2.1.2 (continued). Summary of ecological attributes, assessment measures, and data sources used in the NRCA for GRSM. Citations and additional data sources are found in the appropriate sections of Chapter 4.

Attribute	Assessment Measure	Data Source	Data Description	Data Period
Focal Species or Communities (continued)	Birds	Christmas Bird Counts (National Audubon Society 2015), Shriner 2001	Analyzes winter bird distributions and trends for species over large geographic areas. Assessment of breeding birds in the park	1930s-present; 1996-1999
	Mammals	Mammals of the Smokies (Pivorun et al. 2009)	A compilation of studies on mammals in GRSM	2009
At-risk Biota	T&E plants	Great Smoky Mountains long-term monitoring program	GRSM plan for monitoring rare plant species	1993-Present
	T&E animals	Federal listings of T&E animals, NC and TN listings of T&E animals, NatureServe	Global, federal, and state listings of rare species	1973-Present
Consumptive Use	Exploited plants	Janet Rock, pers. comm.	List of exploitable plants in the park and their uses.	–
Landscape Dynamic	Forest loss and fragmentation (trends from 1992-2011)	National Landcover Database (NLCD) for 1992 (Vogelman et al. 2001), 2001 (Homer et al. 2007), 2006 (Fry et al. 2011), and 2011 (Homer et a. 2015)	National land cover product created by the Multi-Resolution Land Characteristics (MRLC) Consortium	1992-2011
	Historic soil disturbance (relative severity and potential duration of impacts)	Pyle 1988	A vegetation disturbance history for GRSM prior to park establishment	1985-1988
Extreme Disturbance Events	Wind events	Gaffin 2009, Schneider 2010, Gaffin 2011, Gaffin and Hotz 2011, Gaffin 2012, Kemp 2010, Langdon et al. 2011, Peterson and Godfrey 2012	Reports assessing GRSM wind monitoring data	2009-2012

Table 3.2.1.2 (continued). Summary of ecological attributes, assessment measures, and data sources used in the NRCA for GRSM. Citations and additional data sources are found in the appropriate sections of Chapter 4.

Attribute	**Assessment Measure**	**Data Source**	**Data Description**	**Data Period**
Soundscape	Acoustic environment	GRSM staff, Volpe, and the Natural Sounds Program of the National Park Service	Baseline data collected for GRSM at seven locations during winter and summer	2005-2006
Viewscape	Night skies	Duriscoe et al. 2007	Sky brightness values measured at Clingmans Dome	2008

3.2.3. General Approach and Methods

Since the primary purpose of the NRCA is to provide a snapshot of current conditions, this assessment focused largely on the most recent data available. Spatio-temporal trends are important when assessing current conditions for some metrics (e.g., LULC changes, climate, air and water quality); therefore, trends were evaluated where appropriate. Relevant inventory and monitoring data were analyzed quantitatively and applied directly to the assessment of resource condition. Where data were lacking, we conducted a review and synthesis from existing assessment reports, and in some cases, geospatial analyses and modeling to derive necessary information. We relied heavily on input from park staff and resource specialists for all parts of this NRCA.

Condition and Trend Status Ranking Methodology

Data collected as part of the NPS I&M program typically are intended to assess the condition, trend, and confidence of each resource, assessed at level 3. We summarize at this level using the ranking status tables at the end of each natural resource section using the symbols shown in Table 3.2.3.1.

Table 3.2.3.1. Summary of condition assessment symbols used in the GRSM NRCA.

Condition Status		Trend in Condition		Confidence in Assessment	
🟢	Resource is in Good Condition	⇧	Condition is Improving	◯	High
🟡	Resource warrants Moderate Concern	⬄	Condition is Unchanging	○	Medium
🔴	Resource warrants Significant Concern	⇩	Condition is Deteriorating	◌	Low

Chapter 4. Natural Resource Conditions

4.1. Air Quality

Air pollution can significantly affect park resources, visitor enjoyment, and public health. Air quality is federally protected from degradation by the Clean Air Act (CAA) through a series of National Ambient Air Quality Standards (NAAQS), which are thresholds for certain airborne pollutants. Although there are six airborne pollutants for which NAAQS exist, the particularly important ones that are monitored at GRSM include ozone and particulate matter. In addition to the air pollutants covered by the NAAQS, there are other air quality related factors important to GRSM, including ozone exposures that cause damage to vegetation, atmospheric deposition of sulfur, nitrogen and mercury, and visibility impairment from regional haze, primarily from particulate matter.

Air pollutants can affect various ecological processes within the park, from individual species to the ecosystem level. Specifically, air pollution can adversely impact water quality and soil pH, reduce tree productivity, growth, and species distribution, deteriorate cultural features, and impair visibility and human health (NPS 2011). Great Smoky Mountains National Park experiences some of the highest measured air pollution of any national park in the U.S. (NPS 2013). This is likely because the park is located downwind of many sources of air pollution – some of these sources are nearby, while others are more distant (e.g., industrial cities of the Southeast and Midwest [NPS 2013]). Consequently, there are federal mandates for clean air in national parks as part of the CAA of 1970. The 1977 amendments to the CAA designated all national parks as either Class I or Class II ai. Class I areas were determined to be worthy of the highest air quality protection under the act and were mandated to protect all air quality-related values, including natural and cultural resources (NPS 2013). As such, the NPS regulates air quality by using the NAAQS as the maximum allowable levels of air pollution (EPA 2012a). In order to comply with CAA mandates for protection of park resources, the NPS established an air monitoring program that measures long-term air quality trends in parks (NPS 2009). The program has three primary components: visibility, ozone, and atmospheric deposition, each of which can impact park resources, visitor enjoyment, and public health (NPS 2009). GRSM is designated as a Class I airshed; monitoring sites are shown in Fig. 4.1.1.

Air pollutants of concern to managers at GRSM include the following:

- Deposition of nitrogen (N) from nitrate (NO_3^-) and ammonium (NH_4^+), and sulfur (S) from sulfate (SO_4^{2-})
- Deposition of mercury (Hg)
- Concentrations of ground-level ozone (O_3)
- Concentrations of particulate matter ($PM_{2.5}$)
- Visibility (measured in terms of Haze Index, or deciviews) (EPA 2012b)

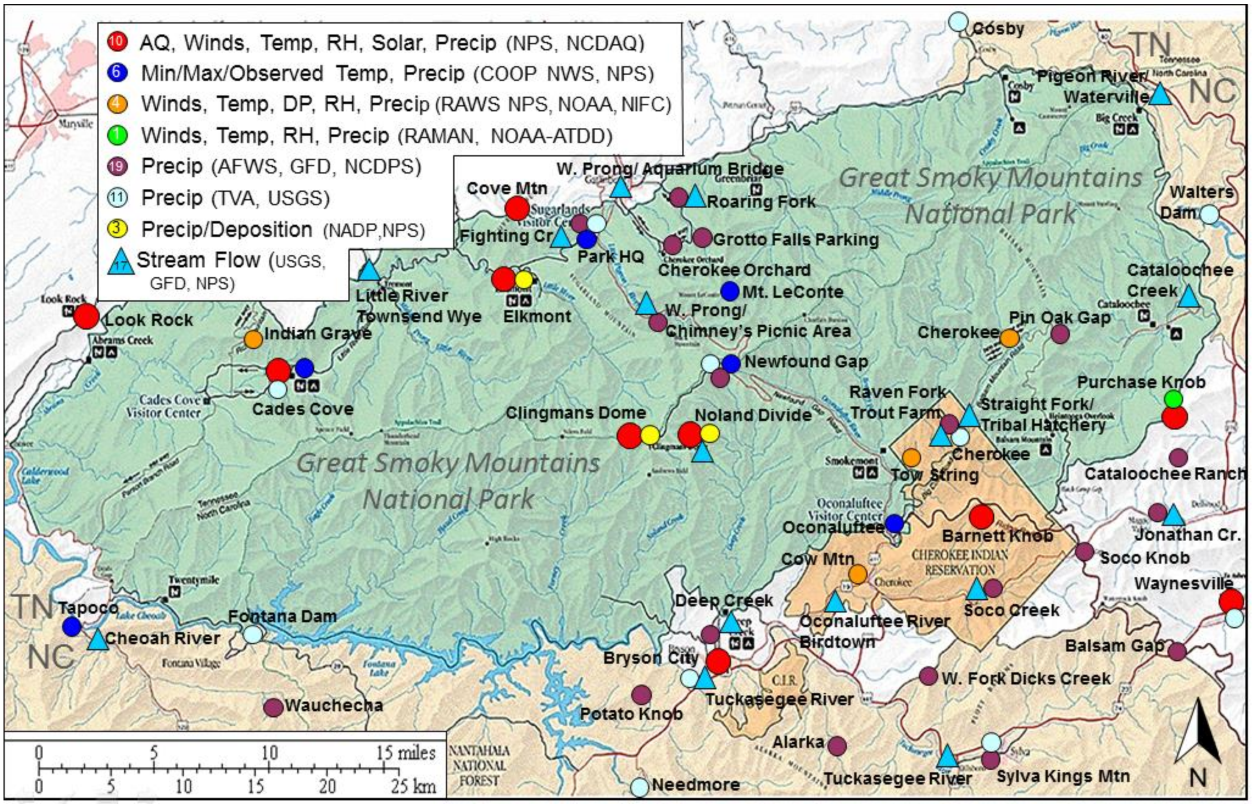


Figure 4.1.1. Climate, air quality, and stream flow monitoring sites in and near Great Smoky Mountains National Park. Source: J. Renfro, NPS.

4.1.1. Acid Deposition

Relevance

During the 1970s, the scientific community saw a rapid increase in literature on acid deposition and concern about its potential effects on the environment. Likens and Bormann (1974) first brought major attention to this issue when they reported an increase in the acidity of rainfall over the eastern United States. Their findings indicated measureable effects on ecosystem structure and function, and suggested that considerations be made in proposals for new energy sources and in the development of air pollution emission standards. The following 20 years saw an abundance of research to measure atmospheric deposition and to study its effects on the environment through the National Atmospheric Deposition Program–National Trends Network (NADP 2013a) and other acid rain studies.

Anthropogenic sources of sulfur dioxide typically include power plants, diesel vehicle emissions, and other industrial sources, while natural sources may include volcanoes, organism emissions, and decaying organic material. The CAA was amended in 1990 to include further controls on atmospheric emissions of sulfur dioxide to reduce sulfate deposition. In addition to sulfur dioxide, nitrogen oxides also react in the atmosphere to produce other pollutants. Nitric acid (HNO_3), for example, is a contributing factor to acid rain while particulate nitrate (NO_3^-) can deposit on the landscape. Agricultural activities can produce ammonia (NH_3), which can be deposited directly or convert to particulate ammonium and be deposited as a major source of nitrogen. Emission levels of sulfur dioxide and nitrogen oxides from power plants associated with acid deposition have dropped over 90% across much of the eastern U.S. as a result of regulatory and emission reduction programs imposed by the CAA (EPA 2013b).

Research has shown that atmospheric deposition of nitrogen and sulfur can directly impact both aquatic and terrestrial systems by lowering pH of streams and soils, affecting forest health, and aquatic wildlife populations (Driscoll et al. 2001). Atmospheric deposition of nitrogen and sulfur can acidify sensitive aquatic and terrestrial resources, both chronically and episodically (Smoot et al. 2000). Research at GRSM has shown that some high-elevation soils in the park are receiving so much airborne nitrogen that it exceeds the assimilation capacity of ecosystems, a condition commonly known as nitrogen saturation (Flum and Nodvin 1995). This limits availability of forest nutrients (mainly calcium) to plants and causes mobilization of toxic ions such as aluminum that can harm vegetation and aquatic biota, and impact forest growth and composition (Eagar and Adams 1992). Ecological concerns include the leaching of nitrogen and depletion of calcium from ecosystems, which affects productivity, soil chemistry, water quality, and resistance/tolerance of biota to other stresses (Eagar et al. 1996).

Sensitive mountain streams and forest soils are being acidified to the point that the health of the park’s high-elevation ecosystems are in jeopardy (Flum and Nodvin 1995, SAMI 2002). Some high-elevation park streams have the highest nitrate levels of any systems in the U.S. that drain undisturbed watersheds (Stoddard 1994). Acidification of streams causes declines in aquatic diversity and native brook trout range and survival (Herlihy et al. 1996, SAMI 2002). In addition, naturally occurring organic acids are thought to play a key role and may confound stream acidification (Cook et al. 1994).

Acid deposition affects various ecosystems in GRSM differently, depending primarily upon their buffering capacity. The higher elevation systems and those areas underlain by non-limestone geology are the most vulnerable to change (Smoot et al. 2000). Nitrate and sulfate concentrations increase with elevation, and pH and acid neutralizing capacity (ANC) decrease with elevation (Smoot et al. 2000); therefore, elevation, forest type, and buffering capacities are important factors in risk assessment.

The park is also part of the Ammonia Monitoring Network (AMoN). Ammonia is a gas readily released into the air from a variety of biological sources, as well as from industrial and combustion processes. While ammonia has many beneficial uses, it can detrimentally affect the quality of the environment through the acidification and eutrophication of natural resources, the associated loss of biodiversity, and the formation of secondary particles in the atmosphere. The dominant source of ammonia emissions in the U.S. is agriculture (85%), largely from animal waste and commercial fertilizer applications. AMoN provides critical data to land managers, air quality modelers, ecologists, and policymakers, allowing them to assess long-term trends in ambient ammonia concentrations and deposition, validate atmospheric models, better estimate total nitrogen inputs to ecosystems, assess changes in atmospheric chemistry due to SO_2 (sulfur dioxide) and NO_x (nitrogen oxide) reductions, and assess compliance with $PM_{2.5}$ standards. There are currently 66 AMoN locations across the U.S. (NADP 2013b).

Data and Methods

The NADP is a national monitoring network of 258 monitoring stations that measure acid anions and major cations. The NADP data used in this assessment consisted of sulfate (SO_4^{2-}), nitrate (NO_3^-), and ammonium (NH_4^+) wet deposition for the years 1981-2013. These data were recorded at an NADP monitoring station (Site TN11) located within the park at Elkmont and provided by J. Renfro, NPS. These data represent a sufficiently long record to examine annual values and assess trends over the past three decades (http://nadp.sws.uiuc.edu/sites/siteinfo.asp?net=NTNandid=TN11). The most recent 10-year trend analyses of annual sulfate, nitrate, and ammonium wet deposition are compared with monitoring data from other parks to provide a national and regional context for levels reported at GRSM (NPS 2013a).

Dry deposition data from the Clean Air Status and Trends Network (CASTNET) is also reported in this assessment. The CASTNET program is a national air quality monitoring network supported by the EPA and NPS, and is designed to provide data to assess trends in air quality, atmospheric deposition, and ecological effects due to changes in air pollutant emissions. CASTNET provides long-term monitoring of air quality in rural areas to determine trends in regional atmospheric nitrogen, sulfur, and ozone concentrations, and deposition fluxes of sulfur and nitrogen pollutants, in order to evaluate the effectiveness of national and regional air pollution control programs (EPA 2013c). CASTNET operates more than 85 regional sites throughout the contiguous United States, Alaska, and Canada. Look Rock is the location of the park's CASTNET monitoring station (GRS420) which began operation in 1998. Status and trends of the data from 1999 to 2013 are reported below.

Annual throughfall and wet N and S deposition monitoring data are available since 1992 for coniferous vegetation at the Noland Divide watershed through a routine monitoring program led by the University of Tennessee. This is a high-elevation watershed (1,740 m [5,700 ft]) in the spruce-fir ecosystem of the park. Throughfall deposition is the hydrologic flux of N and S from the forest canopy to the forest floor. It includes wet, dry, and cloud deposition and is a good technique to measure total deposition. Total deposition is much greater (3-4 times) than wet deposition inputs. Deposition from both wet precipitation and throughfall has declined significantly over the past 20 years (Fig. 4.1.1.1).

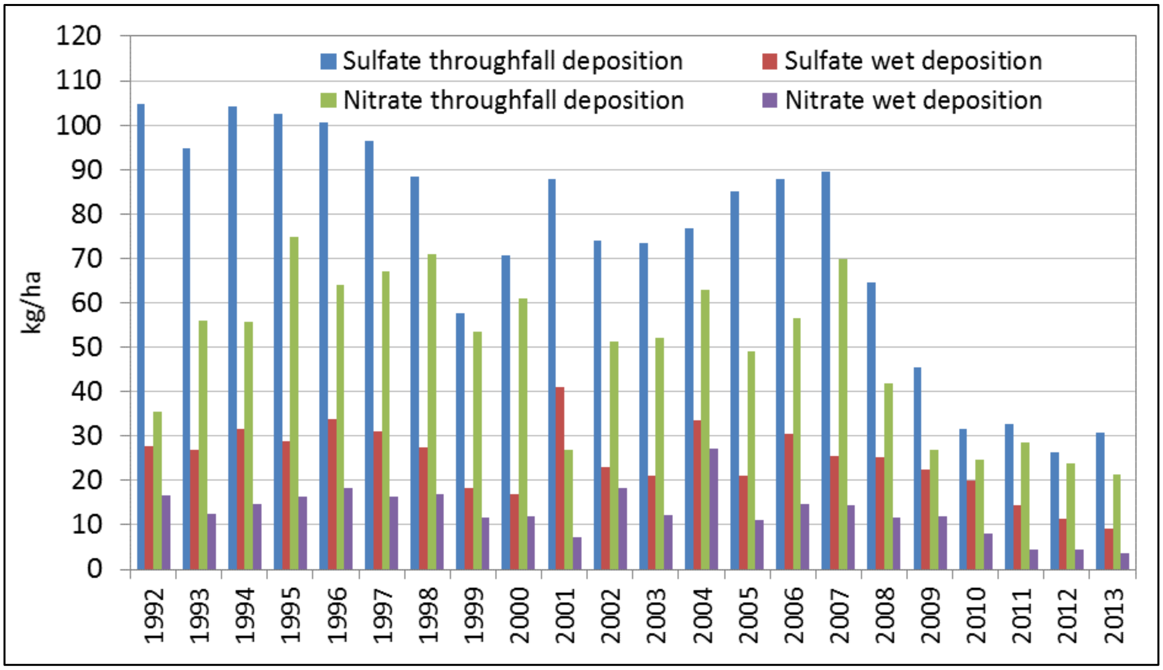


Figure 4.1.1.1. Trends in sulfate and nitrate deposition from throughfall and wet precipitation at Noland Divide, GRSM, 1992-2013. Source: J. Renfro, NPS.

Reference Conditions

Determining the reference condition for total sulfate and nitrate wet deposition is necessary to identify ecosystems and resources in national parks at risk for acidification and excess nitrogen enrichment. Natural background for both total sulfur and total nitrogen deposition in the eastern U.S. is 0.5 kg/ha/yr which equates to a wet deposition of approximately 0.25 kg/ha/yr (Porter and Morris 2007, NPS 2013b). NPS Air Resources Division (NPS ARD) has established sulfate and nitrate wet deposition guidelines as: >3 kg/ha/yr indicates significant concern, 1-3 kg/ha/yr indicates moderate concern; and <1 kg/ha/yr represents good condition (NPS 2013b). For this assessment, the good condition category of <1 kg/ha/yr was used as the ecological threshold and thus, reference condition for both sulfate and nitrate wet deposition. If park ecosystems are ranked high in sensitivity to acidification effects from atmospheric deposition relative to all inventory and monitoring parks, as is GRSM, the condition category is adjusted to the next worse condition category (NPS 2013b).

Conditions and Trends

For 2013, total sulfate wet deposition in GRSM (at Noland Divide) was 9.26 kg/ha and nitrate wet deposition was 3.65 kg/ha (Fig. 4.1.1.1). The average ambient ammonia concentration measured at Look Rock was 0.56 µg/m^3 (Fig. 4.1.1.2) and total wet nitrogen (ammonium and nitrate) at Elkmont was 3.92 kg/ha (Fig. 4.1.1.3). The sulfur and nitrogen deposition values are well above the ecological threshold of <1 kg/ha/yr, and indicate significant concern for acid deposition in the park (NPS 2013b). These conditions are consistent with data from other parks across the U.S. (Figs. 4.1.1.4, 4.1.1.5) (NPS 2013a).

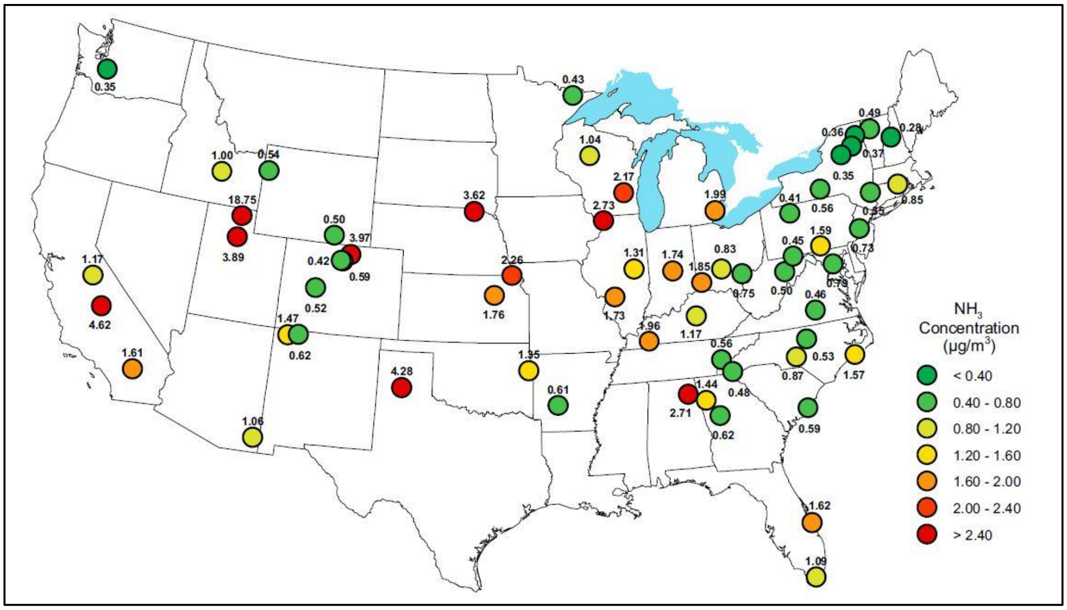


Figure 4.1.1.2. Average ambient ammonia concentrations in the U.S. in 2013 as measured by AMoN. Source: NADP/AMoN, J. Renfro, NPS.

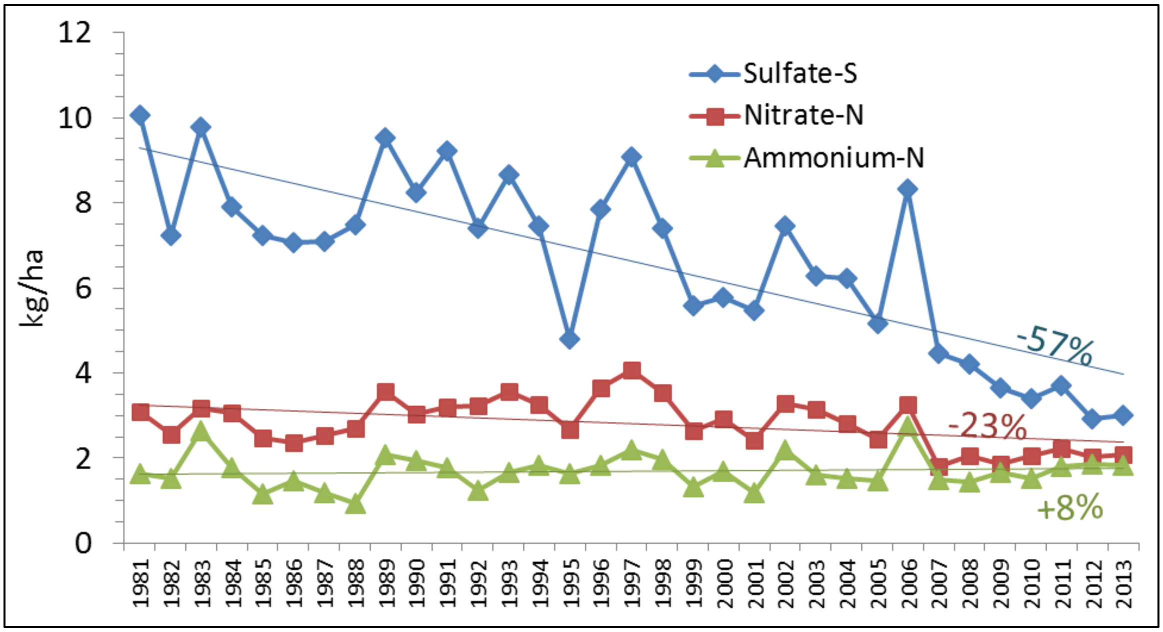


Figure 4.1.1.3. Annual sulfate, nitrate, and ammonium wet deposition at Elkmont, TN, 1981-2013. Source: NADP - Site TN11, J. Renfro, NPS.

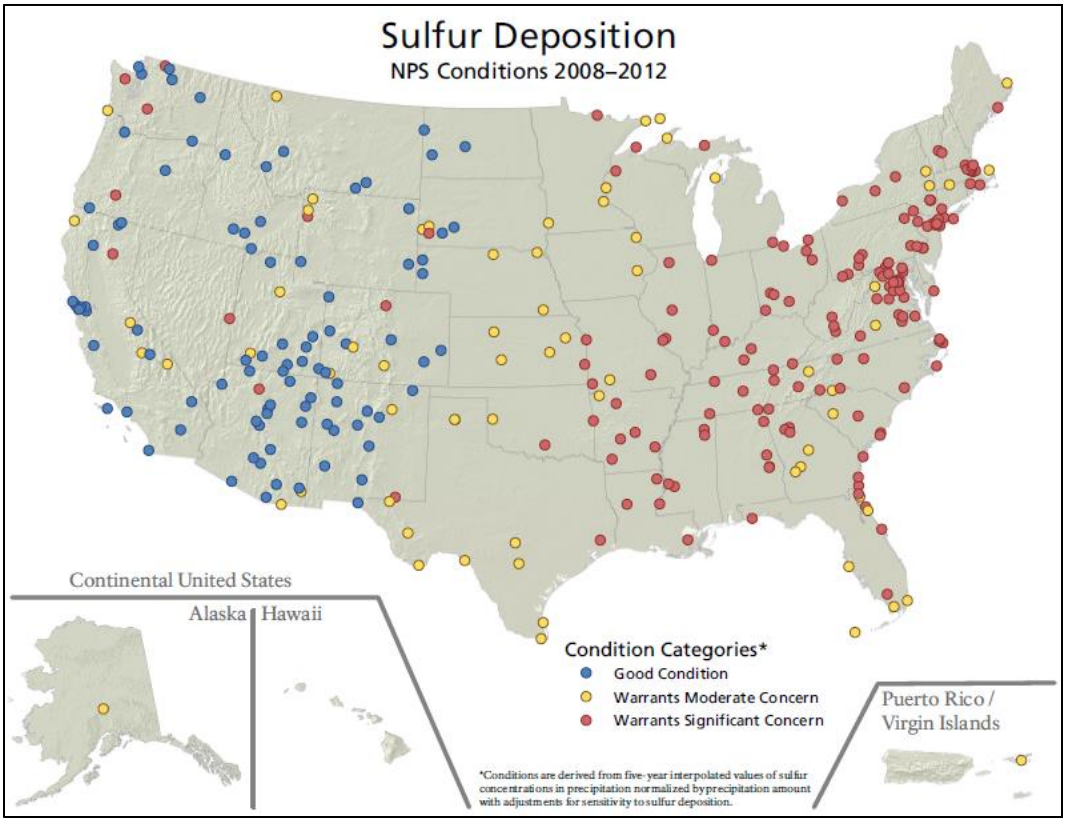


Figure 4.1.1.4. Sulfur deposition conditions in U.S. national parks, 2008-2012. Source: NPS ARD, J. Renfro, NPS.

Sulfate wet deposition within GRSM (at Elkmont) has been reduced substantially since 1981, with values decreasing 57% from 10.7 kg/ha/yr in 1981 to 3.0 kg/ha/yr in 2013 (Fig. 4.1.1.3). GRSM is considered a park unit with a very high ecosystem sensitivity ranking for nutrient enrichment impacts from sulfur deposition (NPS 2013b), and although these data indicate possible improving trends, they also illustrate that major reductions are still needed to lessen adverse impacts on park resources and ecosystems. Nitrate wet deposition within GRSM (at Elkmont) has shown an overall downward trend (-23%) over the past 30 years. However, a close examination of the data by year reveals a slight increasing trend between 1981 and 1997 (3.09 kg/ha/yr and 4.06 kg/ha/yr, respectively), when nitrate wet deposition levels peaked, followed by a decreasing trend between 1997 and 2013 (Fig. 4.1.1.3).

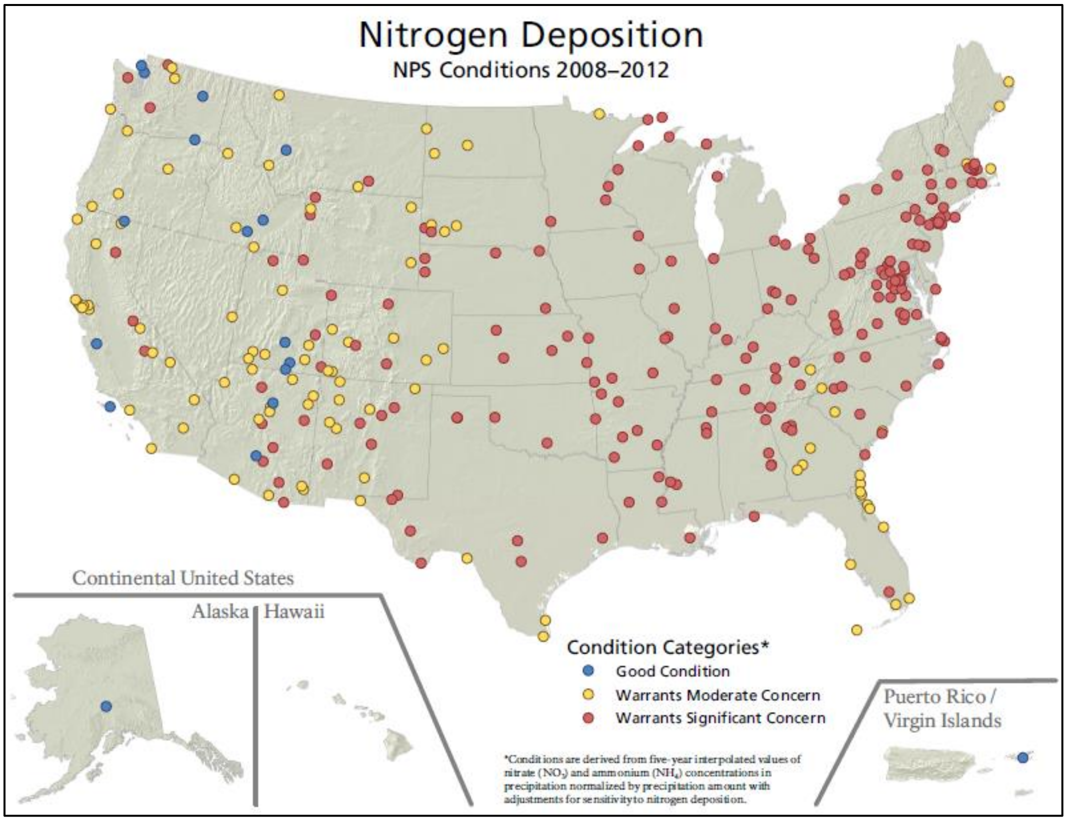


Figure 4.1.1.5. Nitrogen deposition conditions in U.S. national parks, 2008-2012. Source: NPS ARD, J. Renfro, NPS.

Ammonium wet deposition in GRSM (at Elkmont), on the other hand, increased by 8% during this time period, from 1.64 kg/ha/yr in 1981 to 1.84 kg/ha/yr in 2013 (Fig. 4.1.1.3). Thus, the total wet nitrogen deposition trend is unchanged between 2004 and 2013. Nitrate values have declined since 1981 but ammonium values have increased, and these levels still exceed the NPS ARD “significant concern” level of >3 kg/ha/yr wet deposition. These results reflect national trends in sulfate, nitrate, and ammonium emissions, especially since 1997 (Driscoll et al. 2001), and are consistent with trends in most parks across the U.S. (Figs. 4.1.1.6 - 4.1.1.8) (NPS 2013a).

Dry deposition of sulfur and nitrogen measured within GRSM at the Look Rock station as part of the CAST network has also shown a dramatic reduction. Sulfur dry deposition from sulfur dioxide and sulfate has been reduced 84% since 1999 from a peak value of 3.2 kg/ha in 1999 to 0.52 kg/ha in 2013 (Fig. 4.1.1.9). Nitrogen deposition of nitric acid, nitrate, and ammonium has been reduced 72% since 1999 from a peak value of 4.82 kg/ha in 1999 to 1.34 kg/ha in 2013 (Fig. 4.1.1.10).

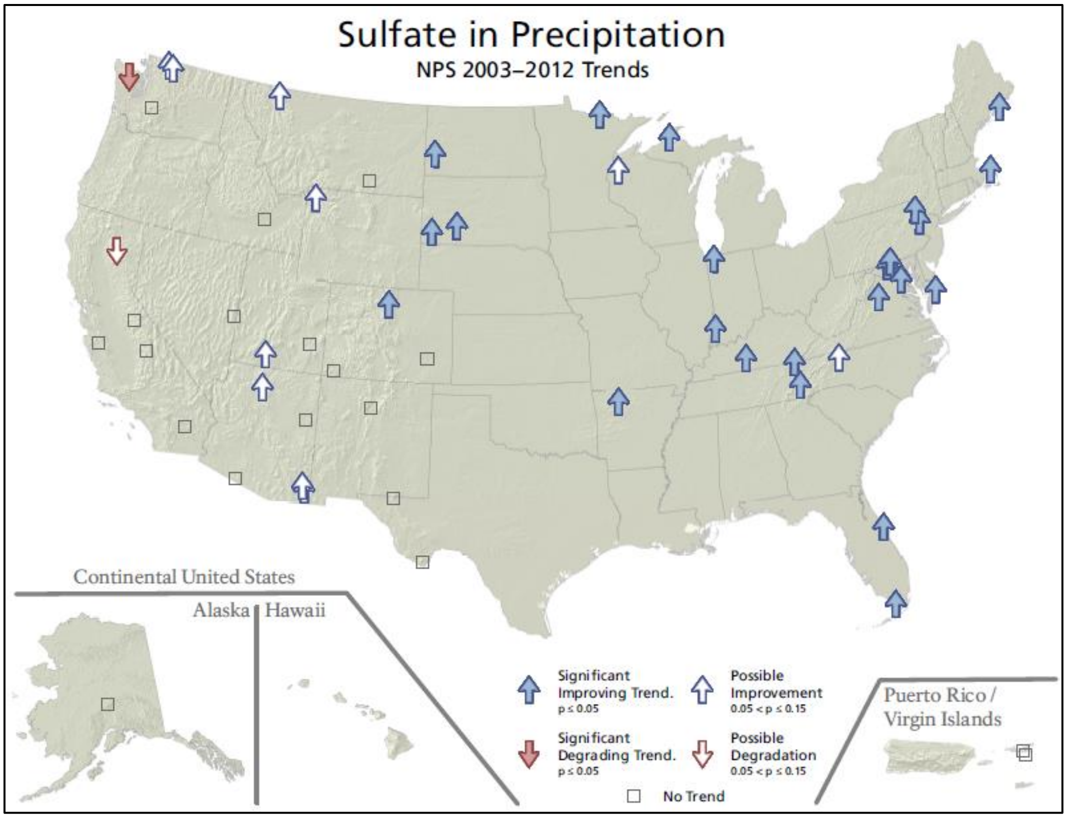


Figure 4.1.1.6. Ten-year trends of sulfate in precipitation, 2003-2012. Source: NADP, NPS ARD, J. Renfro, NPS.

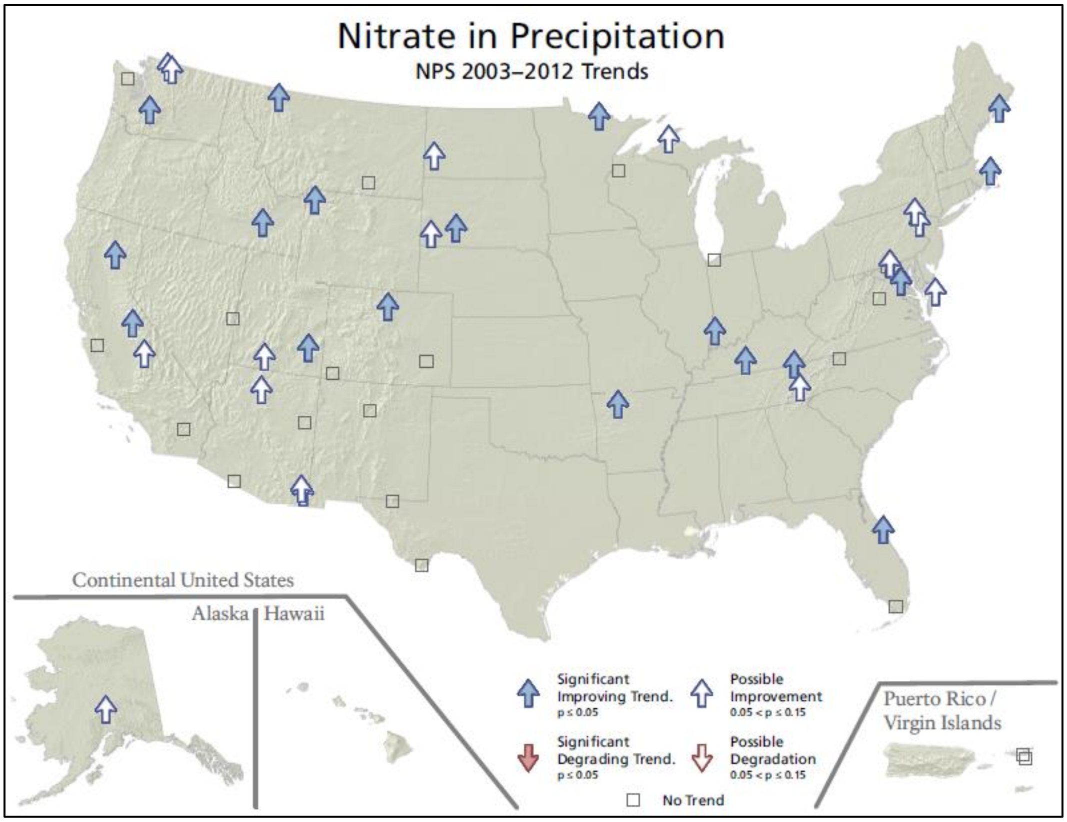


Figure 4.1.1.7. Ten-year trends of nitrate in precipitation, 2003-2012. Source: NADP, NPS ARD, J. Renfro, NPS.

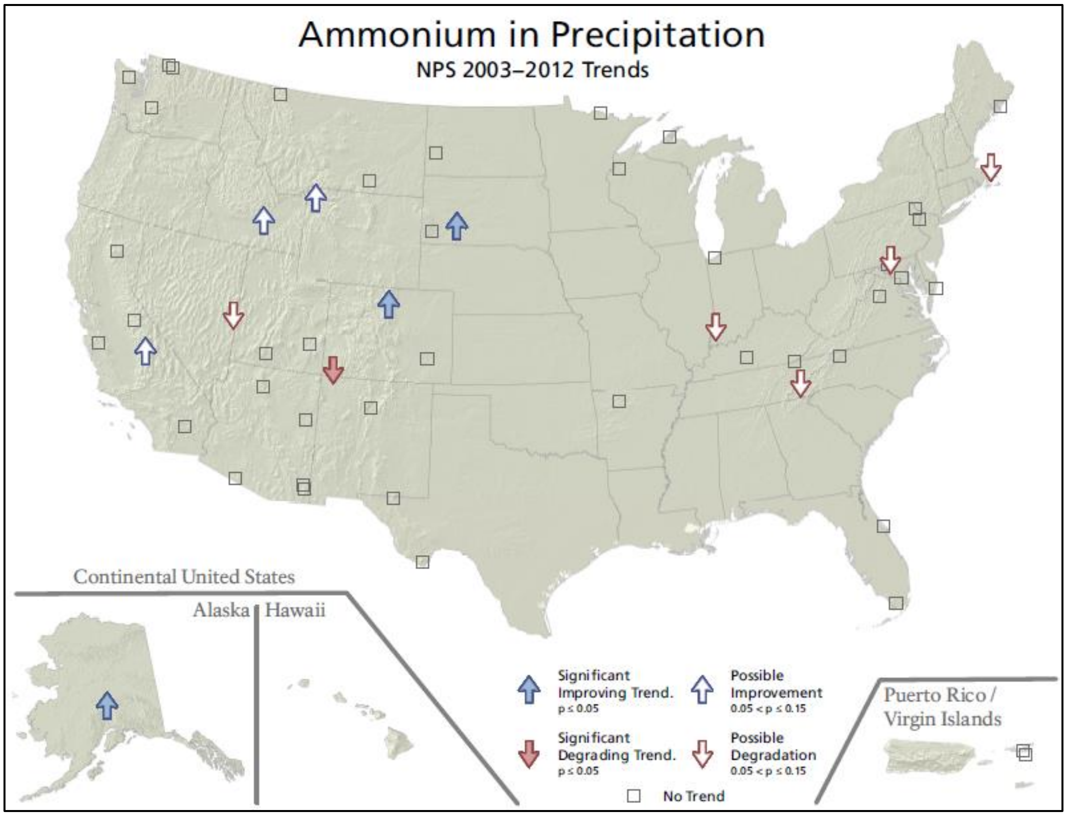


Figure 4.1.1.8. Ten-year trends of ammonium in precipitation, 2003-2012. Source: NADP, NPS ARD, J. Renfro, NPS.

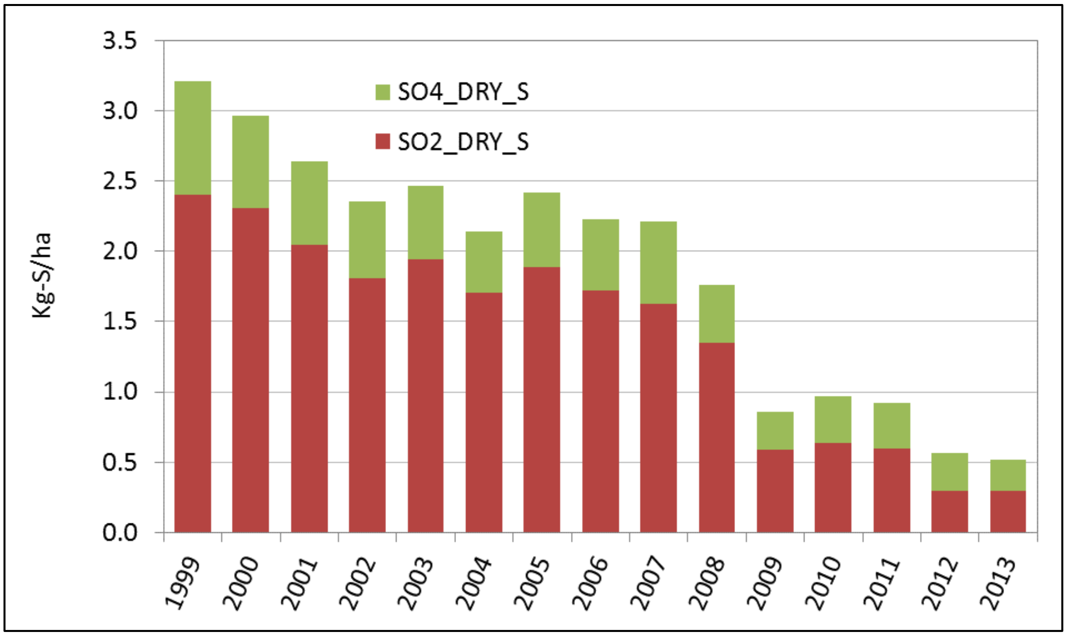


Figure 4.1.1.9. Trends in dry sulfur deposition at Look Rock, GRSM, 1999-2013. Source: CASTNET GRS420, J. Renfro, NPS.

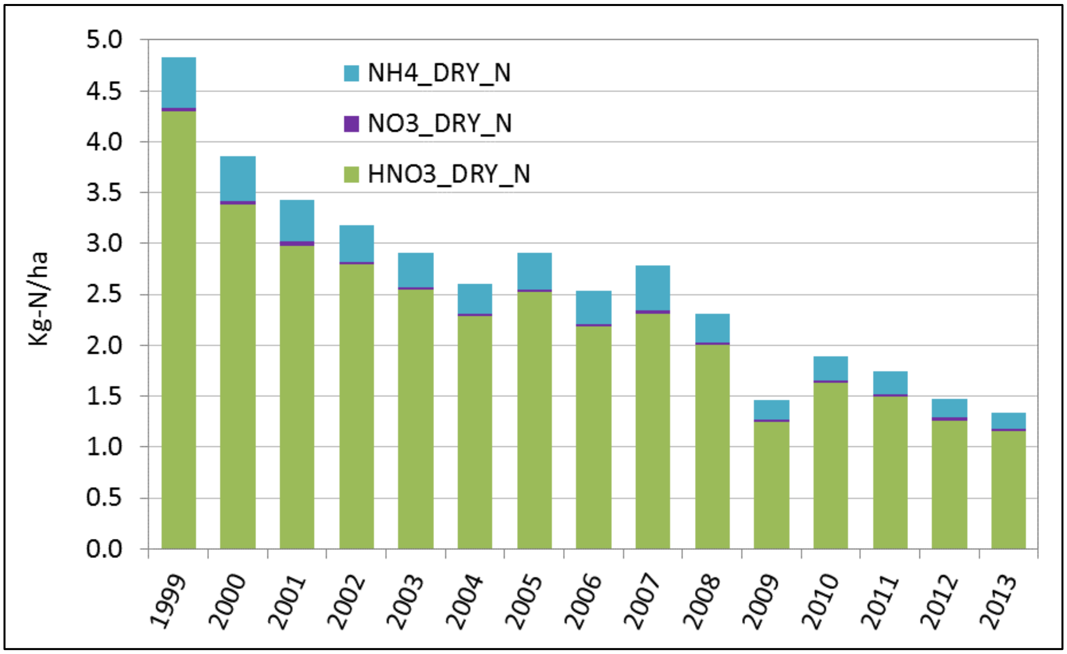


Figure 4.1.1.10. Trends in dry nitrogen deposition at Look Rock, GRSM, 1999-2013. Source: CASTNET GRS420, J. Renfro, NPS.

Confidence and Data Gaps

Monitoring of sulfate and nitrate wet deposition in GRSM began in 1980 as part of the NADP (Site TN11; http://nadp.slh.wisc.edu/data/sites/map/?net=NTN, providing a reliable, long-term record that has been utilized by park scientists and air quality specialists, and in NPS ARD air quality reporting. Confidence in the current assessment of both condition and trend of sulfate and nitrate wet deposition is high (Table 4.1.1.1).

Sources of Expertise

- Jim Renfro, Air Quality Program Manager, Great Smoky Mountains National Park

Summary Condition

Table 4.1.1.1. Summary condition and trend graphic for sulfur and nitrogen wet deposition in GRSM.

Resource	Indicator	Status and Trend	Rationale and Reference Conditions
Air Quality	Sulfur deposition (kg/ha/yr)	⬆	Values have declined since 1981 but still exceed the NPS ARD “significant concern” level of >3 kg/ha/yr wet deposition; 5-yr annual average wet S deposition: 3.33 kg/ha/yr. Data source: NADP Elkmont (Site TN11).

Resource	Indicator	Status and Trend	Rationale and Reference Conditions
Air Quality	Nitrogen deposition (kg/ha/yr)	↔	Total wet N deposition trend is unchanging from 2004-2013. Nitrate values have declined since 1981 but ammonium values have increased; levels still exceed the NPS ARD “significant concern” level of >3 kg/ha/yr wet deposition; 5-yr annual average wet N deposition: 3.79 kg/ha/yr. Data source: NADP Elkmont (Site TN11).

4.1.2 Mercury

Relevance

Mercury (Hg) is a naturally occurring element found in water, air, and soil and exists in several forms. Mercury is primarily emitted by the burning of coal in power plants, which releases mercury into the atmosphere. Atmospheric mercury deposited to surface waters can change into toxic methyl-mercury, which can enter the food chain (Boening 2000). Like N and S, Hg may be deposited as either wet or dry, mostly in elemental (Hg) or ionic (Hg^{2+}) form (NADP 2011a). Deposition of Hg is particularly a problem in forested areas because forest canopies can act as a filter that traps dry particles, which are in turn either re-emitted or transported to the ground as throughfall. Terrestrial transport can also lead to contamination of aquatic systems which can result in human health issues, though generally amounts of mercury transported as runoff are considered to be far less than that which is retained in the soil (EPA 1997).

Once mercury reaches aquatic environments, it can persist in the water column, be carried away, revolatize into the atmosphere, enter the sediment, or be taken up by biota where it is converted to a different form known as methyl-mercury ($[CH_3Hg]^+$). This type of biotic accumulation, known as bioaccumulation, is particularly relevant in aquatic ecosystems. Once methyl-mercury enters the food chain, it accumulates in organisms such as birds and fish as it moves higher in the chain (Scheuhammer et al. 2007). Animals including humans, who eat animals contaminated with mercury, are at greatest risk for exposure. Mercury is of particular concern because it can harm the brain, heart, kidneys, lungs and immune system of people of all ages, particularly unborn babies and young children (EPA 2013a). Until 2011, there were no federal standards that required power plants to limit their emissions of toxic pollutants like mercury, despite available technologies (EPA 2012c). Coal- and oil-fired power plants with a capacity of 25 MW or greater will have 4 years to comply with the new Mercury and Air Toxics Standards (MATS) (EPA 2012c). As a result, it is expected that atmospheric mercury deposition will decrease in the coming years.

Data and Methods

Data used in this assessment consisted of both annual total mercury wet deposition and annual mercury concentrations in precipitation for the years 2002-2013. These data were recorded at a Mercury Deposition Network (MDN) monitoring station (Site TN11) located within GRSM at Elkmont and provided by J. Renfro, NPS. These data represent a sufficient record to examine annual values and assess decadal trends (http://nadp.sws.uiuc.edu/sites/siteinfo.asp?id=TN11andnet=MDN).

Ten-year trends in annual mercury concentration in precipitation are compared with monitoring data from 18 other parks to provide context for levels reported at GRSM (NPS ARD 2013).

Reference Conditions

Defining the reference conditions for mercury deposition is necessary to protect human health and ecosystems at risk of injury from mercury deposition. The United Nations Environment Programme (UNEP) has determined that the annual average atmospheric concentration of gaseous elemental mercury in the troposphere over Europe and North America at background sites (i.e., unaffected by local sources) is between 1.5-1.7 µg/m^3 (AMAP/UNEP 2013). The U.S. Agency for Toxic Substances and Disease Registry (ATSDR) has established background (or natural) levels of mercury in urban outdoor air (10 and 20 µg/m^3), non-urban outdoor air (6 µg/m^3 or less), surface water (5 µg/l of water), and soil (20 to 625 µg/g of soil) (ATSDR 1999). Dry mercury deposition measurements are very limited; therefore, wet mercury deposition measurements (i.e., concentration in precipitation) are used to establish ecological thresholds and characterize mercury trends (NPS ARD 2013). Condition thresholds for mercury deposition have not been established by NPS ARD (2013); however, a value of 3 µg/m^2 is used by park scientists at GRSM as the natural level for local wet deposition (J. Renfro, pers. comm). Meili et al. (2003) suggested that pre-industrial global mercury concentrations in precipitation were ≤2 ng/l. Thus, both of these values (3 µg/m^2 and ≤2 ng/l) were used as reference conditions for this assessment.

Conditions and Trends

For 2013, total mercury wet deposition in GRSM was 20.1 µg/m^2, which is well above the natural background level of 3 µg/m^2 (Fig. 4.1.2.1) and the highest level since monitoring began in 2002. The average total mercury concentration in precipitation for 2013 was 10.1 ng/l (Fig. 4.1.2.2), which is above the ecological threshold of ≤2 ng/l. These values indicate at least some concern for mercury deposition in the park (Meili et al. 2003, NPS 2013).

The rate of mercury wet deposition within GRSM has remained relatively unchanged between 2002 and 2013; however, the decadal high of 20.1 µg/m^2 that occurred in 2013 results in a trend line that shows a slight increase over the entire 12-year time period (Fig. 4.1.2.1). Regardless of what the trend shows, these data illustrate that major reductions are still needed to lessen potential adverse impacts on park ecosystems. Annual mercury concentrations in precipitation within GRSM have also shown little change since 2002 (Fig. 4.1.2.2). The highest annual concentrations occurred in 2012 (10.5 µg/l) and 2013 (10.1 µg/l), and the lowest levels occurred in 2009 (6.5 µg/l). Both of these trends likely relate to annual variation in summer temperatures (and hence, power plant production levels) when mercury deposition and concentrations are at their highest in the southeastern U.S. (NADP 2011b). National trends indicate possible improvement at most monitoring sites (Fig. 4.1.2.3) (NPS ARD 2013). With the new federal standards now in place, we are hopeful that future levels will improve.

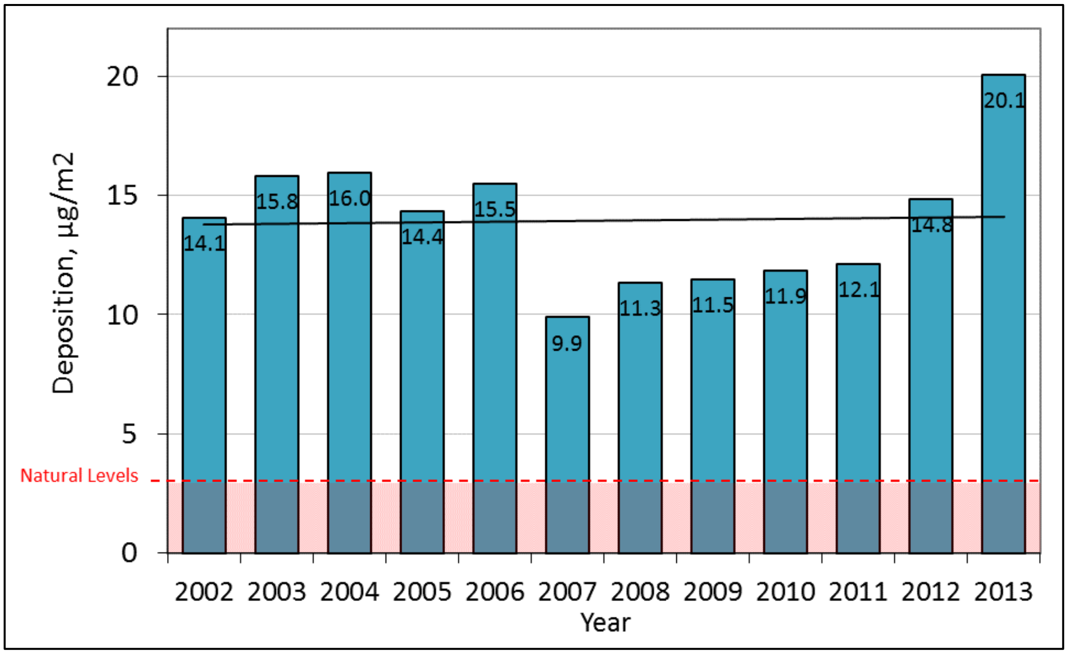


Figure 4.1.2.1. Annual total wet mercury deposition at Elkmont, TN, 2002-2013. Source: MDN, J. Renfro, NPS.

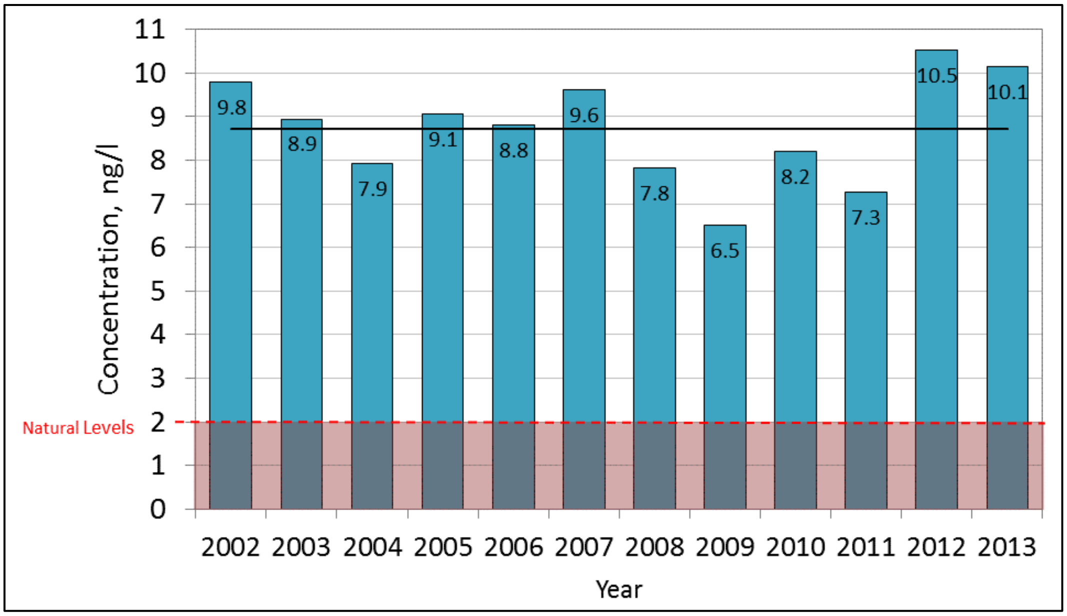


Figure 4.1.2.2. Annual mercury concentrations in precipitation at Elkmont, TN, 2002-2013. Source: MDN, J. Renfro, NPS.

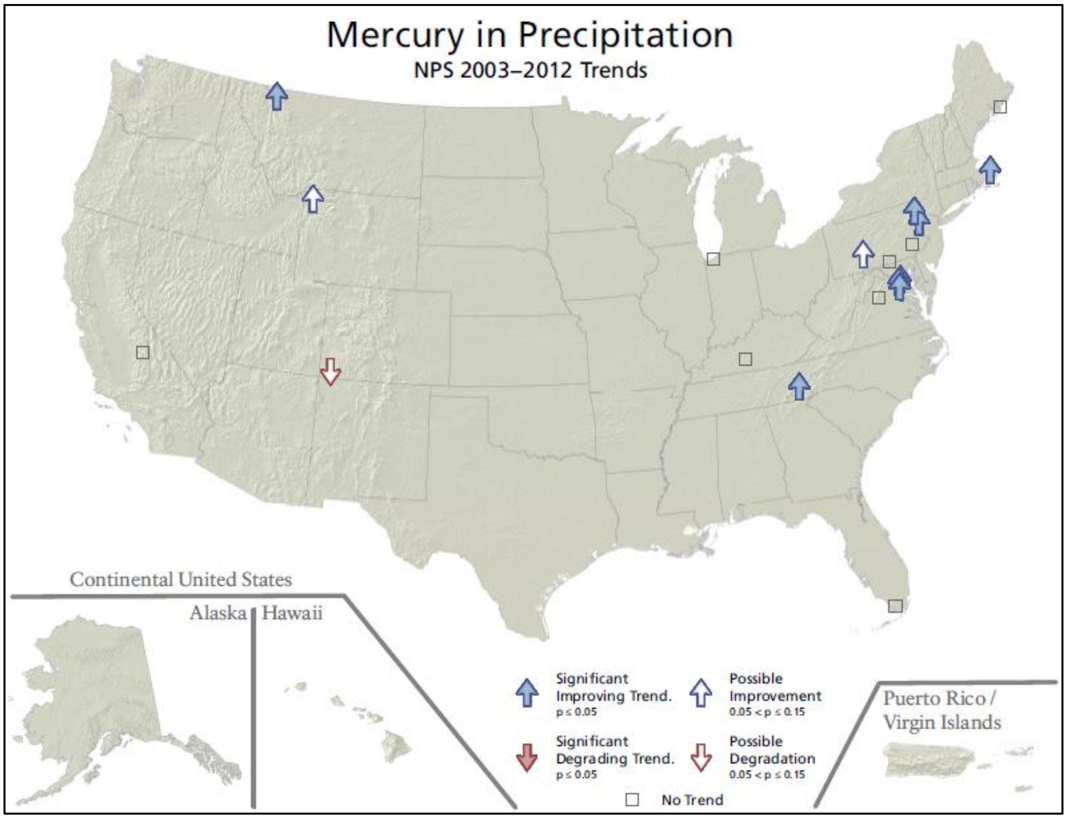


Figure 4.1.2.3. Ten-year trends of mercury in precipitation, 2003-2012. Source: MDN, NPS ARD, J. Renfro, NPS.

Confidence and Data Gaps

Monitoring of mercury wet deposition in GRSM began in 2002 as part of the MDN (Site TN11; http://nadp.sws.uiuc.edu/sites/siteinfo.asp?id=TN11andnet=MDN), providing a reliable, sufficiently long record that has been utilized by park scientists and air quality specialists, and in NPS ARD air quality reporting. Twelve years of monitoring data afford high confidence in the current assessment of trend (Table 4.1.2.1).

Sources of Expertise

- Jim Renfro, Air Quality Program Manager, Great Smoky Mountains National Park

Summary Condition

Table 4.1.2.1. Summary condition and trend graphic for mercury deposition in GRSM.

Resource	Indicator	Status and Trend	Rationale and Reference Conditions
Air Quality	Mercury (µg/l)	⬆	Based on data from 2003-2012, the condition level is of high concern but the trend has been improving (see Fig. 4.1.2.3). Five-yr annual average wet Hg deposition: 14.08 µg/m^3, and Hg in precipitation: 8.52 µg/l. Data source: MDN Elkmont (Site TN11).

4.1.3. Ozone

Relevance

Tropospheric ozone (O_3) has been recognized as the most widespread phytotoxic air pollutant in eastern North America (EPA 1996). Once thought to be prevalent only in urban areas where emissions of nitrogen oxides are high, ozone and its precursors are known to be transported to rural and natural areas downwind (Aneja et al. 1990). Low levels of ozone have been shown to impact human health, causing skin and eye irritation, shortness of breath, and decreased lung function in sensitive individuals; however, high levels of ozone can cause symptoms in anyone in the general population (EPA 1999). Research has also established that ozone is equally detrimental to the health of vegetation. Trees that have been adversely affected by ozone commonly exhibit reduced photosynthesis rates (Grulke 2003), reduced height and/or diameter growth (Somers et al. 1998), biomass loss (Shafer and Heagle 1989), and/or foliar injury (Neufeld et al. 1992). If damage is great enough, an entire forest ecosystem can be significantly altered (McLaughlin and Downing 1995, Chappelka and Samuelson 1998). It has been suggested that the ecological threshold is likely lower than the current primary 8-hour standard of 75 parts per billion (ppb) (Heck and Cowling 1997).

Data and Methods

Data used in this assessment consisted of ozone concentrations for the years 1990-2012. These data were recorded at five monitoring stations located within the park at Look Rock, Cove Mountain, Clingmans Dome, and Cades Cove in TN, and Purchase Knob in NC, and were provided by J. Renfro, NPS. These data represent a sufficiently long record with which to examine annual values and assess trends over the past two decades. Ten-year trends in annual ozone concentrations are compared with monitoring data from other parks to provide a national and regional context for levels reported at GRSM (NPS 2013a).

Reference Conditions

Defining the reference condition for ozone concentrations is necessary to both detect when concentrations reach levels of concern to human health, and to identify park resources at risk for injury from elevated ozone concentrations. Determining natural background concentrations of ozone is challenging, requiring measurements in remote locations when photochemical conditions and winds are not ideal for ozone production and/or transport (Reid 2007). Background concentrations in the 1990s in the U.S., reported by Altshuller and Lefohn (1996), were 35 ± 10 ppb. More recently, Lefohn et al. (2001) have suggested that stratospheric intrusion is responsible for surface ozone concentrations of $\geq$60 ppb. NPS ARD uses EPA’s NAAQS for rating ozone conditions in national parks. To attain the NAAQS, the 3-year average of the annual 4th-highest daily maximum 8-hour average ozone concentration measured at each monitor must not exceed 75 ppb (EPA 2012d). Since 2004, the Blount County portion of the park was in ozone non-attainment for this standard, and was part of the Knoxville marginal non-attainment area (see Fig. 4.1.3.1). However, data from 2013 show attainment of the ozone standard at all locations in the Knoxville area. The Tennessee Department of Environment and Conservation (TDEC) and EPA moved forward with the designation process to attainment, and in July 2015, the Knoxville area, including the park (Blount County portion), was redesignated to attainment of the ozone standard.

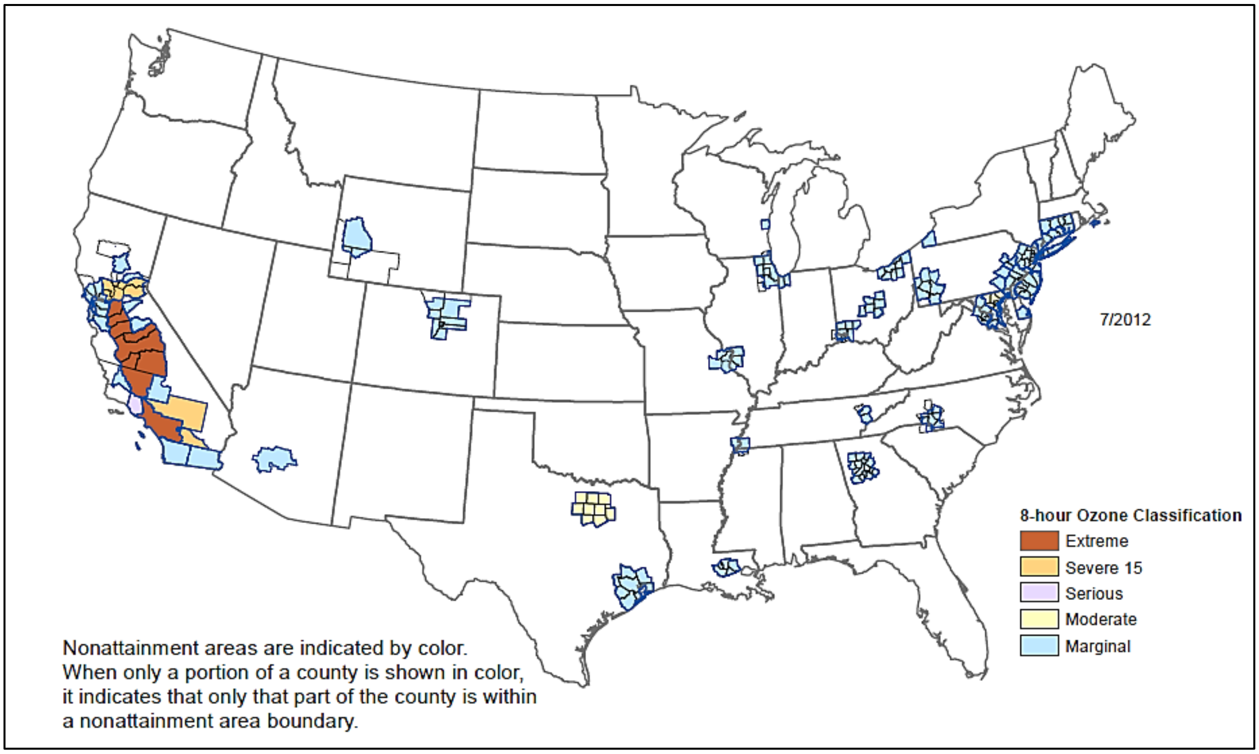


Figure 4.1.3.1. Eight-hour ozone non-attainment areas in the U.S., using the 2008 ozone standard. Source: J. Renfro, NPS.

Based on these regulatory values, NPS ARD has established the following standards: ≥76 ppb indicates significant concern; 61-75 ppb indicates moderate concern; and ≤60 ppb represents good condition (NPS 2013b). For this assessment, the good condition category of ≤60 ppb was used as the reference condition (and ecological threshold) for ozone concentrations. If parks are evaluated as high-risk for ozone injury to vegetation, as was GRSM, the condition category is adjusted to the next worse condition category (NPS 2013b).

In order to describe potential damage to vegetation in GRSM, a biologically relevant ozone index called the W126 exposure index is also used as a reference condition. This is a two-fold description which includes the sum of hourly concentrations during the peak ozone season from March through October. For the hourly sum, the W126 index weights the values using a sigmoidal function according to the following equation:

$$W_i = \frac{1}{1 + M * e^{-(A * C_i)}}$$

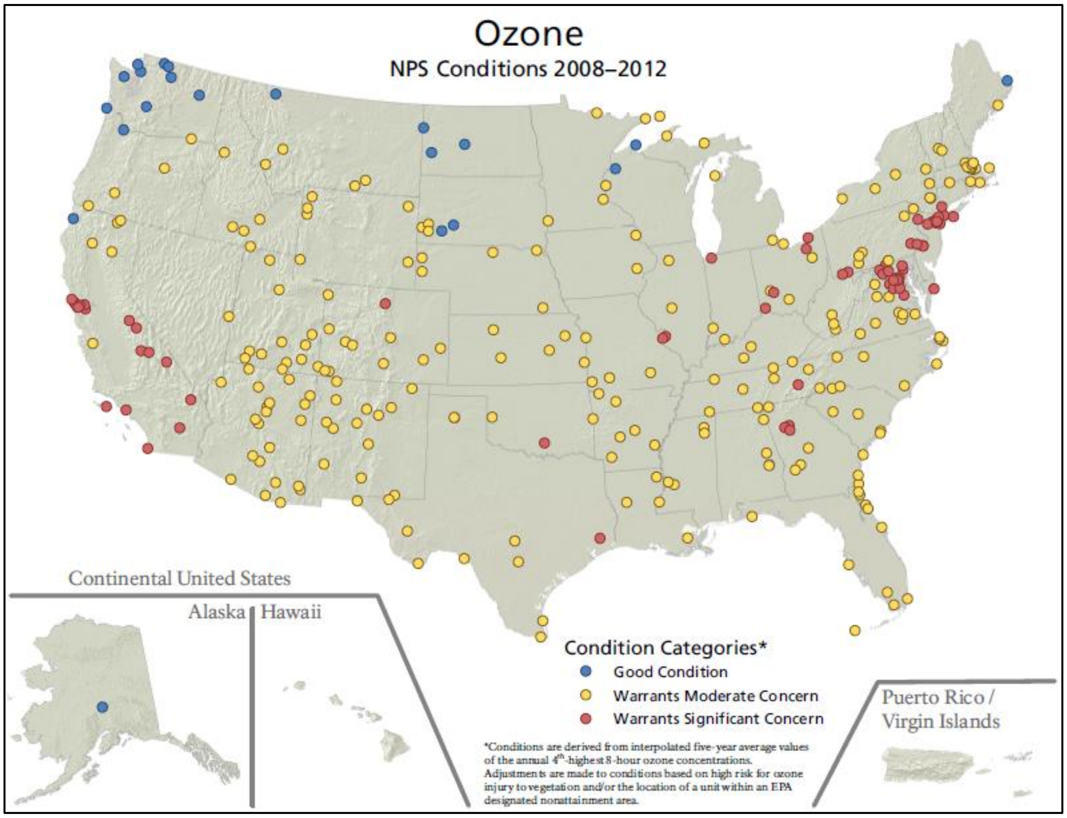
W_i is the weighting factor for concentration *Ci* in ppm, and *M* and *A* are constants representing 4,403 ppm and 126 ppm, respectively. The constant *A* represents the ozone concentration of maximum weighting, and lends itself to the naming of the index. By using this index, higher ozone concentrations are weighted disproportionately greater since they present more of a threat for foliar injury and growth damage (Lefohn and Runeckles 1987). For W126, highly sensitive plant species are affected beginning at 5.9 cumulative ppm-hours, and moderately sensitive species at 23.8. The park has several species highly sensitive to ozone, including black cherry and tulip poplar.

Conditions and Trends

The 5-year average from 2009-2013 for the 4th highest 8-hour ozone average, and the 3-year average of the 4th highest 8-hour ozone average at monitors in GRSM were: Look Rock (74/74 ppb), Cove Mountain (72/71 ppb), Clingmans Dome (72/71 ppb), Cades Cove (65/63 ppb), and Purchase Knob (68/67 ppb). Each of these values fall within the “moderate concern” category (61-75 ppb); however, since GRSM was evaluated as high-risk for ozone injury to vegetation based on an NPS risk assessment, the condition category was adjusted to “warrants significant concern” (NPS 2013b). Although the Knoxville area, including the park (Blount County portion), is in attainment for the ozone standard, the area is now under a maintenance plan, which also requires that it be placed it in the “warrants significant concern” category. These conditions are generally more severe than, and inconsistent with, data from other parks across the U.S. (Fig. 4.1.3.2) (NPS 2013a).

Ozone concentrations within GRSM have steadily declined over the past decade, with design values decreasing 29% from the 20-year high of 104 ppb (at Look Rock) during 1997-1999, to 74 ppb during 2011-2013. The 8-hour ozone design values at Look Rock show an increasing trend between 1989-1991 and 1997-1999 (84 and 104 ppb, respectively), when ozone levels peaked, followed by a substantial decreasing trend between 1997-1999 and 2011-2013 (Fig. 4.1.3.3). These trends reflect the implementation of EPA’s ozone precursor control programs, which began in the mid-1990s (EPA 2005), and are consistent with significantly improving trends in most parks across the U.S. (Fig. 4.1.3.4) (NPS 2013a).

Ozone W126 exposures have also dropped over the past decade. For example, W126 values dropped from 40 ppm-hours in 1999 at Cove Mountain to 12.7 in 2012. That represents a 68% reduction in W126 exposures (Fig. 4.1.3.5). In 2008, EPA recommended a secondary standard to protect sensitive vegetation in the range of 7-15 ppm-hours, but did not promulgate a secondary standard using the W126 exposure index. Although these data indicate improving trends, they illustrate that major reductions are still needed to lessen adverse impacts not only on the health of park visitors, but also park resources and ecosystems. For 2012, the 3-year average of the W126 exposure index ranged from 8.1 ppm-hours at Cades Cove to 16.4 ppm-hours at Look Rock (Fig. 4.1.3.5). These values are above the threshold (5.9 ppm-hours) for protecting highly sensitive vegetation.



*Conditions are derived from interpolated five-year average values of the annual 4th-highest 8-hour ozone concentrations. Adjustments are made to conditions based on high risk for ozone injury to vegetation and/or the location of a unit within an EPA designated nonattainment area.

Figure 4.1.3.2. Ozone conditions in U.S. national parks, 2008-2012. Source: NPS ARD, J. Renfro, NPS.

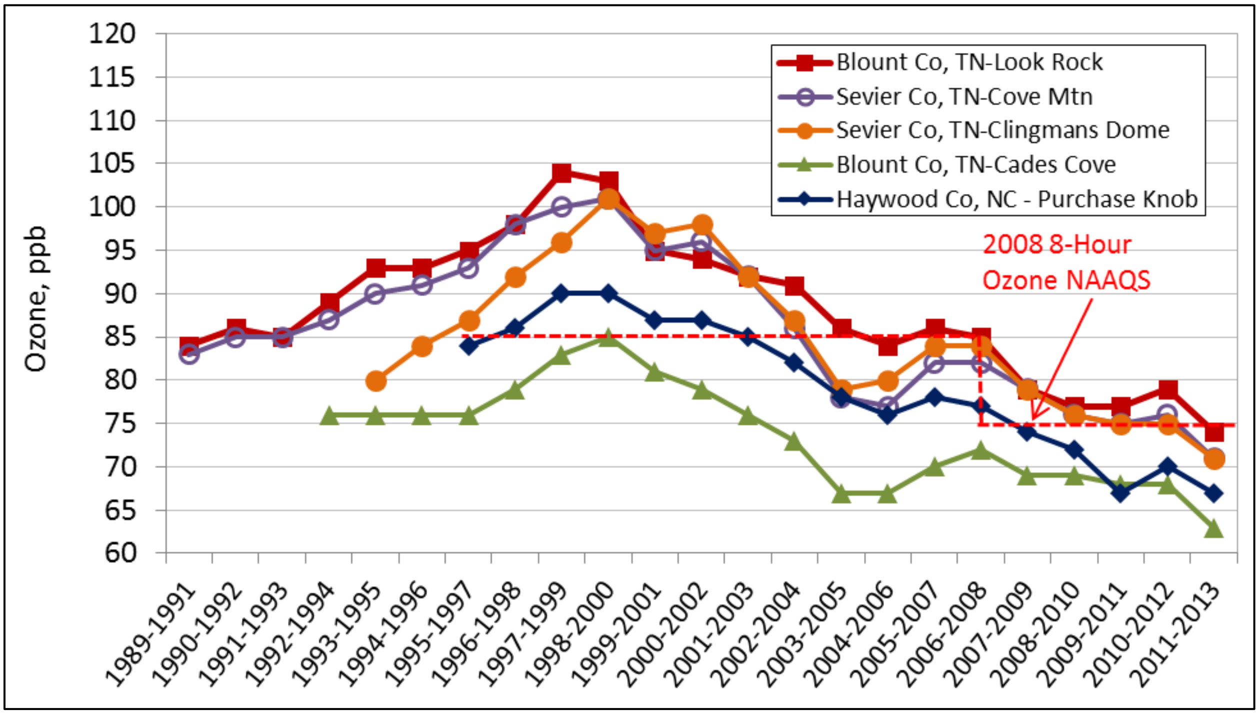


Figure 4.1.3.3. Trends in the 8-hour ozone design values at GRSM (3-year average of the 4th highest 8-hour average), 1989-2013. Source: NAAQS, J. Renfro, NPS.

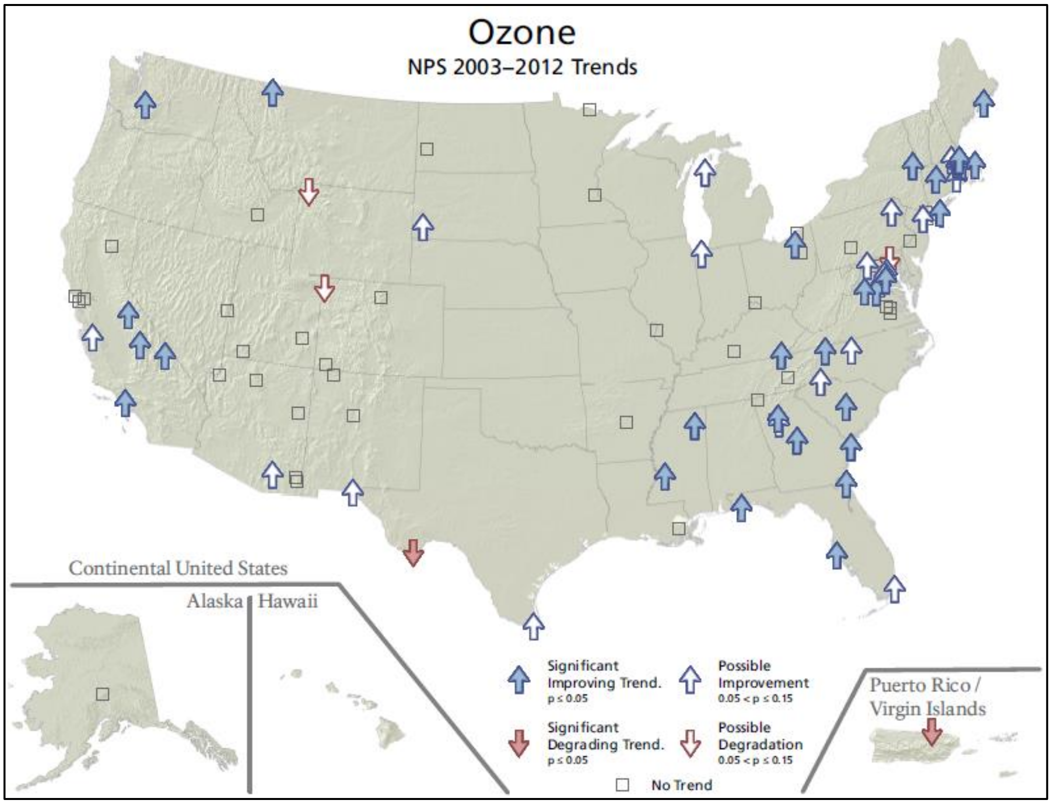


Figure 4.1.3.4. Ten-year trends in annual 4th highest 8-hour ozone concentration. Source: NPS ARD, J. Renfro, NPS.

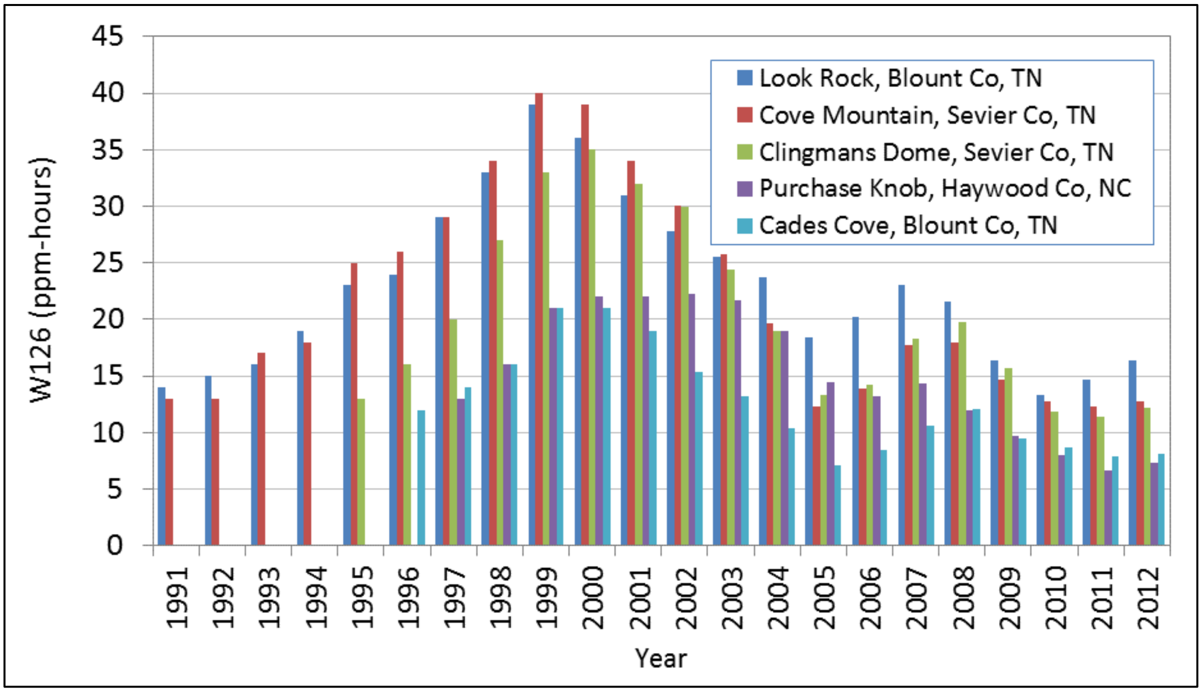


Figure 4.1.3.5. Long-term trends in ozone (W126) in GRSM (3-yr average of the 3-mo maximum daylight [8 am – 8 pm]), 1991-2012. Source: J. Renfro, NPS.

Confidence and Data Gaps

Monitoring of ozone concentrations in GRSM by the NPS began in 1988 (at Look Rock and Cove Mountain) as part of the NPS air quality monitoring network. Continuous ozone monitoring has taken place at five locations within the park since 1995. Data from these stations have provided a reliable, long-term record utilized by park scientists and air quality specialists, and in NPS ARD air quality reporting. Confidence in the current assessment of both condition and trend of ozone pollution is high (Table 4.1.3.1).

Sources of Expertise

- Jim Renfro, Air Quality Program Manager, Great Smoky Mountains National Park

Summary Condition

Table 4.1.3.1. Summary condition and trend graphic for ozone in GRSM.

Resource	Indicator	Status and Trend	Rationale and Reference Conditions
Air Quality	Ozone (ppb)	⇧	Values have declined since 1990; levels at all monitors still exceed NPS ARD "moderate/significant concern" levels of 60 ppb; 5-yr average of 4th highest 8-hr average: 74 ppb. None of the park's O_3 monitors exceed 2008 NAAQS of 75 ppb; "non-attainment." Data source: NPS park monitors.

4.1.4. Particulate Matter ($PM_{2.5}$)

Relevance

Particle pollution is widespread and is one of the most serious human health threats, possibly greater than ozone, because it can occur year-round (EPA 2013e). Particulate matter ($PM_{2.5}$) is a term for a class of atmospheric pollutants that exist suspended in air as liquid or solid particles ≤2.5 µm in diameter (EPA 2004). These very fine particles are released into the air from anthropogenic stationary and mobile sources such as power plants, automobiles, and construction activities, as well as from natural sources like forest fires and dust storms. Particulate matter can be emitted directly or formed in the atmosphere through chemical reactions. Research has indicated that wide variation in source, size, and physical and chemical properties of particulates result in a broad range of effects to human health (e.g., asthma, chronic bronchitis, and premature death) and the environment, altering essential nutrient and biogeochemical cycles (EPA 2004). Numerous physical and chemical effects on ecosystems have been documented and vary depending on mode of deposition, making inputs difficult to quantify (Grantz et al. 2003). Fine particles ($PM_{2.5}$) are also the main cause of reduced visibility (regional haze) in the U.S., including in many of our national parks (EPA 2013e).

Data and Methods

Data used in this assessment consisted of particulate matter concentrations for the years 1999-2013. These data were recorded at eight monitoring stations located within the region (one is located within the park at Look Rock) and provided by J. Renfro, NPS. These data represent a sufficiently long record with which to examine annual values and assess trends over the past two decades. Trends in annual $PM_{2.5}$ concentrations are compared with data from across the U.S. to provide a national and regional context for levels reported at GRSM (EPA 2013c).

Reference Conditions

The reference condition for particulate matter concentrations is necessary to detect when concentrations reach levels of concern to human health, visibility, and park ecosystems; however, natural background concentrations of $PM_{2.5}$ have been difficult to define. The EPA first established NAAQS for fine particle pollution in 1997 and further revised them in 2006 and 2012 (EPA 2012e). There are currently two primary and secondary standards for $PM_{2.5}$: annual primary and secondary standards are attained when the 3-year average of the annual mean concentration is ≤ 12 µg/m^3 and ≤ 15 µg/m^3, respectively; daily (24-h) primary and secondary standards are the same, and are attained when the 3-year average of the annual 98th percentile is ≤ 35 µg/m^3 (EPA 2012). For this assessment, the annual primary standard of ≤ 12 µg/m^3 was used as reference condition (and ecological threshold) for particulate matter concentrations. The Blount County portion of the park is currently in $PM_{2.5}$ non-attainment for this standard and is part of the Knoxville marginal non-attainment area (Fig. 4.1.4.1).

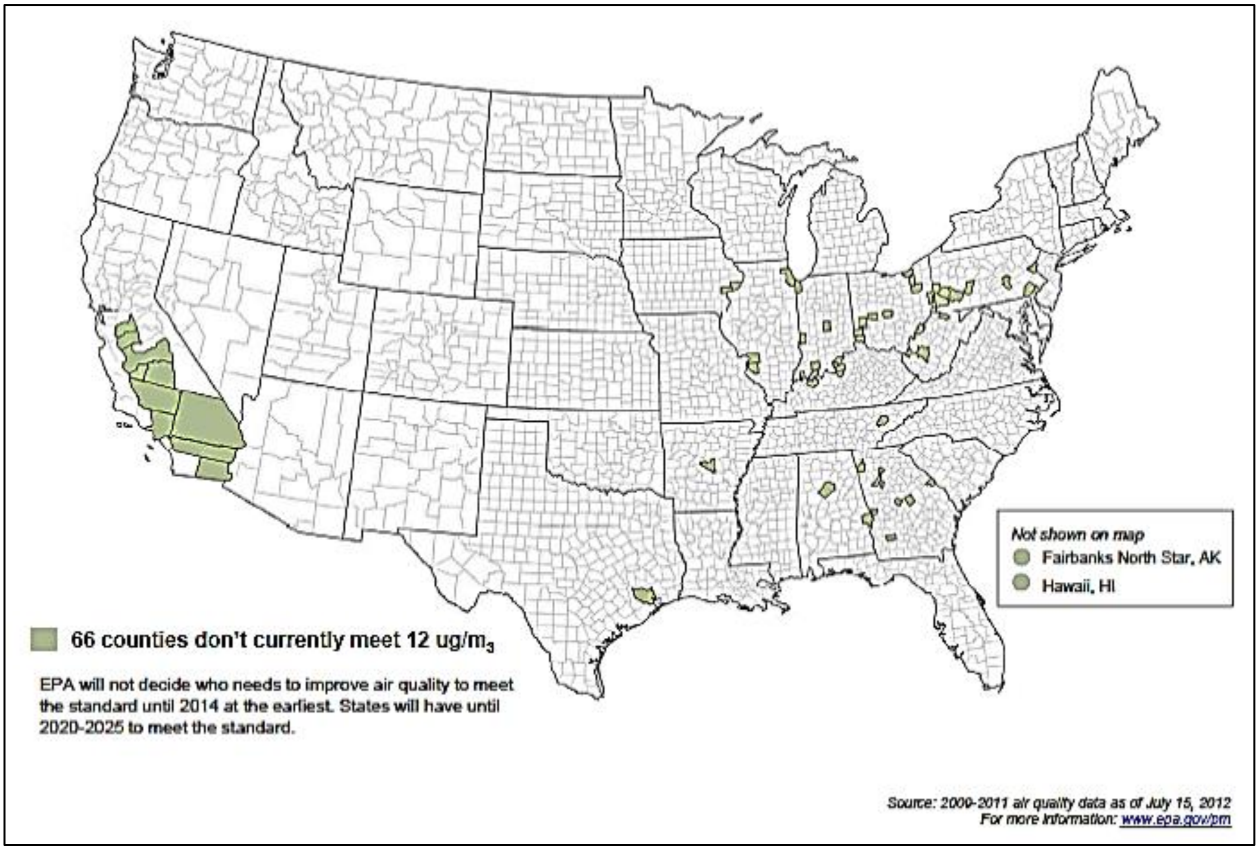


Figure 4.1.4.1. Non-attainment areas in the U.S. for the 2012 annual $PM_{2.5}$ NAAQS. Source: EPA 2012.

Conditions and Trends

For 2013, the 3-year rolling annual average $PM_{2.5}$ concentrations (2011-2013) for the eight monitor locations in and around GRSM were: Look Rock, TN (7.8 µg/m^3), Knox Co., TN (12.2 µg/m^3), Loudon Co., TN (11.3 µg/m^3), Roane Co., TN (10.8 µg/m^3), Blount Co., TN (10.5 µg/m^3), Haywood Co., NC (9.9 µg/m^3), Swain Co., NC (9.6 µg/m^3), and Buncombe, Co., NC (9.1 µg/m^3). These values are all near or below the annual standard (except Knox Co., TN) and indicate minimal to moderate concern for particulate matter condition in the park (IMPROVE 2013, EPA 2013d). Because the Blount County portion of the park is within the Knoxville $PM_{2.5}$ non-attainment area, the condition in this area is adjusted to the "warrants significant concern" category. The State of Tennessee has requested that the Knoxville non-attainment area be redesignated to attainment (or maintenance area) by EPA. This request has been "deferred" until the State of Tennessee collects quality-controlled data for Knoxville monitors.

Particulate matter concentrations within GRSM have steadily declined over the past decade, with values decreasing an average of about 40%, from the 12-year high values of 12.5-20.0 µg/m^3 (1999-2001) to 6.7-12.2 µg/m^3 in 2013 (Fig. 4.1.4.2). The year 2012 marks the first time that values at all monitoring stations in and around GRSM, except one (Knox Co, TN; 12.2 µg/m^3), met annual NAAQS. These trends, which are consistent with improving trends across much of the U.S., reflect EPA's continued efforts to limit fine particle pollution emissions; daily standards were strengthened in 2006, and the annual standards were strengthened in 2012 (EPA 2012e). These regulatory implementations are evident in Fig. 4.1.4.3; note an initial slight decrease in annual $PM_{2.5}$ concentrations until 2003, followed by a leveling off of values until 2008 when they begin to decrease again.

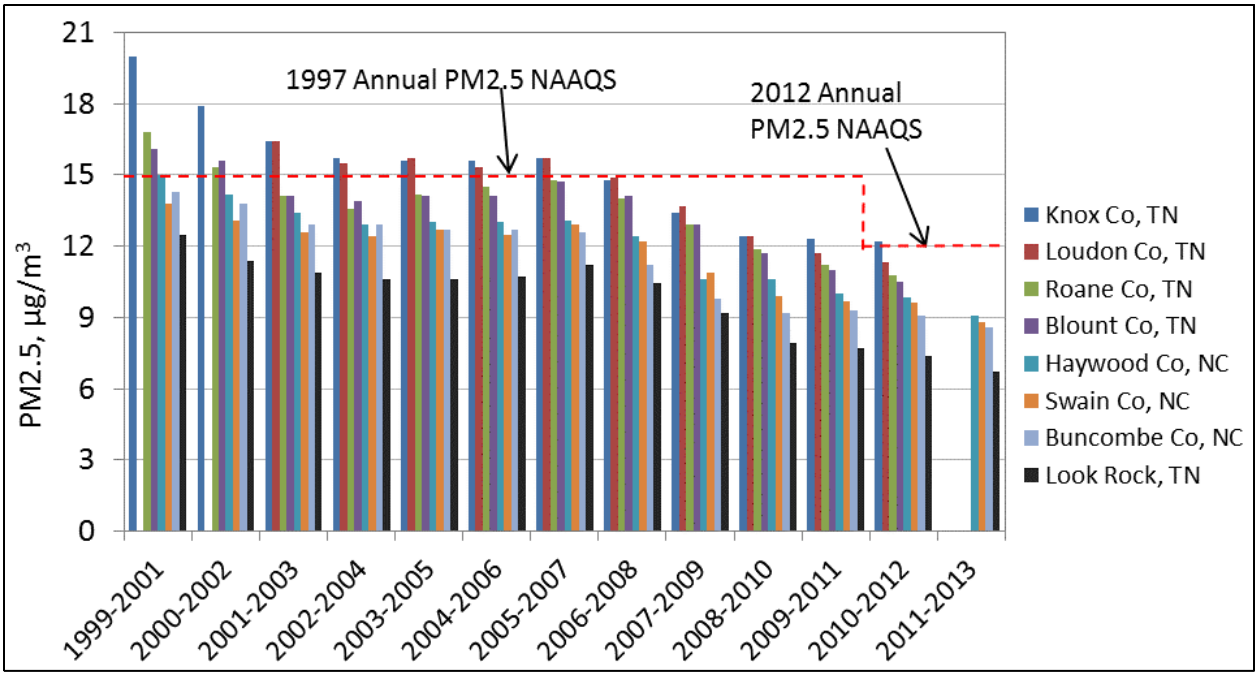


Figure 4.1.4.2. Annual $PM_{2.5}$ design values in the GRSM region (3-year rolling annual average $PM_{2.5}$ concentrations), 1999-2013. Source: NAAQS, TDEC, NCDENR, IMPROVE, J. Renfro, NPS.

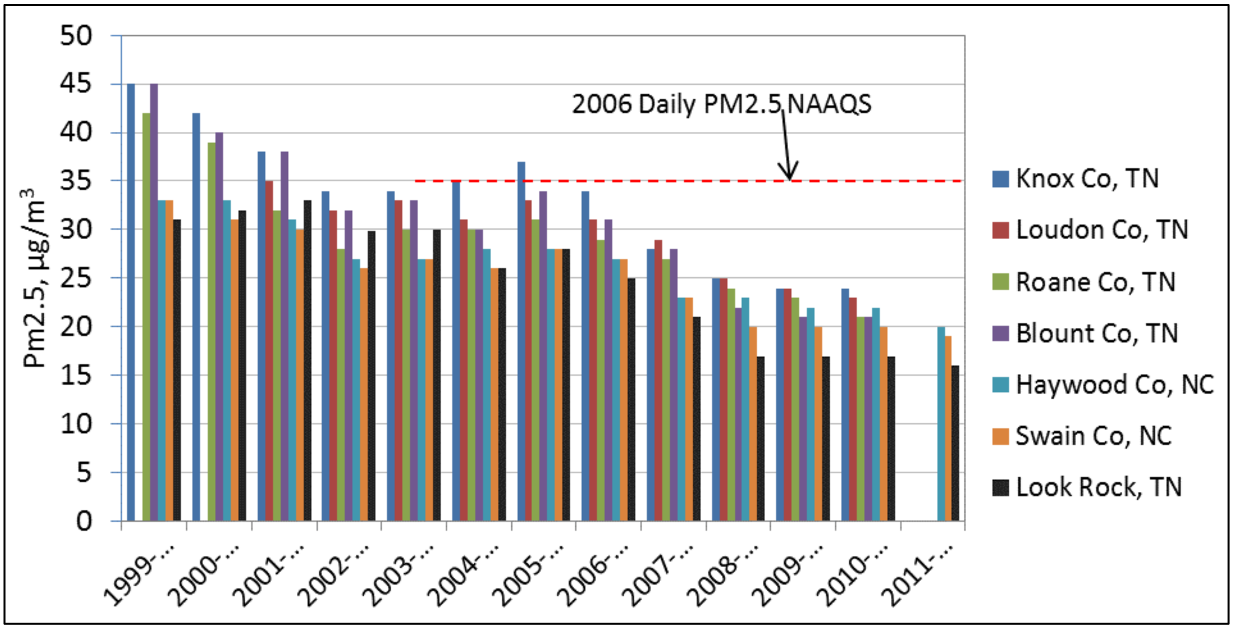


Figure 4.1.4.3. Twenty-four hour $PM_{2.5}$ design values for the GRSM region (3-year rolling annual average of the 98th percentile values), 1999-2013. Source: NAAQS, TDEC, NCDENR, IMPROVE, J. Renfro, NPS.

The longest record of annual average particulate matter data for GRSM is from the Interagency Monitoring of Protected Visual Environments (IMPROVE) program that measures $PM_{2.5}$ mass concentrations to calculate visibility (2013). Particulate matter annual averages from 1988-2013 show that values have dropped 48%, with the high annual average of 14.8 µg/m^3 in 1990 and the lowest annual average of 5.9 µg/m^3 in 2013 (Fig. 4.1.4.4).

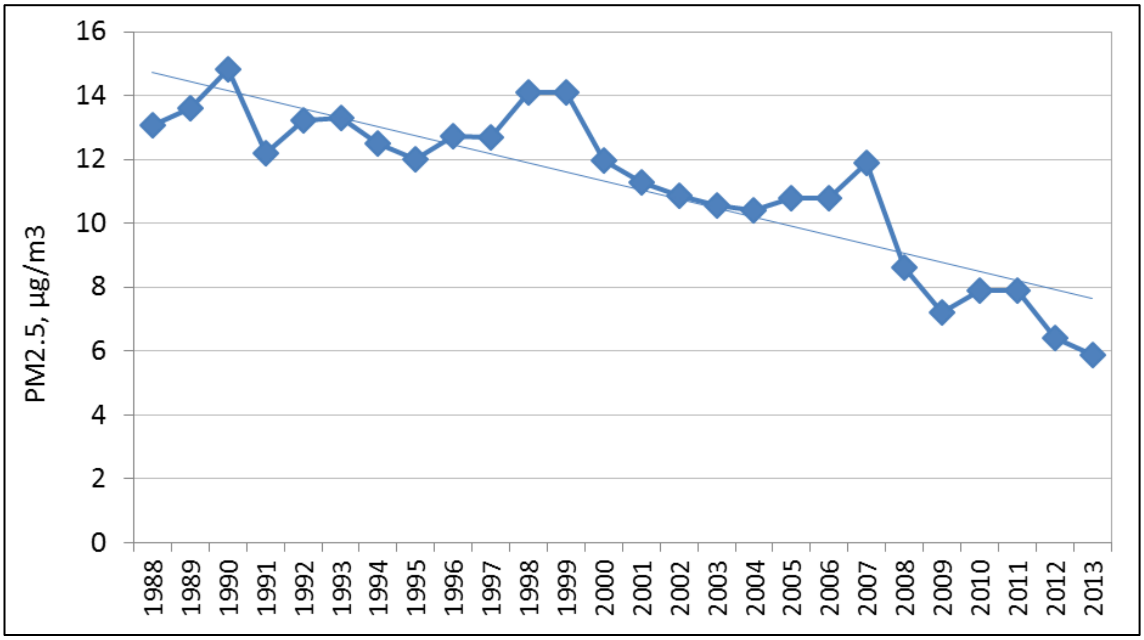


Figure 4.1.4.4. Annual average $PM_{2.5}$ concentrations at Look Rock, GRSM, 1988-2013. Source: IMPROVE, J. Renfro, NPS.

Confidence and Data Gaps

Monitoring of particulate matter (PM$_{2.5}$) concentrations in GRSM began in 1988 (at Look Rock) as part of the IMPROVE program (2013). Continuous fine particle pollution monitoring has also taken place at seven other locations around the park since 1999. Data from these stations have provided a reliable record utilized by park scientists and air quality specialists. Confidence in the current assessment of both condition and trend of particulate matter (PM$_{2.5}$) pollution is high (Table 4.1.4.1).

Sources of Expertise

- Jim Renfro, Air Quality Program Manager, Great Smoky Mountains National Park

Summary Condition

Table 4.1.4.1. Summary condition and trend graphic for particulate matter (PM$_{2.5}$) in GRSM.

Resource	Indicator	Status and Trend	Rationale and Reference Conditions
Air Quality	Particulate matter (μg/m^3)	⬆	Values have declined since 1999; most recent levels at all monitors except Knox Co, TN have fallen below the annual standard of ≤12 μg/m^3. Five-yr average of PM$_{2.5}$ concentration (at Look Rock): 7.06 μg/m^3; “non-attainment.” Data sources: EPA NAAQS, IMPROVE.

4.1.5. Visibility

Relevance

Regional haze is a general term for one of the most basic forms of air pollution that degrades visibility across the landscape. Regional haze is caused when sunlight interacts with fine particles suspended in the atmosphere, which absorb, scatter, and reflect light, reducing the clarity of park viewsheds (EPA 2012a). Both natural (organic matter, dust, soil) and anthropogenic (automobile, utility, industry) sources of particles can cause reduced visibility; however, sulfates formed from coal-fired power plant emissions are particularly good at scattering light, and are thus the major cause of reduced visibility in the eastern U.S. (EPA 2012a). In 1999, the EPA passed strict regulations to initiate a major effort to improve air quality in national parks and wilderness areas (EPA 2012a). Regional haze is a key concern in national parks like GRSM, as viewing scenery is the top reason 10 million visitors come to the park annually and generate nearly $1 billion in tourism revenues every year (J. Renfro, pers. comm. 2012).

Data and Methods

Data used in this assessment consisted of haze index values (deciviews, or dv) for the years 1990-2013. These data were recorded at an IMPROVE monitoring station located within the park at Look Rock and provided by J. Renfro, NPS. These data represent a sufficiently long record with which to examine annual values and assess trends over the past two decades. Trends in annual haze index values for the 20% clearest days and the 20% haziest days are compared with monitoring data from other parks to provide a national and regional context for levels reported at GRSM (NPS 2013a).

Reference Conditions

The reference condition for visibility is necessary to meet the CAA goal of improving and preventing visibility impairment in Class I areas (NPS 2013a). Visibility conditions are based on an interpolated 5-year average visibility minus the estimated average natural visibility, where average visibility is the mean of visibility between the 40th and 60th percentiles, and natural visibility is what is estimated to exist in a given area in the absence of human-induced visibility impairment (NPS 2013b). NPS ARD has established the following standards for visibility: >8 dv above natural conditions indicates significant concern; 2 to 8 dv above natural conditions indicates moderate concern; and <2 dv above natural conditions represents good condition (NPS 2013b). For this assessment, the good condition category of <2 dv above natural conditions was used as reference condition for visibility conditions.

Conditions and Trends

Haze index scores recorded in the park at Look Rock between 2009-2013 were 22.5 dv for 20% worst days (11.31 dv natural conditions) and 10.6 dv for 20% best days (4.62 dv natural conditions). Both of these values are above the threshold of <2 dv above natural conditions and indicate significant concern for visibility in the park (IMPROVE 2013). These conditions are consistent with data from other parks across the U.S. (Fig. 4.1.5.1) (NPS 2013a).

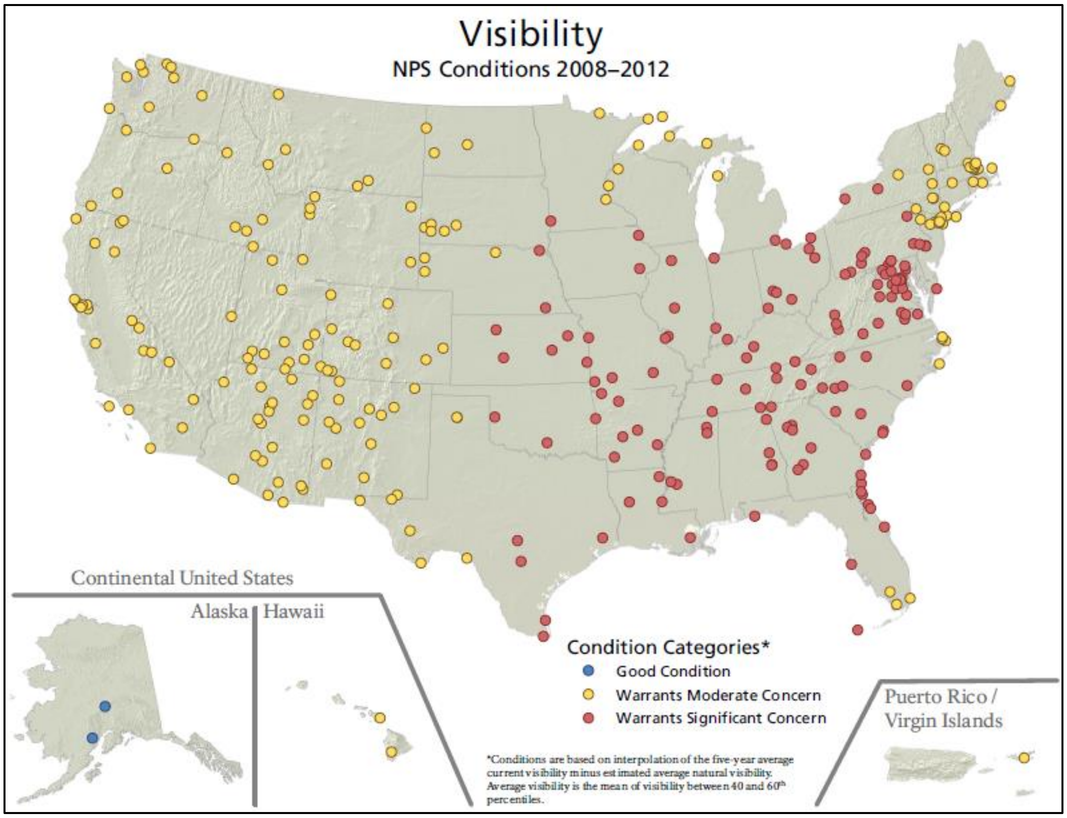


Figure 4.1.5.1. Visibility conditions in U.S. national parks, 2008-2012. Source: NPS ARD, J. Renfro, NPS.

GRSM has consistently experienced annual mean deciview values well in excess of estimated natural conditions, on both the haziest and clearest days (Fig. 4.1.5.2). However, visibility conditions on the haziest days has improved over the past two decades, with values decreasing 137% from the 20-year high of 33.9 dv in 1990 to 20.2 dv in 2013 (Figs. 4.1.5.3, 4.1.5.4).

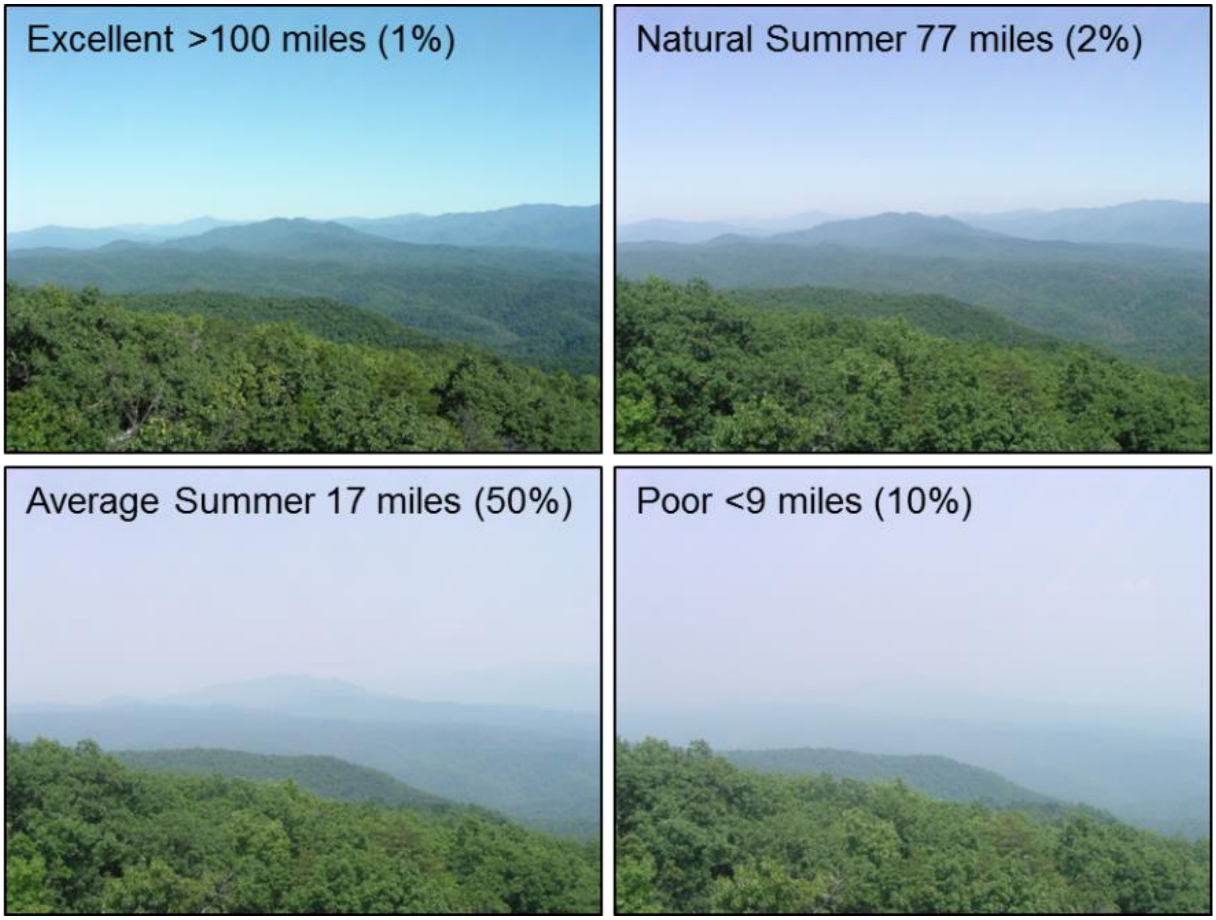


Figure 4.1.5.2. Varying visibility conditions at Great Smoky Mountains National Park. Top left: excellent, > 100 miles (1%); top right: natural summer, 77 miles (2%); bottom left: average summer, 17 miles (50%); bottom right: poor, < 9 miles (10%). Source: J. Renfro, NPS.

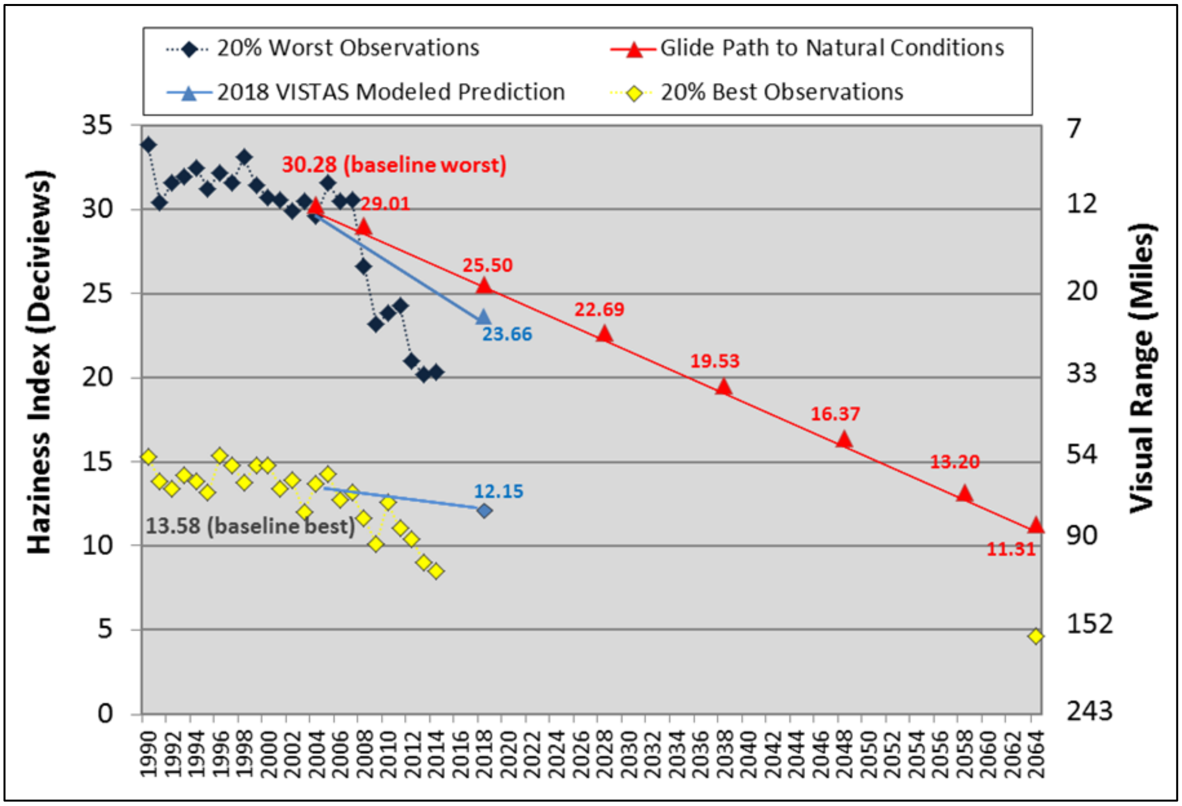


Figure 4.1.5.3. Visibility values on the haziest (worst) days and clearest (best) days in GRSM, 1990-2013, with predictions to 2018, and the glide path to natural conditions for the haziest days. Source: IMPROVE, J. Renfro, NPS.

Figure 4.1.5.4. Improvement in haze on 20% worst days at GRSM, 1998 vs. 2013. Source: J. Renfro, NPS.

Visibility conditions in GRSM on the clearest days have also improved, but to a lesser degree, with values decreasing 63% from 15.3 dv in 1990 to 9.0 dv in 2013. Annual mean deciview values in GRSM during the period 2009-2013 averaged approximately 11.2 dv higher than estimated natural conditions (11.3 dv) on the haziest days, and 6.0 dv higher than estimated natural conditions (4.62 dv) on the clearest days. These trends are consistent with improving trends in most parks across the U.S., (Figs. 4.1.5.5, 4.1.5.6) and are likely due to tighter NAAQS for ozone and $PM_{2.5}$, and Best Available Retrofit Technology (BART) rules and Reasonable Progress Goals (RPG) under the Regional Haze Rule (EPA 2012b, NPS 2013a). Although observed trends over the long-term are improving significantly, these values indicate that major reductions are still needed to reduce regional haze and improve visibility within the park back to natural conditions by 2064. On the haziest days, sulfate is the primary component of the haze, with ammonium sulfate levels in and around the park having a direct influence on visibility trends (Figs. 4.1.5.7, 4.1.5.8).

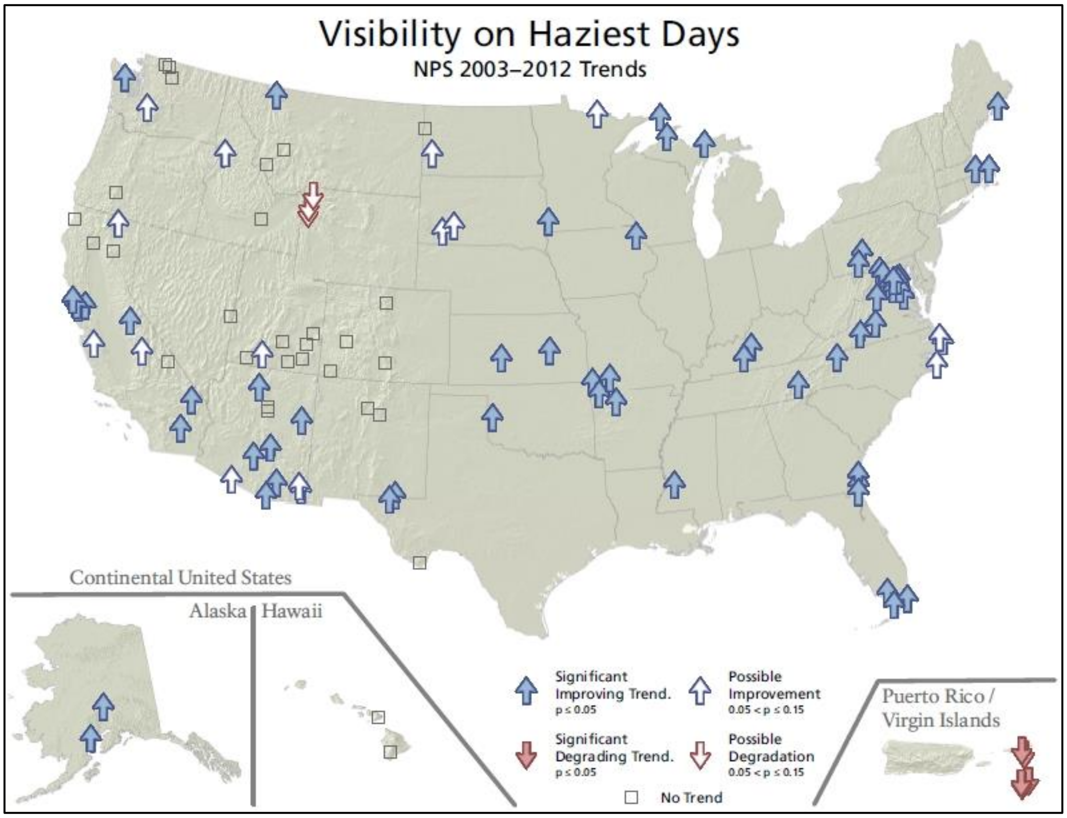


Figure 4.1.5.5. Ten-year trends for visibility on haziest days, 2003-2012. Source: NPS ARD, J. Renfro, NPS.

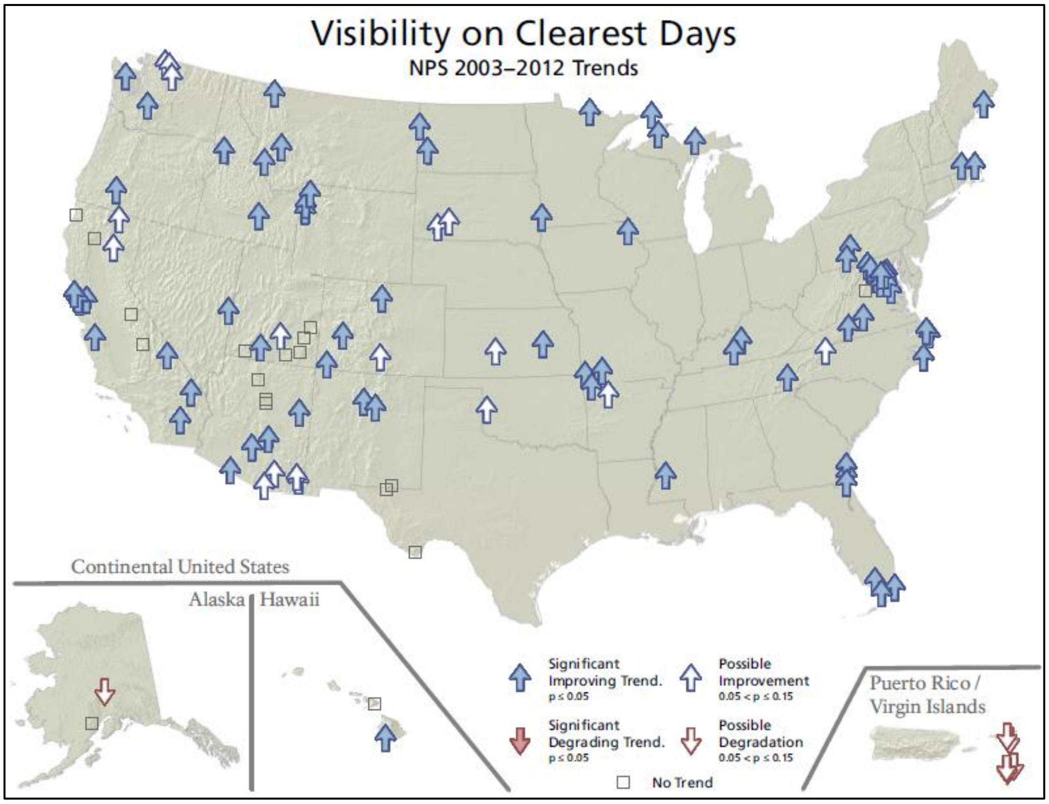
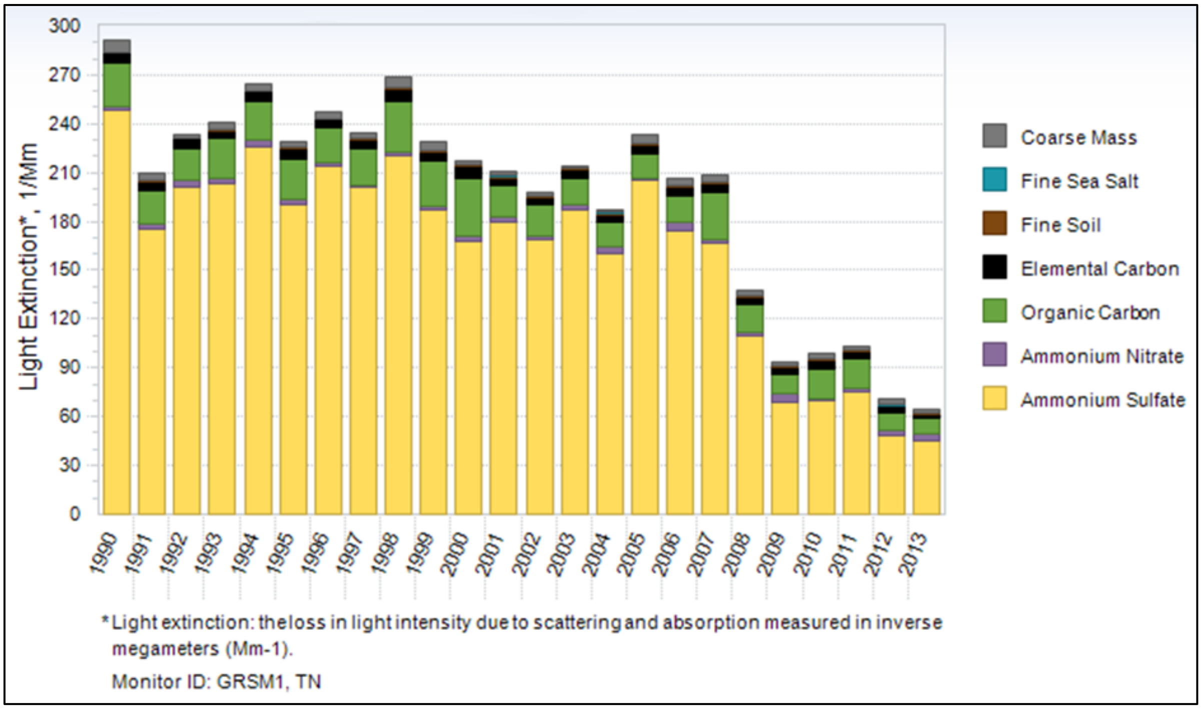


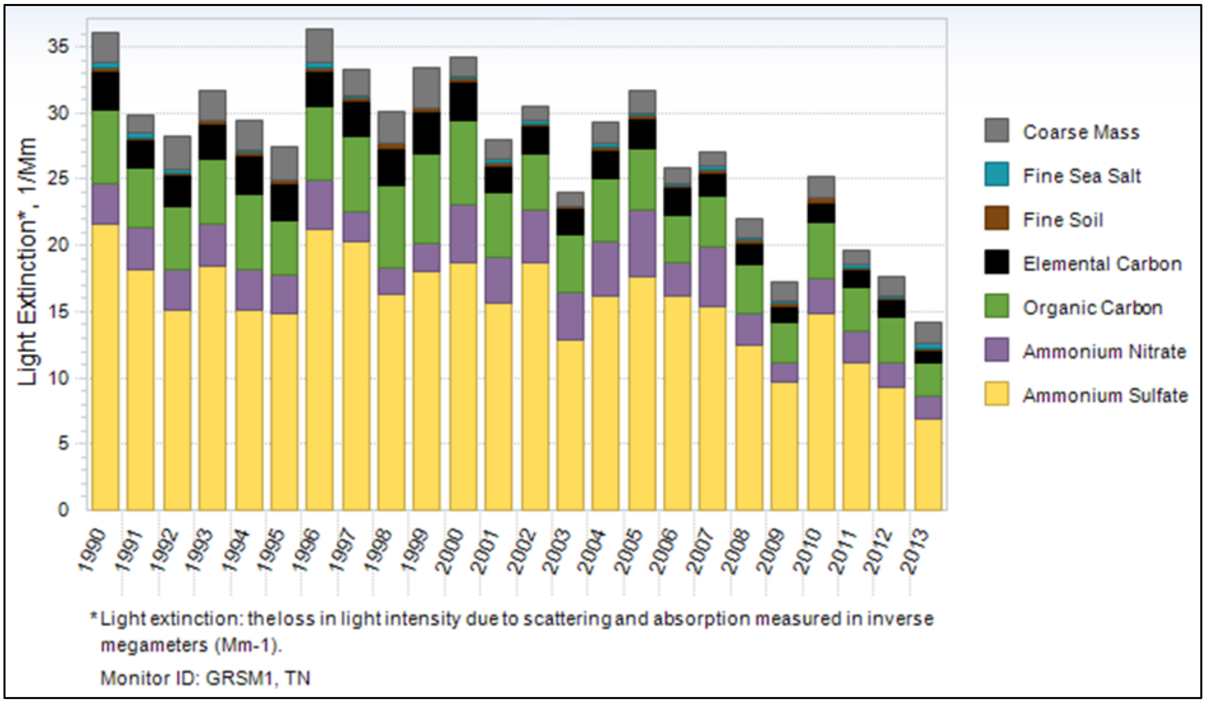
Figure 4.1.5.6. Ten-year trends for visibility on clearest days, 2003-2012. Source: NPS ARD, J. Renfro, NPS.



*Light extinction: the loss in light intensity due to scattering and absorption measured in inverse megameters (Mm-1).

Monitor ID: GRSM1, TN

Figure 4.1.5.7. Light extinction on the haziest days in GRSM, 1990-2013, and components of haze. Source: J. Renfro, NPS.



*Light extinction: the loss in light intensity due to scattering and absorption measured in inverse megameters (Mm-1).

Monitor ID: GRSM1, TN

Figure 4.1.5.8. Light extinction on the clearest days in GRSM, 1990-2013, and the components of haze. Source: J. Renfro, NPS.

Confidence and Data Gaps

Monitoring of visibility conditions in GRSM began in 1988 (at Look Rock) as part of the IMPROVE program. Data from this station has provided a reliable, long-term record utilized by park scientists and air quality specialists, and in NPS ARD air quality reporting. Confidence in the current assessment of both condition and trend of visibility is high (Table 4.1.5.1).

Sources of Expertise

- Jim Renfro, Air Quality Program Manager, Great Smoky Mountains National Park

Summary Condition

Table 4.1.5.1. Summary condition and trend graphic for visibility in GRSM.

Resource	Indicator	Status and Trend	Rationale and Reference Conditions
Air Quality	Visibility (deciviews)	⬆	Values have improved since the late 1990s; levels exceed the NPS ARD "significant concern" level of >8 dv above natural conditions; 5-yr average of 20% haziest days is 22.5 dv (11.2 dv over natural conditions). Data sources: IMPROVE and NPS.

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4.2. Soil Quality

The Great Smoky Mountains are among the oldest mountain ranges in the world. The interaction of mountains, glaciers, and climate is a primary factor behind the park's rich biodiversity. Elevations range from 267 m (875 ft) to 2,025 m (6,643 ft), with the highest point at Clingmans Dome (McCracken et al. 1962). The core of the Smoky Mountains was formed at least 1 billion years ago and consists of metamorphosed sedimentary and igneous rocks. The sedimentary rocks deposited over these older rocks were formed approximately 800 to 450 million years ago, as soils, silt, and gravel accumulated. Approximately 450 million years ago the rocks were metamorphosed by heat and pressure. The last phase of Appalachian mountain building occurred 200 to 300 million years ago when the North American and African plates collided. This process uplifted the entire Appalachian mountain chain from Canada to Georgia (Thornberry-Ehrlich 2008). These series of geologic events have produced a highly complex lithology which has, in large part, given rise to the park's world-renowned biological diversity.

The park lies within the Blue Ridge province, which was formed largely during the Paleozoic era by tectonic shifting and faulting when the Blue Ridge was thrust to the northwest over the Ridge and Valley province (Thornberry-Ehrlich 2008). Although the park lies within the Blue Ridge province, its geology combines several aspects of the Piedmont and Ridge and Valley provinces which run parallel to the north and south of the park. For this reason, it is considered a geologically distinct subdivision as it represents a transition between that of the crystalline Appalachian provinces (Piedmont and Blue Ridge), and the sedimentary Appalachian Valley and Ridge and Cumberland Plateau (Thornberry-Ehrlich 2008). Although no glaciation occurred in the southern Appalachians, glaciers influenced the park's climate and produced alpine conditions in the upper elevations. Today, periglacial features, including boulder deposits are present in the park.

The soils resources in this NRCA report are divided into three broad themes of soil chemistry, soil carbon, and soil hydrology. Soil chemistry focuses on both soil conditions such as pH, acid neutralizing capacity, cation exchange capacity, soil base saturation, and soil Ca:Al (calcium-aluminum ratio). The soil carbon section will highlight changes in organic matter due to recovery from both logging impacts and from steep mountain agriculture impacts, where soils were decimated and soil carbon was dramatically reduced. Over time, this increase in soil organic matter, and its subsequent decomposition, has had a long-term positive impact by increasing soil carbon and plant nutrients which are slowly released to the mineral soil profile. Finally, the water-holding capacity of the soils is evaluated as a product of both soil depth and texture. While precipitation is highly variable across the elevational gradient of GRSM, the soil water holding capacity serves as a buffer to maintain the diverse vegetation through variable precipitation patterns.

A summary of analyses and maps have been completed for the following soil characteristics for GRSM: soil pH, soil acid neutralizing capacity, soil cation exchange capacity, soil base saturation, soil Ca:Al, soil organic layer, soil carbon, and soil C:N (carbon: nitrogen). These analyses will focus on the upper soil horizons and on soil horizon data available via soil surveys. Data from 17 studies based on individual watersheds or study sites generally point toward decreasing soil conditions in

GRSM, especially in the higher elevations. However, the lack of long-term, spatially balanced data leads to lower confidence, and points to soil analysis as a research need.

4.2.1. Soil pH

Relevance

Soil pH is a product of weathered geologic parent material, atmospheric input, biological soil processing, and land use history. When soil pH is low, growth of acid-sensitive plant species can be inhibited; however, other plant species with low sensitivity can tolerate soil pH to as low as 4.0. The resultant impact is a change in plant community structure away from forest species that favor basic soils such as sugar maple (*Acer saccharum*) and redbud (*Cercis canadensis*) and towards forest species that favor acid soils such as rhododendron and sourwood (Burns and Honkala 1990). The impact of low pH is compounded and often overshadowed by the resulting Al and Mn (manganese) toxicity, and deficiencies in Ca, Mg (magnesium), K (potassium), and Na (sodium). These soil pH factors often occur together and interact to compound their effects in a low pH environment.

The resultant impact of a low soil pH will increase the acidity of soil leachate and runoff and decrease streamwater pH and other surface water features including wetlands, bogs, ponds, and lakes. This can impact fish and stream macroinvertebrates by disrupting ion regulation, which can lower blood pressure and lead to circulatory failure. Ion regulation is primarily impacted in low pH conditions by the interference of hydrogen ions with the gill transport system, resulting in a decline in sodium uptake, thereby increasing body sodium loss (Grippo and Dunson 1996, Neff et al.2009).

Data and Methods

The most common soil laboratory measurement of pH is the 1:1 water method (Cai et al. 2011a). A crushed soil sample is mixed with an equal amount of water, and a pH measurement of the suspension is completed (USDA NRCS 2009). For each soil horizon, this attribute is actually recorded as three separate values in the USDA NRCS database. A low value and a high value indicate the range of this attribute for the soil component, and a "representative" value indicates the expected value. For this soil property, only the representative value is used (USDA NRCS 2009).

This section includes six soil pH citations (Taylor 2008, Cai et al. 2010, Grell 2010, Cai et al. 2011a, Cai et al. 2011b, Neff et al. 2013). The authors compile and compare soil pH of soil surface horizons and include both single study sites and comparisons of multiple watersheds.

Reference Conditions

Forested soil pH conditions typically range from 4.0 to 6.5, but can be as basic as 9.0 in the case of soils derived from basic substrates. GRSM contains 59 primary soil series across a wide range of elevations and geologic features (USDA NRCS 2009), resulting in reference conditions that vary widely (Fig. 4.2.1.1). The most sensitive soils in GRSM are at the high-elevation sites where soils are thin and atmospheric deposition is high, resulting in sites that are susceptible to change with little buffering capacity. Other high-elevation sites in the region with at least some soil pH data (Coweeta Hydrologic Laboratory near Otto, NC and Mount Rogers near Marion, VA) have different geologic features than GRSM, and are at lower elevations, and hence are not valid reference points for the sites that are at 1,800+ m (5,900+ ft). Soil pH in peer-reviewed literature on GRSM ranged from 3.8

to 5.2 (Taylor 2008), 4.0 to 4.5 (Cai et al. 2010), and 4.17 to 4.61 (Neff et al. 2013). Knoepp and Swank (1998) at Coweeta Hydrologic Laboratory measured soil pH ranging from 3.9 to 4.2 across an elevational range from 782 to 1,347 m (2,566 to 4,419 ft) in deciduous forest habitats.

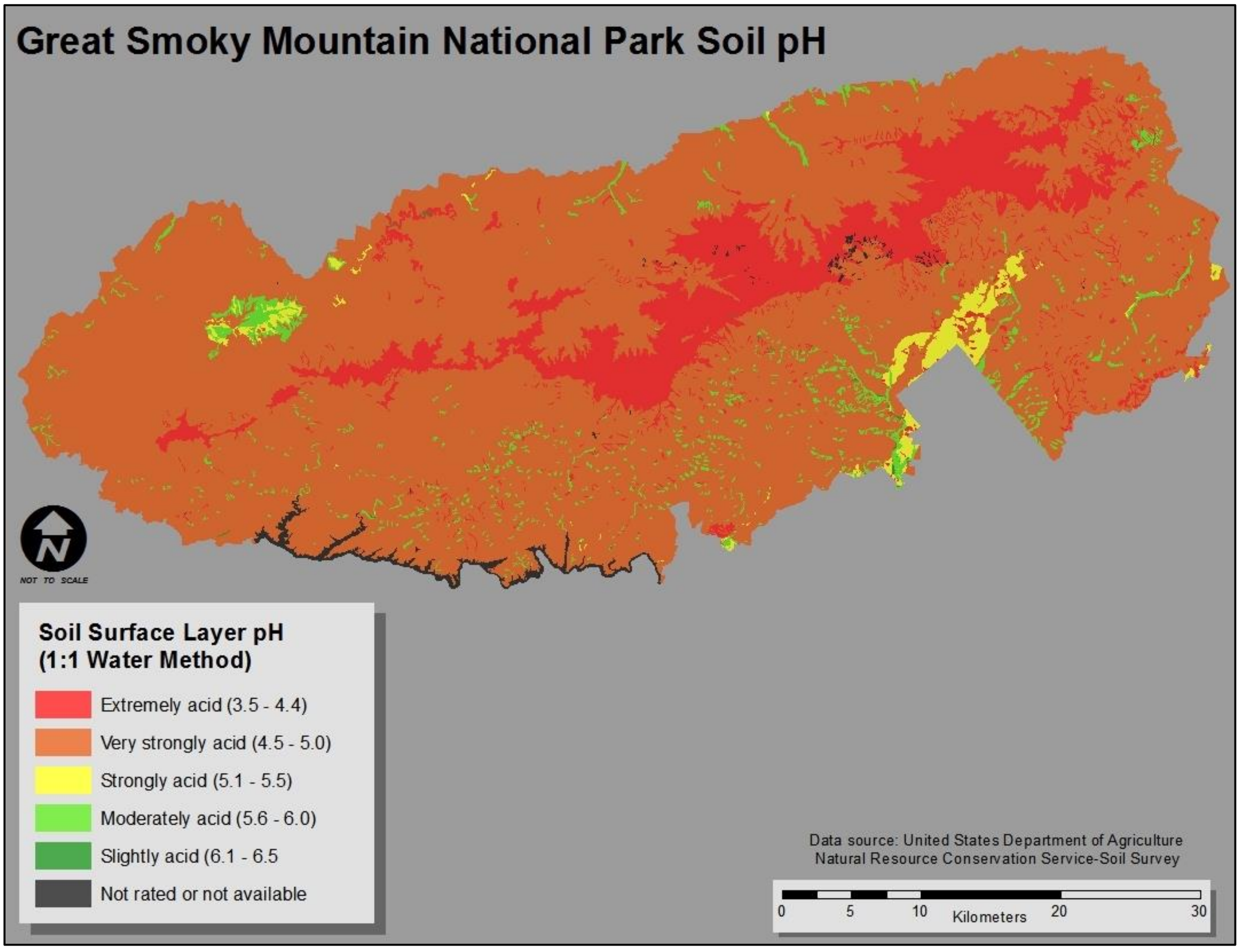

Figure 4.2.1.1. Soil surface pH using the 1:1 water methodology from the GRSM soil survey. Source: USDA NRCS 2009.

<u>Conditions and Trends</u>

GRSM exhibits a broad range of soil pH from extremely acid (3.5 to 4.4) to slightly acidic (6.1 to 6.5). Slightly acidic soils are most prevalent at lower elevations (Fig. 4.2.1.1), where they are deep and have accumulated carbon, calcium, and magnesium. Mid-elevations are dominated by very strongly acidic soils (4.5 to 5.0) that grade into extremely acid soils (3.5 to 4.4) at the highest elevations (Fig. 4.2.1.1). Spatially, the very strongly acidic soils cover 81.15% of GRSM, followed by extremely acid soils at 13.32%, and less than 3% coverage in each remaining category (Table 4.2.1.1).

Table 4.2.1.1. Summary of pH categories in Great Smoky Mountains National Park shown in Figure 4.2.1.1 and based on the GRSM soil survey. Source: USDA NRCS 2009.

Acidic Class	Percent within GRSM	pH Ranges
Extremely Acid	13.32	3.5 to 4.4
Very Strongly Acid	81.15	4.5 to 5.0
Strongly Acid	1.59	5.1 to 5.5
Moderately Acid	3.00	5.6 to 6.0
Slightly Acid	0.04	6.1 to 6.5
N/A	0.90	N/A

Confidence and Data Gaps

We have relatively high confidence in soil pH data (Table 4.2.1.2) at local study sites due to several peer-reviewed papers available (Cai 2010, Cai et al. 2010, Grell 2010, Cai et al. 2011a, Cai et al.2011b, Neff et al. 2013, Zhou et al. 2015). However, soil pH dynamics that can be extrapolated to GRSM come from a limited number of study sites, and there is an inherent risk in reaching park-wide conclusions on soil status and dynamics based on a small number of sites. Zhou et al. (2015) utilized data from 12 watersheds, 10 of which represent the watershed variability within GRSM. Temporal soil pH data sets are rare and infrequent, with short temporal sampling series (e.g., 1991-2006 in Cai et al. 2010) that do not contain a long enough time series to adequately monitor long-term changes; therefore, the long-term dynamics as a result of changes in atmospheric inputs as influenced by air pollution regulation are difficult to quantify. While GRSM has a complete soil survey, it was based on relatively few soil profiles which are then extrapolated across the park based on geologic and topographic features.

Sources of Expertise

- Troy Evans, Forest Ecologist, Great Smoky Mountains National Park
- Matt Kulp, Fisheries Biologist, Great Smoky Mountains National Park

Summary of Condition

Table 4.2.1.2. Summary condition and trend graphic for soil pH in GRSM.

Resource	Indicator	Status and Trend	Rationale and Reference Conditions
Soil Quality	Soil pH	⬇	Soil and water exposure to acids via atmospheric deposition and hematite exposure reduce soil pH. Forested soil pH conditions typically range from 4.0 to 6.5, but can be as basic as 9.0 in the case of soils derived from basic substrates. Soil pH in peer-reviewed literature in high-elevation southern Appalachian forest systems ranged from 3.8 to 5.2 (Taylor 2008), 4.0 to 4.5 (Cai et al. 2010), and 4.17 to 4.61 (Neff et al. 2013).

4.2.2. Soil Acid Neutralizing Capacity

Relevance

The risk of high acidity in soil water and streams due to pyrite-rich soils and geology is greatest at the high elevations in GRSM, where soils are thin and precipitation is high. The high acidity may reduce stream organism biodiversity and reduce plant soil nutrient uptake due to lower soil nutrient availability. Soils with low acid neutralizing capacity (ANC) are most at risk to pH change from acid deposition and hence may create less stable vegetation communities (Driscoll et al. 2001). Stable vegetation communities can provide a steady input of organic matter to the soil surface, which then mineralizes and facilitates greater soil organic carbon content, leading to neutralization of acid inputs.

Data and Methods

Soil ANC data were reviewed from the literature (Cook et al. 1994, Nodvin et al. 1995, Driscoll et al. 2001, Cai et al. 2010, Grell 2010) and compiled for the available elevations and watersheds in GRSM. The data were sporadically available from a variety of sites and studies across a 16-year published timeline (1994 to 2011).

Reference Conditions

Soil ANC in the park was found to range from -174.5 to -18.6 µeq/l (Cai et al. 2010). Cook et al. (1994) summarized the stream water pH and ANC of five high-elevation low-order streams in GRSM, and found the pH at base flow ranged from 4.54 to 6.40 and the ANC ranged from -30 to 28 µeq/l. Low-ANC streams had lower base cation concentrations and higher acid anion concentrations than did the high-ANC streams. The dominant acid anions were NO_3^- and SO_4^{-2} (Cook et al. 1994). Streamwater SO_4^{-2} was attributed to atmospheric deposition and an internal pyrite bedrock source of sulfur. During storm events, pH declined at downstream sites by as much as 0.5 units, and ANC declined by as much as 15 µeq/l (Cook et al. 1994). Soil ANC is tightly linked to stream ANC due to soil water drainage during both storm and non-saturated conditions. The high-precipitation conditions of GRSM cause the soil nutrient and chemical conditions to be reflected in the stream conditions during continual soil drainage and stream flow. Nodvin et al. (1995) observed that the poorly buffered soils in the park have high rates of nitrate-nitrogen leaching occurring within the soil profile, ranging from 100-1,400 eq/ha$^{/}$year. This is due to the high rates of nitrate and sulfur deposition in high-elevation southern Appalachian forests within GRSM.

Conditions and Trends

Areas of the park with pyrite-rich geology and soil (Fig. 4.2.2.1, Table 4.2.2.1) also generally have a low ANC. The greatest risk of pyrite exposure tends to be at the higher elevations, while the lowest risk is generally located at the lower elevations. Zhou et al. (2015) summarized the ANC from 12 sites as ranging from -13.8 µeq/l at 1,168 m (3,832 ft) to 90.3 µeq/l at 780 m (2,559 ft) with an elevational range of the sites from 1,798 to 545 m (5,899 to 1,788 ft).

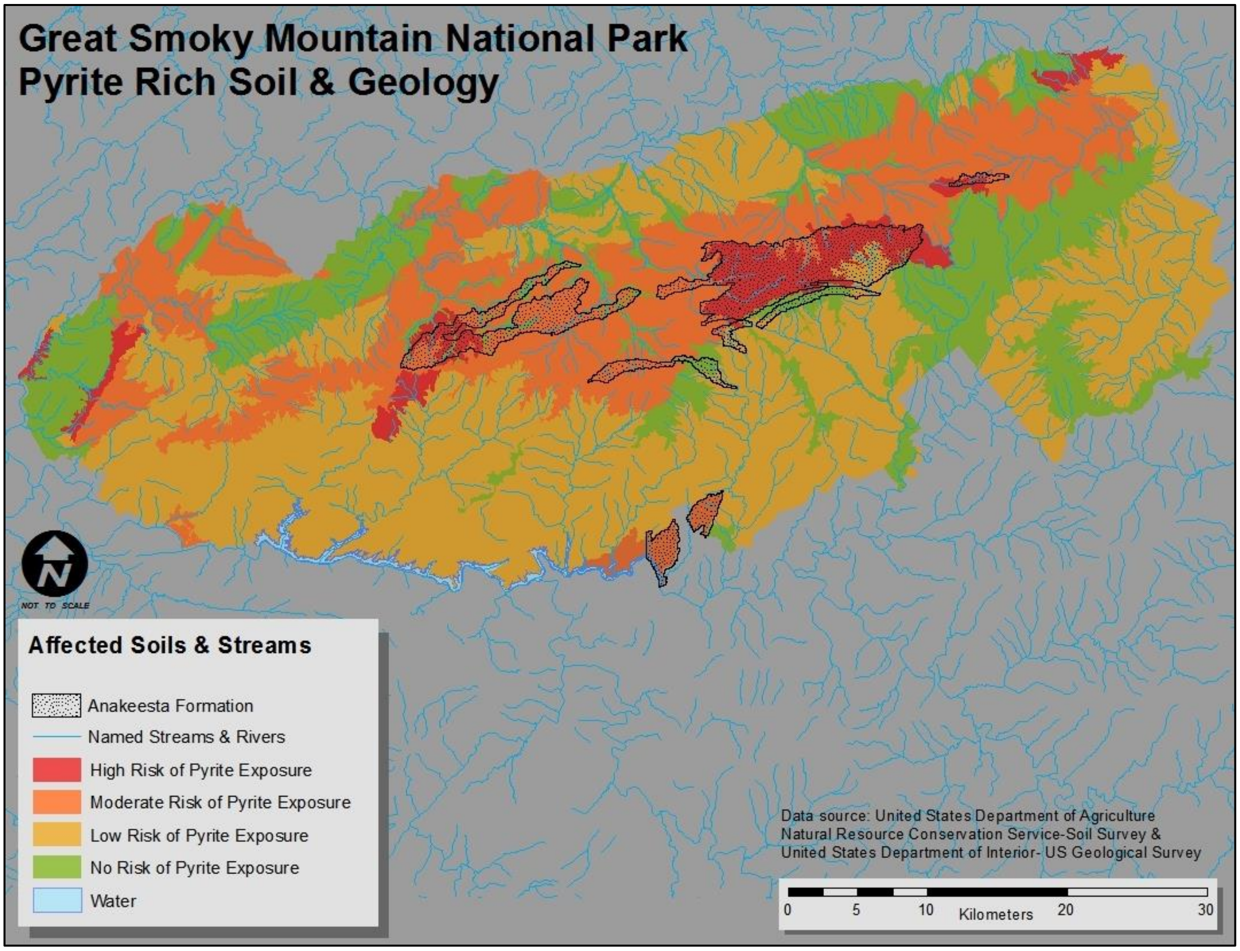

Figure 4.2.2.1. Pyrite rich soil and geology of Great Smoky Mountains National Park and the resulting risk of pyrite exposure. Source: USDA NRCS 2009.

Table 4.2.2.1. General soil units of Great Smoky Mountains National Park listing their relative pyrite exposure and likelihood of stream acidification. These events could occur as a result of landslides, and their elevation and relief characterize the potential risk of these events. Source: USDA NRCS 2009.

General Soil Units	Total Area (ha [ac])	Percent within GRSM	Pyrite Exposure Risk	Stream Acidification Risk	Landslide Risk	Min. Elevation	Max. Elevation	Elevation: Total Relief	Elevation Average
Luftee-Anakeesta	6,037 (14,917)	2.93	High	High	High	1,089	2,010	921	1,537
Breakneck-Pullback	19,660 (48,581)	9.53	Moderate	Moderate	Moderate	621	2,025	1,404	1,458
Oconaluftee	16,167 (39,949)	7.84	Low	Moderate	Low	939	1,878	940	1,494
Wayah	359 (887)	0.17	None	None	Low	1,146	1,550	404	1,421
Cataska-Sylco (slate)	3,913 (9,670)	1.90	High	High	High	267	1,435	1,168	905
Ditney-Unicoi	33,393 (82,515)	16.19	Moderate	Moderate	Moderate	336	1,491	1,156	915
Soco-Stecoah	95,360 (235,640)	46.22	Low	Moderate	Low	302	1,632	1,330	961
Evard-Cowee	2,811 (6,946)	1.36	None	None	Low	545	1,565	1,019	1,106
Cataska-Sylco (schist)	1,559 (3,852)	0.76	Moderate	Moderate	Moderate	514	1,270	756	758
Junaluska-Tsali	15,325 (37,868)	7.43	Low	Low	Moderate	267	1,175	908	566
Spivey-Santeetlah	5,700 (14,085)	2.76	None	None	None	404	1,347	942	782
Lauada-Fannin	166 (411)	0.08	Low	Low	Moderate	598	918	320	702
Rosman-Reddies-Dellwood	379 (936)	0.18	None	None	None	603	828	225	661
Lonon-Cades	1,846 (4,562)	0.89	None	None	None	517	759	242	554
Junaluska-Brasstown-Soco	2,071 (5,118)	1.00	Low	Moderate	Low	513	1,137	624	646

Confidence and Data Gaps

Atmospheric inputs for acidic deposition continue to accumulate in the most sensitive high-elevation soil locations, leading to a reduction in the ANC (Table 4.2.2.2). The long-term impacts of deposition and reduction of ANC is to decrease soil pH, resulting in the acidification of soil water and low-order streams. Few studies contain temporal monitoring of ANC (Cai et al. 2010) and none contain long-term ANC data collection. There are minimal spatial data sets of ANC and most contain only spotty high- or low-elevation study sites (Cook et al. 1994).

Sources of Expertise

- Troy Evans, Forest Ecologist, Great Smoky Mountains National Park
- Matt Kulp, Fisheries Biologist, Great Smoky Mountains National Park

Summary of Condition

Table 4.2.2.2. Summary condition and trend graphic for soil ANC in GRSM.

Resource	Indicator	Status and Trend	Rationale and Reference Conditions
Soil Quality	Soil acid neutralizing capacity	⬇	Soil is exposed to continual atmospheric deposition and cation leaching.

4.2.3. Soil Cation Exchange Capacity

Relevance

Cation exchange capacity (CEC) is the number of exchangeable cations per dry weight that soil is capable of holding and is available for exchange within the soil water solution. It is an indication of a soils' ability to store cations for plant growth and to maintain cation availability during disturbances such as tree falls, surface fires, drought, and floods. Low CEC soils are more likely to leach cations, and therefore become deficient in calcium, potassium, and other cations, which then leads to reduced plant growth. Organic matter tends to increase CEC, but it requires many years to take effect.

Data and Methods

Soil cation exchange capacity (CEC) data were reviewed from the literature (Taylor 2008, Bardhan et al. 2012, Cai et al. 2012, Neff et al. 2013). There were sporadic data available from only four studies with no comprehensive CEC data available for GRSM.

Reference Conditions

Cation exchange capacity in GRSM ranged from 1.3 to 23.1 in High-elevation Spruce-Fir Forests in GRSM (Bardhan et al. 2012). The mean effective CEC was 8.07, 5.06, and 3.57 meq/100 g in the A, Bw, and Cb soil horizons, respectively, in high-elevation GRSM sites (Cai et al. 2012). In a base flow and stormflow study across eight basins in GRSM, CEC was extremely stable from 4.17 to 4.61 (Neff et al. 2013), while in a natural soil acidification and fertilization study in GRSM, CEC averaged 8.5 meq/100 g (Taylor 2008).

Conditions and Trends

CEC is expected to decline as a result of long-term leaching impacts from low pH precipitation (Table 4.2.3.1). As soil structure is altered and cations are not replenished, the ability of the soils to retain their CEC will likely diminish and their long-term productivity will decline.

Confidence and Data Gaps

Soil CEC data are extremely limited and are only sporadically available across GRSM. Only two CEC gradient studies (Bardhan et al. 2012 [pH], Neff et al. 2013 [elevation]) suggest that more data are needed to characterize soil CEC. There are no long-term repeated sampling data, and studies with spatial sampling patterns do not exist in GRSM.

Sources of Expertise

- Troy Evans, Forest Ecologist, Great Smoky Mountains National Park
- Matt Kulp, Fisheries Biologist, Great Smoky Mountains National Park

Summary of Condition

Table 4.2.3.1. Summary condition and trend graphic for soil cation exchange capacity in GRSM.

Resource	Indicator	Status and Trend	Rationale and Reference Conditions
Soil Quality	Soil cation exchange capacity	⬇	Declining as a result of leaching impacts from low pH precipitation (less than 4% of GRSM soils are assessed for CEC).

4.2.4. Soil Base Saturation

Relevance

Soil base saturation is used to characterize how completely occupied the adsorbing surface sites of soil mineral and organic particles are with basic cations. The calcium, magnesium, potassium, and sodium cations commonly found in basic soils are competing with aluminum and hydrogen ions in acidic soils. Acidic soils with a low base saturation are not able to support growing vegetation with an ample supply of cations, and hence low base saturation soils are not considered as fertile as those with high base saturation.

Data and Methods

Soil base saturation data is available from only two studies (Fenn et al. 2011, Cai et al. 2012). Data were compiled and summarized and the soil condition, confidence, and data gaps were noted.

Reference Conditions

Continued leaching of base cations as a result of acidic atmospheric inputs lowers base saturation and increases soil water acidity. Fenn et al. (2011) indicate that there is a risk of nutrient deficiencies in sensitive trees when soil base saturation is less than 10%, and low risk when soil base saturation is greater than 30%.

Conditions and Trends

Cai et al. (2012) determined that the soil base saturation in the A, Bw, and Cb horizons in a high-elevation forested watershed in GRSM was equal to or below 7%. This study did not have a temporal sampling aspect to it, so long-term changes as a result of acidic atmospheric inputs could not be evaluated.

Confidence and Data Gaps

There are few soil base saturation data sets available from GRSM and no datasets with either spatial or temporal collection designs. More data are needed to characterize the long-term impacts of atmospheric input and soil changes on soil base saturation (Table 4.2.4.1).

Sources of Expertise

- Troy Evans, Forest Ecologist, Great Smoky Mountains National Park
- Matt Kulp, Fisheries Biologist, Great Smoky Mountains National Park

Summary of Condition

Table 4.2.4.1. Summary condition and trend graphic for soil base saturation in GRSM.

Resource	Indicator	Status and Trend	Rationale and Reference Conditions
Soil Quality	Soil base saturation	◌	Continued leaching of base cations as a result of acidic atmospheric inputs lower base saturation and increase soil water acidity. There is a lack of data from GRSM on this topic.

4.2.5. Soil Ca:Al

Relevance

Low calcium mineralization rates and high soil calcium leaching, coupled with decreasing soil pH, results in increased aluminum bioavailability and aluminum toxicity, which then results in a decreasing soil Ca:Al. These decreasing ratios result in lower plant-available calcium, and hence reduced plant nutrition. Foliar Ca:Al ratios are analyzed and calculated to determine if the soil conditions are reflected in plant growth conditions (Bintz and Butcher 2007).

Data and Methods

Soil Ca:Al data were compiled from six studies (Bryant et al. 1997, Bintz and Butcher 2007, Cai et al. 2010, Rosenberg and Butcher 2010, Bardhan et al. 2012, Wilson and Butcher 2012), and included both foliar Ca:Al and soil Ca:Al. The data were frequently limited to a single study site or a single forest type and hence are not comprehensive in their findings or their applicability within GRSM.

Reference Conditions

Soil Ca:Al conditions range from 0.120 to 0.362 (Rosenburg and Butcher 2010). These ratios are considerably lower than the foliar Ca:Al of 39 to 72 (Bryant et al.1997), due to relatively high calcium foliar uptake and relatively low aluminum foliar uptake.

Conditions and Trends

Resampling of foliar Ca:Al from the mid 1990s to the mid 2000s indicate an increase in this ratio, likely due to a decrease in acidic deposition (Bintz and Butcher 2007). Also, Rosenburg and Butcher (2010) determined that foliar Ca:Al had increased in red spruce since the 1980s, indicating a possible improvement in red spruce forest health. Wilson and Butcher (2012) indicated that foliar calcium and magnesium had increased, compared to concentrations in the 1990s, again suggesting that pollution controls may have reduced acidic atmospheric deposition. However, increases in foliar Ca:Al do not correlate with any observed levels in the soil Ca:Al. Soil molar Ca:Al at Clingmans Dome was 0.362 in 2009, which is a level considered to be a 90% risk of adverse forest health effects due to acid deposition (Rosenberg and Butcher 2010). Therefore, the condition and trend for soil Ca:Al is stable but warrants significant concern, with low confidence (Table 4.2.5.1).

Confidence and Data Gaps

Soil Ca:Al data are not routinely collected in GRSM and occasional site comparison studies do not sufficiently cover the large geographic area. More spatially-collected soil Ca:Al data are needed to better characterize the impact on soil chemistry and calcium availability. In addition, foliar Ca:Al does not act as a strong surrogate for soil Ca:Al since tree species vary in their ability to extract calcium. Also, young and mature trees vary in their ability to extract calcium, adding further variation to foliar Ca:Al data.

Sources of Expertise

- Troy Evans, Forest Ecologist, Great Smoky Mountains National Park
- Matt Kulp, Fisheries Biologist, Great Smoky Mountains National Park

Summary of Condition

Table 4.2.5.1. Summary condition and trend graphic for soil Ca:Al ratio in GRSM.

Resource	Indicator	Status and Trend	Rationale and Reference Conditions
Soil Quality	Soil Ca:Al ratio	⬌	Low calcium mineralization rates and high soil leaching of calcium, coupled with decreasing soil pH, results in aluminum toxicity.

4.2.6. Soil Organic Layer and Soil Carbon

Relevance

The soil organic layer serves multiple functions on the steep terrain of GRSM. Forested regions continue to accumulate organic matter (i.e., material <2 mm [.08 in] in diameter, and from 0 to 10 cm [0 to 3.9 in] in depth) as they recover from earlier logging disturbances and agricultural impacts. The soil organic layer accumulates detritus from the aboveground biomass and serves as a storage reservoir during detrital decomposition and elemental mineralization. The accumulated detritus minimizes mineral soil surface displacement and erosion by reducing precipitation impacts, as well as absorbing precipitation, to allow for future soil infiltration and to reduce atmospheric evaporation from the soil surface. The soil organic layer also serves as an insulating layer to protect fine roots, soil insects, and small mammals from extreme temperature fluctuations across the range of elevations in GRSM.

Soil organic carbon (SOC) serves as a moderator between the organic matter accumulating at the soil surface and the biologically active soil organic carbon (BASOC), holding nutrients and water in the soil mineral horizon. While SOC declined severely at lower elevations in GRSM where agriculture persisted for decades, it has now begun to accumulate again after mid-successional forests have reestablished. The surface organic matter pool has developed and generates a consistent source of SOC input to soil mineral horizons. While atmospheric and vegetation inputs have continued to change in the park, the soil carbon concentration helps to modify and stabilize those dynamic changes and maintain cation and moisture pools.

Data and Methods

SOC, which is carbon in soil that originated from a biological source, such as plants, animals or microorganisms, is found in organic and mineral layers of the soil. It is calculated as kg C/m^2 x 2 m depth.

Reference Conditions

The average carbon concentration found in dead coarse woody debris biomass, from boles in spruce-fir forests of GRSM, was measured at 47%, while total carbon averaged 34.9 Mg/ha (Rose and Nicholas 2008). The mean stock and the calculated median turnover time of SOC ranged from 4.4 to 12.2 kg C/m^2 and 11 to 31 years, respectively. Both forest SOC stock and the predicted turnover time were found to increase with elevation (Garten and Hanson 2006). Creed at al. (2004) determined the carbon content in organic soil, mineral soil, and total belowground to be 55.3, 18.0, and 73.2 Mg/ha, respectively.

Conditions and Trends

Soil organic carbon in GRSM increases with elevation (Fig. 4.2.6.1), and was found to range from 0 to 44.9 kg/m^2 (0 to 449 Mg/ha), with maximum values occurring at the highest elevations in GRSM (Table 4.2.6.1). This trend is partly due to the agricultural history of lower elevation sites, where soil carbon was reduced as a result of cultivation, and increased soil temperatures, leading to higher soil respiration. In addition, the higher elevations, which were not heavily impacted by agriculture, are colder and accumulate soil carbon as a result of slower rates of decomposition and respiration.

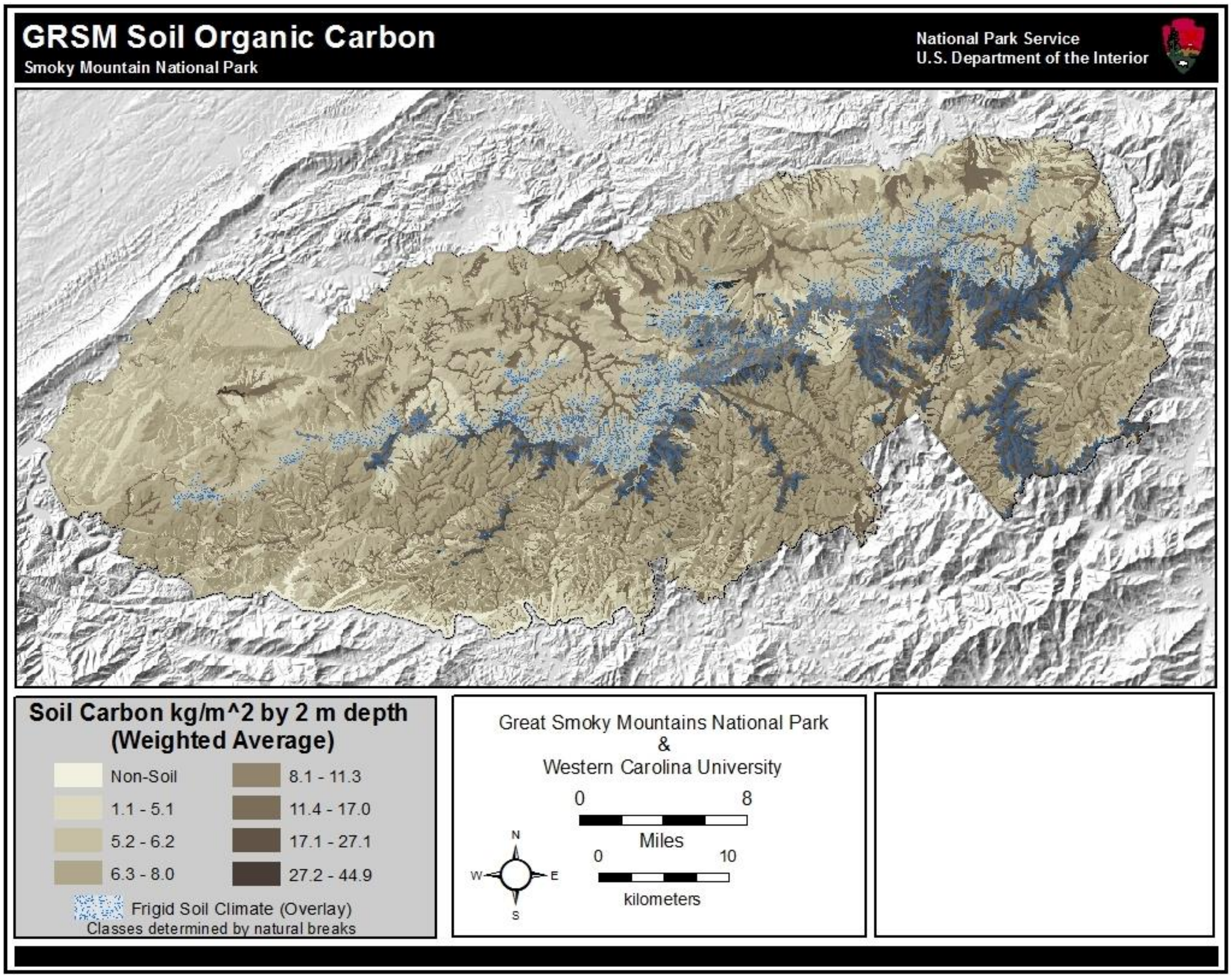

Figure 4.2.6.1. Soil organic carbon in Great Smoky Mountains National Park to a depth of two meters. Source: USDA NRCS 2009.

Table 4.2.6.1. Soil carbon classes in Great Smoky Mountains National Park, delineating temperature regimes, spatial extent, and average elevation. Source: USDA NRCS 2009.

Soil Carbon Class* Ranges (kg/m^2 by 2 m depth)	Soil Moisture Regime	Area within GRSM (ha [ac])	Percent of area within GRSM	Dominant Temperature Regime	Total Area of Frigid Regime (ha [ac])	Percent Frigid Temperature Regimes Within Class	Average Elevation (Area Weighted in m)
Non-Soil	NA	1,866 (4,611)	0.90	N/A	NA	NA	652.57
1.1-5.1	Udic	22,014 (54,398)	10.67	Mesic	157 (387)	0.71	798.20
5.2-6.2	Udic	63,469 (156,835)	30.76	Mesic	15,432 (38,133)	24.31	1,016.61
6.3-8.0	Udic	68,763 (169,918)	33.33	Mesic	1,260 (3,114)	1.83	981.14
8.1-11.3	Udic	16,061 (39,688)	7.78	Mesic	5,758 (14,229)	35.85	1,148.68
11.4-17.0	Udic	23,314 (57,610)	11.30	Mesic	6,039 (14,922)	25.90	1,020.28
17.1-27.1	Udic	10,049 (24,834)	4.87	Mesic	9,723 (24,025)	96.74	1,523.68
27.2-44.9	Udic	781 (1,929)	0.38	Frigid	724 (1,790)	92.82	1,293.09

* Soil carbon classes are determined by using natural breaks in the data. Carbon data values are derived as weighted averages.

Garten et al. (1999) summarized total inventories of soil organic carbon across a forested elevational gradient (to a depth of 30 cm [11.8 in]) and found the range to be from 384 to 1,244 mg/cm^2 (38.4 to 124.4 Mg/ha). Taylor (2008) determined that the soil carbon concentration was 33.4 % in the forest floor and 9.4 % in the mineral soil.

Confidence and Data Gaps

Soil organic layer carbon, and soil carbon resource information came from multiple data sources and some spatial sampling by USDA NRCS (2009). However, the soil organic layer data are available only from select forest types such as spruce–fir (Rose and Nicholas 2008). Soil carbon elevational gradient data are quantified in both Garten et al. (1999) and Garten and Hanson (2006). There are no temporal soil sampling studies to quantify the change in soil organic layer carbon and soil carbon over time. Although the condition of soil carbon is improving, there is moderate concern, with medium confidence (Table 4.2.6.2).

Sources of Expertise

- Troy Evans, Forest Ecologist, Great Smoky Mountains National Park
- Matt Kulp, Fisheries Biologist, Great Smoky Mountains National Park

Summary of Condition

Table 4.2.6.2. Summary condition and trend graphic for soil organic layer and soil C in GRSM.

Resource	Indicator	Status and Trend	Rationale and Reference Conditions
Soil Quality	Soil organic layer carbon and soil carbon	⇧	Forested regions continue to accumulate organic matter and soil carbon as they recover from earlier logging disturbances and areas that had previous agricultural impacts.

4.2.7. Soil C:N

Relevance

The soil C:N indicates the components of soil organic matter and their ease of decomposition. Hard woody materials with a high C:N ratio are more resilient to decay than soft leafy materials with a low C:N ratio. As a result, soils with a high C:N tend to have slow organic matter turnover times, and hence soil nitrogen resources are less readily available for plant uptake (McCracken et al. 1962). As pools of decaying soil organic matter increase and time passes, nitrogen concentration increases in the organic matter, but is not released until late stages of decay, resulting in varied C:N ratios across decay classes and across the landscape.

Data and Methods

Soil C:N is calculated as the ratio of soil carbon to soil nitrogen, by mass, in either the organic soil surface or in the upper mineral soil horizons, depending upon the study.

Reference Conditions

In a study of southern Appalachian landscapes, soil C:N ranged from 13.3 to 19.1 (Taylor 2008). Across a range of elevations in spruce-fir forests in GRSM (1,524 to 2,000 m [5,000 to 6,562 ft]), soil C:N in the O_a horizon ranged from 20.5 to 16.1, whereas in the A horizon C:N ranged from 18.9 to 16.5 (Garten 2000).

Conditions and Trends

Soil carbon availability is increasing in the park, due to recovery from logging and agriculture, and there is a variable increase in soil nitrogen across elevational gradients, due to plant uptake and increasing atmospheric deposition at high elevations (Creed et al. 2004). Taylor (2008) suggests that an increase in nitrogen deposition has led to a reduced soil C:N, enhanced net nitrification, and greater dissolved organic nitrogen (DON). As a result, changes in forest floor and soil C:N, as well as increased nitrogen mobility, has resulted in increased surface water NO_3-N concentrations.

Confidence and Data Gaps

Soil C:N data are limited, with no temporal data and very few spatial data available. Garten (2000) utilized an elevational gradient within the spruce-fir forests in GRSM, but the range was limited to high-elevation sites from 1,524 to 2,000 m (5,000 to 6,562 ft). Creed et al. (2004) developed a decay class gradient to track the changes in soil carbon and nitrogen dynamics in spruce-fir forests, but the study did not extend to other forest types. Soil C:N data are highly variable and have many data gaps in GRSM. Although soil C:N is improving, there is moderate concern, and low confidence in this assessment (Table 4.2.7.1).

Sources of Expertise

- Troy Evans, Forest Ecologist, Great Smoky Mountains National Park
- Matt Kulp, Fisheries Biologist, Great Smoky Mountains National Park

Summary of Condition

Table 4.2.7.1. Summary condition and trend graphic for soil C:N ratio in GRSM.

Resource	Indicator	Status and Trend	Rationale and Reference Conditions
Soil Quality	Soil C:N ratio	⇧	Soil carbon is increasing, but soil nitrogen is variable across elevational gradients, due to plant uptake and atmospheric deposition.

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4.3. Water Quality

The landscape within GRSM can be subdivided into 45 major watersheds (minimum size >5 km^2 [1.93 mi^2]) containing over 4,684 km (2,910 mi) of streams (https://irma.nps.gov/DataStore/Reference/Profile/2202817). Surface waters within the park, including the hundreds of connected riparian wetlands which border the streams and rivers, are viewed as a critical ecological resource and a primary determinant of the park's overall resource condition. Water quality in particular is considered an important ecological indicator, and was identified by the park as the highest ranking vital sign category on the basis of ecological significance (NPS 2011). Poor water quality can act as a significant ecological/biotic stressor, lead to ecological system deterioration, and negatively affect the recreational and aesthetic value of the region (Deschu and Kavanagh 1986).

4.3.1. Data and Methods

Past and Current Monitoring Programs

Prior to 1993, water quality data were sporadically collected within and immediately adjacent to GRSM as part of several regional monitoring efforts and/or local research investigations. Much of this data is summarized in NPS (1995), and is available along with more recent data from STORET (STORage and RETrieval), which is an electronic data system for water quality monitoring data developed by the EPA (http://www3.epa.gov/storet/dw_home.html).

Beginning in July 1991, water quality data was intensively collected within the high-elevation Noland Divide watershed, and has continued to the present (Fig. 4.3.1.1). This watershed was initially selected as an Integrated Forest Study site in the 1980s for investigating the effects of acid rain on forest nutrient cycling, and to assess the response(s) of surface waters to acidic deposition. The Noland Divide watershed encompasses an area of 17.4 ha (43.0 ac) and ranges in elevation from 1,680 to 1,920 m (5,519 to 6,299 ft). The sampling program includes the collection of water associated with wet deposition, throughfall, soil water (via lysimeters), and two headwater streams. Stream water samples were collected weekly from 1991 to 2000; since 2001 samples have been collected bimonthly. Both stream water sampling sites were (and are currently) equipped with an H-flume and a stage recorder, allowing for the calculation of discharge. Most samples have been collected during base flow. The samples are analyzed for pH, ANC (acid neutralizing capacity), conductivity, acid anions (Cl^-, SO_4^{2-}, NO_3^-), ammonia (NH_4^+), and base cations (Ca^{2+}, Mg^{2+}, Na^+, K^+). The base cations Ca^{2+} and Mg^{2+} were not measured between 1993 and 1998.

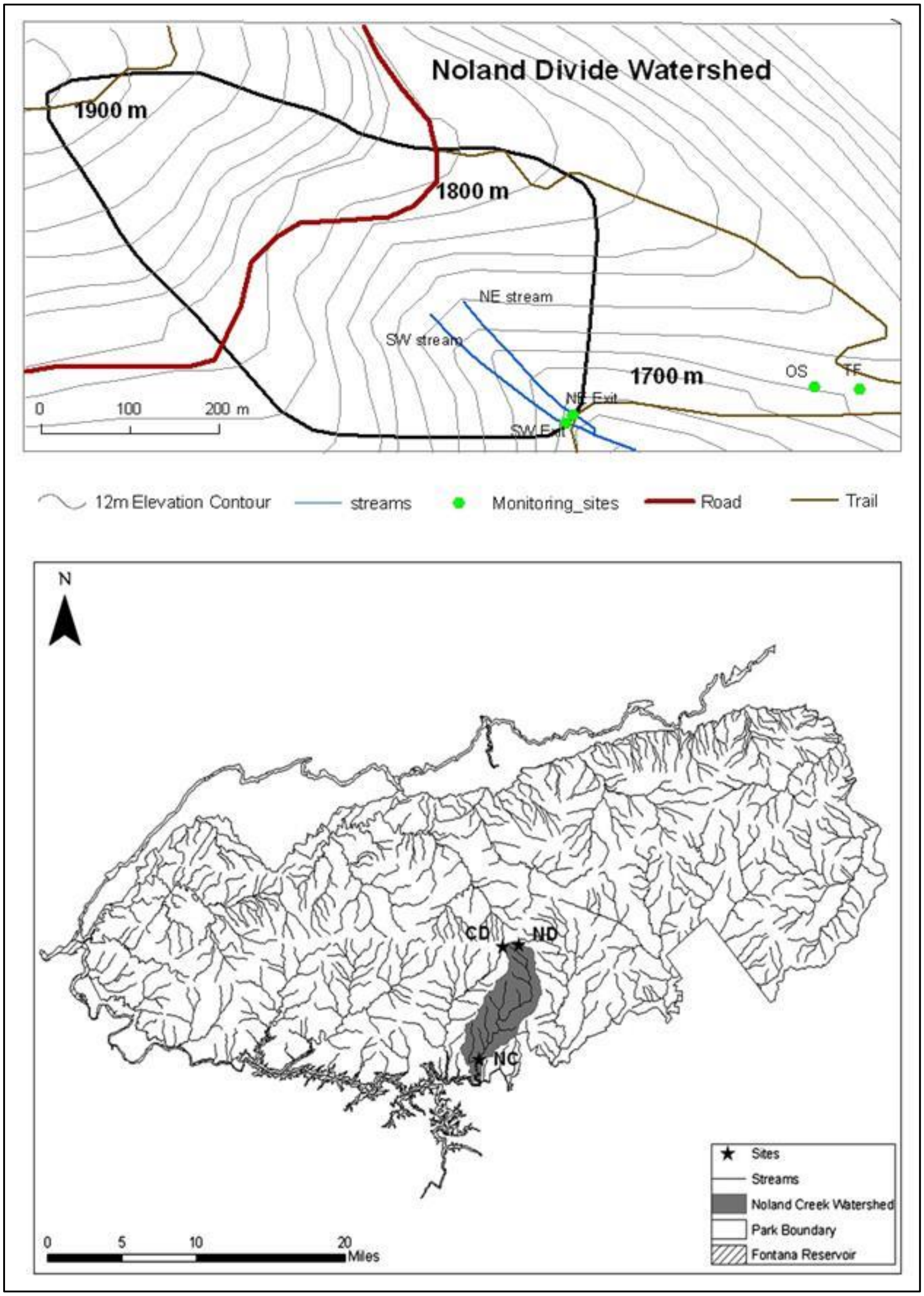


Figure 4.3.1.1. Morphology of the Noland Divide watershed and location of the various monitoring sites (upper), and location of Noland Divide watershed in GRSM (lower). Source: Fisher and Wolfe 2012. (CD – Clingmans Dome; ND – Noland Divide).

Additional data have been collected throughout the park since 1993. The design and implementation of this monitoring network was initiated three years earlier (in 1990) in order to: (1) develop baseline data sets, (2) analyze and report on long-term data for a “modest” set of parameters, and (3) provide data and information on resource conditions to park managers, planners, interpreters, and other groups (Emmott et al. 2005). The program was specifically intended to identify the potential impacts of acid deposition on GRSM stream waters (Vana-Miller et al. 2010). Initial sampling began with the establishment of the park-wide base flow stream survey including 185 monitoring sites (Fig. 4.3.1.2). An additional 119 sites were added in 1994, followed by the addition of 53 sites in 1995 (Cai and Schwartz 2012). These combined 357 sites were selected to evaluate the spatial variability of water quality within the park as a function of topography, geology, forest types, and disturbance history. They were monitored semi-annually from October 1993 to 1995.

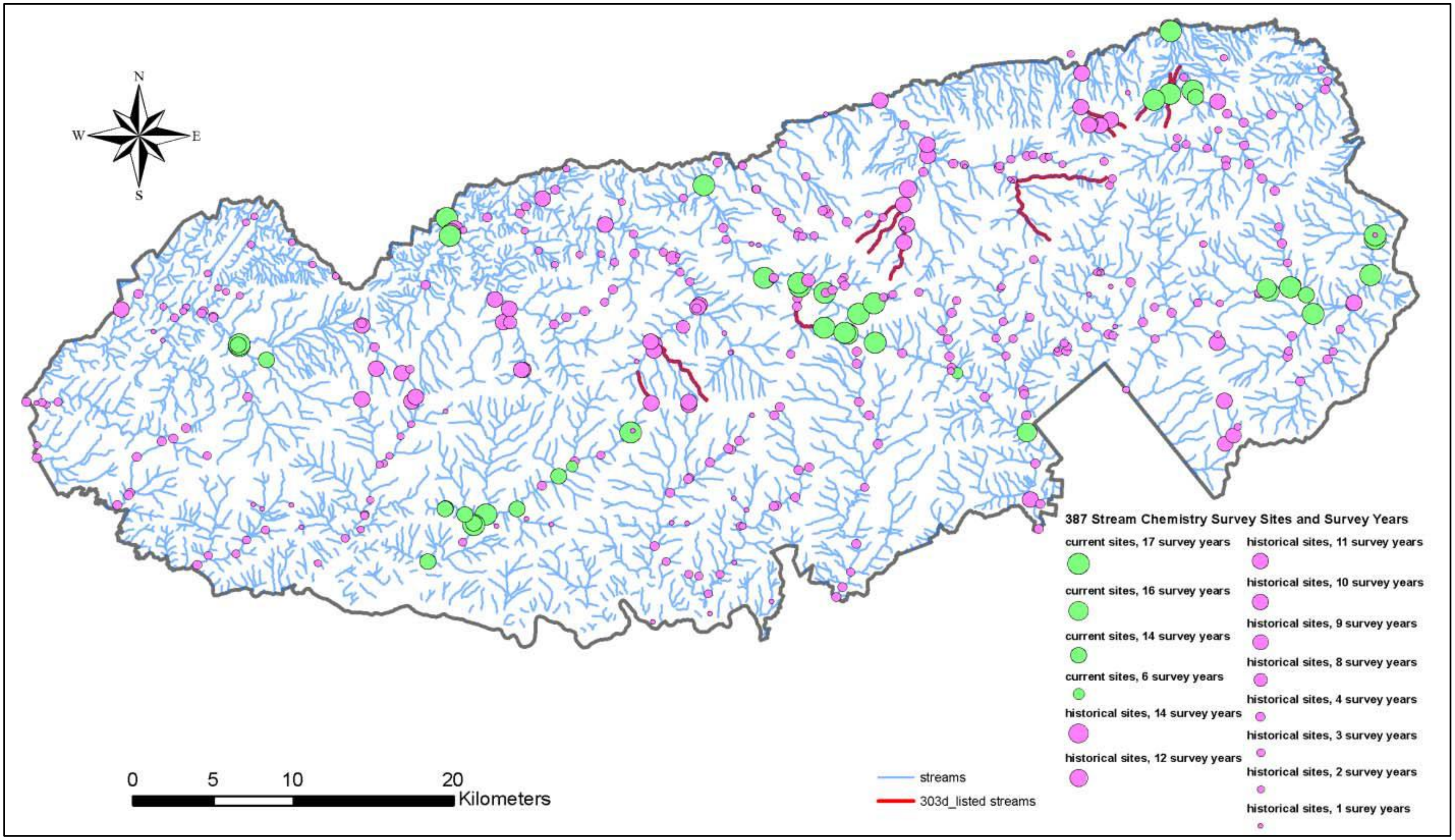


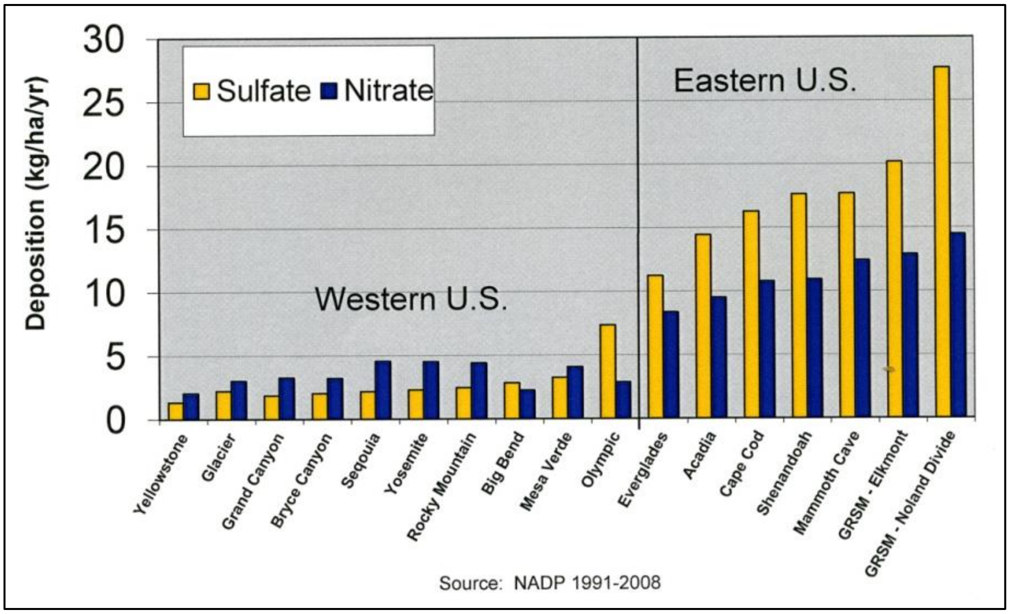
Figure 4.3.1.2. Location of water quality monitoring sites within GRSM since 1993. Listed 303d streams are those listed in 2012. Source: Cai and Schwartz 2012.

Since the initial establishment of the park-wide monitoring network, the number and location of sites have changed, along with the frequency of sampling (Fig. 4.3.1.2). In 1996, data were collected monthly at 160 sampling locations, while in 1997 the number of sampling locations was reduced to 90 and data were collected quarterly (Cai and Schwartz 2012). In 2004, the number of monitoring locations was reduced to 43 sites located in seven watersheds (Abrams Creek-4 sites; Cataloochee Creek-8 sites; Cosby Creek-4 sites; Little River-3 sites; Oconaluftee River-5 sites; Road Prong/Rt.6-8 sites; and Hazel Creek–11 sites). The 11 sites along Hazel Creek are sampled biannually; the remaining 32 sites are sampled bimonthly. Twenty-seven sites have a complete record of monitoring data extending from 1993 to 2014. In 2015, the new Vital Signs monitoring program was initiated, which involved the collection of 46 water samples in each of six primary watersheds (Abrams Creek, East Prong Little River, Middle Prong Little Pigeon River, Cataloochee Creek, Deep Creek, and Hazel Creek) and in the Cosby Creek watershed. Within each watershed, at least one sample is collected in each 305 m (1,000 ft) elevation band represented within the watershed.

Sampling has primarily relied on base flow grab samples without regard to stream flow conditions (i.e., stormflow versus base flow) to capture the full range of chemistry across the collection period. Classification of stream flow as either base flow or stormflow has been conducted by some investigators on the basis of local precipitation records and adjacent USGS gauging station data. Collected water samples were (and continue to be) analyzed for pH, gran ANC, conductivity, major acid anions (Cl^-, SO_4^{2-}, NO_3^-), ammonia (NH^{4+}), major base cations (Ca^{2+}, Mg^{2+}, Na^+, K^+), and from 2003 to the present, selected metals including Al (aluminum), Cu (copper), Fe (iron), Mn (manganese), Si (silicon), and Zn (zinc).

Methods and Analysis

The primary threat/stressor of concern with regard to water quality is atmospheric deposition of acid pollutants in the form of sulfur (S) and nitrogen (N) compounds. Both S and N deposition can potentially lead to long-term (chronic) or episodic (flood related) acidification of surface waters (Baumgardner et al. 2003, Weathers et al. 2006, NADP 2006). Air quality monitoring data collected since the 1980s have shown that GRSM receives some of the highest levels of sulfate and nitrate deposition in the U.S. (e.g., Nodvin et al. 1995, Shubzda et al. 1995, Smoot et al. 2000, NADP 2006, Sullivan et al. 2007) (Fig. 4.3.1.3), with the highest rates of deposition occurring at high elevations (Weathers et al. 2006). Sampling within the Noland Divide watershed has shown that atmospheric deposition rates for both sulfate and total N have decreased during the past several years (Fig. 4.1.1.1) in response to pollutant reduction measures implemented in 2003-2004. These reductions occurred at TVA fossil fuel power plants, and at other fossil fuel plants located within states surrounding GRSM and throughout the middle and upper Midwest (Schwartz et al. 2014).



Source: NADP 1991-2008

Figure 4.3.1.3. Average annual wet deposition of sulfate and nitrate in U.S. National Parks. Source: Vana-Miller et al. 2010, NADP.

Surface waters throughout the eastern U.S., including GRSM, are particularly sensitive to acidification because the underlying bedrock contains limited concentrations of base metals and, therefore, lacks the capacity to buffer the input of acid forming compounds to stream waters (Fig. 4.3.1.4) (Herlihy et al. 1996). Stream acidification has also been linked to exposures of the Anakeesta formation - a slate/phyllite containing sulfide minerals that underlies localized areas in the park (Neff et al. 2013). Upon exposure to water and air the sulfide minerals (e.g., pyrite) are oxidized releasing protons (H^+), sulfate, and other metals to water bodies. Both chronic and episodic stream water acidification has the potential to negatively impact aquatic biota within the park (Deyton et al. 2009, Neff et al. 2009, Cai et al. 2011, Cai and Schwartz 2012). Given the potential ecological threat associated with stream water acidification, pH and ANC were selected as indicators of water quality, whereas sulfate, nitrate, and organic acids were chosen to characterize the primary drivers of acidification. In addition, selected metals were included in the evaluation as they may be mobilized in acidic waters. For example, dissolved aluminum (Al), especially when occurring in the form of inorganic monomeric aluminum (Al_{IM}), is particularly soluble in acidic waters (Driscoll et al. 1980, Driscoll 1985, Hermann et al. 1993, Baldigo and Murdoch 1997). The remaining measures, including specific conductance and water temperature, are required parameters within the NPS Inventory and Monitoring Network, and provide an overall indication of the park's water quality.

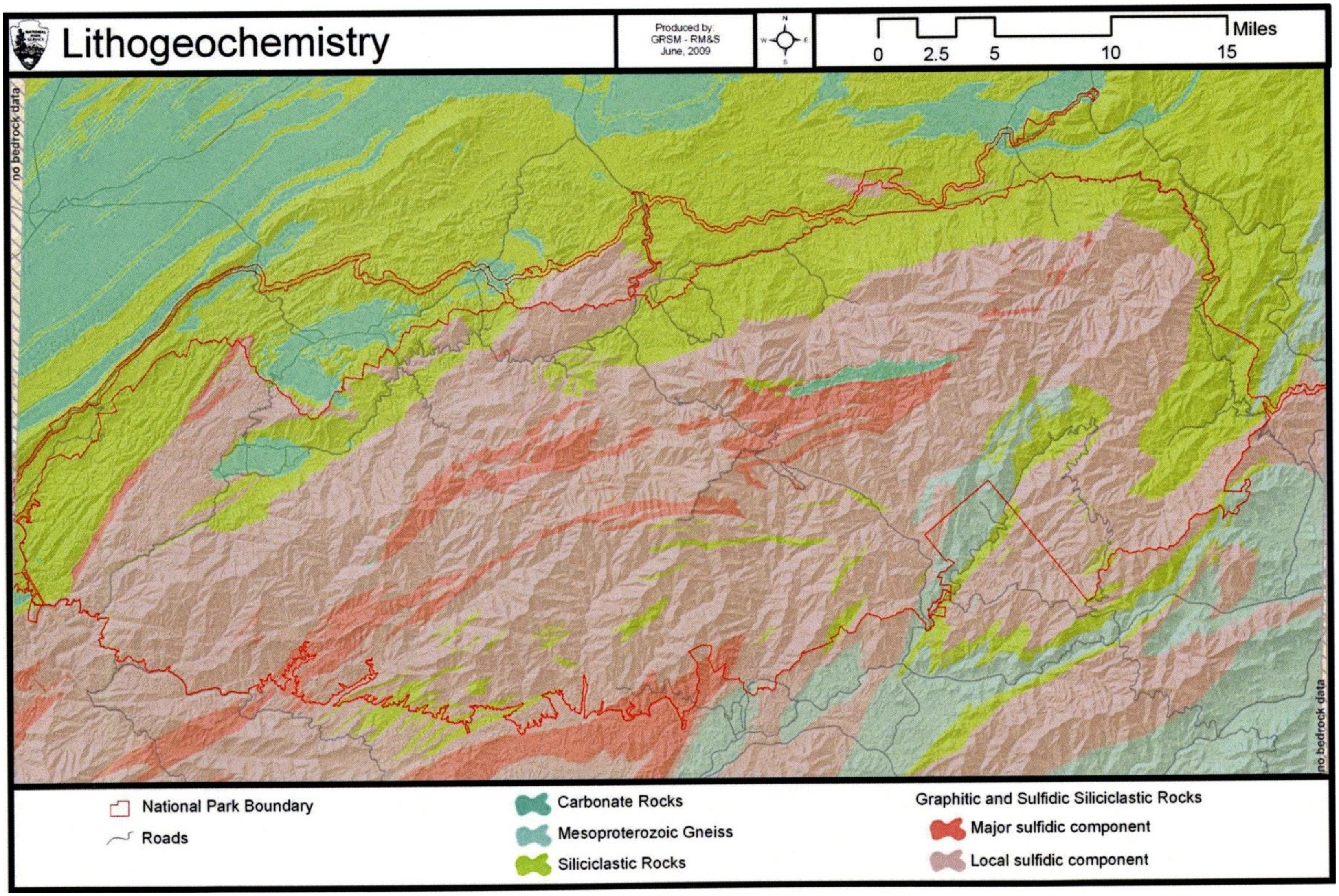


Figure 4.3.1.4. Lithogeochemical map showing the general distribution of rock types by their general geochemical composition. Source: Southworth et al. 2004; Source: Vana-Miller et al. 2010.

Assessment Scale/Reporting Area

The assessment considers both spatial and temporal variations in the examined water quality data. Spatially, the analysis focuses on two scales: (1) data collected at specific locations or watersheds, particularly within the Noland Divide watershed, and (2) data collected at multiple sites throughout the park that are used to assess variations in water quality on a park-wide basis. Temporally, trends in the examined water quality parameters are examined with regard to short-term, storm related events, and over longer, yearly to decadal timeframes.

4.3.2. pH

Relevance

At high concentrations, hydrogen ions (protons, H+) as measured by pH can be lethal or cause sublethal physiological stress to aquatic biota (Woodward et al. 1991, MacAvoy and Bulger 2004, Baldigo et al. 2007, Neff et al. 2009). In fish and macroinvertebrates, the primary effect of acidic conditions (low pH) is the disruption of ion regulation which can lower blood pressure and lead to circulatory failure. Ion regulation is primarily disrupted in low pH waters by the interference of protons with the gill transport system, resulting in a decline in sodium uptake and an increase in whole-body sodium loss (Grippo and Dunson 1996, Neff et al. 2009).

Data and Methods

See section 4.3.1

Reference Conditions

The Tennessee Department of Environment and Conservation has set the water quality standard for pH in wadable streams at 6.0-9.0, but adds that there should be no change of over 1.0 pH unit within a 24-hour period (TDEC 2007). Similarly, the acceptable narrative standard set by the North Carolina Department of Environment and Natural Resources is 6.0-9.0 (NCDENR 2007). The EPA criterion to support freshwater aquatic life and sustain wildlife is set at a pH range of 6.5-9.0 (EPA 1976). Herein, the utilized reference values are based on the more stringent Tennessee standard. It should, however, be recognized that the potential impacts of acidity on aquatic biota may be time (duration) dependent. Evidence provided by Alabaster and Lloyd (1980), for example, suggests that brook trout (*Salvelinus fontinalis*) can survive episodic exposures to low pH waters (below 5) for short periods (<24 h). Nevertheless, direct, lethal effects to fish can occur at pH values below about 5 (Neville and Campbell 1988) even when exposure times are limited (see Cai and Schwartz [2012] for a review of the effects of acidic waters on fish and macroinvertebrates). Amphibian survival also declines in low pH waters (below ~5.0), and some evidence suggests that both amphibian and salmonid egg production begins to decline at pH values below 7.0 (Sadinski and Dunson 1992, Barnett 2003). A classification system has been developed by Baker et al. (1996) listing the potential effects of low pH waters on fish and other aquatic biota within streams of the northeastern U.S. (Table 4.3.2.1). This classification system will be referred to below.

Table 4.3.2.1. Possible ecological consequences of acidic stream waters on biota within the northeastern U.S. Source: Baker et al. 1996.

pH Range	Biological Effects
>6.5	No adverse effects
6.0-6.5	Loss of sensitive benthic invertebrates
5.5-6.0	Loss of acid-sensitive fish Reduced reproduction in sensitive fish species Increase in green algae in periphyton
5.0-5.5	Loss of most fish species Green algae dominates periphyton Loss of most mayflies, stoneflies, caddisflies, and shellfish Reduced biomass and productivity
<5.0	Loss of all fish species Decreased nutrient cycling rates Decline in periphyton species richness Decline in benthic invertebrates Reproductive failure of acid-sensitive amphibians

Conditions and Trends

The degree of stream water acidification at a monitoring site is often determined by examining the pH. Data collected and analyzed since the mid-1980s have shown that pH is highly variable within GRSM, and at some locations and times, exhibits values that fall outside of the utilized reference guidelines. Cook et al. (1994), for example, examined geochemical data collected from five high-elevation (1,100 to 2,000 m [3,280 to 6,560 ft]) watersheds possessing old-growth forests (Clingmans Creek, Walker Camp Prong, and three tributaries to Walker Camp Prong including Cole Creek, Trout Branch, and an unnamed tributary referred to as WP-5). They found that during base flow, mean pH values varied between 4.5 and 6.4. Park-wide data collected between 1993 and 1995 showed that 47 (12%) of the 387 monitored sites from which data had been collected, exhibited a median pH that was <6.0, and 13 (3%) were below a median of 5.0 pH units, a value which Cai and Schwartz (2012) considered to represent severely impaired waters. Over a longer timeframe (1993 to 2009), pH was found to vary for both base- and stormflow measurements from non-impaired (pH>6.4) to severely impaired waters (pH<5; Cai and Schwartz 2012) (Table 4.3.2.2). Twelve streams in GRSM have been placed on the 303(d) list of impaired streams by TDEC due to low stream pH (mean stream pH<6.0) (Table 4.3.2.3).

Table 4.3.2.2. Summary of acid-base water chemistry collected at monitoring sites within GRSM from 1993 to 2009. Source: Cai and Schwartz 2012.

Flow	Statistic	pH	ANC (µeq/l)	NO^{3-} (µeq/l)	SO_4^{2-} (µeq/l)	BCSa (µeq/l)
Base flow	Median	6.63	49.23	11.53	30.41	70.03
	Mean	6.52	68.27	16.12	37.58	88.69
	Std	0.57	104.72	15.39	29.77	117.27
	Minimum	4.44	-28.32	0.00	5.20	-45.30
	Maximum	7.88	1,109.4	89.32	297.63	1,081.20
Stormflow	Median	6.47	43.97	15.02	34.79	67.82
	Mean	6.41	57.86	18.20	43.12	80.41
	Std	0.60	78.11	16.25	35.76	85.94
	Minimum	4.39	-39.48	0.00	5.83	-112.44
	Maximum	7.75	706.43	87.22	361.51	733.00

* – base cation surplus (BCS) = [total base cations]-[anions]

Table 4.3.2.3. Streams in GRSM that are on the 303(d) list of impaired waters of Tennessee; they were listed due to low mean stream pH (<6.0). Source: TDEC 2008, table modified from NPS 2010.

Waterbody ID	Impacted Water Body	County	Kilometers (Miles) Impaired	Cause/TMDL Priority	Pollutant Source
TN06010106 004-0500	Rock Creek	Cocke	4.7 (2.9)	Low pH/ high	Undetermined
TN06010106 004-0610	Inadu Creek	Cocke	4.3 (2.7)	Low pH/ high	Undetermined
TN06010106 004-0810	Otter Creek	Cocke	2.4 (1.5)	Low pH/ high	Undetermined
TN06010106 004-0820	Copperhead Branch	Cocke	1.8 (1.1)	Low pH/ high	Undetermined
TN06010107 007-0700	Buck Fork	Sevier	6.1 (3.8)	Low pH/ high	Undetermined
TN06010107 007-0900	Eagle Rocks Prong	Sevier	10.3 (6.4)	Low pH/ high	Undetermined
TN06010107 007-1120	Shutts Prong	Sevier	7.7 (4.8)	Low pH/ high	Undetermined
TN06010107 007-1130	Lowes Creek	Sevier	3.5 (2.2)	Low pH/ high	Atmospheric deposition - acidity
TN06010107 007-1140	Cannon Creek	Sevier	6.0 (3.7)	Low pH/ high	Atmospheric deposition - acidity
TN06010107 010-1100	Road Prong	Sevier	7.4 (4.6)	Low pH/ high	Undetermined
TN06010201 032-0510	Goshen Prong	Sevier	10.8 (6.7)	Low pH/ high	Undetermined
TN06010201 032-0700	Unnamed trib to Fish Camp Prong	Sevier	2.1 (1.3)	Low pH/ high	Undetermined

Significant variations in pH have been observed between watersheds in the park for both base- and stormflow, and have been found to depend on elevation as well as a host of interrelated watershed characteristics, including bedrock geology, hillslope gradients, dominant vegetation and soil type and properties (Fig. 4.3.2.1) (Cook et al. 1994, Cai et al. 2010, Cai and Schwartz 2012, Neff et al. 2013, Schwartz et al. 2014). The most severely impacted sites are predominantly located at elevations above ~975 m (3,200 ft) which tend to exhibit relatively low pH values (Neff et al. 2013). Cai and Schwartz (2012), for example, showed that park-wide, stream waters collected between 1993 and 2009 exhibited a decrease in pH at a rate of 0.32 pH units per 305 m (1,000 ft) of elevation gain. Decreases in pH with elevation have been attributed, in part, to elevated levels of acid deposition and higher volumes of precipitation at higher elevations (Cai and Schwartz 2012, Neff et al. 2013).

Bedrock type also appears to act as an important control on pH within GRSM. Catchments underlain primarily by sandstones (siliciclastics, Fig. 4.3.1.4) were found to be the most sensitive to acidification, primarily due to their lack of base cations, while those containing carbonate rocks that tend to buffer the effects of acidification (Cai and Schwartz 2012) are less sensitive, however, the latter (carbonate rock) are highly limited within the park, and therefore play a limited role in controlling stream water pH (a notable exception is in Abrams Creek, Cai and Schwartz 2012).

Perhaps of more importance with regards to bedrock geology are exposures of the Anakeesta formation, a rock unit containing sulfide minerals (e.g., pyrite) that upon exposure to water and oxygen may be weathered (oxidized). The oxidation process releases hydrogen ions (H^+), sulfate, and trace metals to stream waters, while lowering pH. Neff et al. (2013), using an 8-block watershed study design that was thought to represent 77% of the park, showed that where the Anakeesta formation was exposed over at least 10% of the basin, pH values were lower and nitrate and sulfate concentrations were higher, particularly during stormflow.

In addition to the spatial variations in pH described above, episodic temporal variations in pH have been documented within the park for individual storm events as well as over longer-periods of time. In most instances, pH was found to decline during rainfall events (Deyton et al. 2009, Neff et al. 2013) (Fig. 4.3.2.2). Thus, stream waters are subjected to short-term episodes of pronounced acidification, primarily as result of the rapid routing of precipitation through the upper soil layers where they may accumulate organic acids as well as sulfur and nitrogen compounds (Neff et al. 2013). The spatial variations in pH observed for flood flows are similar to those observed during base flow, in that higher elevation basins tend to exhibit lower pH values during stormflows than lower elevation watersheds.

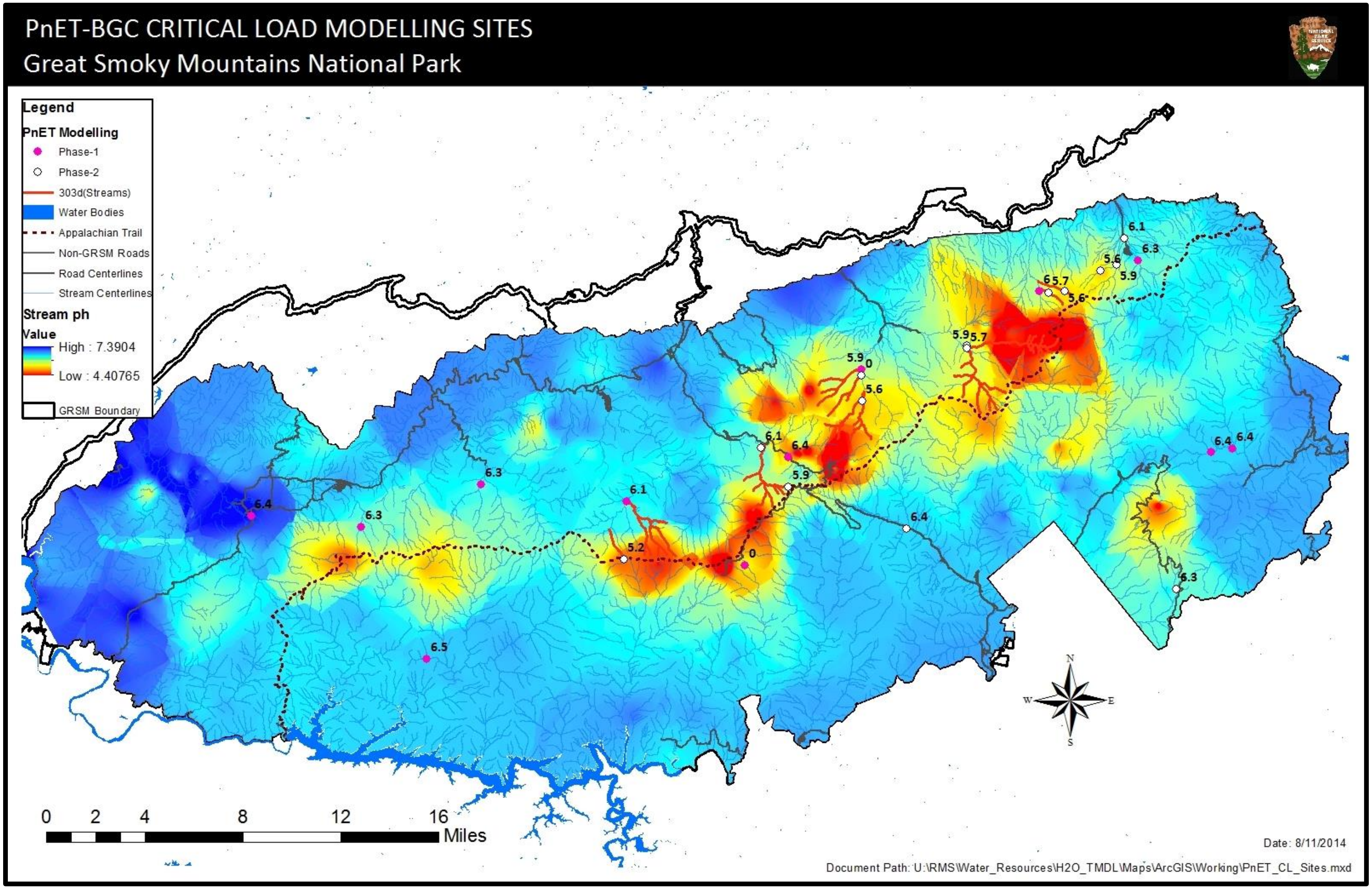


Figure 4.3.2.1. Modeled average stream water pH for GRSM. The lowest pH values coincide with high elevation and the highest acid deposition rates. Approximately 50 to 60% of park streams exhibit an average pH of <6.5. Sources: Cook et al. 1994, Cai et al. 2010, Cai and Schwartz 2012, Neff et al. 2013, Schwartz et al. 2014.

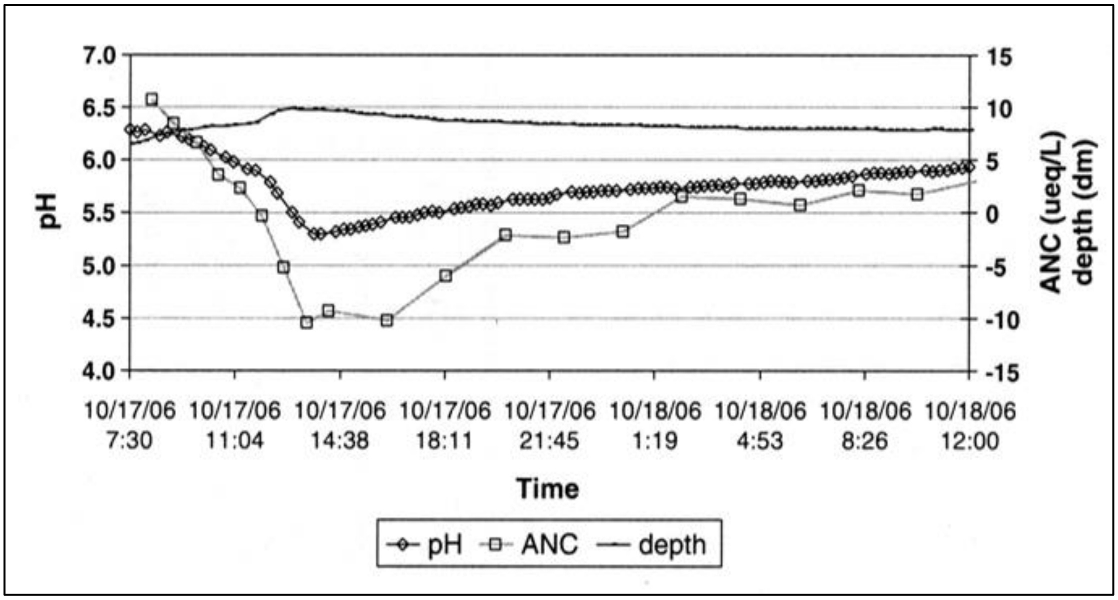


Figure 4.3.2.2. Typical change in stream water pH and ANC during a storm event, as shown for the Middle Prong Little Pigeon River, site GRSM M1 on 17 October, 2006. Source: Deyton et al. 2009.

Basin size, a parameter closely related to basin elevation, also serves as a control on stormwater acidification; smaller basins (<10 km^2 [3.86 ft^2]) tend to exhibit higher stormflow pH conditions (Neff et al. 2013). Trends with regard to basin size are related to the presences of thin, highly conductive soils on steep slopes, which allow acid inducing ions to pass quickly through the soils to the stream channel during rainfall events (Neff et al. 2013). The reduced contact time between the interflow waters and the soils limits ion absorption and consequent buffering, and affects the retention, mobility and chemical processing of sulfate and nitrate in the soil (Cai and Schwartz 2012, Neff et al. 2013). This is supported by the correlation of water chemistry to the hydraulic conductivity (Ksat) of the soil, such that soils with higher hydraulic conductivities can be linked to lower pH and base cation concentrations, and higher nitrate, sulfate, and aluminum concentrations. Neff et al. (2013) found that of all the soil parameters that they examined, Ksat was the soil property that most strongly correlated to water chemistry. Deyton et al. (2009) found that the magnitude of the pH decline (at least within the three high-elevation sites that they studied between March 2006 and May 2007) was also related to both the magnitude of stormflow discharge and the length of the dry period between events. The authors interpreted the latter variable as an indicator of the amount of acid deposition that had accumulated over the landscape and within soil pore waters before sulfate and nitrate was flushed into adjacent channels, increasing their concentrations in stream waters.

Water quality data collected since the early 1990s has made it possible to examine longer-term, decadal-scale temporal variations in pH within GRSM. Analyses of such temporal trends have focused on two differing spatial scales: (1) data from the high-elevation Noland Divide watershed, and (2) data collected from monitoring sites throughout the park. Within the Noland Divide watershed, the pH of stream waters has not changed significantly since 1991 (Cai et al. 2011, Schwartz et al. 2014).

On a park-wide basis, Robinson et al. (2008) used a multiple regression approach to determine whether pH (as well as ANC, sulfate, and nitrate concentrations) in stream waters were correlated with known decreases in atmospheric acidic deposition. Regression models were based on data collected between October 1993 and November 2002 at 90 stream sites dispersed throughout the park. The analysis revealed that pH decreased by 0.016 pH units per year over the monitored period. In addition to characterizing past trends in stream water chemistry, Robinson et al. (2008) developed regression-based forecasting models to assess future changes in water quality. They found that if the observed trends continue into the future, 30% of the sampling sites will reach a pH of <6 (the reference threshold for biological effects) within 10 years; 63.3% will acquire values <6 in 25 years, and 96.7% in less than 50 years.

Zhou et al. (2014) utilized a hydrochemical modeling approach (based on the PnET-BGC model) to assess the critical and dynamic critical loads that would be required for watershed recovery. They also found that watershed recovery in response to decreases in atmospheric deposition would be measured in decades to centuries.

Confidence and Data Gaps

In general, there is a high degree of confidence in the noted pH conditions for stream waters within the park (Table 4.3.2.4). Although limited data were collected for 357 sites from 1991-1995, and a subsample of these sites to present, data continue to be collected from 46 sites that are thought to provide an overview of water quality conditions within the park, allowing for the effects of pH on biota to be interpreted and future temporal changes to be documented. There are, however, a number of minor data gaps including the following:

- The Anakeesta formation contains sulfide minerals that, upon exposure to oxygen, will oxidize and may lead to stream water acidification. Recent exposures of the Anakeesta formation, which may contain unoxidized sulfide minerals, primarily via landslides, and their impact on water quality have yet to be mapped and documented.
- While stormflow water quality data are available from the Tennessee side of the park, these data are lacking for areas in North Carolina (with the exception of sonde data from Straight Fork).
- At the present time, discharge data are collected on a semi-continuous basis at two sites located along relatively high-order streams (Cataloochee and Little River), and at the two sites within the Noland Divide watershed. Flow data are generally lacking for most other monitoring sites located within the park. Thus, only general relationships, typically based on local precipitation records, can be assessed between discharge and pH. Since pH varies as a function of stream flow, the collection of discharge/water level data at additional sites throughout the park is needed to enhance the analysis and interpretation of water quality data on a park-wide basis.

Sources of Expertise

- Matt Kulp, Fisheries Biologist, Great Smoky Mountains National Park

Summary Condition

Table 4.3.2.4. Summary condition and trend graphic for water quality in GRSM, based on pH levels.

Resource	Indicator	Status and Trend	Rationale and Reference Conditions
Water Quality	Hydrogen (H^+) concentration (pH)	↔	There is high spatial variability between watersheds, but base- and stormflows are often below a pH 6.0 and/or exhibit a pH change over one unit within 24 h. Temporal trends are also variable across the park, but significant recovery of pH to meet acceptable targets will likely take decades to centuries. Reference condition: Tennessee State Water Quality Standard for fish and aquatic life.

4.3.3. Acid Neutralizing Capacity (ANC)

Relevance

ANC represents the difference between proton acceptors and proton donors within a water sample. As such, it serves as an index of both the susceptibility of stream waters to acidification (Webb et al. 1989) (Table 4.3.3.1) and the extent to which stream waters have been acidified (Hemond 1990). ANC is not affected by temporal variations in the total inorganic carbon content of the waters and, thus, is often regarded as a more appropriate indicator of the water's acidic condition than pH (Hemond 1990). Acid stream waters that are sensitive to acidification are defined as those in which ANC <50 µeq/l.

Table 4.3.3.1. Summary of stream system sensitivity to acidic conditions. Source: Webb et al. 1989; based on studies of native brook trout in Virginia.

ANC range (µeq/l)	Classification	Percentage of sample sites with median ANC within range
<0	Acidic	4 to 5
0-50	Extremely sensitive	52
50-200	Sensitive	40
>200	Not Classified	3

Data and Methods

See section 4.3.1.

Reference Condition

Currently, state and federal standards for ANC do not exist. However, the Tennessee Department of Environment and Conservation (TDEC 2010) proposed minimum ANC values that would provide a pH within the range of 6 to 9 for the impaired streams listed in Table 4.3.2.3. A default total daily maximum load (TMDL) management target for ANC was set at 50 µeq/l; the default target is used herein as a reference value.

Condition and Trends

ANC, as noted above, is defined as the difference between proton acceptors and proton donors within a water sample, and serves as another measure of stream water acidification (Hemond 1990). As expected, ANC values generally mimic the spatial and temporal trends observed for pH. Of significance, data collected since the mid-1980s show that while ANC is highly variable within GRSM, it often exhibits values that fall outside of the utilized reference guidelines. Cook et al. (1994), for example, found that mean ANC ranged from -31 to 28 µeq/l. The most severely impacted sites as defined by ANC were again those located at elevations above ~1,280 m (4,200 ft). In fact, Cai and Schwartz (2012) found that ANC in stream waters collected between 1993 and 2009 decrease at a rate of -35.73 µeq/l per 305 m (1,000 ft) of elevation gain, park-wide. As was the case for pH, ANC values were typically found to decline during rainfall events (Deyton et al. 2009, Neff et al. 2013) (Fig. 4.3.2.2), again indicating that stream waters are subjected to short-term episodes of pronounced acidification.

One difference between the trends observed for pH and ANC was noted by Robinson et al. (2008). On a park-wide basis, multiple regression analysis performed on data collected between October 1993 and November 2002 at 90 stream sites showed that ANC exhibited no systematic change over the monitoring period (while pH decreased over the same period). In addition, temporal trends in ANC values were mixed between various elevation classes defined by Robinson et al. (2008). However, where a statistical trend in ANC occurred, the values were declining, indicating that there had been no improvement in stream water acidification during the monitoring period (Robinson et al. 2008).

Zhou et al. (2014) applied a hydrochemical modeling approach (based on the PnET-BGC model) to 12 representative streams (including two listed as impaired) in order to assess the levels of atmospheric sulfate and nitrate deposition that were needed to achieve ANC targets of 0, 20, and 50 µeq/l within stream waters. They found that levels required to achieve the reference target varied between watersheds, but in general, the higher the pre-industrial and/or current ANC, the higher the maximum level of sulfate and nitrate deposition that could occur to meet the targets (Zhou et al. 2014). Park-wide, they found that a combined sulfate plus nitrate depositional rate of <1 keq/ha-yr (compared to a current depositional rate on the order of 0.6 to 3.2 keq/ha-yr) would lead to an ANC of 0 µeq/l by 2050 in all of the representative watersheds. Alternatively, they found that a 60% reduction in sulfate and nitrate deposition (which they considered to be a reasonable scenario) would lead to differing results between watersheds; ANC would increase in some basin and decrease in others.

Confidence and Data Gaps

In general, there is a high degree of confidence in the described ANC conditions for stream waters within the park (Table 4.3.3.2). There are a number of minor data gaps including the following:

1. While stormflow water quality data are available from the Tennessee side of the park, these data are lacking for areas in North Carolina (with the exception of sonde data from Straight Fork).

2. At the present time, discharge data are collected on a semi-continuous basis at two sites located along relatively high-order streams (Cataloochee and Little River), and at the two sites within the Noland Divide watershed. Flow data are generally lacking for most other monitoring sites located within the park. Thus, only general relationships, typically based on local precipitation records, can be assessed between discharge and ANC. Since ANC varies as a function of stream flow, the collection of discharge/water level data at additional sites throughout the park is needed to enhance the analysis and interpretation of water quality data on a park-wide basis.

Sources of Expertise

- Matt Kulp, Fisheries Biologist, Great Smoky Mountains National Park

Summary Condition

Table 4.3.3.2. Summary condition and trend graphic for water quality in GRSM, based on ANC.

Resource	Indicator	Status and Trend	Rationale and Reference Conditions
Water Quality	ANC; difference between proton acceptors and donors in stream water (µeq/l)	↔	There is high spatial variability between watersheds, but base- and stormflows are often below the reference target of 50 µeq/l; significant recovery to reasonable declines in atmospheric sulfate and nitrate deposition will likely generate mixed responses between watersheds within the park. Reference condition: Tennessee State ANC TMDL default target set for the GRSM (TDEC, 2010).

4.3.4. Sulfate

Relevance

Sulfate, derived in large part from atmospheric deposition of sulfur compounds, is a significant driver of stream water acidification (also see section 4.1.1).

Data and Methods

See section 4.3.1.

Reference Condition

The drinking water standard for sulfate is 5,205 µeq/l (250 mg/l). However, within GRSM the primary concern is the effect of sulfate on stream water acidification. The influence of sulfate on acidification varies with a host of watershed parameters (e.g., geology, soil type and thickness, discharge, and vegetation cover); thus, freshwater standards at the state or federal level do not directly apply to this assessment. One approach through which a reference value for sulfate concentrations may be defined is to examine the spatial variability in concentrations on a local and regional scale. Argue et al. (2011) characterized water chemistry, including sulfate concentrations, within headwater streams along the Appalachian Trail (from Maine to Georgia). Median sulfate concentrations for nine separate ecoregions were found to vary from 49.76 to 233.18 µeq/l (Table 4.3.4.1).

Table 4.3.4.1. Sulfate concentration in µeq/l of headwater and adjacent streams on the Appalachian National Scenic Trail. Source: Argue et al. 2011.

Ecological Section	Number of Catchments	Minimum	25th Percentile	Median	75th Percentile	Maximum
White Mountains	53	43.10	69.12	83.28	95.980	158.86
Vermont–New Hampshire Upland	7	104.1	114.5	166.56	218.61	270.66
Green–Taconic–Berkshire Mountains	32	73.49	118.2	145.12	169.27	320.63

Table 4.3.4.1 (continued). Sulfate concentration in µeq/l of headwater and adjacent streams on the Appalachian National Scenic Trail. Source: Argue et al. 2011.

Ecological Section	Number of Catchments	Minimum	25th Percentile	Median	75th Percentile	Maximum
Lower New England	27	114.51	189.4	224.86	291.48	520.50
Hudson Valley	19	154.70	203.0	233.18	333.12	2311.0
Northern Glaciated Allegheny Plateau	12	84.52	125.5	139.70	160.73	249.84
Northern Ridge and Valley	40	23.94	102.9	137.20	226.94	1,644.8
Blue Ridge Mountains	305	6.038	30.0	49.76	71.41	499.68
Allegheny Mountains	78	13.74	50.0	64.54	98.48	2,883.6

Zhou et al. (2014) noted that sulfate deposition ranged from 7-42 kg S/ha in 2000 within GRSM. Sullivan et al. (2007) compiled sulfate data from 66 watersheds in North Carolina, Tennessee, and South Carolina to calibrate a model used to assess stream water acidification. Sulfate values within these watersheds ranged from 9.8 to 207.4 µeq/l (Table 4.3.4.2). Sulfate concentrations at the Coweeta Long-term Ecological Research Station were found to exhibit an annual volumetric mean of 12 µeq/l (Hartman et al. 2009). Thus, sulfate values at Coweeta, which is generally characterized by thick soils in relatively undisturbed watersheds, were observed to be ~12 µeq/l, a concentration that is on the low end of the concentration range cited by Sullivan et al. (2007) and USGS (2011).

Using a geochemical modeling approach, Zhou et al. (2015) estimated the mean, pre-industrial sulfate concentration within 12 watersheds in the park to be 9.5±7.1 µeq/l, similar to the concentrations found at Coweeta. Using the same scaling factors that were applied to estimate current spatial patterns of atmospheric deposition through the park (Weathers 2006), Fakhraei et al. (2016) estimated that pre-industrial (1850) wet S deposition spatially ranged from 4.7 to 12.3 $mmol_c/m^2$/yr in the park. Sulfur deposition estimates from Zhou (2015), Fakhraei et al. (2016) and Coweeta indicate that the 4.7 to 12.3 $mmol_c/m^2$/yr range would serve as an accurate reference concentration for pre-industrial S deposition.

Table 4.3.4.2. Stream water chemistry data cited by Sullivan et al. (2007) for streams in North Carolina, Tennessee, and South Carolina.

Site Name	Cal. Year	SO_4^{2-} (μeq/l)	NO_3^- (μeq/l)	Site Name	Cal. Year	SO_4^{2-} (μeq/l)	NO_3^- (μeq/l)	Site Name	Cal. Year	SO_4^{2-} (μeq/l)	NO_3^- (μeq/l)
Adam Camp Br.	2003	17.4	0	Indian Camp	2004	12.8	0.7	Scotsman Creek	2003	16.5	1.5
Bear Branch	2003	71.2	0	Indian Spring Branch	2004	23.7	2	South Fork Fowler Creek	2003	9.80	0.1
Bearpen Branch	2004	30.4	3.8	Kilby Creek	2003	10.4	0.7	Spivey Creek	2004	44.1	5
Beetree Branch	2003	124	0.1	Kirkland Cove	2004	31	11.3	Squibb Creek	1999	77.3	17.8
Big Cove Branch	2004	20.6	23.1	Left Prong South Toe River	2000	17.7	14.6	Stillhouse Branch	2005	33.5	0
Big Laurel Brook	2003	10.6	0.5	Lindy Camp Branch	1999	48	0.6	Unnamed creek A	2004	30.1	11.7
Big Oak Cove Creek	2004	38.1	11.1	Little Prong Hickey Fork	2000	21.4	6.3	Unnamed creek B	2004	45.4	16.9
Briar Creek	2005	55.3	1.2	Little Santetlah Cr. (NuCM site)	2000	32	6.7	Unnamed creek C	2004	27.9	18.3
Bubbling Spring Branch	2003	44.2	1	Long Branch	2000	11.8	0	Upper Creek	2003	33.3	6.1
Bubbling Spring West Tributary	2003	38.7	1.2	Lost Cove	2003	35.3	3.2	UT Flat Laurel Cr.	2000	36.0	3.2
Buckeye Cove Cr.	2003	30.5	7.6	Lower Creek	2003	31.9	6.4	UT Laurel Branch	2004	74.1	5
Cane Creek Tributary	2003	36.7	2.4	McNabb Creek	2004	207.4	0.4	UT Linville River (NuCM site)	2004	52.7	1.2
Cathey Creek	2003	36.0	10.5	Middle Creek	2003	29.4	4.1	UT McNabb Creek	2004	20.3	0.5
Colberts Creek	2003	29.9	5.3	Mill Station Creek	2004	59.5	4	UT N. Fork of Catawba	2005	38.4	0
Courthouse Cr.	2003	26.9	3	Paddy Creek	2005	48	0	UT Paint Creek	1999	45.5	8.8
Dark Prong	2003	27.9	0	Peach Orchard Creek	2000	50.3	20.1	UT Panthertown Cr. (Boggy Creek)	2000	31.3	1.2
Davidson River	2000	27.3	3.1	Pigpen Branch	2000	9.6	0	UT Russell Creek	2005	58.7	0
East Fork Pigeon	2003	21.0	2.2	Rattlesnake Branch	1999	39.3	0.5	White Creek	2005	48.4	0
Flat Laurel Cr.	2003	30.0	2.3	Right Hand Prong	2003	29.4	12.7	Wildcat Branch	2004	16.2	1.3

Table 4.3.4.2 (continued). Stream water chemistry data cited by Sullivan et al. (2007) for streams in North Carolina, Tennessee, and South Carolina.

Site Name	Cal. Year	SO_4^{2-} (μeq/l)	NO_3^- (μeq/l)	Site Name	Cal. Year	SO_4^{2-} (μeq/l)	NO_3^- (μeq/l)	Site Name	Cal. Year	SO_4^{2-} (μeq/l)	NO_3^- (μeq/l)
Glade Creek	2003	10.7	0.4	Roaring Branch	2000	35	21	Wilson Creek	2000	10.5	0.7
Greenland Creek	2003	28.6	1.8	Rough Ridge Creek	2000	26.9	1.8	Wolf Creek	2004	17.3	1.6
Indian Branch	2004	34.0	22.9	Russell Creek	2005	77.3	0	Yellow Fork	2005	48.5	0

Conditions and Trends

Air quality monitoring data collected since the 1980s at Elkmont and Noland Divide have shown that sulfate depositional rates within GRSM have recently declined, but continue to be some of the highest in the U.S. (e.g., Nodvin et al. 1995, Shubzda et al. 1995, Smoot et al. 2000, NADP 2006, Sullivan et al. 2007) (Figs. 4.3.1.3, 4.3.1.4). As a result, in comparison to many regions of the US stream waters within the park exhibit a relatively high mean base flow sulfate concentration of 35.5±16.1 µeq/l (Zhou et al. 2014). This mean concentration is about three times higher than that measured at Coweeta and used as a general reference level.

Spatially, stream water sulfate concentrations do not appear to vary with elevation in the park, prompting Cai et al. (2012) to suggest that soil adsorption in higher-elevation headwater basins plays an important role in affecting sulfate concentrations during base flow. However, Neff et al. (2013) found that watersheds with soils exhibiting high hydraulic conductivities were linked to higher sulfate concentrations than watersheds possessing poorly conductive soils. The authors argue that such highly conductive soils allow acid deposition during rainfall events to pass quickly through to the channel.

Temporally, sulfate concentrations measured between May 2008 and September 2009 did not vary systematically during runoff. Similarly, regression models developed by Robinson et al. (2008) using data collected between October 1993 and November 2002 at 90 stream sites dispersed throughout GRSM suggest that sulfate concentrations did not systematically change over the monitoring period. A similar result was reached by Cai et al. (2011) using data collected at monitoring stations within the high-elevation Noland Divide watershed. They found that between 1991 and 2007, sulfate concentrations remained constant at 30 µeq/l, in spite of the fact that the atmospheric deposition of sulfate declined within the park over this monitoring period (Fig. 4.3.1.4). These differing trends between the rate of atmospheric sulfate deposition and the concentration of sulfate in stream waters may be related to soil biogeochemical processes (Schwartz et al. 2014). Cai et al. (2012), for example, found that while sulfate moved quickly through the watershed during precipitation events, adding to stream water acidification, over the long-term 61% of the sulfate was retained. Thus, soils appear to act as a sink for sulfate, and do not appear to have developed a steady-state condition with respect to atmospheric sulfate deposition. This conclusion is supported by the more recent geochemical modeling work conducted by Zhou et al. (2014). They argued that sulfate concentrations in stream waters were influenced by sulfate adsorption within the soils, and that decreases in nitrate deposition could lead to increases in previously sorbed sulfate in the soils. This is an important conclusion because it suggests that a future increase in soil water pH, related to a decrease in both nitrate and sulfate deposition, may lead to sulfate desorption. Desorption, in turn, may allow for the introduction of sulfate to stream channels, reducing the rate of water quality recovery (Cai et al. 2012, Schwartz et al. 2014, Zhou et al. 2014).

Confidence and Gaps

In general, there is a high degree of confidence in the described sulfate conditions for stream waters within the park (Table 4.3.4.3). However, additional studies on the sorption/desorption of sulfate from soil particles are needed as this process is likely to represent a significant control on the recovery of stream waters from acidification. The contribution of sulfate from naturally weathering sulfidic shales also warrants further studies in order to determine their contribution to soil biogeochemistry across the park.

Sources of Expertise

- Matt Kulp, Fisheries Biologist, Great Smoky Mountains National Park

Summary Condition

Table 4.3.4.3. Summary condition and trend graphic for water quality in GRSM, based on sulfate concentration.

Resource	Indicator	Status and Trend	Rationale and Reference Conditions
Water Quality	Concentration of sulfate (μeq/l)	↔	Sulfate concentrations are well above the 12 μeq/l proposed as a general reference target. Reference condition: based on estimated pre-industrial concentrations and values measured at Coweeta Hydrologic Laboratory.

4.3.5. Nitrate

Relevance

Nitrate, derived in large part from atmospheric deposition of automobile and agricultural sources (see section 4.1.1), is also a significant driver of stream water acidification (Cook et al. 1994, Neff et al. 2001, Cai and Schwartz 2012).

Data and Methods

See section 4.3.1.

Reference Condition

The drinking water standard for nitrate is 161 μeq/l (10 mg/l); however, as noted for sulfate, the primary concern for GRSM is the effect of nitrate on stream water acidification. Because the influence of nitrate on acidification varies with a host of watershed parameters (e.g., geology, soil type and thickness, discharge, and vegetation cover), freshwater standards at the state or federal level are not directly applicable to this assessment. A reference condition is proposed here on the basis of nitrate concentrations observed on a local and regional scale.

Argue et al. (2011) characterized water chemistry, including nitrate concentrations, within headwater streams along the Appalachian Trail (from Maine to Georgia) and determined that the median nitrate concentrations for nine separate ecoregions varied from 1.02 to 6.71 μeq/l (Table 4.3.5.1). Sullivan et al. (2007) compiled nitrate data from 66 watersheds in North Carolina, Tennessee, and South Carolina to calibrate a model for assessing stream water acidification and found that nitrate values within these watersheds ranged from 0 to 23.1 μeq/l. Nitrate concentrations at the Coweeta Long-term Ecological Research Station, an area generally characterized by thick soils and relatively undeveloped watersheds, were <5 μeq/l throughout the year (Hartman et al. 2009), which is on the low end of the concentration ranges cited by Sullivan et al. (2007) and Argue et al. (2011). In the park, Zhou et al. (2014) noted that nitrate deposition ranged from 5-31 kg N/ha, and the estimated mean pre-industrial nitrate concentration was 1.2±0.7 µeq/l, within the range found at Coweeta. Thus, a concentration of <5 µeq/l, as found at Coweeta and estimated as a pre-industrial (1850) value, is used as a general reference concentration here.

Conditions and Trends

Air quality monitoring data, collected since the 1980s at Elkmont and since the 1990s at Noland Divide, have shown that while nitrate deposition has recently declined in GRSM, it still receives some of the highest levels of nitrate deposition in the U.S. (e.g., Nodvin et al. 1995, Shubzda et al. 1995, Smoot et al. 2000, NADP 2006, Sullivan et al. 2007) (Figs. 4.3.1.3, 4.1.1.1). These high rates of atmospheric deposition are apparent in the water quality data, exhibiting mean volume-weighted nitrate concentrations of 23.2±12.2 µeq/l (Zhou et al. 2014), a value that is an order of magnitude above the proposed reference concentration. It is also relatively high in comparison to many regions of the U.S., including the east (Tables 4.3.4.2 and 4.3.5.1).

Table 4.3.5.1. Nitrate concentrations (µeq/l) in headwater and adjacent streams along the Appalachian National Scenic Trail. Source: Argue et al. 2011.

Ecological Section	Number of Catchments	Minimum	25th Percentile	Median	75th Percentile	Maximum
White Mountains	6	0.42	0.48	1.11	1.77	9.03
Vermont–New Hampshire Upland	6	0.37	2.39	4.20	6.94	22.90
Green–Taconic–Berkshire Mountains	15	0.34	4.12	5.32	10.08	13.55
Lower New England	28	0.34	0.94	2.08	6.44	32.26
Hudson Valley	16	0.15	0.35	1.90	4.21	14.97
Northern Glaciated Allegheny Plateau	12	0.31	0.60	1.61	5.00	15.48
Northern Ridge and Valley	37	0.23	2.41	6.71	9.29	70.33
Blue Ridge Mountains	210	< 0.13	0.61	2.05	5.53	72.91
Allegheny Mountains	35	< 0.13	0.24	1.02	2.40	29.84

Spatially, nitrate concentrations within stream waters are highly variable. In general, higher nitrate concentrations are observed in relatively high-elevation basins (Cai and Schwartz 2012, Neff et al. 2013), presumably reflecting more precipitation and higher rates of atmospheric nitrogen deposition. Soil characteristics have also been found to influence nitrate concentrations; higher stream water nitrate concentrations are found in basins with thin, steep soils characterized by high hydraulic conductivities (Ksat values), reduced interflow contact time, and relatively high soil organic matter percentages (Driscoll et al. 1995, Neff et al. 2013). In addition, watersheds dominated by high-elevation forests exhibit relatively high nitrate concentrations as a result of higher rates of nitrification and mineralization (Neff et al. 2013).

Short-term (flood related) variations in nitrate concentrations appear to vary between watersheds. Neff et al. (2013), for example, using data collected between May 2008 and September 2009, determined that nitrate concentrations exhibited no systematic response to changing stream flow. Over longer time periods, however, Robinson et al. (2008) used a multiple regression approach to show that nitrate concentrations between October 1993 and November 2002 at 90 stream sites dispersed throughout GRSM, exhibited a systematic decline over the monitoring period.

Cai et al. (2011) examined seasonal and long-term trends in stream water chemistry between 1991 and 2007 at monitoring stations within the high elevation Noland Divide watershed. They found that monthly volume-weighted nitrate concentrations in throughfall increased over the monitoring period by approximately 1.24 µeq/l/yr, whereas concentrations and fluxes of nitrate significantly declined in stream waters by 0.56 µeq/l/yr and 139.56 µeq/yr, respectively. In addition, inorganic nitrogen was found to be exported before 1999, but has been retained within the watershed ever since. The noted retention of inorganic nitrogen suggests that nitrate export is regulated by soil biogeochemical processes (Cai et al. 2012), a conclusion supported by soils data. Surface soil horizons exhibit much higher concentrations of organic and inorganic nitrogen as well as base cations than lower horizons. All of these high levels of organic nitrogen, combined with high nitrogen transformation rates, suggest that nitrate export to stream channels is biologically controlled by such processes as forest uptake, microbial mineralization and nitrification. These processes vary seasonally as they are dependent on precipitation, soil moisture, and temperature. Thus, nitrate export tends to be enhanced during the winter months (Cai et al. 2010). More importantly, the data imply that a reduction in atmospheric nitrogen deposition might not directly and immediately affect nitrogen loss to stream waters. Rather, watershed characteristics (e.g., elevation and forest type) that influence microbial activity will have a significant influence on nitrogen export to streams (Cai et al. 2012). Moreover, the data support biogeochemical cycling models that suggest the recovery of watersheds from acidic deposition may take several decades to occur (Cai et al. 2011, Zhou et al. 2014).

Confidence and Gaps

In general, there is a high degree of confidence in the described nitrate conditions for stream waters within the park (Table 4.3.5.2). However, additional studies on nitrogen cycling and the nitrogen saturation of watershed soils would help to improve estimates of future nitrate loads to stream waters, and the certainty in the estimated time required for the recovery of stream waters to acidification.

Sources of Expertise

- Matt Kulp, Fisheries Biologist, Great Smoky Mountains National Park

Summary Condition

Table 4.3.5.2. Summary condition and trend graphic for water quality in GRSM, based on nitrate concentration.

Resource	Indicator	Status and Trend	Rationale and Reference Conditions
Water Quality	Concentration of nitrate (μeq/l)	↔	Nitrate concentrations are well above the 5 μeq/l proposed as a general reference target. Reference condition: based on estimated pre-industrial concentrations and values measured at Coweeta Hydrological Laboratory.

4.3.6. Temperature

Relevance

Temperature, or the intensity of heat stored within a body of water, is an important water quality parameter, in that it affects the solubility of oxygen and chemical pollutants in the water, and influences metabolic oxygen demand and growth rates. Increases in water temperatures enhance metabolic oxygen demand while reducing the dissolved oxygen content of the water. In general, chemical pollutants are also more soluble at higher temperatures.

Data and Methods

See section 4.3.1.

Reference Condition

Aquatic biota have a preference/tolerance for a particular range of water temperatures. Above and below these values, their health may suffer. In most instances, issues with regard to water temperature involve an increase during the summer months in response to the input of warm water from anthropogenic sources, or from the alteration of aquatic and riparian habitat (e.g., the removal of shade associated with the loss of stream side vegetation). Table 4.3.6.1 provides the water quality criteria set by the states of Tennessee and North Carolina. A reference value of 20 °C (68 °F) is used in this evaluation, which is consistent with both states' water quality criteria for the protection of fish and aquatic life in trout streams.

Table 4.3.6.1. Tennessee and North Carolina water quality criterion for temperature.

Parameter	Tennessee	North Carolina
Temperature	The maximum water temperature change shall not exceed 3 °C (37.4 °F) relative to an upstream control point. The temperature of the water shall not exceed 30.5 °C (86.9 °F) and the maximum rate of change shall not exceed 2 °C per hour. The temperature of recognized trout waters shall not exceed 20 °C (68 °F). There shall be no abnormal temperature changes that may affect aquatic life unless caused by natural conditions (TDEC 2007).	Temperature is not to exceed 2.8 °C (5.04 °F) above the natural water temperature and in no case to exceed 29 °C (84.2 °F) for mountain and upper Piedmont waters. The temperature for trout waters shall not be increased by more than 0.5 °C (0.9 °F) due to the discharge of heated liquids, but in no case to exceed 20 °C (68 °F) (NCDENR 2007).

Conditions and Trends

Stream water temperatures within 12 first- and second-order streams within the park were measured at hourly increments between June 2005 and March 2006 by Roberts et al. (2009). Water temperatures at all 12 sites were below the reference criteria, ranging from 10.00±5.63 to 14.22±5.78 °C. Only two streams exhibited temperatures above 12.5 °C (54.5 °F). Similarly, Nickerson et al. (2002) measured water temperatures within 13 streams between August 21 and October 15, 2000, and with one exception (Abrams Creek), they found that water temperatures were at or below the 20 °C (68 °F) reference criteria. The temperature at Abrams Creek was 20.8 °C (69.4 °F); however, this would be considered a coolwater section of stream, and not trout water. The cool stream waters are likely to reflect the climatic conditions associated with the relatively high elevations of the southern Appalachians as well as the shade provided by riparian vegetation. Water temperatures along a larger, lower elevation stream were monitored from 1976 to 2014 at the USGS stream gage located along Little River above Townsend, TN (gage 03497300). The data show that mean daily temperatures are below 20 °C (68 °F) for eight months of the year. However, temperatures for three days in June, all of July, nine days in August, and seven days in September exceed, on average, 20 °C (68 °F) by about 1 °C or less. While water temperatures along such lower elevation streams may slightly exceed the water quality criteria during the summer, high water temperatures do not appear to be a significant concern, as these lower sections of the park’s larger stream systems are characterized as coolwater streams and not trout waters as defined by the states of North Carolina and Tennessee.

Confidence and Data Gaps

In general, there is a high degree of confidence in the described temperature conditions for stream waters within the park (Table 4.3.6.2).

Sources of Expertise

- Matt Kulp, Fisheries Biologist, Great Smoky Mountains National Park

Summary Condition

Table 4.3.6.2. Summary condition and trend graphic for water quality in GRSM, based on stream temperature.

Resource	Indicator	Status and Trend	Rationale and Reference Conditions
Water Quality	Stream water temperature (°C)	↔	Temperatures of headwater streams are consistently below reference standard; higher-order streams may occasionally exceed reference standard by ~1 °C during summer months. Reference condition: based on North Carolina and Tennessee standards for aquatic life.

4.3.7. Specific Conductance

Relevance

Specific conductance is a measure of the water's ability to conduct an electric current, and is usually reported in microsiemens per centimeter (µS/cm). It is closely linked to the concentration of ions in the water; the higher the concentration, the more conductive the water. For this reason, specific conductance is often used to assess the concentration of total dissolved solids (including pollutants) within water, and it provides an indicator of overall water quality.

Data and Methods

See section 4.3.1.

Reference Condition

Conductivity in uncontaminated rivers in the U.S. range from about 5 to 1,500 µS/cm. Due to this inherent natural variability, there are no state or federal water quality criteria for specific conductance. However, uncontaminated stream water within the southern Appalachians is typically below 50 µS/cm. For example, researchers have found that specific conductance within the forested Allen Creek watershed in Haywood County, NC, ranged from 12 to 22 µS/cm between March 2007 and December 2011. Similarly, Webster et al. (2012) found that specific conductance within watersheds of the southern Appalachians, including at Coweeta Hydrologic Laboratory, ranged between 9.3 and 63.5 µS/cm, and exhibited a strong, indirect relationship with forested land cover and a number of other variables used to describe development. Given the noted ranges for specific conductance, 50 µS/cm is put forth here as a maximum reference value for predominantly forested watersheds in the park.

Conditions and Trends

Data collected from monitored sites throughout the park between 1993 and 2008 exhibited mean specific conductance values of 14.52 and 15.93 µS/cm for base flow and stormflow, respectively (Fig. 4.3.7.1) (Cai and Schwartz 2012). Specific conductance values are currently measured for 43 sites within seven watersheds throughout the park. These sites are thought to provide the data necessary to characterize the current condition of stream waters within GRSM and to detect trends in stream water conditions through time (Odom 2003). Specific conductance was measured more than

2,400 times between 1993 and 2008 at these sites; the mean value was 16.73 µS/cm. Less than 7% of measurements exceeded 50 µS/cm, which is the utilized reference criterion.

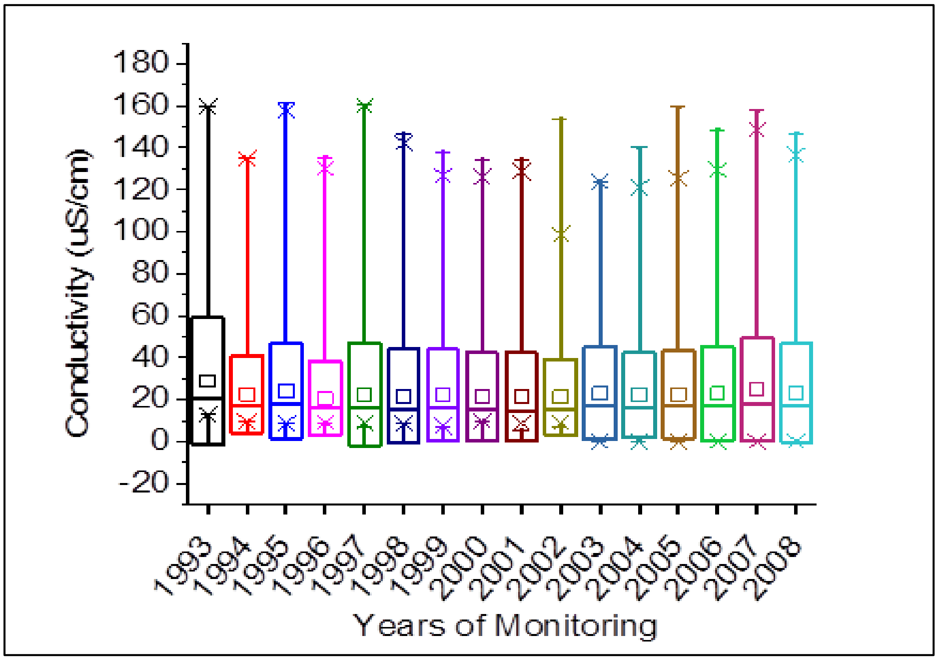


Figure 4.3.7.1. Specific conductivity measured at the 43 currently monitored sites within GRSM between 1993 and 2008. * Box is one standard deviation; whiskers are maximum and minimum values; small square is the mean; x's are the 1% and 99%; line in the box is the median. Source: Cai and Schwartz 2012

On a site by site basis only two sites, both on Abrams Creek, exceeded 50 µS/cm (Table 4.3.7.1). The relatively high values along Abrams Creek can be attributed to the presence of carbonate bedrock within the watershed; thus, the values are not believed to denote a contaminant problem. Specific conductance remained constant between 1993 and 2009 for the currently monitored sites within the park. More recent data collected in 2013 suggests that conductivity has remained constant since 2009 (Schwartz 2014). On a site by site basis, regression analysis showed that weak, but statistically significant (R^2 values of less than 0.1) temporal trends in specific conductance occurred at six of the 43 sites, but the direction of the trends was mixed.

Table 4.3.7.1. Descriptive statistics for specific conductance measured at 43 currently monitored sites in GRSM between 1993 and 2009. All measurements are listed in µS/cm.

Site Name	Site Number	N	Median	Mean	Minimum	Maximum	Standard Deviation
Lower Rock Creek	4	–	–	–	–	–	–
Little River at boundary	13	–	–	–	–	–	–
Lower West Prong Little River	24	74	22.25	22.78	7.01	35.1	5.13

Table 4.3.7.1 (continued). Descriptive statistics for specific conductance measured at 43 currently monitored sites in GRSM between 1993 and 2009. All measurements are listed in µS/cm.

Site Name	Site Number	N	Median	Mean	Minimum	Maximum	Standard Deviation
West Prong Little Pigeon at Headquarters	30	72	20.45	20.94	15.73	25.9	2.08
West Prong Little Pigeon at Chimneys Picnic Area	66	77	19.78	20.25	15.17	26.8	2.3
Road Prong above barrier cascade	71	73	15.82	15.98	5.36	23	2.04
Walker Camp Prong above Road Prong	73	75	20.9	21.16	15.6	26.9	2.55
Walker Camp Prong above Alum Cave Creek	74	74	25	25.38	16.17	35.1	3.88
Cosby Creek at log bridge	114	62	17.28	17.64	11.1	30.82	2.78
Upper Rock Creek	137	73	14.9	15.06	10	20.3	1.91
Inadu Creek	138	45	13.76	13.75	10.94	17.5	1.49
Beech Creek above Lost Bottom Creek	142	69	11.18	11.14	8.27	13.59	1.39
Lost Bottom Creek	143	70	10.7	10.94	7.5	16.04	1.43
Palmer Creek above Pretty Hollow Creek	144	68	11.48	11.7	8.3	19.95	2.22
Lower Cataloochee Creek	147	71	14.8	14.72	10.5	18.6	1.77
Lower Little Cataloochee Creek	148	64	17.02	17.3	12.59	23.6	2.46
Cataloochee Creek at bridge	149	63	14.54	14.66	11	20.3	1.69
Mill Creek above Abrams Creek	173	74	17.35	23.55	11.3	122.7	19.86
Abrams Creek below Cades Cove	174	72	106.55	102.62	0.71	161.1	43.13
Sugar Fork above Little Fork	182	35	14	13.91	6.78	19.3	2.19
Hazel Creek above cascades	221	37	10.7	10.65	6.32	16.3	1.82
Hazel Creek below Proctor Creek	224	8	11.3	10.86	6.56	12.42	1.88
Walker Camp Prong above Alum Cave	233	72	24.3	24.45	16.6	35.3	3.45
Upper Road Prong	234	60	16.04	15.7	9.9	17.88	1.45
Walker Camp Prong at last bridge	237	74	20.55	20.57	16.73	26.3	2.15

Table 4.3.7.1 (continued). Descriptive statistics for specific conductance measured at 43 currently monitored sites in GRSM between 1993 and 2009. All measurements are listed in µS/cm.

Site Name	Site Number	N	Median	Mean	Minimum	Maximum	Standard Deviation
Beech Flats above	251	71	31.6	30.26	9.33	40.3	6.92
Beech Flats below roadcut	252	71	49.8	45.86	15.38	76.4	14.94
Beech Flats above roadcut	253	72	24.5	26.28	17.93	94.81	10.62
Oconaluftee River below Smokemont	268	73	41.22	40.51	18.86	63.52	7.94
Beech Flats at Kephart footbridge	270	28	12.88	12.95	11.35	14.84	1.03
Rough Fork at Caldwell House	293	73	16.63	16.68	12.39	19.85	1.77
Bone Valley Creek	310	42	12.57	12.81	6.72	19	2.31
Hazel Creek below Haw Gap Creek	311	41	11.8	11.98	6.64	17.5	1.86
Hazel Creek at campsite 86	479	37	11.84	11.9	6.64	18.5	2.12
Haw Gap Creek at bridge near campsite 84	480	37	13.5	13.55	6.75	19	2.26
Little Fork above Sugar Fork Trail	481	36	17.77	18.24	6.6	28.4	3.85
Sugar Fork above Haw Gap Creek	483	37	14.78	14.64	6.73	20.8	2.34
Hazel Creek at Cold Spring Gap Trail	484	36	10.66	10.87	6.6	16.9	1.64
Walker Creek above Hazel Creek trail	485	35	11.26	11.38	6.68	14.44	1.66
Mill Creek at Pumphouse on Forge Creek Road	488	60	12.19	12.25	7.8	16.4	1.54
Abrams Creek 300 m below trailhead bridge	489	57	84.5	88.75	18.15	142.2	30.12
Camel Hump Creek off Low Gap Trail 2	492	59	16.57	17.02	11.57	23.4	2.16
Palmer Creek at Davidson Branch Trail	493	55	12.19	13.04	9.6	27	2.76

Confidence and Data Gaps

There is a high degree of confidence in the described specific conductance conditions for stream waters within the park (Table 4.3.7.2).

Sources of Expertise

- Matt Kulp, Fisheries Biologist, Great Smoky Mountains National Park

Summary Condition

Table 4.3.7.2. Summary condition and trend graphic for water quality in GRSM, based on specific conductance.

Resource	Indicator	Status and Trend	Rationale and Reference Conditions
Water Quality	Specific conductivity of water (µS/cm)	↔	Conductivity values of stream waters are consistently below reference standard. Reference condition: based on regional data collected from “reference” basins.

4.3.8. Organic Acids

Relevance

Organic acids include a wide range of organic compounds that exhibit acidic properties, and that range in molecular weight from several hundred to about 2,000. Two of the most important organic acids include the less soluble humic acids and the more soluble fulvic acids. In natural waters organic acids tend to be yellow in color and are primarily derived from the decomposition of plant (and animal) materials. Organic acids can serve as important controls on stream water acidification, and some (e.g., fulvic acids) form metal complexes, which can increase the solubility of metals in natural waters. Previous studies also have shown that H^+ ions released from organic solutes following the decline in sulfate and nitrate deposition may decrease the rate at which stream waters can recover from acidification (Palmer et al. 2014).

Data and Methods

The concentration of organic acids is not routinely collected as part of the long-term, park-wide monitoring program, nor has it been collected as part of the monitoring program within the Noland Divide watershed. Thus, data are primarily restricted to a limited number of watersheds where specific studies were carried out by Cook et al. (1994) (Clingmans Creek, Walker Camp Prong, and three tributaries to Walker Camp Prong), Deyton et al. (2009) (Middle Prong of the Little Pigeon River, Ramsey Prong, and Eagle Rocks Prong), and Neff (2010) (Newt Prong, Road Prong, Rock Prong, Lost Bottom Creek, Jakes Creek, Eagle Rocks Prong, Cosby Creek, Palmer Creek, and Walker Camp Prong). With the exception of the work by Deyton et al. (2009), dissolved organic carbon (DOC) was used as a surrogate for organic acid concentrations (see section 4.3.9 below).

Reference Condition

No state or federal guidelines exist for the concentration of organic acids in natural waters. In fact, data pertaining to the concentration of organic acids in stream waters is limited primarily as a result of the difficulty inherent in its determination. The most common approach for determining organic acid concentrations is to access the charge balance discrepancy between selected anions and cations. Thus, its determination requires the analysis of a large set of parameters, some of which need to be estimated using chemical models (e.g., inorganic monomeric aluminum, Al_{IM}). The need for chemical modeling, and other factors, has made it challenging to compare data between studies and sites, as differences exist in the ions that are included in the charge balance calculations. Al_{IM}, for example, is commonly left out of the calculation due to the difficulty involved in its determination. In light of the above, most studies use alternative parameters (e.g., DOC) as a surrogate for organic acid concentrations in natural waters.

Data provided by Wellington and Driscoll (2004) for three sites within the Hubbard Brook Experimental Forest in New Hampshire provide a general reference for the concentrations that might be expected in GRSM. They found that the concentration of organic acids during three separate runoff events ranged from approximately 60 to 120 µeq/l and were higher during high flows.

Conditions and Trends

Deyton et al. (2009) measured and analyzed organic acid concentrations during both base flow and stormflow conditions at three sites within GRSM. Organic acid concentrations ranged from 9.63 to 11.74 µeq/l. The charge balance calculations used by Deyton et al. (2009) did not include Al_{IM}. Thus, estimated concentrations would be inherently lower than those presented by Wellington and Driscoll (2004), which did include Al_{IM}. Nonetheless, the large differences in organic acid concentrations between the two areas suggest that organic acid concentrations are significantly below those measured at Hubbard Brook.

Temporally, organic acid concentrations were higher during stormflows than base flows, particularly during events occurring while leaves were on. In fact, while variations existed between events, organic acids were found to be the dominant contributor to declines in ANC during five of the 15 monitored events. These data suggest that organic acids may play a significant role in the episodic acidification of streams in the park.

Confidence and Gaps

Data pertaining to organic acid concentrations are highly limited within the park. As a result, spatial and temporal trends are indeterminate (Table 4.3.8.1).

Sources of Expertise

- Matt Kulp, Fisheries Biologist, Great Smoky Mountains National Park

Summary Condition

Table 4.3.8.1. Summary condition and trend graphic for water quality in GRSM, based on organic acids.

Resource	Indicator	Status and Trend	Rationale and Reference Conditions
Water Quality	Organic acids, charge balance discrepancy (µeq/l)	◌	Limited data both within the park and nationally.

4.3.9. Dissolved Organic Carbon

Relevance

Dissolved organic carbon is an operationally defined term that refers to organic carbon in natural waters that can pass through a 0.45 µm filter. Such organic carbon can be subdivided into two broad categories: (1) non-humic substances consisting of carbohydrates, peptides, proteins, fats, and other types of low-molecular weight complexes, and (2) polymeric organic acids (humic substances) that range in molecular weight from about 1,000 to 2,000. Humic substances are typically dominant, comprising about 50-75% of the total dissolved carbon in natural waters (Thurman 2012). As a result, it is often used as a surrogate measure of the influx and quantity of organic acids in streams and rivers. Put differently, DOC is an indicator of the degree to which organic acids may affect surface water acidification. In addition, DOC plays a key role in the export of carbon from watersheds, and also is an important component in nutrient cycling, and increases the solubility of metals, including Al, in surface waters (both by decreasing pH and through the formation of organic complexes) (Gannon et al. in press).

Data and Methods

DOC is not routinely collected as part of the long-term, park-wide monitoring program, nor has it been collected as part of the monitoring program within the Noland Divide watershed. Thus, data are primarily restricted to a few individual studies carried out within a limited number of watersheds by Cook et al. (1994) (Clingmans Creek, Walker Camp Prong, and three tributaries to Walker Camp Prong), Deyton et al. (2009) (Middle Prong of the Little Pigeon River, Ramsey Prong, and Eagle Rocks Prong), and Neff (2010) (Newt Prong, Road Prong, Rock Prong, Lost Bottom Creek, Jakes Creek, Eagle Rocks Prong, Cosby Creek, Palmer Creek, and Walker Camp Prong). DOC will be added to the suite of metrics collected during annual vital signs water chemistry surveys in 2016.

Reference Condition

Streams generally have DOC concentrations ranging from about 1 to 10 mg/l (Thurman, 2012). For example, the EPA found that the median concentration of DOC at base flow within 92% of the streams studied as part of the Episodic Response Project ranged between 1.2 and 4.8 mg/l (although 20% exhibited concentrations greater than 4.0 mg/l) (Wigington et al. 1996). Undeveloped (more pristine) streams in basins without wetlands tend to have relatively low DOC concentrations, ranging from about 1 to 3 mg/l (Thurman 2012). This lower range of DOC values serve as target reference conditions for GRSM.

Conditions and Trends

Thirty-four measurements made during base flow conditions in eight watersheds (listed above) by Neff (2010) found that DOC concentrations ranged between 0.5 and 1.0 mg/l; the median DOC concentration was 0.75 mg/l. Observations by Cook et al. (1994) and Deyton et al. (2009) for base flow found that DOC concentrations could be slightly higher, reaching concentrations exceeding 3 mg/l. All three studies (Cook et al. 1994, Deyton et al. 2009, Neff 2010) found that in general, DOC was higher during stormflows than during base flow (Fig. 4.3.9.1). In addition, DOC measured within high-elevation sites tended to exhibit a higher DOC concentration than for lower elevation sites (Neff 2010).

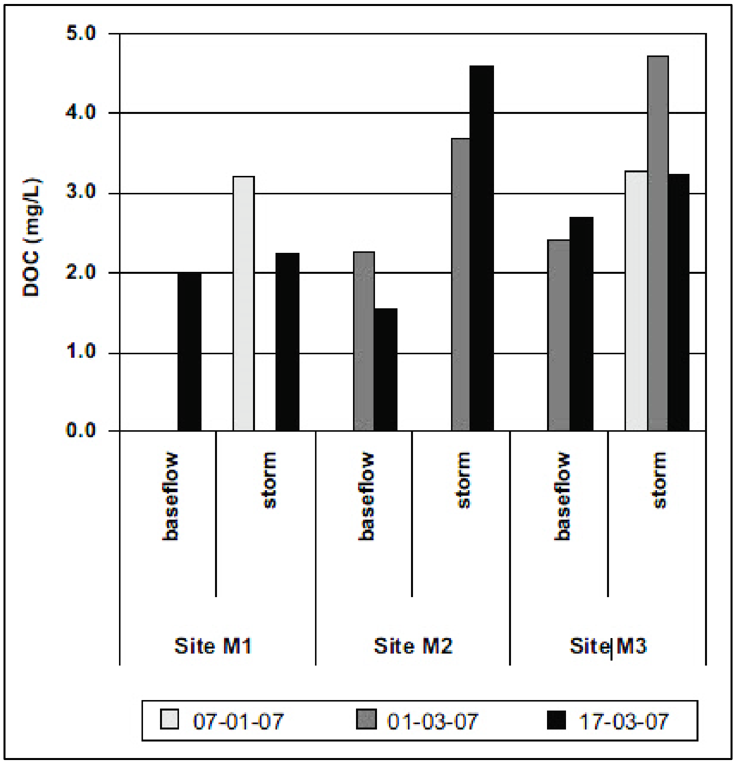


Figure 4.3.9.1. Differences in dissolved organic carbon (DOC) concentrations measured in base flow and stormflow for three sites within the park Source: Deyton et al. (2009).

The increase in DOC during runoff events is presumably related to the primary source of the dissolved carbon. A number of investigators have found that DOC is primarily derived from the movement of water through organic rich soil horizons within the riparian zone as water tables are elevated during precipitation events (Easthouse et al. 1992, Boyer et al. 1997, Inamdar et al. 2004, Winderdahl et al. 2011). DOC may also be derived from hillslope soils during runoff events (McGlynn and McDonnell 2003, Terajima et al. 2013, Ågren et al. 2014) as water tables rise into the organic-rich surface layers, or from hillslope soils that receive runoff from bedrock outcrops covered in organic matter (Gannon in press). Thus, the observed increases in DOC during stormflows within GRSM are consistent with the presumed sources of DOC. Regardless of the source, the data suggest that organic acids, as measured in terms of DOC, may contribute to episodic stream acidification during floods, in spite of the fact that the range of DOC values measured with GRSM during both base flow and stormflow are on par with those observed for undeveloped watersheds.

Confidence and Data Gaps

Data concerning DOC concentrations in stream waters are spatially and temporally limited within the park. Given the importance of organic acids in general, and DOC in particular, the addition of DOC to the monitoring program would, (1) increase our understanding of the role of organic acids in causing stream water acidification, particularly during runoff events, and (2) improve upon the ability to estimate concentrations of Al_{IM} concentrations in natural waters using chemical models (Schwartz et al. 2014).

Sources of Expertise

- Matt Kulp, Fisheries Biologist, Great Smoky Mountains National Park

Summary Condition

Table 4.3.9.1. Summary condition and trend graphic for water quality in GRSM, based on dissolved organic carbon.

Resource	Indicator	Status and Trend	Rationale and Reference Conditions
Water Quality	Dissolved organic carbon, carbon content in water passing through 0.45 µm filter (mg/l)	◌	Limited data collected during base and storm-flows suggest values are similar to those measured in relatively undisturbed basins. Reference condition: based on national data.

4.3.10. Toxic Metals

Relevance

At relatively high concentrations, metals and metalloids are toxic to aquatic biota and may affect water quality within the park. A metal of particular concern in acidic waters is aluminum (Al), as its solubility increases with decreasing pH (increasing acidity). Mercury (Hg) is considered a priority pollutant on a global scale, and is a pervasive contaminant of both aquatic and terrestrial ecosystems in the U.S. Although numerous sources of Hg exist, atmospheric deposition serves as an important, if not the predominant, source of Hg to many terrestrial and aquatic ecosystems. As described in Section 4.1.2, data collected at Elkmont, TN since 2002 show that total Hg wet deposition rates are well above background values, while average total Hg concentrations in precipitation are above the ecological threshold of $\leq$2 ng/l. These values indicate that Hg may also be of concern within aquatic water bodies of the park. With regard to other potentially toxic trace metals, recent studies in the southern Appalachians have shown that they may be derived from sulfide-enriched layers within bedrock units that underlie the region (Miller and Mackin 2013), including the Anakeesta formation which locally exists within the park. Thus, their analyses bear monitoring.

Data and Methods

Data pertaining to aluminum (Al), copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn) have been collected as part of the park-wide monitoring program since 2003. Less extensive data sets were developed for other metals, primarily before 1995, including arsenic (As), cadmium (Cd), chromium (Cr), lead (Pb), nickel (Ni), silver (Ag), and mercury (Hg). See Section 4.3.1 for additional information.

Reference Condition

The EPA Water Quality Criterion for Al in freshwater is 87 µg/l for chronic exposure, and 750 µg/l for acute exposure over a pH range of 6.5 to 9.0. The criteria represent the total recoverable Al within the waters (rather than the dissolved Al concentration). It should be noted, however, that the aqueous chemistry of Al is complex, as it can exist as free Al or form a number of inorganic and organic complexes (species), depending on a wide range of parameters including pH, temperature, DOC content, and the concentration of other ions and ligands.

The pH of the water acts as a particularly important control on its solubility and speciation (Howells et al.1983, Spry and Wiener 1991, Driscoll and Postek 1996). Aluminum is relatively insoluble under neutral pH conditions (6.0-8.0), but its solubility increases under acidic and alkaline conditions (pH <6 or >8), or where complexing ligands are present. Free Al and inorganic monomeric Al (Al_{IM}) are considered to be the most toxic chemical forms to fish and other aquatic biota (Gagen and Sharpe 1987). The toxicity of Al also is influenced by several factors, including the pH, calcium, base cation, and DOC content of the water. The effect of these external influences on both Al toxicity and solubility suggests that the universal applicability of the EPA criteria to the park may not be an appropriate reference condition to use herein. An alternative is to use the toxic threshold data, generated by a number of investigators, for trout and other fish species as well as for macroinvertebrates. Cai and Schwartz (2012), for example, reviewed the available literature and found that toxic effects occurred in salmonids (trout) and benthic macroinvertebrates at a concentration of >0.2 mg/l (200 µg/l) for both total dissolved Al and Al_{IM}. This value is consistent with investigations by Neff et al. (2009), who found that southern brook trout suffered physiological stress during acidic runoff episodes when Al_{TD} concentrations of 210, 202, and 202 µg/l were observed. Thus, 200 µg/l is used here as reference value.

With regard to other potentially toxic metals, Table 4.3.10.1 provides a comparison of the various water quality criteria that have been put forth by North Carolina, Tennessee, and the EPA, for metals of primary concern. With the exception of Fe, the utilized reference values are based on the freshwater maximum and continuous water quality criterion provided for fish and aquatic life by the Tennessee Department of Environment and Conservation (TDEC; 2007). Iron is based on the EPA and North Carolina guidelines.

Table 4.3.10.1. Comparison of state and federal water quality standards for selected metals. Criteria used are for freshwater and/or the protection of fish and aquatic life. See references (bottom of table) for variations in values related to water chemistry (e.g., hardness) and/or restrictions on criteria use.

Metal	North Carolina^A (total recoverable) (µg/l)	Tennessee^B (dissolved) (µg/l)	EPA^C (µg/l)
Arsenic (As)	50	340 (maximum); 150 (continuous) (for As III)	340 (acute); 150 (chronic)
Cadmium (Cd)	2	2 (maximum); 0.25 continuous); for hardness of 100 mg/l	2 (acute); 0.25 (chronic); for hardness of 100 mg/l

A. NC Freshwater standard (NCDENR 2007);

B. Standards for fish and aquatic life TDEC (2007), Chapter 1200-04-03;

C. National Recommended Water Quality Criteria EPA (2013).

Table 4.3.10.1 (continued). Comparison of state and federal water quality standards for selected metals. Criteria used are for freshwater and/or the protection of fish and aquatic life. See references (bottom of table) for variations in values related to water chemistry (e.g., hardness) and/or restrictions on criteria use.

Metal	**North Carolina^A (total recoverable) (µg/l)**	**Tennessee^B (dissolved) (µg/l)**	**EPA^C (µg/l)**
Copper (Cu)	7	13 (maximum); 9 (continuous) (for hardness of 100 mg/l)	Based on Biotic Ligand Model which requires 10 input parameters (temperature, pH, DOC, calcium, magnesium, sodium, potassium, sulfate, chloride, and alkalinity)
Chromium (Cr)	50	570 (maximum);74 (continuous); for Cr III at a hardness of 100 mg/l	570 (acute);74 (chronic); for Cr III at a hardness of 100 mg/l
Iron (Fe)	1000	–	1000
Lead (Pb)	25	65 (maximum); 2.5 (continuous) (for hardness of 100 mg/l)	65 (acute); 2.5 (chronic); for hardness of 100 mg/l
Manganese (Mn)	–	–	–
Mercury (Hg)	0.012	1.4 (maximum); 0.77 (continuous)	1.4 (acute); 0.77 (chronic)
Nickel (Ni)	88	470 (maximum); 52 (continuous) (for hardness of 100 mg/l)	470 (acute); 52 (chronic) (for hardness of 100 mg/l)
Silver (Ag)	0.06	3.2 (maximum); for hardness of 100 mg/l	3.2 (acute); for hardness of 100 mg/l
Zinc (Zn)	50	120 (maximum and continuous) (for hardness of 100 mg/l)	120 (acute and chronic) (for hardness of 100 mg/l)

A. NC Freshwater standard (NCDENR 2007);

B. Standards for fish and aquatic life TDEC (2007), Chapter 1200-04-03;

C. National Recommended Water Quality Criteria EPA (2013).

Conditions and Trends

Dissolved aluminum (Al) is of particular concern within the park due its relatively high potential toxicity in acidic waters. As a result, a number of investigations have examined the concentration of dissolved Al within GRSM, and its potential effects on aquatic biota (Huckabee et al. 1975, Deyton et al. 2009, Neff et al. 2009, Cai and Schwartz 2012, Neff et al. 2013). On a park-wide basis, Cai and Schwartz (2012) found that mean dissolved Al concentrations for both base flow and stormflow conditions were below the 0.2 mg/l reference value utilized herein (Table 4.3.10.2). However, dissolved Al locally and episodically reached values in excess of 0.4 mg/l at monitoring sites within the park, well above the 0.2 mg/l level cited as a potential criterion for biological effects. Thus, it appears that Al is currently a significant water quality concern within the park.

Significant variability in dissolved Al concentrations was observed both spatially within the park and temporally at any given monitoring station. The observed variability in Al concentrations correlated strongly with pH and ANC, presumably because the solubility of Al increases with decreasing pH. Thus, higher dissolved Al concentrations were generally found within higher elevation watersheds that tend to be characterized by higher rates of acid deposition, and lower pH and ANC. Cai and Schwartz (2012), using stream sensitivity maps for GRSM, demonstrated that the toxicological impacts of pH, ANC, and dissolved Al primarily exceed toxicological thresholds along higher elevation streams (Fig. 4.3.10.1). However, they also noted that seven mid-elevation locations that should have trout were predicted on the basis of stream chemistry to be devoid of fish.

Table 4.3.10.2. Summary of acid-base water chemistry collected at monitoring sites within GRSM, from 1993 to 2009 for Al, and 2003-2009 for the remaining metals. Source: Cai and Schwartz 2012.

Flow	Statistic	Al mg/l)	Cu (mg/l)	Fe (mg/l)	Mn (mg/l)	Zn (mg/l)
Base flow	Median	0.04	0.00	0.02	0.00	0.01
	Mean	0.06	0.01	0.02	0.01	0.02
	Std	0.06	0.01	0.03	0.03	0.03
	Minimum	0.01	0.00	0.00	0.00	0.00
	Maximum	0.45	0.11	0.23	0.26	0.16
Stormflow	Median	0.04	0.00	0.02	0.00	0.01
	Mean	0.06	0.00	0.02	0.01	0.02
	Std	0.06	0.01	0.02	0.05	0.03
	Minimum	0.00	0.00	0.00	0.00	0.00
	Maximum	0.41	0.08	0.10	0.38	0.16

Temporally, higher dissolved Al concentrations were observed at a given site during stormflow events when pH and ANC episodically declined (Deyton et al. 2009, Neff et al. 2009, 2013) (Fig. 4.3.2.2). The magnitude of the change in Al concentration during an event can be significant. Data collected between March 2006 and May 2007 at three monitoring sites within the Little Pigeon River watershed in GRSM showed that Al concentrations increased by approximately 0.1 mg/l during storm events (Deyton et al. 2009). Thus, trout could be episodically subjected to toxic levels of dissolved Al.

In terms of long-term temporal trends, concentrations appear to be stable, and are unlikely to change until pH and ANC within the stream waters recover. Recovery is likely to vary from site to site as demonstrated by mixed changes in Al concentration observed between monitoring stations. For instance, Cai and Schwartz (2012) found that changes in annual dissolved Al concentrations exhibited no statistical change between 1993 and 2009 at 67 of the 92 sites. Ten sites, however, exhibited decreasing annual dissolved concentrations over the same period (in the range of 0.005 to 0.51 mg/l), and one site exhibited an increase in dissolved Al concentrations over the monitoring period.

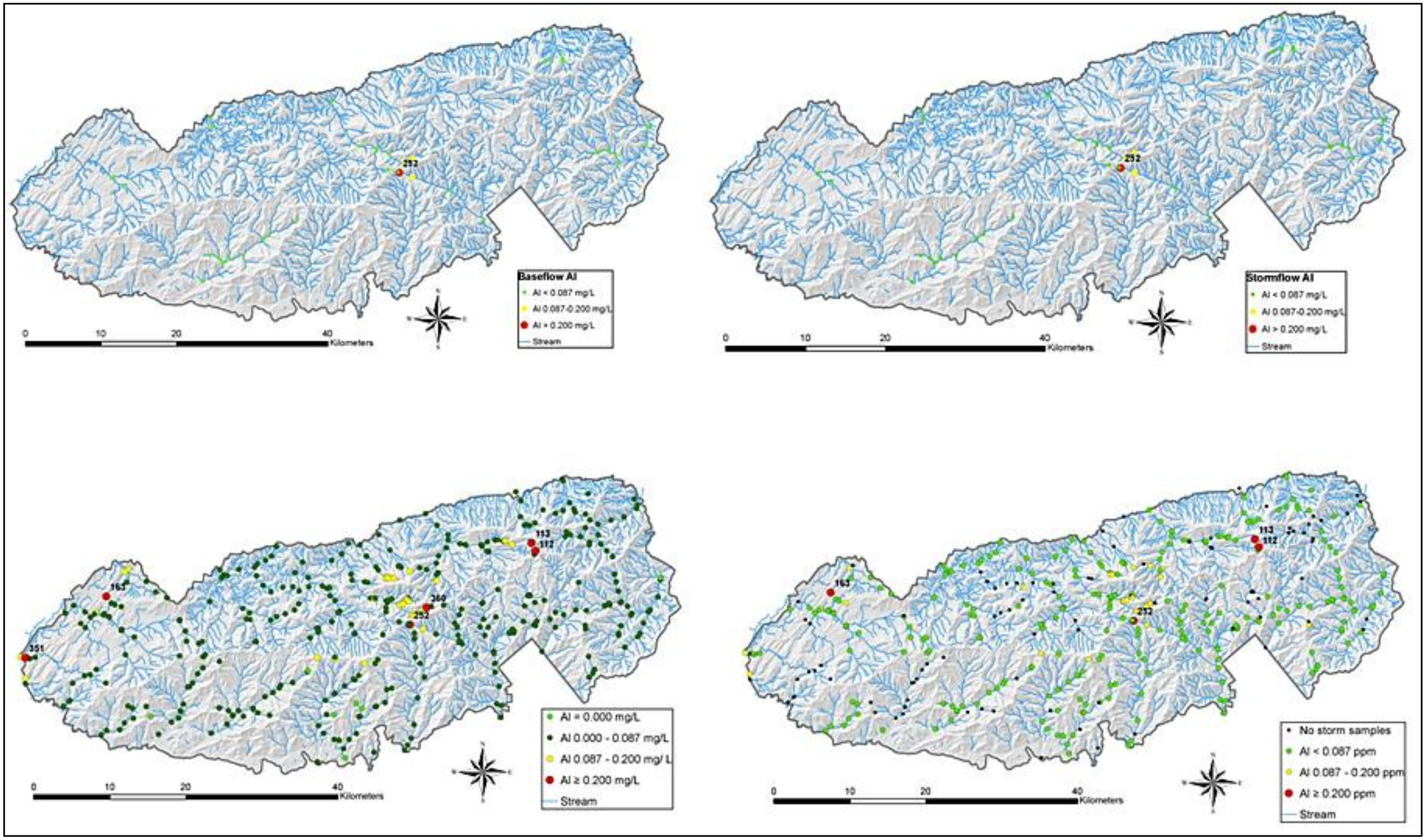


Figure 4.3.10.1. Sensitivity maps showing the median aluminum concentrations during base flow (left) and stormflow (right) conditions for the 43 currently monitored stream survey sites (upper) and the 387 historical sites (lower) in GRSM. Data were collected between1993-2009. Aluminum concentrations are presented in mg/l and are estimates computed by a multiple regression model using [H^+] and [$SO4^{2-}$] as predictors. Source: Cai and Schwartz 2012.

Data concerning the dissolved concentrations of other trace metals in stream waters within the park are primarily limited to Cu, Fe, Mn, and Zn. The concentrations of these elements from samples collected across all monitoring sites between 2003 and 2009 (Table 4.3.10.3) are generally below the threshold toxicity criteria cited in Table 4.3.10.1 (Deyton et al. 2009, Cai and Schwartz 2012). Data collected from 2003-2008 at the 43 currently-monitored sites were also examined. These sites (located within seven watersheds) are thought to provide the data necessary to characterize the current condition of stream waters within GRSM and to detect trends in stream water conditions through time (Odom 2003). Metal concentrations for these sites are also below the toxicity thresholds (reference values) (Table 4.3.10.1). In fact, the majority of the Cu and Zn values were below the detection limit, whereas more than 40% of the samples were below the detection limit for Fe and Mn.

Table 4.3.10.3. Descriptive statistics* for metal data collected at 43 sites in GRSM, monitored between 2003 and 2008.

Statistic	Cu	Fe	Mn	Zn
Median	0.030	0.028	0.144	0.018
Mean	0.038	0.086	0.483	0.142
Standard deviation	0.038	0.962	0.827	2.28
Minimum	0.012	0.002	0.002	0.008
Maximum	0.344	23.3*	4.40	51.71*
% Non-Detects	82.4	43.3	47.4	57.8

*Extreme outlier removed from data

Two drainages within the park possessing inactive copper mines (Eagle Creek and Hazel Creek) appear to exhibit Cu concentrations higher than those observed within other GRSM streams. These mines operated between approximately 1926 and 1944 and were closed when access roads to the mines were flooded by the closure of Fontana Dam. Visual observations suggest that acid mine drainage from the mines containing high metal concentrations may be of concern (Thornberry-Ehrlich 2008). For example, Sugar Fork, a tributary to Hazel Creek, drains tailings from the Hazel Creek mine, and mine tailings are visible along the channel. In addition, observations in 1992 and 2000 noted a lack of vegetation and aquatic biota for about 1 km (0.62 mi) downstream of the mines (Thornberry-Ehrlich 2008), and dissolved Cu concentrations along the axial channel of Hazel Creek (including Sugar Creek) are statistically different ($p<0.05$) from, and higher than, Cu measured at the remaining sites currently monitored within the park. Drainage from the Eagle Creek Mine to Eagle Creek is via an ephemeral channel, and the effects are less visible. Nonetheless, additional trace metal concentration data are needed for both drainages (NPS 2010).

Analyses of Cu, Fe, Mn, and Zn concentrations reveal no significant temporal trends between 2003 and 2009. However, Fig. 4.3.10.2 and 4.3.10.3 show that there was a significant increase in the range and maximum concentration of Fe and Zn in 2007 and 2008 when data from all 43 sites are considered. Currently insufficient data are available to determine if these values represent a longer-term trend or a statistical anomaly.

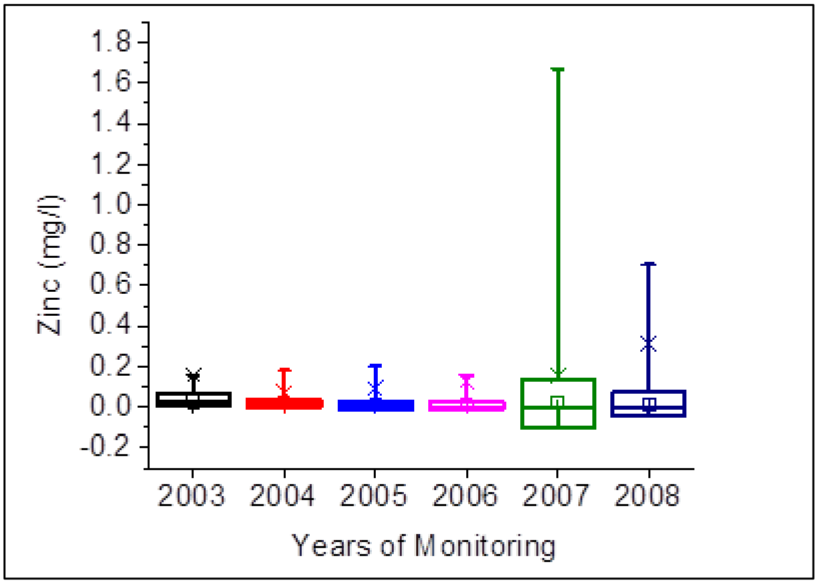


Figure 4.3.10.2. Zinc concentrations in Great Smoky Mountain National Park. Data from 43 surface water quality monitoring sites and arranged by year. An outlier (51.71 mg/l) was removed from the 2008 data.
* One standard deviation; whiskers are maximum and minimum values; small square is the mean; x's are the 1%.

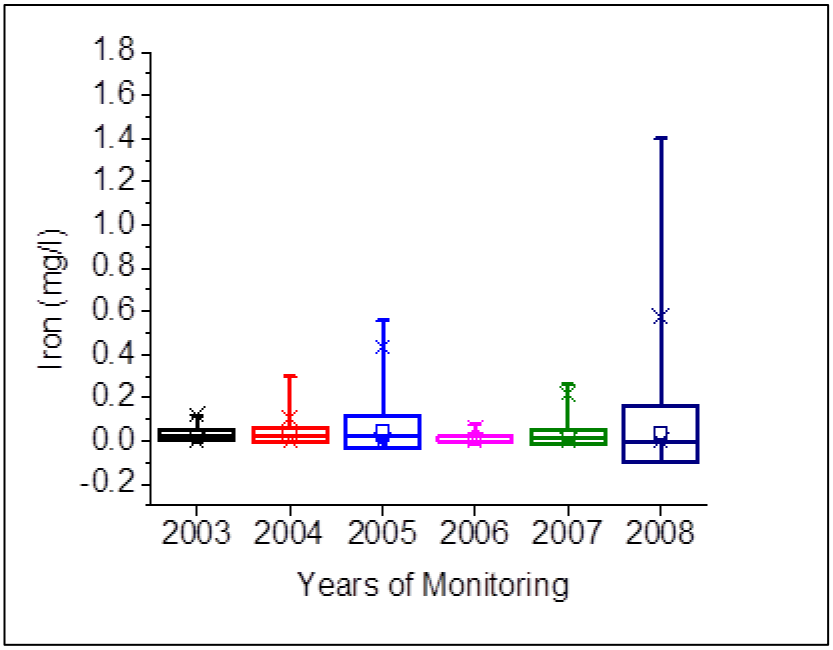


Figure 4.3.10.3. Iron concentrations in Great Smoky Mountain National Park. Data from 43 surface water quality monitoring sites and arranged by year. An outlier (23.37 mg/l) was removed from the 2008 data.
* One standard deviation; whiskers are maximum and minimum values; small square is the mean; x's are the 1%.

Additional trace metal data were summarized in the 1995 baseline water quality data inventory and analysis project within GRSM (NPS 1995) (Table 4.3.10.4). The data set includes monitoring sites both within and immediately adjacent to GRSM. While the data show that the drinking water and/or freshwater criteria were occasionally exceeded, no particular element was observed to consistently exceed threshold values. Trace metal concentrations often increase during flood events; therefore it is possible that the occasional measurements that exceed the criteria were collected during floods. However, available data do not allow for an assessment of the changes in metal concentrations during runoff events.

Table 4.3.10.4. Summary of water quality criteria compiled during the baseline water quality data inventory and analysis project within GRSM. Source: NPS 1995.

Parameter	Period of Monitoring	# of Observations (# Stations)	Drinking Water Standard (µg/l)	Drinking Water Standard # Exceeded	Freshwater Criterion: Standard (µg/l)	Freshwater Criterion: # Exceeded
Arsenic (As)	1970-1994	636 (31)	50	41	–	–
Cadmium (Cd)	1968-1994	374 (44)	5.0	7	3.9	9
Copper (Cu)	1967-1994	660 (72)	1,300	5	18	100
Chromium (Cr)	1967-1994	687 (47)	100	2	–	–
Iron (Fe)	–	–	–	–	–	–
Lead (Pb)	1967-1994	731 (45)	5	97	82	19
Manganese (Mn)	–	–	–	–	–	–
Mercury* (Hg)	1970-1994	691 (66)	2	6	2.4	6
Nickel (Ni)	1967-1994	461 (57)	100	13	–	–
Silver (Ag)	1968-1994	112 (25)	50	11	19	4.1
Zinc (Zn)	1967-1994	861 (74)	–	–	120	38

*Data quality suspect

Data pertaining to Hg concentrations in water are limited; however, GRSM is currently assessing Hg concentrations in water, sediment, and dragonfly larvae via a citizen science project (Eagles-Smith et al. 2013). Dragonfly larvae collected between 2011 and 2013, which presumably reflect the concentrations of bioavailable Hg stream waters, exhibited elevated levels of Hg at select sites in the park (Nelson and Flanagan Pritz 2014). In addition, there is a statewide advisory for the consumption of fish in North Carolina that results from elevated levels of Hg in fish tissues. This advisory includes Lake Fontana and other GRSM waters. The advisory sets recommendations on the frequency and amount of fish that should be consumed based on fish species and body weight to keep the amount of ingested Hg at a safe level. While temporal trends in Hg concentrations within park waters cannot be determined on the basis of the current data, the trend in wet mercury concentration in precipitation remained relatively unchanged between 2004 and 2013. Thus, it is unlikely that significant changes in Hg concentrations stream waters have or will occur.

Confidence and Gaps

With the exception of Hg, there is general a high degree of confidence in the metal concentrations documented within stream waters of the park (Table 4.3.10.5). However, the potential contribution of metals from bedrock containing sulfide minerals and from historic mining operations warrants further studies to determine their contribution to aquatic environments. Data concerning Hg concentrations and its biogeochemical cycling in stream waters are spatially and temporally limited within the park. Given the noted atmospheric deposition rates of Hg, modeled predictions of Hg methylation, the elevated concentrations of Hg in dragonfly larva, its potential impacts on aquatic and human health, additional studies of Hg within the aquatic environment are needed.

Sources of Expertise

- Matt Kulp, Fisheries Biologist, Great Smoky Mountains National Park

Summary Condition

Due to differences in the available data and potential toxic effects on aquatic biota, Al, Hg, and other trace metals are summarized separately.

Table 4.3.10.5. Summary condition and trend graphic for water quality in GRSM, based on levels of toxic metals.

Resource	**Indicator**	**Status and Trend**	**Rationale and Reference Conditions**
Water Quality	Dissolved aluminum concentration, aluminum in water passing through 0.45 µm filter (µg/l)	🔴⇔	Concentrations of dissolved aluminum frequently exceed the 200 µg/l reference value. Reference condition: based on review of toxic effects to biota by Cai et al. (2012).
Water Quality	As, Cu, Mn, Fe, Zn concentration, total and/or dissolved concentrations (µg/l)	🟢⇔	Concentrations of these metals rarely exceed the reference values. Reference condition: based on EPA and/or state guidelines.
Water Quality	Hg concentration, total and/or dissolved Hg (µg/l)	◌	Data within the park are limited. Reference condition: based on EPA guidelines.

4.3.11. Contaminants of Emerging Concern

Relevance

As defined by the EPA, contaminants of emerging concern (CEC) includes a wide range of compounds that (1) are not commonly monitored in the environment, (2) can potentially have negative effects on aquatic biota, and (3) have only recently been identified in natural waters, but which are likely candidates for future monitoring because of their potential ecotoxicity. This group of contaminants not only includes new chemicals that possess unknown environmental issues, but previously used (old) compounds (or their degradation products) that have only recently become a concern. Interest in these compounds is related to their somewhat ubiquitous occurrence in natural waters, and their potential to affect aquatic biota even at low concentrations.

Data and Methods

As a group, CECs have not been monitored within the park.

Reference Condition

CECs include a wide range of chemical substances including: (1) pharmaceuticals (e.g., antidepressants, blood pressure medicines, antibiotics, ibuprofen), (2) personal care products (sunscreens, insect protection products), (3) endocrine-disrupting chemicals (EDCs; e.g., synthetic estrogens and androgens, organochlorine pesticides, alkylphenols), and (4) nanomaterials (e.g., carbon nanotubes and particulate titanium dioxide) (EPA 2008). While federal or Tennessee aquatic life criteria for a few individual contaminants of emerging concern (mainly pesticides) exist, guidelines for the majority do not (EPA 2008). Given the wide and increasing range of chemical contaminants of emerging concern, and the lack of data that exist for them within the park, reference conditions for specific chemicals are not provided here.

Trends and Conditions

Water quality trends and conditions within the park cannot be determined for this group of chemicals given the lack of data currently available (Table 4.3.11.1).

Confidence and Data Gaps

Contaminants of emerging concern are released to the environment from a variety of sources. The source that has received the most attention is wastewater treatment plants (Barnes et al. 2002, Kolpin et al. 2002, Lietz and Meyer 2006, Vajda et al. 2007, Barber et al. 2015). Kolpin et al. (2002), for example, analyzed stream waters at 139 sites in 30 states that receive effluent from wastewater treatment facilities, and found that organic wastewater contaminants (including pesticides, pharmaceuticals, and personal care products) could be identified at 80% of the sites. The most abundant compounds were steroids, detergent metabolites, and plasticizers, and with regard to pharmaceuticals, nonprescription drugs. More recently, the ability of CECs to pass through wastewater treatment systems led Landewe (2008) to state that “it is reasonable to assume that most, if not all, national parks that have a WWTF (waste water treatment facility)….have CECs in their waterways, to which aquatic biota are being exposed and potentially affected.”

The atmospheric deposition of semivolatile organic compounds (e.g., PCBs, historic- and current-use pesticides like endosulfan sulfate, and PAHs) may represent another potential source of CECs. In fact, the ability of these compounds to be atmospherically transported and deposited has led to their occurrence in remote areas, including a number of national parks in the western U.S. (Landewe 2008, Flanagan Pritz et al. 2014). Previous studies have shown that depositional rates vary as a function of elevation, the quantity and type of precipitation, snowpack accumulation, altitude, latitude, and proximity to their source (e.g., agriculture) (Daley and Wania 2005, Hagenman et al. 2010, Flanagan Pritz et al. 2014). The accumulation of these semivolatile CECs appear to be particularly high in cold, mountainous, and circumpolar regions (Wania and MacKay 1993, Daly and Wania 2005). The atmospheric deposition of these CECs in GRSM may be promoted by an abundance of precipitation (precipitation scavenging), especially at high elevations. Other potential sources of CECs within the park may include the input of personal care products (e.g., sunscreen, fragrances, DEET) by swimmers, anglers, etc., and various natural sources (Landewe 2008). Given the potential for CECs to exist within GRSM stream waters, a reconnaissance survey of CECs should be undertaken in the park.

Sources of Expertise

- Matt Kulp, Fisheries Biologist, Great Smoky Mountains National Park

Summary Condition

Table 4.3.11.1. Summary condition and trend graphic for water quality in GRSM, based on various contaminants of emerging concern.

Resource	Indicator	Status and Trend	Rationale and Reference Conditions
Water Quality	Various chemicals, dissolved concentration (µg/l)	◌	Data within the park are lacking. Reference condition: EPA and/or Tennessee guidelines exist for a few contaminants in this class; no guidelines exist for a majority.

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4.4. Invasive Species

Invasive species are identified as one of the five major threats to global biodiversity, the others being: habitat change, exploitation, nutrient loading/chemical pollution, and climate change (CBD 1992). The seriousness of the impact of invasive species in the U.S. resulted in Executive Order 13112 (1999) that, among other actions, established the National Invasive Species Council (NISC), whose members are the heads of 13 federal departments and agencies. The NISC provides high-level coordination to ensure that federal programs and activities are coordinated, effective, and efficient (NISC 2015). The council is chaired by the Secretaries of Interior, Agriculture, and Commerce, and it has an advisory committee made up of members from outside the federal government that focuses on specific issues for the council to consider (NISC 2015).

Management Policies of the NPS (2006) are explicit about the difference between native and exotic species, and how invasive exotics are to be managed:

> *Native species are defined as all species that have occurred, now occur, or may occur as a result of natural processes on lands designated as units of the national park system. Native species in a place are evolving in concert with each other. Exotic species are those species that occupy or could occupy park lands directly or indirectly as the result of deliberate or accidental human activities. Exotic species are also commonly referred to as non-native, alien, or invasive species. Because an exotic species did not evolve in concert with the species native to the place, the exotic species is not a natural component of the natural ecosystem at that place."* (NPS 2006, excerpt from section 4.4.1.3)
>
> *All exotic plant and animal species that are not maintained to meet an identified park purpose will be managed—up to and including eradication—if (1) control is prudent and feasible, and (2) the exotic species … interferes with natural processes and the perpetuation of natural features, native species or natural habitats, disrupts genetic integrity of native species…"* (Five other itemized

circumstances follow, relevant to cultural resources, park operations, health and safety). *"High priority will be given to managing exotic species that have, or potentially could have, a substantial impact on park resources, and that can reasonably be expected to be successfully controlled."* (NPS 2006, excerpt from section 4.4.4.2).

4.4.1. Non-native Invasive Plants

Relevance

Non-native invasive plants (NNIP), with regard to GRSM, are those that are not native to the park, but that will survive and spread if introduced into the park. Although many non-native plants are relatively innocuous, some species are more aggressive and can invade semi-natural and natural areas, causing harm to the natural vegetation structure. If left unchecked, these NNIP species may negatively impact key ecological processes by reducing native species richness and altering plant community structure (Schofield 1989, Hobbs et al. 1992, Kourtev et al. 2002). Some park resources that are particularly vulnerable to NNIP invasions include rare native plants, wetlands, riparian zones, cultural landscapes, aquatic communities, visual resources, and soils. The park's varying topography, geology, and soils create diverse habitats for a wide array of exotic plant species. The park's climate is similar to parts of Europe and Asia, and plants introduced from these areas thrive in the park's environment in the absence of natural competitors. Historic land disturbances, including settlement, logging, farming, and wildfire, have created a heterogeneous distribution of exotic species throughout the park. This makes it difficult to identify where damaging populations exist and how best to treat them. Key challenges to mitigating NNIP include adequate funding, and collaborating with the thousands of landowners who border the park and whose lands are a continual source of exotic plants. Finally, some exotic invasive species are so ubiquitous that control under current conditions may not be feasible.

Data and Methods

Data used in this assessment include a prioritized list of invasive species that are managed by park resource managers (Table 4.4.1.1). The park's list is based on the 2014 Tennessee Exotic Pest Plant Council's ranking of invasive exotic plant species, which is based on the invasive characteristics of each species.

Table 4.4.1.1. Non-native invasive plant species of concern at Great Smoky Mountains National Park. Data source: GRSM 2014.

Category*	Common Name	Scientific Name	Susceptible Habitats
1	Tree of heaven	*Ailanthus altissima*	Urban areas, cultivated fields, roadsides, natural areas
1	Mimosa, silk tree	*Albizia julibrissin*	Roadsides, vacant lots, natural areas, including streambanks
1	Garlic mustard	*Alliaria petiolata*	Natural areas, roadsides, trail edges floodplains, streambanks, and forest edges and interiors
1	Oriental bittersweet	*Celastrus orbiculata*	Old homesites, forest edges, hedgerows, fields, disturbed woodlands, roadsides
1	Chinese yam, cinnamon vine	*Dioscorea batatas*	Roadsides, stream banks, drainage ways, old homesites, other disturbed areas
1	Autumn olive	*Elaeagnus umbellata*	Natural areas, forest openings, open forests, roadsides, pastures, grasslands, disturbed areas
1	Climbing euonymus	*Euonymus fortunei*	Natural areas
1	English ivy	*Hedera helix*	Undisturbed and disturbed forests
1	Bush clover	*Lespedeza cuneata*	Fields, meadows, marshes, pond borders, woodlands, roadsides
1	Common privet hedge	*Ligustrum vulgare*	Roadsides, fencerows, bottomlands, low woods, streamsides, disturbed areas
1	Japanese honeysuckle	*Lonicera japonica*	All types of forests and fields, forest margins, rights-of-way, other disturbed areas
1	Bush honeysuckle	*Lonicera maackii*	Old homesites, disturbed forests, urban/suburban woodlands
1	Purple loosestrife	*Lythrum salicaria*	Wetlands, stream and river banks, lake shores, ditches, disturbed moist areas
1	Japanese grass	*Microstegium vimineum*	Natural areas, disturbed shaded floodplains, utility corridors, lawns, gardens, roadside ditches
1	Princess/empress tree	*Paulownia tomentosa*	Roadsides, disturbed natural areas including forests, streamsides, steep rocky slopes
1	Japanese knotweed	*Polygonum cuspidatum*	Riparian and wetland habitats,
1	Multiflora rose	*Rosa multiflora*	Roadsides, pastures, wetlands, other non-forested areas

*Category: 1: invasive, aggressive, capable of displacing native species and noxious to native plant communities. Exhibits rapid spread from localized communities; eradication unlikely once established. 2: same as category 1 except eradication is possible with considerable labor resources. 3: less invasive, aggressive, and capable of displacing native species than categories 1 and 2; distribution is variable but typically localized. Source: TNEPPC 2014.

Table 4.4.1.1 (continued). Non-native invasive plant species of concern at Great Smoky Mountains National Park. Data source: GRSM 2014.

Category*	Common Name	Scientific Name	Susceptible Habitats
1	Kudzu	*Pueraria montana*	Roadsides, old fields, forest edges, sunny disturbed areas
1	Johnson grass	*Sorghum halepense*	Agricultural fields, open forests, old fields, ditches, stream banks
1	Japanese spiraea	*Spiraea japonica*	Streamsides, riversides, forest edges and openings, old fields, roadsides, utility rights-of-way
2	Burdock	*Arctium minus*	Roadsides and waste areas
2	Japanese barberry	*Berberis thunbergii*	Closed canopy forests, open woodlands, pastures, meadows
2	Field mustard	*Brassica napus*	Throughout temperate climates
2	Musk thistle	*Carduus nutans*	Disturbed areas, roadsides, grazed pastures, old fields, native grasslands
2	Spotted knapweed	*Centaurea biebersteinii*	Open areas, roadsides, disturbed areas
2	Brown knapweed	*Centaurea jacea*	Open fields, roadsides, woodlands, disturbed areas
2	Canada thistle	*Cirsium arvense*	Open mesophytic areas, disturbed areas, agricultural land, roadsides, ditches, overgrazed pastures
2	Bull thistle	*Cirsium vulgare*	Meadows, disturbed areas, roadsides, drainage ditches, open forests
2	Leatherleaf clematis	*Clematis terniflora*	Roadsides, thickets, woodland edges, forests
2	Crown vetch	*Coronilla varia*	Roadsides, rights-of-way, open fields, waste areas, stream gravel bars
2	Burning bush	*Euonymus alata*	Forests, coastal scrublands, prairies
2	Tall fescue	*Festuca pratensis*	Abandoned fields, meadows, pastures, roadsides, grazed woods, stream banks, open natural communities
2	Hydrilla	*Hydrilla verticillata*	Reservoirs, lakes, ponds, slow moving streams and rivers
2	Bicolor lespedeza	*Lespedeza bicolor*	Fields, open woodlands, clearings, fence and hedgerows, roadsides, natural areas
2	White sweet clover	*Melilotus alba*	Grasslands, wildfire areas
2	Miscanthus	*Miscanthus sinensis*	Fields, disturbed sites
2	Brazillian watermilfoil	*Myriophyllum aquaticum*	Lakes, ponds, slow moving streams
2	White poplar	*Populus alba*	Forest edges, fields

*Category: 1: invasive, aggressive, capable of displacing native species and noxious to native plant communities. Exhibits rapid spread from localized communities; eradication unlikely once established. 2: same as category 1 except eradication is possible with considerable labor resources. 3: less invasive, aggressive, and capable of displacing native species than categories 1 and 2; distribution is variable but typically localized. Source: TNEPPC 2014.

Table 4.4.1.1 (continued). Non-native invasive plant species of concern at Great Smoky Mountains National Park. Data source: GRSM 2014.

Category*	Common Name	Scientific Name	Susceptible Habitats
2	Bulbous buttercup	*Ranunculus bulbosus*	Lawns, pastures, open fields, grasslands
2	Coltsfoot	*Tussilago farfara*	Roadsides, streamside gravel bars, disturbed ground
2	Common mullein	*Verbascum thapsus*	Pioneer species colonizing roadsides, pastures, woodland margins
2	Common periwinkle	*Vinca minor*	Old homesites
2	Large periwinkle	*Vinca major*	Old homesites, suburban woodlands
2	Wisteria	*Wisteria floribunda*	Forest edges, roadsides
3	Winter-cress	*Barbarea vulgaris*	Moist areas, roadsides, stream banks, hedges
3	Paper mulberry	*Broussonetia papyrifera*	Waste areas, disturbed thickets
3	Chickory	*Cichorium intybus*	Roadsides, grasslands, fence rows, waste ground, lawns, fields, pastures
3	Orange-red hawkweed	*Hieracium aurantiacum*	Moist pastures, forest openings, abandoned fields, clearcuts, roadsides
3	European watercress	*Nasturtium officinale*	Slow flowing streams, wet creek banks, lake margins, marshes, roadside ditches, seeps
3	Canarygrass	*Phalaris canariensis*	Disturbed areas
3	Bamboo	*Pseudosasa japonica*	Moist well-drained soils
3	Wineberry	*Rubus phoenicolasius*	Fields, roadsides, various edge habitats, floodplain forests, upland grasslands, shale bluffs
No Assigned Category	Climbing euonymus	*Euonymous fortunei*	–
No Assigned Category	Lesser celandine	*Ficaria verna*	–

*Category: 1: invasive, aggressive, capable of displacing native species and noxious to native plant communities. Exhibits rapid spread from localized communities; eradication unlikely once established. 2: same as category 1 except eradication is possible with considerable labor resources. 3: less invasive, aggressive, and capable of displacing native species than categories 1 and 2; distribution is variable but typically localized. Source: TNEPPC 2014.

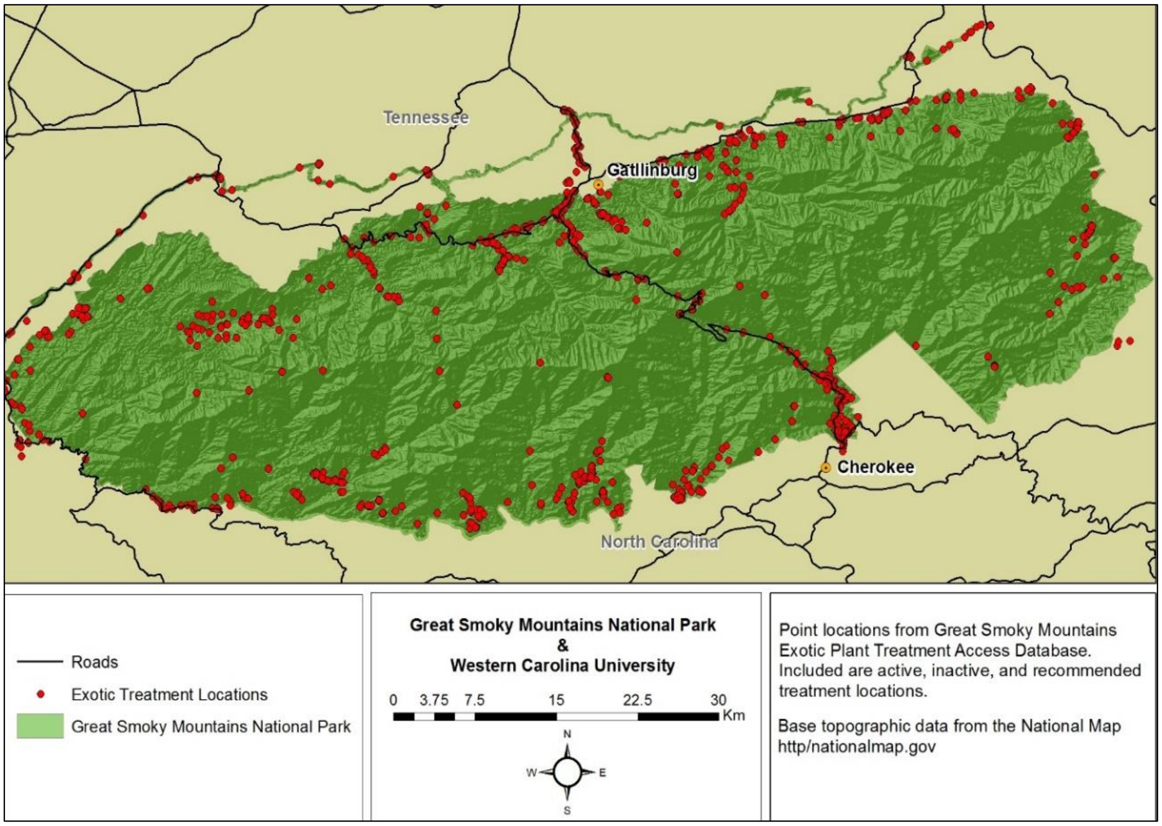
Reference Conditions

Ideally, no NNIP species would be present in the park. However, the extreme difficulty of controlling their entry, as well as locating and treating all populations across the park's extensive and varied terrain, makes their complete elimination impossible. Therefore, the reference condition will be defined as maintaining NNIP species at manageable and non-damaging levels.

Conditions and Trends

Approximately 380, or 20%, of the vascular plant species found in the park are non-native. Many of these plants are found in disturbed areas, such as roadsides, areas of past wildfire, construction sites, and on old home sites. The park has identified 53 NNIP that are of concern to resource managers (Table 4.4.1.1). These species are categorized based on significance of impact and feasibility of control. They have been identified as invasive enough to displace native plant communities, hybridize with native plants, or interfere with cultural landscapes (NPS 2014).

The GRSM Exotic Plant Management Plan (2014) outlines policies and rationale for controlling NNIPs. Currently, there are over 1,200 treatment locations (Fig. 4.4.1.1), where park staff and volunteers employ a variety of methods to remove or control the spread of NNIPs, including mechanical cutting, hand-pulling, and selective use of herbicides. Treatment is extremely labor-intensive, with many sites in remote, rugged areas where equipment must be carried in. There are many challenges in the management of non-native invasive species, but over the years, these efforts have successfully managed or even eliminated invasive plants at many sites.



Point locations from Great Smoky Mountains Exotic Plant Treatment Access Database. Included are active, inactive, and recommended treatment locations.

Base topographic data from the National Map http/nationalmap.gov

Figure 4.4.1.1. Locations where exotic plant species are being treated in GRSM. Source: NPS 2014.

The vectors by which NNIPs enter the park are numerous and varied, and while little can be done to prevent them from being carried inside the park boundaries by wind, streams, and visitors, the park works diligently to prevent their entry. For example, the park has had some success working with adjacent landowners to control their own exotics, and in the case of construction projects, all materials must be inspected for seeds before entering the park, and cooperation between contractors and facility management staff is necessary to prevent introductions in fill dirt, quarry material, and hydroseeding. A continuous and vigilant monitoring program is necessary for the effective management of NNIP species in the park. We assign a moderate level of concern with a stable condition to this resource.

Confidence and Data Gaps

Park resource managers have a well-established exotic invasive plant species management program and every effort to control and manage these plants is being used. Therefore, we assign a high confidence to this assessment (Table 4.4.2). Data gaps include a complete inventory of all NNIP species populations within the park.

Sources of Expertise

- Kristine Johnson, Supervisory Forester, Great Smoky Mountains National Park

Summary Condition

Table 4.4.1.2 Summary condition and trend graphic for non-native invasive plants in GRSM.

Resource	Indicator	Status and Trend	Rationale and Reference Conditions
Invasive Species	Presence of non-native invasive plant species	⇩	Reference condition is defined as maintaining NNIP species at manageable and non-damaging levels. There are serious challenges to preventing the introduction of NNIP species into the park, and identifying and treating all existing populations.

4.4.2. Non-native Invasive Animals

Relevance

Invasive animals are one of the leading threats to native wildlife. Approximately 42% of threatened and endangered animals are at risk due to invasive animals, which can cause harm in many ways. An invasive animal has the ability to thrive and spread aggressively outside of its native range, often without any predators or other controls. Native wildlife may not have evolved any defenses against invasive species, or they cannot compete for food resources. Invasive animals also may introduce new diseases to an area that they are invading. Indirect threats include alteration of food webs, decreasing biodiversity, and altering ecosystem conditions. Invasive exotic species include all taxa of organisms and are recognized as one of the major drivers in losses of biodiversity in natural areas (NPS 2015a).

Data and Methods

There are usually many species that can be found in a landscape that are not indigenous to that ecosystem and are therefore referred to as “exotic;” however, not all exotics are invasive. To be an invasive exotic, the species must present the potential to cause “environmental harm” (NISC 2006), which in the context of a national park would mean a significant disruption in natural processes, or impacts on native species, principally in the natural areas of the park. Intact, functioning natural ecosystems are usually somewhat resistant to new biological invasions (Elton 1958), but increasing numbers of exotic animal species are successful invaders.

Species included in this section are exotic and also have a demonstrated capacity to invade natural areas of the park. Exceptions are invasive exotic forest insects, which are discussed in other sections of the NRCA. Additionally, there are many other exotic invertebrates which have been discovered in the park but are not encountered frequently enough to indicate that they are a significant concern at this point. These types of species (e.g., red imported fire ants [*Solenopsis invicta*]) are overwhelmingly found in disturbed sites in the park. If any of these species begin to invade and persist in natural zones in the future, they should be included in any future analyses.

The following exotic animal species are, or have the demonstrated potential to be, significant invasive exotics in Great Smoky Mountains National Park:

Wild hog (Sus scrofa)

European wild hogs are native to Eurasia but were accidentally released from a private hunting reserve south of the park early in the 20th century. They appeared in the park for the first time in the late 1940s (Pivorun et al. 2009). They are opportunistic feeders on plant tubers, insects, amphibians, reptiles, carrion, and worms, and will root up grassy balds, wetlands, and cultural zones in the park (Pivorun et al. 2009).

The park began control efforts in the late 1950s, but by the 1970s and 1980s there were estimated to be as many as 3,000 wild hogs (Pivorun et al. 2009). Control efforts received higher priority in the late 1980s and the estimated population is now believed to be stabilized at a much lower level, perhaps 400-600 (Pivorun et al. 2009). These levels are maintained by trained resource management personnel who trap and shoot the hogs.

Sensitive ecological areas, especially wetlands, continue to sustain intensive soil disturbance from groups of hogs (T. Evans, pers. comm 2015.). Recently there has been concern about the repeated illegal re-introduction of hogs in the western area of the park by unknown hunting groups. These clandestine actions appear to have also introduced hog pseudorabies, a herpes-type virus whose symptoms mimic those of rabies (Cavendish et al. 2008). While there are some concerns about this contagion affecting native wildlife, state authorities have expressed great concern that this new virus could spread to the commercial pork industry, of which North Carolina is a national leader.

Rainbow trout (Oncorhynchus mykiss) and Brown trout (Salmo trutta)

Before the park was established in the 1930s, most of the forests had been cut during industrial-scale logging starting around 1900 (Brown 2000). Both logging and agriculture degraded water quality, which in turn greatly reduced native brook trout to the point that logging companies began stocking rainbow trout (from the western U.S.) and European brown trout to “improve” the fishing (Brown 2000). These two species subsequently invaded most of the lower elevation stream reaches in the Smokies. Since fishing was popular with recreationalists in the new national park, stocking with the exotics continued after the park was established and until the 1970s. Meanwhile, the native brook trout was displaced by the larger and more competitive rainbow and brown trout. The brook trout was relegated to the smaller headwater streams, mostly above 910 m (3,000 ft) elevation (NPS 2015b), and it is estimated that they lost about 75% of their original stream distribution in the park since about 1900. The rainbow and brown trout species often occur together in streams; and occasionally also with brook trout in some upper stream reaches (NPS 2015b).

In recent years, park fisheries staff have removed rainbow and brown trout from select streams. This is done in areas where there are barriers, such as waterfalls, to upstream movement of exotic trout. They use electro-fishing techniques, sometimes in conjunction with specialized biocides. Rainbow and brown trout have now been removed from 23 km (14 mi) of stream so that brook trout may be re-patriated there. With about 80% of the park's streams inventoried for trout, brook trout now inhabit 323 km (201 mi) of stream, of which 183 km (113 mi) are inhabited without the non-native trout species. Rainbow trout now occupy 569 km (354 mi) of the park's streams, whereas the brown trout occupies 172 km (107 mi).

European honey bee (Apis mellifera)

These familiar bees are highly valued in society as pollinators of agricultural crops and producers of commercial honey. There are several geographic races from Europe and Africa in eastern North America; all are exotic. They are also highly invasive, not only in agricultural landscapes but throughout the well-forested park.

Charismatic to the general public, the honey bee is not usually visualized as an invasive species that causes harm to the natural environment. However, honey bees have had an immense impact on local native pollinators, due to their large colonies (up to 40,000-60,000 bees; MAAREC 2015), and their well-known ability to rapidly communicate the location of nectar sources and swamp them with foragers from their hive (Buchman and Nabhan 1996). Honey bees do not show much aggression to one another at nectar or pollen sources; instead they use their energy in "scramble competition" to collect resources, and by their sheer numbers are able to dominate the most desirable nectar patches. Native bees and other pollinators are thereby relegated to less productive patches (Buchmann and Nabhan 1996).

The park has over 200 species of native bees, most of which are solitary, although some (e.g., bumble bees) form small colonies. In addition, there are many other pollinators in several other insect orders (B. Nichols, pers. comm.).

Multicolored Asian lady beetle (Harmonia axyridis) and Seven-spotted lady beetle (Coccinella septempunctata)

These brightly colored lady beetles have been introduced into the U.S. on multiple occasions as biocontrol agents for aphids. The multicolored Asian lady beetle, native to Japan, was first introduced in the U.S. starting around 1916 (ARS 2015). It has since spread over much of the U.S. and Canada (ARS 2015), and is now found throughout the park, including in old-growth forests and from lower elevations to the Clingmans Dome summit. This species often becomes a nuisance to homeowners in autumn when large numbers of beetles try to seek shelter in homes (ARS 2015).

The seven-spotted lady beetle, or C-7, is native to Europe and parts of Asia and was also introduced into the U.S. purposefully for aphid control, from 1951 to 1971 (EOL 2015). These introductions were not thought to be successful; however, a thriving population of unknown origin was found at the Meadowlands, New Jersey in 1973. From there, it rapidly spread across the U.S. and Canada (EOL 2015).

Several native North American species of lady beetle have declined precipitously with the introduction of the voracious exotic invasive lady beetles (Gardiner et al. 2011). The native nine-spotted lady beetle (*Coccinella novemnotata*) declined abruptly in the 1980s and was not seen in the eastern U.S. from 1992 until 2006, when a few were discovered in the suburban Washington DC area. This was formerly a very common species in the east and there are early records from the park, but none for several decades. Apparently these native lady beetles have been lost or are being ecologically suppressed; their status is currently unknown. It is possible that the park, with its large expanse of forest and very high elevations, affords the nine-spotted and other declining native species, specialized or isolated habitats where they still may occur.

Japanese rock pool mosquito (Aedes japonicus japonicus)

A very recent invasive exotic to the park, this mosquito was not known in the U.S. until the 1990s, but it has since invaded much of eastern North America (Kaufman and Fonseca 2014). It is an aggressive, cold-tolerant species that is a daytime and crepuscular feeder on mammals and birds. It appears to prefer forested environs and breeds in rock holes along streams and sometimes in tree holes or containers. It is considered a highly competent vector for West Nile virus, Japanese encephalitis virus, and St. Louis encephalitis virus, and a moderately competent vector for eastern equine encephalitis virus and La Crosse encephalitis virus. Field-collected Japanese rock pool mosquito larvae in east Tennessee have been confirmed as being hosts for La Crosse virus (Westby et al. 2011).

Native mosquito larvae can sometimes out-compete or prey upon larvae of other species; however, the Japanese rock pool mosquito tends to out-compete native larval mosquitoes (Kaufman and Fonseca 2014) in the limited number of rock holes available. This species has not been established long enough in the park to fully understand its distribution, ecological relationships, or impact as a disease vector. It is possible that it could become a significant carrier for West Nile virus or other diseases impacting humans, other mammals, or birds, and thereby possibly have other far-reaching effects on ecological systems in the park.

Asian jumping earthworm (Amynthas agrestis)

This earthworm is a large species (Fig. 4.4.2.1) that vigorously wiggles and jumps when initially handled, and it lives principally in the organic layers of the soil-humus interface, rather than in the mineral soil horizons. It was apparently brought to the U.S. from Asia as bait for fishing.

Figure 4.4.2.1. Image of *Amynthas agrestis*. The broad beige band of the clitellum is a useful character for this species. Source: Anita Juen, University of Innsbruck.

In established populations, Asian jumping worms consume most of the partially-decomposed organic layers on the forest floor, so that when the most recently fallen leaves are brushed away, only a layer of worm fecal pellets remain. The decrease in the organic layer has been found to decrease native millipede species' diversity and abundance (Snyder et al. 2013). This is a concern for the rich millipede fauna (~70 species) of the park, and a host of other native invertebrates (Snyder et al. (2013).

Reynolds (1978) sampled 1,600 sites in Tennessee in his statewide survey of earthworms but found *A. agrestis* at only 16 sites, eight of which he classified as refuse dumps. But Callaham et al. (2003) found this Asian exotic at numerous places in northern Georgia in 2002; alarmingly, it was found in relatively undisturbed soils and at upper elevations. Juen (2010) studied the ecological relationships between soil organisms and *A. agrestis* in the park, and documented populations of *A. agrestis* in the following areas: Tremont, Elkmont, Little River Road, Sugarlands VC area, Twin Creeks, Old Sugarlands trail, Greenbrier, Huskey Gap trail and Deep Creek.

Coyote (Canis latrans)

Coyotes are canids native to the American southwest, but they have expanded their range eastward. Their expansion is thought to have occurred mainly through natural dispersal, once the gray wolf (*Canis lupus*) and red wolf (*Canis rufus*) populations were decimated by control actions in the latter part of the 19th and early 20th centuries (Pivorun et al. 2009). The first coyotes were documented in the park in ca. 1982 and their numbers appear to be gradually increasing; they currently are found park-wide, but probably in greater numbers near open areas and edges (Pivorun et al. 2009).

Though coyotes are technically not native to the park, they have not been suppressed in the park like some other exotic species; instead park management views them as a species that arrived quasinaturally and is filling an important vacant ecological position as a mid-sized predator. Nevertheless, coyotes are known to kill or competitively drive off red foxes and probably other similar sized predators, although the presence of prey species may influence these competitive interactions (Gese et al. 1996).

Green tree frog (Hyla cinerea)

This frog is a very recent invader into the Cades Cove area of the park, but it is native to the eastern forest biome in regions east, south, and west of the park (Fig. 4.4.2.2). Asper (2015) has studied this newly-arrived amphibian, and in just a few years it has apparently spread to several wetlands and probably has a population of several thousand animals. The park is concerned about its impact on the dozen or more anurans native to the Cove.

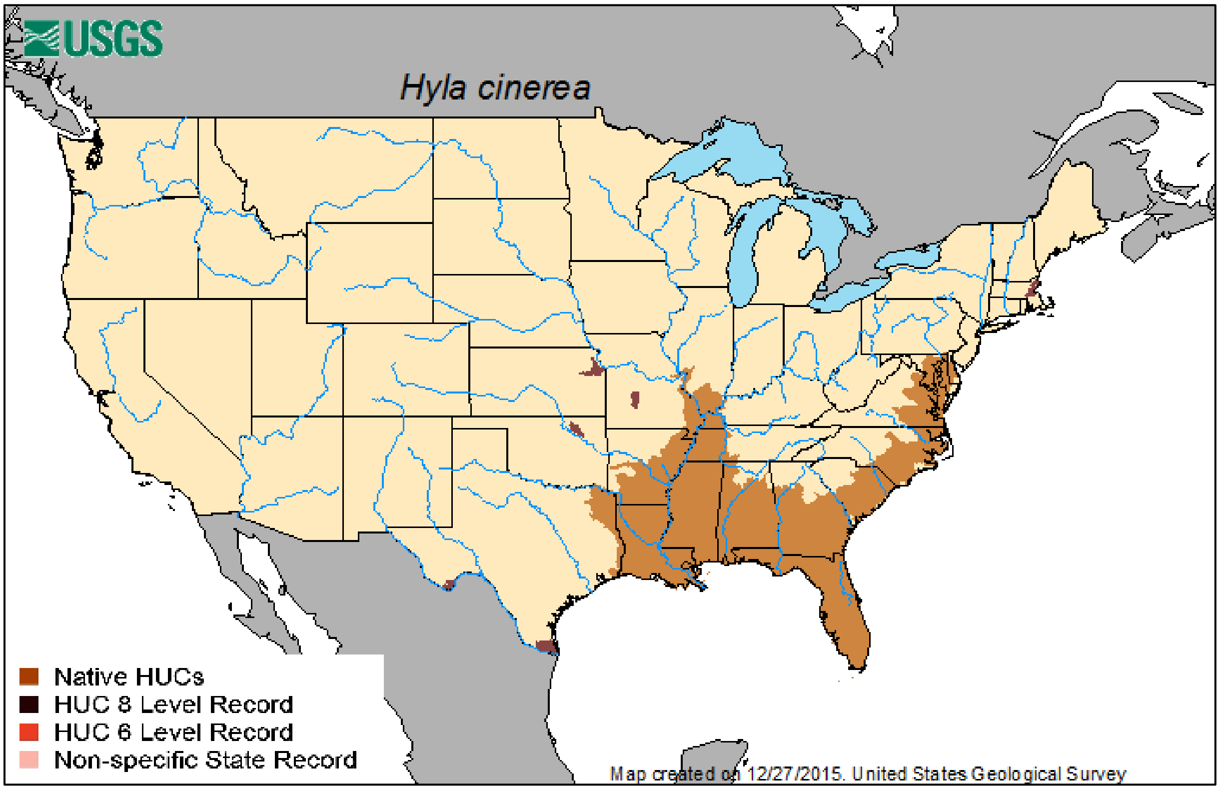


Figure 4.4.2.2. Native range of the green tree frog (*Hyla cinerea*) in orange. Recent isolated expansions in the states of Texas, Oklahoma, Kansas, Missouri, and Massachusetts are shown in red. Source: USGS 2015, nonindigenous aquatic species fact sheet.

The green tree frog prefers ponds and pools with emergent or floating vegetation to breed in the summer, and it is nocturnally active (Martof et al. 1980). Many of the native frogs in Cades Cove are vernal breeders, with the exception of the narrow-mouthed toad (*Gastrophryne carolinensis*), which breeds in the summer. This is a very small, subterranean toad that eats primarily ants and comes above ground to breed in temporary pools following significant rainfall in summer. There is some habitat overlap between the larval stages of the narrow-mouthed toad and the green tree frog, which may lead to competitive interactions (Asper 2015). The narrow-mouthed toad is rare and local in the park (Dodd 2004).

The green tree frog and the Cope's gray tree frog (*Hyla chrysoscelis*) apparently produced at least one hybrid in Cades Cove that was collected by Asper (2015). The genetic risk to the Cope's gray tree frog appears to be low, since it is found over much of the park and the green tree frog may be restricted to pools. Also, both species naturally occur sympatrically across a wide swath of the Atlantic coastal plain (Martof el al. 1980).

The green tree frog is another case where a species from a neighboring eco-region has invaded, but the impact is expected to be much less than catastrophic, compared to an "inter-continental invasive." The fact that the Cades Cove area has a concentration of vascular and non-vascular plants that are typical of coastal plain wetlands may be indicative of a larger coastal plain community of plants and animals that existed in the hypsithermal period several thousands of years ago. It is speculative but possible that the green tree frog could have been native to the Cove at that time.

Rusty crayfish (Orconectes rusticus)

A species native to the Ohio River drainage, the rusty crayfish is an opportunistic feeder, eating aquatic plants, detritus, macroinvertebrates, and other organic material (USGS 2015). It has rapidly expanded its range in recent decades (USGS 2015; Fig. 4.4.2.3), probably due to anglers emptying bait buckets; it has also been sold in large numbers by biological supply houses. The rusty crayfish is a relatively large species and is aggressive in defending itself from attack, which often results in displacement of native crayfish. It also has been shown to hybridize with other *Orconectes* sp., accelerating reductions in native species (Perry et al. 2001).

The rusty crayfish was first documented in park streams on the Foothills Parkway, Wears Valley area, in 1995 (Etnier 1995). The park has recently had a survey of its crayfish species completed (Loughman 2012), and although the rusty crayfish was not encountered, it is known from areas just outside the park in both TN and NC, and therefore is a concern. In areas where the rusty crayfish has invaded, there have been noted reductions in aquatic plant biomass and diversity (Olsen et al. 1991). Reductions in certain fish species (Kreps 2009) and unionid mussels (Klocker and Strayer 2004) have also been documented post-rusty crayfish invasion. Charlebois and Lamberti (1996) found that the rusty crayfish reduced overall aquatic macroinvertebrate densities by 47-58%, and herbivore densities by 55-72%. This reduction in benthic herbivores then led to a four- to seven-fold increase in algal periphyton (Charlebois and Lamberti 1996).

The park has documented rare fish, at least one rare freshwater mussel, and rare aquatic plants in Abrams Creek, and the spread of this aggressive species of crayfish into this area would be highly concerning. Control alternatives for exotic crayfish have recently been comprehensively documented by Hyatt (ca. 2003), but there are currently no easily applied measures, especially for national parks.

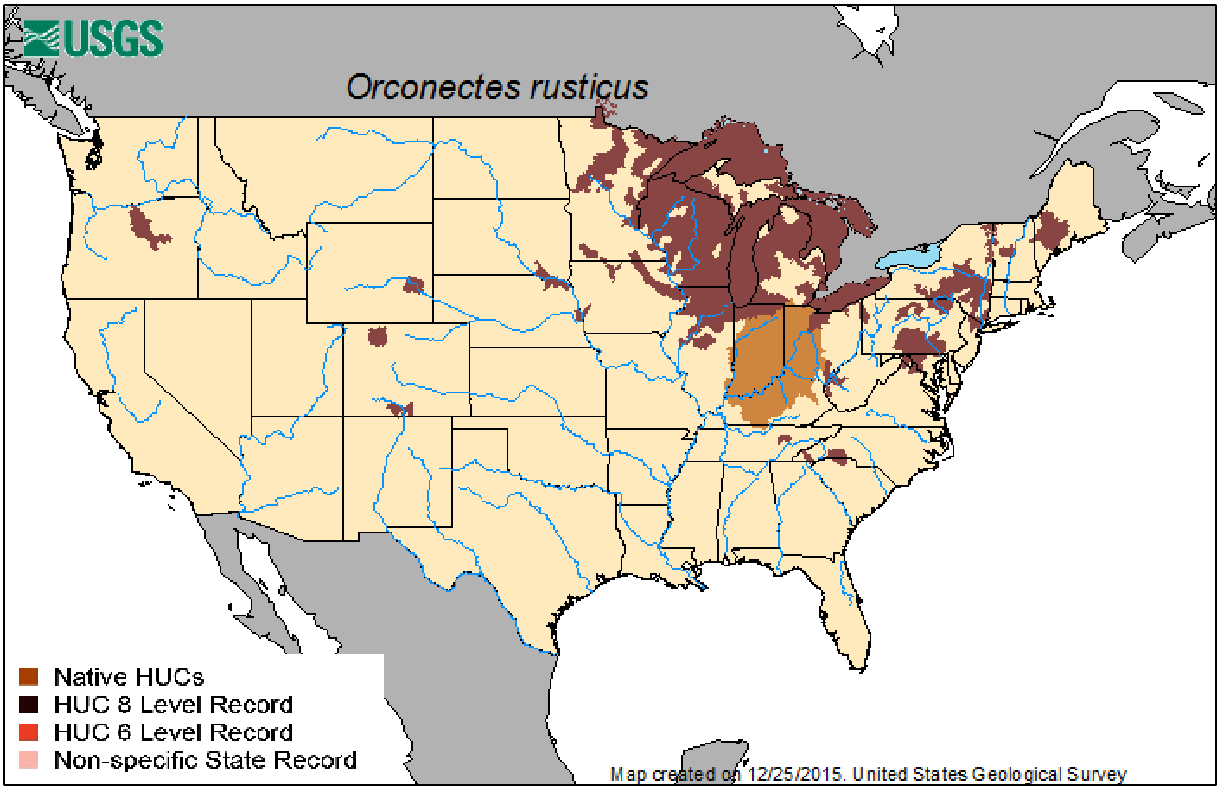


Figure 4.4.2.3. Native range of the rusty crayfish (*Orconectes rusticus*), in orange. Range expansions to other regions are shown in red. Source: USGS 2015, nonindigenous aquatic species fact sheet.

Reference Conditions

The reference condition for any of these invasive exotic species in the park is zero animals, which was the condition before they arrived. However, some species are known to have increased to a certain point, and then decreased because of park management actions or changing ecological conditions. With some that have been the focus of quantitative data collections, it is possible to track estimated changes in numbers, populations, distributions, and densities.

Conditions and Trends

In addition to the species discussed, there are many other potentially invasive animal species that are near or are approaching the park, and some are from other regions. For example, the nine-banded armadillo (*Dasypus novemcincus)* and the virile crayfish (*Orconectes virilis*) may be considered “native transplants” from other regions of the U.S., but others such as the zebra mussel (*Dreissena polymorpha*) and the quagga mussel (*Dreissena rostiformis bugensis*) are “intercontinental exotics” and are more concerning (Taulman and Robbins 2014).

With the expanding international trade in exotic species for pets and hobbyist interest, it is reasonable to assume that there is much unpredictability in what the next exotic invasive will be, or what native species and natural systems it will affect. Updated websites on invasive exotic species should be consulted periodically: http://www.invasivespeciesinfo.gov/unitedstates. We assign a moderate level of concern, and a declining condition for this category (Table 4.3.3.3). Trends for the above-listed invasive species are as follows:

European wild hog

Since the high populations of the 1970s and 1980s, active management has brought the total park population of hogs down to about 400-600 animals (about 15-20% of the initial estimate), and has kept it at that relatively low number.

Rainbow and brown trout

Selected upstream sections of park streams have been restored by removing rainbow and brown trout, and bolstering or re-patriating the native brook trout. To date, over 23 km (14 mi) of stream have been restored, but approximately 569 km (354 mi) are still populated by invasive trout species.

European honey bee

This is probably one of the first invasive species to occupy the park; no active control measures have been taken. Some hives have likely been killed by pests and pathogens of the European honey bee (e.g., tracheal mites [*Acarapis woodi*], varroa mites [*Varroa destructor*], small hive beetles [*Aethina tumida*], greater wax moths [*Achroia grisella*], etc.), but there is uncertainty regarding their overall impact on the feral European honey bee populations. The honey bee is still found in varying numbers at all places in the park, including at high elevations.

Multicolored Asian lady beetle and seven-spotted lady beetle

The multicolored lady beetle used to occur in very high numbers in the late 1990s and early 2000s; it is now present at reduced levels, but still common. There are fewer data for the seven-spotted lady beetle in the park.

Japanese rock pool mosquito

Newly invaded, this species has only recently been surveyed comprehensively. There are little data currently available and therefore no trends to discern.

Asian Jumping earthworm

This worm is presumed to be slowly spreading geographically in the park, probably up valleys along disturbed corridors. Since it primarily inhabits the organic layer just below the litter surface, it may be susceptible to drought conditions. Snyder (2007) measured local retractions in *Amynthas* populations on dry slopes during a drought.

Coyote

This canid has become common and is probably found at all elevations in established populations.

Green tree frog

Asper (2015) has documented the current invasion of this regional exotic in the Cades Cove area of the park. It is expected to expand to other areas in the park from multiple sources in the vicinity.

Rusty crayfish

This species has not been detected in the main body of the park at this time; it has been found only in the Foothills Parkway area, Sevier County, TN. However, it is also upstream of the park in the Little

Tennessee River in North Carolina and may be expected to invade the park on that side, which is where several rare/endemic crayfish occur.

Confidence and Data Gaps

The confidence is fairly high regarding the condition of most of these invasive exotics. However, there are data gaps that could be filled and questions that could be answered by future work:

- What is the long-term impact of pseudorabies on the European wild hog population in the park?
- What is the distribution, phenology and ecological status of the Japanese rock pool mosquito in the park?
- How do the densities of European honey bees – and their pests/parasites – vary across the park? Is there a correlation with native bee distributions or densities? Is it reasonable that the current concern about native pollinators is exacerbated by European honey bees?
- Are the declining or "lost" native lady beetles still extant in the Smokies? What were their historic habitats in the park?
- Will Asian jumping worms affect other taxa beyond millipedes, such as plants?
- Is the red fox gone or just suppressed by the coyote? With the loss of the red fox as a predator due to coyote competition, is there now a "release" in the fox's natural prey species?
- Is the green tree frog affecting the narrow-mouthed toad population? If so, will the narrow-mouthed toads survive in Cades Cove? Additionally, will the green tree frog serve as a vector for ranavirus or other diseases?
- New control measures are needed for rusty crayfish. Given that the Ohio River (the rusty crayfish's native range) and the Tennessee River join in western Kentucky, is it known what natural controls have prevented the rusty crayfish from further invasion?

Sources of Expertise

- Jennifer Asper, University of Georgia
- David Etnier, University of Tennessee
- Troy Evans, Forest Ecologist, Great Smoky Mountains National Park
- Anita Juen, University of Innsbruck, Austria (formerly)
- Matt Kulp, Fisheries Biologist, Great Smoky Mountains National Park
- Zachary Loughman, West Liberty University, WV
- Becky Nichols, Entomologist, Great Smoky Mountains National Park
- Bruce Snyder, Kansas State University
- William Stiver, Supervisory Wildlife Biologist, Great Smoky Mountains National Park

Summary Conditions

Table 4.4.2.1 Summary condition and trend graphic for non-native invasive animals in GRSM.

Resource	Indicator	Status and Trend	Rationale and Reference Conditions
Invasive Species	Invasive/exotic animals	⇩	Invasive hogs and trout numbers are reduced, but Eurasian insects and earthworms and rusty crayfish are generally increasing. Other exotic invasives are approaching this region. Future increased hobbyist animal trade and accidental introductions are very unpredictable.

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4.5. Focal Species or Communities

This section covers resource assessments for the following focal species or communities:

- Major vegetation communities
- Freshwater invertebrates
- Terrestrial invertebrates
- Fishes
- Amphibians and reptiles
- Birds
- Mammals
- Rare communities

4.5.1. Introduction and Methods for Assessing Major Vegetation Communities

Introduction to Vegetation Communities

Great Smoky Mountains National Park is one of the largest tracts of primary forest in eastern North America. Complex ecological gradients within the park give rise to a diverse mosaic of plant communities (Whittaker 1956, Madden et al. 2004, Jenkins 2007). The park's varied microclimates, topography, geology, soils, numerous streams (Fig. 4.5.1.1), and its apparent role as a refugium during past climatic shifts make it one of the most species-rich parks in the United States. The park is internationally renowned as a center of biological diversity, and is designated as an International Biosphere Reserve and World Heritage Site (UNESCO 2015).

Figure 4.5.1.1. Spring wildlflowers next to a stream in Great Smoky Mountains National Park. Source: Luong 2003

Environmental gradients (particularly moisture and elevation) strongly influence species distribution and vegetation community composition in the park (Whittaker 1956, Madden et al. 2004) (Fig. 2.2.2.6). White et al. (2003) identified 79 vegetation associations within the park, which are defined as plant communities of definite floristic composition, uniform habitat conditions, and uniform physiognomy (Flahault and Schroter 1910). Twenty-six of these associations are ranked as either critically imperiled (G1) or imperiled (G2) (Table 4.5.1.1). Many of the imperiled associations are found at the highest elevations and along ridgelines, and their status is due to their uniqueness, and stressors such as exotic pests and acidic deposition (Fig. 4.5.1.2).

Table 4.5.1.1. Vegetation associations in GRSM that are ranked G1 or G2. Source: White et al. 2003.

Association Name	G-Rank[A]	CEGL[B]	Vegetation Community
Grassy Bald (Southern Grass Type)	G1	CEGL004242	Grassy Balds/Grasslands
Southern Appalachian High-elevation Rocky Summit (High Peak Type)	G1	CEGL004277	Spruce-Fir Forest
Southern Appalachian High-elevation Rocky Summit (Anakeesta type)	G1	CEGL004278	–
Montane Floodplain Slough Forest	G1	CEGL004420	Montane Alluvial Forest
Fraser Fir Forest (Deciduous Shrub Type)	G1	CEGL006049	Spruce-Fir Forest
Southern Appalachian Beech Gap (South Slope Sedge Type)	G1	CEGL006130	High-elevation Hardwood Forest
Southern Appalachian Beech Gap (North Slope Tall Herb Type)	G1	CEGL006246	High-elevation Hardwood Forest
Fraser Fir Forest (Evergreen Shrub Type)	G1	CEGL006308	Spruce-Fir Forest
Red Spruce-Fraser Fir Forest (Evergreen Shrub Type)	G1	CEGL007130	Spruce-Fir Forest
Southern Appalachian Heath Bald	G1	CEGL007876	Heath Bald
Red Spruce-Northern Hardwood Forest (Shrub Type)	G1?	CEGL004983	High-elevation Hardwood Forest
Blue Ridge High-elevation Seep (Mt. LeConte Type)	G1Q	CEGL007877	Wetlands
Shortleaf Pine/Little Bluestem Appalachian Woodland	G2	CEGL003560	Pine-Oak Forest
Southern Blue Ridge Spray Cliff	G2	CEGL004302	Wetlands
Blue Ridge Calcareous Shale Slope Woodland (Shrubby Type)	G2	CEGL004995	–
Red Spruce-Northern Hardwood Forest (Herb Type)	G2	CEGL006256	Spruce-Fir Forest
Red Spruce-Fraser Fir Forest (Deciduous Shrub Type)	G2	CEGL007131	Spruce-Fir Forest
High-elevation Red Oak Forest (Tall Herb Type)	G2	CEGL007298	High-elevation Hardwood Forest
Southern Appalachian Acid Cove Forest (Silverbell Type)	G2	CEGL007693	Acid Cove Forest
Blue Ridge High-elevation Seep (Sedge Type)	G2	CEGL007697	Wetlands
Blue Ridge Acid Shale Woodland	G2?	CEGL003624	–
Floodplain Canebrake	G2?	CEGL003836	Montane Alluvial Forest
Montane Low-elevation Seep	G2?	CEGL003909	Wetlands
Appalachian Montane Alluvial Forest	G2?	CEGL004691	Montane Alluvial Forest
Red Spruce-Fraser Fir Forest (Hemlock Type)	G2?	CEGL006272	Spruce-Fir Forest
Blue Ridge Acid Shale Forest	G2?	CEGL007539	–
Montane Alluvial Forest (Cades Cove/Oconaluftee)	G2Q	CEGL007339	Montane Alluvial Forest/Wetlands

A. Conservation status ranks are based on a 1-5 scale, ranging from critically imperiled (G1) to secure (G5). G2 communities are imperiled. A “?” modifier indicates uncertainty about the rank in the range of 1 either way. A “Q” modifier denotes questionable taxonomy. It modifies the degree of imperilment and is only used in cases where the type would have a less imperiled rank if it were not recognized as a valid type.

B. Community Element Global code

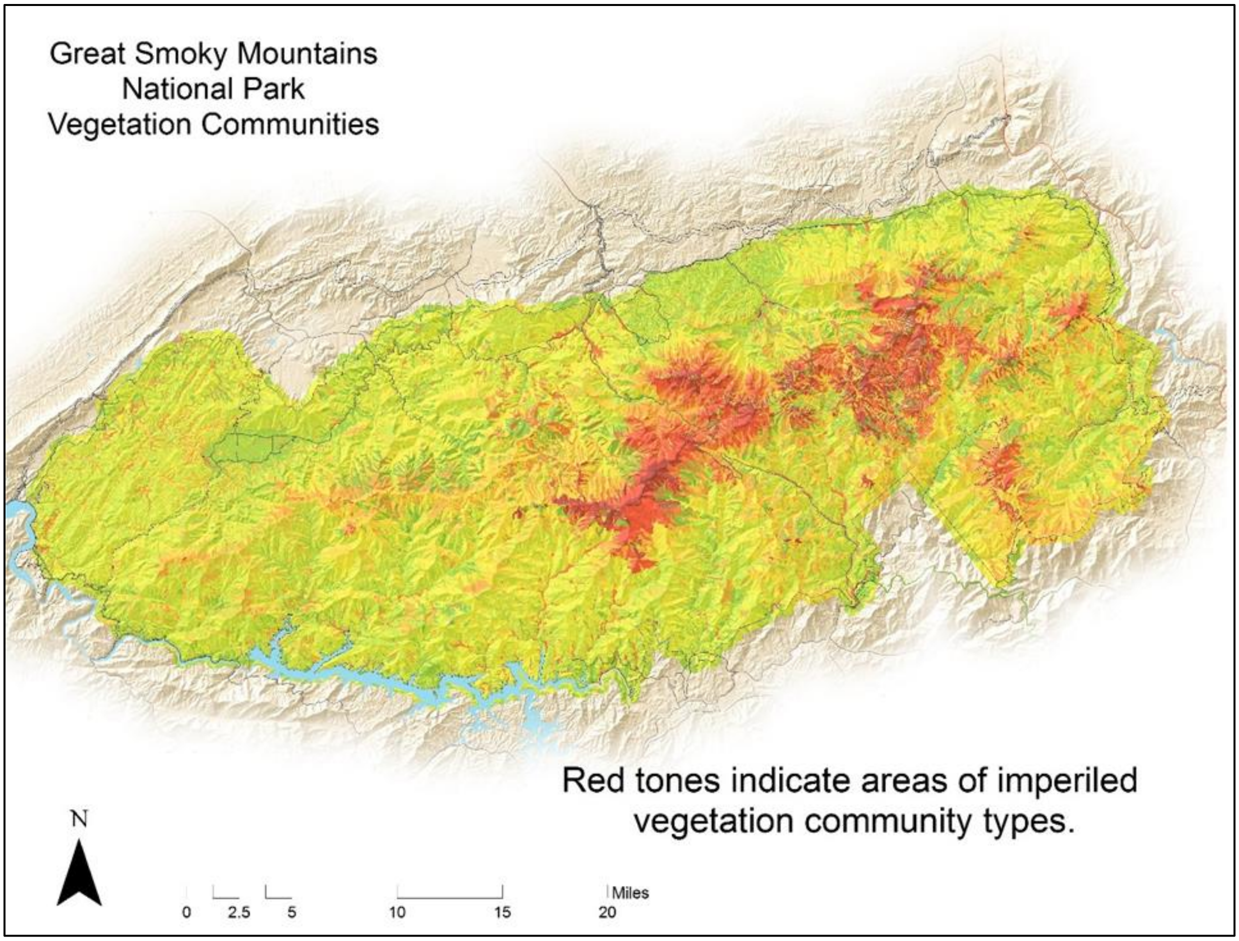

Figure 4.5.1.2. A majority of the park's imperiled vegetation communities (G1 and G2) occur on ridgelines and at higher elevations. Source: Madden at al. 2004.

Methods for Evaluating Vegetation Communities

Current conditions for each of the 11 major vegetation communities were estimated from vegetation classification summaries (White et al. 2003, Jenkins 2007) and input from park staff. Location and areal extent were based on vegetation community maps produced by Madden at al. (2004) (Fig. 4.5.1.3), which was produced using heads-up digitization of aerial photographs informed by site visits, ground-truthed data, and biophysical gradient layers.

The reference condition for each community was the estimated species composition and structure that existed prior to European settlement. In situations where keystone species are largely gone (e.g., American chestnut), reference condition consists of a species composition and structure that would maintain historic ecological function to a degree that is feasible. Reference conditions were based on park vegetation summaries by White et al. (2003), Jenkins (2007), vegetation classifications for North Carolina (Schafale 2012), LANDFIRE (Landscape Fire and Resource Management Planning Tools) Biophysical Settings models (TNC 2016), and discussions with park staff. Park resource managers have identified the primary stressors that are, or may, impact each major vegetation community (Table 4.5.1.2). Trends for each community were estimated based on the documented, suspected, and/or potential impacts of these stressors. The potential impacts of climate change were further evaluated using the Climate Change Atlas (USFS 2016). Two outputs from the Climate Change Atlas models were used to inform park trends: The first is forest type, which reflects how the geographic range of each forest type would migrate across the eastern U.S. It should be emphasized that these projections are not modeled at the park scale, but instead for the broader eastern U.S. The second output projects how the importance value (IV) of each tree species might change. Importance values were calculated at the park-level, and are based on each species' entire range as opposed to specific communities. Reported IV's would likely be higher for species within their associated forest types than for the entire park.

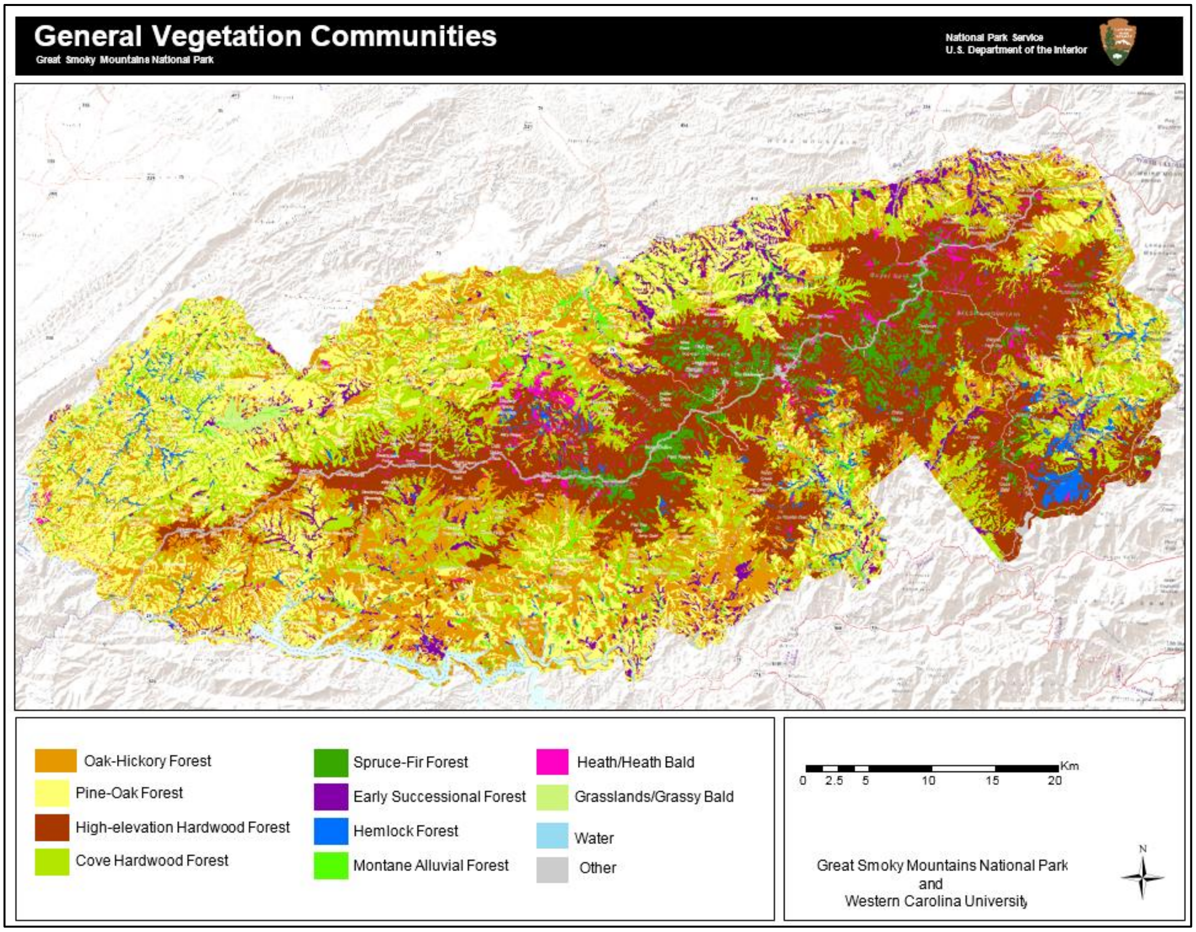

Figure 4.5.1.3. Map of the general vegetation communities found in GRSM. Source: Madden at al. 2004.

Also, trends for individual species may not necessarily follow the trends of the associated forest types, since the latter were calculated using conditions across the entire eastern U.S., and species interactions and site conditions within the park may vary from these. The park's complex terrain creates microclimates that compound the difficulty of predicting the response of an organism to atmospheric warming; therefore, reported climate change effects on the tree species and forest types within the park should be used to help inform possible long-term trends, but not with absolute certainty.

Table 4.5.1.2. Perceived effects (sensitivity to change) of key drivers and stressors on major vegetation communities in GRSM. Source: GRSM staff 2014.

Categories of Key Drivers and Stressors	**Sensitivity to Change: High: H; Intermediate: I; Low: L**	**Vegetation Community Type (% Cover)**										
		Oak-Hickory Forests (34%)	**Pine-Oak Forests (11%)**	**High-elevation Hardwood Forests (24%)**	**Cove Hardwood Forests (15%)**	**Spruce-Fir Forests (3%)**	**Early Successional Forests (4%)**	**Hemlock Forests (2%)**	**Montane Alluvial Forests (1%)**	**Heath Balds (1%)**	**Grassland /Grassy Balds (<1%)**	**Wet-lands (<1%)**
Chronic/Global Stressors	Particulates and Visibility	I	I	H	I	H	L	L	L	L	L	L
	Ozone Pollution	L	L	H	H	H	H	L	I	I	L	L
	Acid Deposition	L	L	H	I	H	L	L	L	I	L	H
	Toxics*	L	L	L	L	L	L	L	L	L	L	H
	Climate Changes*	H	H	H	I	H	I	I	I	L	L	H
Acute/Local Stressors	Invasive Plants	L	L	L	L	L	H	I	I	L	H	H
	Invasive Animals	L	L	H	H	L	I	I	I	L	H	H
	Infestations and Diseases	H	H	H	I	H	L	H	I	I	L	L
	Landscape-Park Changes (fire)	H	H	L	L	L	I	I	L	L	H	L
	Human Impacts	L	L	L	L	I	L	L	H	L	I	I
Drivers Soil Quality	Soil Quality	L	L	H	L	H	L	I	L	I	L	I
	Water Chemistry	L	L	H	L	H	L	L	I	L	L	H
	Groundwater	L	L	L	I	L	L	I	I	L	L	H
	Water/Hydrology	L	L	L	I	L	L	I	I	L	L	H

*Perceived effects based on incomplete (e.g., Toxics) or uncertain knowledge (e.g., Climate Changes).

4.5.2. Oak-Hickory Forests

Relevance

Oak-Hickory Forests occupy 34% of the park area, making it the most common forest community in the park (Fig. 4.5.2.1). Oaks and hickories provide a significant source of hard mast for mammals and invertebrates. Prior to the arrival of the chestnut blight in the 1940s, American chestnut (*Castanea dentata*) was a dominant tree species in this community. Large portions of this forest type were partially maintained by fire, and fire suppression and other stressors are altering species composition and structure (Holzmueller et al. 2009, Flatley et al. 2015).

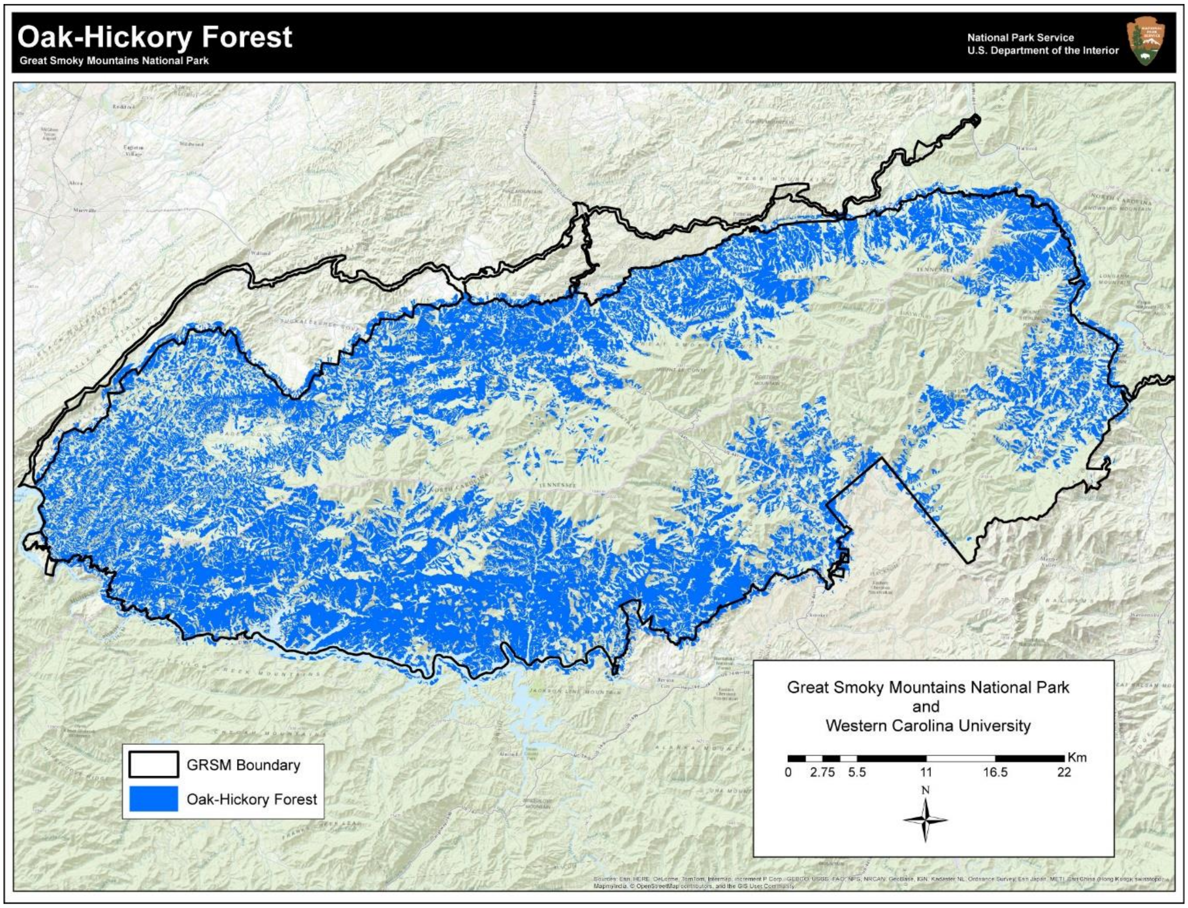

Figure 4.5.2.1. Oak-Hickory Forests are the most common forest community in the park. Source: White et al. 2003

Data and Methods

See section 4.5.1.

Reference Conditions

Reference conditions for Oak-Hickory Forests reflect stand characteristics that existed prior to European settlement. These widely occurring forests occur across a range of aspects and at elevations ranging from 340 m to 1,370 m (1,115 to 4,495 ft) (Jenkins et al. 2007). Though inherently diverse, the composition and structure of these forests has been greatly altered by a number of stressors during the past 100 years. Key among them are native and non-native insects and diseases, fire suppression, and climate change. It is impractical to define a reference condition where all of these stressors, and their effects, are eliminated. Therefore, for the purposes of this assessment, the reference condition for this community type is a mosaic of Oak-Hickory Forests across the park landscape that possess the species composition, structure, and natural processes required to perpetuate forests containing a significant component of oak and hickory species, and other associated native plants. This condition is represented by stands ranging from open woodlands to closed forests, with natural disturbances that include periodic low intensity fires and storm-related wind events. Oaks and hickories are represented in all canopy layers, including regeneration. They would contain minimal amounts of non-native insects, diseases, and plants.

Conditions and Trends

This broadly classified forest community includes chestnut oak, oak-hickory, red oak cove, and white pine-mesic oak forests. These forests generally occur on dry slopes and ridges in low to moderate elevations (Fig. 4.5.2.2). Common overstory species include chestnut oak (*Quercus montana*), scarlet oak (*Q. coccinea*), northern red oak, white oak (*Q. alba*), hickory, red maple, eastern white pine, tulip poplar, sourwood, and black gum (*Nyssa sylvatica*). Shrub layers vary from sparse to dense and may include deciduous or evergreen heaths such as mountain laurel and rhododendron, huckleberry (*Gaylussacia* spp.), and blueberry (*Vaccinium* spp.), among others. Herb layers also vary widely, from sparsely populated, to well-developed with mesic herbs.

Figure 4.5.2.2. Oak-Hickory Forest in fall at Great Smoky Mountains National Park. Source: NPS Photo 2012.

Oak-Hickory Forests have, and continue to be, impacted by a number of stressors, including native and non-native insects and diseases, fire suppression, and climate change. Some of these key stressors are discussed below.

Chestnut Blight

Oak-Hickory Forests, which include the former range of Oak-Chestnut Forests, have undergone wide-ranging compositional and structural changes for the past century. The American chestnut tree composed approximately 25-50% of the forest canopy throughout its range in the early 20th century (Dalgleish and Swihart 2012) (Fig. 4.5.2.3). It was the former dominant canopy species in what are now Oak-Hickory Forest communities. The tree was once the largest hardwood in the east, averaging 25-30 m (80-100 ft) in height and a diameter of 2.5 m (8 ft) with many specimens reaching well beyond the average size. By the 1940s, essentially all mature chestnut trees had succumbed to chestnut blight caused by the bark-inhabiting fungus *Cryphonectria parasitica*, which forms blistering cankers and effectively girdles the tree. Chestnuts are now a minor component of the understory, existing as sprouts from stumps and roots. Occasionally they may reach 20 to 25 cm (8 to 10 in) in diameter before dying back to the root system. Following the chestnut's demise, important ecological shifts occurred in southeastern forests. Woods and Shanks (1959) found that the five most abundant tree species to occur in openings created by chestnut mortality were chestnut oak (17%), northern red oak (16%), red maple (13%), eastern hemlock (6%), and Carolina silverbell (5%). A more recent survey conducted in western North Carolina found that importance values of chestnut oak, red maple, flowering dogwood (*Cornus florida*), eastern hemlock, tulip poplar, and sourwood increased 2 to 5% following death of the chestnut, depending on environmental conditions. Eastern hemlock increased in abundance near streams, across elevations, and tulip poplar trees replaced chestnuts in moist coves (Elliott and Swank 2007). Also, white oak has been shown to decrease in forests that were once dominated by chestnut (Stephenson 1986), and post-blight hard mast production has decreased from pre-blight levels, which suggests the loss of mature chestnuts has reduced the southern Appalachian's carrying capacity for certain wildlife species (Diamond et al. 2000, Dalgleish and Swihart 2012). Additionally, chestnuts have a higher protein content than acorns or hickories, which would have further affected overall wildlife habitat and health.

Figure 4.5.2.3. A group of American chestnuts, Big Gap Creek, TN. Source: American Environmental Photographs Collection, Univ. of Chicago Library.

Dogwood anthracnose

The dogwood anthracnose fungus (*Discula destructiva*), which arrived in the southern Appalachians in 1987, thrives in cool, moist conditions and primarily infects flowering dogwood. Drought and winter injury to dogwood trees make them more vulnerable to the fungus, and currently, nearly all dogwoods in some watersheds in the park have died due to this fungus (NPS 2014a).

Dogwood is an important understory tree species in second-growth stands, as well as in old-growth forests. Its high protein fruit is important food for migratory birds in the fall and the twigs and leaves are the favored browse for the park’s herbivores. Dogwood is also a calcium pump, drawing the mineral from deep soil and then depositing it on the soil surface with its leaf litter. Dogwood foliage contains significantly higher amounts of calcium than almost any other forest species (Jenkins et al. 2007), making it a major soil builder in forests and a significant component to calcium cycling. Decreases in annual calcium cycling, due to declines in dogwood, could have cascading effects on forest biota (Jenkins et al. 2007). For example, snail densities may decline as a result of the lower calcium input, which may lead to a lower reproduction rate in passerine birds that depend on snail shells as a calcium source for egg production (Graveland et al. 1994).

Infrequent fires have been shown to reduce the virulence of anthracnose fungus by helping to keep forest stands in Oak-Hickory Forests open (Holzmueller et al. 2008). While there are preventative steps to protect individual trees, there is currently no practical treatment on a landscape scale and/or for use in the park (NPS 2014a).

Gypsy Moth and Oak Decline

Gypsy moth (*Lymantria dispar*) defoliates oaks but also feeds on nearly 300 other species of trees and shrubs. Old-growth oak stands are at special risk since they are not as vigorous as younger trees (NPS 2014a). Since oak species are a major component of Oak-Hickory Forests, the gypsy moth could potentially have far-reaching impacts on forest composition and structure. Spot infestations have been discovered outside the park in eastern Tennessee, western North Carolina, and northern Georgia. The park has captured occasional male moths in pheromone traps that were placed in picnic areas and campgrounds, but there have been no infestations documented inside the park (G. Taylor, pers. comm. 2015).

Fire Exclusion

From a period beginning several thousand years ago and ending in the early 1900s, natural and man-made fires regularly burned in areas occupied by Oak-Hickory Forests (Harmon 1982, Delcourt and Delcourt 1998, Flatley et al. 2013). These were typically low-intensity burns that maintained a more open forest canopy, and encouraged shade-intolerant, fire-tolerant plant species. Native American populations, particularly those in low-elevation river valleys, used fire to clear and maintain agriculture areas, and to suppress insect populations. As Europeans moved into the area, they adopted the same practices up until corporate logging activities eliminated the agrarian-based society in the early 1900s.

Following the park’s creation, fires were actively suppressed. This allowed forest canopies to close, creating cooler, damper conditions that made the forests less flammable. This created a positive-feedback loop, referred to as mesophication, where conditions continually improve for mesophytic, fire-intolerant species (e.g, maples, birches, and beeches) and deteriorate for fire-adapted species (e.g, oaks and hickories) (Nowacki and Abrams 2008, Kreye et al. 2013). Mesophication alters forest composition and structure, and leads to declining species richness in the herbaceous layer. Notwithstanding the high-intensity fires in the park that were associated with heavy timbering activities that occurred from the late 1800s into the 1930s, the Oak-Hickory Forests are likely undergoing mesophication as has been observed in other parts of the Appalachians (Harrod et al. 1998, Holzmueller et al. 2008, Flatley et al. 2015).

Along with an increase in mesophytic conditions, the suppression of low intensity fires may have also inadvertently increased the virulence of exotic diseases. For example, Holzmueller et al. (2008) examined the impacts of dogwood anthracnose in previously burned and unburned stands in Oak-Hickory Forests, and found there to be less crown dieback in flowering dogwood stands that had burned compared to those that had not burned. Stands that burned twice in a 20-year period contained the highest density of dogwood stems. Fire creates a more open stand structure, which may result in conditions that are less conducive for dogwood anthracnose. Additionally, their results suggested that burning favored species historically associated with Oak-Hickory Forests (Holzmueller et al. 2009).

In the 1990s, GRSM began a prescribed burn program with the intent of restoring historical fire regimes, and their associated oak and pine forest communities, to pre-settlement conditions. However, with the decline in oak and pine and increase in more mesic species such as red maple, frequent, repeated burning may be required to restore these forests. Because Oak-Hickory Forests compose the majority of forests in the park, the consequences of fire-exclusion may have far-reaching ecological consequences at the landscape scale. However, management of naturally caused fires in combination with prescribed burning may help mitigate the impacts of both mesophication and exotic diseases such as dogwood anthracnose.

Climate Change

Climate change projections indicate a shift in areas where habitat will be suitable for Oak-Hickory Forests in the southeastern U.S. (Rustad et al. 2012). Climate change scenarios generally predict that species will move into slightly higher latitudes and altitudes. Low carbon emission scenarios suggest Oak-Hickory Forests will migrate from the North Carolina piedmont to the southern Appalachians, and this could increase the area of Oak-Hickory Forests within the park (Fig. 4.5.2.4). High carbon emission scenarios predict a decrease in the area of Oak-Hickory Forests within the park's vicinity as they are replaced by mixed oak/pine forests. When looking at individual species at the park scale, importance values of some species found in Oak-Hickory Forests (e.g., chestnut, scarlet, and northern red oaks) are projected to decrease under both scenarios (Table 4.5.2.1). These results reflect that within Oak-Hickory Forests, oaks will become less prominent as they are replaced by more xeric species.

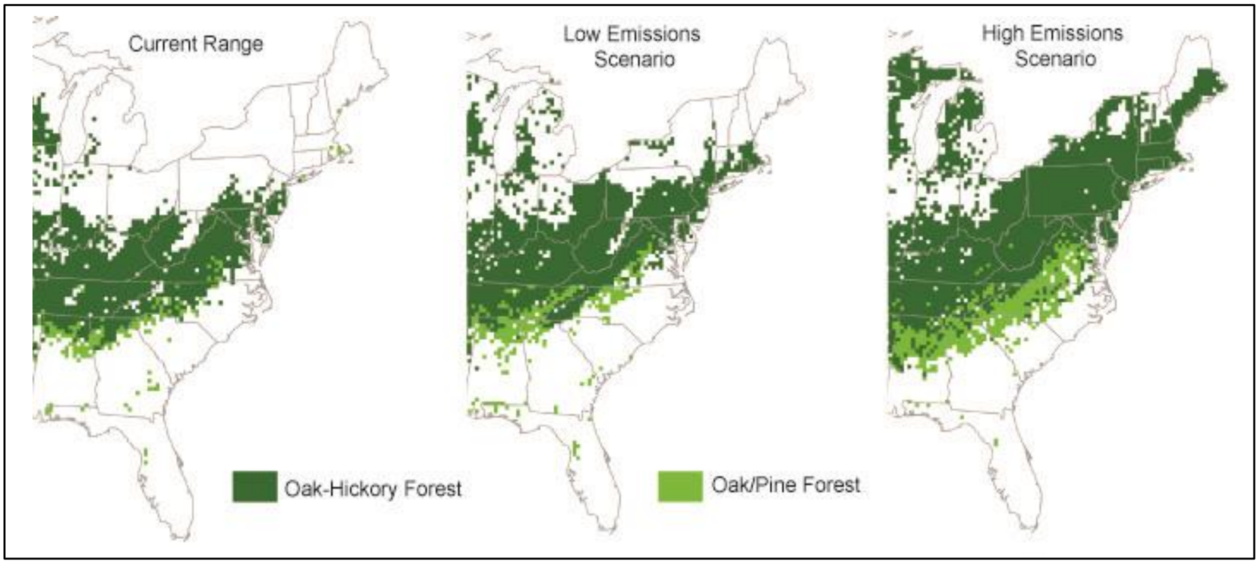

Figure 4.5.2.4. Climate change emissions models indicate that habitat suitable for Oak-Hickory Forests may expand with increasing emission levels. Source: Landscape Change Research Group 2014.

Table 4.5.2.1. Modeled species importance values, based on park-wide species abundance (not just within a major forest community). Source: Landscape Change Research Group 2014.

Common Name	Scientific Name	Model Reliability [A]	Mod CurIV [B]	AvgHi [C]	[D] AvgLo
Chestnut oak	*Quercus montana*	1	6.48	-1.44	-0.28
Scarlet oak	*Quercus coccinea*	1	3.12	-1.37	-0.06
Northern red oak	*Quercus rubra*	1	4.54	-1.15	-0.86
White oak	*Quercus alba*	1	3.51	2.1	1.04
Bitternut hickory	*Carya cordiformis*	3	0.03	1.21	0.19
Pignut hickory	*Carya glabra*	1	1.89	-0.15	0
Shagbark hickory	*Carya ovata*	2	0.14	1.46	0.3
Mockernut hickory	*Carya tomentosa*	1	1.99	0.1	-0.2
Red maple	*Acer rubrum*	1	12.38	-5.86	-1.4
Eastern white pine	*Pinus strobus*	1	3.84	2.03	2.52
Tulip poplar	*Liriodendron tulipifera*	1	6.22	-2.82	-0.82
Sourwood	*Oxydendrum arboreum*	1	3.89	-0.64	-0.25
Flowering dogwood	*Cornus florida*	1	4.62	-0.49	-0.15
Black gum	*Nyssa sylvatica*	1	3.14	0.4	0.03

A. Model reliability: 1=high; 2= medium; 3=low

B. ModCurIV: Modeled current importance values of species in park

C. AvgHi: General Circulation Models (three different models and their averages) under High emission levels scenario (current trend)

D. AvgLo: General Circulation Models (three different models and their averages) Under Low emissions scenario (conservation measures are put into place)

Considering all of the above-listed stressors, Oak-Hickory Forests have undergone significant historical shifts in species composition and structure in the last century. Formerly dominated by American chestnut, these forests are now composed primarily of oak and hickory species. American chestnuts provided a greater amount and higher quality mast than do oaks and hickories, but unless blight-resistant American chestnuts are successfully re-introduced, they will never be a major canopy component as they once were. Historic fire suppression may be contributing to the forest's long-term trend of mesophication. Decades of fire suppression have increased canopy closure, creating shadier and wetter conditions that are causing a shift in species composition away from fire-tolerant oaks and hickories to more mesic species including black gum, red maple, white pine, and hemlock. Additionally, the shift in forest structure may create conditions in which Oak-Hickory Forests are more vulnerable to exotic diseases. Forest diseases and pests, such as the chestnut blight, gypsy moth, and dogwood anthracnose are either currently affecting or may affect characteristic species that define Oak-Hickory Forests. However, carbon emissions may counter that trend. If carbon emissions continue to increase and atmospheric warming becomes more prevalent, habitat for Oak-Hickory Forests will trend toward higher latitudes and altitudes, and areas currently occupied by Oak-Hickory Forests may become dominated by more xeric species. When considering the above threats and stressors and the current conditions of the park's Oak-Hickory Forests, we assign a stable trend with a moderate level of concern.

Confidence and Data Gaps

The virtual extirpation of American chestnut within the park's boundaries has fundamentally changed forest structure and composition. It is too soon to fully understand and evaluate whether the reintroduction of fire will affect Oak-Hickory Forest health. While there are no known studies focused on mesophication of the park's forests, this cycle is likely taking place in the park and may have profound impacts on the future role of oak within the park. Further monitoring and analysis of existing data is needed to fully understand the impacts this cycle may have already had inside the park's boundaries and the ultimate role of fire in restoring these forests. Knowledge of insects and pathogens are well-documented in the park. Dogwood anthracnose is currently impacting calcium cycling and the gypsy moth has been discovered in the park, but has not become established. The impact of climate change on Oak-Hickory Forests is uncertain; however, if emission levels remain stable, oak-hickory habitat may become more prevalent in the park. Therefore, a moderate level of confidence has been assigned to this assessment (Table 4.5.2.2).

Sources of Expertise

- Troy Evans, Forest Ecologist, Great Smoky Mountains National Park
- Kristine Johnson, Supervisory Forester, Great Smoky Mountains National Park
- Rob Klein, Fire Ecologist, Great Smoky Mountains National Park
- Tom Remaley, Inventory and Monitoring Coordinator, Great Smoky Mountains National Park
- Glenn Taylor, Biologist, Great Smoky Mountains National Park

Summary Condition

Table 4.5.2.2. Summary condition and trend graphic for Oak-Hickory Forests.

Resource	Indicator	Status and Trend	Rationale and Reference Conditions
Focal Species or Communities	Oak-Hickory Forests	⇔	Reference condition is a mosaic of stands ranging from open woodlands to closed forests. Oaks and hickories are represented in all canopy layers, with minimal amounts of non-native insects, diseases, and plants. Threats include shifts in species composition and a more closed forest canopy due to fire suppression, infestations of non-native insects and diseases, and climate change.

4.5.3. Pine-Oak Forests

Relevance

Pine-Oak Forests represent approximately 11% of park area with most occurring in the western portion (Fig. 4.5.3.1). They include yellow pine, oak-pine, white pine, and white pine-xeric oak forests. Table mountain pine is of particular concern for park resource managers, with populations of this southern Appalachian endemic species threatened by nearly a century of fire exclusion. There is one imperiled vegetation association, Shortleaf Pine/Little Bluestem Appalachian Woodland, in this community (Table 4.5.1.1), although this association is not currently mapped within the park. Pine-Oak Forests provide important habitat for several threatened and endangered (T&E) species including Indiana bat and northern long-eared bat (*Myotis septentrionalis*). Many Pine-Oak Forests existed historically as more open woodlands that were maintained by frequent fires. These important habitats are declining in response to fire suppression, pine beetle outbreaks, and other stressors.

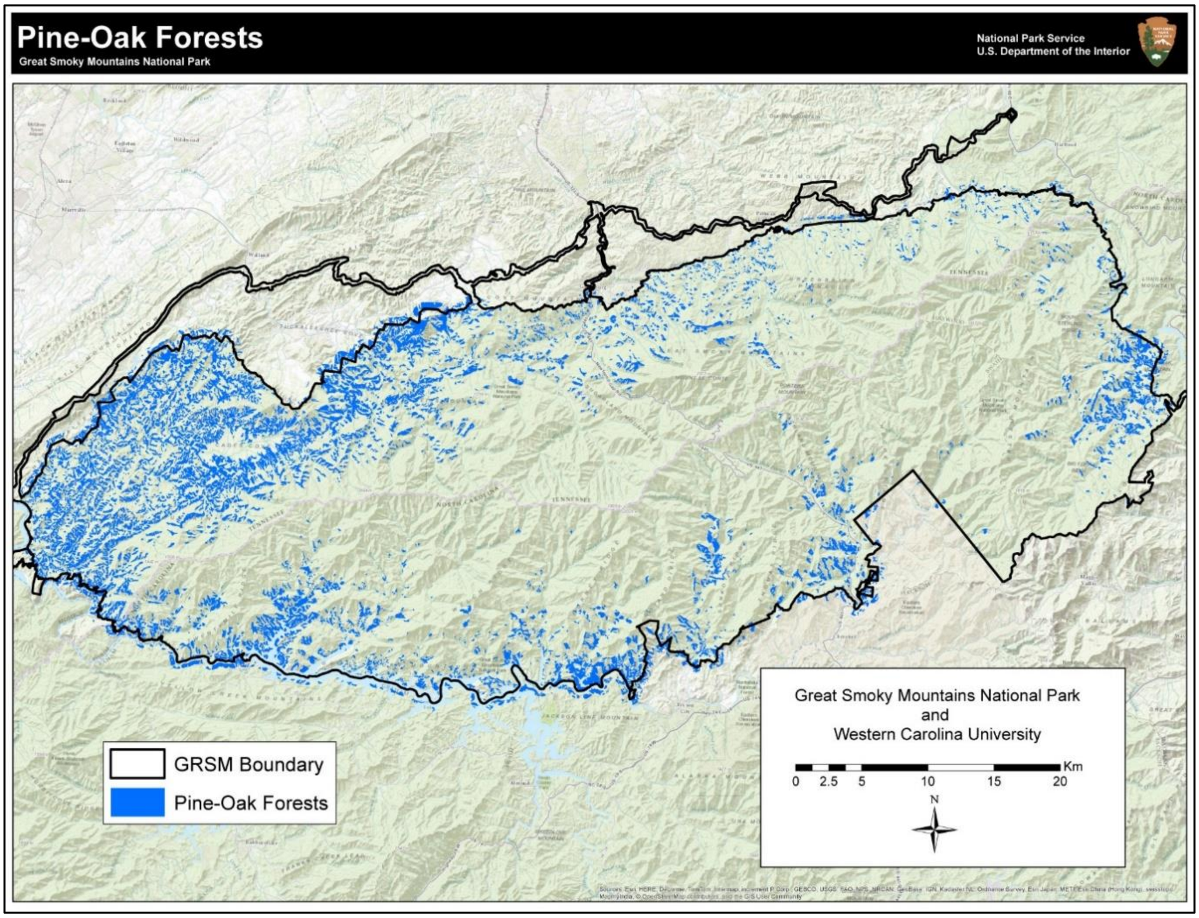

Figure 4.5.3.1. Much of the western portion of the park consists of Pine-Oak Forests. Source: White et al. 2003.

Data and Methods

See section 4.5.1.

Reference Conditions

Reference conditions for Pine-Oak Forests reflect forest characteristics that existed prior to European settlement. During this time, periodic fires helped keep the canopy and subcanopy open, regulated duff thickness to where yellow pine seedling could regenerate, and maintained a moderately diverse herbaceous layer. Additionally, a regular fire regime limited mesophytic and shade tolerant species such as red maple, blackgum, and eastern white pine, and encouraged fire adapted species, especially yellow pines such as pitch, Virginia, shortleaf, and table mountain pine, and some oak species such as scarlet and chestnut oak. Pine-Oak Forests under these conditions likely appeared across the landscape as a mosaic of open woodlands and closed canopy forests dominated by pine species and some oak species (Harrod et al. 1998).

Current Conditions and Trends

Pine-Oak Forests include yellow pine, white pine, and white-pine-xeric oak forests, and occur in wide-ranging environments generally between 275 to 1,370 m (900 to 4,500 ft) at varying aspects and landscape positions. Where these forests occur on xeric ridges and exposed south- to west-facing slopes, common overstory species include pitch pine, Virginia pine, eastern white pine, table mountain pine, and shortleaf pine. Other common overstory species include chestnut oak, and scarlet oak. Subcanopies in these forests are dominated by shade tolerant species including blackgum, eastern white pine, red maple, eastern hemlock, and sourwood. Shrub layer densities vary, but can include great rhododendron, mountain laurel, blueberry, huckleberry, American chestnut, and others.

The condition of Pine-Oak Forests in many areas is declining due to several stressors. Perhaps most important is fire exclusion, which has led to reductions in pine and oak regeneration, increased leaf litter and duff thickness, exacerbated southern pine beetle outbreaks, increased mountain laurel density, and decreased overall herb abundance and diversity (Jenkins 2007).

Fire Exclusion

Relatively frequent, low- to medium-intensity fires are critical to the establishment and maintenance of Pine-Oak Forests. There is strong evidence of a long history of frequent burning across much of the eastern U.S., including the Appalachian mountain forests. Radio-carbon dated charcoal fragments suggest relatively frequent, stand-level fires occurred throughout a significant portion of the Holocene in and around the park (Fesenmyer and Christensen 2010, Underwood 2013). Historically, frequent burning is also supported by more direct evidence. Observations during forest exams conducted at the turn of the 20th century documented widespread fires throughout the southern Appalachians (Ayers and Ashe 1905). Aldrich et al. (2014) examined cross sections of fire-scarred pine trees growing in pine-dominated patches within a hardwood matrix in the central Appalachians, and found evidence of fires back to the 17th and 18th centuries, with a fire return interval averaging between six and eight years.

Within the park, cross sections of pine taken from the Licklog Ridge area showed evidence of frequent fires for at least two centuries prior to the implementation of fire suppression policies in the early 1900s (Flatley et al. 2013). LaForest (2012) studied tree-ring chronologies from three lower elevation Pine-Oak Forests in the western portion of the park, and concluded that wildfire events occurred frequently prior to park establishment and peaked in the 1800s, with an average fire return interval of two years. Harmon (1982) reported that between 1856 and 1940, the fire rotation intervals on the western side of the park were between 10 and 40 years. After fire suppression policies were in place, the fire return intervals increased to over 2,000 years.

Whether human-caused or natural, it is clear that the relatively frequent fire regime under which Pine-Oak Forests evolved has been largely absent since the park's establishment. The lack of fire has caused compositional and structural changes to Pine-Oak Forests (Harrod et al. 1998, Harrod and White 1999, Underwood 2013, Flatley et al. 2015). Decades of fire suppression have led to increases in the overstory density of mesophytic species and suppression of shade intolerant species such as oaks and pines. The lack of fire has also increased litter and duff thickness in the forest floor, impeded pine regeneration and growth, and reduced the abundance and diversity of herbaceous vegetation (Jenkins 2007).

The park is now using prescribed burning in an attempt to preserve and restore table mountain, shortleaf, and pitch pines, and their associated communities (Fig. 4.5.3.2). Jenkins et al. (2011) found that successful regeneration of yellow pine species required significant reductions in overstory, understory, and shrub densities of existing stands, as well as a duff thickness of less than 4 cm (1.6 in), but cautioned that these changes were best achieved over a course of multiple burns. The results of this research make it apparent that a significant amount of management may be required to reverse the downward trend of Pine-Oak Forests in the park.

Figure 4.5.3.2. Prescribed burn used to thin hardwood understory in Great Smoky Mountains National Park. Source: NPS Photo 2015.

Southern Pine Beetle

Southern pine beetle (SPB) is a native insect that has evolved with its pine hosts. Research conducted within the park indicates that pine forests, SPB, and fire form a triangle of interaction. By killing trees (Fig. 4.5.3.3), the beetles dramatically increase the dry, resinous fuels which cause fires to burn more intensely, which then creates the mineral soil seedbed required for pine germination (NPS 2014a). Fires also reduce the density of the forest overstory, which allows individual trees to maintain more vigor. Ecologists speculate that years of fire suppression exacerbate the impacts SPB on Pine-Oak Forests, making stands more susceptible to SPB outbreaks, particularly during periods of drought. Canopy die-off due to SPB makes forests more susceptible to exotic-invasive trees, such as princess tree (*Paulownia tomentosa*) and tree of heaven (*Ailanthus altissima*).

Figure 4.5.3.3. Southern pine beetle induced mortality in Great Smoky Mountains National Park. Source: NPS 2012.

Climate Change

Pine-Oak Forests appear to be on a downward trend due to fire suppression and the southern pine beetle. However, a warming atmosphere may counteract this trend, as suitable habitat for these forests expands northward in the eastern U.S. Along with an overall warming trend in the southeastern U.S., associated extreme heat and drought events in some areas may encourage an increase in wildfire (Karl et al. 2009). A low climate emissions scenario indicates moderate Pine-Oak expansion in the park and its vicinity, while a high emissions scenario predicts Pine-Oak Forests would expand throughout the park, as well as the whole of the southern Appalachian Mountains terminus. Importance values of the species that characterize these forests are projected to increase within the park under both low and high emissions scenarios (Table 4.5.3.1).

A combination of SPB outbreaks and decades of fire suppression in the park have resulted in species composition and forest structural shifts in the park’s Pine-Oak Forests. These shifts are suppressing yellow pine and oak regeneration and allowing white pine and fire-intolerant hardwood species to become more dominant. Subsequent research in the western portion of the park indicates that significant reductions in forest density and duff thickness are likely necessary to restore yellow pine-oak forests. Climate change poses a complicating factor. Models suggest that habitats for Pine-Oak Forests may expand in the park, suggesting climate change may counter the effects of fire suppression and SPB. However, it would not be assured that Pine-Oak Forests would develop in these areas if habitats changed in response to climate. Climate change could also lead to greater concerns with fire control.

Table 4.5.3.1. Projected importance values of species characteristic of Pine-Oak Forests under high and low emissions scenarios. Source: Landscape Change Research Group 2014.

Common Name	Scientific Name	Model reliability [A]	Mod CurIV [B]	GCM3 AvgHi [C]	GCM3 AvgLo [D]
Short-leaf pine	*Pinus echinata*	1	1.41	6.46	1.08
Table mountain pine	*Pinus pungens*	2	0.58	0.57	0.37
Pitch pine	*Pinus rigida*	1	1.49	0.27	0.12
Eastern white pine	*Pinus strobus*	1	3.84	2.03	2.52
Virginia pine	*Pinus virginiana*	1	3.44	1.03	1.04
Chestnut oak	*Quercus prinus*	1	6.48	-1.44	-0.28
Scarlet oak	*Quercus coccinea*	1	3.12	-1.37	-0.06
White oak	*Quercus alba*	1	3.51	2.1	1.04
Pignut hickory	*Carya glabra*	1	1.89	-0.15	0
Mockernut hickory	*Carya tomentosa*	1	1.99	0.1	-0.2
Red maple	*Acer rubrum*	1	12.38	-5.86	-1.4
Flowering dogwood	*Cornus florida*	1	4.62	-0.49	-0.15
Redbud	*Cercis canadensis*	2	0.3	0.79	0.01
Sourwood	*Oxydendrum arboretum*	1	3.89	-0.64	-0.25

A. Model reliability: 1=high; 2= medium; 3=low

B. AvgHi: General Circulation Models (three different models and their averages) under a high emission level scenario (current trend).

C. AvgLo: General Circulation Models (three different models and their averages) under a low emission scenario (conservation measures are put into place).

Confidence and Data Gaps

Regional and park research has documented species composition and structural shifts in the Pine-Oak Forests following fire suppression. The combined effects of southern pine beetle outbreaks and fire suppression have encouraged more mesic species in areas once occupied by Pine-Oak Forests. We assign a decreasing trend warranting a moderate concern. We have a medium level of confidence in this assessment (Table 4.5.3.2).

Sources of Expertise

- Troy Evans, Forest Ecologist, Great Smoky Mountains National Park
- Kristine Johnson, Supervisory Forester, Great Smoky Mountains National Park
- Rob Klein, Fire Ecologist, Great Smoky Mountains National Park
- Tom Remaley, Inventory and Monitoring Coordinator, Great Smoky Mountains National Park

Summary Condition

Table 4.5.3.2. Summary condition and trend graphic for Pine-Oak Forests.

Resource	Indicator	Status and Trend	Rationale and Reference Conditions
Focal Species or Communities	Pine-Oak Forests	⇩	Reference condition is a mosaic of open woodlands and closed canopy forests dominated by pine species and some oak species, especially chestnut and scarlet oaks, with a rich herbaceous layer. Concerns include reductions in pine and oak regeneration, increased litter and duff thickness, exacerbated southern pine beetle outbreaks, increased mountain laurel density, and decreased overall herb abundance and diversity.

4.5.4. High-elevation Hardwood Forests

Relevance

The park's High-elevation Hardwood Forests, which represent 24% of park area (Fig. 4.5.4.1), are one of the largest relatively undisturbed forests in the U.S. (Vandermast 2005). There are 11 associations within this class, four of which are imperiled communities (White et al. 2003) (Table 4.5.1.1). These forests provide habitat for numerous wildlife species that also rely on adjacent spruce-fir forests.

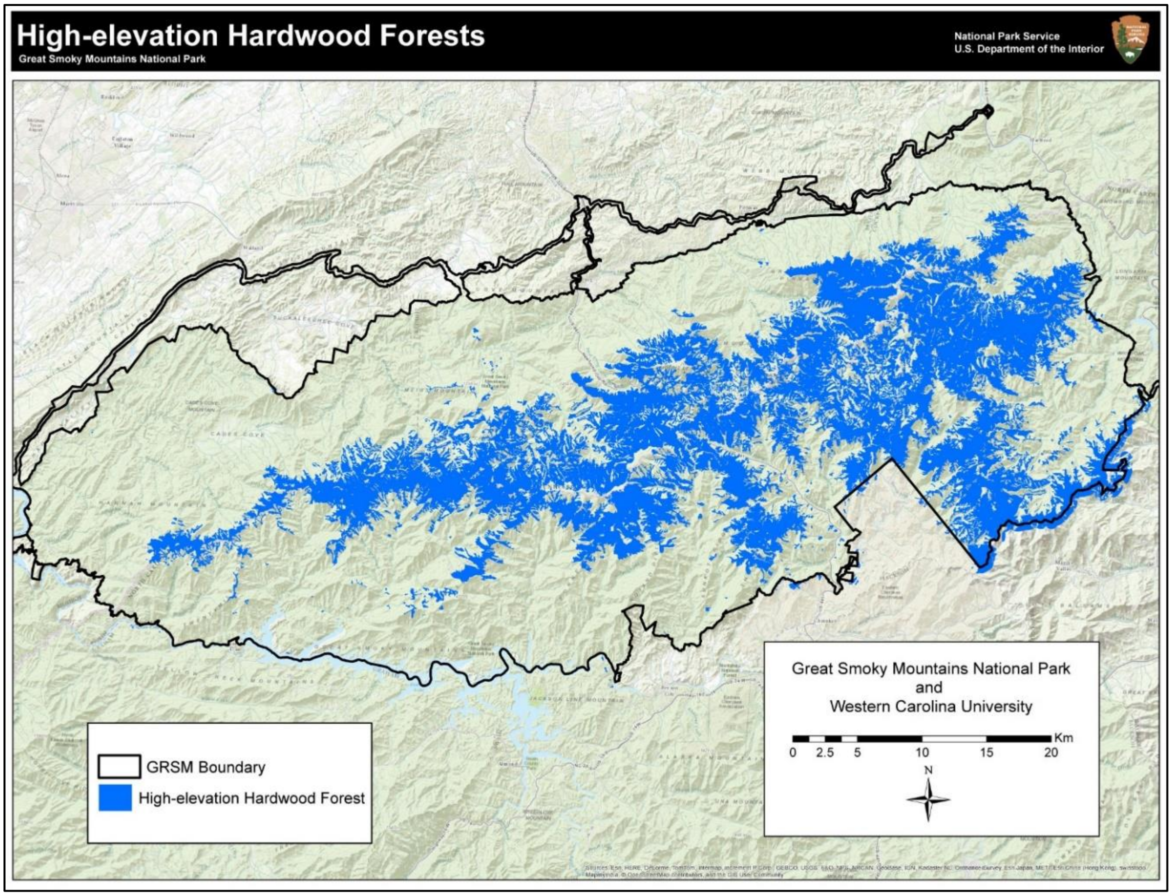

Figure 4.5.4.1. High-elevation Hardwood forests comprise 24% of the park's forests. Source: White et al. 2003.

Data and Methods

See section 4.5.1.

Reference Conditions

Reference conditions for High-elevation Hardwood Forests reflect conditions that existed prior to European settlement, as reflected in the range of stand conditions described below. These forests occur at elevations above 1,040 m (3,412 ft) in areas with a cool climate and abundant rainfall. Dominant tree species include yellow birch, American beech, yellow buckeye, and sugar maple. In high-elevation beech forests (Fig. 4.5.4.2), beech density may exceed 90% (Russell 1953). Areas with more exposed southerly aspects are often dominated by northern red oak or white oak. Sites with more northerly aspects contain a number of northern hardwood species including yellow birch, sugar maple, yellow buckeye, and American beech (Jenkins 2007). Habitats may be quite variable with understory vegetation ranging from dense rhododendron to open sedge. Numerous potential combinations of herbaceous and shrub components exist.

Figure 4.5.4.2. Beech gap community in Great Smoky Mountains National Park. Source: NPS Photo 2013.

Conditions and Trends

High-elevation Hardwood Forests occur between 1,040 m (3,412 ft) and as high as 1,645 m (5,397 ft). Soils tend to be very acidic, having pH values as low as 3.5 in some areas. This forest type includes high-elevation oak forests, forested boulderfields, and beech gap forests that are considered climax communities (Jenkins 2007). Typically, regeneration results from natural disturbances such as ice damage that cause limbs to break or trees to fall creating gaps in the formerly closed canopy (NC Wildlife Commission 2014). Several stressors are impacting high-elevation forests with the potential to significantly impact species composition and forest structure. These include diseases, wild hogs, air pollution, and climate change.

Beech Bark Disease

Beech gap communities are one of the most threatened communities in the southern Appalachians due to beech bark disease (BBD). BBD is a disease complex caused by the beech bark scale (*Cryptococcus fagisuga*), which creates infection sites for various species of *Nectria* fungus, leading to tissue death, cankering, and in many cases tree mortality. The disease first became apparent around 1993 (Vandermast 2005), and approximately a decade later, BBD had caused heavy beech mortality. In 1994, park staff installed 10 long-term plots in beech forests and observed an increase in BBD severity in 2004, and by 2012, all plots showed high mortality of mature beech trees, although small trees were abundant (Fig. 4.5.4.3; NPS 2014a). Some plots responded with a dense growth of blackberry (*Rubus* spp.) while other plots have had prolific regeneration of beech root suckers from parent trees. However, since the root sprouts are genetically identical to the parent trees, the offspring will also be susceptible to BBD. The U.S. Forest Service (2013) estimated that there will be a 26% reduction in beech basal area between 2013 and 2027 (Fig. 4.5.4.4).

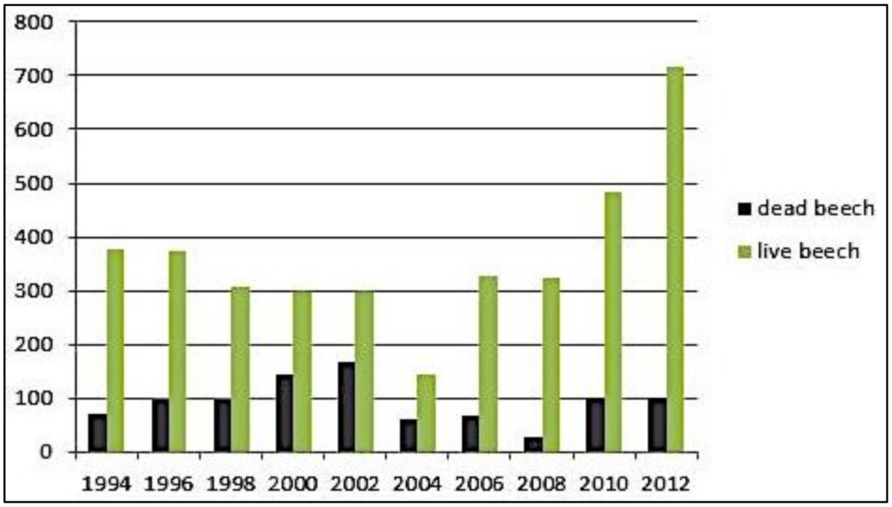

Figure 4.5.4.3. Number of live and dead American beech in monitoring plots >3.5 cm diameter at breast height. Source: NPS 2014a.

European Wild Hog

High-elevation Hardwood Forests are the preferred summer habitat for European wild hog (*Sus scrofa*) (Howe et al. 1981), and they have severely impacted these forests through their rooting and grazing, which disturbs soils and eliminates understory plants. In mesic sites within beech forests, hogs have been found to reduce understory cover from nearly 100% to as low as 2% (Bratton 1975). Additionally, High-elevation Hardwood Forests are home to a large number of salamanders that are consumed by wild hogs (Jolley et al. 2010). Hog damage to beech also facilitates beech bark disease.

Ozone

The effects of ozone damage on plant species in High-elevation Hardwood Forests are greater than in lower elevation communities because total ozone exposure is greater in higher elevations. High ozone levels disrupt a plant's ability to photosynthesize, thus causing reduced growth of leaves, stems, and roots (Somers et al. 1998). Ultimately, reduced vigor and increased stress causes plants to become more susceptible to insect and disease attacks.

Acid Deposition

High-elevation Hardwood Forests have long experienced high levels of acid deposition (Shaver et al. 1994, SAMI 2002). Higher elevations in the park experience long exposures to cloud water containing sulfate, nitrate, and ammonium. Acid deposition has reduced the soil's acid buffering capacity and increased the acidity of soils at higher elevations. Vandermast (2005) found significant declines in high-elevation deciduous forest integrity. He also found a reduction in basal area and stem density, and these were correlated with increases in soil aluminum, increased soil acidity, and a reduction in soil base cations.

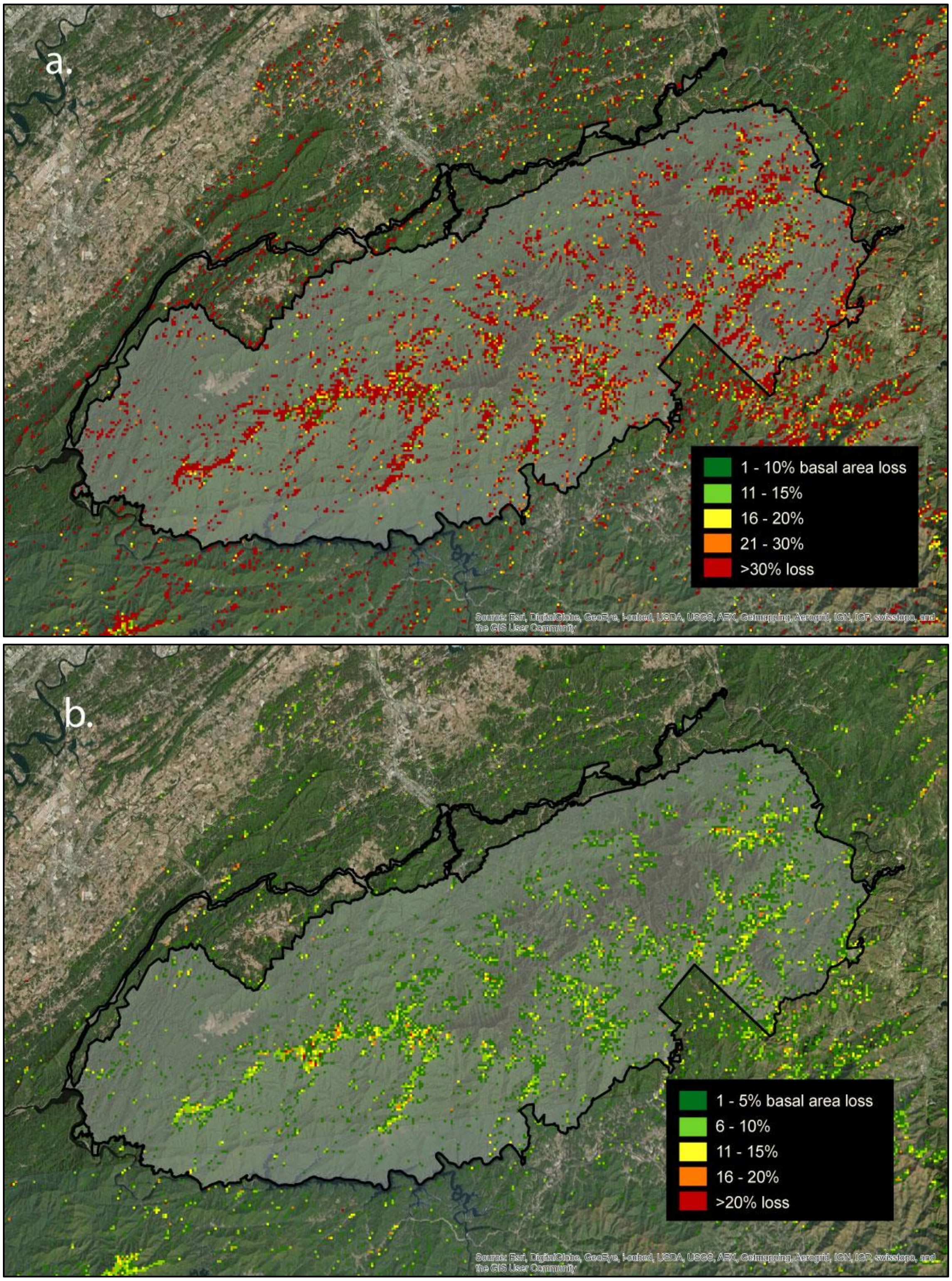

Figure 4.5.4.4. (a) Models indicate a 26% loss of beech due to beech bark disease between 2013 and 2027; (b) With all tree species in the park combined, the predicted loss is 1%. Source: U.S. Forest Service.

Climate Change

Climate change could significantly reduce the occurrence of High-elevation Hardwood Forests. Carbon emission models predict that the importance values for six of the seven characteristic species for which data are available in High-elevation Hardwood Forests will likely decrease (Table 4.5.4.1). American beech, yellow birch, sugar maple and other high-elevation forest species require cool areas with abundant precipitation. With higher temperatures and less precipitation, these species will likely become less abundant, migrate to the highest elevations in the park, or may even disappear from the park completely.

Overall, the quality and composition of High-elevation Hardwood Forests is threatened by European wild hog grazing and rooting, beech bark disease, and acid deposition. With soil degradation, beech mortality, and acid deposition, these threats and stressors may have far-reaching effects for the overall quality and composition of the High-elevation Hardwood Forests. Additionally, climate change may reduce key species' ranges in the future. Therefore, a decreasing trend with a moderate level of concern is assigned to High-elevation Hardwood Forests in the park.

Table 4.5.4.1. Projected importance values of species characteristic of High-elevation Hardwood Forests under high and low emissions scenarios. Data source: Landscape Change Research Group 2014.

Common Name	Scientific Name	Model reliability^{A}	Mod CurIV ^{B}	GCM3 AvgHi ^{C}	GCM3 AvgL ^{D} o
American beech	*Fagus grandifolia*	1	5.21	-2.52	-2.69
Northern red oak	*Quercus rubra*	1	4.54	-1.15	-0.86
Yellow birch	*Betula alleghaniensis*	1	2.27	-0.42	-0.42
White oak	*Quercus alba*	1	3.51	2.1	1.04
Sugar maple	*Acer saccharum*	1	4.79	-2.95	-1.45
Yellow buckeye	*Aesculus flava*	2	1.24	-0.04	-0.04
Pin cherry	*Prunus pensylvanica*	N/A	N/A	N/A	N/A
Mountain ash	*Sorbus americana*	N/A	N/A	N/A	N/A
Eastern hemlock	*Tsuga canadensis*	1	4.83	-0.32	-0.15
Mountain maple	Mountain maple	N/A	N/A	N/A	N/A

A. Model reliability: 1=high; 2= medium; 3=low

B. ModCurIV: Modeled current importance values of species in park

C. AvgHi: General Circulation Models (three different models and their averages) under High emission levels scenario (current trend).

D. AvgLo: General Circulation Models (three different models and their averages) Under Low emissions scenario (conservation measures are put into place).

Confidence and Data Gaps

Heavy mortality from beech bark disease in High-elevation Hardwood Forests is well documented and beech gap communities are now one of the most endangered communities in the southern Appalachian Mountains. European wild hogs are continually monitored and population control plans are in place; however, the hogs continue to disturb soils to the extent that understory native species are being eliminated in this forest. Acid deposition has been found to indirectly decrease the basal area and density in many tree species in this forest, and most of the key species are projected to decrease in importance by 2100, due to climate change. With this decrease, a shift in species composition will occur, which will likely bring major changes to the habitat and overall ecological system of the High-elevation Hardwoods Forests. Stressors to this community type are known; therefore, we assign a high confidence level to this assessment (Table 4.5.4.2).

Sources of Expertise

- Troy Evans, Forest Ecologist, Great Smoky Mountains National Park
- Kristine Johnson, Supervisory Forester, Great Smoky Mountains National Park
- Rob Klein, Fire Ecologist, Great Smoky Mountains National Park
- Keith Langdon, Inventory and Monitoring Coordinator (retired), Great Smoky Mountains National Park
- Tom Remaley, Inventory and Monitoring Coordinator, Great Smoky Mountains National Park

Summary Condition

Table 4.5.4.2. Summary condition and trend graphic for the High-elevation Hardwood Forests.

Resource	Indicator	Status and Trend	Rationale and Reference Conditions
Focal Species or Communities	High-elevation Hardwood Forests	⇩	Reference conditions include a mosaic of stands with a high component of northern hardwood species, intact and undisturbed soils, and a dense and diverse herbaceous layer in most areas. Impacts include disease, wild hogs, acidic deposition, and climate change, causing reductions in basal area and density of key species, soil acidification and physical disturbances, reductions in herbaceous vegetation and soil fauna.

4.5.5. Cove Forests

Relevance

Cove Hardwood Forests are the most floristically diverse hardwood community in the park, contributing greatly to its biodiversity. White et al. (2003) lists three Cove Hardwood associations that account for about 12% of park area (Fig. 4.5.5.1).

Data and Methods

See section 4.5.1.

Reference Conditions

Reference conditions for Cove Hardwood Forests consist of a mosaic of uneven-aged forests with dense tree canopies and rich herbaceous layers. They typically occur in protected positions on some of the most productive soils in the park and support a large number of mesic tree, shrub, and herbaceous species.

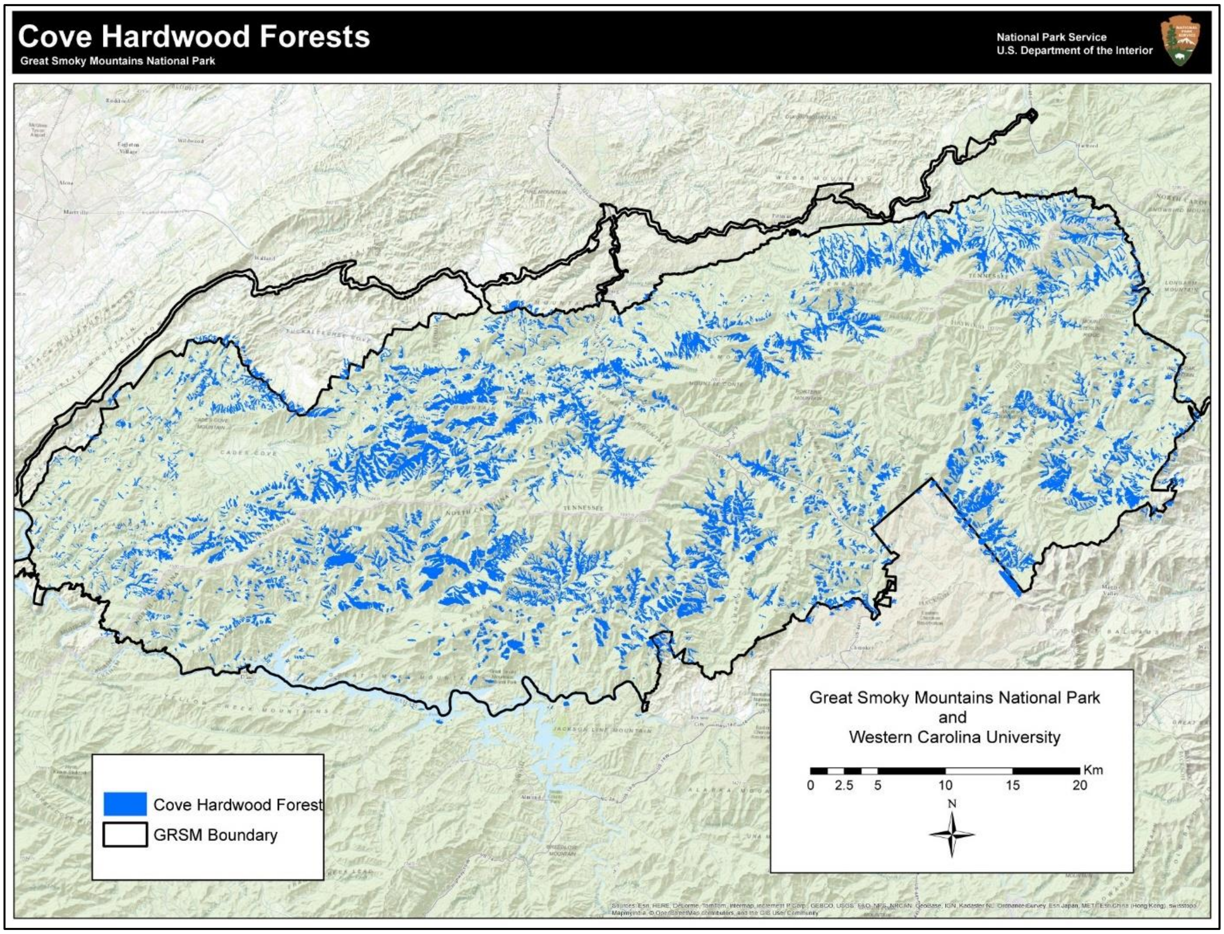

Figure 4.5.5.1. Cove Hardwood Forests comprise about 12% of the park’s area. Source: White et al. 2003.

<u>Current Conditions and Trends</u>

The park’s Cove Hardwood Forests typically have an open midstory with woodland herbs including trillium and ferns thriving below the tree canopy. Common trees are tulip poplar, red maple, yellow buckeye, white ash, basswood, and cucumber tree (*Magnolia acuminata*). Cove forests support a diversity of species, and as such, they contain a number of species that are potential targets for native and non-native insect and disease pests, air pollution, and climate change. However, the species diversity found in these forests may make them more resilient to these stressors than other forest communities. Important stressors to this community include:

Ozone

Ozone has been shown to have negative effects on foliage and growth in many plant species and ultimately may cause compositional shifts (SAMI 2002). Cove hardwood species that are particularly susceptible to elevated ozone levels include tulip poplar, white ash, green ash (*Fraxinus pennsylvanica*), black cherry, and redbud (*Cercis canadensis*) (NPS 2003).

Emerald Ash Borer

Emerald ash borer (EAB; *Agrilus planipennis*) (Fig. 4.5.5.2), a non-native beetle from Asia, was first found in the park in 2012. It attacks both white and green ash species, which are found in Cove Hardwood Forests. Infested trees can die within three to four years after successive branch die-back.

Figure 4.5.5.2. Emerald ash borer. Source: Leah Bauer USDA Forest Service N. Research Station, Bugwood.org.

In 2012 six EABs were found in detection traps at the Sugarlands Visitor Center and at the entrance to Greenbrier. In the fall of the same year, several ash trees were found with advanced EAB infestations along Injun Creek and along the Gatlinburg Trail. The park implemented a treatment plan in 2013 that included systemic insecticide treatment of trees in developed areas, and at selected ash-dominated backcountry stands. In March 2015, the park implemented a policy to allow only heat-treated firewood to enter the park. It is hoped that this will slow the spread of EAB from infested areas.

Dutch Elm Disease/Elm Yellows

There are two diseases that infect American elm (*Ulmus americana*), slippery elm (*Ulmus rubra*), and winged elm (*Ulmus alata*), which commonly occur in Cove Hardwood Forests. Dutch elm disease (DED) is a fungus that is transmitted by elm bark beetles. Elms become particularly susceptible to DED when beetles carrying the fungus reach the canopy and start to feed. USDA Agricultural Research Service geneticists have identified elms resistant to DED, and disease-free seedlings are now available (NPS 2014a). A second disease, elm yellows, is a mycoplasma-like organism transmitted by leafhoppers. Initial visible symptoms of the disease include yellowing of foliage in summers.

Thousand Cankers Disease

Thousand cankers disease (TCD) is the result of attack by the walnut twig beetle (*Pityophthorus juglandis*) and subsequent canker development around beetle galleries caused by a fungal associate (*Geosmithia morbida*). The first eastern U.S. infection appeared in July 2010 when it was identified in Knoxville, TN. In 2012 a survey of black walnut trees was conducted in the park, and samples from the North Caroline side of the park (Haywood County) were screened and confirmed positive for TCD. Since this was the first report of TCD in North Carolina, the North Carolina Department of Agriculture implemented a quarantine on unprocessed walnut wood from Haywood County (NPS 2014a).

Butternut Canker

The butternut canker (*Ophiognomonia clavigigenenti-juglandacearum*) is a stem-canker fungus that causes cankers to appear on the trunk, limbs, and twigs (Fig. 4.5.5.3). It can also penetrate the nut, causing it to abort. Although black walnut may be infected, the fungus is lethal only to the butternut.

Figure 4.5.5.3. Canker on butternut. Source: Mike Ostry, U.S. Forest Service.

The park has been monitoring 70 trees from 1987 to 2010, and all have become infected with the fungus; however, it was noted that trees in full sun grow vigorously, heal their cankers, and reproduce successfully (NPS 2014a). Without disturbance, butternut regeneration will continue to be restricted to road and stream corridors since they are shade intolerant.

Climate Change

Cove Hardwood Forests occur in cool, moist environments. Climate change projections show that conditions could become warmer and drier, and this would negatively impact many species that are common to Cove Hardwood Forests. The importance values of eight of 11 species that are characteristic of Cove Hardwood Forests are projected to decrease under both high and low carbon emission scenarios (Table 4.5.5.1).

Overall, conditions of Cove Hardwood Forests are currently declining and are of moderate concern. Ozone levels have declined in recent years; however, it will remain a stressor in the foreseeable future, and sensitive species will require on-going monitoring. With the recent detection of emerald ash borer inside the park’s boundaries, ash species will also need to be monitored and treated where practical. Diseases including Dutch elm and butternut canker are lethal to several of the park's native trees. Climate change models indicate that many species characteristic of Cove Hardwood Forests may decline over the century.

Confidence and Data Gaps

Diseases and pests inside the park are currently being monitored. The long-term effects of the emerald ash borer, thousand cankers disease, and butternut canker have yet to be determined; however, the latter two diseases are currently undermining some tree species' health. Additionally, climate change models indicate that many species may decline in importance over the next 100 years. Therefore, we assign a medium level of confidence to this assessment (Table 4.5.5.2).

Table 4.5.5.1. Projected importance values of species characteristic of Cove Hardwood and Acid Cove Forests under high and low emissions scenarios. Source: Landscape Change Research Group 2014.

Common Name	Scientific Name	Model reliability[A]	Mod CurIV [B]	GCM3 AvgHi [C]	GCM3 AvgLo [D]
American beech	*Fagus grandifolia*	1	5.21	-2.52	-2.69
Northern red oak	*Quercus rubra*	1	4.54	-1.15	-0.86
Yellow birch	*Betula alleghaniensis*	1	2.27	-0.42	-0.42
Sweet birch	*Betula lenta*	1	3.47	-1.27	-0.66
White oak	*Quercus alba*	1	3.51	2.1	1.04
Yellow buckeye	*Aesculus flava*	2	1.24	-0.04	-0.04
Eastern hemlock	*Tsuga canadensis*	1	4.83	-0.32	-0.15
Silverbell	*Halesia tetraptera*	2	1.71	0.47	0.61
Fraser magnolia	*Magnolia fraseri*	N/A	N/A	N/A	N/A
Tulip poplar	*Liriodendron tulipifera*	1	6.22	-2.82	-0.82
American basswood	*Tilia americana*	1	0.36	0.35	0
Sugar maple	*Acer saccharum*	1	4.79	-2.95	-1.45

A. Model reliability: 1=high; 2= medium; 3=low

B. ModCurIV: Modeled current importance values of species in park

C. AvgHi: General Circulation Models (three different models and their averages) under High emission levels scenario (current trend).

D. AvgLo: General Circulation Models (three different models and their averages) Under Low emissions scenario (conservation measures are put into place).

Sources of Expertise

- Troy Evans, Forest Ecologist, Great Smoky Mountains National Park
- Kristine Johnson, Supervisory Forester, Great Smoky Mountains National Park
- Tom Remaley, Inventory and Monitoring Coordinator, Great Smoky Mountains National Park

Summary Condition

Table 4.5.5.2. Summary condition and trend graphic for Cove Hardwood Forests.

Resource	Indicator	Status and Trend	Rationale and Reference Conditions
Focal Species or Communities	Cove Hardwood Forests	⬇	Reference conditions for Cove Hardwood Forests consist of a mosaic of uneven-aged forests with dense tree canopies and rich herbaceous layers. They typically occur in protected positions on some of the most productive soils in the park and support a large number of mesic tree, shrub, and herbaceous species.

4.5.6. High-elevation Spruce-Fir Forests

Relevance

High-elevation Spruce-Fir Forests represent about 3% of park area (Fig. 4.5.6.1). The park contains 74% of all High-elevation Spruce-Fir Forests in the southern Appalachians, providing an important refugium for this ecosystem (Dull 1988). White et al. (2003) identified eight associations within High-elevation Spruce-Fir Forest, all of which are imperiled (Table 4.5.1.1). Considered a relict vegetation community, High-elevation Spruce-Fir Forests are at their southern limit in the Smokies, are topographically and geographically isolated, and are rich in rare and endemic species. High-elevation Spruce-Fir Forests host a number of nationally and globally rare bryophytes, and are also home to the federally endangered spruce-fir moss spider (*Microhexura montivaga*), and Fraser fir, which is a federal species of concern (NPS 2014a). Many species found in the park's spruce-fir forests are typically found in more northern locales. It is theorized that they have either evolved here or after being isolated from their northern cousins after the last ice age, have remained in small areas where the high elevation provides conditions similar to more northern latitudes (NC Wildlife Commission 2014c).

Data and Methods

See section 4.5.1.

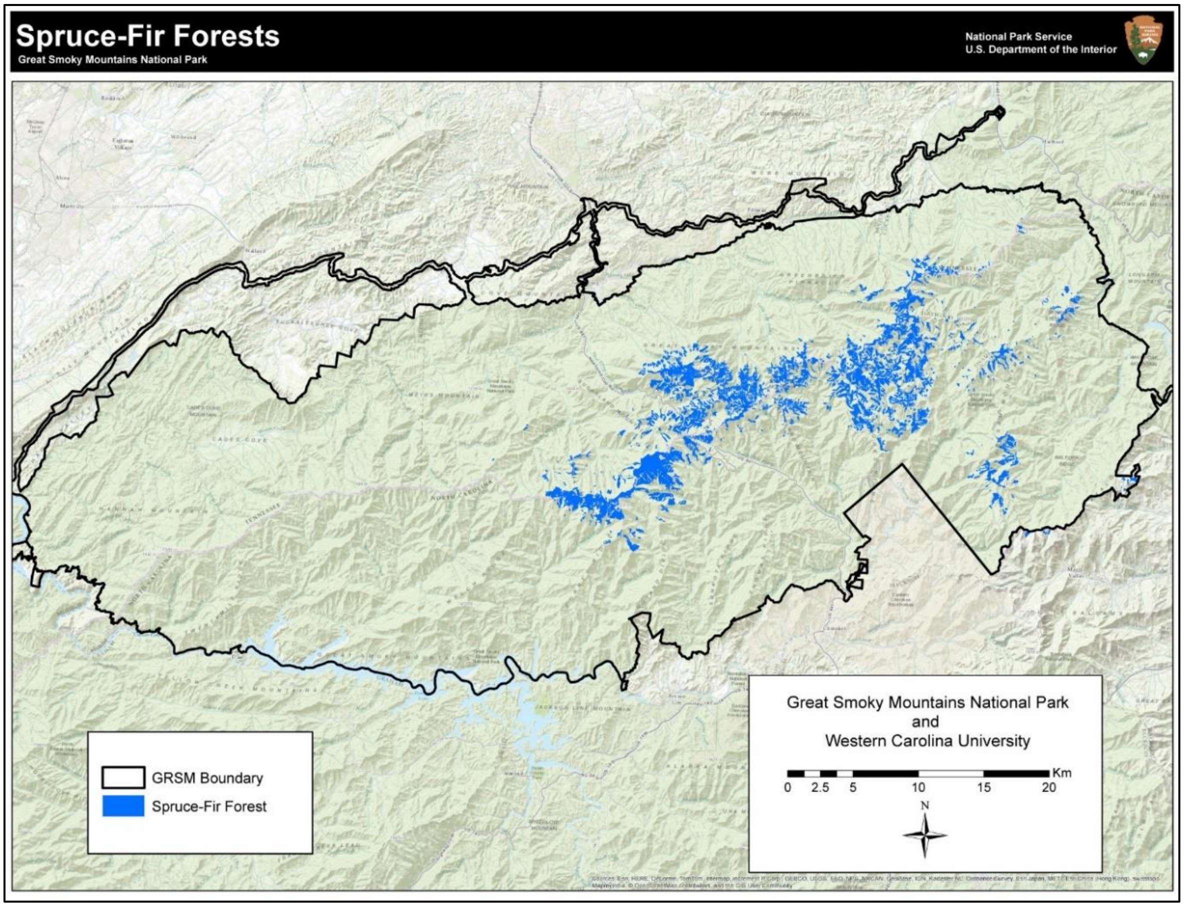

Figure 4.5.6.1. High-elevation Spruce-Fir Forests comprise about 3% of the park’s forests. Source: White et al. 2003.

Reference Conditions

Reference conditions for the park’s High-elevation Spruce-Fir Forests consist of forests growing on a well-developed organic soil layer, and with a dense, healthy overstory dominated by red spruce, Fraser fir, and yellow birch. Additionally, these forests are mostly uneven-aged forests formed by a disturbance pattern where small gaps are created due to mortality of individual or small groups of trees (White et al. 1985).

Conditions and Trends

High-elevation Spruce-Fir Forests occur at the very highest elevations in the park down to about 1,200 m (3,937 ft), and are dominated by varying combinations of red spruce and Fraser fir. Common hardwood species in these communities include yellow birch, mountain maple (*Acer spicatum*), pin cherry (*Prunus pensylvanica*), and American mountain ash (*Sorbus americana*); shrubs, grass, and sedge species also are abundant. High-elevation hardwood associations may occur as patches within spruce-fir forests. These forests in the park experience high amounts of moisture in the form of fog deposition and abundant rainfall. Soils vary from shallow rocky substrates to deeper mineral soils with well-developed organic layers in many areas. The environment in which these forests occur is harsh, and natural disturbance events including low temperatures, frost, ice, and high winds have a great influence. These forests have been greatly impacted by past land uses, as well as non-native insects, air pollution, and climate change.

Land use history

During World War I, timber companies logged red spruce on the high-elevation steep slopes in the park. The clear-cutting methods that were used, such as cable logging, caused tremendous damage to the soil organic layer, and often destroyed regenerating spruce and fir. High amounts of rainfall in logged areas then led to substantial erosion. Evidence of these events can still be seen today; for example, the grassy area on Mount Buckley is due to a logging slash fire in 1925, which was the same year as a severe drought (Fig. 4.5.6.2a; Pyle and Schafale 1988). Intensive logging also left long-term permanent patterns on the landscape (Figs. 4.5.6.2b, 4.5.6.2c).

These resulting conditions post-logging favored establishment of hardwoods such as pin cherry and yellow birch, and on some south-facing slopes where no tree species regenerated, large grassy areas are now prominent features in the landscape. Drying of the soil due to loss of the canopy, competition from hardwood and grass species, and erosion further deteriorated conditions for spruce-fir regeneration at high elevations. Pyle (1984) estimates that 25% of the original High-elevation Spruce-Fir Forests have converted to hardwood forests. Nicholas et al. (1999) found logging records indicating that red spruce used to be found at elevations lower than 1,200 m (4,000 ft); however, today, spruce-fir forests are restricted to elevations above 1,700 m (4,800 ft).

Activities such as logging, which result in rapid deforestation, have been linked to changes in fungi diversity and altered frequency of forest community re-establishment (Ingham and Thies 1996). Studies have also shown that associations between plant roots and rhizosphere microbes may limit the ability of plants to reestablish themselves (Klironomos 2002, Bardgett et al. 2005, Kardol et al. 2006). Baird et al. (2014), suggest that reductions in ectomycorrhizal fungi may have a negative effect on the re-establishment of Fraser fir in some areas.

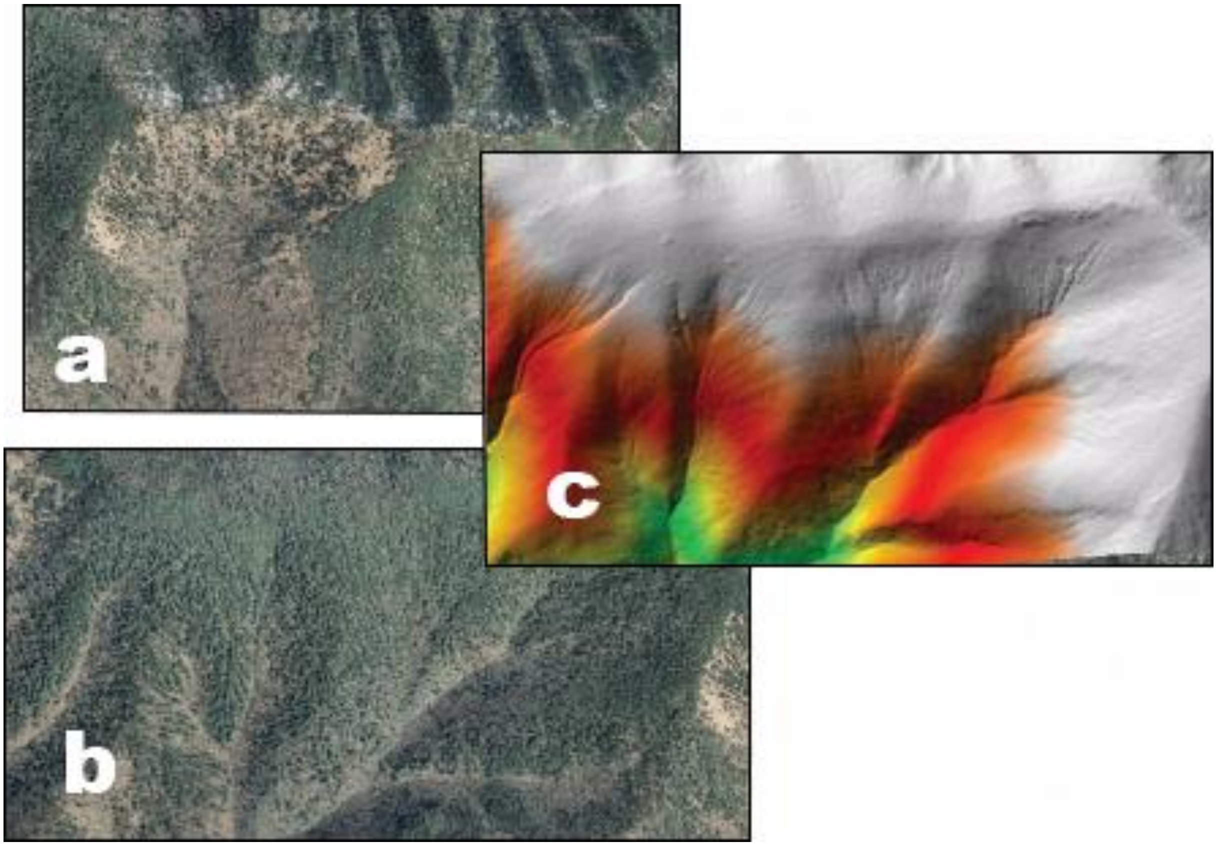

Figure 4.5.6.2. (a) High-intensity wildfires burned the organic soil and killed spruce and fir saplings decades ago; 100 years later, only intermittent shrubs and trees grow. (b) Herringbone pattern created by intense cable-logging can be seen today. (c) Lidar-derived digital elevation model showing scars left behind from cable logging. Source: Pyle and Schafale 1988.

Balsam Woolly Adelgid

The balsam woolly adelgid (BWA; *Adelges piceae*) is an exotic insect from Europe that was first detected in the park in 1963. BWA nymphs are dispersed by wind, birds, or other natural pathways, and once they are in a suitable place on a Fraser fir, the stylet mouthparts are inserted into the bark. Following a dormant period, the nymph begins actively feeding, which causes cell enlargement and disrupts water conduction to the tree crown. Ultimately, tree growth is inhibited and the tree eventually dies (Amman and Speers 1965). Approximately 91% of the park's mature fir trees died in 1963 following the introduction of BWA. Fir mortality over the years is evident throughout the highest elevations, and some of these areas have become choked with blackberry and other competing shrub species. In recent decades, BWA populations have been very low and heavily regenerated patches of young Fraser fir trees can be found.

Beginning in 1986, park staff began formally monitoring untreated trees on Mt LeConte, Clingmans Dome, Mt. Sterling, and along Balsam Mountain Road, for BWA density, crown ratio, number of cones, and diameter at breast height (NPS 2014a). The density of BWA has been found to vary greatly between individual trees, monitoring sites, and year, but overall has decreased substantially (G. Taylor, pers. comm. 2012). Vigorous fir regeneration was reported in some areas, including

Clingmans Dome, due to the loss of the tree canopy (NPS 2014a); however, as these trees mature, they may become infested with BWA, particularly if stressed by drought and warm temperatures. Franklin and Kaylor (2014) examined the trend of fir regeneration and BWA loading across 37 long-term monitoring plots, and found similar results.

BWA indirectly threatens other plant and animal species in High-elevation Spruce-Fir Forests. Busing and Pauley (1994) determined that although BWA does not directly affect red spruce, the proportion of red spruce mortality attributable to wind, post-fir mortality, increased from less than 60% to 90%. BWA and the resulting decline in Fraser fir trees have also resulted in breeding bird declines. For example, Rabenold et al. (1998) reported a 50% decline of all breeding birds at Mt. Collins. BWA-induced mortality is also a threat to T&E species, including high-elevation bryophytes, northern flying squirrel (*Glaucomys sabrinus*), and the spruce-fir moss spider.

The current state of Fraser fir varies greatly from site to site, but overall regeneration is strong and there is no evidence for a community type shift to hardwood-dominated forests. Also, current BWA levels are low, which leaves the future condition of regenerating stands unknown.

Air Pollution

Air pollution in the form of acid deposition has been linked to the decline of red spruce in the southern Appalachians. Wet, dry, and cloud water are the three primary pathways of acid deposition to a forest, and since high elevations in the southern Appalachians receive abundant rainfall and are frequently immersed in clouds, they are subject to some of the highest pollution loadings in the eastern U.S. Cloud water has higher concentrations of sulfate and nitrate than rainfall, and therefore it increases acid deposition two to four times than that of low elevations that receive only rain. High-elevation Spruce-Fir Forest soils are naturally acidic and therefore lack the buffering capacity necessary to reduce the impacts of acid deposition. This highly acidic environment results in nitrogen saturation and aluminum toxicity in soils. Consequently, it affects nutrient availability in the form of calcium and magnesium uptake, lowers the pH in leaf litter and soil, and leaches cations in the upper soil horizons. High levels of acid in the ever-present mist surrounding the forests may also result in foliar injury by causing cuticle damage and discoloration, followed by defoliation. Acid deposition has also been shown to predispose red spruce to freezing damage (Eager and Adams 1992).

Climate Change

High-elevation Spruce-Fir Forests may be particularly susceptible to climate change since they are restricted to their habitat by a narrow range of environmental conditions. The ecotone between High-elevation Spruce-Fir Forests and lower elevation deciduous forests is largely representative of climate-vegetation relationships in eastern North America. The typical elevations at which these forests have been found in the past have ranged from less than 1,000 m (3,280 ft) in its southernmost range during 18,000-12,000 BP, to greater than 1,700 m (5,580 ft) during the post-glacial temperature maximum around 5,000 BP. Future changes in climate, such as the changes occurring in the present day, will most likely continue to affect the range of this forest type (Delcourt and Delcourt 1993). High and low carbon emission scenarios show reduced importance values for red spruce and balsam fir (*Abies balsamea*) (Table 4.5.6.1). Rustad et al. (2012) suggest that suitable habitat for spruce-fir forests in the northeastern United States will disappear in the next 100 years (Fig. 4.5.6.3).

Table 4.5.6.1. Projected importance values of species characteristic of Spruce-Fir Forests under high and low emissions scenarios. Data source: Landscape Change Research Group 2014.

Common Name	Scientific Name	Model reliability[A]	Mod CurIV[B]	GCM3 AvgHi[C]	GCM3 AvgLo[D]
Red spruce	*Picea rubens*	1	1.51	-0.1	-0.11
Fraser fir/southern balsam fir	*Abies fraseri/Abies balsamea*	1	1.07	-1.07	-1.07
Yellow birch	*Betula alleghaniensis*	1	2.27	-0.42	-0.42
Mountain maple	*Acer spicatum*	N/A	N/A	N/A	N/A
Yellow buckeye	*Aesculus flava*	2	1.24	-0.04	-0.04
Pin cherry	*Prunus pensylvanica*	N/A	N/A	N/A	N/A
Mountain ash	*Sorbus americana*	N/A	N/A	N/A	N/A

A. Model reliability: 1=high 2=medium 3=low

B. ModCurIV: Modeled current importance values of species in park

C. AvgHi: General Circulation Models (three different models and their averages) under High emission levels scenario (current trend).

D. AvgLo: General Circulation Models (three different models and their averages) Under Low emissions scenario (conservation measures are put into place).

While the park’s highest elevations experience similar climate conditions to the northeastern U.S, the park’s High-elevation Spruce-Fir Forest habitats may not be as vulnerable to climate change as those in the northeast. Fridley (2009) modeled ground temperatures in the West Prong and Noland Creek watersheds and found that the high moisture levels, both in the soil and cloud cover, may buffer these ecosystems from the effects of future temperature increases.

Past land-use, exotic species, and air pollution have impacted High-elevation Spruce-Fir Forests by causing direct removal of tree populations, permanent changes in the physical environment, and adjustments in the biophysical environment. Climate change may also threaten these forests in the future. Significant alterations in the community composition have occurred since Euro-American settlement and the areal extent has decreased by as much as 35%. Based on the level of disturbance that has occurred in Spruce-Fir Forests, we assign a level of “significant concern” to this type; however, due to the abundant regeneration of fir, and the unknown future of BWA populations in GRSM, we assigned a stable trend (Table 4.5.6.2).

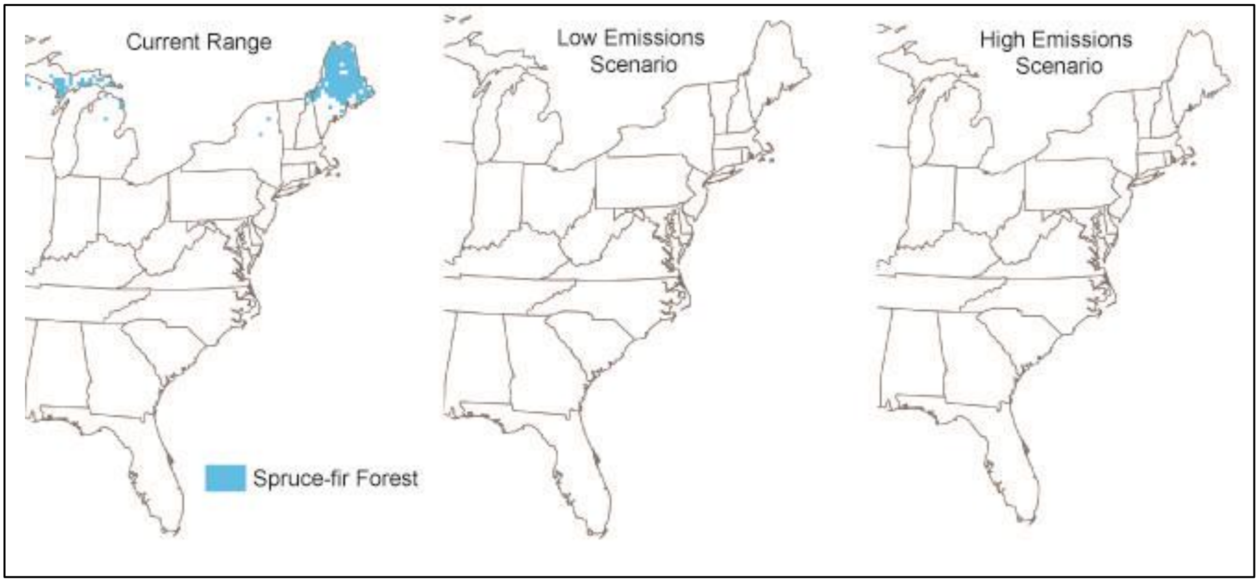

Figure 4.5.6.3. Emissions scenarios indicate the northeastern U.S. Spruce-Fir Forests will disappear by the year 2100. Source: USFS 2015.

Confidence and Data Gaps

There is well-documented evidence on the negative impacts associated with past land use, atmospheric pollution, and the balsam woolly adelgid on these forests. Therefore, we assign a high confidence level to this assessment.

Sources of Expertise

- Troy Evans, Forest Ecologist, Great Smoky Mountains National Park
- Kristine Johnson, Supervisory Forester, Great Smoky Mountains National Park
- Rob Klein, Fire Ecologist, Great Smoky Mountains National Park
- Tom Remaley, Inventory and Monitoring Coordinator, Great Smoky Mountains National Park

Summary Condition

Table 4.5.6.2. Summary condition and trend graphic for the High-elevation Spruce-Fir Forests.

Resource	Indicator	Status and Trend	Rationale and Reference Conditions
Focal Species or Communities	High-elevation Spruce-Fir Forests	↔	Reference conditions consist of uneven-aged forests dominated by a dense, healthy overstory dominated by red spruce, Fraser fir, and yellow birch growing on a well-developed organic soil layer. Impacts include Balsam wooly adelgid and acid deposition.

4.5.7. Early Successional Forests

<u>Relevance</u>

Early Successional Forests are very common in the southern Appalachians. In the park, they consist of four associations and cover about 4% of its area (Fig. 4.5.7.1). These areas are transitional in nature, where the forest is regenerating on abandoned agriculture land, areas of historic heavy settlement, or heavily logged areas. At the park's inception, nearly all of the level valleys were about to transition from areas of settlement and agricultural activity to Early Successional Forest. Jenkins (2007) notes that many stands of this forest type were formerly Montane Alluvial or Cove Hardwood Forest.

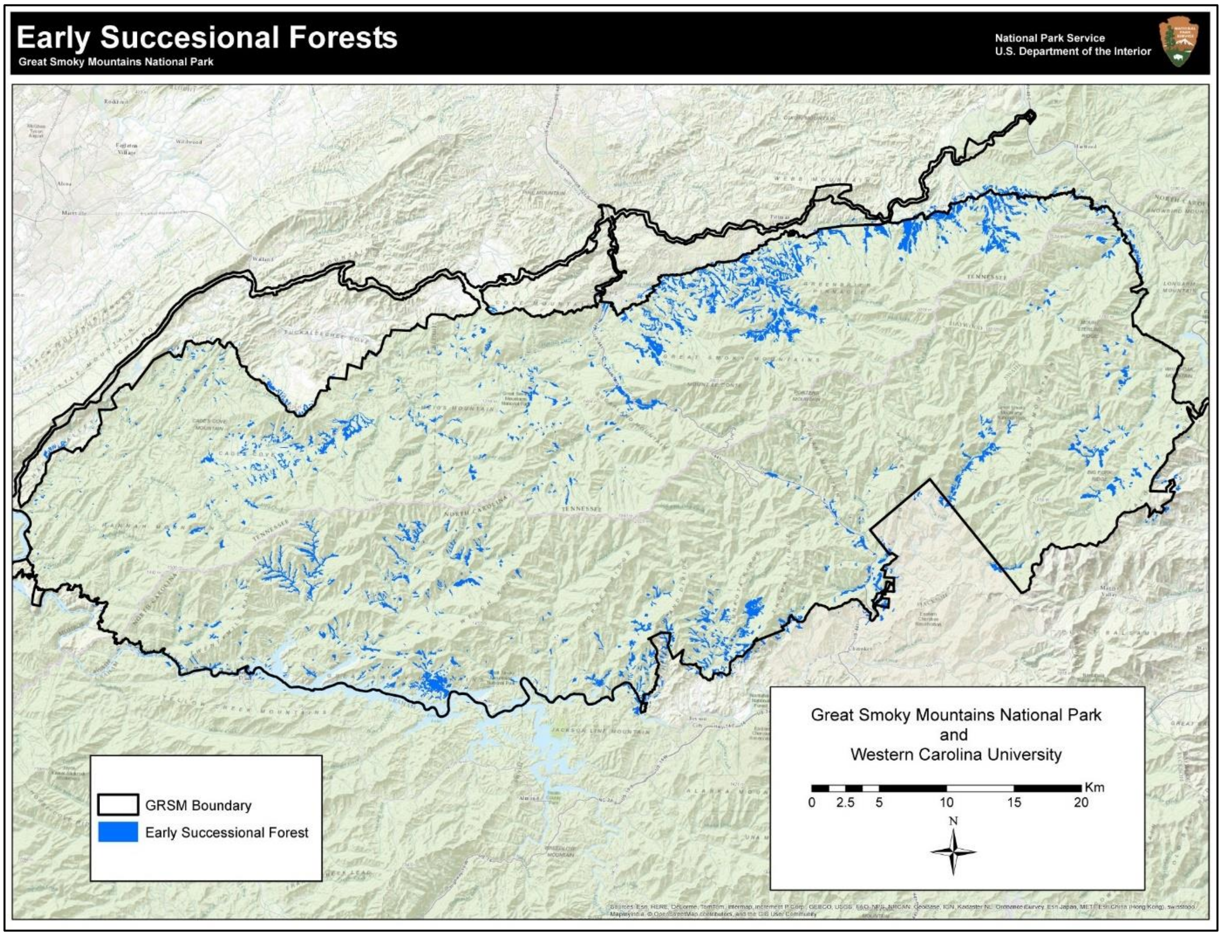

Figure 4.5.7.1. Early Successional Forests comprise approximately 4% of the park's forests. Source: White et al. 2003.

<u>Data and Methods</u>

See section 4.5.1.

<u>Reference Conditions</u>

Determining reference conditions for Early Successional Forests in the park is difficult. Forest succession is a dynamic process involving unpredictable natural- and human-caused disturbances. How different forest types respond depends on the types and intensities of disturbances, and their frequency, and severity. We will consider a reference condition to be communities comprised of native, early successional species that are resilient following potential future disturbances, or if left undisturbed, would develop into a Montane Alluvial, Cove Hardwood, or other native forest community.

Current Conditions and Trends

Early Successional Forests occur on narrow ridges, steep slopes, low slopes, flats, exposed topographic locations, and any other location that has recently experienced natural or anthropogenic disturbance. These sites can be characterized by high plant productivity, complex food webs, large nutrient fluxes, and high structural and spatial complexity (Swanson et al. 2011). Tree species common to Early Successional Forests include tulip poplar, black locust, and Virginia pine. Other canopy species may include red maple, eastern white pine, and sweet birch. Some sites that have experienced severe disturbance where the mineral soil is exposed may be dominated by eastern white pine. Shrub and herbaceous layers tend to be sparse to moderate with mixed species.

Early Successional Forests are being impacted by native and non-native insects and diseases, air pollution, climate change, and invasion by non-native, exotic plants. These forests are only created following natural- or human-caused disturbances, and as succession continues, they will develop into other types. Relying solely on natural disturbances may not maintain a sufficient area of this community. Stressors to these forests include the following:

Southern pine beetle

Pine species are an important component in Early Successional Forests, and southern pine beetle infestations will consequently affect key forest properties. Stressed pines appear to be more susceptible to outbreaks than healthy trees, and heavily stocked slow-growing pine stands, resulting from the lack of fire, are more susceptible to infestations than mixed pine-hardwood stands. SPB experts contend that the park is more susceptible to high pine mortality for this reason, and during the late 1980s and again in the early 2000s, the park experienced high pine mortality from infestations (K. Langdon, pers. comm.). Kuykendall (1978) reported that the southern pine beetle greatly reduced the importance of pine in infested stands, and this often resulted in converting pine-dominated stands into mixed pine hardwoods.

Thousand Cankers Disease

Thousand cankers disease (TCD) is the result of attack by the walnut twig beetle (*Pityophthorus juglandis*) and subsequent canker development around beetle galleries caused by a fungal associate (*Geosmithia morbida*). See Section 4.5.5 for further discussion of thousand cankers disease.

Butternut Canker

Butternut (*Juglans cinerea*) is an important component of many Early Successional Forests, and is highly susceptible to butternut canker. See section 4.5.5 for a discussion of butternut canker.

Ozone

Typically, fast-growing species such as those that are first to colonize a site are more sensitive to ozone than other species. Generally, many of these same species may be found growing in Early Successional Forests in the park. In 2003, NPS resource managers convened and held a workshop to review ozone research literature and compile a list of ozone sensitive plants in the parks. Table 4.5.7.1 lists the ozone-sensitive plants that may be found in Early Successional Forests in the park. Ozone damage to these plant species results in reduced vigor (Fig. 4.5.7.2), and increased stress causes plants to become more susceptible to insect and disease attacks.

Table 4.5.7.1. Ozone-sensitive plant species that may be found in Early Successional Forests in GRSM. Source: NPS 2003

Plant Species Category	Common Name	Scientific Name
Trees	Tulip poplar	*Liriodendron tulipifera*
	Black locust	*Robinia pseudoacacia*
	Sassafras	*Sassafras albidum*
	American elder	*Sambucus canadensis*
	Chokecherry	*Prunus virginiana*
	Virginia pine	*Pinus virginiana*
	Pitch pine	*Pinus rigida*
	Table mountain pine	*Pinus pungens*
Shrubs and Vines	Hazelnut	*Corylus americana*
	Northern fox grape	*Vitis labrusca*
	Black huckleberry	*Gaylussacia baccata*
	Alleghany blackberry	*Rubus alleghaniensis*
	Thornless blackberry	*Rubus canadensis*
Herbaceous Perennials	Spreading dogbane	*Apocynum androsaemifolium*
	Common dogbane	*Apocynum cannabium*
	Common milkweed	*Asclepias syriaca*
	Bigleaf aster	*Eurybia macrophylla*
	Goldenrod	*Solidago altissima*

Figure 4.5.7.2. Photo of healthy (left) and ozone-injured (right) tulip poplar tree foliage. Source: NPS 2015c

Non-native Exotic Plants

Early Successional Forests result from disturbances, and since many non-native invasive species also thrive in disturbed areas, the native vegetation can be threatened. Invasive plant species that produce abundant seeds, have early germination times, and are habitat generalists, can easily outcompete native early-successional species that, under natural conditions, can relatively quickly colonize a disturbed area. Invasive species can disrupt natural succession by outcompeting native early-colonizers, and ultimately shift species composition and reduce plant diversity. Approximately 20% of all exotic plant treatment locations are within the park's Early Successional Forests, which is the most locations in a single forest type.

Climate Change

As with other forest types, the influences of climate change are projected to significantly impact the future structure and composition of Early Successional Forests. Importance values of *Pinus* spp. are projected to increase while other early successional species, including black locust, are expected to decrease (Table 4.5.7.2). This compositional shift is in line with the expected expansion of Pine-Oak Forests in and around the park under low and high emissions scenarios.

Table 4.5.7.2. Projected importance values of species characteristic of Early Successional Forests under high and low emissions scenarios. Source: Landscape Change Research Group 2014.

Common Name	**Scientific Name**	**Model reliability**[A]	**Mod CurIV**[B]	**GCM3 AvgHi**[C]	**GCM3 AvgLo**[D]
Black locust	*Robinia pseudoacacia*	3	3.07	-1.46	-1.08
Virginia pine	*Pinus virginiana*	1	3.44	1.03	1.04
Red maple	*Acer rubrum*	1	12.38	-5.86	-1.4
Eastern white pine	*Pinus strobus*	1	3.84	2.03	2.52
Sweet birch	*Betula lenta*	1	3.47	-1.27	-0.66
Tulip poplar	*Liriodendron tulipifera*	1	6.22	-2.82	-0.82

A. Model reliability: 1=high; 2= medium; 3=low

B. ModCurIV: Modeled current importance values of species in park

C. AvgHi: General Circulation Models (three different models and their averages) under High emission levels scenario (current trend).

D. AvgLo: General Circulation Models (three different models and their averages) Under Low emissions scenario (conservation measures are put into place).

Early Successional Forests are in good condition, but are declining, due to continued succession, as well as the threats and stressors listed above. Outbreaks of southern pine beetle, coupled with overstocked pine stands resulting from the absence of fire, may result in more severe impacts than would occur in healthy pine stands. Severe outbreaks may result in compositional shifts in the communities. Thousand cankers disease has been detected in the park and will need to be continually monitored as with butternut canker. Ozone levels have declined in recent years; however, it will remain a stressor in the foreseeable future, and sensitive early successional species will require on-going monitoring. Exotic invasive plant species will continue to be a threat to Early Successional

Forests; even so, the park's current invasive species monitoring protocol (see section 4.4.1) has led to early detection and a reduction of many of these species in the park.

Confidence and data gaps

The stressors affecting Early Successional Forests are well documented. In addition, the park prioritizes monitoring and treatment of non-native exotic plants in this forest type. Early Successional Forests occur along some of the most heavily trafficked roads and trails, and often occur at the interface between park interior and surrounding private land. We assign a high confidence level to this assessment (Table 4.5.7.3).

Sources of Expertise

- Troy Evans, Forest Ecologist, Great Smoky Mountains National Park
- Kristine Johnson, Supervisory Forester, Great Smoky Mountains National Park
- Rob Klein, Fire Ecologist, Great Smoky Mountains National Park
- Keith Langdon, Inventory and Monitoring Coordinator (retired), Great Smoky Mountains National Park
- Tom Remaley, Inventory and Monitoring Coordinator, Great Smoky Mountains National Park
- Glenn Taylor, Biologist, Great Smoky Mountains National Park

Summary Condition

Table 4.5.7.3. Summary condition and trend graphic for the Early Successional Forests.

Resource	Indicator	Status and Trend	Rationale and Reference Conditions
Focal Species or Communities	Early Successional Forests	↔	Reference conditions consist of communities comprised of native, early successional species that are resilient following future disturbances, or if left undisturbed, would develop into Montane Alluvial, Cove Hardwood, or other native forest communities. Impacts include southern pine beetle, thousand cankers disease, butternut canker, and other insects and diseases, ozone climate change, and invasion by non-native exotic plants.

4.5.8. Hemlock Forests

Relevance

Hemlock Forests comprise only 3% of park area (Fig. 4.5.8.1), but eastern hemlock is one of the most common tree species in the park, with total acreage estimated to be 55,440 ha (137,000 ac) (NPS 2014b). Hemlock occurs as a co-dominant or subcanopy tree across a broad range of forest community associations (Madden et al. 2004, Jenkins 2007), and is also a dominant component of acidic coves, which occupy about 4% of park area (Madden et al. 2004). One of these associations, Southern Appalachian Acid Cove Forest (Silverbell Type), is imperiled (Table 4.5.1.1).

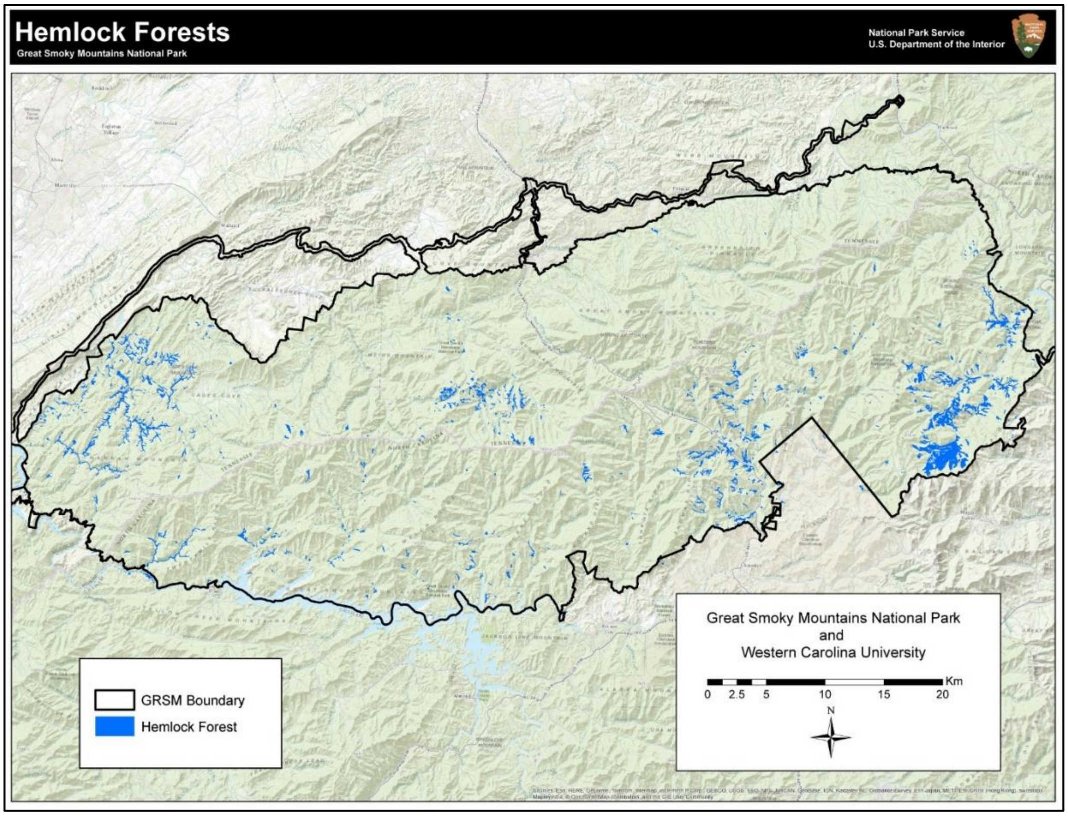

Figure 4.5.8.1. Approximately 3% of the park's forests are Hemlock Forests. Source: White et al. 2003.

Eastern hemlock is the most shade tolerant and longest-lived tree species in eastern North America. Its ability to grow in moist shaded areas enables it to form deep dense stands, which create cool damp microclimates that provide habitat for unique arthropod and avian assemblages, as well other plant and animal species (Shriner 2001, Buck et al. 2005). In addition, hemlock stands often grow along streams, thus keeping water cooler in the summer and warmer in the winter. This thermoregulation is significant to many aquatic species, including brook trout, a native fish and species of concern in the southern Appalachian Mountains (Siderhurst et al. 2010). Hemlocks may take 250-300 years to reach maturity and can live up to 800 years (Fig. 4.5.8.2). Approximately 600 ha (1,500 ac) of old-growth hemlock, containing some trees in excess of 500 years old, have been documented in the park. It is a foundation species that forms the canopy in coves and riparian areas, and fills an important ecological niche in the southern Appalachian Mountains.

Figure 4.5.8.2. Old-growth hemlock forest at Great Smoky Mountains National Park. Source: NPS Photo 2011.

Data and Methods

See section 4.5.1.

Reference Conditions

The reference condition for Hemlock Forests consists of having 50% or more of the canopy dominated by hemlock trees in a mesic environment. The undergrowth consists of acid-tolerant species with low species richness. They occur in coves, gorges, and sheltered slopes. Schafale (2012) states that although hemlock forests are currently experiencing significant mortality due to the hemlock woolly adelgid (HWA), "…forests that were dominated by *Tsuga* that are now dead should be regarded as Canada Hemlock Forests." We will not use Schafale's description of these dead hemlock forests as a reference, but instead consider Hemlock Forests in which the species is healthy and thriving and free of exotic invasive pests as our reference condition.

Current Conditions and Trend

Hemlock is most frequent at 610-1,520 m (2,000-4,987 ft) elevation and is mostly restricted to north- and east-facing slopes, coves, and valleys (Burns and Honkala 1990). Optimal habitat for reproduction includes moist to very moist, acidic, well-drained soils rich in organic material. Young trees can endure considerable amounts of shade and oftentimes form the understory in mixed stands. Two associations of hemlock forests have been delineated in the park (White et al. 2003); within the white pine type, the canopy is dominated or co-dominated by *Pinus strobus*, whereas the canopy of the typic type is dominated by hemlock. Other vegetation communities that have a significant presence of hemlock in the canopy, as well as in the understory, include acid cove forests and spruce-fir forests. Hemlock also dominates two acidic cove associations (White et al. 2003), and one, the southern Appalachian acid cove forest (silverbell type), is imperiled (Table 4.5.1.1).

The historical extent of Hemlock Forests before European settlement in the park is uncertain. Previous research indicates that following the demise of American chestnuts in the southern Appalachian Mountains during the first third of the 20th century, eastern hemlock, among other species, filled openings in the forest canopy created by chestnut mortality (Elliot and Swank 2008). Given the evidence, forest communities which currently have major components of eastern hemlock in the overstory and understory, likely looked very different before the American chestnut disappeared as a dominant tree species throughout the park. However, forests that had already been dominated by hemlock likely remained unaffected by chestnut mortality, as these forests occupy a dissimilar position and habitat than that of the American chestnut trees. Therefore, for the purposes of this assessment, hemlock-dominated forests will be used as the reference condition. Stressors affecting Hemlock Forests include the following:

Hemlock Woolly Adelgid (HWA)

The hemlock woolly adelgid (*Adelges tsugae*), an exotic insect pest accidently introduced from Asia to Virginia in the 1950s, has decimated eastern hemlock trees in large areas of their native range, and Hemlock Forests in the park are in serious decline. Hemlock trees are an important natural resource, and the HWA is a major threat to this keystone species (see Figs. 4.5.8.3, 4.5.8.4). Because hemlocks make up a large proportion of tree species in the park, HWA-related mortality will likely result in a "…cascade of associated environmental consequences involving species found within hemlock communities" (Soehn et al. 2005). Of elevated concern are virgin hemlock stands, because the trees in these stands are old, and have smaller live crowns and thus lack the vigor to weather a heavy HWA infestation.

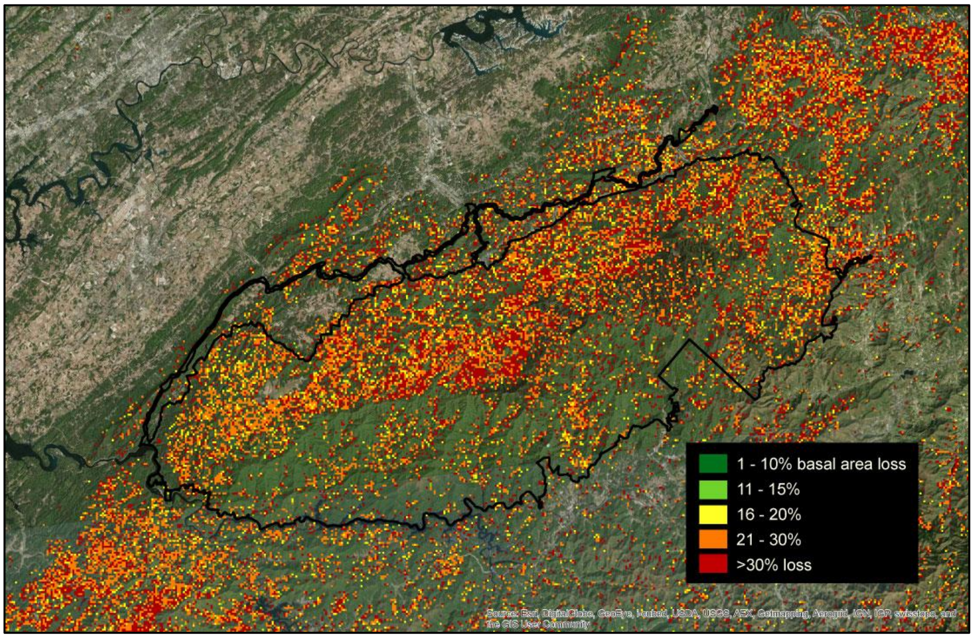

Figure 4.5.8.3. Models predict an 18% loss of hemlock basal area due to the HWA between 2013 and 2027. Source: U.S. Forest Service 2013.

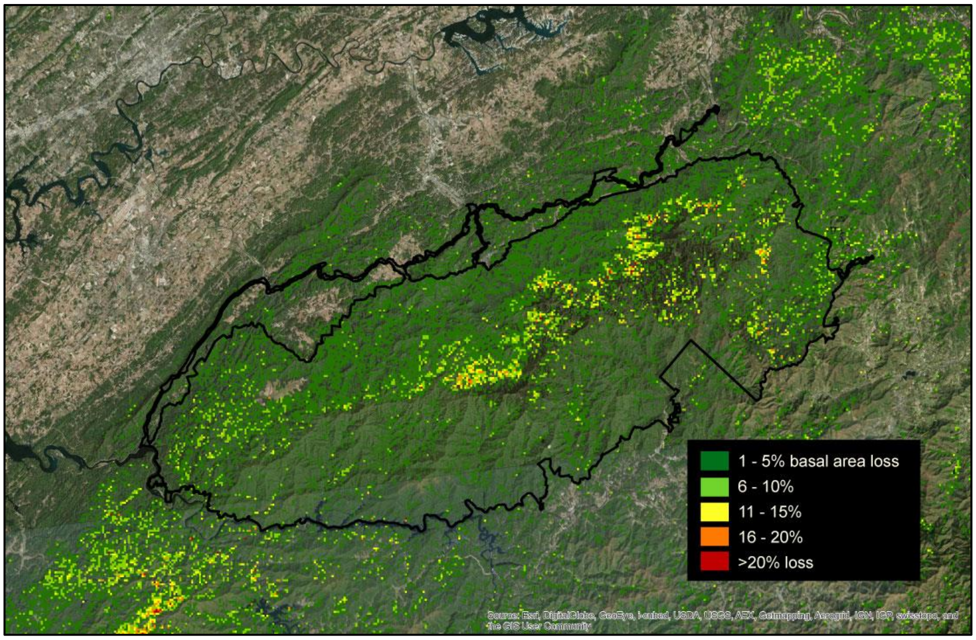

Figure 4.5.8.4. With all trees in the park combined, including hemlock, the overall loss of basal area is predicted to be 1%. Source: U.S. Forest Service 2013.

The hemlock woolly adelgid was first confirmed in GRSM in 2002 (NPS 2005). It attacks hemlocks of all ages, from seedlings to trees that are hundreds of years old. Trees may die within two to five years of infestation, and those that do not die outright become susceptible to other diseases (Soehn et al. 2005). In the park, HWA is primarily dispersed by birds and wind, and as with other invasive exotic pests, it has the potential to severely alter forest composition, structure, microenvironments, and ecosystem processes, and enable further infestation from invasive species (Koch et al. 2006). For example, as hemlocks experience leaf-dieback following infestation, changes in light transmittance and soil moisture will impact the growth of canopy species, as well as shrub and ground layer species. Consequently, shifts in species composition and structure will follow hemlock dieback (Ford et al. 2012). Other fast-growing hardwood tree species that grow well in mesic environments, including Betula spp., rhododendron, Liriodendron and Acer spp., will likely take the place of the slow-growing hemlock. Furthermore, eastern hemlocks fill distinct eco-hydrological roles as an evergreen species that transpires year-round, and as a riparian tree that has high transpiration rates in the spring. Some predict that with the loss of eastern hemlock in the southern Appalachians, changes in hydrological processes, including discharge and stream flow amplitude, are likely to occur (Ford and Vose 2007).

As hemlock declines, short-term impacts to aquatic ecosystems include increased light levels reaching streams, causing more variable and inconsistent temperatures. In the long-term, canopy decline will allow for the growth of other tree species, and shrubs will accelerate. This change has the potential to warm streams, especially in the winter months (Ford et al. 2012). Additional impacts include a pulse in woody debris, and stream chemical composition shifts as dying and dead hemlocks shed tannin-laden bark into streams (Johnson et al. 2008).

Following environmental assessments that were completed in 2005, the park proceeded to aggressively treat HWA with chemical and biological controls. Park staff follow NPS Integrated Pest Management policies and coordinate with various federal and state agencies. Additionally, the park cooperates with several researchers conducting projects related to HWA (e.g., arthropod, avian, and ectomycorrhizal [Johnson et al. 2008] diversity studies). The park's treatment methods for HWA has shown to be effective, and has been conducted in backcountry hemlock-dominated stands (Conservation Areas), and in developed areas including roadsides, campgrounds, and heavily visited areas. One hundred ten conservation areas have been established and all developed areas and backcountry campsites have been treated. Through fiscal year 2015, the park has treated approximately 250,000 trees, which is still only an estimated 5% of hemlock trees within GRSM.

Control methods in developed areas include foliar treatments with horticultural oil, and systemic insecticides applied through the soil or trunk of individual trees. Stem injection treatments have enabled park managers to significantly increase the number of hemlocks treated in close proximity to streams. Substantial rain following the drought of 2007, and consecutive severe winters have resulted in positive responses to systemic treatments in conservation areas. Small untreated stands of hemlock at higher elevations continue to survive because of cold winter temperatures and rime ice.

In order to sustainably treat HWA on a larger landscape level, the park has released over 526,000 predatory beetles that feed exclusively on HWA. Five species of predatory beetles have been utilized to date, with *Laricobius nigrinus* and *L. osakensis* being the most easily established. Overall, the park's efforts have saved hundreds of thousands of trees, and data analyses are showing positive effects of treatments compared to areas with no treatments (Fig. 4.5.8.5; NPS 2014b).

Current HWA populations appear to be lower than during the initial outbreak, but thousands of hectares of dead hemlocks now present great ecological shifts in forest composition, and difficulties in removing hazard trees. Until there are tolerable levels of HWA in Hemlock Forests, the cost of treatment programs brings into question the sustainability of chemical control efforts. Long-term solutions are underway for re-establishment of Hemlock Forests in the event that HWA eliminates, or nearly eliminates hemlock populations. For example, gene conservation efforts will ensure the preservation of regional hemlock genotypes for re-establishment purposes once a long-term management solution is found (USDA 2007).

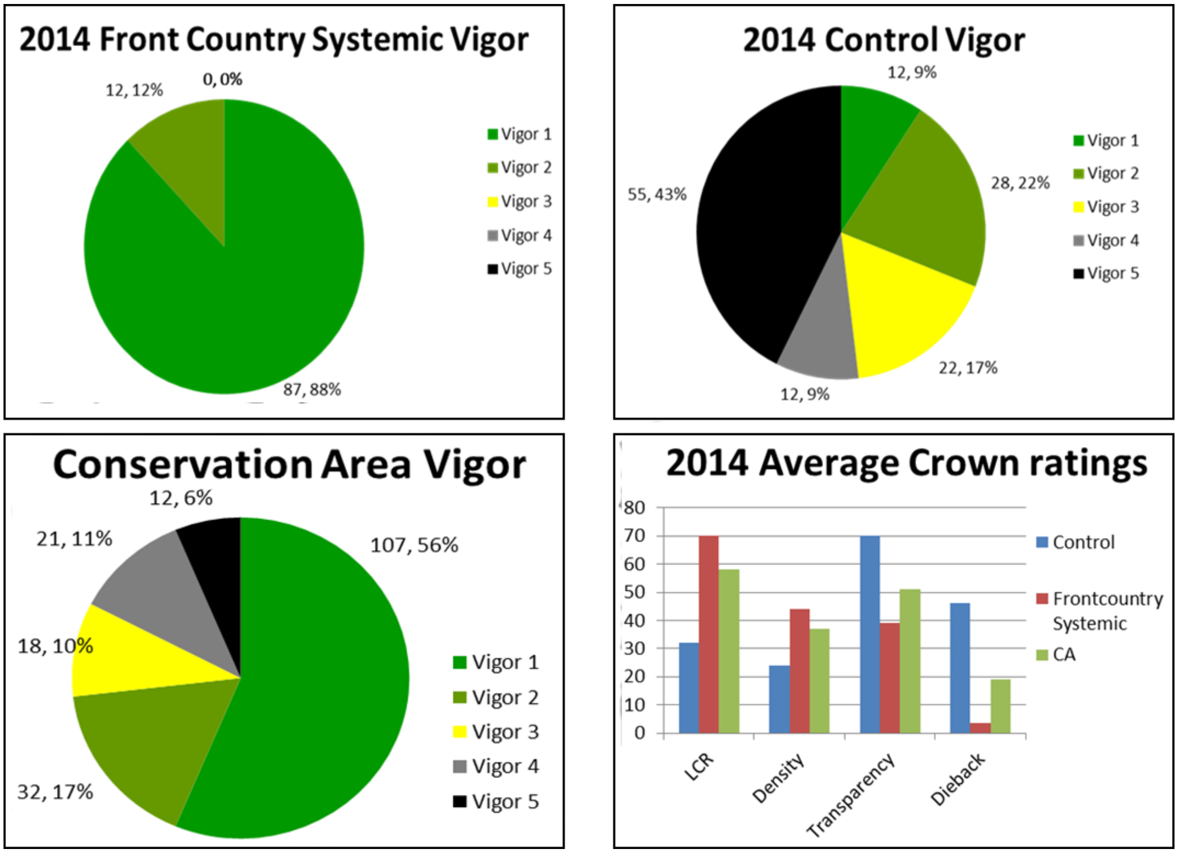

Figure 4.5.8.5. Vigor ratings of monitored trees with four treatment types. Vigor 1=healthy, Vigor 2=light decline, Vigor 3=moderate decline, Vigor 4=severe decline, Vigor 5=dead. Control trees are not treated. Source: NPS 2014b.

Confidence and Data Gaps

The majority of hemlock trees in the park face HWA infestation and mortality, unless they are chemically treated or there is an effective establishment of biological control agents. Many Hemlock Forests have perished and all are undergoing great change, and consequently there is uncertainty regarding the future survival of hemlocks in the park. Biological controls such as predatory beetles are the best possibility for long-term, landscape-level control of HWA. Additionally, continued monitoring will be required to fully assess impacts to the park's forest structure and composition, water quality, associated biota, and other resources that will come with the hemlock's demise. Therefore, we assign a medium level of confidence to this assessment (Table 4.5.8.1).

Sources of Expertise

- Troy Evans, Forest Ecologist, Great Smoky Mountains National Park
- Kristine Johnson, Supervisory Forester, Great Smoky Mountains National Park
- Tom Remaley, Inventory and Monitoring Coordinator, Great Smoky Mountains National Park

Summary Condition

Table 4.5.8.1. Summary condition and trend graphic for Hemlock Forests.

Resource	**Indicator**	**Status and Trend**	**Rationale and Reference Conditions**
Focal Species or Communities	Hemlock Forests	↔	The reference condition for Hemlock Forests consists of having 50% or more of the canopy dominated by hemlock trees in a mesic environment, and an undergrowth consisting of acid-tolerant species with low species richness. Trees in developed areas and selected stands have been treated for hemlock woolly adelgid and many have survived, but outside treatment areas, high mortality has occurred. However, until there is a permanent solution, the cost of treatment programs brings into question the sustainability of such efforts.

4.5.9. Montane Alluvial Forests

Relevance

Montane Alluvial Forests occupy approximately 1% of park area and are rare because they occupy a topographically discrete position in the park (Fig. 4.5.9.1). There are four imperiled vegetation associations in this forest type (Table 4.5.1.1), and according to the North Carolina Natural Heritage program, a large percentage of remaining Montane Alluvial Forests in the region are located on U.S. Forest Service and U.S. National Park lands (K. Langdon, pers. comm.); therefore, the protection of this forest type within GRSM is particularly important. Additionally, many of the park's facilities, including visitor centers and campgrounds, are located in Montane Alluvial Forest habitat.

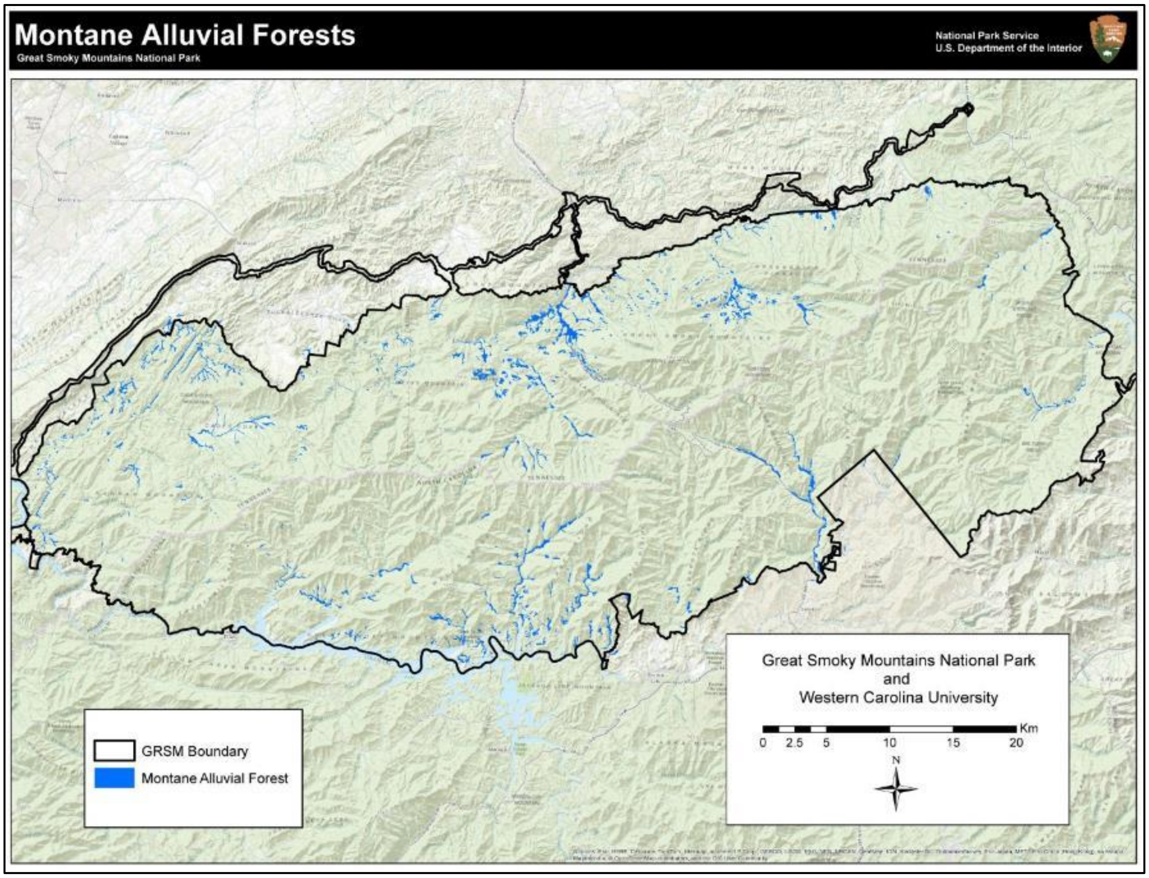

Figure 4.5.9.1. Montane Alluvial Forests comprise roughly 1% of the park's forests. Source: White et al. 2003.

Data and Methods

See section 4.5.1.

Reference Conditions

It is unclear how much of this forest type occupied the park prior to Euro-American settlement. However, since they occurred on floodplains along larger rivers, they were likely heavily disturbed or eliminated by agriculture, human settlement, and other anthropogenic activities. Reference conditions consist of forests dominated with species similar to those found in Cove Hardwood Forests, though also containing American sycamore, river birch, smooth alder (*Alnus serrulata*), and Butternut (*Juglans cinerea*) growing on fertile alluvial soils that are periodically flooded.

Current Conditions and Trends

Montane Alluvial Forests occur in lower elevation, narrow, rocky floodplains along larger mountain rivers and as islands on these rivers. They also occur to a lesser extent on smaller and higher elevation river floodplains. The latter floodplain forests occur on high-gradient streams and often have riparian zones embedded within other habitat types (NC Wildlife Resources Commission 2014a). Typical species include basswood (*Tilia americana* var. *heterophylla*), yellow buckeye, sweet birch, tulip poplar, yellow birch, eastern hemlock, Carolina silverbell, rosebay rhododendron, green ash, and butternut, among others. Common understory tree and shrub species include flowering dogwood, hornbeam (*Carpinus caroliniana*.), witch hazel (*Hamamelis virginiana*), rosebay rhododendron, dog-hobble, and alder. Herbaceous species vary significantly from site to site.

Anthropogenic activities have greatly altered many of these forests through land clearing, tillage, and artificial soil drainage. Non-native exotic plants, insects and disease (e.g., butternut canker, see section 4.5.5), and climate change are other stressors impacting these forests.

Historic Land Use

Historically, areas where Montane Alluvial Forests occurred were also areas that supported the bulk of agriculture in the park. As a result, past agricultural practices, including farming and pasturing, have altered, or in some areas, eliminated this forest community. An example is Cataloochee Valley, which is a historic district in the park that was settled by the 1850s. This area contained fully self-sustaining communities, with livestock, cropland, and gardens providing food and income. Forests and woodland areas next to streams were cleared in order to take advantage of the fertile floodplain soils. Water was often diverted away from fields so as to prevent flooding and to expedite drainage, and as a result, floodplain forests were restricted to the very margins of waterways, and, in some cases, completely removed (Fig. 4.5.9.2). Other former settlements in the park mirrored Cataloochee's settlement patterns. Today, park managers are removing water diversion systems in an effort to restore natural flood regimes.

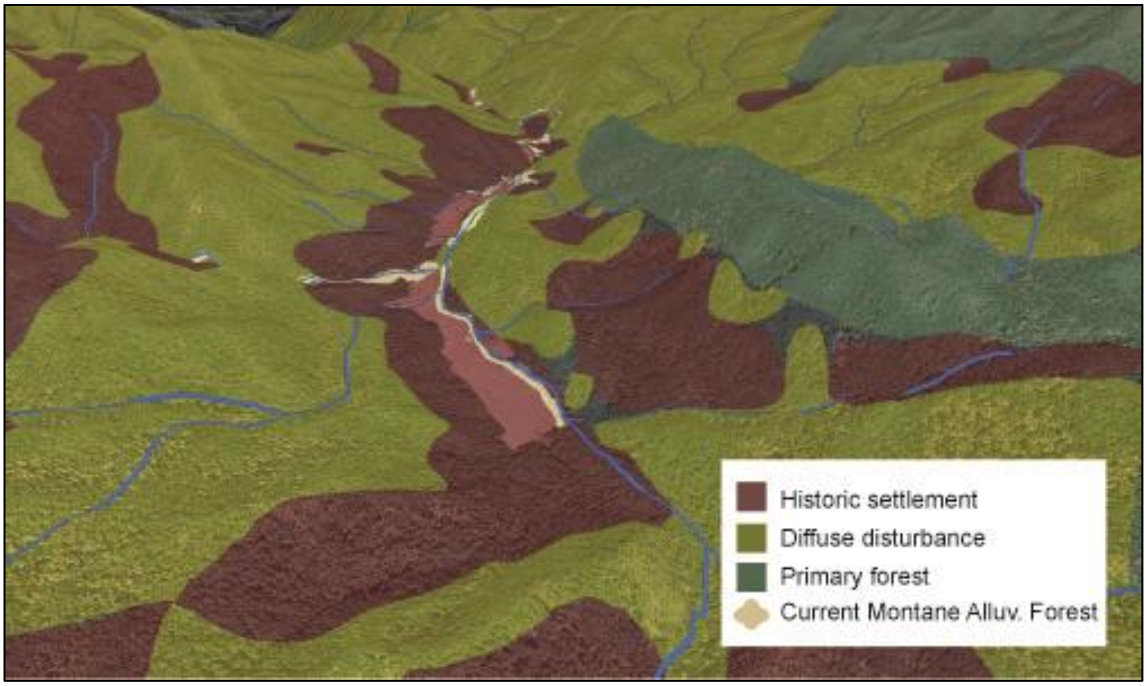

Figure 4.5.9.2. Digital elevation model of Cataloochee Valley depicting areas of former settlements along

creek drainages. Remnants of Montane Alluvial Forests still remain along the narrow margins of Cataloochee Creek. Sources: Pyle 1985, Madden et al. 2004.

Non-native exotic plants

When introduced outside their native environment, invasive plant species have the ability to thrive and out-compete native species, particularly in areas of disturbance. Many areas formerly occupied by Montane Alluvial Forests were converted to agriculture and associated land uses. Inside the park, where these forests are now recovering, invasive species that were either intentionally or unintentionally introduced, are a persistent problem. Privet (*Ligustrum* spp.), Japanese honeysuckle (*Lonicera japonica*), vinca (*Vinca* spp.), wintercreeper (*Euonymus fortunei*), English ivy (*Hedera helix*), Japanese barberry (*Berberis thunbergii*), multiflora rose (*Rosa multiflora*), kudzu, and wisteria (*Wisteria floribunda*), among other species, were planted as ornamentals, for erosion control, and other purposes around home sites. The park has had success in removing many invasive plant populations following the GRSM Exotic Plant Management Plan (2014). However, consistent monitoring and treatment will need to continue as persistent populations and new invasions will continue to threaten these forests.

Climate Change

Several species that are characteristic of Montane Alluvial Forests are projected to decrease in abundance under climate change models. American basswood and silverbell are projected to stay the same or increase (Table 4.5.9.1). Silverbell grows in warm areas in the mountains and therefore, may become more important under projected climate regimes.

Table 4.5.9.1. Projected importance values of species characteristic of Montane Alluvial Forests under high and low emissions scenarios. Source: Landscape Change Research Group 2014.

Common Name	Scientific Name	Model Reliability[A]	Mod CurIV[B]	GCM3 AvgHi[C]	GCM3 AvgLo[D]
Yellow birch	*Betula alleghaniensis*	1	2.27	-0.42	-0.42
Sweet birch	*Betula lenta*	1	3.47	-1.27	-0.66
Yellow buckeye	*Aesculus flava*	2	1.24	-0.04	-0.04
Eastern hemlock	*Tsuga canadensis*	1	4.83	-0.32	-0.15
American basswood	*Tilia americana*	1	0.36	0.35	0
Silverbell	*Halesia tetraptera*	2	1.71	0.47	0.61
Green ash	*Fraxinus pennsylvanica*	2	1.06	-0.18	-0.19
Butternut	*Juglans cinerea*	N/A	N/A	N/A	N/A

A. Model reliability: 1=high; 2=medium; 3=low

B. ModCurIV: Modeled current importance values of species in park

C. AvgHi: General Circulation Models (three different models and their averages) under High emission levels scenario (current trend).

D. AvgLo: General Circulation Models (three different models and their averages) Under Low emissions scenario (conservation measures are put into place).

Overall, Montane Alluvial Forests that were eliminated for cropland, pastureland, logging, and settlement now appear to be recovering. Years of succession and protection from clearing has enabled typical species to re-colonize areas. Additionally, the park's Exotic Plant Management Program continues to control and/or eliminate invasive populations, enabling native species to grow unimpeded in the natural environment. Efforts to restore lowland forest communities through the removal of drainage systems in historic settlements will help encourage re-growth of Montane Alluvial Forest species. However, the recovering Montane Alluvial Forest is not likely to expand farther into its historical range.

Due to successional forces, the park's Exotic Plant Management Program, and other restoration efforts over the years, we assign a stable trend to this assessment. However, these forests will continue to be threatened by exotic invasive species and will need constant monitoring and treatment as new species and populations appear. Therefore, they warrant a high level of concern (Table 4.5.9.2).

Confidence and Data Gaps

Areas in which Montane Alluvial Forests occur, and may potentially occur, are mostly known to resource managers. The impacts of stressors, including historic land use and exotic invasive plant species, on these forests is also fairly well understood. Therefore, we assign a medium confidence level to this assessment.

Sources of Expertise

- Troy Evans, Forest Ecologist, Great Smoky Mountains National Park
- Kristine Johnson, Supervisory Forester, Great Smoky Mountains National Park
- Rob Klein, Fire Ecologist, Great Smoky Mountains National Park
- Keith Langdon, Inventory and Monitoring Coordinator (retired), Great Smoky Mountains National Park
- Tom Remaley, Inventory and Monitoring Coordinator, Great Smoky Mountains National Park

Summary Condition

Table 4.5.9.2. Summary condition and trend graphic for the Montane Alluvial Forests.

Resource	Indicator	Status and Trend	Rationale and Reference Conditions
Focal Species or Communities	Montane Alluvial Forests	🔴↔	Reference conditions consist of forests dominated similar to what would be found in Cove Hardwood Forests, though also containing American sycamore (*Platanus occidentalis*), river birch (*Betula nigra*), and smooth alder (*Alnus serrulata*), and Butternut (*Juglans cinerea*) growing on fertile alluvial soils that are periodically flooded. Impacts of historical land use, non-native exotic plants, and climate change.

4.5.10. Heath Balds

Relevance

Heath Balds account for roughly 1% of the park's area (Fig. 4.5.10.1), and have been in existence for thousands of years (Conkle et al. 2003). There are two associations within this vegetation type, one of which is imperiled (Table 4.5.1.1). Heath Balds are stable evergreen shrub communities within a matrix of heavily forested deciduous landscapes (White et al. 2001), but their origins remain a mystery. Conkle et al. (2003) suggest their origin is driven by natural causes and is independent of glacial or post-glacial climate changes or post-Euro-American disturbance, as many of the previous studies have theorized. Soils underlying Heath Balds are by far the most organically rich in the park. These soils are extremely acidic with pHs below 3, highly saturated with aluminum, and have a very low productivity rating. Radiocarbon data indicate that the age of these soils is around 3,000 years BP (Conkle et al. 2003).

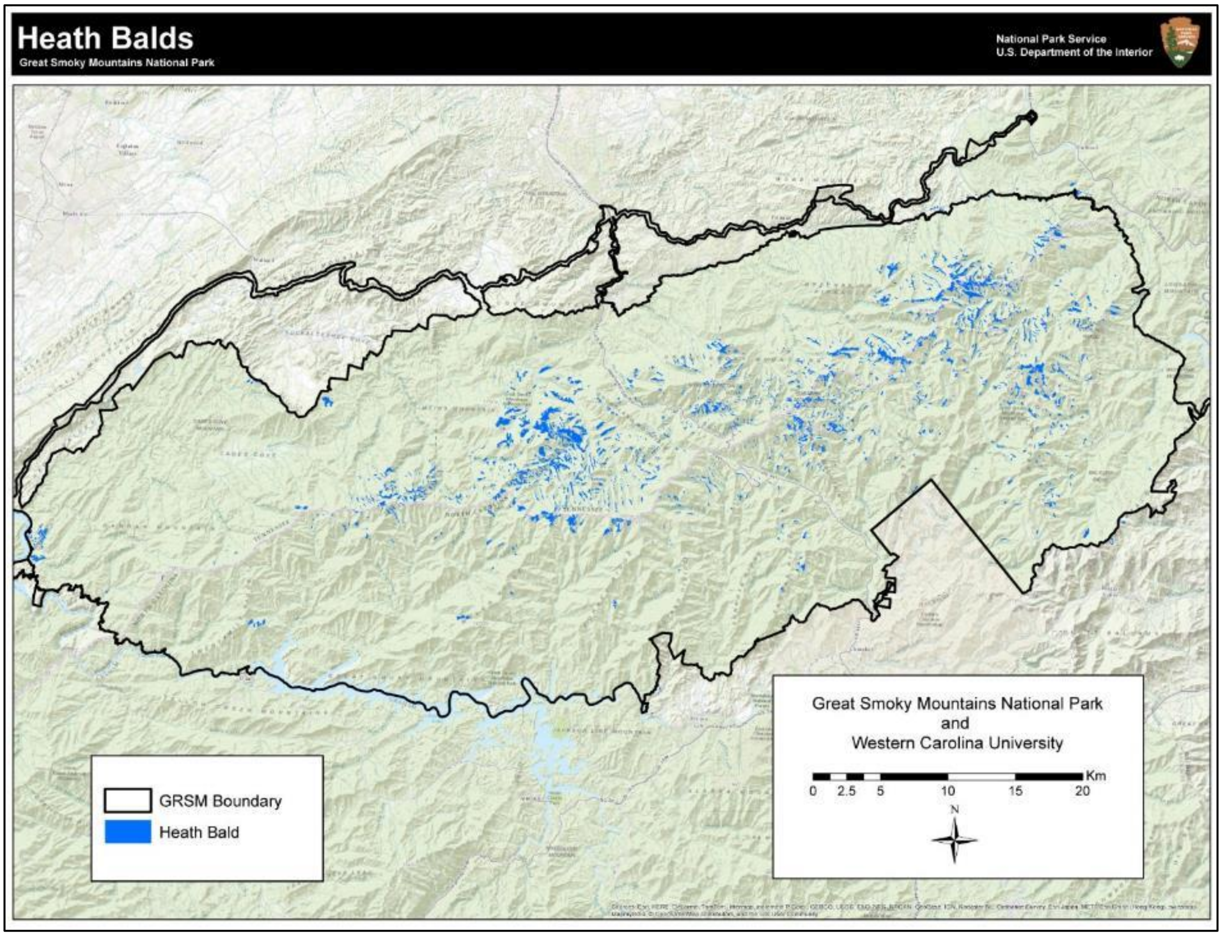

Figure 4.5.10.1. Heath Balds account for less than 1% of the park's area. Source: White et al. 2003.

Data and Methods

See section 4.5.1.

Reference Conditions

Reference condition for Heath Balds are dense stands of ericaceous shrubs with few to no trees and little to no herb layer growing on acidic, organic soils.

Conditions and Trends

Heath Balds occur at elevations above 1,270 m (4,165 ft) and are located on exposed ridges, steep slopes, and rock outcrops. They are distinguished from all other community types by the dominance of dense shrubs in the Ericaceae family and the absence of trees. Heath Balds may be dominated by Catawba rhododendron (*Rhododendron catawbiense*), Carolina rhododendron (*Rhododendron carolinianum*), and/or sand myrtle (*Kalmia buxifolia*). A slate subtype of this community was created to cover examples of Heath Balds in the park found on quartzite and sulfidic slate, which are areas with extremely acidic soils that are prone to landslides (Schafale 2012). White et al. (2001) states that once the ericaceous shrub community becomes established on a site, it will perpetuate itself by preventing any re-establishment of trees. Heath Balds in the park are in good condition, and there are no known stressors other than landslides for this community. Climate change may create more intense weather events that would increase the rate of landslides.

Confidence and data gaps

Other than relatively rare landslides, there are no known stressors or threats. Based on existing conditions and knowledge of the formation of Heath Balds, we assign a high level of confidence to this assessment (Table 4.5.10.1).

Sources of Expertise

- Troy Evans, Forest Ecologist, Great Smoky Mountains National Park
- Kristine Johnson, Supervisory Forester, Great Smoky Mountains National Park
- Tom Remaley, Inventory and Monitoring Coordinator, Great Smoky Mountains National Park

Summary Condition

Table 4.5.10.1. Summary condition and trend graphic for Heath Balds in GRSM.

Resource	Indicator	Status and Trend	Rationale and Reference Conditions
Focal Species or Communities	Heath Balds	⇔	Reference condition for Heath Balds are dense stands of ericaceous shrubs with few to no trees and little to no herb layer growing on acidic, organic soils. With the exception of landslides, there are no major stressors.

4.5.11. Grassy Balds

Relevance

Grassy Balds represent less than 1% of park area (Fig. 4.5.11.1). They have been of interest to ecologists and historians for many years, as their origin and maintenance are a source of speculation (Wells 1938, Mark 1958, Gersmehl 1969, Lindsay 1976, Conkle et al. 2003). There are no definitive answers as to the origins of southern Appalachian Grassy Balds; some believe they were formed from natural processes while others believe they are anthropogenic in origin. Noss (2012) proposed a widely recognized hypothesis suggesting they originated during drier periods with assistance from lightning fires, and they were maintained during wetter climate periods by continued fire, herbivore grazing, or unusual soil properties. After European settlement, livestock continued to keep these areas clear of shrub and tree species. Regardless of how they formed, experts agree that non-native herbivores, including sheep, goats, cows, and horses, grazed many of the balds from the 1800s until the 1930s, when the park was created (Noss 2012). Following the removal of livestock, woody species rapidly invaded the areas. Ecologically, these are species-rich communities and harbor rare plants and contribute to local and regional biodiversity.

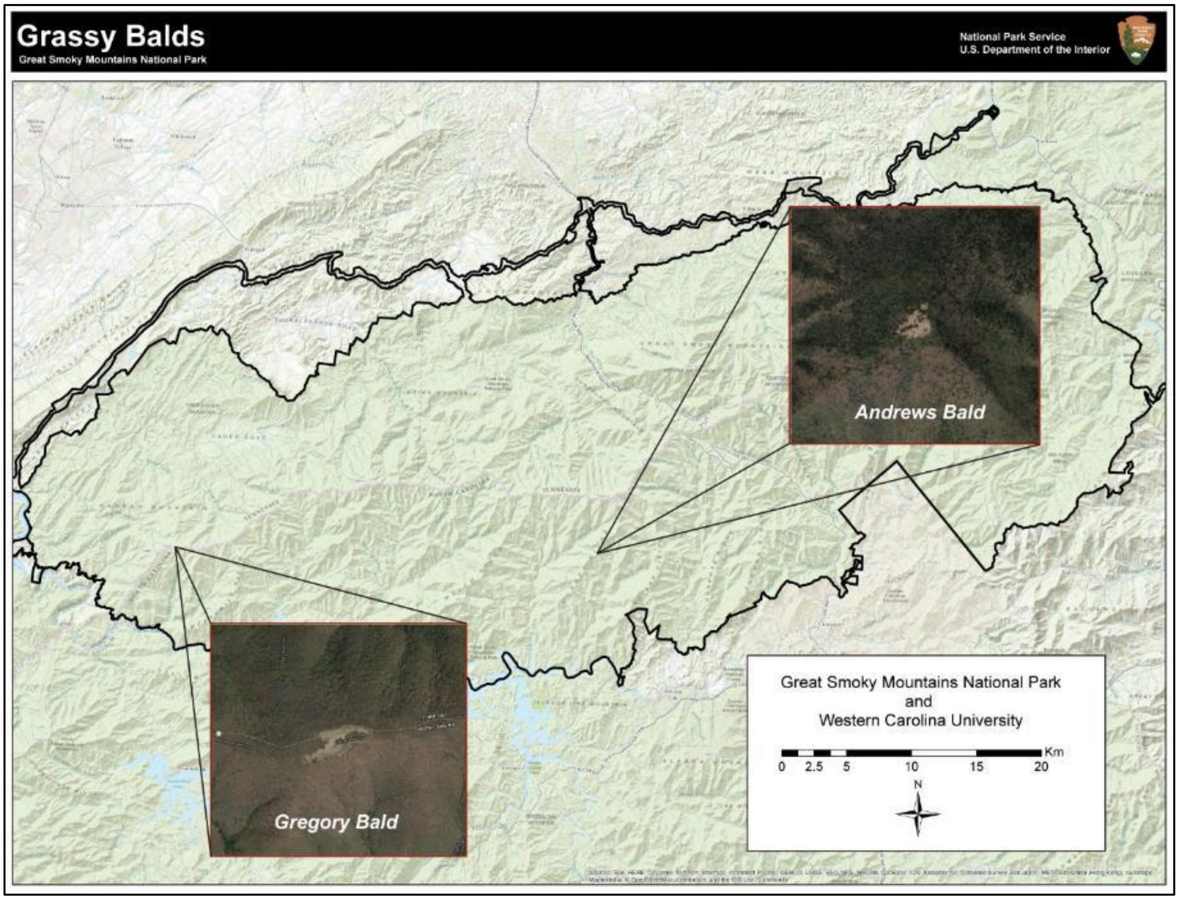

Figure 4.5.11.1. Great Smoky Mountains National Park contains areas that are quickly transitioning from Grassy Balds to forests. Two balds, Gregory and Andrews Balds are actively maintained by the park to retain their unique plant assemblages and vistas.Source: White et al. 2003; Photo inserts from GRSM Archives.

Data and Methods

See section 4.5.1.

Reference Conditions

Reference conditions for Grassy Balds reflect conditions described by Schafale (2012). These include natural, or apparently natural, non-forested high mountain complexes dominated by grasses and sedges.

Conditions and Trends

The park's Grassy Balds (Fig. 4.5.11.2) are primarily treeless communities historically dominated by graminoid species, mostly notably flattened oatgrass (*Danthonia compressa*). They are found on gentle ridges and mountaintops between elevations of 1,315 m (4,320 ft) and 1,615 m (5,300 ft) in the park. Grassy Balds are found within a matrix of different vegetation communities including spruce-fir forests, high-elevation hardwoods, and mixed oak forests, and may contain substantial bare rock along with small patches of herbaceous vegetation. Parsons and Gregory Balds have been confirmed to predate European settlement.

Figure 4.5.11.2. Andrews Bald is located within a matrix of spruce-fir and high-elevation hardwood forests. Source: GRSM Archives.

Natural Succession

With the exception of Gregory (Fig. 4.5.11.3) and Andrews Balds, the park's Grassy Balds are quickly disappearing or have disappeared altogether along the main crest of the Smokies and on the secondary ridges due to natural succession (Barden 1978, Schafale 2012). Former balds tended to be dominated by native plants and contained multiple shade intolerant rare plants. As succession proceeds, these plants are in danger of disappearing. Exotic invasive plant species are a threat to these areas by outcompeting native vegetation, and wild hog rooting further puts balds at risk by opening the areas to invading woody plant species.

Figure 4.5.11.3. Gregory Bald circa 1925. Before park establishment, livestock grazing maintained the balds' characteristic openness. Source: GRSM Archives.

One past study suggests that 47% of all Grassy Balds in the southern Appalachians have been lost due to succession (Gersmehl 1971). Lindsay and Bratton (1980) estimate that Andrews and Gregory Balds lost 33% and 50% of their areas, respectively. The park's resource managers recognized the need for active management in order to keep the balds open; however, selective cuts were found to be temporary, and livestock grazing was found to be cost-prohibitive and ineffective, as livestock do not selectively graze on invading woody plants versus rare or grassland plants. Selective cutting and mowing became the preferred methods for maintaining the balds, and in the park's 1982 General Management Plan, Gregory and Andrews Balds were designated to be kept open (NPS 1982) in order to maintain native vegetation, including rare plants and native azaleas, and to suppress non-native exotic species. These management methods continue today, retaining the two balds' open vistas. Even with active management, Grassy Balds are estimated to lose 1 to 2% of their area to shrubs and trees each year (White and Sutter 1999).

Non-native Invasive Species

Lindsay and Bratton (1979) conducted a floristic survey of Grassy Balds in the park, and they found that 15.7% of the plant species on balds located among oak forests were non-native invasives. Of the species found on balds in beech forests, 6.2% were non-native invasives, and in spruce-fir balds, 2.1% were non-native invasives. Additionally, they also found that 11% of plant species in cleared fields (e.g., Russell and Spence Fields) were non-native invasives. The use of Grassy Balds for livestock grazing may have negatively impacted native species and encouraged non-native invasives (Fig. 4.5.11.4). Also, recreational horseback riding has led to continuing introduction of invasive exotic plants. Although non-native invasive species continue to impact the park's Grassy Balds, the remaining species are effectively monitored and controlled by resource managers. The park has been actively maintaining two naturally occurring Grassy Balds with regular mowing and monitoring of invasive species since the early 1980s. While native azaleas are selectively protected from mowing, this method has effectively suppressed most invasive species and woody shrubs. Resource managers report that the two balds are now close to the original perimeters identified when the park was established.

Figure 4.5.11.4. Domesticated pigs grazing on Gregory Bald. Date unknown.Source: GRSM archives.

Wild Hogs

European wild hogs (*Sus scrofa*) entered the park in the late 1940s and now occupy most of its vegetation communities. The hog quickly interbred with domesticated pigs and populations spread. The wild hog causes severe damage to native biota by rooting for insects, small animals, graminoids, starchy tubers, bulbs, rhizomes, and other vegetation. Hog rooting activity has been found to change through the course of the year among forest types; however, Grassy Balds have been found to be rooted both in summer and winter, although the food items sought and the rooting patterns change with the seasons. Howe and Bratton (1976) summarize the overall impacts of wild hog rooting as: (1) exposure and loosening of the soil surface, leading to erosion, compaction, and stream siltation; (2) reduction in the populations of a number of plant species by selective feeding; and (3) normal successional processes are being modified, which may alter future plant species composition. The third impact may be most applicable to Grassy Balds. Under undisturbed conditions, Grassy Balds retain a thick cover of grassy species, eliminating competition from other plant species. The hogs' rooting activity exposes soils and interrupts the dominant grass cover, which opens opportunities for the establishment of invading shrub and tree species.

Confidence and Data Gaps

There is solid evidence that most areas that were Grassy Balds have either reverted back to forest or are in a state of transition to forest. Therefore, we have assigned a high confidence level to this assessment (Table 4.5.11.1). Data gaps include surveys for rare plant species occurring on Grassy Balds.

Sources of Expertise

- Troy Evans, Forest Ecologist, Great Smoky Mountains National Park
- Kristine Johnson, Supervisory Forester, Great Smoky Mountains National Park

- Keith Langdon, Inventory and Monitoring Coordinator (retired), Great Smoky Mountains National Park
- Tom Remaley, Inventory and Monitoring Coordinator, Great Smoky Mountains National Park

Summary Condition

Table 4.5.11.1. Summary condition and trend graphic for Grassy Balds in GRSM.

Resource	Indicator	Status and Trend	Rationale and Reference Conditions
Focal Species or Communities	Grassy Balds	↔	Reference conditions include natural, or apparently natural, non-forested high mountain complexes dominated by grasses and sedges. Impacts of plant succession, non-native invasive plants, horses, and wild hog. Most areas that were grassy balds have either reverted back to forest or are in a state of transition to forest.

4.5.12. Wetlands

Relevance

Wetland communities occur at all elevations throughout the park, and most are small isolated systems (Fig. 4.5.12.1). Wetland communities are in alluvial or non-alluvial areas and are dominated by plants adapted to anaerobic conditions due to substrate saturation or inundation during 10% or more of the growing season (White et al. 2003); they represent less than 1% of the park's area (Fig. 4.5.12.2). Eight of these community types are ranked as either critically imperiled (G1) or imperiled (G2) (Table 4.5.1.1).

Figure 4.5.12.1. Spring fed wetland seep in Great Smoky Mountains National Park. Source: NPS Photo 2011.

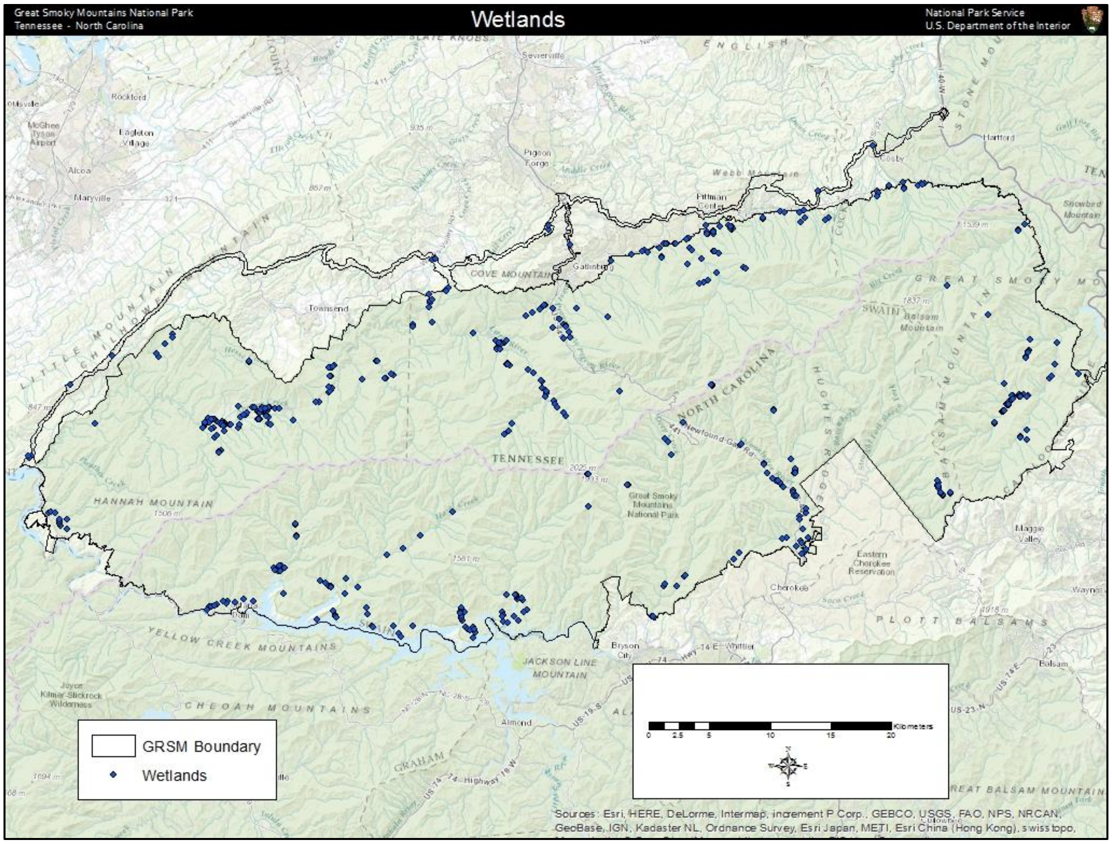

Figure 4.5.12.2. Wetlands account for less than 1% of the park's area. Source: White et al. 2003.

The park's wetlands provide important ecological functions, such as water quality improvement, as well as providing habitat for endemic, globally rare species, such as Smoky Mountain mannagrass and Smoky Mountain sedge (*Carex fumosimontana*). They're also important for wildlife, and wetland communities often are very species-rich, and contribute greatly to the park's biodiversity. Wetlands may also provide a baseline for monitoring climate change, as they may be sensitive to shifts in precipitation, temperature, and air pollution in the form of acid and mercury deposition (NPS 2015d).

Data and Methods

In 2010, park staff began a comprehensive field-based survey of park wetlands for the purpose of creating a baseline inventory. Data is recorded for each wetland, and includes location, vegetation composition, estimated area, Cowardin type community classification (Cowardin et al. 1979), degree and type of hydrologic alteration, wild hog disturbance, and other site characteristics. As of 2015, 522 individual wetland units were located in the park, and approximately 80% of these have been surveyed. They vary in size from being too small to determine the boundary, to 1.5 ha (3.8 ac), and are located at all elevations and within all of the broad vegetation communities in the park. Two hundred forty of the wetlands have experienced some type of hydrological alteration, whether through anthropogenic activities or native and non-native animal activities. There are six imperiled wetland associations in the park, and eight G1 and G2 species are found in these areas (Table 4.5.1.1).

Reference Conditions

The original (pre-settlement) extent of wetlands in the park is difficult to determine. Since many occur on floodplains along larger rivers and in other previously settled areas such as Cades Cove, Oconaluftee, and Cataloochee, many wetlands were likely disturbed or eliminated by agriculture, settlement, drainage, or other anthropogenic activities. Reference conditions for wetlands include plant communities dominated by native, hydrophytic vegetation growing in areas where soils are saturated throughout much of the growing season.

Conditions and Trends

Palustrine forested wetlands are the dominant type, though scrub/shrub and emergent habitats are also common. Wetlands in the park are typically maintained by seepage, springs, or regular flooding, although some may be influenced by natural processes such as beaver (*Castor canadensis*) activity, downed trees, or elk browsing. They vary in form and include fens, bogs, emergent marshes and ponds, high-elevation seeps, sinkholes, bottomland hardwoods, riparian wetlands, and floodplain alluvial flats. Vegetation is highly variable and contains a diverse mix of herbaceous and woody vegetation. Composition is dependent upon factors such as hydrology, soils, geographic location, disturbance history, land use activities, and other factors (NC Wildlife Resources Commission 2014b). Non-native exotic plants, wild hog rooting, and possibly climate change are also stressors impacting these communities.

Land Use

Historic and modern day human activities have altered many of the park's wetlands. Past land use, including farming and pasturing, required soil draining; therefore, adjacent streams were ditched and channelized, and rock walls were used to impound water, diverting it away from fields to prevent crop destruction. Additionally, floodplain forests were cleared to take advantage of fertile soils. Wetlands have also been impacted by park administrative and visitor activities, with many of the park's facilities, including campgrounds and visitor centers, located in potential wetland habitat. Pollution from run-off into wetlands may be attributed to adjacent paved and gravel roads, campsites, and hiking trails. Some hiking and horse trails actually bisect individual wetlands. More recently, park resource managers have completed wetland restoration projects in Chilogatee Branch, adjacent to the Foothills Parkway, in cooperation with the Tennessee Stream Mitigation Program, in Cades Cove, and in the area around Oconaluftee.

Wild Hog

Wetlands provide ideal conditions for wild hog wallowing. Hogs are attracted to the wet conditions where they can root for food and wallow in the mud to cool and repel insects. In doing so, they root-up wetlands (Fig. 4.5.12.3), negatively impacting hydrology, native vegetation, and insect and amphibian populations.

Figure 4.5.12.3. Wild hog wallow damage in a wetland at GRSM. Source:NPS Photo 2013.

Exotic Invasive Plant Species

Park resource managers include invasive species removal and treatment as part of their management of the park's wetlands. The most common exotic invasive species found in wetlands are privet, Japanese honeysuckle, multiflora rose, Japanese stiltgrass (*Microstegium vimineum*), and mimosa (*Albizia julibrissin*). The park has had success in removing and controlling many invasive plant populations, though monitoring and treatment will need to continue, as invasive plant populations will continue to threaten wetland resources throughout the park.

Climate Change

Currently, no datahas been collected on the impacts of climate change, atmospheric deposition, or other toxins (e.g., chemical run-off from roads) on park wetlands. Wetlands, and those species that occur in wetlands, in the southern Appalachians may be particularly susceptible to climate change since they are linked to water quality, ground and surface water sources, and a narrow range of environmental conditions. Therefore, they may serve as important sites to monitor climate change and other climate change-related impacts. Future research and management efforts in the park may be directed towards monitoring such impacts.

Confidence and Data Gaps

Great Smoky Mountains National Park contains many wetlands communities, which are diverse and variable, and occur at all elevations. Field work conducted since 2010 has provided a more comprehensive listing of wetland resources in the park, an improved understanding of the diversity and condition of this community type, and the information needed to better direct management efforts. These data have also provided information on exotic plant invasions, wild hog damage, and rare and threatened plant locations. The significance of wetlands, as well as the information gaps and continued threats, show a need for continued surveying (Table 4.5.12.1).

Sources of Expertise

- Troy Evans, Forest Ecologist, Great Smoky Mountains National Park
- Kristine Johnson, Supervisory Forester, Great Smoky Mountains National Park
- Tom Remaley, Inventory and Monitoring Coordinator, Great Smoky Mountains National Park

Summary Condition

Table 4.5.12.1. Summary condition and trend graphic for GRSM wetlands.

Resource	Indicator	Status and Trend	Rationale and Reference Conditions
Focal Species or Communities	Wetlands	↔	Reference conditions include plant communities dominated by native, hydrophytic vegetation growing in areas where soils are saturated throughout much of the growing season. Impacts include hydrologic alterations, non-native invasive plant species, and wild hog rooting. There is a need for more surveying.

4.5.13. Freshwater Invertebrates

Relevance

GRSM contains over 4,640 km (2,883 mi) of stream channels (Colson 2015), and surface waters within the park are viewed as critical ecological resources. Aquatic macroinvertebrates are directly exposed to changes in physical and chemical conditions of the water, and integrate the day-to-day variations; consequently, they have become the most widely used organisms in freshwater biomonitoring (Bonada et al. 2006). Also, due to their relatively short life spans, they allow for detection of annual to decadal environmental trends. When the NPS initiated a long-term monitoring program in 1992, aquatic macroinvertebrates were chosen to form a key part of the protocols, and in the new Vital Signs monitoring program, freshwater communities form one of the six Vital Signs to be monitored (NPS 2011).

Data and Methods

For this report, data and analyses from studies conducted between 2011 and 2015 were compared to reference conditions from studies conducted between 1990 and 2010. Between 1993 and 2004, annual samples were collected from 27 permanent sites using the "Standard Qualitative Method" sampling protocols developed by the North Carolina Department of Environment and Natural Resources (NCDENR 2011). Additionally, to cover the 45 principle watersheds found in the park, other sites were sampled on a less frequent basis, and were selected to represent varying elevational gradients, stream orders, and basin characteristics. During the 1993-2004 timeframe, 106 sites throughout the park were sampled, and from 2004-2011, only occasional quantitative macroinvertebrate community sampling was done (Fig. 4.5.13.1; Nichols 2012b). In the new Vital Signs monitoring program, macroinvertebrate sampling sites are co-located with fish community and water quality sampling sites. Biotic indices are still used as the metric allowing for direct comparison to previous data. Altogether, 118 sites were sampled using comparable protocols from 1993 to 2003 (Fig. 4.5.13.2; Schwartz et al. 2014).

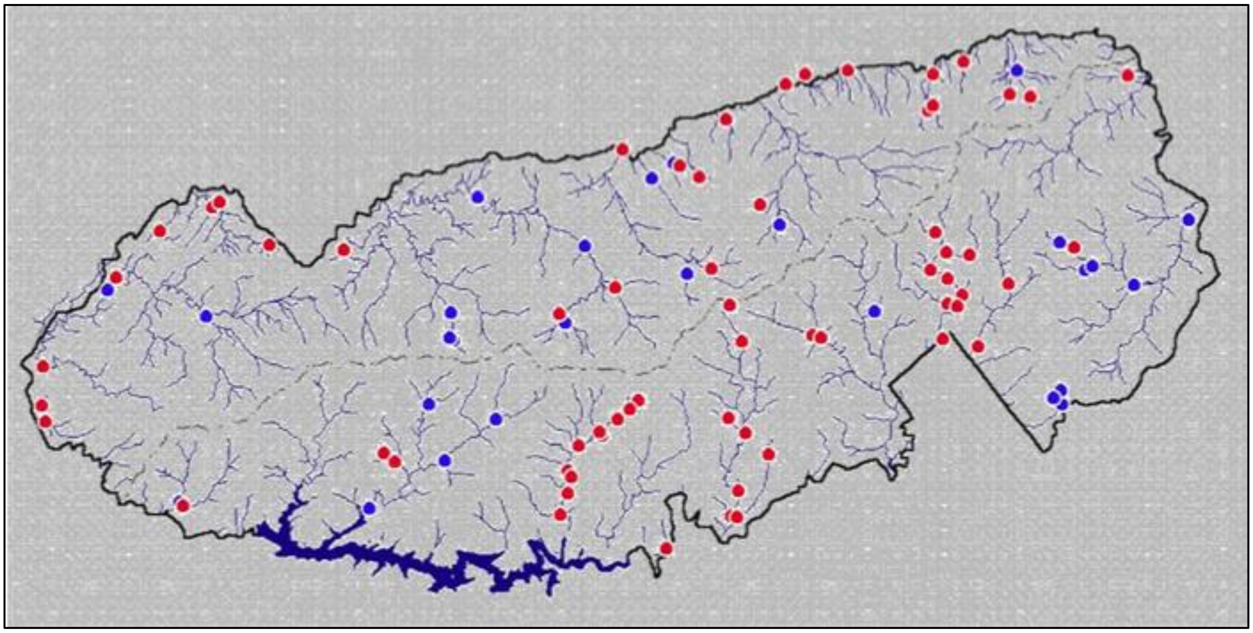

Figure 4.5.13.1. Aquatic macroinvertebrate monitoring sites in GRSM. Blue dots indicate permanent sites, and red dots indicate other sites sampled occasionally to better represent the breadth of conditions in the park. Source: Nichols 2012b.

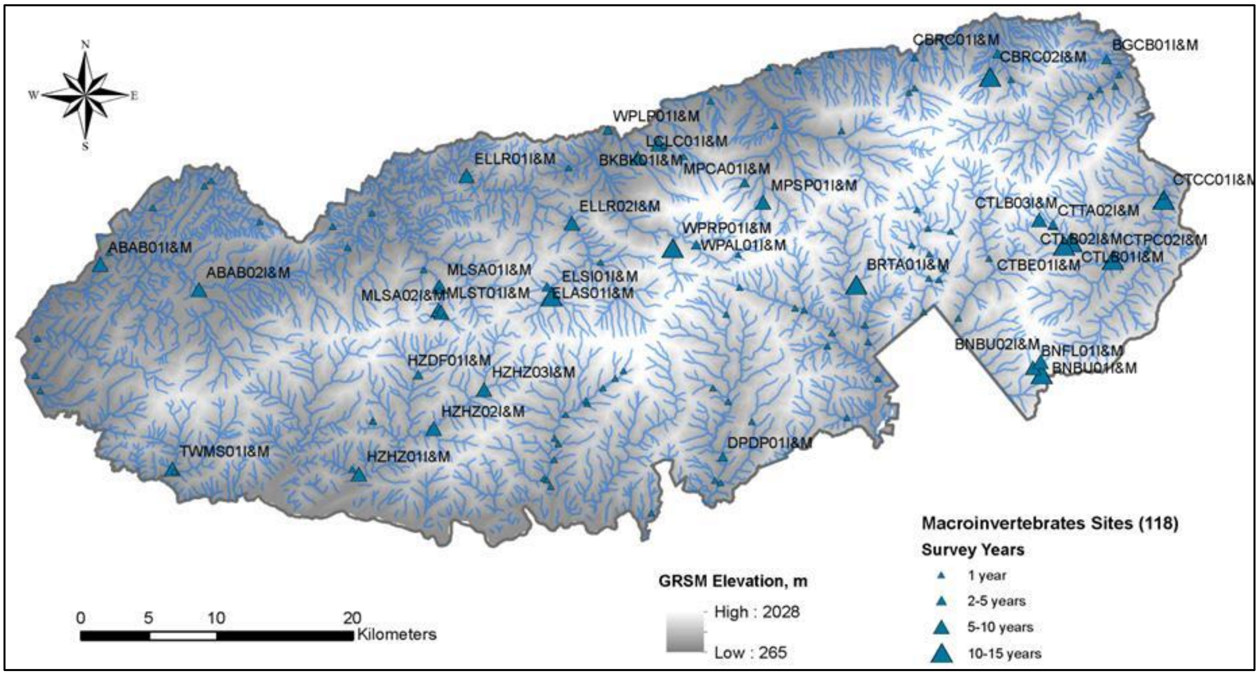

Figure 4.5.13.2. Aquatic macroinvertebrate monitoring sites in GRSM from 1990 to 2003. Source: Schwartz et al. 2014.

Prior to 1993, macroinvertebrate sampling was more sporadic, although there was an intensive study of the Noland Creek watershed initiated in 1991 as part of the Integrated Forest Study, which was funded by the Electric Power Research Initiative (Nichols 2012a). In that study, drift-net samples were collected over a 24-hour period, each week for four years, then monthly until 2001.

Parameter Criteria

The Standard Qualitative Method for macroinvertebrate biomonitoring may be summarized using some standard metrics (NCDENR 2011):

- **EPT Richness and Abundance**. The insect orders, Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies) have long been used to monitor water quality. EPT Richness refers to the total number of species found representing these three insect orders, while EPT Abundance refers to the total number of these individuals.
- **Taxa Richness and Abundance**. Similar to the EPT measures, but covering all species of macroinvertebrates collected.
- **North Carolina Biotic Index (NCBI)**. This index is based on the Field Biotic Index (also sometimes called the Family Biotic Index) first described by Hilsenhoff (1987), but requires species-level identification. The index incorporates the tolerance value as a weight for abundance of each taxon when calculating an average score for each site. It is calculated as:
- $\boldsymbol{NCBI} = \frac{\sum_{i=1}^{S}(TV_i)(n_i)}{N}$

  where TV_i is the tolerance value for species i as provided by NCDENR (2011), n_i is the abundance value of species i (recorded as 1,3, or 10), and N is the sum of all abundance values.
- **Bioclassification Scores**. NCDENR (2011) provides guidance and corrections for season and ecoregion as well as a table to produce a final bioclassification score for both the EPT Richness values and the NCBI. These two scores are then typically averaged to produce a final score, unless there is a difference of one bioclassification unit between the two values. If there is a discrepancy, the EPT Abundance values are used to decide whether to round down, or round up the bioclassification score. This score ranges from 1 (Poor) to 5 (Excellent).

Reference Conditions (1990–2010)

Between 1990 and 2005, 536 species of aquatic macroinvertebrates were documented from stream sites within the park (Nichols 2012b). Most of these species have been identified through the standard sampling programs described above, but some taxa were documented via taxon-specific sampling conducted as part of All Taxa Biodiversity Inventory (ATBI) projects. Observed taxa richness typically correlates with sampling effort, indicated by a rapid increase in documented aquatic species between 1992 and 1997 (Fig. 4.5.13.3).

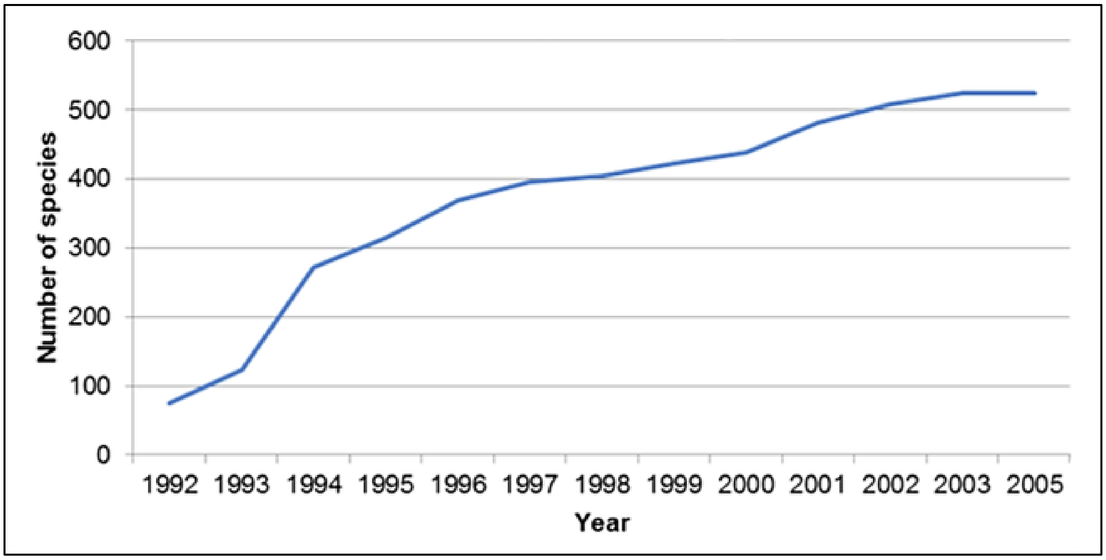

Figure 4.5.13.3. Species accumulation curve for aquatic macroinvertebrates documented as part of the long-term aquatic macroinvertebrate monitoring program in GRSM. Source: Nichols 2012b.

Over the 396 aquatic macroinvertebrate samples summarized by Schwartz et al. (2014), most received a bioclassification score of good to excellent (Table 4.5.13.1). Of the 27 permanent sites monitored on an annual basis, two sites located on Abrams Creek exhibited a decline over the monitoring period, with Abrams Creek site-1 showing a decline from an excellent (5) rating in 1996 to fair (3) rating in the years 2000-2005 (Fig. 4.5.13.4). Abrams Creek is somewhat unique in that it is a medium sized coolwater river while most of the streams in the park are smaller coldwater streams.

Table 4.5.13.1. Summary of stream macroinvertebrate metrics for GRSM stream data collected between 1990 and 2003.

Metric	Median	Mean	SD	Min	Max
NCBI	2.2	2.3	0.6	0.9	4.6
EPT richness	30	31	7	4	56
Bioclassification	Good (4)	–	–	Good-Fair (3)	Excellent (5)

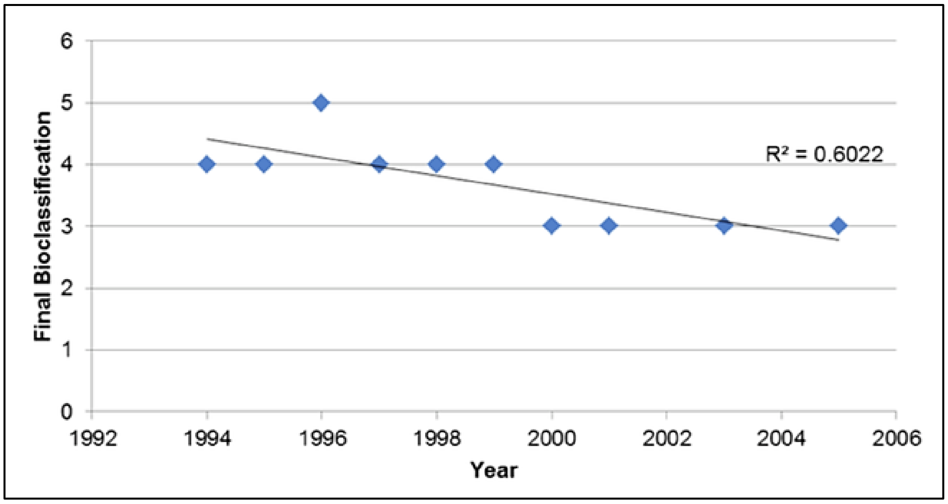

Figure 4.5.13.4. Final bioclassification values for Abrams Creek site 1 from 1994-2005 (Nichols 2012b). Bioclassification scores range from poor (1) to excellent (5). Source: Nichols 2012b.

Conditions and Trends (2011–2015)

Sampling under the new Vital Signs monitoring program began with two watersheds sampled in 2012 and three sampled in 2013 (GRSM 2013, 2014). In 2014, nine sites were sampled - four within the Abrams Creek watershed, four within the Hazel Creek watershed, and one in the Cataloochee Creek watershed (Nichols and Kulp 2015). EPT richness data for Abrams Creek and Hazel Creek sites were available for 2014 (Fig. 4.5.13.5; Nichols and Kulp 2015), and the resulting stream bioclassification scores were all Good (4), with the exception of Anthony Creek 1 site within the Abrams Creek watershed, which scored a Good-Fair (3), and Abrams Creek 1 site which scored an Excellent (5). Considering that Abrams Creek site 1 had shown a bit of a decline between 1994 and 2005 (from Good to Good-Fair), a score of Excellent suggests that there has been a recovery. An overall median score of Good suggests a flat trend in the aquatic macroinvertebrate community.

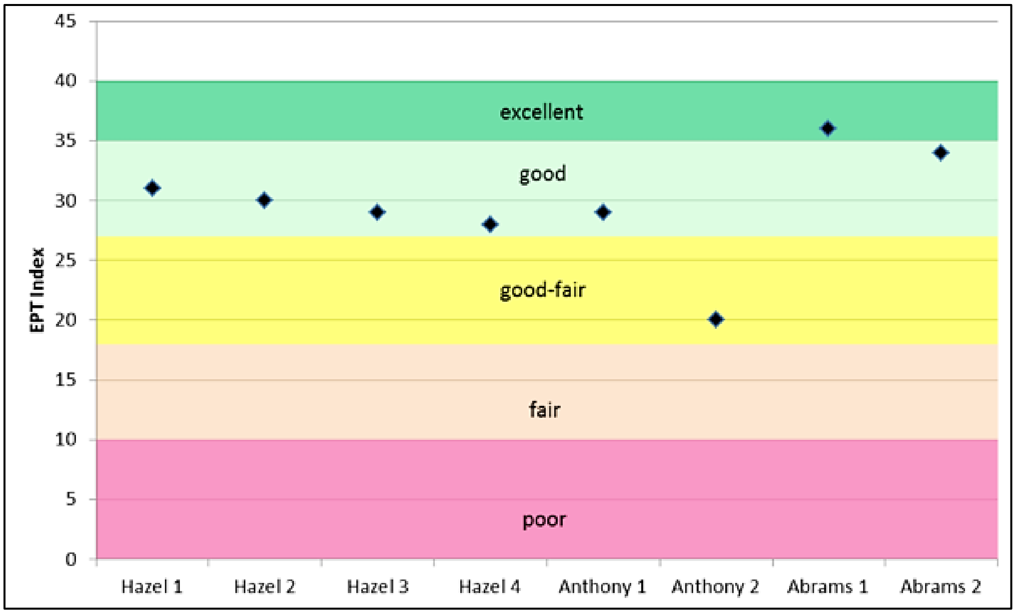

Figure 4.5.13.5. EPT (Ephemeroptera, Plecoptera, and Trichoptera) richness index scores for macroinvertebrate sample sites within the Abrams Creek watershed (Abrams 1, Abrams 2, Anthony 1, Anthony 2) and Hazel Creek watershed (Hazel 1-4). Source: Nichols and Kulp 2015.

Confidence and Data Gaps

The “Standard Qualitative Method” sampling protocols developed by the North Carolina Department of Environment and Natural Resources (NCDENR 2011) provide an established set of metrics with which to monitor trends in water and habitat quality reflected in the aquatic invertebrate assemblage. The protocols do demand considerable taxonomic expertise, but are efficient for the information obtained. For this report, only EPT richness data for eight sites were available to compare to reference conditions based on 118 sites. Confidence in the data for the sites sampled is high, and confidence in determining overall trends in the aquatic invertebrate assemblage is high.

Sources of Expertise

- Becky Nichols, Entomologist, Great Smoky Mountains National Park

Summary Condition

Table 4.5.13.2. Summary condition and trend graphic for freshwater invertebrates in GRSM.

Resource	Indicator	Status and Trend	Rationale and Reference Conditions
Focal Species or Communities	Freshwater Invertebrates	↔	The NCBI was used to assess status and trends using the guidelines established by NCDENR. Confidence in the assessment is based on many years of bioclassification scores.

4.5.14. Terrestrial Invertebrates

Relevance

Terrestrial invertebrates make up the vast majority of the species on land (Fig. 4.5.14.1; Purvis and Hector 2000). Among the insects, about 900,000 species have been identified worldwide and account for about 80% of all described species (Smithsonian 2015). Most insects, arachnids, and a considerable number of land mollusks, nematodes, and others are found on terrestrial habitats. For the purpose of this section, terrestrial invertebrates does not include those groups that spend the majority of their life in freshwater (e.g., caddisflies [Trichoptera], dragonflies [Odonata], water mites [Hydracarina], and others).

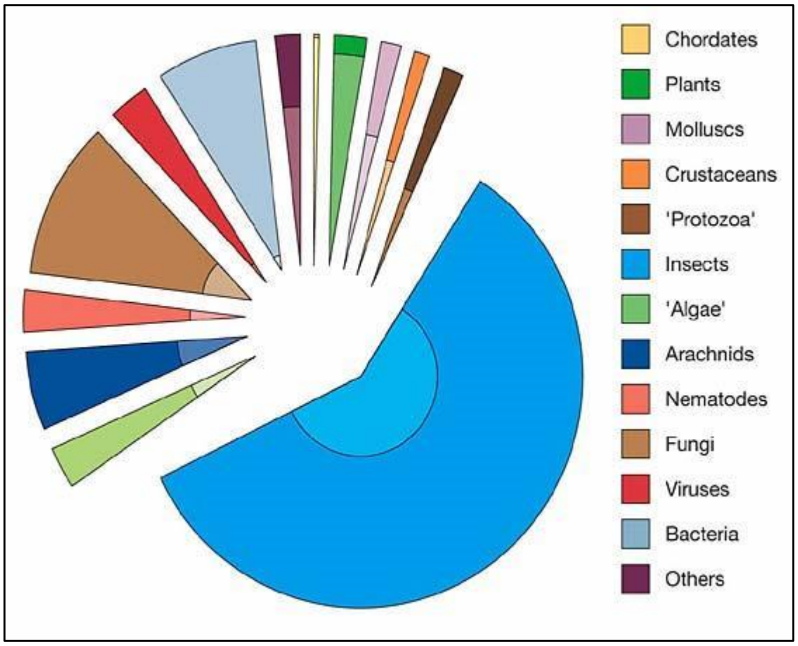

Figure 4.5.14.1. Pie chart of estimated all life globally, each slice is bisected by a line, the inner portion of which is meant to indicate the relative ratio of scientifically described taxa of that group. Source: Purvis and Hector 2000.

Biological inventory work at GRSM, especially the intensive All Taxa Biodiversity Inventory (ATBI), has currently documented 10,384 invertebrate species (by 2016), the majority of which are terrestrial. The ATBI has also documented 474 species of vertebrates, 2,188 plants, and 2,798 species of fungi in the park. All vertebrates combined make up only about 2.5% of the species of the park, while insects and other invertebrates make up nearly 60% of the park's biodiversity (Fig. 4.5.14.2).

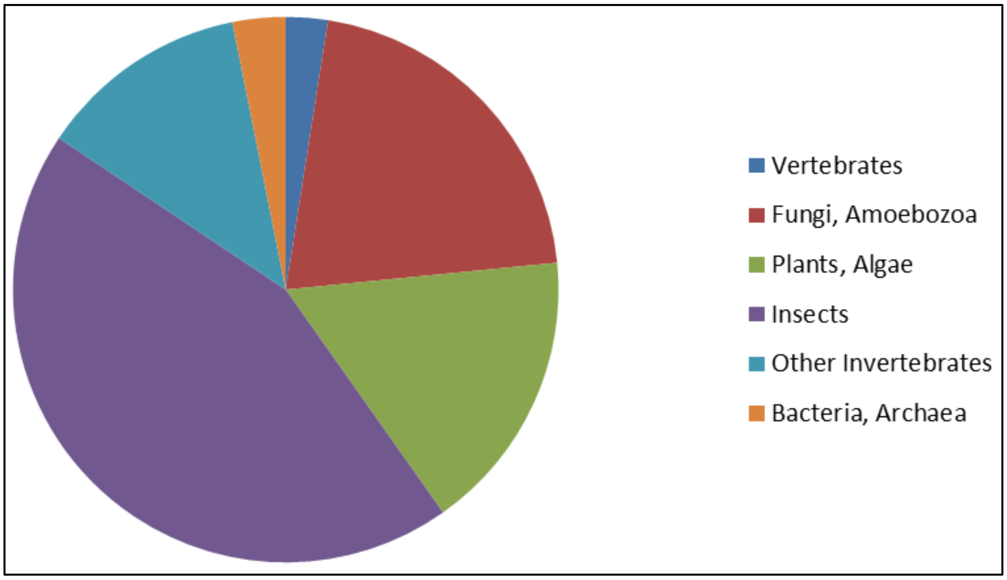

Figure 4.5.14.2. Approximate proportions of major taxonomic groups in GRSM. Source: Discover Life in America website (www.dlia.org) 2015

Of the terrestrial invertebrates in the Smokies, below are tallies of species for each major group documented in the park:

- Mollusks (land snails) - 157
- Hymenoptera (bees, ants, wasps) - 923
- Lepidoptera (moths, butterflies, skippers) - 1,871
- Diptera (flies) - 1,090
- Coleoptera (beetles) - 2,387
- Other insect orders - 1,021
- Mites - 321
- All others - 1,820
- Total terrestrial invertebrates ~9,590 or approximately half of all species known in GRSM.

Terrestrial invertebrates exhibit the widest possible array of ecological roles, including herbivores, predators, parasites, detritivores, pollinators, and seed dispersers. The sheer number of terrestrial invertebrate taxa coupled with their complex and integrated roles, is a subject too massive for a summary here, but their ecological impact cannot be overstated. Many groups are not well studied; therefore, the focus of the assessment on terrestrial invertebrates will be on the following:

- The park's pollinators**,** due to their key role in maintaining plant reproduction, and
- Invertebrate species endemic to the park and the immediate southern Appalachian region, given the park's responsibility for protecting habitat crucial to the survival of so many species.

Pollinators

Several groups of terrestrial insects are involved in pollination (Buchmann and Nabhan 1996), but it is important to note that most insects that visit flowers are not very effective pollinators. Effectiveness varies widely from species to species of both the insect and the plant; in general, the size and hairiness of a pollinator influences its ability to dislodge and carry pollen. Some groups are mostly "nectar thieves" (that is, not transporting or delivering pollen), while others lack "flower constancy" during their foraging, visiting relatively few flowers (Sheperd et al. 2003). Therefore, these insects are only incidental in the transfer of pollen from one plant to the reproductive receptacle of another plant of the same species (Table 4.5.14.1).

Table 4.5.14.1. Major groups of insects and their generalized effectiveness as pollinators, as roughly categorized by GRSM park staff.

Pollinator Group	# Documented Species in GRSM	General Effectiveness
Bees	266	Most effective
Moths	1,772	Effective
Flies	1,090	Somewhat effective
Beetles	2,387	Relatively ineffective
Butterflies, skippers	99	Relatively ineffective

Bees are generally considered to be the most important group involved in pollination (Sheperd et al. 2003). Some are plant species- or family-specialists; however, many are generalists and contribute to pollination of many different plants (Sheperd et al. 2003). Of the Smokies' documented 266 bee species, one of the most effective groups at pollination is the genus *Bombus*, which are the bumble bees.

Recently, many agencies and environmental groups in North America and Europe have voiced concern over apparent losses of bees (Kluser and Peduzzi 2007). Much focus is on the well-known European honey bee (*Apis mellifera*) and its loss as related to agricultural crops. However, in March 2015, the International Union for the Conservation of Nature (IUCN) released the first continent-wide study of Europe's bee species, finding that 9.2% are facing extinction and an additional 5.2% are considered likely to be threatened in the near future (IUCN 2014).

Meanwhile, bee species native to North America are believed to have declined as well. The threat to native plants from loss of native pollinators is not just theoretical; recent work in Britain and the Netherlands has discovered a 70% loss of wildflower species in recent decades, and a parallel shift in pollinator species composition, with uncommon species becoming rarer and common species becoming more abundant (Thomas et al. 2004, Biesmeijer and Roberts 2006). A recent Presidential Memorandum (The White House 2014) calls the decline of pollinators "severe" and requires all federal departments to undertake coordinated measures to counter the loss. Among the targeted actions are monitoring of native bee populations.

Endemic Invertebrates

In any large species group such as the insects or mollusks, there will be some species that have restricted distributions, usually in specialized habitats. This is especially true in mountainous landscapes where there are strong gradients of moisture and temperature (Duellman 1999). Combined with terrain impediments, these conditions create reproductive isolation between genetically related populations of low vagility (e.g., mollusks, beetles, springtails, millipedes). Further, the complex geology in the Smokies may also contribute to the differentiation of species. Over time, with changing climates, species populations may migrate locally upslope or around to a cooler aspect of a mountain rather than migrate long distances north or south. This would genetically isolate them from related populations that have trans-located longer distances, setting the stage for genetic drift. The biological results of this environment are illustrated in the list of terrestrial endemics currently known for the park (Table 4.5.14.2).

Table 4.5.14.2. Terrestrial invertebrates endemic, or nearly so, to GRSM. Source: North Carolina and Tennessee Natural Heritage Programs, 2015.

Terrestrial Invertebrate	Species Name	TN Status[A]	NC Status[B]	Fed Status[C]	Notes
Land Snails	*Anguispira knoxensis*	“rare”	SR	–	SH in NC, low elevations
	Carychium arboreum[D]	–	SR	–	New taxon for GRSM, NC side
	Fumonelix clingmanica[D]	“rare”	T	FSC	Spruce-fir and northern hardwood forests, >1,500 m elevation
	Fumonelix jonesiana[D]	“rare”	T	–	Newfound Gap area, in litter under beech/birch
	Fumonelix langdoni[D]	–	SR	–	High elevation; talus in beech gaps/northern hardwood
	Glyphyalinia junaluskana	“rare”	SC	–	Upland rich mixed hardwood forests
	Glyphyalinia pentadelphia	“rare”	SC	–	Low elevations, mixed hardwood
	Haplotrema kendeighi	“rare”	SC	–	Hardwoods at higher elevations, and gorges
	Heliodiscus hexadon	“rare”	–	–	Low elevations, extreme west end of GRSM
	Inflectaris ferrissi	“rare”	T	–	High elevations, talus; most of range is in GRSM

A. Tennessee does not legally list most invertebrates, so their rankings are in quotes.

B. North Carolina: SR= Significantly Rare, SC= Special Concern, T= Threatened, SH=Historical in state.

C. Federal listings: FSC=Federal Species of Concern, E=Endangered.

D. Denotes a species believed to be a strict endemic to GRSM.

Table 4.5.14.2 (continued). Terrestrial invertebrates endemic, or nearly so, to GRSM. Source: North Carolina and Tennessee Natural Heritage Programs, 2015.

Terrestrial Invertebrate	Species Name	TN Status[A]	NC Status[B]	Fed Status[C]	Notes
Land Snails (continued)	*Inflectaris verus*[D]	–	SR	–	Northeast GRSM, rock talus, 450-1,100 m elevation
	Mesodon altivagus	"rare"	SR	–	Spruce-fir mostly, acidic sites, >1,400 m elevation
	Mesomphix cupreus f. politus[D]	–	–	–	GRSM west end, calcium-rich sites
	Mesomphix latior f. monticola	–	–	–	Leaf litter, Fontana Reservoir area
	Paravitrea andrewsae	"rare"	SC	–	Northern hardwood litter and talus, Cataloochee area
	Paravitrea clappi[D]	"rare"	SC	–	High-elevation talus
	Paravitrea umbilicaris	"rare"	SC	–	Low elevation, southwest GRSM
	Paravitrea umbilicaris f. dentata[D]	–	–	–	Low elevation, extreme west end of GRSM
	Paravitrea variablis	"rare"		–	Low elevation calcium-rich sites
	Stenotrema depilatum	"rare"	SC	–	Rich hardwoods, >1,000 m elevation
	Stenotrema sp.1 (of Dourson)[D]	–	–	–	Cove hardwood litter, low elevations
	Ventridens supressus magnidens[D]	–	–	–	Wetland edges, west GRSM
	Zonitoides patuloides	"rare"	SC	–	Low/mid elevations, deep hardwood litter
Spiders	*Microhexura montivaga*	"rare"	SR	E	Cloud forests of highest elevations
Moths & Butterflies	*Apameine* (new genus, new species 1 (of Quinter)	–	SR	–	Being described, in park and perhaps one county; hill cane feeder
	Apameine (new genus, new species 4[D] (of Quinter)	–	SR	–	Being described, perhaps in GRSM only; hill cane feeder
	Cherokeea attakullakulla	–	SR	–	Mostly in GRSM, cane feeder

A. Tennessee does not legally list most invertebrates, so their rankings are in quotes.

B. North Carolina: SR= Significantly Rare, SC= Special Concern, T= Threatened, SH=Historical in state.

C. Federal listings: FSC=Federal Species of Concern, E=Endangered.

D. Denotes a species believed to be a strict endemic to GRSM.

Table 4.5.14.2 (continued). Terrestrial invertebrates endemic, or nearly so, to GRSM. Source: North Carolina and Tennessee Natural Heritage Programs, 2015.

Terrestrial Invertebrate	Species Name	TN Status[A]	NC Status[B]	Fed Status[C]	Notes
Moths and Butterflies (continued)	*Eulithis propulsata*	–	SR	–	High elevation, feeds on *Ribes* spp.
	Gazoryctra sciophanes	–	SR	–	>1,500 m elevation, larges population may be in GRSM; life history unknown
	Lygdia wagneri[D]	–	–	–	Known only on TN side of GRSM, *Euonymus* feeder
	Papaipema astuta	–	SR	–	*Collinsonia* feeder, best population may be in GRSM
	Phyciodes batesi macounensis	–	SR	FSC	Mid-elevation, prefers openings, aster feeder
	Speyeria diana (montane race)	“rare”	–	FSC	Low elevations; new research shows Southern Appalachian populations genetically differentiated, violet feeder
Fly	*Eulonchus marialiciae*	–	–	–	Hemlock/hardwoods at higher elevations, endemic to park area
Grasshoppers	*Melanoplus cherokee*	–	SR	–	Mid-elevations, park and two adjacent counties
	Melanoplus deceptus	–	SR	–	Haywood County portion of GRSM and three adjacent counties, high elevations
	Melanoplus decoratus	–	SR	–	Dry woodlands
	Melanoplus divergens	–	SR	–	Grassy balds, high elevations, recent GRSM records, but SH in NC

E. Tennessee does not legally list most invertebrates, so their rankings are in quotes.

F. North Carolina: SR= Significantly Rare, SC= Special Concern, T= Threatened, SH=Historical in state.

G. Federal listings: FSC=Federal Species of Concern, E=Endangered.

H. Denotes a species believed to be a strict endemic to GRSM.

The ATBI in the Smokies has resulted in the discovery of a large number of new-to-science invertebrates. Most of these groups are still undergoing evaluation, and have not yet received park or state rarity rankings. These groups include flies, millipedes, springtails, tardigrades, and many others.

Doubtless they contain many species restricted to the park and surrounding mountains. Beetles are one of the better known insect groups, and research has revealed at least 56 species that are endemic to the park or the immediate surrounding vicinity.

Data and Methods

Pollinators

Relatively little data on pollinators and pollination processes were collected by independent researchers prior to 2000, and these efforts were mostly qualitative, small-scale studies, or ancillary to pollinators themselves (NPS 2015a). Park staff collected data from four years of butterfly and skipper transects in Cades Cove during the late 1990s, and they also collected occurrence data on pollinator species (unpublished), but these efforts have been more opportunistic rather than systematic.

The best data available for pollinators are from the ATBI Malaise traps (Fig. 4.5.14.3), which were collected continuously for about 2.5 years at 11 sites (Parker and Bernard 2006). The sites were selected to provide a cross section of major park communities, including High-elevation Spruce-Fir Forests (1 site); Northern Hardwoods, including beech gap forest (3 sites); high- and low-elevation grasslands (2 sites); Cove Hardwoods, old-growth and second-growth (4 sites); and Heath (1 site). This study did not include the dry forest communities of the park. All 200+ bee species collected were identified by a nationally recognized bee taxonomist (Rob Jean, Indiana State University). There were subsequent searches and sampling for *Bombus* spp. by several researchers including Sheila Colla in 2006, and there have also been short-term ATBI collections in other locales since initial comprehensive sampling began.

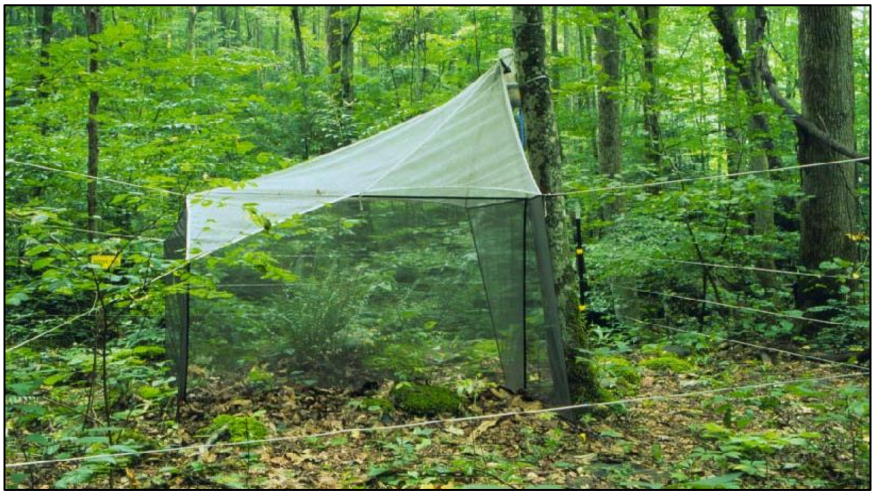

Figure 4.5.14.3. Malaise trap for flying arthropods. The insects self-collect in the collection bottle at the summit and are retrieved at set times, allowing for a quantified sample vs. effort catch. Source: NPS Photo 2014.

Endemic Invertebrates

The discovery of endemic species is mostly due to the activity of a wide variety of invertebrate authorities who have been encouraged to assist the park in understanding what species occur here. Using their knowledge of favorable microhabitats and specialized sampling techniques, they are adept at discovery and documentation of their particular group. Although taxonomic authorities have collected in the park sporadically for decades, the pace accelerated in the late 1990s and early 2000s with the beginning of the ATBI.

Reference Condition

Large changes occurred on the landscape in pre-park times, with probable increases in wildland fire and deforestation over the majority of the park during the 1800s and early 1900s. In addition, large sections in lowland valleys and coves were intensely cultivated for several decades before park establishment, and slopes and some mountain ridgelines were grazed. Gradual reforestation has occurred since park establishment in the 1930s. The changing landscape conditions before and since park establishment, without any baseline data for either pollinators or endemic species, requires us to use more recently collected data as reference conditions.

Pollinators

Qualitative data on species that pollinate, particularly butterflies, were occasionally collected in the park for various independent research projects in the latter part of the 20th century. The best reference data for pollinators are the systematic Malaise trap collections of the ATBI that occurred from 1999 to 2002 at 11 sites (Parker and Bernard 2006).

Endemic Invertebrates

Little is known of the life history of many invertebrates, and this is especially true of endemic invertebrates which are usually obscure. Additionally, rare species are usually difficult to sample unless intensive effort is focused on that taxon. However, several groups, including land snails, are better known than others.

There are a number of rare and endemic land snail species in this region (Pilsbry 1940, Hubricht 1985, Dourson 2013), and most depend on available free calcium in their habitat in order to produce competent shells. Unfortunately, GRSM has suffered some of the most chronic acidic precipitation in North America over the past several decades. Although dramatic reductions in deposition have occurred in the last 20 years (see section 4.1.1, Acid Deposition), the accumulated acidic deposition may have altered park habitats. Keller's (2012) work on potential bird reproduction disruptions due to lack of snails that supply calcium (Graveline and Van der Wal 1994), involved the collection of detailed land snail data from sixty 20 x 20 m (65.6 x 65.6 ft) plots in the high elevations of the park. All snails were collected in each plot, both live and dead, identified to species, and measured pending assay for calcium. Detailed soils analyses were also conducted. These 60 plots of Keller (2012) are the reference for endemic land snails, and other high-elevation endemic invertebrates.

Current Condition

Pollinators

Park bumble bees have declined demonstrably in recent years, and continued loss is anticipated. Thirteen species of *Bombus* are documented in GRSM, but two, *Bombus affinis* (Fig. 4.5.14.4) and *B. terricola,* have probably become extirpated from the park since ca. 2002 and appear close to biological extinction. *Bombus affinis* has disappeared over almost all of its original range across the eastern U.S., and is currently being considered for listing by the U.S. Fish and Wildlife Service.

Figure 4.5.14.4. The nearly extinct rusty-patched bumble bee (*Bombus affinis*), formerly common in GRSM, was last recorded about 2002. Source: NPS Photo 2012.

Several threats have been postulated to account for the decline of bees, such as pesticide overuse, habitat destruction, and climate change (Williams et al. 2014); however, with the potential exception of climate change, these are not major factors in the Smokies. The most likely threat to *Bombus* species appears to be "pathogen spillover" (Williams et al. 2014) from commercial greenhouse cultivation of vegetables, where *Bombus* spp. are used as effective pollinators (Colla et al. 2006). The source of the pathogen most likely was from captive commercially-raised bumble bees that were infected with parasites, and escaped confinement. The microsporidian *Nosema bombi* has specifically been implicated, in both laboratory and field experiments, to cause dramatic loss of fitness in the reproductive capacity of bumble bee colonies (Otti and Schmid-Hempel 2008). This exotic parasite has also been recorded in the park (Sokolova et al. 2009).

In recent years, park staff, citizen scientists, and several university researchers have searched for the apparently extirpated species of bumble bees in the Smokies - to no avail (NPS, Investigator's Annual reports). Therefore, this condition finding has an overall moderate confidence level. A very high confidence would be attained with subsequent quantitative sampling at baseline data sites.

Endemic Invertebrates

In recent decades, a series of air quality issues were identified as having a deleterious effect on the high elevations of the park, where many endemic species live. These include chronic acid deposition, high ozone episodes, mercury deposition, and the loss of three dominant forest trees (Fraser fir, eastern hemlock, American beech) to introduced insects and fungal pathogens.

For the vast majority of endemic terrestrial invertebrates, there is little data on their current condition, other than recent records of occurrence. The exception is land snails, which have been extensively studied in the park. Several malacologists have expressed concern about observing fewer land snails in the higher elevations, where acid deposition impacts are the most severe (Dourson 2013). In 2011, following extensive field surveys, researchers found that the park-endemic Jones' middle-toothed snail (*Fumonelix jonesiana*) could no longer be located in areas of former occupation, except along one road where calcium-rich limestone gravel had accumulated due to the park's wintertime operations (Dourson 2011). It is believed that the snail is at real risk of extinction due to long-term acidification of their entire high-elevation range, and is only being prevented by the happenstance accrual of fine limestone gravel used for vehicle traction in winter.

On the high ridges of the park are a number of beetle species, including several peculiar, snail-eating beetles that are each known only from one to several mountain peaks. The park is aware of at least two poaching cases where quantities of specimens of these beetles were bound for hobbyist collectors in Europe. Speculation is that we probably are not detecting most illegal take incidents, and that direct losses to these relatively small populations due to poaching, compounded by reduction in prey (land snails) due to acidification, may be causing a decline.

Trends

Pollinators

Two species of GRSM bumble bees are believed extirpated, and of the 11 *Bombus* species currently remaining, nine species are believed to be stable, with two species exhibiting evidence of a range-wide decline. *Bombus pensylvanicus* was formerly one of the most widespread species in the southern U.S., but now is in decline in the northern parts of its range (Williams et al. 2014). *Bombus fervidus* is also exhibiting a slow decline in parts of its range (Williams et al. 2014). It is reasonable to assume that if the trends continue, GRSM will lose four species (or about 25%) of its *Bombus* species, which is one of the most effective groups of pollinators. The trends in other bees are unknown.

Endemic Invertebrates

While populations of most terrestrial invertebrates in the park are assumed to be stable, endemic species at high elevations appear to be at risk (see section 4.1.1, Acid Deposition). For land snails alone, 10 species are strict park endemics and an additional 12 taxa are known only from the park and immediate surrounding counties. There is insufficient data on most endemic terrestrial invertebrates to discern a trend, but it is reasonable to assume that those at higher elevations, at least, are at similar risk.

Confidence and Data Gaps

Pollinators

A critical data need for pollinators is to re-sample a selection of the 11 ATBI Malaise trap sites of 1999-2002, and re-trap for an optimum period of time (e.g., one month in active season). In comparison with the baseline data, the subsequent species composition at each site, and enumeration of each bee species, would provide data for a park-wide quantification of trends for many of the park's 200+ bee species. A dry forest site should be included. These should become permanent "biodiversity reference sites" for bees, to be sampled at regular intervals of about 3-5 years. An alternative would be to utilize “bee bowls” (Shapiro et al. 2014), which have been used in the park in different locations. Additionally, a four-year transect survey of butterflies and skippers in the Cades Cove area of GRSM, utilizing "Pollard" transect methodology, should be repeated and then published. This will expand the breadth of pollinators for which quantified data are available. Overall, the condition of pollinators in the park is declining, and warrants significant concern (Table 4.5.14.3).

Endemic Invertebrates

Many of the very speciose terrestrial invertebrate groups discovered in recent years are currently being evaluated for rarity by park staff; therefore, no trends are available, but populations are assumed to be stable, with one significant exception - those species living at higher elevations in the park. A number of human-related perturbations have caused, and will continue to cause, clear concern for all rare species in this ecological zone. The sustainability of snail populations in this calcium-poor and extremely acidic environment is an issue. Keller’s 60 high-elevation plots should be re-sampled for land snails in such a way as to provide a quantitative metric of change from her initial 2006-2007 measurement, and co-collection of other invertebrates as well as vegetation and soil samples should be considered. Overall, the condition of endemic invertebrates in the park is declining, and warrants significant concern; however, the confidence in this assessment is low (Table 4.5.14.3).

Several invasive terrestrial invertebrates that are not traditional forest pests (see section 4.4.2, Invasive Animals) are causing concern, and additional data are needed to clarify their status and potential impacts on endemic invertebrates:

- Fire ants (*Solenopsis invicta*) have been in the park since at least 2001, and could have impacts on other invertebrates and vertebrates in areas of frequent wildland fire (see section 4.5.16, Reptiles).
- Asian earthworms in the genus *Amynthas* have invaded disturbed areas of the lower elevations of the park (NPS 2015b), and may have an adverse effect on other invertebrates and vertebrates (Craft 2009, Synder et al. 2009).
- Hematophagous invertebrates such as mosquitoes, other biting flies, and ticks are perhaps important ecological regulators of animal populations; however, they also are host to pathogens which can be vectored to humans and other animals (Reeves et al. 2004). During a survey of disease exposure among national park employees from GRSM and Rocky Mountain National Park, a significant percentage were found to have been exposed to over a dozen potentially serious diseases, including West Nile virus and spotted fever rickettsiae (Adjemian et al. 2012). Some of these infectious agents are newly invasive to North America, while others are native, but may be at elevated rates of infection in the native invertebrates due to unknown influences.

Sources of Expertise

- Sheila Colla, University of York, Ontario
- Dan Dourson, Biological Consultant

- Sam Droege, USGS Patuxent Wildlife Research Center
- Terry Griswold, Logan Bee Lab, USDA
- Becky Nichols, Entomologist, Great Smoky Mountains National Park
- Chuck Parker, Research Biologist (retired), USGS

Summary Condition

Table 4.5.14.3. Summary condition and trend graphics for pollinators and endemic invertebrates in GRSM.

Resource	Indicator	Status and Trend	Rationale and Reference Conditions
Focal Species or Communities	Pollinators	⬇	The best reference data for pollinators are the systematic Malaise trap collections of the ATBI that occurred from 1999 to 2002 at 11 sites (Parker and Bernard 2006). Threats include pesticide overuse, habitat destruction, and climate change.
	Endemic invertebrates	⬇	The 60 plots surveyed by Keller (2012) are the reference for endemic land snails, and other high-elevation endemic invertebrates. Air quality issues and the loss of three dominant tree species are the major threats to these species.

4.5.15. Fishes

Relevance

The southern Appalachian Mountains in general, and the upper Tennessee River drainage in particular, are home to one of the most diverse fish faunas in the world. GRSM streams contain 71 species of fish representing 12 families (NPSpecies 2015). In the 20th century, North American freshwater fishes had the highest extinction rate of all vertebrates in the world, estimated to be 877 times greater than the background extinction rate for this group (Burkhead 2012). Three species of fish found in the park are currently listed as federally endangered or threatened - the Citico darter, formerly called the duskytail darter (*Etheostoma sitikuense*) is listed as endangered, the smoky madtom (*Noturus baileyi*) is listed as endangered, and the yellowfin madtom (*Noturus flavipinnis*) is listed as threatened. Additionally, the spotfin chub (*Erimonax monacha*), which is listed as threatened, was historically found in GRSM.

There is a long history of sport fishing for trout in the park (Kulp and Moore 2005), focusing primarily on non-native rainbow trout (*Oncorhynchus mykiss*), which had been stocked extensively in streams prior to park establishment, and then were stocked by park staff from 1934 until 1975 (Kulp and Moore 2005). The range of the native brook trout (*Salvelinus fontinalis*) became restricted to mostly the upper stream reaches (Larson and Moore 1985), having lost an estimated 75% of their original range within the park (Moore et al. 2005).

Data and Methods

For this report, data from studies conducted between 2011 and 2015 were compared to reference conditions taken from studies conducted between 1990 and 2010. Standardized annual three-pass depletion fish surveys began in the 1980s and continue through the present. Between 1990 and 2009, 362 fish survey sites had been monitored, many for multiple years (Fig. 4.5.15.1) (Schwartz et al. 2014). Fish diversity is strongly correlated with drainage area, with upper stream reaches tending to have naturally low species diversity. These streams have been monitored primarily to estimate population sizes and condition of trout. Lower elevation streams, with greater diversity, have been monitored with an emphasis on measuring diversity as well as abundance and condition of all sport fish. Beginning in 2012, sampling began under a new Vital Signs monitoring program with a focus on co-locating fish, macroinvertebrate, and water quality sampling sites, and using an index of biotic integrity (IBI) to monitor fish communities.

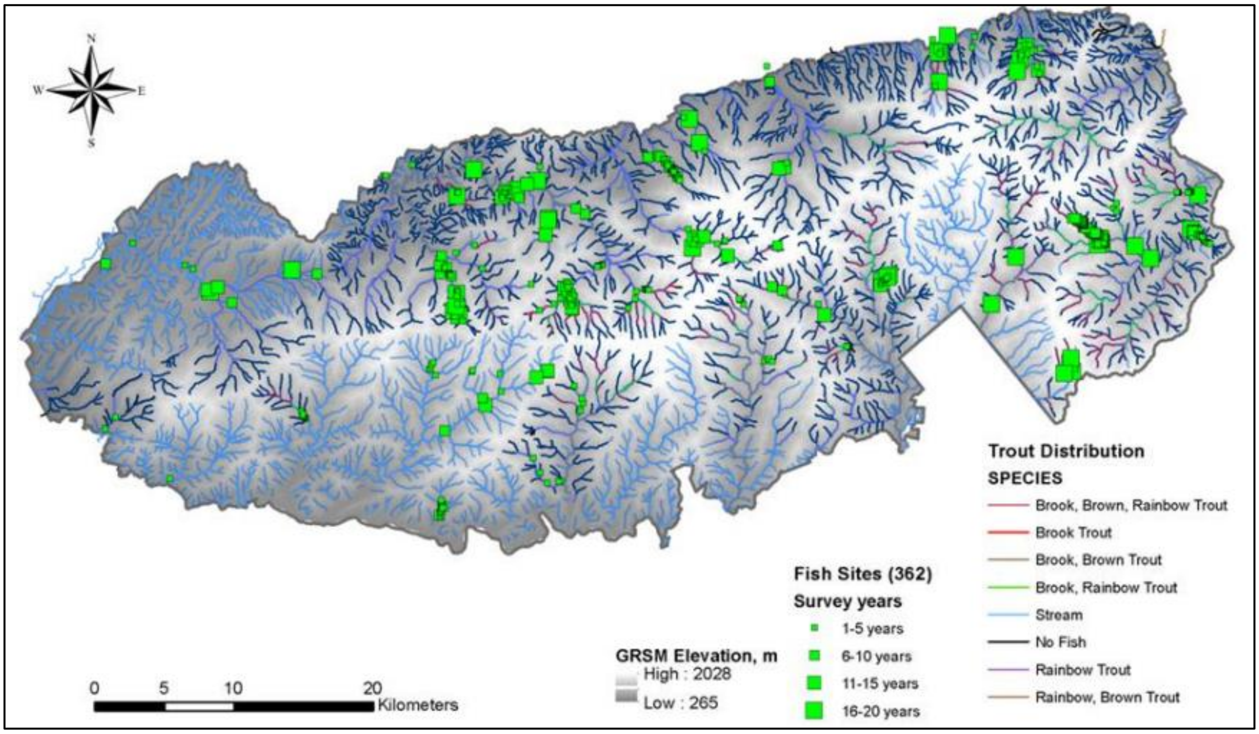

Figure 4.5.15.1. Fish survey sites and trout distribution in Great Smoky National Park. Fish surveys were conducted from 1990 to 2009, and trout distribution is based on sampling from 1994 to 2000. Source: Schwartz et al. 2014.

In 1986, further efforts to restore populations of extirpated species were begun using captive propagation and stocking (Shute et al. 2005). Citico darter, smoky madtom, spotfin chub, and yellowfin madtom were re-introduced to Abrams Creek, where they were presumed to have been extirpated by an effort to establish a trophy rainbow trout fishery in 1957. Nearby Citico Creek served as a source of paternal stock for captive-reared madtoms and darters, while spotfin chubs were initially trans-located from the Little Tennessee River upstream of Fontana Reservoir in North Carolina, but later stockings relied on captive spawning (Shute et al. 2005). Between 1986 and 2010, monitoring of reintroduction success was accomplished by night and day snorkel surveys conducted in the summer. From 2011 to present, a standardized sampling protocol has been used to sample at least 200 m (656 ft) of preferred habitat in each of three zones on lower Abrams Creek using snorkel surveying techniques.

Parameter Criteria

The three-pass depletion method, scaled to stream size by using one electrofishing unit for each 3-4 m (9.8-13.1 ft) of stream width, is used to estimate fish biomass and density. Biomass is calculated by multiplying the estimated number of fish by their average weight (g), dividing by the area (m^2), and multiplying by 10 to convert the units to kg/ha. Density is calculated by dividing the estimated number of fish by the area (m^2) and then multiplying by 100 to convert the units to number of fish/100 m^2. Trout biomass and density are used to assess trends in high-elevation, low-diversity streams. In larger, lower elevation streams, abundance and diversity of other common species, particularly game fish, are noted. For both high-elevation and lower elevation streams, narrative summaries of abundance are used to document resource condition.

The new Vital Signs monitoring protocol uses three-pass depletion sampling at high to mid-elevation sites (≥ 610 m [2,000 ft]) and calls for calculation of an index of biotic integrity (IBI) for each low-elevation (≤ 610 m [2,000 ft]) aquatic monitoring site. Three-pass depletion sites are to be visited annually, whereas IBI monitoring sites will be visited each year, with individual sites visited on a three-year rotation. IBIs are multi-metric indices that include measures of diversity, distribution among functional groups, and health of the fish (Karr 1991), and provide a standardized score that can be used to establish an integrity class (Table 4.5.15.1) by comparison to established reference conditions. IBI scores were not available for studies conducted between 1990 and 2009, so trends in IBI scores are not available.

Table 4.5.15.1. Upper Blue Ridge IBI fish community ratings. Source: Karr et al. 1986.

IBI Range	Rating
58-60	Excellent
48-52	Good
40-44	Fair
28-34	Poor
12-22	Very Poor

Reference Condition

High-elevation Streams

Schwartz et al. (2014) reported on data collected between 1990 and 2009, and stated that the median adult brook trout density for the 298 stream sites surveyed was approximately 6 fish/100 m^2 (range=0–52), and median biomass density was 14.7 kg/ha (range=0-114.6 kg/ha) (Table 4.5.15.2).

Table 4.5.15.2. Summary of adult brook trout abundance for 298 high-elevation fish sample sites between 1990 and 2009. Modified from Schwartz et al. (2014).

Statistic	Density (fish/100 m^2)	Biomass Density (kg/ha)
Median	5.9	14.7
Mean	8.1	18.3
SD	8.0	15.9
Minimum	0	0
Maximum	51.8	114.6

Low-elevation Streams

While the calculation of IBIs for low-elevation streams has only begun in recent years, researchers have recorded species richness for many years. For example, historic species richness for the largest low-elevation stream reach in the park, the lower section of Abrams Creek, was reported as 46 species (Lennon and Parker 1959). Species richness is strongly correlated with a number of factors, including stream size and drainage area (Perkin and Gido 2012, Sheldon 2013), fragmentation (Nislow et al. 2011, Perkin and Gido 2012), and nutrients (Azevedo et al. 2013), and the reference-condition varies accordingly (typically 10-22 species).

Extirpated and Reintroduced Species

Between 1986 and 2003, four extirpated fish species were stocked into Abrams Creek (Table 4.5.15.3). The stocked individuals were either trans-located from nearby sources, or propagated by Conservation Fisheries, Inc. Researchers conducting subsequent snorkel surveys between 1986 and 2003 recorded many observations of stocked (marked) individuals and young-of-year for the Smoky madtoms, yellowfin madtoms, and the Citico darter (123, 74, and 433 respectively). Spotfin chubs were observed less often and observations declined between 1998 and 2001 (91, 46, 8, 0), though evidence of reproduction (three young-of-year individuals) was observed in 2000 (Shute et al. 2005). Researchers sampling between 2007 and 2010 (Gibbs 2009, Gibbs et al. 2014a, Gibbs et al. 2014b) reported that Smoky madtoms were occupying ~52% of available river kilometer in the portion of Abrams Creek where they had been stocked, yellowfin madtoms occupied ~77%, and Citico darters occupied ~22%. No spotfin chubs were observed.

Table 4.5.15.3. Timeline of stocking efforts (number introduced) into Abrams Creek between 1986 and 2003 for four extirpated fish (adapted from Shute et al. 2005).

Year	Smoky madtom	Yellowfin madtom	Citico darter	Spotfin chub
1986	0	18	0	0
1987	92	115	0	0
1988	118	155	0	250
1989	174	90	0	38
1990	151	0	0	340

Table 4.5.15.3 (continued). Timeline of stocking efforts (number introduced) into Abrams Creek between 1986 and 2003 for four extirpated fish (adapted from Shute et al. 2005).

Year	Smoky madtom	Yellowfin madtom	Citico darter	Spotfin chub
1991	134	0	0	0
1992	0	0	0	0
1993	52	0	85	0
1994	38	26	51	709
1995	166	94	118	1,200
1996	116	0	667	0
1997	438	0	396	0
1998	116	61	216	3,500
1999	369	247	203	3,350
2000	604	365	0	500
2001	264	85	1,694	1,480
2002	315	286	0	0
2003	20	32	0	0
Total	**3,167**	**1,574**	**3,430**	**11,367**

Conditions and Trends (2011 – 2015)

High-elevation Streams

Narrative summaries of annual brook trout abundance sampling from 2012-2014 (129 stream sites; Table 4.5.15.4) stated that abundances did not vary significantly from long-term expectations. Adult brook trout biomass, measured from 11 sites on eight vital signs streams in 2014, ranged from 2.8-14.3 kg/ha for populations sympatric with other trout species, and 12.3-37.7 kg/ha for allopatric populations (Nichols and Kulp 2015). Schwartz et al. (2014) reported a median biomass density of 14.7 kg/ha for data collected from 298 sites between 1990 and 2009. Nichols and Kulp (2015) also provided control charts for two streams based on at least 10 years of sampling. Samples from 2011 through 2014 fall within the 99% confidence band or above the upper band (Fig. 4.5.15.2).

Table 4.5.15.4. Narrative summaries of annual brook trout sampling, quoted from annual administrative reports, for the years 2012 through 2014.

FY Reported	Number of Streams (sites)	Narrative Assessment
2012	26 (57)	"The biomass of most brook trout populations was at or above average, with mostly above-average age-0 year classes."
2013	18 (40)	"The biomass of most brook trout populations were within normal variation"
2014	16 (32)	"The biomass of brook trout populations was highly variable in 2014 compared to normal variation."

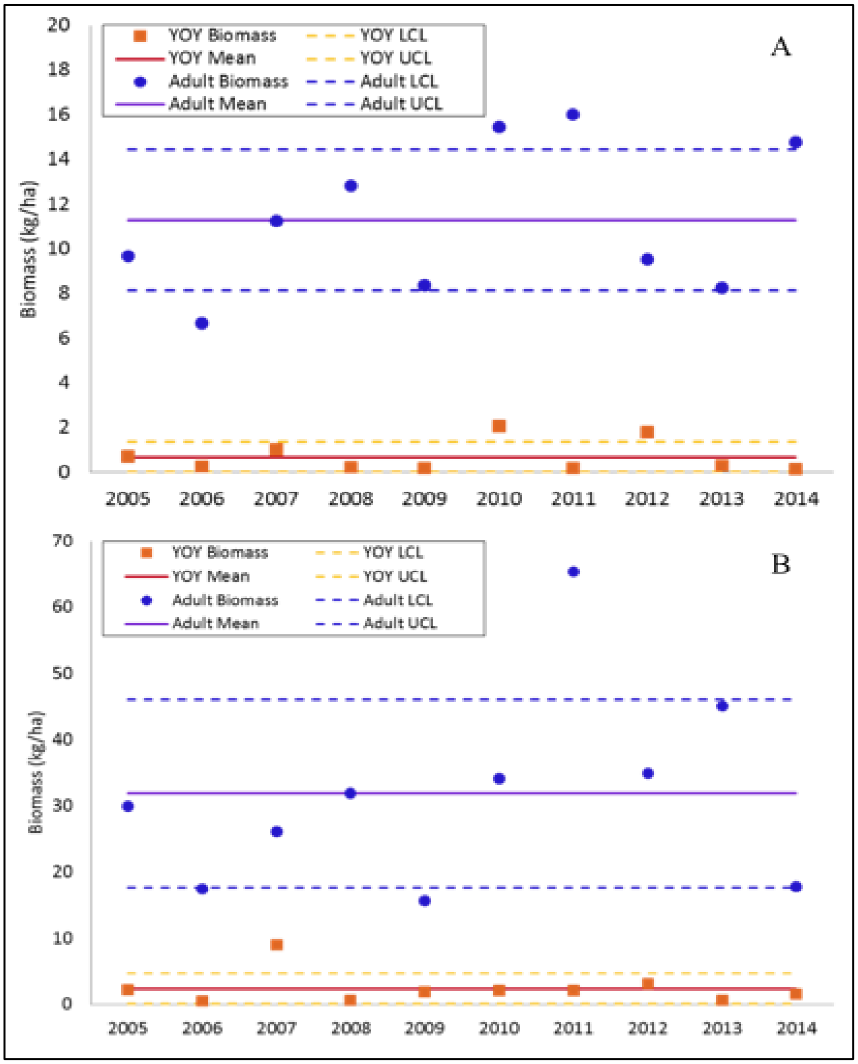

Figure 4.5.15.2. Control chart of young-of-year and adult brook trout biomass density, in A) Rock Creek, and B) Cosby Creek, between 2005 and 2014. Note the mean represents 10 years of data during the collection period. The lower and upper confidence intervals represent three standard errors above and below the mean. Source: Adapted from Nichols and Kulp 2015.

Low-Elevation Streams

Narrative summaries of annual large-stream sampling from 2011-2014 (17 stream sites; Table 4.5.15.5) stated that diversities did not vary significantly from long-term expectations. Nichols and Kulp (2015), reporting on the first three years of IBI data collection from six streams, found that scores reflected integrity classes of good to poor (Fig. 4.5.15.3). These lower-than-expected IBI scores reflect the reduced diversity at higher elevation sites, rather than poor stream quality (Nichols and Kulp 2015). Elevation was found to be strongly negatively correlated with IBI score ($P < 0.05$, $r=-0.91$), and species richness for the sites ranged from lows of 4 and 5 species for upper elevation sites on East Prong Little River and Cataloochee Creek, to highs of 15 and 17 for Abrams Creek and the lower elevation site on East Prong Little River. Reference conditions were typically in the range of 10 to 20 species (Nichols and Kulp 2015).

Table 4.5.15.5. Narrative summaries of annual large-stream sampling, quoted from annual administrative reports, for the years 2011-2014.

FY Reported	Number of Stream Sites	Narrative Assessment
2011	2	"Comparisons with data from previous years demonstrated that population levels were within the range of natural variation observed during the last 25 years."
2012	4	"In general, the fish communities sampled appeared to be healthy and representative of typical low-elevation stream communities in the Blue Ridge region. Species diversity was high and the general condition of the species present was good to excellent. There were no obvious signs of stress or disease in the species collected, other than ubiquitous and benign commensal parasites like black spot (black grub) and the occasional leech."
2013	3	"In general, the fish communities sampled appeared to be healthy and representative of typical low-elevation stream communities in the Blue Ridge region. Species diversity was high and the general condition of the species present was good to excellent. There were no obvious signs of stress or disease in the species collected, other than ubiquitous and benign commensal parasites like black spot (or black grub) and the occasional leech."
2014	8	"In general, the fish communities sampled appeared to be healthy and representative of typical low-elevation stream communities in the Blue Ridge region. Species diversity was high and the general condition of the species present was good to excellent. There were no obvious signs of stress or disease in the species collected, other than ubiquitous and benign commensal parasites like black spot (black grub) and the occasional leech."

Extirpated and Reintroduced Species

Conservation Fisheries Inc. conducted a three-year survey (2012-2014) of reintroduced smoky madtoms, yellowfin madtoms, and Citico darter populations in Abrams Creek. They found a negative correlation between abundance of smoky madtoms and Citico darters, with yellowfin madtoms maintaining a smaller, but less variable average density across survey zones (Fig. 4.5.15.4). Juveniles of all three species were observed, indicating continued reproductive success. Shute et al. (2005) suggest that historical records of the spotfin chub in Abrams Creek may have been seasonal, as Abrams Creek is considerably smaller than those streams where it is now considered to have resident populations. Thus it appears that while populations may vary among years, depending on the vagaries of weather and stream flow, the reintroductions of these three species has been successful.

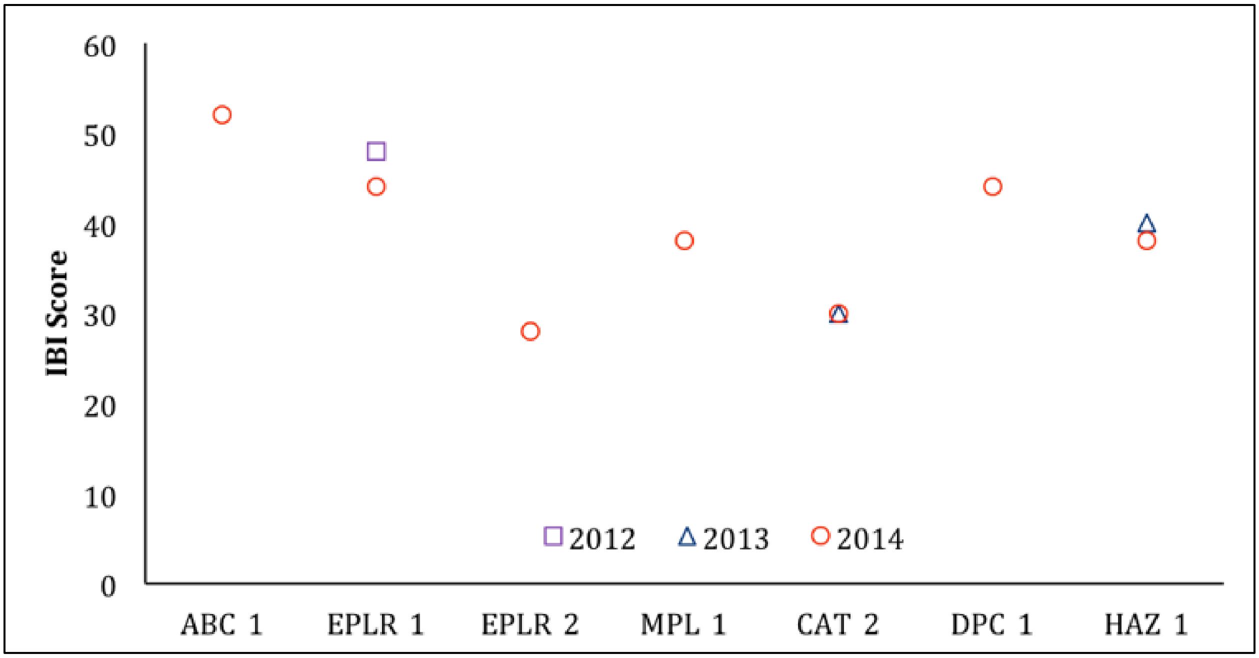

Figure 4.5.15.3. IBI scores obtained for vital signs streams, 2012-2014 Source: Nichols and Kulp 2015. ABC=Abrams Creek, EPLR=East Prong Little River, MPLP=Middle Prong Little Pigeon River, CAT=Cataloochee Creek, DPC=Deep Creek, and HAZ=Hazel Creek. The Blue Ridge stream metric was used as the scoring metric for all IBI scoring.

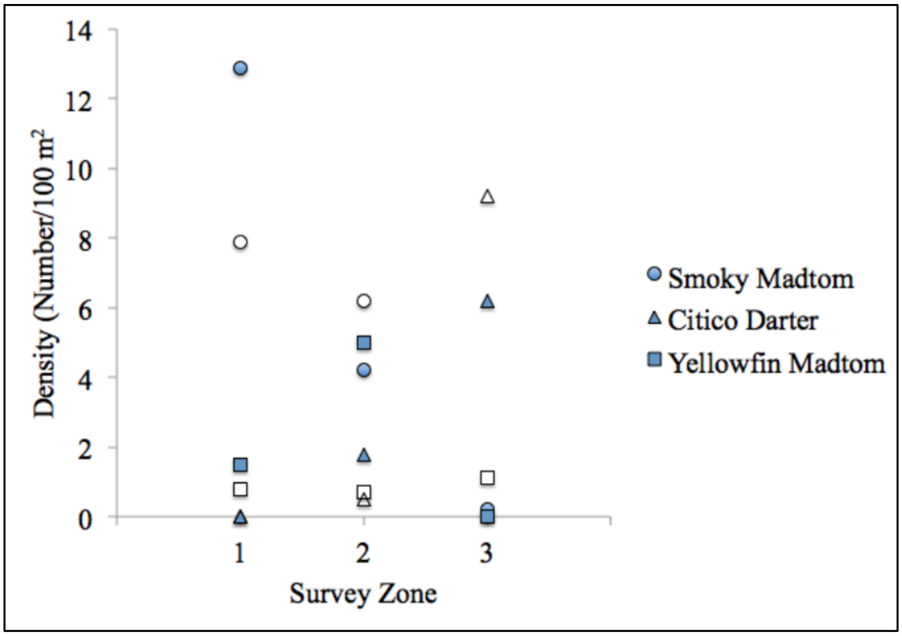

Figure 4.5.15.4. Density of smoky madtom, Citico darter, and yellowfin madtom in three zones of Abrams Creek within Great Smoky Mountains National Park. Filled symbols represent 2013 data and open symbols represent 2014 data. Source: Adapted from GRSM 2013 and GRSM 2014.

Confidence and Data Gaps

Great Smoky Mountains National Park has a long history of monitoring sport fish (Kulp and Moore 2005), and a somewhat shorter, but also strong, history of monitoring the total fish assemblage (Schwartz et al. 2014). The vital signs approach to monitoring aquatic communities hasn't been in place long enough to allow the establishment of expected reference scores for the different watersheds and elevation zones. Status and trends of GRSM fishes are presented in Table 4.5.15.6.

Sources of Expertise

- Matt Kulp, Fisheries Biologist, Great Smoky Mountains National Park

Summary Condition

Table 4.5.15.6. Summary condition and trend graphics for fishes in GRSM.

Resource	Indicator	Status and Trend	Rationale and Reference Conditions
Focal Species or Communities	High-elevation fishes	⇔	Brook trout density trends and professional opinion were used to assess status and trends. Abundances were variable, but there were no obvious upward or downward trends.
	Low-elevation fishes	⇔	Historic large-stream sampling and professional opinion plus recent IBI scores were used to assess status and trends. Lower confidence is based on the small number of IBI scores currently available.
	Extirpated and reintroduced species	⇧	Densities and evidence of reproduction of three re-introduced species were used to assess status and trends.

4.5.16. Amphibians and Reptiles

Relevance

Amphibians

Amphibians are the most numerous vertebrate in GRSM, with some salamander density estimates of one per square meter over extensive areas (Petranka 1998). This number is probably higher along streams and lower on dry slopes, but if accepted as a rough estimate, could indicate roughly 20 million salamanders park-wide. Salamanders are voracious predators of insects and other invertebrates on the forest floor, along stream corridors, and sometimes up in vegetation. Recent studies (Wyman 1998, Best and Welsh 2014) have assessed the significant ecological role of plethodontid salamanders (a family of lungless salamanders) by conducting exclosure experiments. The researchers found that predation on leaf-eating invertebrates by red-backed salamanders (*Plethodon cinereus*) led to an 11-17% increase in forest leaf litter retention (Wyman 1998). In another similar experiment (Best and Welsh 2014), the presence of single salamanders (*Ensatina eschscholtzii*) in small enclosures led to a 13% increase in litter retention, which extrapolates to about 200 kg/ha of captured carbon.

The southeastern U.S. has the greatest diversity of salamanders in the world, and in phylogenetic respects it is a "deeper" diversity than in other regions, with 7 families, 19 genera, and over 75 species. There are 30 salamander species documented in GRSM and 14 species of frogs and toads (P. Super, pers. comm.). For its 2,000 km^2 (772 mi^2) size, the park is one of the most species-rich sites in the world for this group (Petranka 1998). One species, Jordan's salamander (*Plethodon jordani*), has almost its entire range within the park, and several others have significant portions of their distribution in the park (Dodd 2004).

[Note: Amphibians and reptiles are not closely related, are generally found in different habitats, and may be influenced differently by the same environmental factors. They are considered here together due to a tradition based on similar body form and size.]

Reptiles

Snakes, lizards, and turtles are far less abundant in GRSM and there are fewer species than amphibians; 23 species of snakes, nine species of lizards, and eight species of turtles are currently documented (P. Super, pers. comm.). Snakes and lizards perform an especially significant role in drier sites, where they exert some control over rodent and insect populations. Turtles are omnivorous and all are associated with aquatic habitats in the park, with a single exception - the long-lived eastern box turtle (*Terepene c. carolina*).

Data and Methods

Amphibians

Numerous studies on amphibians have been conducted in the park over the last several decades, with 78 scientific citations for the park since about 1980 (IRMA 2015). The majority were peer-reviewed, published journal articles, graduate dissertations, or book chapters (NPS 2015a). Studies have been focused primarily on taxonomy/genetics, behavior, ecology, diseases, methods in monitoring, and other topics. Also, most were focused on salamanders, rather than anurans (frogs and toads).

Hairston et al. (1992) has been conducting one of the longest-running amphibian monitoring projects in the U.S., sampling every autumn in the park along Heintooga Road. Two night-surveys are conducted every September, with large teams doing timed searches at the same points. Although this project started in the mid-1970s as a measure of hybrid zones of plethodontid salamanders, it has been modified and expanded in recent years, and 2015 was its 40th year of sampling (NPS 2015b). A multi-year intensive study of park amphibians was conducted from 1998-2002, and the resulting book discusses methodology and other detailed information on the park's amphibians (Dodd 2004). Also, a significant treatise on monitoring amphibians in the park was published, with details on different methodologies that have been employed in the park and elsewhere (Dodd 2003).

Reptiles

Reptiles have received much less research attention, probably because all of the reptile species in the park are also found outside the park in greater numbers. Qualitative inventories were conducted as early as the 1930s (King 1939, 1944); however, significant recent work occurred during the ATBI in the early 2000s. Using cover boards and active searching to sample remote sections of the park, almost 800 reptile point locations were recorded for 33 taxa (Cash 2004). More recently, in work related to wildland fires, Fouts (2014) used transect searches to quantify post-fire habitat use by snakes and lizards.

Reference Condition

No quantitative work was conducted on amphibians or reptiles in the pre-park era; however, it is logical to assume that over a century of widespread logging and agriculture had a destructive effect on them (Brown 2000, Dodd 2004). With park establishment, and King's early work on amphibians and reptiles in 1939 and 1944, a reference condition of about 1940 is selected. Detailed records, for both amphibians and reptiles, on geography, elevation, and abundance for each species from this era until the mid-1960s, are published in Huheey and Stupka (1967). This was a period of rapid re-forestation throughout most of the lower elevations and lower slopes of the park.

Dodd (2004) felt that, despite widespread forest destruction and several thousand people dwelling in the park at its creation, sufficient source populations of amphibians must have remained and re-colonized terrestrial and aquatic sites. He also surmises that after several decades of recovery, the amphibian community may be approaching what it was like before human settlement, although subtle differences undoubtedly remain in terms of distribution, species richness, and abundance.

Current Condition

Amphibians

Prior to 1934, the majority of lands that became the park were disturbed. These lands have since been re-forested by natural succession (Pyle 1988), which is presumed to have had a major positive impact on the moisture-obligate amphibians (Dodd 2004). However, the diversity and abundance of salamanders in second-growth forests are not yet at the level found in the park's remnant old-growth cove forests, although monitoring results are highly variable and populations are difficult to census. (Hyde and Simons 2001).

After decades of sampling plethodontid salamanders at thousands of sites in the Appalachians, Highton (2005) reported significant declines at over 150 sites over a 30-year period. These declines might suggest a disease epidemic, perhaps caused by the aquatic fungus *Batrachochytrium dendrobatidis* (Bd), which has caused devastating epidemics in recent decades in amphibians nearly worldwide, especially in Central America and Australia (Daszak et al. 1999). Caruso and Lips (2013) tested the assumption of a Bd epidemic by re-sampling salamanders in the genus *Plethodon* at 35 of Highton's sites in the park, which were selected across elevation gradients. Their results also indicated that populations had declined throughout the park, and at 22 of 35 sites, they were unable to find one or more species that were historically present, despite multiple sampling dates. However, out of 665 salamanders tested, only one was positive for Bd (0.0015%). They concluded that they were unable to substantiate the cause of the reported decline as Bd, over-collection, logging, acid precipitation, or changes in temperature or precipitation. They were unable to rule out however, other diseases or climatic shifts (Caruso and Lips 2013). Additional research confirms that Bd is rare in mountainous areas (Hossack et al. 2010), being limited somewhat by low temperatures. The cold season at GRSM may therefore limit Bd infections, at least in colder habitats (Piotrowski et al. 2004), and the stream dwelling and higher elevation salamanders appear to be less at risk. Generally, temperate stream environments are not believed to develop extremely high concentrations of the fungus (Chinnadurai et al. 2009, Hossack et al. 2010).

Large die-offs of vernal pool amphibians have been reported at a natural limestone pond in Cades Cove; the cause of death was attributed to a family of viruses known as Iridoviridae. One genus in this family, *Ranavirus*, is a known pathogen of amphibians, having been suspected of causing declines elsewhere at sites in North America and Europe (Dodd 2004). In 2009, the affected site was re-sampled for ranavirus, and high degrees of infection were found in two species (84% in larval ambystomids, and over 44% in adult red-spotted newts [*Notophthalmus v. viridescens*]), but negative for adult plethodontid salamanders (Todd-Thompson 2010). Two nearby ponds with similar species composition were tested for ranavirus, and results were negative despite similar sampling effort. It appears the viral infection threat remains in the original site, but for unknown reasons has not spread to nearby populations (Todd-Thompson 2010). Dodd (2004) speculated these incidents could possibly be explained by the original site having a deep muck bottom, which might somehow act as a reservoir for the virus. Surveys for ranavirus in other areas of the park (Gray et al. 2009, Sutton et al. 2014) showed that it was prevalent in 11 species of plethodontids, and there was an 81% infection rate across all species, perhaps due to stress induced by a record drought. Subsequent annual sampling in plethodontid salamanders, at the same sites each year, indicates that the rate of infection varies widely from season to season and year to year (NPS 2015c), probably due to climatic stresses (Sutton et al. 2014). The infection rate appears to be greater in lower elevations.

Hellbenders (*Cryptobranchus a. alleganiensis*), which are the largest amphibian species in the hemisphere, have been in apparent decline in GRSM and the region since the reference period, and are now listed as a federal species of concern (Dodd 2004). Hellbenders inhabit the lowest reaches of the largest streams and rivers in the park, and are known historically from several streams where there are now only very few older animals, or they appear absent. Only Little River has a thriving population (Dodd 2004). Souza et al. (2012), found 12 out of 20 hellbenders (60%) in the Little River tested positive for ranavirus, only one for Bd (5%), and one animal was positive for both (5%). Contaminants have been sampled in tissue, but both DDE (dichlorodiphenyldichloroethylene) metabolites and mercury appear to be very low (Freake 2006). Investigations continue.

Mercury accumulation may be a significant issue in amphibian populations. Of special concern are those sites downstream from high mercury deposition areas, principally at high elevations. Recent work by Hamed (2014) demonstrates that mercury accumulation has been occurring in southern Appalachian salamanders, especially at high elevations and on the windward slopes where increased interception of contaminants occurs. The issue related to current condition is to what degree are the postulated declines in park plethodontids (Highton 2005, Caruso et al. 2014) driven by contaminants.

Reptiles

As cold-blooded animals, reptiles must thermoregulate in order to forage or successfully reproduce in an environment that may switch between being too cold or too hot several times a day (Fouts 2014). Snakes, lizards, and box turtles, as terrestrial reptiles, benefit from forest stands with some open canopy in order to mobilize and take advantage of thermoregulation opportunities, thereby extending their hours of activity during each diurnal period (Fouts 2014). In pre-European times, lightning-caused and aboriginal wildland fires, windstorms, and other disturbances to old-growth forests kept a certain amount of forest canopy open (i.e., with some sunlight penetration) (Fouts 2014). The destruction of these forests during settlement, agricultural activity, and massive logging (Brown 2000) meant loss of habitat for terrestrial reptiles, but with the park's establishment and forest re-growth, they probably flourished - until sunlight was substantially reduced by canopy closure. For example, two park lizards –the northern green anole (*Anolis c. carolinensis*) and the eastern six-lined racerunner (*Aspidoscelis s. sexlineata)* – were both recorded near park headquarters by Huheey and Stupka (1967), but they have not been seen in this area for decades, being relegated to the fire-prone west end of the park (K. Langdon, pers. comm.). The park is now re-introducing wildland fire to zones of the park where it was historically frequent; however, repetitive application of fire will apparently be needed in order to keep terrestrial reptiles at sustainable population levels.

The park has several species of reptiles that are almost entirely subterranean: the northern pinesnake (*Pituophis m. melanoleucus*), scarlet kingsnake (*Lampropeltis elapsoides*), northern scarletsnake (*Cemophora coccinea copei*), and the eastern slender glass lizard (*Ophisaurus attenuatus longicaudus*). All four of these species are considered rare in the park and of unknown condition and trend; the northern pinesnake is a federal species of concern. Because several decades of observation have produced only a few records for each of these species, the park requires an effective methodology to ascertain their distribution and abundance.

Other issues impacting the park’s reptiles include diseases caused by bacterial and fungal infections. The “snake fungal disease," thought to be caused by the fungus *Ophidiomyces ophiodiicola*, has been detected in states around the eastern U.S. It causes scabs, lesions, crusts and prematurely separating skin on snakes (Fig. 4.5.16.1) (USGS 2013). It may cause death in some individuals, and isolated populations of rarer species may be more at risk to population declines.

Figure 4.5.16.1. Eastern rat snake (*Pantherophis alleghaniensis*) showing signs of a fungal infection. Obvious external abnormalities are an opaque infected eye (spectacle) and roughened, crusty scales on the snout. Source: D.E. Green, USGS National Wildlife Health Center

This disease may already be in the park undetected, and the cryptic nature of snakes could allow substantial declines to take place without being detected. Additionally, there are occasional die-offs of snapping turtles in Cades Cove, which has been determined to be caused by a bacterial infection of the liver.

Trends

Amphibians

Amphibians appear to be suffering some locally-intense declines and perhaps more widespread sporadic declines in abundance, possibly due to ranavirus infections (Dodd 2004, Highton 2005, Gray et al. 2009, Caruso and Lips 2013, Caruso et al. 2014). Vernal pond breeding species are more easily monitored, and may be responding to different stressors than the terrestrial plethodontid salamanders which are cryptic, spending the vast majority of their time below ground. Some scientists familiar with these groups in the park are convinced that a prolonged decline is in progress (Highton 2005, Caruso et al. 2014). Others disagree and point out flaws in the studies that explain the alleged "declines" (Hairston and Wiley 1993, Grant 2014). Very recent work in western Virginia (Hamed 2014) makes a strong case for a role by mercury contamination, and a related study also analyzes historic data that does not lend support to climate change as a driver. Overall, the trends are unclear at this time, but concerning.

Given increased pet trade between continents, it may be that the abundance, biomass, and diversity of amphibians in the southern Appalachians are at inherently higher risk to new infections (Gray et al. 2009). Other diseases are probable in the future; the one of most concern being *Batrachochytrium salamandrivorans,* a fungus believed to have originated in southeast Asia and is currently devastating salamanders in northern Europe (Martel et al. 2014). It is not known in North America at this time.

Reptiles

In a survey of 10 major NPS units over several decades, Davis and Hansen (2011) found that GRSM had the greatest loss of natural habitat outside of its boundaries. As surrounding areas become more urbanized, the populations of reptiles and other species protected in the park may become more ecologically significant in the long-term conservation of these species. Prescribed fire may lead to an increase in reptiles, especially if an area is burned every several years. However, the pine-woodland type forest, with relatively more open canopy, may allow colonization by exotic fire ants, especially if soils are disturbed. Therefore, reptile trends in general are guardedly optimistic.

Confidence and Data Gaps

Amphibians

There is concern that park salamanders are declining, based on published research by experienced amphibian authorities that work in the region. However, a number of other regionally-experienced experts do not agree with their conclusions, and there is even less agreement on the cause(s) of the purported decline. Therefore, our confidence that a park-wide amphibian decline is occurring is moderate (Table 4.5.16.1).

A permanent array of monitoring plots is needed in order to verify whether or not park salamanders are indeed declining. These plots should be designed specifically to provide reliable quantified metrics on the health/status of plethodontid populations in the park. Ideal plots would be stratified randomly for extrapolation over a larger area, near to where other resources are monitored (e.g., at long-term monitoring sites), and would include some subjectively placed plots at suspected critical points on the park landscape (e.g., at presumed methylation pathway sites for elemental mercury). Also, there are pressing needs to comprehensively sample for multiple contaminants in amphibians across environmental gradients in the park, and to identify any ecological pathways for mercury bio-magnification that threaten specific amphibian (and other) species.

Other research topics that should be explored are related to disease prevalence in amphibians (e.g., Bd, ranavirus), amphibian responses to climate change, and the impacts of invasive exotics, such as green tree frogs and the red imported fire ant. Also, there is a need to determine the cause(s) of historic hellbender declines in the park, and once established by research, how do these factors influence our management of the remaining healthy population. Along with population abundance monitoring, genetic monitoring should be considered in order to determine historical genetic metrics and quantify loss of genetic fitness associated with known anthropogenic perturbations.

Reptiles

There is not as much recent research on reptiles in the park as on amphibians. Based on the very recent work of Fouts (2014), it is confidently held that terrestrial reptiles will increase back towards a presumed pre-settlement abundance, if the prescribed burning program in the park is accelerated (Table 4.5.16.1). Research questions that should be addressed include the degree to which restoration of reptile populations will be affected by invasive fire ants, and what snake species, if any, are at risk to emerging diseases.

Sources of Expertise

- Kenneth Dodd, USGS (retired)
- Matt Gray, University of Tennessee
- Joe Pechmann, Biologist, Western Carolina University
- James Petranka, University of North Carolina-Asheville
- Paul Super, Biologist & Research Coordinator, Great Smoky Mountains National Park

Summary Condition

Table 4.5.16.1. Summary condition and trend graphic for amphibians and reptiles in GRSM.

Resource	Indicator	Status and Trend	Rationale and Reference Conditions
Focal Species or Communities	Amphibians	⇩	Ideal reference condition would be the pre-settlement condition. Amphibians generally may be declining. Ranavirus, Bd, invasive species, and climate change are the major concerns.
Focal Species or Communities	Reptiles	⇔	Ideal reference condition would be the pre-settlement condition. Reptiles will likely increase as prescribed fire is increased. Closed canopies, lack of fire, and emerging diseases are the major concerns.

4.5.17. Birds

Relevance

GRSM contains some of the largest and most biologically complex tracts of protected forest in the eastern U.S., and breeding bird distribution patterns reflect this complexity. There are 246 species of birds documented as occurring in GRSM, which is more species than any other vertebrate group in the park. Of this number, 121 species are believed to have breeding populations in the park, 56 are permanent residents, and 71 species are migrants and/or wintering species. Another 54 species are considered accidental occurrences. About 150 species, both breeding and migratory, are neo-tropical migrants, spending the winter in the Caribbean, and Central and South America. As birds are highly mobile animals, widespread monitoring and research efforts in the region have focused on the impact of habitat fragmentation, and have been used for comparison to other regions (Shriner 2001).

Data and Methods

Birds have been the subject of numerous studies in the park over the past several decades and continue to receive attention from researchers and citizen scientists. Species diversity changes in the Smokies are best evaluated within the context of avifaunal changes that have also occurred throughout eastern North America (Askins 2000).

Two Breeding Bird Survey (BBS) routes were established in GRSM in about 1990 by volunteers in the region. These routes are along road corridors that are 39.4 km (24.5 mi) long, and are sampled once during the spring-summer peak breeding season. Stops are made along the roadway at 0.8 km (0.5 mi) intervals, and all birds seen or heard within 0.4 km (0.25 mi) of the point, within a 3-min period, are recorded. [For detailed protocols on BBS routes: https://www.pwrc.usgs.gov/bbs/participate/instructions.html] Although these two routes were sampled intermittently at first, they have been reliably sampled since 2010. The Cades Cove route (BBS route #82904) includes portions of the low-elevation Cades Cove loop road and, perhaps illogically, the high-elevation Clingmans Dome road. The other route, Newfound Gap (BBS route #82903), is along an upper portion of the heavily-traveled Newfound Gap road and also along the lightly-traveled Heintooga road.

The Audubon Society's Christmas Bird Counts (CBC) have occurred for over 78 years, in the Gatlinburg area of the park and in Cades Cove, from 1999 to present (National Audubon Society 2015). The USGS's Patuxent Wildlife Research Center (PWRC) considers the CBC to be the oldest continuous wildlife survey in North America, and one of the most valuable historic data sets for wintering birds (USGS 2015).

By far the most comprehensive project to assess breeding birds in the park was the 4-yr research project of Shriner (2001), from 1996-1999, which established 4,157 permanently geo-referenced, circular variable-plot point counts (Reynolds et al. 1980). These surveys were conducted from mid-May to the end of June. Of the over 4,000 plots, 355 were sampled for four years, 981 for three years, and 351 for two years. High-resolution (30 m) species distribution models for birds have since been produced, based on comprehensive bird and forest habitat data (Shriner 2001, Simmerman et al. 2012). The large amount of data available, and its geographic extent, has allowed for it to be overlaid with other high-resolution Geographic Information System (GIS) data layers to produce these models. The resulting maps are important for evaluating the current condition of birds in the park. It should be noted that maps derived from presence-only data are more properly considered habitat suitability maps, rather than species distribution maps. To date, high-resolution maps and web pages have been completed for about 60 breeding bird species (http://seelab.eecs.utk.edu/alltaxa/). Except for the uncommon species, all breeding birds will eventually have high-resolution habitat suitability models completed, and they will be periodically updated. Point maps will be created for those breeding birds without the required threshold of points for habitat suitability modeling.

In addition to the studies mentioned, park natural resources staff, and skilled long-term volunteers contribute many observations of birds around the park, and especially in Cades Cove. These data are in local ornithological newsletters, on websites (e.g., Tennessee Ornithological Society 2015), and if unusual, in the park's biodiversity database.

Reference Condition

The desired condition of the park’s avifauna would be the species composition, distribution, and abundance that would naturally occur in the absence of region-wide landscape practices of the 19th and 20th centuries (i.e., forest clearing, lumbering, agriculture, unlimited hunting). Unfortunately, there is little or no scientific data, pre-park, on which to base a reference condition. With park establishment, data slowly began to be archived and published on what bird species occurred in the new national park and which ones were breeding. This early period in the park's history, ca. 1940, is the reference condition used to assess bird species in this section. It is important to remember that the majority of the park's forests had been clear-cut and most valleys were in agriculture at the time of park creation, and natural re-forestation proceeded rapidly.

Current Condition

Twenty-four of the known breeding bird species in the park have some level of rarity status in either Tennessee or North Carolina, or have federal designations with the USFWS (Table 4.5.17.1). These listings do not include the more abundant "watch list" taxa, and the designations generally apply only to populations that breed here, and not migratory populations. These listed birds are of concern due to changes occurring regionally, nationally and internationally, and not exclusively in the park. Three species are increasing in occurrence, and three are thought to be extirpated; the park is collecting data on the others but considers them relatively stable, especially when viewed concurrently with populations outside of the park. This list will change over time as more data become available and as species are de-listed or listed. Over the long term, the number and rarity of bird species could become one of the metrics used for condition assessment of the park’s avifauna.

As the largest high-elevation area in eastern North America, the southern Appalachians have provided a landscape speciation mechanism for many taxonomic groups, including birds. Several bird species have differentiated populations or subspecies in the region, and since the Smokies protect about 3/4 of the high elevations in the region (Dull et al. 1987), the park is critical to maintaining this genetic diversity. Ten breeding bird taxa are considered endemic to the southern Appalachian region, and are listed below, along with their general habitat. These populations are considered stable, and five of these taxa also appear on the list of birds with rarity status (Table 4.5.17.1).

- Appalachian yellow-bellied sapsucker: Sphyrapirus varius appalachiensis – northern hardwood forests and edges
- Southern Appalachian population of northern saw-whet owl: Aegolius acadicus – spruce-fir forest
- Appalachian blue-headed vireo: Vireo solitarius alticola – moist forests throughout
- Southern Appalachian black-capped chickadee: Poecile atricapillus practica – upper elevation forests
- Brown creeper: Certhia americana nigrescens – upper elevation forests
- Veery: Catharus fuscescens pulichorum – upper elevation forests
- Cairns' black-throated blue warbler: Dendroica caerulescens cairnsi – upper elevation forests
- Carolina dark-eyed junco: Junco hyemalis carolinensis – upper elevation forests
- Winter wren: Troglodytes troglodytes pullus – spruce-fir forests
- Appalachian red crossbill: Loxia curvirostra (type 1) – erratic, spruce-fir, other coniferous forests; principal breeding area is in southern Appalachians

Table 4.5.17.1. Rarity status for breeding birds in GRSM, and notes on breeding status.

Common Name	Scientific Name	Federal[A]	TN[B]	NC[B]	GRSM Breeding Status[C]
Cooper's hawk	*Accipiter cooperii*	–	D	–	–
Sharp-shinned hawk	*Accipiter striatus*	–	D	SR	Uncommon resident
Saw-whet owl, population "type 1"	*Aegolius acadicus,* population "type 1"	FSC	T	T	Fairly common resident
Bachman's sparrow	*Aimophila aestivalis*	FSC	E	SC	Rare summer/extirpated?
Henslow's sparrow	*Ammodramus henslowii*	FSC	D	–	Uncommon migrant
Hermit thrush	*Catharus guttatus*	–	–	SR	Uncommon summer, increasing
Swainson's thrush	*Catharus ustulatus*	–	–	SR	Uncommon summer, increasing
Brown creeper, southern. Appalachian population	*Certhia americana nigrescens*	–	–	SC	Fairly common resident

A. Federal listings include E=Endangered, T=Threatened, FSC=Federal Species of Concern, and BEPA=Bald Eagle Protection Act.

B. State listings include SR=significantly rare (NC), and D=Deemed in need of management (TN).

C. GRSM status key: Common: 5-25 seen per day in proper habitat/season; Fairly Common: at least 1 individual per day in proper habitat/season; Uncommon: at least 1 seen per season of occurrence or several per year; Rare: has occurred in the park at least once, but is not to be expected; Sources: Tennessee Natural Heritage Program (2009), North Carolina Natural Heritage Program (2014), Great Smoky Mountains Association (2010).

Table 4.5.17.1 (continued). Rarity status for breeding birds in GRSM, and notes on breeding status.

Common Name	Scientific Name	Federal^A	TN^B	NC^B	GRSM Breeding Status^C
Black-billed cuckoo	*Coccyzus erythropthalmus*	–	–	SR	Uncommon summer
Olive-sided flycatcher	*Contopus cooperi*	–	D	–	Rare summer
Common raven	*Corvus corax*	–	T	–	Fairly common resident
Cerulean warbler	*Dendroica cerulea*	FSC	D	SC	Uncommon summer
Magnolia warbler	*Dendroica magnolia*	–		SR	Rare summer, increasing
Alder flycatcher	*Empidonax alnorum*	–	D?	SR	Rare summer
Peregrine falcon	*Falco peregrinus*	–	E	E	Uncommon summer
Bald eagle	*Haliaeetus leucocephalus*	BEPA	D	T	Uncommon resident
Swainson's warbler	*Limnothlypis swainsonii*	–	D	–	–
Red crossbill, population "type1"	*Loxia curvirostra*, "type 1"	FSC	–	SC	Uncommon resident
Red cockaded woodpecker	*Piciodes borealis*	E	–	E	Believed extirpated
Southern Appalachian black-capped chickadee	*Poecile atricapilla practica*	FSC	D	SC	Common resident
Vesper sparrow	*Pooecetes gramineus*	–	D	SC	Rare summer, uncommon migrant
Yellow-bellied sapsucker, southern Appalachian population	*Sphyrapicus varius*	–	D	SR	Uncommon resident
Appalachian Bewick's wren	*Thryomanes bewickii*	FSC	–	E	Rare/extirpated?
Golden-winged warbler	*Vermivora chrysoptera*	FSC	D	SC	Rare summer

D. Federal listings include E=Endangered, T=Threatened, FSC=Federal Species of Concern, and BEPA=Bald Eagle Protection Act.

E. State listings include SR=significantly rare (NC), and D=Deemed in need of management (TN).

F. GRSM status key: Common: 5-25 seen per day in proper habitat/season; Fairly Common: at least 1 individual per day in proper habitat/season; Uncommon: at least 1 seen per season of occurrence or several per year; Rare: has occurred in the park at least once, but is not to be expected; Sources: Tennessee Natural Heritage Program (2009), North Carolina Natural Heritage Program (2014), Great Smoky Mountains Association (2010).

These endemic taxa are mostly described subspecies, but some have not yet been scientifically described. GRSM is not the only place that any of these species/subspecies breed, but it does include a significant fraction of their breeding range; therefore, their survival in the park is essential or even critical to its continued existence. As more research is completed on these populations, their taxonomic position will become clearer. In any event, NPS Management Policies (NPS 2006, Section 4.4.1.2) require that conserving genetic diversity within a species is to be considered in NPS land management decision-making.

Recent analyses have shown that the genetically-isolated southern Appalachian populations of some birds, salamanders, and plants (and probably many other groups) are more genetically diverse than the often much larger and geographically extensive populations to the north (Tamashiro 1996, Pulgarin-R and Burg 2012). Tamashiro (1996) attributes this phenomenon to northbound post-glacial populations repeatedly encountering genetic bottlenecks during founder events, as they re-migrated north over vast geographic areas in a short period of time. Tamashiro postulates that this may have depleted their genetic diversity, whereas the southern Appalachian populations, only migrating locally upslope, faced few bottlenecks and therefore may be considered a genetic reservoir for the entire species, and merit high conservation priority.

Trends

Several ecological processes have influenced changes in bird species diversity at GRSM in recent decades. First, the park has transitioned from an open agrarian landscape at lower elevations in the 1930s to being covered in thick second-growth forests within a few years. This led to a decline in some grassland birds, such as the eastern meadowlark (*Sturnella magna*) and northern bobwhite (*Colinus virginianus*), since the park's establishment (Stupka 1963). In the future these open-land species may increase their local populations in existing areas like Cades Cove, which is undergoing a conversion to native grasses; however, they are not expected to expand their distribution.

Second, fire suppression for many decades has caused the loss of at least two species - the federally endangered red-cockaded woodpecker (*Piciodes borealis*), which requires old-growth pine forests with an open understory usually kept low by ground fires, and perhaps the Bachmann's sparrow (*Aimophila aestivalis*), which may have utilized fire-prone sites and old fields. Recent prescribed fires and extensive wildfires in the park's backcountry have helped to maintain remaining populations of dry woodland bird species, and there is a chance that the woodpecker and sparrow could return. The very recent observation of the brown-headed nuthatch (*Sitta pusilla*), a new park record and open pineland species, is encouraging.

Third, there have been significant changes in the spruce-fir forests due to Balsam woolly adelgid (*Adelges piceae*)-induced mortality of Fraser fir (Taylor 2012). Long-term breeding bird data from high-elevation forests show that the avifauna changed significantly when the introduced adelgid killed almost all of the mature Fraser fir stands in the park, mostly in the 1970s and 1980s (Rabenold et al. 1998). As the closed canopy forest of red spruce and Fraser fir opened up after the demise of the fir, more disturbance-oriented birds such as the chestnut-sided warbler (*Dendroica pensylvanica*) and eastern towhee (*Pipilo erythrophthalmus*) started to colonize the study sites. It is unknown how long it will take or even if the bird fauna will return to its pre-adelgid species composition (Rabenold et al. 1998).

The birds of the high-elevation forests, including most of the regional endemic taxa, exist in an ecological zone with chronic acidification, low calcium, contaminants, forest impacts, and other anthropogenic changes. Although there is no compelling evidence of additional long-term decline at this point, we consider their populations tenuous; their trends for the future are uncertain and need careful, quantified surveillance. Breeding birds that have apparently recovered to some degree, and are at their former pre-park abundance levels, include turkey (*Meleagris gallopavo),* peregrine falcon

(*Falco peregrinus*), bald eagle (*Haliaeetus leucocephalus*), wood duck (*Aix sponsa*), and many closed forest species. Birds that appear to have recently expanded their range into the park include the following: Swainson's thrush (*Catharus ustulatus*), hermit thrush (*Catharus guttatus*), perhaps the magnolia warbler (*Dendroica magnolia*), and the brown-headed nuthatch. Canada goose (*Branta canadensis*) has changed from a migrant only, to migrant and occasional breeder along low-elevation open areas near water.

Currently there are not enough BBS samples to perform an analysis, and because sample routes are disturbed corridors with altered microclimates and vegetation, they do not allow for direct extrapolation to the park's 2,000 km^2 (772 mi^2) backcountry; however, BBS routes could become an annual, general indicator of breeding bird condition.

The CBC has been used extensively for analyzing winter bird species distributions and trends over large geographic areas; however, according to the PWRC, the use of the data is controversial due to a number of standardization issues (USGS 2015). This would especially seem to be the case for analysis of individual count circles. Both of the count circles in GRSM (each 24.1 km [15 mi] in diameter) include substantial area outside of the park, and one of them is in a now-urbanized/commercial portion of the city of Pigeon Forge, TN. Since competent use of CBC data will require that the biases be addressed, no trend analysis has been performed.

Confidence and Data Gaps

Overall, the avifauna of Great Smoky Mountains National Park is considered in good condition, is relatively stable, and there is moderate confidence in the assessment (Table 4.5.17.2).

It has been many years since the park-wide Shriner breeding bird study (2001) was initiated. It should be repeated, with careful selection of a significant number of plots from among the original ~4,100. These should be stratified by ecological criteria, and become permanent plots to be re-surveyed periodically. While the park has moderate confidence that the assessment is correct for most breeding species, there are many ongoing stressor impacts to consider, especially in the high-elevation forests. Re-sampling the Shriner plots will be essential for assessing the condition of the 10 endemic taxa; however, these species also require special investigations of their individual populations to gain an accurate assessment, since each may be responding to different factors in the stressed high elevations. Additionally, these 10 taxa should eventually be analyzed genetically.

Sources of Expertise

- Fred Alsop, East Tennessee State University
- Kerry Rabenold, Purdue University (retired)
- Theodore Simons, Research Biologist, USGS
- Paul Super, Biologist & Research Coordinator, Great Smoky Mountains National Park

Summary Condition

Table 4.5.17.2. Summary condition and trend graphic for birds in GRSM.

Resource	Indicator	Status and Trend	Rationale and Reference Conditions
Focal Species or Communities	Birds	⇔	There is little or no scientific data on which to base a reference condition. However, generally the condition of birds in the park is stable.

4.5.18. Mammals

Relevance

Mammals are included in the NPS Management Policies (NPS 2006) with respect to protection and management under the 1916 Organic Act. The policies state that the Service is to "…maintain all native plants and animals and their habitats." Mammals are important herbivores, predators, and omnivores, and are critical to maintaining ecological balance in park habitats. Their presence is essential to a healthy, resilient ecosystem.

Data and Methods

Very little focused research on park mammals occurred until the efforts of Edwin and Roy Komarek, who conducted several years of mammal research in the mid-1930s in what would become the park (Komarek and Komarek 1938). They conducted studies on both larger species and small mammals, such as rodents and shrews. Their comprehensive work is an important foundation for examining mammal species through the changing park landscape, but it was an initial inventory, and not quantitative monitoring.

In recent years, park staff and cooperating researchers have more thoroughly studied several species of mammals, often in conjunction with restoration efforts. In particular, black bears, white-tailed deer, elk, red wolves, river otter (*Lontra canadensis*), and cave-dwelling bats have been the focus of inventories, monitoring, and research. These various studies have been compiled into publications, such as the popularly-written *Mammals of the Smokies* (Pivorun et al. 2009), and scientific articles and databases, which were utilized to develop this assessment. Currently, the park is using the vast amount of mammal occurrence data to develop distribution models and park-wide habitat suitability maps for individual species.

Reference Conditions

The NPS strives to manage the park as close to a natural condition as possible. In the 1930s, the newly-established park was a much different landscape than it currently is, with the lower elevations having extensive abandoned farmland that re-forested in the mid-20th century, and has continued to mature since (Brown 2000). Game species were hunted to scarcity or extirpation, but smaller mammal species that prefer open, non-forested or brushy land thrived, at least until the forest canopy closed again (Brown 2000). Many mammal species have recovered, although the habitat for wildlife in general, and mammals specifically, may not yet be the presumed natural condition. Therefore, the reference condition is a qualitative one, based on the apparent status of each species.

Conditions and Trends

There are 69 species of native mammals that are documented as occurring, or that probably occurred, in Great Smoky Mountains National Park (Table 4.5.18.1). This number excludes escaped exotic species, various livestock, and species known only through the archeological record. All 69 mammals and their summary condition/trend are listed in Table 4.5.18.2.

Table 4.5.18.1. Complete listing of native mammals documented as of 2015, with notes on each species' status in the park.

Native Mammal	Common Name	Scientific Name	Status Notes
Marsupials	Virginia opossum	*Didelphis virginiana*	Common and seen at lower elevations in the park.
Shrews & Moles	Least shrew	*Cryptotis parva*	Little recent data.
	Northern short-tailed shrew	*Sorex brevicauda*	This large shrew is believed common at all elevations. It is often found dead on trails.
	Masked shrew	*Sorex cinereus*	Relatively common in the upper elevations.
	Long-tailed shrew	*Sorex dispar blitchi*	Uncommon in upper elevations, especially rocky, coniferous areas.
	Smoky shrew	*Sorex fumeus*	Common in upper elevations.
	Pygmy shrew	*Sorex hoyi*	Little recent data.
	Southeastern shrew	*Sorex longirostris*	Rare in the park, common outside the park, inhabits brushy areas, wetlands.
	Southern water shrew	*Sorex palustris punctulatus*	A rare, seldom observed species, aquatic with semi-webbed feet, inhabits streams at mid to high elevations. Some of these streams are episodically acidified (Deyton et al. 2009) and the effect on this shrew's primary food source of aquatic insect larvae is unknown.
	Hairy-tailed mole	*Parascalops breweri*	Common at all elevations, often found dead on trails.
	Eastern mole	*Scalopus aquaticus*	Few records, little recent data, but believed extant in deep soils of lowlands.
	Star-nosed mole	*Condylura cristata*	Associated with wetlands and low gradient streams, this species is seldom observed and/or rare.
Bats	Rafinesque's big-eared bat	*Corynorhinus rafinesquii*	Utilizes trees, caves, or mines. There is a large hibernating population associated with an abandoned mine (Pivorun et al. 2009). This species has not shown a significant decline, post WNS infection in caves thus far (O'Keefe et al. 2015).
	Big brown bat	*Eptesicus fuscus*	This bat is known to be susceptible to WNS, but currently data show no year effect when comparing pre- to post-infection counts (O'Keefe et al. 2015).
	Silver-haired bat	*Lasionycteris noctivagans*	Silver-haired bats are believed non-symptomatic for WNS, and analysis by O'Keefe et al. (2015) shows a modest positive effect post WNS infection.

Table 4.5.18.1 (continued). Complete listing of native mammals documented as of 2015, with notes on each species' status in the park.

Native Mammal	Common Name	Scientific Name	Status Notes
Bats (continued)	Eastern red bat	*Lasiurus borealis*	This common bat utilizes trees and is not believed to be affected significantly by WNS.
	Hoary bat	*Lasiurus cinereus*	Uncommon to rare bat in the park, usually utilizing trees, not caves. It is not believed to be significantly affected by WNS.
	Seminole bat	*Lasiurus seminolis*	Only one record, from the summer of 2015 near Abrams creek (B. Stiver, pers. comm. 2015).
	Eastern small-footed bat	*Myotis leibii*	Found in small numbers, sometimes in buildings, this very small species does not seem to have been significantly affected by WNS, at this time (O'Keefe et al. 2015).
	Little brown bat	*Myotis lucifugus*	This small bat has suffered about 95% population losses in wintertime counts, post WNS infection (O'Keefe et al. 2015). Like several other bat species, its presence in the park is in jeopardy.
	Northern long-eared bat	*Myotis septentrionalis*	Severe decline very recently due to WNS. Population counts indicate a loss of 94% post WNS infection in caves (O'Keefe et al. 2015).
	Indiana bat	*Myotis sodalis*	This endangered species has suffered a very recent extreme decline of 99% post WNS infection in caves (O'Keefe et al. 2015).
	Evening bat	*Nycticeius humeralis*	A recent discovery in the western end of the park, not much is known about its status.
	Tricolored bat	*Perimyotis subflavus*	This species has suffered a significant decline of ~73% post WNS infection in caves (O'Keefe et al. 2015).
Rabbits	Eastern cottontail	*Sylvilagus floridanus*	Common throughout park, especially abundant near open areas.
	Appalachian cottontail	*Sylvilagus obscurus*	Rare, expected at higher elevations, but poorly known in park. Definitively separated from the very common eastern cottontail only by skull characters.
Rodents	Beaver	*Castor canadensis*	Has become frequent in low-elevation gradients of most large watersheds in the park in recent decades. A "keystone" species that creates valuable wetland habitats and ponds in the mountains, although occasionally these impoundments affect park neighbors (B. Stiver, pers. comm.).
	Southern rock vole	*Microtis chrotorrhinus carolinensis*	Little recent data, except a new population discovered during the North Shore Road EIS at low elevation (Gumbert and Dourson 2004). Rare in part due to its specialized habitat of boulder fields and rocky areas.
	Meadow vole	*Microtis pennsylvanicus*	Uncommon, may be locally common in meadows and other open areas with dense ground cover where it can form populations.

Table 4.5.18.1 (continued). Complete listing of native mammals documented as of 2015, with notes on each species' status in the park.

Native Mammal	Common Name	Scientific Name	Status Notes
Rodents (continued)	Woodland vole	*Microtis pinetorum*	Little is known of this burrowing vole in the park.
	Southern red-backed vole	*Myodes (Clethrionomys) gapperi*	Common small rodent of the upper elevations.
	Eastern woodrat (Southern Appalachian subspecies)	*Neotoma floridanus haematoreia*	This species has been confused until very recently with the Appalachian woodrat (*Neotoma magister*) which occurs to the north of the park extending to NY and CT. The Appalachian woodrat, which is larger and heavier than our species (USFS 2002), has been decimated at the north end of its range and is now considered extirpated from several states, perhaps due to the ingestion of raccoon roundworm (*Baylisascaris procyonis*) parasites (IUCN 2015) from unnaturally abundant raccoons. The impact of this parasite or other stressors on the Eastern woodrat in the park are unknown.
	Golden mouse	*Ochrotomys nuttalli*	Uncommon, but seemingly associated with tall brushy sites, such as roadsides edges and powerline right-of-ways, where its round leaf nests can be located in dormant season.
	Muskrat	*Ondatra zibethicus*	Common in low gradient streams at lower elevations.
	Marsh rice rat	*Oryzomys palutris*	Little recent data, this species is rare in the park at lowest elevations, although common throughout most of the southern U.S.
	Cotton mouse	*Peromyscus gossypinus*	Apparently uncommon, little recent data.
	White-footed mouse	*Peromyscus leucopus*	Common at all elevations, although cyclical in populations.
	Deer mouse	*Peromyscus maniculatus*	Abundant at all elevations, especially higher elevations although cyclical in population levels.
	Eastern harvest mouse	*Reithrodontomys humulis*	An uncommon species outside the park and rare inside, mostly in grassy areas such as Cades Cove.
	Hispid cotton rat	*Sigmodon hispidus*	This is an open-land animal known principally from Cades Cove and other agricultural areas. It is common outside the park in weedy fields and abandoned agricultural lands (Pivorun et al. 2009)
	Southern bog lemming	*Synaptomys cooperi stonei*	An uncommon and local animal of upper elevation grassy/sedgy sites.
	Woodland jumping mouse	*Napaeozapus insignis*	Few recent records, believed to be primarily a woodland species.
	Meadow jumping mouse	*Zapus hudsonicus*	Few recent records, older records in grasslands, meadows and brushy edges.

Table 4.5.18.1 (continued). Complete listing of native mammals documented as of 2015, with notes on each species' status in the park.

Native Mammal	Common Name	Scientific Name	Status Notes
Rodents (continued)	Carolina northern flying squirrel	*Glaucomys sabrinus coloratus*	Recent surveys only on the NC side of its high-elevation habitat. Upper elevations receive multiple stressor influences, including high acid deposition, which could affect one of this species primary food sources - fungi.
	Southern flying squirrel	*Glaucomys volans*	Not much recent data, assumed to be common especially in oak and hickory forested stands.
	Woodchuck	*Marmota monax*	Common in open areas.
	Gray squirrel	*Sciurus carolinensis*	Abundant except in the higher elevations.
	Fox squirrel	*Sciurus niger*	Not confirmed since the 1950s. This distinct and large squirrel requires an open understory forest. In many areas of the U.S., reduction in wildland fires results in loss of this species.
	Eastern chipmunk	*Tamias striatus*	Common, especially on rocky slopes with mature oak and hickory forests.
	Red squirrel	*Tamiasciurus hudsonicus*	Common and easily observed in upper elevations, especially in coniferous forests. Periodicity in cone crops may result in fluctuating populations.
Carnivores	Coyote	*Canis latrans*	Increasing. This species is not considered strictly native to the park, having arrived in the early 1980s from native populations in the south-central states. It probably fills the predatory niche of some missing predators, although it is implicated in the apparent decline of the red fox in the park.
	Gray wolf	*Canis lupus*	Probably extirpated around the 1890s in Great Smoky Mountains (Pivorun et al. 2009). It may have occurred with or at different times from the red wolf. There are no plans to re-patriate it.
	Red wolf	*Canis rufus*	This species can hybridize with the gray wolf and both apparently occurred in this area at one time or another. The red wolf was re-patriated from remnant populations into GRSM 1991-98, but was terminated due to failure of pups to reach maturity, hybridization with coyotes, and proclivity to go outside the heavily forested park (Pivorun et al.2009). The wolves were re-trapped and re-located in 1998. The speculation is that some red wolf genes may be persisting in the park's coyote population.
	Gray fox	*Urocyon cinereoargenteus*	Widespread throughout the park, especially in the lower elevations.
	Red fox	*Vulpes*	This species was most common along the Clingmans Dome road until the early 2000s when coyotes became more numerous there. This species is believed to have declined significantly in recent years, no very recent reliable records.

Table 4.5.18.1 (continued). Complete listing of native mammals documented as of 2015, with notes on each species' status in the park.

Native Mammal	Common Name	Scientific Name	Status Notes
Carnivores (continued)	Bobcat	*Lynx rufus*	Believed widespread in the park, seldom observed.
	Mountain lion	*Puma concolor couguar*	Believed extirpated in the region about 1920, although many reports have been received in recent years (Bolgiano and Roberts 2005). Recent multi-year work by Dr. Donald Linzey utilizing urine stations and hair snagging, has failed to produce conclusive evidence of this species in the park.
	Striped skunk	*Mephitus mephitus*	Common and commonly observed at lower elevations.
	Eastern spotted skunk	*Spilogale putorius*	Rare and seldom observed, but observations are from around the park from low to middle elevations.
	Northern river otter	*Lontra canadensis*	Extirpated by the 1930s, this aquatic predator re-patriated in the mid-1980s and is now found in larger creeks and rivers in the park. Abrams Creek sightings are common.
	Long-tailed weasel	*Mustela frenata*	Although probably throughout the park, most observations are from higher elevations.
	Least weasel	*Mustela nivalis*	A verified specimen was not discovered until summer 2015, at Clingmans Dome (D. Linzey, pers. comm. 2015). This is a rare species in the park.
	Mink	*Mustela vison*	Uncommon, thought to be along most medium to larger streams in the park.
	Fisher	*Pekania (Martes) pennanti*	Extirpated, perhaps in the late 1880s; has recently been re-patriated in areas near the park on the Tennessee side.
	Raccoon	*Procyon lotor*	Common, especially in lower elevations.
	American black bear	*Ursus americanus*	Our largest carnivore, this species has recovered dramatically since the establishment of the park, when it was rarely seen. It now numbers about 1,600 animals and the park "base" population appears to still be stable (B. Stiver, pers. comm. 2015).
Hoofed Mammals	American bison	*Bison bison*	Believed extirpated before or around 1800 in the region (Pivorun et al.2009). The park has no current plans to re-patriate these very large herbivores.
	Elk	*Cervus elaphus*	Extirpated in the early 1800s and re-patriated to Cataloochee Valley, thence dispersing to Balsam Mountain area, Purchase Knob and the Oconoluftee area.
	White-tailed deer	*Odocoileus virginianus*	Common in vicinity of open lands and woods edges. The population in Cades Cove was very high in the early 1970s but has decreased to a healthier, stable population.

Table 4.5.18.2. Summarized categorization of GRSM mammal species status in 2015. These categorizations are compiled from various sources, including professional opinions of park wildlife staff.

Common Name	● **Probably Extirpated**	⬇ **Significant Decline**	↔ **Believed Stable**	⬆ **Increasing**	◌ **Status Unknown/Not Documented**
Virginia opossum	–	–	X	–	–
Least shrew	–	–	–	–	X
Northern short-tailed shrew	–	–	X	–	–
Masked shrew	–	–	X	–	–
Long-tailed shrew	–	–	–	–	X
Smoky shrew	–	–	X	–	–
Pygmy shrew	–	–	–	–	X
Southeastern shrew	–	–	–	–	X
Southern water shrew	–	–	–	–	X
Hairy-tailed mole	–	–	X	–	–
Eastern mole	–	–	–	–	X
Star-nosed mole	–	–	–	–	X
Rafinesque's big-eared bat	–	–	X	–	–
Big brown bat	–	–	X	–	–
Silver-haired bat	–	–	–	–	X
Eastern red bat	–	–	X	–	–
Hoary bat	–	–	–	–	X
Seminole bat	–	–	–	–	X
Eastern small-footed bat	–	–	–	–	X
Little brown bat	–	X	–	–	–
Northern long-eared bat	–	X	–	–	–
Indiana bat	–	X	–	–	–
Evening bat	–	–	–	–	X
Tricolored bat	–	–	–	–	–
Eastern cottontail	–	–	X	–	–
Appalachian cottontail	–	–	–	–	X
Beaver	–	–	–	X	–
Southern rock vole	–	–	–	–	X
Meadow vole	–	–	–	–	X
Woodland vole	–	–	–	–	X
Southern red-backed vole	–	–	X	–	–

Table 4.5.18.2 (continued). Summarized categorization of GRSM mammal species status in 2015. These categorizations are compiled from various sources, including professional opinions of park wildlife staff.

Common Name	Probably Extirpated	Significant Decline	Believed Stable	Increasing	Status Unknown/Not Documented
Eastern woodrat (Southern Appalachian subspecies)	–	–	–	–	X
Golden mouse	–	–	X	–	–
Muskrat	–	–	X	–	–
Marsh rice rat	–	–		–	X
Cotton mouse	–	–		–	X
White-footed mouse	–	–	X	–	–
Deer mouse	–	–	X	–	–
Eastern harvest mouse	–	–		–	X
Hispid cotton rat	–	–	X	–	
Southern bog lemming	–	–	–	–	X
Woodland jumping mouse	–	–	–	–	X
Meadow jumping mouse	–	–	–	–	X
Carolina northern flying squirrel	–	–	–	–	X
Southern flying squirrel	–	–	X	–	–
Woodchuck	–	–	X	–	–
Gray squirrel	–	–	X	–	–
Fox squirrel	X	–	–	–	–
Eastern chipmunk	–	–	X	–	–
Red squirrel	–	–	X	–	–
Coyote	–	–	–	X	–
Gray wolf	X	–	–	–	–
Red wolf	X	–	–	–	–
Gray fox	–	–	X	–	–
Red fox	–	X	–	–	–
Bobcat	–	–	–	–	X
Mountain lion	X	–	–	–	–
Striped skunk	–	–	X	–	–
Eastern spotted skunk	–	–	–	–	X
Northern river otter	–	–	–	X	–
Long-tailed weasel	–	–	–	–	X

Table 4.5.18.2 (continued). Summarized categorization of GRSM mammal species status in 2015. These categorizations are compiled from various sources, including professional opinions of park wildlife staff.

Common Name	● Probably Extirpated	⬇ Significant Decline	⬌ Believed Stable	⬆ Increasing	○ Status Unknown/Not Documented
Least weasel	–	–	–	–	X
Mink	–	–	X	–	–
Fisher	X	–	–	–	–
Raccoon	–	–	X	–	–
American black bear	–	–	–	X	–
American bison	X	–	–	–	–
Elk	–	–	–	X	–
White-tailed deer	–	–	–	X	–

Several mammal species were already extirpated from the area before the establishment of the park. These include bison (*Bison bison*), elk, gray wolf, red wolf, mountain lion (*Puma concolor couguar*), fisher (*Pekania* [*Martes*] *pennant*), beaver, and river otter. Three of these species (river otter, elk, red wolf) were reintroduced to the park, although one was unsuccessful (red wolf). Also, beavers released into a nearby ecosystem in the late 20th century, dispersed throughout the area, including the park. Coyotes were first observed in the park in the early 1980s as they moved into the region from the west.

Overall, there has been success in preserving the park's mammal fauna that existed in the 1930s; the decline in species was halted upon park establishment. Two species, however, are of concern - the fox squirrel (*Sciurus niger*), and the red fox. The fox squirrel is a large tree squirrel that apparently occurred in the larger valleys of the park and fed on a wide variety of seeds, fruits, buds, and even bird eggs, while depending on reliable supplies of oak acorns, hickory nuts, and walnuts to sustain it through the winter. The last reliable report of fox squirrels in the park was in the 1950s, and currently, the closest reliable populations appear to be in certain areas of the Cumberland Plateau to the west.

The loss of this large squirrel (Fig. 4.5.18.1) after park establishment is believed informative of the changes wrought by total protection of the landscape. Fox squirrels not only require ample nut tree crops, but they also require much more open forest conditions than the smaller gray squirrel. Their optimum preferred tree canopy cover is reported to be 20 to 60%, with an optimum shrub layer closure of 0 to 30% (Tesky 1993). Wildland fire, browsing by native large herbivores, and possibly recurrent flooding are all possible disturbances that would have maintained fox squirrel populations. The cutting of most mature mast-bearing trees in the early 20th century reduced food and cavity nesting opportunities (Brown 2000), and the establishment of the park initiated the systematic suppression of wildland fire, allowing shrub layers to expand, thereby further degrading fox squirrel habitat (Tesky 1993). With mature mast bearing forests of oak, hickory and walnut now common again, and prescribed fires being utilized as a management tool to re-create pre-European fire regimes, this species could probably be re-patriated in several areas of the park.

Figure 4.5.18.1. Fox squirrel skin in the GRSM natural history collection. This specimen was from Wear Cove, Great Smoky Mountains, collected in the 1930s. Note the black face and legs/feet, gray nose, and reddish color on the sides of the tail. Source: NPS Photo 2011.

The red fox is a common native canid that occurs throughout most of the U.S. It prefers more open habitat than the gray fox (Feldhamer et al. 2003), and was once recorded over much of the park (Linzey and Linzey 1971); however, in recent decades, red fox adults and pups have only been observed in the Clingmans Dome road area of the park. In the early 2000s, no further observations of red foxes were recorded, and coyotes became much more common in places where red foxes were formerly frequent. The coyote is not considered native to the park, since there were no pre-European records of them in the region. They appear to have expanded eastward following elimination of wolves (Feldhamer et al. 2003). They started to become prevalent in the park in the early 1980s and are now considered to be evident in all parts of the park. Coyotes are known to both kill and competitively exclude red foxes (Feldhamer et al. 2003), which is likely what occurred in the Smokies. Red foxes still do occur outside the park, where coyotes are less frequent due to suppression by local land owners.

Diseases: A Special Concern for Mammals

Diseases of park mammals are of concern since they may indicate new exotic organism stressors, unnatural population densities, stresses in natural zones that have increased mammals’ risk to native diseases, and/or risks to human health. Below are several of the diseases of mammals that in recent years have been of management concern, according to park biologists (B. Stiver, pers. comm. 2015).

Rabies:

Rabies is a viral disease caused by *Rabies lyssavirus* (family Rhabdoviridae). It is known to infect a number of mammal species in the eastern U.S., but in the park, laboratory confirmed rabies has only occurred in a few bats in the Oconoluftee, headquarters, and Twin Creeks areas. There have been two human exposures to rabies-positive bats for which treatment was required (B. Stiver, pers. comm. 2015).

The USDA-Animal and Plant Health Inspection Service (APHIS) has been concerned about the western spread of the raccoon-variant of rabies, and has been aerially dispersing inoculation baits for wild raccoons in the region (APHIS 2015). In 2015, in the east Tennessee-western Virginia-western North Carolina area, over one million baits were dropped by air, and over 14,000 along roadways (APHIS 2015). Currently the park has been opportunistically sampling road-killed raccoons, coyotes, foxes, and skunks, but all specimen results indicate no exposure to rabies.

Pseudorabies:

Pseudorabies is a disease found only in living hogs, and is caused by the virus *Suid herpesvirus* 1 (SuHV1). The symptoms resemble rabies, but the two diseases are not related. Other mammal species could be infected from physical contact with live infected hogs, by predation of infected hogs, or by scavenging fresh kills. The virus does not survive for long outside of a living host (Merck 2015).

This is a relatively new disease in the park and is believed to have arrived via illegal releases of hogs near the perimeter (Cavendish et al. 2008). Samples from 497 wild hogs that were either trapped or shot from 2001 to 2007, resulted in only 16 pseudorabies-positive animals, mostly from the southwest portion of the park, an area where repeated illegal introductions of wild hogs have been documented. From 2005 to 2010, positive samples from wild hogs varied from 2.7% to 6.6%, but by 2011 it had increased to 16%. The risks here are to native wildlife that are believed to incidentally contract the disease, and also to agricultural interests outside the park where swine production is economically important.

White-nose Syndrome (WNS):

The fungus causing WNS (*Pseudogymnoascus destructans*) thrives in a cold environment. It was first observed killing bats in hibernacula in New York in the winter of 2006-2007, and has rapidly spread south to the southern Appalachian region (FWS 2015). Some bat hibernacula in the northeastern U.S. have experienced 90-100% mortality, and nearly six million bats are believed to have succumbed to the disease nationwide thus far (FWS 2015).

Half of the park’s 12 species of bats are believed susceptible. The following species are known to exhibit symptoms of the disease (FWS 2015): big brown bat, eastern small-footed bat, Indiana bat, little brown bat, northern long-eared bat, and tricolored bat. An additional three species have been documented as being infected with WNS, but are believed resistant to the disease (FWS 2015): red bat, silver-haired bat, and Rafinesque’s big-eared bat. Currently some cave-hibernating bat species in the park have exhibited up to a 99% decline, post-infection (O’Keefe et al. 2015). There is research underway nationally to understand resistance and the ecological requirements of the fungus (FWS 2015). The impact of the loss of so many bats in the park ecosystem is unknown, as is the ability of the species to recover from such a drastic reduction. Monitoring of bats in the park continues, and the next few years will be critical for the continued existence of these bat species in the park.

Bats have an important role in the park's ecological relationships, and the loss of so many thousands of these active predatory animals will have ecological reverberations in the park. The degree to which other organisms may be affected positively (i.e., many nocturnal flying insects) or negatively (other cave species in several taxonomic orders) is also unknown.

Hantavirus:

Hantaviruses are in a family of viruses (Bunyaviridae) hosted by rodents and some shrews and moles. Hantaviruses that occur in eastern North America are principally found in four rodent species, all of which occur in the park (CDC 2015):

- Deer mouse (*Peromyscus maniculatus*)
- White-footed mouse (*Peromyscus leucopus*)
- Cotton rat (*Sigmodon hispidus*)
- Rice rat (*Oryzomys palustris*)

The virus variants found in the New World form a group that can cause Hantavirus Pulmonary Syndrome in humans, and the primary method of infection is through contact with rodent urine, saliva, or feces. This disease is serious but rare; in the last five years only 20-30 cases have been reported nationwide annually, with a varying mortality rate of 36 to 50%, depending on the year (CDC 2015). Fortunately, no case has ever been recorded in Tennessee and in the 20-year period ending in 2013, only one case has been documented in North Carolina (CDC 2015).

A new strain of hantavirus (Newfound Gap hantavirus; type locality Newfound Gap) has been confirmed in park animals, mostly in deer mice (*Peromyscus maniculatus*) (Lewis 2005). Nearly 9% of the animals sampled had sero-positive results for the virus, but positives were only at eight of the 18 sites examined (Lewis 2005). Portacci (2005) examined the sites of Lewis (2005) for landscape elements that might indicate where the virus was most prevalent in the park, and results indicated that it was mostly found at upper elevations, where the deer mice were presumed to be at denser population levels. The exception was at Elkmont, where the highest level of sero-positive deer mice was found. Suitable deer mouse habitat seems to be concentrated in the upper elevations, although more point locations are needed to increase confidence in the habitat suitability map. Also, the prevalence of hantavirus is thought to vary significantly from year to year with cyclical population levels of the mice (Portacci 2005).

Epizootic Hemorrhagic Disease (EHD):

This disease is caused by a virus (Reoviridae: *Orbivirus* sp.) transmitted to deer, and sometimes cattle, typically by biting midges (Diptera: Ceratopogonidae: *Culicoides* sp.). The disease is native to the southern U.S. and usually is associated with dense populations of deer. It usually occurs in late summer to early fall after a period of wet weather. Mortality is generally high, but the disease is not contagious between deer and ends at first frost when the midges die (IICAB 2006). In 1971, a massive die-off of white-tailed deer in Cades Cove was reported (Fox and Pelton ca.1973), with an estimated 84% mortality. The deer population in the Cades Cove area has declined and leveled off in the last ~20 years (B. Stiver, pers. comm. 2013).

Confidence and Data Gaps

Confidence varies with each species group within mammals. There are species-specific, current, quantified data associated with most bat species and selected other mammals such as bears, white-tailed deer, and elk. There also are reliable park-wide observations of many other mammals; however, some species, especially among the insectivores (shrews and moles) and rodents (mice, rats and squirrels, etc.), are not well studied. The uneven nature of the data, depending on the mammal group or species, makes for uneven confidence across all mammals, although there is high confidence in some groups (Table 4.5.18.3). Overall, declines in the groups/species discussed above are concerning.

Sources of Expertise

- Kim Delozier, Wildlife Biologist, Great Smoky Mountains National Park (retired)
- Donald Linzey, Mammalogist, Wytheville Community College, VA (retired)
- Mary Miller, Wildlife Biologist, Cherokee National Forest
- Joy O'Keefe, Center for Bat Research, Outreach, and Conservation, Terre Haute, IN
- Edward Pivorun, Clemson University
- William (Bill) Stiver, Supervisory Wildlife Biologist, Great Smoky Mountains National Park

Summary Condition

Table 4.5.18.3. Summary condition and trend graphic for mammals in GRSM.

Resource	Indicator	Status and Trend	Rationale and Reference Conditions
Focal Species or Communities	Mammals	⇩	No previous reference thresholds. Nearly half of park's bat species are in serious, rapid decline. There have been recent re-patriations, but other single-species losses. Many small species with no recent data.

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4.6. At-Risk Biota

4.6.1. Threatened, Endangered, and Rare Plant Species

Relevance

The park's outstanding biodiversity is one of its most compelling traits, and the protection of this biodiversity is a critical park management objective. This goal is particularly important in light of the threats posed by air pollution, climate change, and non-native invasive plants, which may cause the extirpation of many threatened and endangered plants throughout the region. With its varied topography, geology, and soils, the park may become an increasingly important refuge for these plants.

Data and Methods

The park has formally monitored rare plants since 1993 as part of the long-term monitoring program (Rock 2011). Populations of 36 rare plant species were selected by park staff to be actively monitored and managed in order to ensure population survival. These species were selected based on potential or documented threats, federal and state listing, and park rarity (Table 4.6.1.1). Definitions for the federal and state status, and park and global rankings used it Table 4.6.1.1 are provided below.

Federal Status Definitions:

E	Endangered; a taxon "in danger of extinction throughout all or a significant portion of its range."
T	Threatened; a taxon "likely to become an endangered species within foreseeable future throughout all or a significant portion of its range."
FSC	Federal Species of Concern; a species under consideration for listing, for which there is insufficient information to support listing at this time.

State Status Definitions:

E	Endangered; any species or higher taxon whose continued existence as a viable component of the state's flora is determined to be in jeopardy.
T	Threatened; any species or higher taxon which appears likely, in the foreseeable future, to become endangered throughout all or a significant portion of its range in the state.
S	Special Concern Species; any species or higher taxon that is uncommon in Tennessee, or has unique or highly specific habitat requirements or scientific value and therefore requires careful monitoring of its status.
SC	Special Concern; any species of plant in North Carolina which requires monitoring
SR	Significantly Rare; any species of plant which is rare in North Carolina but is not listed by the NC Plant Conservation Program as Endangered, Threatened, or Candidate.
CE	Commercially Exploited due to large numbers being taken from the wild.

W Watch list; any other species believed to be rare and of conservation concern in the state but not warranting active monitoring at this time.

Park Rank Definitions:

P1	Five or fewer occurrences with generally small populations; vulnerable to extinction.
P2	Six to 20 occurrences, uncommon and potentially vulnerable to extirpation.
P3	Twenty-one to 100 occurrences known, uncommon.
P4	Apparently secure, probably with many occurrences.
P5	Demonstrably secure; generally encountered or characteristic and dominant.

Global Rank Definitions

G1	Extremely rare and critically imperiled, generally with five or fewer occurrences in the world, or very few remaining individuals.
G2	Very rare and imperiled, generally with six to 20 occurrences and less than 3,000 individuals.
G3	Very rare and local throughout its range, or found locally in restricted ranges. Generally between 21 and 100 occurrences and fewer than 10,000 individuals.
G4	Apparently secure globally, though it may be quite rare in parts of its range, especially at the periphery.
G5	Demonstrably secure globally, though it might be quite rare in parts of its range, especially at the periphery.

Table 4.6.1.1. Rare plant species currently being monitored by GRSM, with the level of monitoring, state status, park rank, and global rank. Source: Rock 2013. Definitions for federal and state status, and park and global ranks are provided above.

Common Name	Scientific Name	Monitoring Level	Federal Status	*State Status	Park Rank	Global Rank
Climbing fumitory	*Adlumia fungosa*	I	–	SR/T	P1	G4
Heart-leaf paper birch	*Betula papyrifera var. cordifolia*	II	–	SR/E	P1	G5
Lance-leaf moonwort	*Botrychium lanceolatum*	II	–	SR/SR	P1	G5
Daisy-leaf moonwort	*Botrychium matricarifolium*	II	–	SR/S	P1	G5
Cain's reed grass	*Calamagrostis cainii*	I	FSC	E/E	P1	G1
Marsh bellflower	*Campanula aparinoides*	I	–	SR/S	P1	G5

Table 4.6.1.1 (continued). Rare plant species currently being monitored by GRSM, with the level of monitoring, state status, park rank, and global rank. Source: Rock 2013. Definitions for federal and state status, and park and global ranks are provided above.

Common Name	Scientific Name	Monitoring Level	Federal Status	*State Status	Park Rank	Global Rank
Small mountain bittercress	*Cardamine clematitis*	I	FSC	SR/T	P2	G2G3
Blue Ridge bittercress	*Cardamine flagellifera*	II	–	/T	P1	G3
American watercress	*Cardamine rotundifolia*	II	–	SR/S	P1	G4
White-leaf leatherflower	*Clematis glaucophylla*	II	–	SR/E	P1	G4?
Shootingstar	*Dodecatheon meadia*	–	–	SR/	P1	G5
Crested wood fern	*Dryopteris cristata*	II	–	W/T	P1	G5
Glade spurge	*Euphorbia purpurea*	I	FSC	SR/	P1	G3
American columbo	*Frasera caroliniensis*	I	–	SR/	P1	G5
Spreading avens	*Geum radiatum*	II	E	E/E	P1	G1
Smoky Mountain manna grass	*Glyceria nubigena*	I	FSC	T/E	P1	G2
Rock gnome lichen	*Gymnoderma lineare*	II	E	E/E	P1	G1
A liverwort	*Gymnomitrion laceratum*	II	–	/T	P1	G1
White-leaf sunflower	*Helianthus glaucophyllus*	I	–	W/T	P1	G3
Appalachian club-moss	*Huperzia appalachiana*	I	–	SR/	P1	G4G5
Goldenseal	*Hydrastis canadensis*	I	–	E-SC/S	P1	G4
Long-stalk holly	*Ilex collina*	I	–	T/	P1	G3
Fen orchid	*Liparis loeselii*	II	–	SR/E	P1	G5
American ginseng	*Panax quinquefolius*	III	–	W/S-CE	P2	G3G4
Sharp's mock-orange	*Philadelphus sharpianus*	I	–	–	P1	GUQ

Table 4.6.1.1 (continued). Rare plant species currently being monitored by GRSM, with the level of monitoring, state status, park rank, and global rank. Source: Rock 2013. Definitions for federal and state status, and park and global ranks are provided above.

Common Name	Scientific Name	Monitoring Level	Federal Status	*State Status	Park Rank	Global Rank
Purple fringeless orchid	*Platanthera peramoena*	I	–	SR/T	P1	G5
Rugel's ragwort	*Rugelia nudicaulis*	I	FSC	T/E	P3	G3
Rock skullcap	*Scutellaria saxatilis*	II	–	SR/T	P1	G3
Blue Ridge catchfly	*Silene ovata*	III	FSC	SR/E	P1	G2
Virginia spiraea	*Spiraea virginiana*	II	T	E/E	P1	G2
Yellow nodding ladies'-tresses	*Spiranthes ochroleuca*	I	–	SR/E	P1	G4
Guyandotte-beauty	*Synandra hispidula*	I	–	SR/T	P1	G4
Allegheny golden-banner	*Thermopsis mollis*	II	–	SR /S	P1	G3G4?
Dwarf bristle fern	*Trichomanes petersii*	I	–	T/T	P1	G3

The types of threats impacting rare plant species include road and trail maintenance, wild hog rooting, deer browsing, forest succession, trampling and vandalism by park visitors, poaching, decline of associated species or vegetation communities, and non-native plant invasions (Fig. 4.6.1.1). However, some rare plant populations in the park have an unknown status and have not been included in long-term monitoring (Rock 2013).

The rare plant monitoring program includes three objectives designed to measure changes in the park's rare plant populations: (1) determine long-term trends in the distribution and abundance of selected rare plant species, (2) determine size-class distributions for selected rare plant species to help predict population trends, and (3) determine how plant populations respond to changes in natural and human disturbance through changes in density and/or cover. Park staff then prioritized the level of monitoring intensity for each species, with Level I being the least intense (presence/absence) and Level III being the most intense (quantitative estimates of abundance and vigor, and demographic studies). Currently, there are 15 Level I species, 19 Level II species, and two Level III species being monitored. Management strategies that have proven effective in maintaining, and in some cases increasing, population sizes include prescribed burning, mechanical clearing, and non-native plant removal.

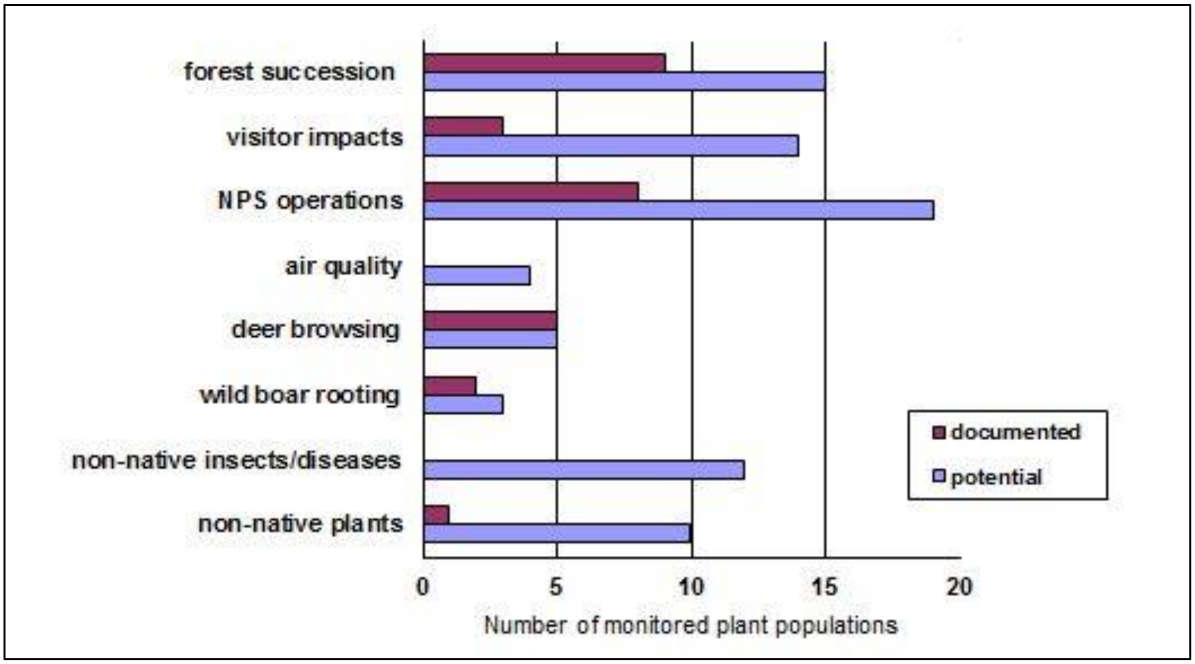

Figure 4.6.1.1. Number of rare plant populations for which documented and potential threats have been observed. Source: Rock 2013.

Reference Condition

The reference condition is considered to be when all threatened and endangered plant species currently existing in the park have viable populations.

Current Condition

The highest monitoring priority has been federally-listed plant species, and state-threatened or endangered plant species with documented threats (as opposed to park rare plants that have no state or federal listing) (Rock 2013). Brief summaries of some of these species are provided below.

Spreading avens (Geum radiatum)

(NatureServe: G2, TN: endangered, NC: endangered): Spreading avens is a federally endangered species, and it is listed as endangered in the states of North Carolina and Tennessee - the only states in which it occurs. This plant reproduces primarily vegetatively and occurs in a highly specialized habitat of high-elevation crevices (>1,310 m [4,300 ft]) on northwest-facing cliffs. Threats throughout its narrow range include trampling by humans, horticultural collection, and rock climbing. Drought, acid precipitation, and other pollutants may also be a factor (NatureServe 2014). There is one population known to exist in the park, and in 1997 the area was closed off to rehabilitate the habitat. Seedlings were planted among the existing population to restore the area damaged by visitor trampling. Although few of the transplants survived due to a subsequent drought, the park reports that the site is recovering following the closure. In 2010 and 2014, comprehensive surveys showed the park's population to be presently stable.

Rock gnome lichen (Gymnoderma lineare)
(NatureServe: G3, TN: critically imperiled, NC: vulnerable): The federally endangered rock gnome lichen is endemic to the southern Appalachian Mountains and occurs on shady rocks and vertical rock faces in Fraser fir forests, and on boulders in mid- to high-elevation stream corridors (NatureServe 2014). Fraser fir has declined for the past several decades due to balsam woolly adelgid infestations, which has caused changes to the local microclimate, including desiccation and increased temperatures. Hemlock decline due to the hemlock woolly adelgid may also impact several park populations of the lichen.

Virginia spiraea (Spiraea virginiana)
(NatureServe: G2, TN: endangered, NC: threatened): According to NatureServe Explorer, Virginia spiraea is listed as federally threatened primarily due to its limited range, a small number of populations, and its lacks of adequate seed set. In North Carolina and Tennessee, this species occurs along creek edges and rocky bars at river edges, as well as in alluvial silt that has collected within cracks in the bedrock. These sites are seasonally saturated and experience periodic flooding. Rangewide threats include changes in the hydrologic regime (severe flooding, impoundment), lack of disturbance (periodic scouring), exotic invasive plant species, roadside maintenance, and wildlife browse. This species is located in a remote drainage on the western end of the park and at this time appears stable (Rock 2013).

White-leaf leatherflower (Clematis glaucophylla)
(NatureServe: G4? TN: endangered; NC: no ranking): White-leaf leatherflower is a sprawling herbaceous vine that occurs in rich woods, river banks, sandstone boulders, and cobble bars. According to NatureServe Explorer (2014), overall threats to this species include land-use conversion, habitat fragmentation, and forest management practices. In the park, threats to one population include roadside mowing and herbicide treatment. An additional population was discovered in 2012 growing on a rocky slope with no signs of disturbance.

Fen orchid (Liparis loeselii)
(NatureServe TN: threatened; NC: endangered): The fen orchid occurs in moist open areas and has a mycorrhizal fungi association that limits its distribution. Within the park, one known population has been inadvertently eliminated due to roadside mowing and other habitat changes.

Rock skullcap (Scutellaria saxatilis)
(NatureServe: G3, TN: threatened; NC: no ranking): Rock skullcap occurs in moist forest floors, and its primary threats are loss of forest canopy and invasion of exotic species. Burning, grazing, and recreational activities are also threats to this species throughout its range. In the park, Japanese grass (*Microstegium vimineum*) must be routinely pulled in order to maintain rock skullcap populations.

Blue Ridge catchfly (Silene ovata)
(NatureServe: G3; TN: endangered, NC: special concern): Blue Ridge catchfly is rare throughout its range and most populations are small. Overall threats include logging, grazing, trampling, road construction, and right-of-way maintenance. Inside the park, six populations have been monitored over two decades. The populations consist of 2 to 16 clumps each, and occur on trailsides in the

eastern portion of the park. The species may respond well to fire; a prescribed burn in 2000 stimulated an increase in stems and flowers the following year.

Confidence and Data Gaps

The disturbances and other potential stressors affecting monitored plant populations have been well-documented. For this reason, we are highly confident that these populations warrant significant concern due to their rarity, and are relatively stable within the park at this time (Table 4.6.1.2).

Sources of Expertise

- Janet Rock, Botanist, Great Smoky Mountains National Park

Summary Condition

Table 4.6.1.2. Summary condition and trend graphic for threatened, endangered, and rare plants in GRSM.

Resource	Indicator	Status and Trend	Rationale and Reference Conditions
At-risk Biota	Threatened, endangered, and rare plants	↔	The reference condition is considered to be viable populations of all threatened and endangered plant species currently existing in the park. The stressors that negatively impact these species, such as road and trail maintenance, wild hog rooting, deer browsing, forest succession, trampling by park visitors, poaching, decline of associated species, and non-native plant invasions are well documented throughout the park.

4.6.2. Threatened, Endangered, and Rare Animal Species

Relevance

The protection and recovery of rare, threatened, and endangered species are at the heart of conservation in the stewardship of national parks. At-risk species are in all taxonomic groups – vertebrates, invertebrates, plants, fungi, protists, etc. When viewed together, they are presumed to be an effective metric of the park's biological health over time. This section will consider rare animal species as a group.

NPS Management Policies (NPS 2006) recognizes the importance of proactively protecting federal, state, and locally listed taxa (Section 4.4.2.3):

> *The Service will fully meet its obligations under the NPS Organic Act and the Endangered Species Act to both proactively conserve listed species and prevent detrimental effects on these species.*

And further in that section:

> *The National Park Service will inventory, monitor, and manage state and locally listed species in a manner similar to its treatment of federally listed species to the greatest extent*

> *possible. In addition, the Service will inventory other native species that are of special management concern to parks (such as rare, declining, sensitive, or unique species and their habitats) and will manage them to maintain their natural distribution and abundance.*

It is important to remember that species are added to threatened and endangered lists so that protective actions can be taken by conservation agencies and citizens, which hopefully will lead to recovery, and removal from the list. Listing actions of rare species by state and federal agencies are a primary way that conservation programs are initiated for species. However, the legal listing process is subject to public input and is often politically influenced, rather than being based strictly on scientific criteria. For example, there are restrictions in both NC and TN on the listing of most invertebrate animals as threatened or endangered (TDEC 2009, North Carolina Natural Heritage Program 2014). Therefore, some very rare animal species considered imperiled with extinction are ignored in the listing processes, even though they are important in national park stewardship. Other species may stay on official lists longer than the scientific data would support, based on other factors such as public concern.

The rarity ranking system of NatureServe, however, is entirely scientific, easily understood, and geographically scalable from local, state, national, and global resolutions. Each ranking is backed by a database of factors on which that ranking is based. NatureServe rankings are used by all state governments in consideration of their state rarity listings, and also by federal agencies (NatureServe 2015).

Data and Methods

The total number of animal species that are rare and vulnerable enough to be of concern to park management is unknown, but may exceed several hundred. Each animal group probably has some species at real risk, and we are just starting to understand the numerous invertebrate groups. The number and complexity of stressors affecting Great Smoky Mountains National Park no doubt contribute to the number of species at risk to extirpation in the park.

This section used specific criteria to develop a list of species of manageable scope for consideration in park stewardship. Species were included only if they met at least one of the following criteria:

- They hold some current federal designation of rarity, including: federal species of concern, candidate for listing, proposed for listing, Bald and Golden Eagle Protection Act (BGPA), or officially listed as a federally threatened or endangered (T&E) species (USFWS, http://www.fws.gov/raleigh/species/cntylist/swain.html).
- They are officially listed as T&E with either North Carolina or Tennessee (TDEC 2009, North Carolina Natural Heritage Program 2014). This does not include any of the numerous categories each state has for “state rare,” “watch list,” “deemed in need of management” or similarly designated species.
- The taxon is ranked by NatureServe as “critically imperiled globally” (G1) or “imperiled globally” (G2), or any ranking combination that includes G1 or G2 (NatureServe 2015) The NatureServe rankings are a scientific “check” for species in groups that are excluded from listings.

This selection process creates a list of 92 species (Table 4.6.2.1). Note that this list does not include species that were extirpated from the southern Appalachian region before the establishment of the park, including the red wolf (*Canis rufus*). The disadvantages to this approach include: 1) there is usually a delay of years between when concern for a particular species becomes known, to when it is approved for governmental listing or given a rank, and 2) most invertebrate groups are excluded from state listings and are not ranked. Therefore, Table 4.6.2.1 is best interpreted as a dynamic list of species with designations current for 2015. Each revision by any of the four agencies will change the list.

Table 4.6.2.1. Ninety-two animal species in GRSM with various federal, state, and NatureServe listings/rankings in 2015. Common names in quotes were derived by the author for those species with no known common names, for use in this project only.*

Category	Common Name	Scientific Name	Global Rank	Fed Status	NC Status	TN Status
Mammals	Rafinesque's big-eared bat	*Corynorhinus rafinesquei*	G3G4T3	FSC	T	–
	Carolina northern flying squirrel	*Glaucomys sabrinus coloratus*	G5T2	E	E	E
	Southern rock vole	*Microtus chrotorrhinus caroliensis*	G4T3	FSC	–	–
	Gray bat	*Myotis grisescens*	G3	E	E	E
	Small-footed bat	*Myotis leibii*	G1G3	FSC		
	Northern long-eared bat	*Myotis septentrionalis*	G1G2	T	T	T
	Indiana bat	*Myotis sodalis*	G2	E	E	E
	So. water shrew	*Sorex palustris punctulus*	G5T3	FSC	–	–
	Appalachian cottontail	*Sylvilagus obscurus*	G4	FSC	–	–
Birds	Saw-whet owl	*Aegolius acadicus* (pop. 1)	G5T3	FSC	T	T
	Golden eagle	*Aquila chrysatos*	G5	BGPA	–	T
	Common raven	*Corvus corax*	G5	–	–	T
	Peregrine falcon	*Falco peregrinus*	G4T3	–	E	E
	Bald eagle	*Haliaeetus leucocephalus*	G5	BGPA	T	–
	So. App. red crossbill	*Loxia curvirostra* (pop. 1)	G5T3	FSC	–	–

***Explanation of symbols: E=endangered, T=threatened, BGPA=Bald and Golden Eagle Protection Act, FSC=Federal Species of Concern, PE=proposed endangered, C=candidate for T&E review. NatureServe symbols: the same quantitative criteria are used for different geographic scales, e.g., state (S), national (N) or global (G). Global ranks are for the entire range of the species, 1=extremely imperiled, usually only 1-5 occurrences known; 2=imperiled, usually 6-20 occurrences known; 3=vulnerable, 21-100 occurrences; 4=apparently secure; 5=demonstrably secure. Sometimes a species is given a range of ranks, e.g., G2G3, indicating it is on the cusp of the ranks given; T=a subspecies or population which may be genetically distinct, it receives both a global ranking and a T rank using the same 1-5 criteria

Table 4.6.2.1 (continued). Ninety-two animal species in GRSM with various federal, state, and NatureServe listings/rankings in 2015. Common names in quotes were derived by the author for those species with no known common names, for use in this project only.*

Category	Common Name	Scientific Name	Global Rank	Fed Status	NC Status	TN Status
Birds (continued)	Red-cockaded woodpecker	*Piciodes borealis*	G3	E	E	E
	So. App. black-capped chickadee	*Poecile atricapillus practica*	G5T3	FSC	–	–
	Cerulean warbler	*Setophaga cerulea*	G4	FSC	–	–
	So. App. Bewick's wren	*Thryomanes bewickii atus*	G5T2?	FSC	E	E
	Golden-winged warbler	*Vermivora chyrsoptera*	G4	FSC	–	–
Reptiles	Northern pine snake	*Pituophis m. melanoleucus*	G4T2	FSC	–	T
Amphibians	Green salamander	*Aneides aeneus*	G3G4	FSC	E	–
	Hellbender	*Cryptobranchus alleghenensis*	G3G4	FSC	–	–
	Southern pygmy salamander	*Desmognathus wrighti*	G3	FSC	–	–
	Seepage salamander	*Desmognathus aeneus*	G3G4	FSC	–	–
	Junaluska salamander	*Eurycea junaluska*	G3	FSC	T	–
Fishes	"Smoky dace"	*Clinostomus* sp.1	G5T3Q	FSC	–	–
	Spot-fin chub	*Erimonax monachus*	G2	FSC	T	T
	Banded sculpin	*Cottus carolinae*	G5	–	T	–
	Tuckaseegee darter	*Etheostoma gutselli*	G4	–	–	E
	Citico darter	*Ethostoma sitikuense*	G2	E	–	E
	Wounded darter	*Etheostoma vulneratum*	G3	FSC	–	–
	American brook lamprey	*Lampetra appendix*	G4	–	T	–

*****Explanation of symbols: E=endangered, T=threatened, BGPA=Bald and Golden Eagle Protection Act, FSC=Federal Species of Concern, PE=proposed endangered, C=candidate for T&E review. NatureServe symbols: the same quantitative criteria are used for different geographic scales, e.g., state (S), national (N) or global (G). Global ranks are for the entire range of the species, 1=extremely imperiled, usually only 1-5 occurrences known; 2=imperiled, usually 6-20 occurrences known; 3=vulnerable, 21-100 occurrences; 4=apparently secure; 5=demonstrably secure. Sometimes a species is given a range of ranks, e.g., G2G3, indicating it is on the cusp of the ranks given; T=a subspecies or population which may be genetically distinct, it receives both a global ranking and a T rank using the same 1-5 criteria

Table 4.6.2.1 (continued). Ninety-two animal species in GRSM with various federal, state, and NatureServe listings/rankings in 2015. Common names in quotes were derived by the author for those species with no known common names, for use in this project only.*

Category	Common Name	Scientific Name	Global Rank	Fed Status	NC Status	TN Status
Fishes (continued)	"Sicklefin redhorse"	*Moxostoma* sp.2	G2?	C	T	–
	Smoky madtom	*Noturus baileyi*	G1	E	–	E
	Yellowfin madtom	*Noturus flavipinnis*	G1	T	–	T
	Blotchside logperch	*Percina burtoni*	G2G3	FSC	E	–
	Logperch	*Percina caprodes*	G5	–	T	–
	Olive darter	*Percina squamata*	G3	FSC	–	–
Bivalves	Tennessee clubshell	*Pleurobema oviforme*	G2G3	FSC	E	–
	Mountain creekshell	*Villosa vauxemensis*	G4	–	T	–
	Tennessee pigtoe	*Pleuronaia barnesiana*	G2G3	FSC	E	–
Land Snails	Rustic tigersnail	*Anguispira knoxensis*	G1G2	–	–	–
	Summit covert	*Fumonelix clingmanica*	GNR	FSC	T	–
	Clifty covert	*Fumonelix wetherbyi*	G2G3	–	–	–
	Big tooth covert	*Fumonelix jonesiana*	G1	–	T	–
	Light glyph	*Glyphyalinia junaluska*	G2	–	–	–
	Pink glyph	*Glyphyalinia pentadelphia*	G2G3	–	–	–
	Blue-footed lancetooth	*Haplotrema kendeighi*	G2	–	–	–
	Smoky Mountain covert	*Inflectarius ferrissi*	G2	–	T	–
	Fuzzy covert	*Inflectarius verus*	G1	–	–	–
	Wandering globe	*Mesodon altivagus*	G2G3	–	–	–
	High mountain supercoil	*Paravitrea andrewsae*	G2	–	–	–
	Mirey ridge supercoil	*Paravitrea clappi*	G2G3	–	–	–

*****Explanation of symbols: E=endangered, T=threatened, BGPA=Bald and Golden Eagle Protection Act, FSC=Federal Species of Concern, PE=proposed endangered, C=candidate for T&E review. NatureServe symbols: the same quantitative criteria are used for different geographic scales, e.g., state (S), national (N) or global (G). Global ranks are for the entire range of the species, 1=extremely imperiled, usually only 1-5 occurrences known; 2=imperiled, usually 6-20 occurrences known; 3=vulnerable, 21-100 occurrences; 4=apparently secure; 5=demonstrably secure. Sometimes a species is given a range of ranks, e.g., G2G3, indicating it is on the cusp of the ranks given; T=a subspecies or population which may be genetically distinct, it receives both a global ranking and a T rank using the same 1-5 criteria

Table 4.6.2.1 (continued). Ninety-two animal species in GRSM with various federal, state, and NatureServe listings/rankings in 2015. Common names in quotes were derived by the author for those species with no known common names, for use in this project only.*

Category	Common Name	Scientific Name	Global Rank	Fed Status	NC Status	TN Status
Land Snails (continued)	Lamellate supercoil	*Paravitrea lamellidens*	G2	–	–	–
	Open supercoil	*Paravitrea umbilicaris*	G2	–	–	–
	Great Smoky slitmouth	*Stenotrema depilatum*	G2	–	–	–
Arachnids	"Surprizing" daddy-long legs	*Fumontana deprehendor*	G1G2	–	–	–
	Spruce-fir moss spider	*Microhexura montivaga*	G1	E	–	–
Crustaceans	French Broad crayfish	*Cambarus reburrus*	G3	FSC	–	–
	Tuckaseegee crayfish	*Cambarus tuckaseegee*	G1G2	–	–	–
	Gregory cave amphipod	*Stygobromus fecundus*	G1G2	–	–	–
	Sparse bristle amphipod	*Stygobromus sparsus*	G1G2	–	–	–
Springtails	Copeland's springtail	*Triacantha copelandi*	G1	–	–	–
Mayflies	“Pale” epeorus mayfly	*Epeorus subpallidus*	G1Q	–	–	–
	Sinclair's mayfly	*Maccaffertium sinclairi*	G2G3	–	–	–
Stoneflies	Smokies snowfly	*Allocapnia fumosa*	G2	–	–	–
	Georgia stonefly	*Beloneuria georgiana*	G2	–	–	–
	Mountain needlefly	*Leutra monticola*	G1Q	–	–	–
	Smokies' needlefly	*Megaleutra williamsae*	G2	FSC	–	–
	Hairy springfly	*Oconoperla innubila*	G2	–	–	–
	NFG tiny winter black stonefly	*Zapada chila*	G2	–	–	–
Caddisflies	“Flint's” caddisfly	*Goerita flinti*	G2G3	–	–	–

*****Explanation of symbols: E=endangered, T=threatened, BGPA=Bald and Golden Eagle Protection Act, FSC=Federal Species of Concern, PE=proposed endangered, C=candidate for T&E review. NatureServe symbols: the same quantitative criteria are used for different geographic scales, e.g., state (S), national (N) or global (G). Global ranks are for the entire range of the species, 1=extremely imperiled, usually only 1-5 occurrences known; 2=imperiled, usually 6-20 occurrences known; 3=vulnerable, 21-100 occurrences; 4=apparently secure; 5=demonstrably secure. Sometimes a species is given a range of ranks, e.g., G2G3, indicating it is on the cusp of the ranks given; T=a subspecies or population which may be genetically distinct, it receives both a global ranking and a T rank using the same 1-5 criteria

Table 4.6.2.1 (continued). Ninety-two animal species in GRSM with various federal, state, and NatureServe listings/rankings in 2015. Common names in quotes were derived by the author for those species with no known common names, for use in this project only.*

Category	Common Name	Scientific Name	Global Rank	Fed Status	NC Status	TN Status
Caddisflies (continued)	“Chattanooga” caddisfly	*Hydroptila chattanooga*	G2	–	–	–
	“Excavating” caddisfly	*Lepidostoma excavatum*	G2G3	–	–	–
	“Lobate” caddisfly	*Lepidostoma lobatum*	G2	–	–	–
	“Stylis” caddisfly	*Lepidostoma stylifer*	G2G3	–	–	–
	Kolodski's caddisfly	*Neophylax kolodskii*	G1	–	–	–
	“Singular” caddisfly	*Pseudogoeria singularis*	G2G3	–	–	–
	“Neighbor” caddisfly	*Rhyacophila accola*	G1G2	–	–	–
	“Friendship” caddisfly	*Rhyacophila amicis*	G2G3	–	–	–
	Celadon caddisfly	*Rhyacophila celadon*	G2G3	–	–	–
	“Mohr's” caddisfly	*Wormaldia mohri*	G2G3	–	–	–
Dragonflies	Mountain river cruiser	*Macromia margarita*	G3	FSC	–	–
Moths/Butterflies	So. App. Bates crescent	*Phyciodes batesii maconensis*	G4T2T3	FSC	–	–
	"Milne's" looper moth	*Euchlaena milnei*	G2G4	–	–	–
	Yellow stoneroot borer moth	*Papaipema astuta*	G2G4	–	–	–
Bees	Rusty patched bumble bee	*Bombus affinis*	G1	–	–	–
	Yellow banded bumble bee	*Bombus terricola*	G2G4	–	–	–

*****Explanation of symbols: E=endangered, T=threatened, BGPA=Bald and Golden Eagle Protection Act, FSC=Federal Species of Concern, PE=proposed endangered, C=candidate for T&E review. NatureServe symbols: the same quantitative criteria are used for different geographic scales, e.g., state (S), national (N) or global (G). Global ranks are for the entire range of the species, 1=extremely imperiled, usually only 1-5 occurrences known; 2=imperiled, usually 6-20 occurrences known; 3=vulnerable, 21-100 occurrences; 4=apparently secure; 5=demonstrably secure. Sometimes a species is given a range of ranks, e.g., G2G3, indicating it is on the cusp of the ranks given; T=a subspecies or population which may be genetically distinct, it receives both a global ranking and a T rank using the same 1-5 criteria

Table 4.6.2.1 (continued). Ninety-two animal species in GRSM with various federal, state, and NatureServe listings/rankings in 2015. Common names in quotes were derived by the author for those species with no known common names, for use in this project only.*

Category	Common Name	Scientific Name	Global Rank	Fed Status	NC Status	TN Status
Grasshoppers	Cherokee spur-throat	*Melanopus cherokee*	G1G3	–	–	–
	Deceptive spur-throat	*Melanopus deceptus*	G2G4	–	–	–
	Lobecercus short-wing	*Melanopus divergens*	G2G3	–	–	–

*****Explanation of symbols: E=endangered, T=threatened, BGPA=Bald and Golden Eagle Protection Act, FSC=Federal Species of Concern, PE=proposed endangered, C=candidate for T&E review. NatureServe symbols: the same quantitative criteria are used for different geographic scales, e.g., state (S), national (N) or global (G). Global ranks are for the entire range of the species, 1=extremely imperiled, usually only 1-5 occurrences known; 2=imperiled, usually 6-20 occurrences known; 3=vulnerable, 21-100 occurrences; 4=apparently secure; 5=demonstrably secure. Sometimes a species is given a range of ranks, e.g., G2G3, indicating it is on the cusp of the ranks given; T=a subspecies or population which may be genetically distinct, it receives both a global ranking and a T rank using the same 1-5 criteria

Some of the listed animals have small to very small natural ranges and may be referred to as endemic species. Some GRSM species are naturally endemic to the southern Appalachians, or to the park, and if an extreme endemic, to one particular specialized habitat in the park. The smaller the endemics' range, the greater the risk from random local extinction events.

This analysis evaluated all 92 rare animal species together, against a set of known general stressors, without bias of which organization designated it, what species group, or type of rarity. A view of general condition for these rare animals was thereby achieved. The results of the rating are shown in Table 4.6.2.2 as a first approximation of risk against six known ecological stressors. It should be noted that these six general stressors do not represent all of the stressors that influence rare animals.

Table 4.6.2.2. Approximation of risk* on listed species in GRSM from six known ecological stressors. (See notes for abbreviation meanings).

Category	Common Name	Lack of fire	Unnatural competition/ predation	Climate Change	Airborne chemical deposition	Direct habitat loss	Dis-ease	Points/ species
Mammals	Rafinesque's big-eared bat	L	–	–	–	–	L	2
	Carolina northern flying squirrel	–	–	L	M	–	–	4

* Each species was subjectively rated one of four risk conditions: "–"**=0** points, minor or no risk known; **L=1** point, some concern about present condition for that species; **M=3** points, evidence of stressors apparent, but impact not believed critical; **H=5** points, stressor and significant impact probable/documented. See Appendix A for notes regarding each species, on which these first approximation ratings were based.

Table 4.6.2.2 (continued). Approximation of risk* on listed species in GRSM from six known ecological stressors. (See notes for abbreviation meanings).

Category	Common Name	Lack of fire	Unnatural competition/ predation	Climate Change	Airborne chemical deposition	Direct habitat loss	Dis-ease	Points/ species
Mammals (continued)	Southern rock vole	–	–	–	L	–	–	1
	Gray bat	–	–	–	–	–	H	5
	Small-footed bat	–	–	–	–	L	M	4
	Northern long-eared bat	L	–	–	–	–	H	6
	Indiana bat	L	–	–	–	–	H	6
	Southern water shrew	–	–	L	L	–	–	2
	Appalachian cottontail	–	M	L	L	–	–	5
Birds	Saw-whet owl	–	–	L	L	–	–	2
	Golden eagle	–	–	–	–	M	–	3
	Common raven	–	–	–	L	–	–	1
	Peregrine falcon	–	–	–	L	L	–	2
	Bald eagle	–	–	–	L	–	–	1
	Southern Appalachian red crossbill	L	–	–	L	–	–	2
	Red-cockaded woodpecker	H	–	–	–	–	–	5
	Southern Appalachian black-capped chickadee	–	–	L	M	–	–	4
	Cerulean warbler		L	L				2
	Southern Appalachian Bewick's wren	–	M	–	–	–	–	3
	Golden-winged warbler	L	–	–	–	H	–	6

* Each species was subjectively rated one of four risk conditions: "–"**=0** points, minor or no risk known; **L=1** point, some concern about present condition for that species; **M=3** points, evidence of stressors apparent, but impact not believed critical; **H=5** points, stressor and significant impact probable/documented. See Appendix A for notes regarding each species, on which these first approximation ratings were based.

Table 4.6.2.2 (continued). Approximation of risk* on listed species in GRSM from six known ecological stressors. (See notes for abbreviation meanings).

Category	Common Name	Lack of fire	Unnatural competition/ predation	Climate Change	Airborne chemical deposition	Direct habitat loss	Dis-ease	Points/ species
Reptiles	Northern pine snake	M	–	–	–	–	L	4
Amphibians	Green salamander	–	–	L	–	–	L	2
	Seepage salamander	–	M	L	–	–	L	5
	Hellbender	–	–	L	L	M	L	6
	Pygmy salamander	–	–	L	L	–	L	3
	Junaluska salamander	–	–	L	–	L	L	3
Fishes	“Smoky dace”	–	L	–	–	–	–	1
	Spotfin chub	–	–	–	–	H	–	5
	Banded sculpin	–	–	–	–	–	–	0
	Tuckaseegee darter	–	–	–	–	H	–	5
	Citico darter	–	–	–	–	M	–	3
	Wounded darter	–	–	–	–	L	–	1
	American brook lamprey	–	L	–	–	–	–	1
	"Sicklefin redhorse"	–	–	–	–	M	–	3
	Smoky madtom	–	–	–	–	M	–	3
	Yellowfin madtom	–	–	–	–	M	–	3
	Blotchside logperch	–	–	–	–	H	–	5
	Common logperch	–	L	–	–	–	–	1
	Olive darter	–	L	–	–	M	–	4
Bivalves	Tennessee clubshell	–	L	–	–	M	–	4

* Each species was subjectively rated one of four risk conditions: “–“**=0** points, minor or no risk known; **L=1** point, some concern about present condition for that species; **M=3** points, evidence of stressors apparent, but impact not believed critical; **H=5** points, stressor and significant impact probable/documented. See Appendix A for notes regarding each species, on which these first approximation ratings were based.

Table 4.6.2.2 (continued). Approximation of risk* on listed species in GRSM from six known ecological stressors. (See notes for abbreviation meanings).

Category	Common Name	Lack of fire	Unnatural competition/ predation	Climate Change	Airborne chemical deposition	Direct habitat loss	Dis-ease	Points/ species
Bivalves (continued)	Mountain creekshell	–	L	–	–	M	–	4
	Tennessee pigtoe	–	L	–	–	M	–	4
Land Snails	Rustic tigersnail	–	–	L	L	–	–	2
	Summit covert	–	–	L	H	–	–	6
	Big tooth covert	–	–	L	H	–	–	6
	Light glyph	–	–	L	L	–	–	2
	Pink glyph	–	–	L	L	–	–	2
	Blue-footed lancetooth	–	–	L	M	–	–	4
	Smoky Mountain covert	–	–	L	H	–	–	6
	Fuzzy covert	–	–	L	M	–	–	4
	Wandering globe	–	–	L	H	–	–	6
	High mountain supercoil	–	–	L	H	–	–	6
	Mirey ridge supercoil	–	–	L	H	–	–	6
	Lamellate supercoil	–	–	L	H	–	–	6
	Open supercoil	–	–	L	L	–	–	2
	Great Smoky slitmouth	–	–	L	H	–	–	6
Arachnids	"Surprizing" daddy-long legs	–	L	L	–	–	–	2
	Spruce-fir moss spider	–	–	M	M	–	–	6
Crustaceans	French Broad crayfish	–	M	–	–	M	–	6

* Each species was subjectively rated one of four risk conditions: “–“**=0** points, minor or no risk known; **L=1** point, some concern about present condition for that species; **M=3** points, evidence of stressors apparent, but impact not believed critical; **H=5** points, stressor and significant impact probable/documented. See Appendix A for notes regarding each species, on which these first approximation ratings were based.

Table 4.6.2.2 (continued). Approximation of risk* on listed species in GRSM from six known ecological stressors. (See notes for abbreviation meanings).

Category	Common Name	Lack of fire	Unnatural competition/ predation	Climate Change	Airborne chemical deposition	Direct habitat loss	Dis-ease	Points/ species
Crustaceans (continued)	Tuckaseegee crayfish	–	M	–	–	L	–	4
	Gregory cave amphipod	–	–	M	–	–	–	3
	Sparse bristle amphipod	–	–	M	–	–	–	3
Springtails	Copeland's springtail	–	–	L	–	–	–	1
Mayflies	Pale epeorus mayfly	–	–	–	–	–	–	0
	Sinclair's mayfly	–	–	–	–	–	–	0
Stoneflies	Smokies snowfly	–	–	L	M	–	–	4
	Georgia stonefly	–	–	L	–	–	–	1
	Mountain needlefly	–	–	L	–	–	–	1
	Smokies' needlefly	–	–	L	–	–	–	4
	Hairy springfly	–	–	–	M	–	–	3
	Newfound Gap tiny winter black stonefly	–	–	L	H	–	–	6
Caddisflies	Flint's caddisfly	–	–	L	M	–	–	4
	Chattanooga caddisfly	–	–	–	–	L	–	1
	Excavating caddisfly	–	–	–	M	–	–	3
	Lobate caddisfly	–	–	–	–	–	–	0
	Stylis caddisfly	–	–	–	–	–	–	0
	Kolodski's caddisfly	–	–	L	M	–	–	4
	"Singular" caddisfly	–	–	–	M	–	–	3

* Each species was subjectively rated one of four risk conditions: "–"**=0** points, minor or no risk known; **L=1** point, some concern about present condition for that species; **M=3** points, evidence of stressors apparent, but impact not believed critical; **H=5** points, stressor and significant impact probable/documented. See Appendix A for notes regarding each species, on which these first approximation ratings were based.

Table 4.6.2.2 (continued). Approximation of risk* on listed species in GRSM from six known ecological stressors. (See notes for abbreviation meanings).

Category	Common Name	Lack of fire	Unnatural competition/ predation	Climate Change	Airborne chemical deposition	Direct habitat loss	Dis-ease	Points/ species
Caddisflies (continued)	"Neighbor" caddisfly	–	–	–	–	–	–	0
	"Friendship" caddisfly	–	–	–	–	–	–	0
	Celadon caddisfly	–	–	L	M	–	–	4
	Mohr's caddisfly	–	–	–	–	–	–	0
Dragonflies	Mountain river cruiser	–	–	–	L	M	–	4
Moths/Butter-flies	Southern Appalachian Bates crescent	M	–	–	–	–	–	3
	"Milne's" looper moth	–	–	–	–	–	–	0
	Yellow stoneroot borer moth	–	M	–	–	–	–	3
Bees	Rusty patched bumble bee	**–**	–	–	–	–	H	5
	Yellow-banded bumble bee	**–**	–	–	–	–	H	5
Grasshoppers	Cherokee spur-throat	L	–	–	–	–	–	1
	Deceptive spur-throat	L	–	–	L	M	–	5
	Divergent spur-throat	L	–	–	L	M	–	5
Total Stressor Points:		**23**	**27**	**47**	**106**	**60**	**35**	**–**

* Each species was subjectively rated one of four risk conditions: "–"**=0** points, minor or no risk known; **L=1** point, some concern about present condition for that species; **M=3** points, evidence of stressors apparent, but impact not believed critical; **H=5** points, stressor and significant impact probable/documented. See Appendix A for notes regarding each species, on which these first approximation ratings were based.

Stressors Used in Table 4.6.2.2

Lack of Fire:

The lack of fire has been an issue for many species of animals in the lower elevations and especially in the west end of GRSM. The animals and plant communities in these areas appear to have had a natural wildland fire regime capable of sustaining them (White et al. 2003). Although the park has, in recent years, had approval to conduct prescribed burns, this has not been the case for most of its 80-year history, and funding for expanded burning is limited.

Unnatural Competition and Predation:

When exotic species invade natural habitats of the park, they often will negatively influence populations of a rare species. This stressor category includes exotic insects and also incursions by species native to the U.S. but not believed to be native to the park, e.g., coyote (*Canis latrans*).

Climate Change:

Climate changes may become more of a factor in the future, but for this analysis, the possible impacts were limited to current conditions. This is admittedly a best professional judgement of the influence of recent extremes in precipitation, temperature, and wind the park has experienced, as well as the earlier warming documented in spring months in the most recent two decades (J. Renfro, pers. comm.).

Air Quality:

Acid deposition and other air quality-related values are well-documented stressors to both terrestrial and aquatic systems in the upper elevations of GRSM (NPS, http://www.nps.gov/grsm/learn/nature/air-quality.htm). As used here, this category includes acidification and the deposition of chemicals such as mercury and pesticides.

Direct Habitat Loss:

This category attempts to represent the loss of original habitat, such as from reservoir impoundments, or the lack of access to specialized habitat that was formerly available.

Disease:

This category is meant to encompass diseases caused by possible introduction to park populations. Disease impacts not reasonably suspected or actually documented in the park were not included.

Reference Condition

Only an assessment over the long-term can fully capture the trends in species endangerment and extinction. Although there is a long history of information for a few species in the park, the majority of animal groups have only become well studied, at least scientifically, in the late 20th century. The conservation status, or even the life histories, of many invertebrate groups are still relatively or even profoundly unknown, and some groups are still being discovered and documented. Therefore, the reference condition for which to compare this condition assessment does not exist; the reference condition starts with this assessment.

Condition and Trends

As a group, the 92 rare animals selected were rated subjectively for six general stressors known in the park, and accumulated points based on an arbitrary weighted point system for approximate seriousness of the stressor's impact for each taxon (Table 4.6.2.2). The scores of the 92 species were totaled, and resulting scores per species ranged from 0 to 6 points.

Following the described scoring system, the number of species per point value are listed:

- 0 points – 8 species (These were mostly invertebrates at lower elevations, probably escaping the acidification at upper altitudes).

- 1 point – 13 species
- 2 points – 12 species
- 3 points – 14 species
- 4 points – 16 species
- 5 points – 11 species
- 6 points – 16 species

Over 40 species scored four or more points, indicating high influence from at least one stressor or multiple stressor impacts. A number of the higher 5- and 6-point scores were for species at higher elevations in the park. They accumulated points due to the high amounts of acid that have been deposited and continue to occur there. Some higher elevation species are no doubt more adaptive to acidification than others. Those with low mobility, such as land snails, garnered high points for both being very sensitive to acidification/calcium loss and due to climate change, as endemic summit species unable to rapidly move to hospitable habitats when extreme weather regimes are occurring.

While all of these species deserve some conservation stewardship attention, the species scoring 5's and 6's probably should receive more timely investigation as to their specific on-going conservation status. When the six stressors were summed across species by the same points given, they clearly indicate the overwhelming impact of higher elevation air quality issues to rare animals (Fig. 4.6.2.1). Although somewhat auto-correlated with air quality, the climate change scores were usually lower, indicating uncertainty about the degree to which the park's recent climate extreme events have an impact.

Not all stressors have a broad impact like air quality or climate changes do. For example, certain bat species and certain bumble bees have been victims of virulent infestations of introduced disease organisms to the point of extirpation. Similarly, wildland fire exclusion has very specific site impacts, but has also led to at least one extirpation.

Overall the current condition of rare animals as represented by the legal/scientific criteria chosen is serious, with about half of the 92 species probably experiencing strong impacts from one or more stressors. This is a downward trend, of which we are at least moderately confident (Table 4.6.2.3).

Only the lack of data keeps us from becoming highly confident. Strong, sustained agency efforts will be necessary to curtail this trend. Management actions should be at two resolutions: 1) that of the individual species needs, and 2) larger programs in air pollution, exotics control, reintroduction of fire and preventing other diseases to wildlife.

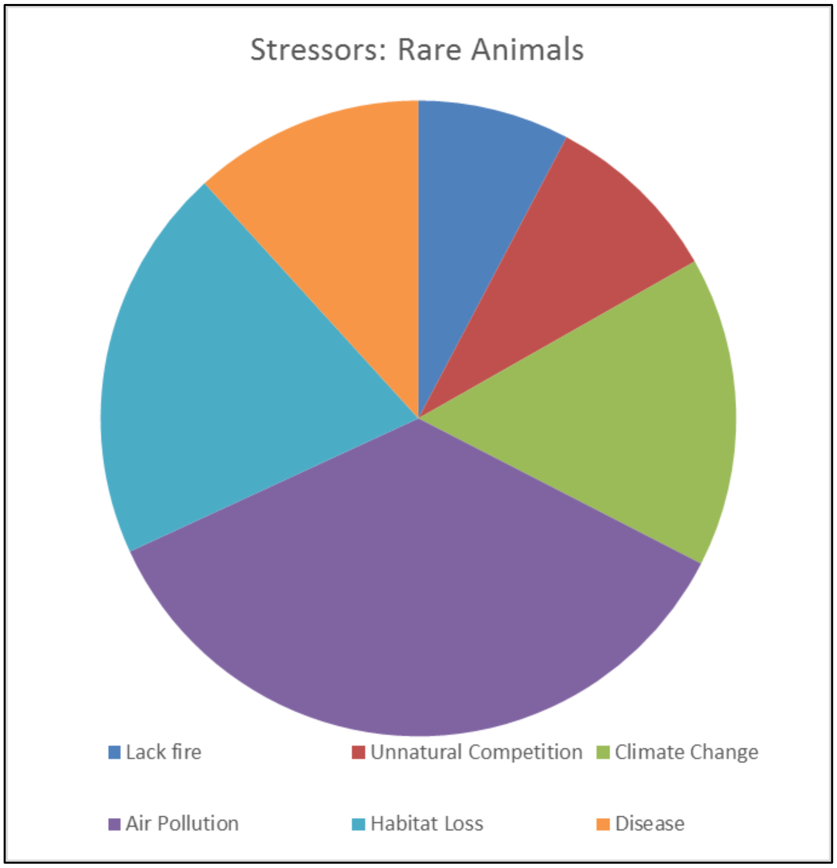

Figure 4.6.2.1. First approximation of the general impact of six known stressors on rare animal species in GRSM. The pie slices represent the number of points summed across all 92 rare animal species for each stressor. (see Table 4.6.2.2 for ratings).

Confidence and Data Gaps

There are thousands of species of animals documented in GRSM, and this effort examined only 92 of them. There are probably hundreds more in various species groups that are rare enough to be of conservation concern to the park. Many of these will be listed/ranked in future years according to the same criteria used here, which will make clear comparisons with this section difficult. However, the generalized impact of the stressors may indeed change and be measureable for a future condition assessment.

The subjective rating of weighted stressor factors is meant as a first approximation example of what could be a periodic rating of species by a team of relevant professionals. This would be similar to what occurs in state conservation agencies and NatureServe when ranking numerous species, and it would provide a more defensible foundation for management actions. As noted previously, the bias by which states approach listing invertebrate animal groups, and the lack of data on non-traditional groups, make for an inherent lack of confidence in this analysis of 92 species as being representative of all rare animals. It does clearly illustrate for those species which ones are more in need of prompt management actions in the way of inventories, monitoring, research, and direct management action.

Sources of Expertise

- Harry LeGrand, North Carolina Natural Heritage Program
- Jim Renfro, Air Quality Program Manager, Great Smoky Mountains National Park
- David Withers, Zoologist, Tennessee Department of Conservation
- NatureServe, North Carolina Field Office http://www.natureserve.org/region/natureserve-durham-office, Durham
- U.S. Fish and Wildlife Service, Ecological Services Office, Asheville, NC
- Park Resource Management and Science Division, multiple offices (Wildlife, Fish, Inventory and Monitoring)

Summary Condition

Table 4.6.2.3. Summary condition and trend graphic for threatened and endangered animals in GRSM.

Resource	Indicator	Status and Trend	Rationale and Reference Conditions
At-risk Biota	Threatened and endangered animals	⬇	No previous reference thresholds; in current weighted analysis of 92 rarest animals, nearly 1/2 indicated high influence from at least one stressor.

4.6.3. Literature Cited

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4.7. Exploited Plants

4.7.1 Overview

Relevance

Collecting wild plants for medicinal and nutritional uses in the southern Appalachian Mountains is a tradition that dates back to the Native Americans' occupancy. Many of their traditional medicinal uses were subsequently passed on to Euro-American settlers in the region. However, modern-day overharvesting for commercial interests is now a serious issue for sustaining certain plant species populations. Medicinal plants such as American ginseng (*Panax quinquefolius*) command high prices, making it a prime target for poachers. Other plants such as log mosses are sought after for use in floral arrangements. Orchid and trillium species are prized for their delicate beauty and are popular in the plant trade. Until recently, the park's target plants have been relatively protected due to their remote locations. However, recent data show a declining trend in remote populations, particularly for ginseng, due to poaching.

Data and Methods

Table 4.7.1 lists exploitable species that are of concern to resource managers because they are likely targets for illegal harvesting. Although resource managers are aware of illegal harvesting of many of these species, data are only available for ginseng and ramps (*Allium tricoccum*). Therefore, the condition and trends for exploitable plants were based solely on those two species.

Table 4.7.1. Exploitable plants in the park. Source: J. Rock, pers. comm. 2014.

Common Name	Scientific Name	Uses
Bloodroot	*Sanguinaria canadensis*	medicinal
Goldenseal	*Hydrastis canadensis*	medicinal
Black cohosh	*Actaea racemosa*	medicinal
Fairywand	*Chamaelirium luteum*	medicinal
Mayapple	*Podophyllum peltatum*	medicinal
Jack-in-the-pulpit	*Arisaema triphyllum*	medicinal
Blue cohosh	*Caulophyllum thalictroides*	medicinal
Solomon's seal	*Polygonatum biflorum*	medicinal
Galax	*Galax urceolata*	floral arrangement
Log moss	several species	floral arrangement
Pink lady's slipper	*Cypripedium acaule*	plant trade
Yellow lady's slipper	*Cypripedium parviflorum* var. *pubescens*	plant trade
Downy rattlesnake plantain	*Goodyera pubescens*	plant trade
Other orchids	several species	plant trade
Trillium	several species	plant trade

Park resource managers performed a ramp harvesting experiment to evaluate harvesting effects on ramp populations, and another study to model potential ramp habitat. These data, along with direct communication with park resource managers, were used to qualitatively establish a trend and condition for ramps.

Reference Conditions

The reference condition for exploitable plants is viable populations that will sustain themselves into the foreseeable future throughout their native habitats. It is inferred that this condition will receive little to no illegal harvesting.

Current Conditions and Trends

The following summarizes our current state of knowledge for various species that are, or have been, poached in the park:

American Ginseng

American ginseng is a small, slow-growing herb with gnarled, branching roots that are valued as a cure-all remedy, commanding high prices in East Asian markets (Fig. 4.7.1). The plant's habitat is typically in rich cove forests where soils are high in calcium and the pH higher than 5.5. When harvested, the entire plant is destroyed, making populations particularly sensitive to exploitation. The problem is exacerbated when the plant is harvested before it has matured and produced viable seeds. Ginseng has been harvested from forests in North America for more than 250 years, and evidence indicates that genetic diversity is higher within protected populations than in populations where harvesting is permitted (Cruse-Sanders and Hamrick 2004). While ginseng is legally harvested using a limited permitting system on adjacent public lands, it has been illegally collected in GRSM since the park's establishment in 1934. Beginning in 1991, park law enforcement rangers began counting the number of roots seized from poachers (Fig. 4.7.2). As of 2014, rangers have confiscated over 15,000 roots, although they believe that they are detecting only a small percentage of those people that are poaching ginseng within the park (Rock et al. 1999). Fig. 4.7.3 shows the number of ginseng roots harvested per watershed in the park. Population projections based on detailed demographic studies of six GRSM populations show that ginseng populations in the park overall are just barely regenerating enough to replace lost plants and cannot tolerate additional harvesting (Rock et al. 2012).

Figure 4.7.1. Ginseng is prized for its traditional medicinal uses that date back centuries, and is often poached in the park. Confiscated roots are shown on the right. Source: NPS Photo 2010.

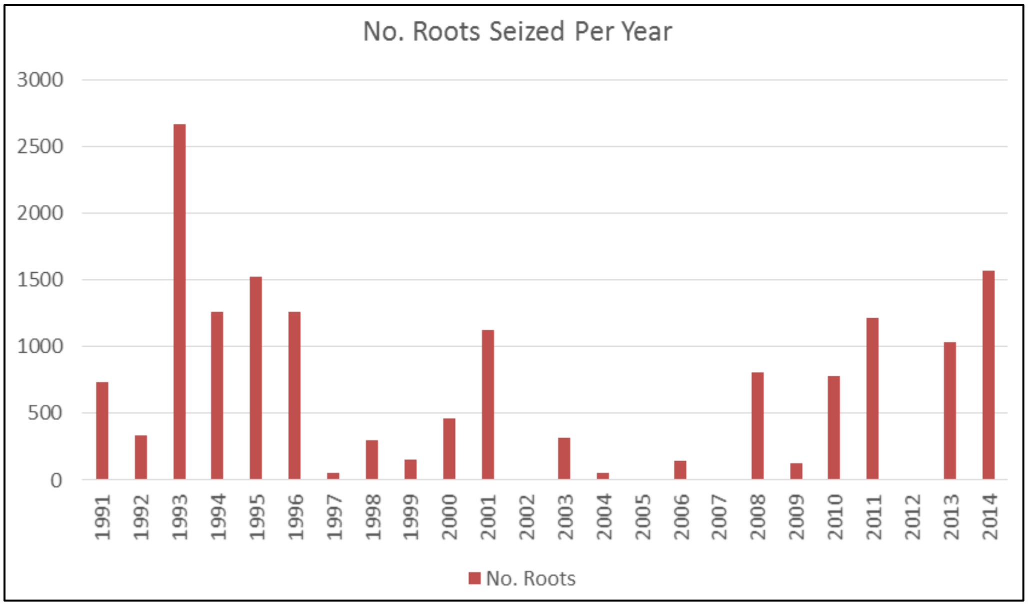

Figure 4.7.2. Between 1991 and 2014, park rangers seized over 15,000 ginseng roots. Source: GRSM Ginseng Roots Database 2014.

The park's large area, rough and varied terrain, and limited staff resources pose significant obstacles for monitoring populations and preventing illegal harvesting. Illegal harvesting is expected to continue, and recent research suggests that it will negatively affect the park's populations by reducing genetic diversity and reducing populations to the point where regeneration will not be sustainable. Park resource managers have been tracking illegal harvesting and recording locations, number of roots harvested, and other associated information in a database since 1991. Therefore, we assign a deteriorating trend that warrants significant concern with a high confidence level.

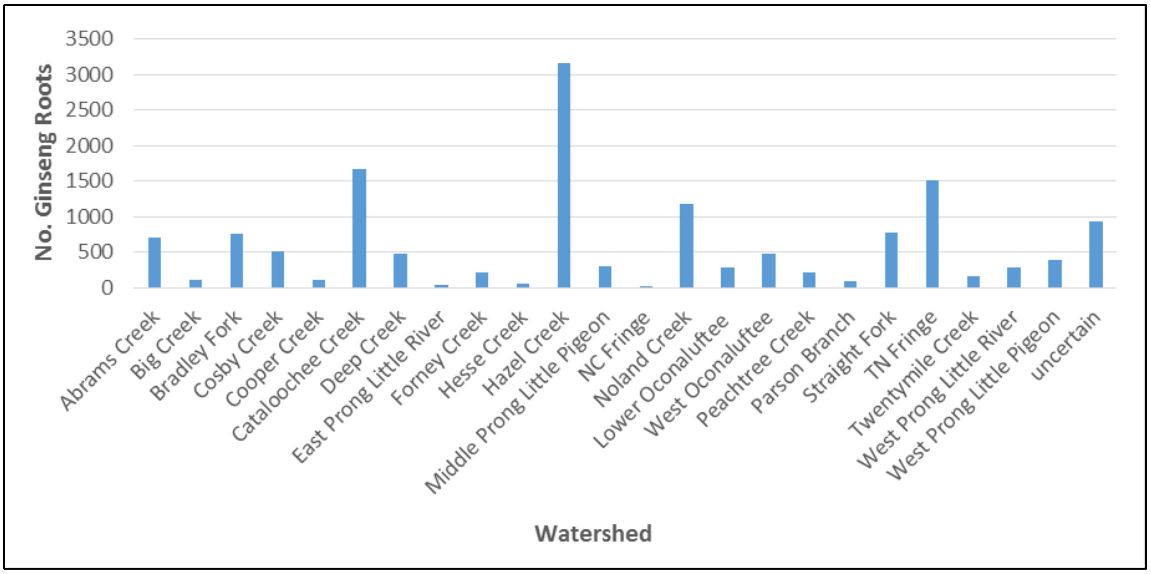

Figure 4.7.3. Number of ginseng roots illegally harvested per watershed since 1991. Source: GRSM Ginseng Roots Database 2014.

Ramps

Allium tricoccum, commonly called ramps in the southern Appalachians, grows in patches in rich, moist, deciduous forests and bottomlands (Fig. 4.7.4). Ramps send up smooth broad leaves in early spring and disappear by summer before the white flowers appear. The bulbs are prized for their sweet taste of spring onions and strong garlic aroma.

Harvesting roughly one grocery bag of ramps per person per day (1/2 peck) was legal in the park until spring 2002 when the park banned the practice. This was prompted not only by the increasing popularity of ramp festivals, and a greater awareness among culinary chefs, but also, the results of a 5-year experiment showed that harvesting as little as 25% of a population was detrimental (Rock et al. 2004).

In response to the continuing illegal harvesting problem, a ramp habitat model was developed for the purpose of predicting potential ramp habitat and identifying previously unknown ramp populations for future protection (Rock 2003). Additionally, previous research has found that there is a negative impact on ramp populations as the intensity of harvest increases. For example, when 5% of a ramp population was harvested, researchers projected that it would take 2.5 years for that population to recover. When 95% of a population was harvested, it would take approximately 148 years for the population to fully recover. It was concluded that a 10% harvest once every ten years would, on average, be a sustainable harvest for the species (Rock et al. 2004).

Figure 4.7.4. Ramp patch in Great Smoky Mountains National Park. Source: NPS Photo 2009.

The ramp's popularity is still extremely high. In the spring of both 2002 and 2003, 27 warnings were issued for the illegal harvesting of ramps. In 2005, 6,000 ramps were seized, and in 2013, 850 ramps were seized. While there are no updated data regarding the intensity of current illegal harvesting, it is highly likely that it is still occurring at unsustainable levels in the park (J. Rock, pers. comm. 2014). Therefore, we assign a deteriorating trend that warrants significant concern with a moderate confidence level.

Bloodroot

Bloodroot (*Sanguinaria canadensis*) is a spring ephemeral with delicate white flowers, and stems and rhizomes that exude a bright red fluid. The species grows in rich, mesic to somewhat dry deciduous forests and coves in fertile soils. It was traditionally used by Native Americans for body paint, dyes, and medicinal uses. Consumption is moderate compared to other herbs. It is currently used in toothpaste products and mouthwash, as it reportedly has anti-plaque qualities. The root is actively sought on the Chinese and Korean black market where it may bring prices between $15-30 per pound. Additionally, it is used in landscaping, gardening, and other ornamental purposes and is collected by wildcrafters for medicinal use (NatureServe 2014). Most bloodroot used for animal and human consumption is sold to Europe and Asian companies for processing (Greenfield et al. 2006). Although there is not a formal monitoring program concerning bloodroot populations in the park, resource managers know the species has been illegally harvested in the past. However, because there is no formal monitoring program, we have no datawith which to assign a current condition and trend to bloodroot.

Goldenseal

Goldenseal (*Hydrastis canadensis*) grows in dense isolated patches throughout eastern deciduous forests. It is popularly used for treating the common cold and other upper respiratory tract infections. Occasionally it is used for digestive tract disorders. Goldenseal patches are reportedly becoming more rare and smaller in size due to habitat loss and overharvesting. Additionally, the genetic diversity of these patches may be compromised due to the species clonal reproduction via rhizomes. However, little is known about the amount and distribution of genetic diversity within patches versus between patches (Torgerson and DeWald 2012). Goldenseal's value as a medicinal herb makes it a target for illegal harvesting in the park. However, because there is no formal monitoring program, we have no datawith which to assign a current condition and trend to this herb.

Fairywand

Fairywand (*Chamaelirium luteum*) is a slow-growing plant that grows in widely varying habitats including moist slopes, bottomlands, open calcareous wet meadows, dry woods, barrens, and bluffs. Flowering occurs from May to June, and harvesting usually occurs when the plants are about four to eight years old. The species was known as a "woman's herb" and used by native American Indians to prevent miscarriage, treat menstrual problems, and to improve fertility. In Western medicine it has been used to treat pregnancy problems and ovarian cysts. Demand for the plant has continued to rise slowly and steadily, and as of 2012, prices paid to growers and harvesters were $30-$50 per pound (Davis and Dressler 2012). Approximately 90% of specimens are collected from the wild, and as of 2000, estimated annual use in the medicinal industry ranges from 2,000-3,000 dry pounds per year. Fairywand's value as a medicinal herb makes it a target for illegal harvesting in the park. However, because there is no formal monitoring program, we have no datawith which to assign a current condition and trend to this herb.

Solomon's Seal

Solomon's seal (*Polygonatum biflorum*) occurs in partially-shady rich mesic sites and may grow up to 2.1 m (7 ft) tall on stout arching stems. The small bell-like whitish flowers grow from the leaf axil along and underneath the stems. The starchy rhizomes were formerly used by Native Americans as a potato-like food, and powdered roots were used in poultices to treat bruises, inflammation, and other ailments. The plant is also used as a laxative, sedative, and young shoots are reportedly edible. The species is also used as an ornamental in gardens. Solomon's seal's value as a medicinal herb makes it a target for illegal harvesting in the park; however, because there is no formal monitoring program, we have no datawith which to assign a current condition and trend to this herb.

Log Moss

The cool humid conditions in many locations across the park provide ideal growing conditions for several species of log moss. In the past, moss was used to chink cabins, stuff mattresses, and line cradles and coffins. Growing on logs, rocks, and the forest floor, these mosses have been illegally collected in the park for use in floral arrangements and personal gardens. Mosses are also used as soil cover for potted plants, hanging baskets, and terrariums, as well as in arts and crafts, and on green roofs. The value of log moss for floral arrangements and gardens makes it a target for illegal harvesting in the park. However, because there is no formal monitoring program for log moss, we have no datawith which to assign a current condition and trend.

Yellow Lady's Slipper

Yellow lady's slipper (*Cypripedium parviflorum* var. *pubescens*) is a long-lived deciduous perennial that grows in wetlands and wooded areas with rich humus and decaying leaf litter, rocky bluffs, and moist creek sides. This orchid's attractive yellow slipper-like flower makes it prone to poaching and over-collecting by plant collectors and traders. Although it has been poached in the park, there is no formal monitoring program for this species; therefore, we have no datawith which to assign a current condition and trend to this plant.

Downy Rattlesnake Plantain

Downy rattlesnake plantain (*Goodyera pubescens*) is one of the most common North American orchids. It grows in dry to moist uplands with acidic soil. The evergreen leaves, which grow close to the ground, have a prominent silvery mid-vein with a network of smaller silvery veins branching off. Native Americans formerly used it to treat snakebites, burns, and other ailments. This species has been poached for use in woodland wildflower plantings and terrariums. The only data available in the park are from 2005, when 14 pounds of downy rattlesnake plantain were seized. Downy rattlesnake plantain's value as a medicinal and collector's plant makes it a target for illegal harvesting in the park. However, because there is no formal monitoring program, we have no datawith which to assign a current condition and trend to this plant.

Confidence and Data Gaps

Determining a trend for exploitable plants is difficult due to uncertainties of the locations of plant populations and the intensity of exploitation directed towards any one species. However, based on popularity and other trends, the park has focused on ginseng and ramps to the extent that resources allow (Table 4.7.2). The park has been monitoring ginseng populations since the 1990s. Resource managers have been able to make solid conclusions about the decreasing trend of ginseng populations based on previous monitoring and research efforts, and overall popularity and commercial trends. A habitat model for ramps in the park has been developed to identify populations of the plant for future protection. Some research on ramps has also been conducted, but to date, there is not a monitoring protocol to assess trends in populations. There are no formal monitoring protocols for other exploitable plant species and respective population trends are unknown. Therefore, we assign a low level of confidence to this assessment. A major data gap exists regarding the condition and trend for the majority of exploitable plants in the park.

Sources of Expertise

- Janet Rock, Botanist, Great Smoky Mountains National Park

Summary Condition

Table 4.7.2. Summary condition and trend graphic for exploited plants in GRSM.

Resource	Indicator of Condition	Status and Trend	Rationale and Reference Conditions
Consumptive Use	Ginseng and ramps	⬇	The reference condition includes viable populations that will sustain themselves into the foreseeable future throughout their native habitats. It is inferred that this condition will require little to no illegal harvesting. Ginseng populations in the park are just barely regenerating enough to replace lost plants and cannot tolerate illegal harvesting. Ramp popularity remains extremely high and it is highly likely that illegal harvesting of ramps is occurring at unsustainable levels.
Consumptive Use	All other species	◌	The reference condition is viable populations that will sustain themselves into the foreseeable future throughout their native habitats. It is inferred that this condition will require little to no illegal harvesting. Because there is no formal monitoring program, we have no information on the current condition or trend for these plants.

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4.8. Landscape Dynamics

4.8.1 Overview

Relevance

Managers of protected lands such as national parks are increasingly faced with threats from human land use activities outside of park boundaries. Ironically, the presence of the park itself may be one factor attracting such activity near or adjacent to park lands (Gimmi et al. 2011), thus potentially impacting its protective role (Wade et al. 2011). By the end of the 20th century, national parks, forests, and other protected areas throughout the U.S. had shown a dramatic increase in the density of housing within a close proximity; an estimated 85,000 housing units were located within 1 km (0.62 mi) of national parks (Radeloff et al. 2010). In the southern Appalachians, pressure from rural housing development has increased in areas near parks, national forests, and other protected lands (Hansen et al. 2005), which has fragmented or altered the spatial distribution of forest ecosystems (SAMAB 1996, Turner et al. 2003) and reflects an ongoing trend in the U.S. Along the boundary of GRSM, an increase in housing and subsequent fragmentation of adjacent forested lands was noted as far back as the mid-20th century (Ambrose and Bratton 1990). Potential impacts to adjacent protected lands include declines in biodiversity, increased threat from exotic species, and loss of habitat quality and connectivity (Hansen et al. 2013), thus increasing the need for evaluating park resources in a regional landscape context (Wade et al. 2011).

While the formation of the park protected a significant amount of forested land from development and resource extraction, many areas within what would become the park were subject to a variety of land use changes, including human settlement and agriculture, commercial and selective logging, and wildfires (Pyle 1988). The impacts of such disturbances can linger for years, affecting vegetation structure, species composition, and soil conditions such as soil horizon recovery, soil acidity, and nutrient cycling (Foster et al. 2003).

This resource evaluation examines the general changes in Land Use-Land Cover (LULC) within and adjacent to GRSM in order to

- Quantify pattern and trends in LULC and potential forest fragmentation within and adjacent to GRSM from 1992-2011.
- Summarize historical disturbance and land use changes within GRSM and identify soils most impacted by human disturbance within GRSM prior to park establishment.

Data and Methods

LULC around GRSM was evaluated using the 30 x 30 m pixel resolution National Landcover Database (NLCD) for 1992 (Vogelman et al. 2001), 2001 (Homer et al. 2007), 2006 (Fry et al. 2011), and 2011 (Homer et al. 2015). As these layers were not specifically developed for pixel by pixel comparisons of change detection (Fry et al. 2011), and because of differences in classifications used among years, we simplified the classes in an effort to improve comparability. Modified classes are shown in Table 4.8.1 and include: 1) forest (deciduous, conifer, mixed), 2) non-forest vegetation (scrub, grass, pasture), 3) developed (low, moderate, and high levels), and 4) non-vegetation (barren, rock, water). We then compared the proportion of area occupied by each class within the park and a series of distance bands outside the boundary (1,000 m, 5,000 m) for the years 1992-2001, 2001-2006, and 2006-2011.

Table 4.8.1. Classification developed from NLCD to evaluate landscape conditions at GRSM.

NRCA Classification	NLCD Classification-1992	NLCD Classification-2001, 2006, 2011
Non-vegetation	Open water	Open water
	Bare rock, sand, clay	Bare rock, sand, clay
Developed-Low, Medium, High	–	Developed, open space
	Low-intensity residential	Developed, low-intensity
	High-intensity residential	Developed, medium-intensity
	High-intensity residential	High-intensity residential
	Commercial, industrial, transportation	Commercial, industrial, transportation
	Commercial, industrial, transportation	Commercial, industrial, transportation
Forest	Deciduous forest	Deciduous forest
	Evergreen forest	Evergreen forest
	Mixed forest	Mixed forest
	Woody wetlands	Woody wetlands
Non-forest Vegetation	Pasture, hay	Pasture, hay
	Row crops	Row crops
	Urban recreational grasses	Emergent herbaceous wetlands
	Emergent herbaceous wetlands	Emergent herbaceous wetlands

To evaluate potential fragmentation, we extracted all non-forest classes and applied a Euclidean distance function (ArcGIS 10.3.1 Spatial Analyst). This approach produces a raster image where individual pixel values reflect the distance from non-forested landcover. We then calculated the mean distance within the same bands around GRSM for each year. In evaluating landscape pattern, we combined all development into a single class along with other non-forest classes. While many areas classified as low-intensity development have a forest component, we were intending to focus on the changes in areas considered to be only forest. Although numerous landscape indices have been developed, they are often unitless values and their functional implications for ecology and management are often more assumed than actually validated in the field (Kupfer 2012). In selecting a simple distance-based measure, we intended to provide a more intuitive indicator of the encroachment of edge.

Landscape Patterns and Fragmentation

To evaluate potential fragmentation, we extracted all non-forest classes from each NLCD layer and applied a Euclidean distance function (ArcGIS 10.3.1 Spatial Analyst) which produces a raster layer where each pixel reflects the distance from non-forest landcover. We then calculated the mean distance within the same distance bands around GRSM for each year.

Historic Land Use and Disturbance of Soils

Historic land use information was derived from the work of Charlotte Pyle (1985, 1988), which examined numerous archival maps, reports, and photographs in order to compile a vegetation disturbance history for GRSM prior to park establishment. A GIS layer adapted from this work was provided by GRSM and contained a vector data layer representing the following disturbance categories prior to 1934.

- Corporate logging (“heavy cut”): Large tracts of land with mechanized harvesting occurring particularly after 1900.
- Concentrated settlement: Areas of land intensely cleared for home sites, agriculture, pasture, and other related land uses, including roads and trails. Generally distributed in lower elevations near the perimeter of the park.
- Diffuse disturbances (“light and selective cut”): Mixed land cover consisting of forested areas with smaller more intense land uses (light or selective logging, grazing, and fire) interspersed.
- Undisturbed: Areas exhibiting little or no human disturbance (though natural disturbances are present) and in some cases containing areas of old-growth type forest conditions, although it is unclear how much of this land is truly undisturbed (Pyle 1988).

In addition, we considered fire history and slope, with condition based upon the level and expected duration of impacts to soils. Human settlement or heavy logging can have long-lasting impacts on the composition and structure of both the recovering forests, and in areas where these practices occurred on steeper slopes, and/or were followed by wildfire. These areas were considered to have the most severe and longest lasting soil impacts (Pyle 1988). Specific assessment classes are described in Table 4.8.2 below.

Table 4.8.2. Historic land use disturbance and fire history, used to develop a relative ranking of potential impacts to soils within GRSM.

Relative Impact	Description
High	Areas of either settlement or heavy logging followed by wildfire and/or occurring on steeper slopes (>30%).
Moderate	Areas of either settlement or heavy logging not followed by wildfire and occurring on lower slopes. Areas of light or selective logging followed by wildfire and/or occurring on steeper slopes. Areas of wildfire occurring on steep slopes.
Light	Areas experiencing only light/selective cut, or prescribed fire or wildfire only.
None	Areas with no reported history of settlement, logging or fire.

Reference Conditions

The ideal condition for any natural landscape would be zero loss of forest vegetation structure or residual impacts to soils. Given the long and varied history of disturbance at GRSM, areas having absolutely no disturbance are probably rare, as some level of forest loss due to natural factors, disease/infestations, or just natural turnover is inevitable. Since the NLCD datasets are the most readily available information for evaluating changes in land-use and fragmentation, we used conditions in 1992 as a starting condition and examined trends since that time.

Evaluating conditions related to historic soil disturbance are somewhat less clear, as the actual disturbances occurred many years ago, and thus detailed knowledge of not only the impacts but their duration is lacking. Subsequently we based condition assessments on the relative level of disturbance and its potential duration on the landscape. While the effects of even relatively light disturbance (i.e., selective harvest) can linger for decades (Latty et al. 2004), the disturbances that alter physical properties of soil (structure, pore space, infiltration capacity, etc.) create conditions beyond the natural range of variation, from which recovery is the most difficult (Grigal 2000). Human settlement (and subsequent agricultural practices) and heavy logging represent the most severe physical disturbances to soils (Pyle 1988), and can result in long-term alterations of species composition, soil chemistry, and overall forest productivity (Flinn et al. 2007). In addition, soil properties prior to disturbance will also impact the duration of impact and recovery, and thus we considered relative level of vulnerability to landslides and weathering (and hence stream acidification and pyrite exposure) presented in the most recent soil survey for GRSM (Table 4.8.3).

Table 4.8.3. Abundance and relative level of risk from landslide, pyrite exposure, and stream acidification for the major soil series in GRSM. Source: USDA NRCS 2009.

Soil Series	Percent of Total Park Area per Series	Landslide Risk	Relative Risk Level (USDA) Pyrite Exposure	Stream Acidification
Mesic Soft Metasandstone: Soco-Stecoah	46.64	Low	Low	Moderate
Mesic Hard Metasandstone: Ditney-Unicoi	16.33	Moderate	Moderate	Moderate
Frigid Hard Sandstone: Breakneck Pullback	9.65	Moderate	Moderate	Moderate
Frigid Soft Sandstone: Oconaluftee	7.93	Low	Low	Moderate
Mesic Siltstone and Phyllite: Junaluska-Tsali	7.40	Moderate	Low	Moderate
Frigid Anakeesta Slate: Luftee-Anakeesta	2.96	High	High	High
Large Basins of Colluvium: Spivey Santeelah	2.79	None	None	None
Mesic Anakeesta Slate: Cataska-Sylco	1.91	High	High	High
Mesic Gneiss: Evard-Cowee	1.38	Low	None	None

Table 4.8.3 (continued). Abundance and relative level of risk from landslide, pyrite exposure, and stream acidification for the major soil series in GRSM. Source: USDA NRCS 2009.

Soil Series	Percent of Total Park Area per Series	Landslide Risk	Relative Risk Level (USDA) Pyrite Exposure	Stream Acidification
Mesic Copperhill Sandstone/Slate Rolling Hill Phase: Junaluska-Brasstown-Soco	1.02	Low	Low	Moderate
Cades Cove: Lonon-Cades	0.91	None	None	None
Mesic Wehutty Schist: Cataska-Sylco	0.76	Moderate	Moderate	Moderate
Floddplains and Terraces: Rosman-Reddies-Dellwood	0.18	None	None	None
Mesic Interbedded Mica Schist and Mica Metasandstone: Lauada-Fannin	0.08	Moderate	Low	Low
Frigid Gneiss: Wayah	0.06	Low	None	None

Current Conditions

Landscape Patterns and Fragmentation

As expected, LULC conditions in the park itself changed much less than in adjacent areas, with all classes showing less than 1% change for all years (Table 4.8.4). Beyond the boundaries of the park the most dramatic changes occurred between 1992 and 2001, with the amount of forested land decreasing in each location, and development increasing (Table 4.8.5).

Table 4.8.4. Changes in landcover represented as percent of total area within GRSM and adjacent areas between 1992 and 2011.

Year	Distance	Forest	Development	Non-Vegetation	Non-Forest
1992-2001	GRSM	-0.92	0.66	0.02	0.24
	1-km	-10.31	5.90	2.63	0.79
	5-km	-9.22	5.96	0.40	2.86
2001-2006	GRSM	-0.12	0.00	0.00	0.07
	1-km	-0.73	0.10	0.06	0.54
	5-km	-0.52	0.08	0.00	0.39
2006-2011	GRSM	-0.02	0.00	0.00	0.07
	1-km	-0.27	0.38	-0.04	-0.03
	5-km	-0.27	0.33	0.02	-0.03

Forest changes within the park have been the result of factors such as natural disturbances or insect infestations like hemlock woolly adelgid. However, the coarse scale of the NLCD layers makes differentiating specific impacts difficult, as there is some mixing of deciduous and evergreen forest classes within the park. In looking at changes within NLCD forest classes (deciduous, evergreen, and mixed), both deciduous and mixed classes showed some change while the evergreen class showed a very slight increase (0.03%) (Table 4.8.5). A similar pattern of overall forest loss was reflected in the

Landsat TM-based estimates of global forest loss produced by Hansen et al. (2013), although this product predicted higher levels of loss within and outside of the park (Table 4.8.5).

Table 4.8.5. Estimates of forest loss occurring between 2000 and 2014 from Landsat image analyses by Hansen et al. (2013).

Area	Global Forest Change 2000-2014	NLCD 2001-2011			
		Deciduous	**Evergreen**	**Mixed**	**Total NLCD Forest**
GRSM	-0.47	-0.15	0.03	-0.03	-0.21
1-km	-1.44	-0.81	-0.11	-0.12	-1.04
5-km	1.94	-0.74	-0.08	-0.11	-0.93

Decadal analyses of MODIS satellite imagery show numerous areas of “evergreen decline” of some level within GRSM. These images were based upon the widely used Normalized Difference Vegetation Index (NDVI), which provides a means of estimating above-ground vegetation biomass or productivity (Leyequien et al. 2007). In leaf-on conditions, forest overstory biomass would be the predominant characteristic of this value, with younger, more even-aged stands producing higher NDVI values compared to more complex canopies containing gaps (Lillesand et al. 2004). In leaf-off conditions, only evergreen overstory and understory vegetation will contain chlorophyll, and thus produce the highest NDVI values. According to Norman et al. (2013), the analysis of hemlock loss in a portion of Great Smoky Mountains National Park shows a decline in NDVI values beginning in 2006-2007, corresponding to the spread of the hemlock woolly adelgid within the region.

The average distance to the nearest edge followed similar patterns as the general landcover changes, with the mean distance to the nearest non-forest edge declining the most from 1992-2001, but successive declines occurring each year thereafter (Table 4.8.6). Within the park, much of the reduced distance-to-edge is likely associated with loss of hemlock forests. This has fragmented forests and thus reduced the average distance to human impacted forest or non-forest by half between 1992 and 2001 (Table 4.8.6).

Table 4.8.6. Average and maximum distance to edge habitats within GRSM and adjacent areas between 1992 and 2011. Minimum values were zero for all years and locations, and were omitted from the table.

Year	Location	Mean Distance	Max Distance	SD
1992	GRSM	1,647.59	7,368.04	1,357.60
	1-km	354.66	2,591.14	391.56
	5-km	383.78	3,084.02	401.74
2001	GRSM	1,267.02	5,209.30	1,005.46
	1-km	207.83	2,274.07	282.97
	5-km	222.69	1,701.56	252.71
2006	GRSM	1,231.65	5,197.02	993.88

Table 4.8.6 (continued). Average and maximum distance to edge habitats within GRSM and adjacent areas between 1992 and 2011. Minimum values were zero for all years and locations, and were omitted from the table.

Year	Location	Mean Distance	Max Distance	SD
2006 (continued)	1-km	200.99	2,184.03	273.25
	5-km	213.06	1,698.38	244.29
2011	GRSM	1,125.52	4,937.26	926.64
	1-km	197.61	2,177.02	271.66
	5-km	210.99	1,909.66	249.17

Historic Land Use and Disturbance of Soils

The majority of park soils received at least a light level of historic disturbance and almost 40% of the park received moderate or high levels (Table 4.8.7, Fig. 4.8.1). In general, the area impacted within each soil class was proportional to the total park area occupied by that soil type, with the majority of the impacts occurring within mesic soft metasandstone and hard metasandstone soils (Table 4.8.8).

Table 4.8.7. Proportion of total park area receiving varying levels of historic soil disturbance.

Impact	Percent of Park Area
High	16.58
Moderate	22.72
Light	38.52
None	22.19

While much of the park has experienced some level of historic soil disturbance, the area has also been protected and hence recovering for decades. Subsequently, many areas within the park may well have largely recovered, although without specific field measures there is no way to evaluate the duration of impacts. Some studies have suggested that post-agricultural soils can recover to resemble lesser-disturbed forest sites within 100 years or less (Flinn and Marks 2007), while others imply that impacts to soils can last much longer (McLauchlan 2006).

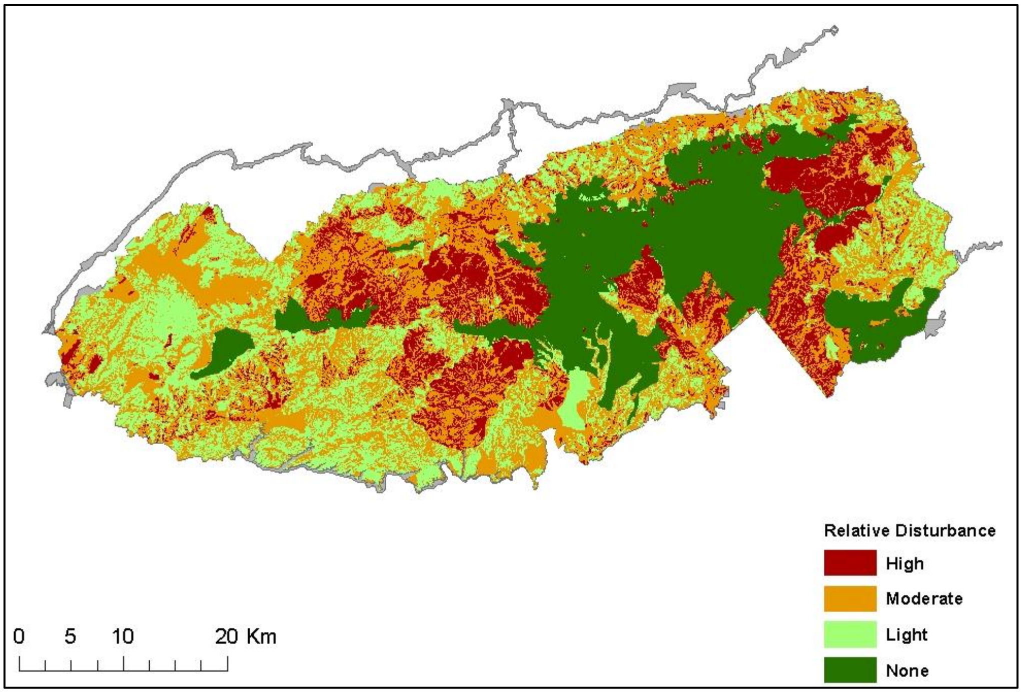

Figure 4.8.1. Distribution of potentially impacted soils based upon historical land use, fire history, and slope within GRSM. Source: Adapted from Pyle 1988.

Table 4.8.8. Proportion of total park area occupied by each soil type and level of historic impact.

Soil Series	Percent of Park Area	Percent of Park Area by Impact Level			
		High	Moderate	Light	None
Mesic Soft Metasandstone: Soco-Stecoah	46.64	6.50	20.08	14.21	5.84
Mesic Hard Metasandstone: Ditney-Unicoi	16.33	3.86	5.64	3.33	3.50
Frigid Hard Sandstone: Breakneck Pullback	9.65	2.14	1.40	1.04	5.07
Frigid Soft Sandstone: Oconaluftee	7.93	1.76	1.51	0.61	4.06
Mesic Siltstone And Phyllite: Junaluska-Tsali	7.40	0.88	4.04	2.32	0.15
Frigid Anakeesta Slate: Luftee-Anakeesta	2.96	0.18	0.05	0.01	2.73
Large Basins of Colluvium: Spivey Santeelah	2.79	0.27	2.02	0.29	0.21
Mesic Anakeesta Slate: Cataska-Sylco	1.91	0.51	0.9	0.45	0.05
Mesic Gneiss: Evard-Cowee	1.38	0.37	0.44	0.05	0.52
Mesic Copperhill Sandstone/Slate Rolling Hill Phase: Junaluska-Brasstown-Soco	1.02	0.07	0.38	0.56	0.00
Cades Cove: Lonon-Cades	0.91	0.01	0.81	0.09	0.00
Mesic Wehutty Schist: Cataska-Sylco	0.76	0.01	0.59	0.17	0.00
Floddplains and Terraces: Rosman-Reddies-Dellwood	0.18	0.01	0.17	0.00	0.00
Mesic Interbedded Mica Schist and Mica Metasandstone: Lauada-Fannin	0.08	0.01	0.05	0.03	0.00
Frigid Gneiss: Wayah	0.06	0.00	0.00	0.00	0.06

Confidence & Data Gaps

Since the NLCD products were developed for the entire U.S. and not intended to make pixel-wise comparisons, specific estimates for individual locations are likely to over or underestimate the actual degree of change within any given LULC class. However, more general and regional trends can be highly informative, particularly if these values are supported by other sources of information. All datasets evaluated here clearly indicate that the amount human land use has increased immediately adjacent to the park, and confidence in this trend is fairly high (Table 4.8.9). What is less clear are the specific impacts these landcover trends have had on park resources. Development of higher resolution measures of LULC change and collection of field data designed to specifically monitor potential fragmentation impacts would allow much more specific assessments of condition. As for evaluating historic soil disturbance, current condition is a best guess based mainly upon the time since disturbance and the protected status of the resources since the 1930s. We have therefore assigned a score of good but with low confidence (Table 4.8.9).

Summary Condition

Table 4.8.9. Summary condition and trend graphic for landscape patterns/fragmentation, and soil disturbance in GRSM.

Resource	Indicator	Status and Trend	Rationale and Reference Conditions
Landscape Dynamics	Landscape patterns and fragmentation (trends from 1992-2011)	⇩	Trends in all indicators show a loss of forest and an increase in fragmentation adjacent to GRSM. LULC changes inside the park may have stabilized, although the potential impacts of adjacent LULC changes in nearby areas are of concern.
Landscape Dynamics	Historic soil disturbance (relative severity and potential duration of impacts)	⇔	While some areas were heavily impacted, historic impacts occurred prior to park establishment and many areas are assumed to have recovered. Trend is assumed given the protected status of these areas now.

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4.9. Extreme Disturbance Events – Wind and Wind Throw

4.9.1 Overview

Relevance

Extreme climatic disturbance events in the southern Appalachian Mountains commonly occur in the form of mountain wave winds, tornadoes, and derechos. Mountain wave winds are hurricane velocity, mountain-induced winds that are extremely isolated and generally occur in a narrow zone along the foothills of the Tennessee side of the park. These cool-season winds can occur without precipitation and have velocities in excess of 160 kph (Gaffin 2009, Langdon et al. 2011). National Weather Service (NWS) and National Park Service scientists have only recently recognized the presence of mountain wave winds because weather stations with wind speed instruments were not installed in the park until the mid-1990s. Since these winds are very isolated, they rarely show up in data from the nearby weather station at the local airport (McGhee-Tyson, Knoxville). Mountain wave wind events have been increasing in recent decades (Kemp 2010, Langdon et al. 2011), perhaps due to gradient winds associated with low pressure centers (Langdon et al. 2011).

Mountain wave winds traverse the park from the south, and then rush down the lee mountain faces on the Tennessee side (Langdon et al. 2011). Extensive tree blowdowns and property damage has occurred in these short events, which only last a few hours (Kemp 2010, Gaffin 2011). Analyses by the NWS indicate possible changes in intense low pressure cell tracking, which appear to be more to the north than in past decades, which has resulted in more extreme wind events on the Tennessee side of GRSM (Gaffin 2009, Gaffin 2011).

Much more rare and infrequent in GRSM are the occurrence of tornadoes and derechos. On April 27, 2011, the park experienced a super tornado outbreak, with an EF-4 tornado passing through the northwest corner of the park (Fig. 4.9.1). This was followed by a major derecho convective event on July 5, 2012. Each of these events resulted in significant blowdowns and tree damage, and the 2012 event killed two people and injured seven in the park (Schneider 2010, Gaffin and Hotz 2011, Gaffin 2012). This illustrates the significant implications to visitor safety and ecosystem disturbance. The mountainous terrain of the southern Appalachians generally acts as a barrier to slow down winds, preventing these events from occurring in or near the park. However, analyses by the NWS indicate that the complex conFig.uration of southeast-to-northwest oriented mountains and valleys surrounding GRSM was largely responsible for the evolution of significant convection, and the resulting damaging winds during those catastrophic events in April 2011 and July 2012 (Schneider 2010, Gaffin and Hotz 2011, Gaffin 2012).

Figure 4.9.1. Aerial and ground view of downed trees resulting from an EF-4 tornado that tracked through GRSM on April 27, 2011. Source: NPS 2011, NPS 2015.

Data and Methods

No raw wind data sets were available for this assessment; however, information was extracted from the NWS (Gaffin 2009, Schneider 2010, Gaffin 2011, Gaffin and Hotz 2011, Gaffin 2012) and other reports (Kemp 2010, Langdon et al. 2011, Peterson and Godfrey 2012) provided by J. Renfro (NPS), within which GRSM wind monitor data have been previously assessed (Fig. 4.9.2). These data represent isolated events and thus are not sufficient to examine annual values or assess long-term trends; however, they do allude to recent trends within the park, and that information will be provided herein.

Figure 4.9.2. Wind monitor at Clingmans Dome in Great Smoky Mountains National Park. Source: J. Renfro, NPS.

Reference Conditions

Natural disturbance is a part of every ecosystem on Earth. Because of this, and its inherent spatial and temporal variability, there are no specific reference conditions for extreme disturbance events.

Conditions and Trends

Wind Speed and Direction

Three of the air quality monitoring stations at GRSM also monitor wind speed and direction. Figures 4.9.3, 4.9.4, and 4.9.5 show a 16-point wind rose depicting cumulative wind speed and direction over the period of 2004-2013 for Cades Cove, Look Rock, and Cove Mountain, respectively. For the ridgetop sites at Cove Mountain and Look Rock throughout that period, winds were calm (<1 meters per second – m/s) only 5-6% of the time, compared to Cades Cove, a valley site, where winds were calm 24% of the time. There were no hourly average wind speeds greater than 9.9 m/s at Cades Cove, unlike Cove Mountain where nearly 8% of the time, wind speeds were >9.9 m/s. Predominant directions of wind origin for Cades Cove are from the W during the daytime and ENE-ESE during nighttime hours. Predominant directions of wind origin for Look Rock are from the SSE during the nighttime hours, and WNW-NNW during the daytime hours. Predominant directions of wind origin for Cove Mountain are from the SSE-WSW and speeds are also greatest from that direction. Calm winds for Cove Mountain are from the N, and are from the E for Cades Cove.

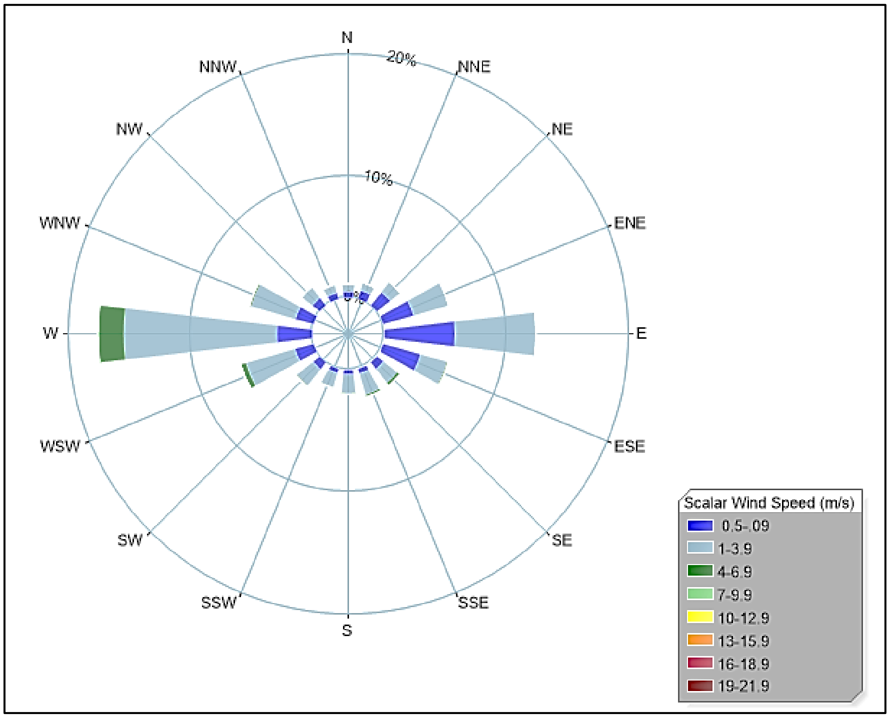

Figure 4.9.3. Wind rose for Cades Cove, TN for Jan. 2004 to Dec. 2013. Colors represent wind speed, and lengths of colored bars represent proportion of wind in a given direction. Source: J. Renfro, NPS.

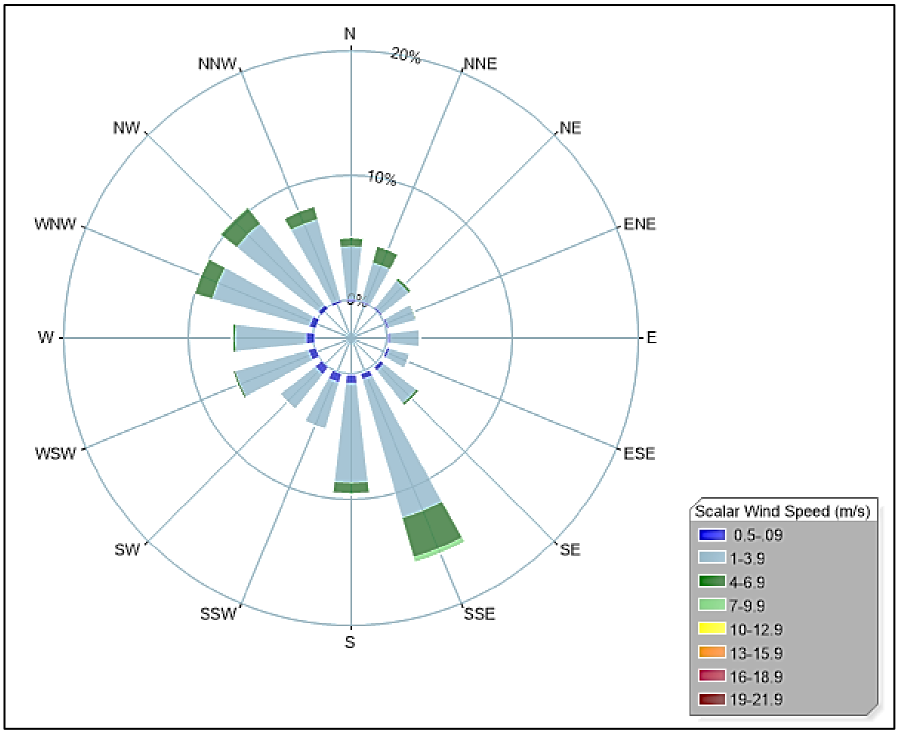

Figure 4.9.4. Wind rose for Look Rock, TN for Jan. 2004 to Dec. 2013. Colors represent wind speed, and lengths of colored bars represent proportion of wind in a given direction. Source: J. Renfro, NPS.

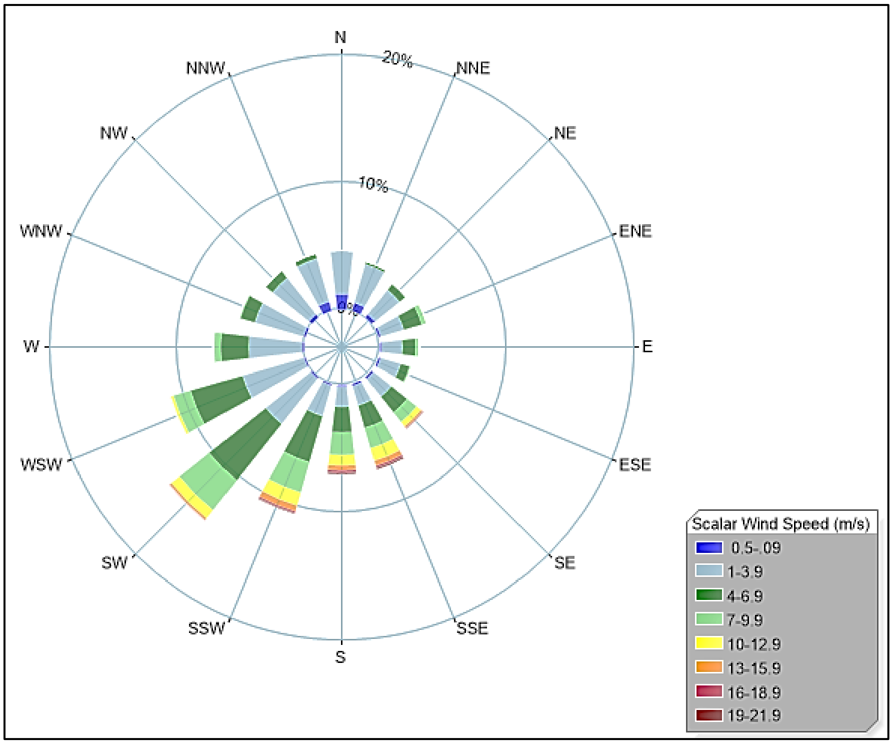

Figure 4.9.5. Wind rose for Cove Mountain, TN for Jan. 2004 to Dec. 2013. Colors represent wind speed, and lengths of colored bars represent proportion of wind in a given direction. Source: J. Renfro, NPS.

Two Remote Automatic Weather Stations (RAWS) at GRSM monitor wind speed and direction. Figs. 4.9.6 and 4.9.7 show 16-point wind roses for Indian Grave, TN and Cherokee, NC, respectively, depicting cumulative wind speed and direction from January 2004 to December 2013. Throughout that period, winds were calm (<1.3 m/s) approximately half the time (50 and 55.1%, respectively) for the two sites, and predominant directions of wind origin were SW for Indian Grave, and were W and N for Cherokee, NC. Speeds were typically below 5.8 m/s, and only occasionally exceeded that threshold.

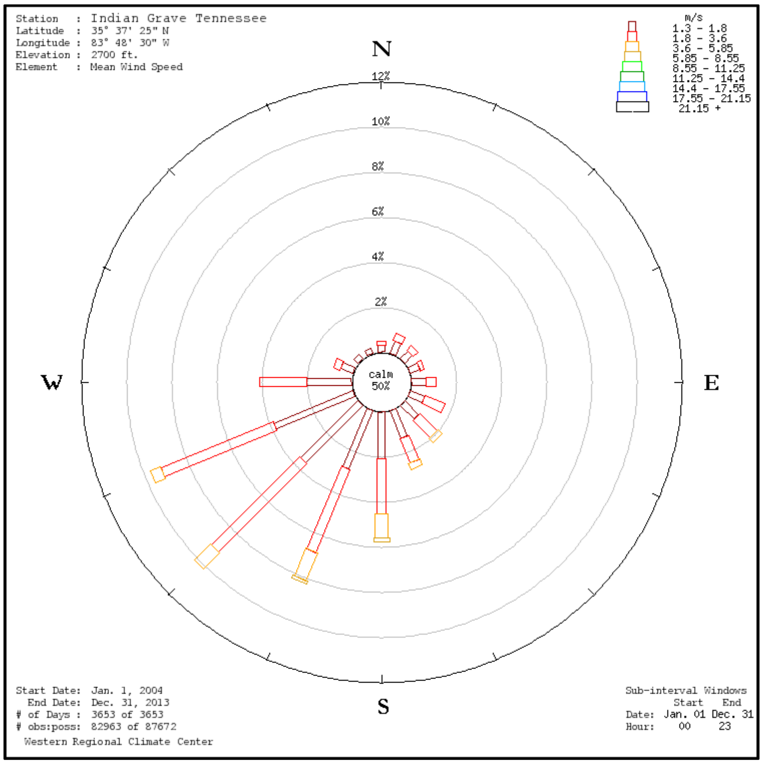

Figure 4.9.6. Wind rose for Indian Grave, TN for Jan. 2004 to Dec. 2013. Colors represent wind speed, and lengths of colored bars represent proportion of wind in a given direction. Source: J. Renfro, NPS.

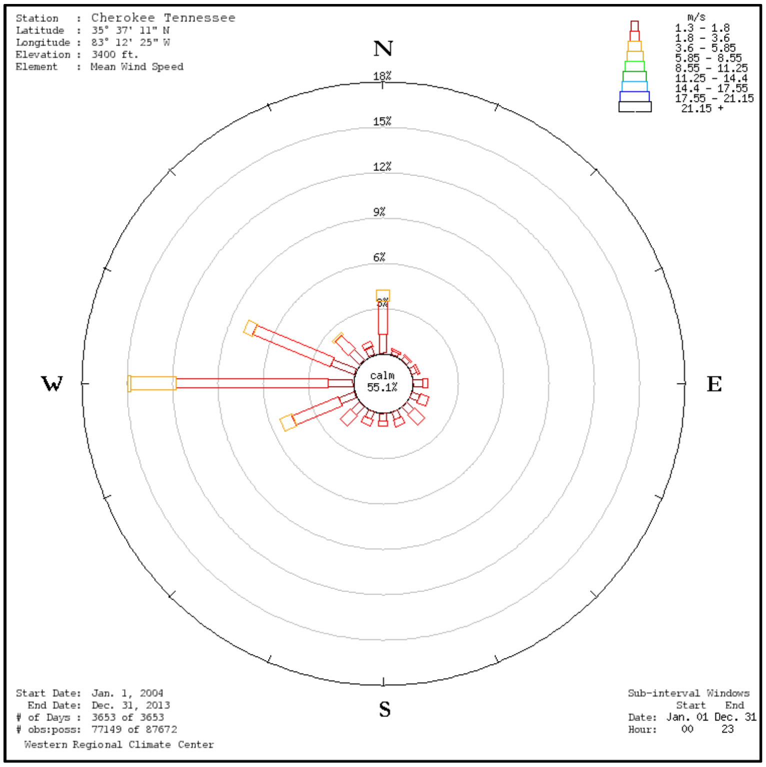

Figure 4.9.7. Wind rose for Cherokee, NC for Jan. 2004 to Dec. 2013. Colors represent wind speed, and lengths of colored bars represent proportion of wind in a given direction. Source: J. Renfro, NPS.

Cool Season Wind Events – Mountain Wave Winds

Mountain wave wind events have been documented several times over the past decade in GRSM. Strong wind gusts from mountain waves typically only affect a narrow zone in the foothills where the bottom of the wave intersects the ground. During a mountain wave event, many people outside of the foothills will not experience much wind, while those who live in the narrow foothills corridor where waves intersect the ground can sometimes experience hurricane-force wind gusts (i.e., >118 kph). Cove Mountain routinely experiences strong winds due to its favorable terrain location (Gaffin 2009, Gaffin 2011) (Fig. 4.9.8), which refers to its steep slopes on the leeward side of the mountain - the side opposite the direction from which the wind comes (Gaffin 2009, Gaffin 2011). Mountain waves can also occur along the eastern foothills when wind flow is from the northwest. These wind events occur more frequently on the eastern side of the mountains, due to the frequency of northwest versus southeast winds; however, it is likely that high winds from mountain waves are stronger on the western side because of the steeper slopes that quickly descend into the Great Tennessee Valley (Gaffin 2009, Gaffin 2011). Due to lack of observations in and near the mountains, this theory cannot be proven, but most documented mountain wave wind events affecting GRSM have occurred on the western side (Table 4.9.1).

Figure 4.9.8. Clouds of a mountain wave wind event over Great Smoky Mountains National Park, and the significant tree damage resulting from such events. Source: J. Renfro, NPS.

Table 4.9.1. Some recent documented extreme wind events in GRSM, 2004-2013.

Date	Event	Location	Max Speed (kph)	Comments	Data Source
December 22-23, 2004	Mountain wave	Cove Mountain	177	Widespread reports of wind damage (i.e., large trees and power lines down).	Kemp 2010; Gaffin 2009
October 17, 2006	Mountain wave	Cove Mountain	171	Winds knocked down so many trees that nearly every road in the national park was closed for a few days.	Kemp 2010; Gaffin 2009
February 24-25, 2007	Mountain wave	Cove Mountain	155	Numerous trees and power lines down; almost all roads in these areas closed. Several homes were damaged and a few barns were destroyed.	Kemp 2010; Gaffin 2009
March 1, 2007	Mountain wave	Cove Mountain	151	Widespread reports of wind damage (i.e., large trees and power lines down).	Kemp 2010; Gaffin 2009
December 24, 2009	Mountain wave	Cove Mountain	163	Winds flattened the historic Caughron barn in Cades Cove, and destroyed the greenhouse at the park's Twin Creeks Science Center.	Kemp 2010
April 27-28, 2011	Super tornado outbreak	Blount Co, TN	140	Numerous tornadic supercells in the SE, including one EF-4 tornado that hit the western portion of GRSM.	Gaffin 2012; Peterson and Godfrey 2012
July 5, 2012	Derecho	Laurel Creek Valley	119	Significant blowdown of trees killed two people and injured seven within GRSM.	Gaffin 2012; Peterson and Godfrey 2012

A 12-year climatology of high wind events induced by mountain waves at Cove Mountain was constructed by Gaffin (2009). This climatology revealed that these events occurred primarily at night during the cool months of November and March (Fig. 4.9.9). Composite maps of mountain-wave events that produced warning-level and advisory-level winds, revealed that an axis of stronger 850-

hPa (hecto Pascals) winds typically were located west of the mountains, away from the foothills (Gaffin 2009). This finding further suggests that low-level divergence normally contributes to the intensity of mountain wave wind events in the western foothills of the southern Appalachian Mountains (Gaffin 2009).

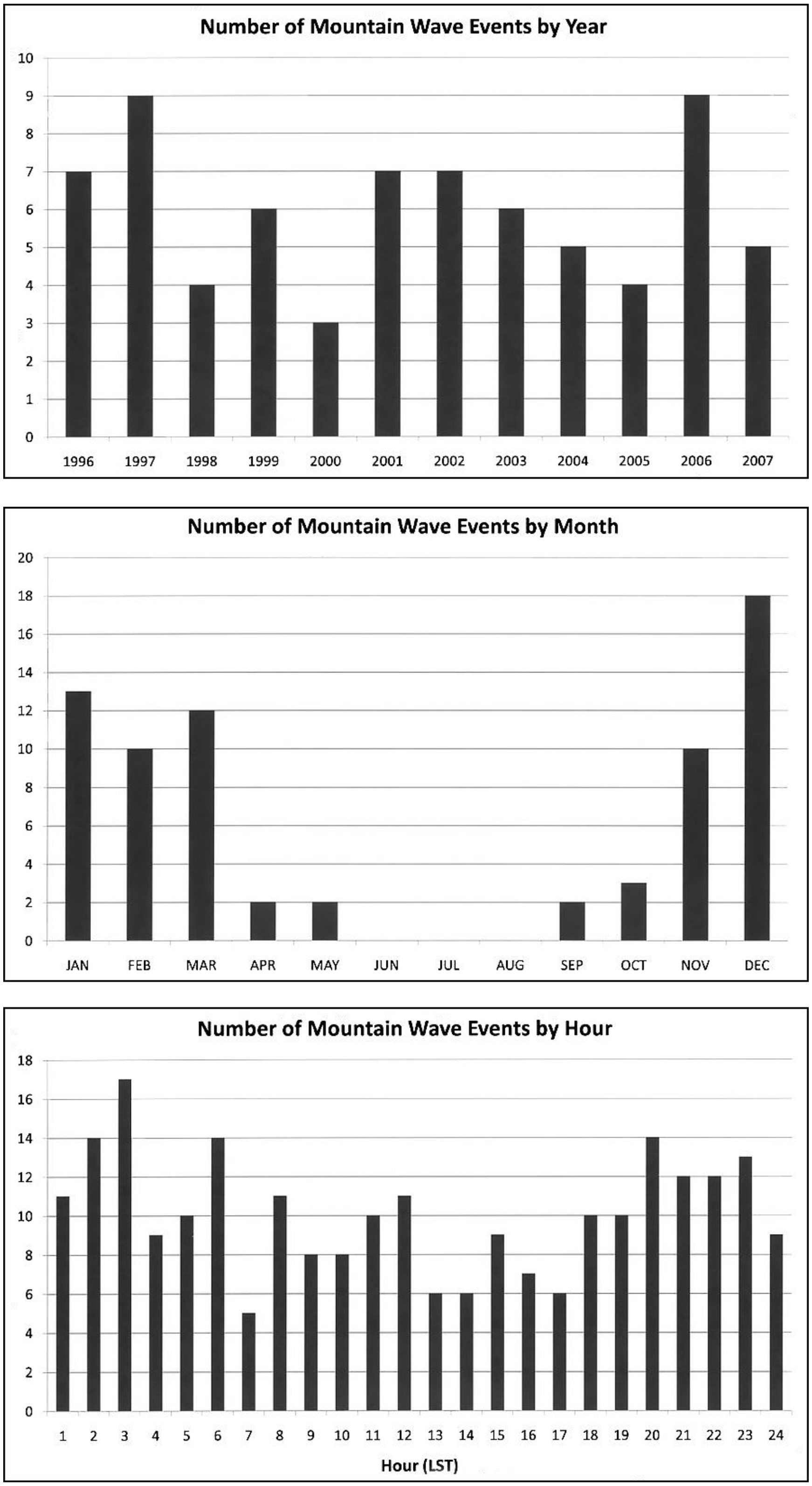

Figure 4.9.9. Number of high wind events induced by mountain waves at Cove Mountain by (top) year, (middle) month, and (bottom) hour. Source: Gaffin 2009.

Warm-season Wind Events – Tornadoes and Derechos

During the Super Tornado Outbreak of April 27-28, 2011, numerous tornadoes were produced across the southern Appalachian region, mainly around the openings of southeast- to northwest-oriented valleys of eastern Tennessee. A strong low pressure system moving northeastward brought southeasterly winds into the region, which accelerated through these valleys due to constricted flow, and may have encouraged tornadogenesis within the supercells (Schneider 2010, Gaffin and Hotz 2011, Gaffin 2012). As part of this outbreak, an EF-4 tornado cut through the northwest corner of the park on April 27, 2011 leaving a 27-km long (17 mi) swath of tree blowdown, which resulted in the closing of 43 km (27 mi) of trails (NPS 2011) (Fig. 4.9.10).

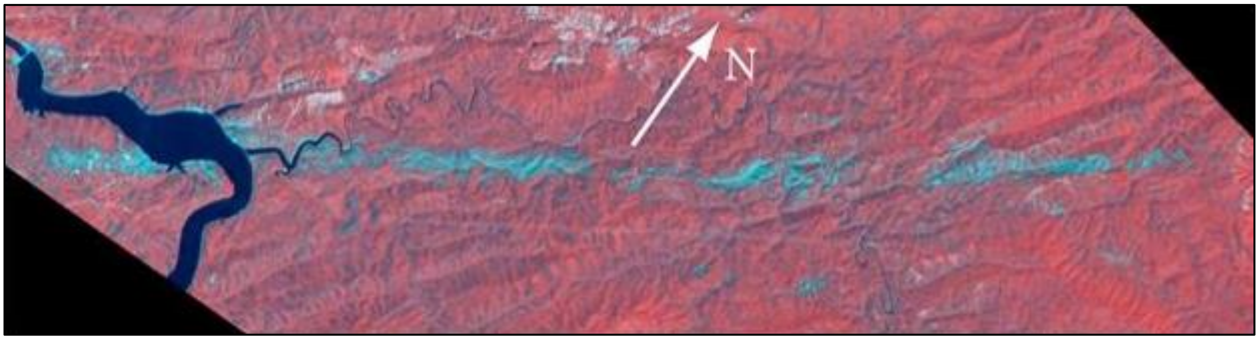

Figure 4.9.10. False-color satellite image of EF-4 tornado track in GRSM (SPOT, May 29, 2011). Vegetation appears red, water dark blue, and tornado track light blue. Source: Peterson and Godfrey 2012.

During the derecho event of July 5, 2012, terrain played a different, yet equally complex, role in storm severity. While a large upper-level high was lingering over the central U.S. producing unusually high temperatures, a derecho moved from the mid-Atlantic region southwestward across the Great Tennessee Valley. High temperatures intensified the convective system as it moved inland, eventually heading southwestward down the northeast- to southwest-oriented Great Tennessee Valley. The strong northeasterly winds likely flowed unimpeded or possibly even accelerated through these valleys due to constricted flow, and also because there are no mountain barriers to slow them down. The National Weather Service (Schneider 2010, Gaffin and Hotz 2011, Gaffin 2012) stated that tree damage from this event was so significant possibly because the convective winds came from an unusual direction (Fig. 4.9.11). Since roots are strongest in the direction of prevailing winds (from the southwest in the southern Appalachian region), trees could have been more vulnerable to a blowdown created by strong northeasterly winds (Schneider 2010, Gaffin and Hotz 2011, Gaffin 2012).

Figure 4.9.11. Clouds of the July 5, 2012 derecho event over Great Smoky Mountains National Park and the significant tree blowdown resulting from such event. Source: J. Renfro, NPS.

Due to potential loss of human life from these unexpected wind events throughout the year, extreme disturbance events (i.e., wind and wind throw) warrant significant concern to park managers.

Confidence and Data Gaps

Monitoring of wind direction and speed in GRSM began in 1993 (at Cades Cove, Look Rock, and Cove Mountain) as part of the NPS air quality monitoring network. Continuous wind monitoring has taken place since 1993 and is currently measured at five locations within the park. Data from these stations have provided a reliable, long-term record utilized by park scientists and air quality specialists, and in NWS extreme climatic event reporting. Due to the infrequent nature of these events, and their inherent natural occurrence, the current assessment of both condition and trend of extreme disturbance events (i.e., wind and wind throw) is not applicable (Table 4.9.2), nor can these data be used to predict future trends. Rather, forecasting should rely on synoptic-scale climatology data, intimate knowledge of the terrain, and high level of awareness of storm-specific environments.

Sources of Expertise

- David Gaffin, Senior Forecaster, National Weather Service Forecast Office
- Jim Renfro, Air Quality Program Manager, Great Smoky Mountains National Park

Summary Condition

Table 4.9.2. Summary condition and trend graphic for extreme disturbance events (wind and wind throw) in GRSM.

Resource	Indicator	Status and Trend	Rationale and Reference Conditions
Extreme Disturbance Events	Wind and wind throw	◌	Potential loss of human life warrants significant concern. Due to infrequent nature of events, and their inherent natural occurrence, assessment of both condition and trend is not applicable.

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4.10. Acoustic Environment

4.10.1 Overview

Relevance

Our ability to see is a powerful tool for experiencing our world, but sound adds a richness that sight alone cannot provide. In many cases, hearing is the only option for experiencing certain aspects of our environment or to quote Anne Fernald, "sound is touch at a distance" (Abumrad 2006). An unimpaired acoustic environment is an important part of overall visitor experience and enjoyment as well as vitally important to overall ecosystem health.

Visitors to national parks often indicate that an important reason for visiting the parks is to enjoy the relative quiet that parks can offer. In a 1998 survey of the American public, 72% of respondents identified opportunities to experience natural quiet and the sounds of nature as an important reason for having national parks (Haas and Wakefield 1998). Additionally, 91% of NPS visitors "consider enjoyment of natural quiet and the sounds of nature as compelling reasons for visiting national parks" (McDonald et al. 1995). Despite this desire for quiet environments, anthropogenic noise continues to intrude upon natural areas and has become a source of concern in national parks (Lynch et al. 2011).

Sound also plays a critical role in intraspecies communication, courtship and mating, predation and predator avoidance, and effective use of habitat. Studies have shown that wildlife can be adversely affected by sounds that intrude on their habitats. While the severity of the impacts varies depending on the species being studied and other conditions, research strongly supports the fact that wildlife can suffer adverse behavioral and physiological changes from intrusive sounds (noise) and other human disturbances. Documented responses of wildlife to noise include increased heart rate, startle responses, flight, disruption of behavior, and separation of mothers and young (Selye 1956, Clough 1982, USFS 1992, Anderssen et al. 1993, NPS 1994).

The natural soundscape is an inherent component of "the scenery and the natural and historic objects and the wildlife" protected by the Organic Act of 1916. NPS Management Policies (§ 4.9) require the NPS to preserve the park's natural soundscape and restore the degraded soundscape to the natural condition wherever possible. Additionally, NPS is required to prevent or minimize degradation of the natural soundscape from noise (i.e., inappropriate/undesirable human-caused sound). Although the management policies currently refer to the term *soundscape* as the aggregate of all natural sounds that occur in a park, differences exist between the physical sound sources and human perceptions of those sound sources. The physical sound resources (i.e., wildlife, waterfalls, wind, rain, and cultural or historical sounds), regardless of their audibility, at a particular location are referred to as the *acoustic environment*, while the human perception of that *acoustic environment* is defined as the *soundscape*. Clarifying this distinction will allow managers to create objectives for safeguarding both the *acoustic environment* and the *visitor experience*.

The acoustic environment within GRSM is unique in that it contains both cultural and natural sounds. Some of the culturally significant sound sources include grinding mills, blacksmithing, Appalachian music, and Native American culture. Sounds from these sources play an important role in keeping the local culture alive while providing an important tool of interpretation to current and future generations. Natural sounds such as elk bugling, bird songs, frog calls, and rain are also important to the acoustic environment of GRSM. Together, the natural sounds and cultural sounds of GRSM create an acoustic tapestry that is under threat from a variety of noise sources. The two largest sources of noise within GRSM are likely aircraft and traffic. Additional noise sources include recreation, facility/trail maintenance, and boundary development. Through mitigation and minimization of these noise sources within GRSM, the acoustic environment and visitor experience can be preserved.

Data and Methods

Sound Science 101

Humans and wildlife perceive sound as an auditory sensation created by pressure variations that move through a medium such as water or air. Sound is measured in terms of frequency and amplitude (Templeton and Sacre 1997, Harris 1998). Noise, essentially the negative evaluation of sound, is defined as extraneous or undesired sound (Morfey 2001).

Frequency, measured in Hertz (Hz), describes the cycles per second of a sound wave, and is perceived by the ear as pitch. Humans with normal hearing can hear sounds between 20 Hz and 20,000 Hz, and are most sensitive to frequencies between 1,000 Hz and 6,000 Hz. High frequency sounds are more readily absorbed by the atmosphere or scattered by obstructions than low frequency sounds. Low frequency sounds diffract more effectively around obstructions, and therefore travel farther.

Besides the pitch of a sound, we also perceive the amplitude (or level) of a sound. This metric is described in decibels (dB). The decibel scale is logarithmic, meaning that every 10 dB increase in sound pressure level (SPL) represents a ten-fold increase in sound energy. This also means that small variations in sound pressure level can have significant effects on the acoustic environment. For instance, a 6 dB increase in a noise source will double the distance at which it can be heard, increasing the affected area by a factor of four. Sound pressure level is commonly summarized in terms of dBA (A-weighted sound pressure level). This metric significantly discounts sounds below 1,000 Hz and above 6,000 Hz to approximate human hearing sensitivity. Table 4.10.1 provides examples of A-weighted sound levels measured in national parks.

Table 4.10.1. Examples of sound levels measured in national parks.

Decibel Level (dBA)	Sound Source
10	Volcano crater (Haleakala NP)
20	Leaves rustling (Canyonlands NP)
40	Crickets at 5 m (Zion NP)
60	Conversational speech at 5 m (Whitman Mission NHS)

Table 4.10.1 (continued). Examples of sound levels measured in national parks.

Decibel Level (dBA)	**Sound Source**
80	Snowcoach at 30 m (Yellowstone NP)
100	Thunder (Arches NP)
120	Military jet, 100 m above ground level (Yukon-Charley Rivers NP)
126	Cannon fire at 150 m (Vicksburg NMP)

The natural acoustic environment is vital to the function and character of a national park. Natural sounds include those sounds upon which ecological processes and interactions depend. Examples of natural sounds in parks include:

- Sounds produced by birds, frogs, or insects to define territories or attract mates
- Sounds produced by bats to navigate or locate prey
- Sounds produced by physical processes such as wind in trees, flowing water, or thunder

Although natural sounds often dominate the acoustic environment of a park, human-caused noise has the potential to mask these sounds. Noise impacts the acoustic environment much like smog impacts the visual environment, obscuring the listening horizon for both wildlife and visitors. Examples of human-caused sounds heard in parks include:

- Aircraft (i.e., high-altitude and military jets, fixed-wing, helicopters)
- Vehicles
- Generators
- Watercraft
- Grounds care (lawn mowers, leaf blowers)
- Human voices

Characterizing the acoustic environment

Oftentimes, managers characterize ambient conditions over the full extent of the park by dividing total area into “acoustic zones” on the basis of different vegetation zones, management zones, visitor use zones, elevations, or climate conditions. Then, the intensity, duration, and distribution of sound sources in each zone can be assessed by collecting sound pressure level (SPL) measurements, digital audio recordings, and meteorological data. Indicators typically summarized in resource assessments include natural and existing ambient sound levels and types of sound sources. *Natural ambient* sound level refers to the acoustical conditions that exist in the absence of human-caused noise and represents the level from which the NPS measures impacts to the acoustic environment. *Existing ambient* sound level refers to the current sound intensity of an area, including both natural and human-caused sounds.

The influence of anthropogenic noise on the acoustic environment is generally reported in terms of SPL across the full range of human hearing (12.5-20,000 Hz), but it is also useful to report results in a much narrower band (20-1,250 Hz) because most human-caused sound is confined to these lower frequencies.

Reference Conditions

Reference criteria should address the effects of noise on human health and physiology, the effects of noise on wildlife, the effects of noise on the quality of the visitor experience, and finally, how noise impacts the acoustic environment itself.

Various characteristics of sound can contribute to how noise may affect the acoustic environment. These characteristics may include rate of occurrence, duration, amplitude, pitch, and whether the sound occurs consistently or sporadically. In order to capture these aspects, the quality of the acoustic environment is assessed using a number of different metrics including existing ambient and natural ambient sound level (measured in dB), percent time human-caused noise is audible, and noise free interval. In summary, if we are to develop a complete understanding of a park’s acoustic environment, we must consider a variety of sound metrics. This can make selecting one reference condition difficult. For example, if we chose to use just the natural ambient sound level for our reference condition, we would focus only on sound pressure level and overlook the other aspects of sound mentioned above.

Ideally, reference conditions would be based on measurements collected in the park, but this is not always logistically feasible. In cases where on-site measurements have not been gathered, one can reference meta-analyses of national park monitoring efforts such as those detailed in Lynch et al. (2011) and Mennitt et al. (2013). The former aggregated data from 189 sites in 43 national parks, and reported that the median L_{90} across all sites and hours of the day was 21.8 dBA (between 20 and 800 Hz). L_{90} is the sound level that is heard 90% of the time - an estimate of the background against which individual sounds are heard. The latter, a similarly comprehensive geospatial modeling effort (which assimilated data from 291 park monitoring sites across the nation), revealed that the median daytime existing sound level in national parks rests around 31 dBA. In addition, among 89 acoustic monitoring deployments analyzed for audibility, the median percent time audible of anthropogenic noise during daytime hours was found to be 35%.

Conditions and Trends

Acoustical Conditions

In cases where acoustic data have been collected on site, a balanced assessment of acoustical conditions in a park will report natural and existing sound levels (for either daytime, nighttime, or 24 h time periods), percent time audible for natural sounds and noise sources of interest, and noise free intervals. Human responses can actually serve as a proxy for potential impacts to other vertebrates because humans have more sensitive hearing at low frequencies than most species (Dooling and Popper 2007), so a resource assessment might also consider the time that SPL levels exceed those mentioned in Table 4.10.2. The first value (35 dBA) is designed to address the health effects of sleep interruption. Recent studies suggest that sound events as low as 35 dB can have adverse effects on blood pressure while sleeping (Haralabidis et al. 2008). The second threshold addresses the World Health Organization’s recommendations that noise levels inside bedrooms remain below 45 dBA (Berglund et al. 1999). Park visitors camping in or near the park could experience either of these two effects. The third level (52 dBA) is based on the EPA’s speech interference threshold for speaking in a raised voice to an audience at 10 m (33 ft). This threshold addresses the effects of noise on interpretive programs in parks. The final threshold (60 dBA) provides a basis for estimating impacts on normal voice communications at 1 m (3.3 ft). Hikers and visitors viewing scenic vistas in the park would likely be conducting such conversations.

Table 4.10.2. Effects of sound pressure levels (SPL) on humans.

SPL (dBA)	Relevance
35	Blood pressure and heart rate increase in sleeping humans (Haralabidis et al. 2008)
45	World Health Organization’s recommendation for maximum noise levels inside bedrooms (Berglund et al. 1999)
52	Speech interference for interpretive programs (EPA 1974)
60	Speech interruption for normal conversation (EPA 1974)

Baseline data for GRSM was collected at seven locations during both winter and summer from 2005-2006. This data was collected in cooperation between GRSM staff, Volpe (The National Transportation Systems Center), and the Natural Sounds Program (now called Natural Sounds and Night Skies Division) of the National Park Service. General information about these sites can be seen in Table 4.10.3 while a map of these locations can be seen in Fig. 4.10.1.

Table 4.10.3. Acoustic monitoring sites in GRSM.

Site	Site Name	Dates Deployed	Vegetation	Elevation (m)	Latitude	Longitude
GRSM001	Mt. Collins	5/30/06-7/3/06 & 11/8/05-12/7/05	Mixed Forest	1713	35.56291	-83.47027
GRSM002	Parsons Branch	5/31/06-7/3/06 & 11/9/05-12/6/05	Open Field Grass/ Pasture	561	35.60357	-83.78545
GRSM003	Porter’s Creek	6/1/06-7/4/08 & 11/9/05-12/6/05	Cove Hardwood	862	35.67207	-83.49226
GRSM004	Purchase Knob	6/2/06-7/1/06 & 11/10/05-12/5/05	Hardwood/Deciduous	1551	35.58857	-83.07713
GRSM005	Bull Head Trail	6/1/06-7/4/06 & 11/10/05-12/5/05	Hardwood	749	35.68637	-83.40206
GRSM006	Cades Cove	5/31/06-7/5/06 & 11/10/05-12/5/05	Northern Hardwood	699	35.55861	-83.8569
GRSM007	Noland Divide	5/30/06-7/2/06 & 11/15/05-12/7/05	Spruce/Evergreen	1804	35.59227	-83.47372

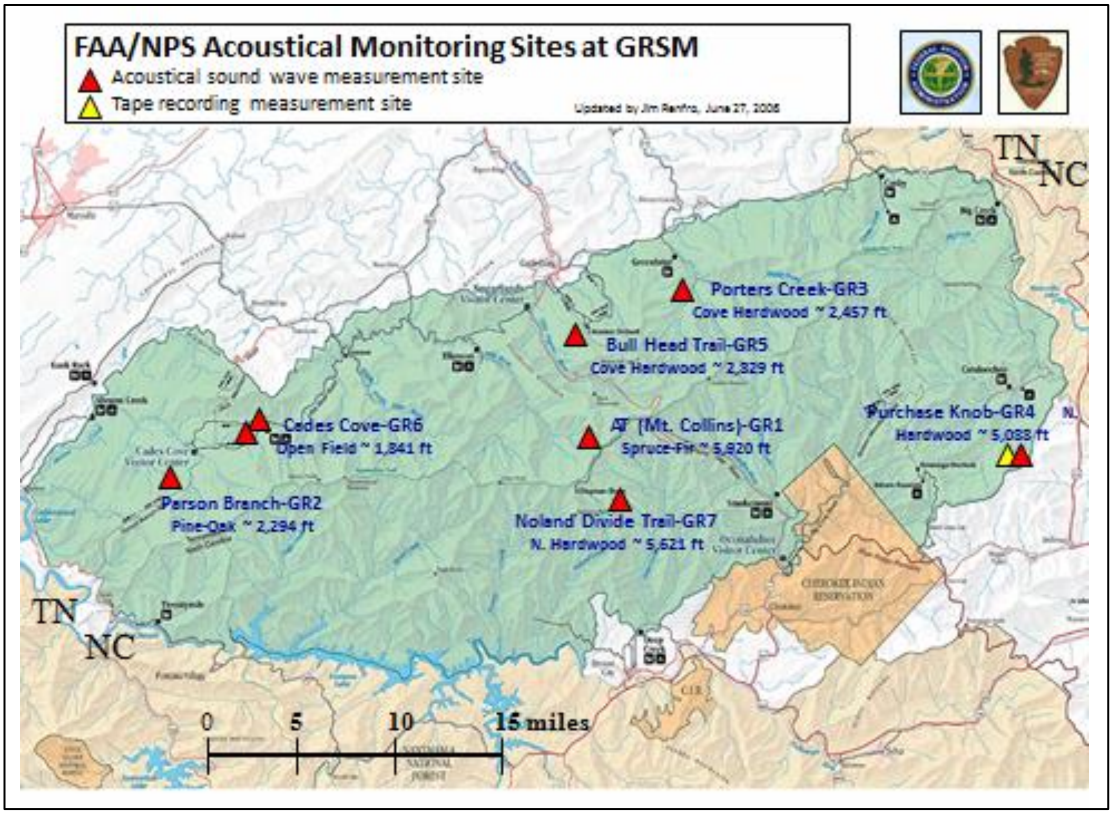

Figure 4.10.1: Acoustic monitoring locations within GRSM Source: Jim Renfro

Metrics

Since sound levels fluctuate, several metrics are presented in order to provide some detail about the characteristics of the soundscape. “Time above” metrics provide information about how much time sound levels are above specified values. By comparing the amount of time that sound levels are above certain values, variations in sound levels can be illustrated. Tables 4.10.4 and 4.10.5 report the percent of time that measured levels were above the values in Table 4.10.2. These values should not be construed as thresholds of impact. The top value in each cell focuses on typical frequencies produced by transportation noise, whereas the lower values use the conventional full frequency range.

Table 4.10.4. Winter percent time above metrics.

Site	Frequency (Hz)	% Time Above Sound Level: 0700 to 1900				% Time Above Sound Level: 1900 to 0700			
		35 dBA	45 dBA	52 dBA	60 dBA	35 dBA	45 dBA	52 dBA	60 dBA
GRSM001	100-800	26.40	0.83	0.13	0.01	47.08	8.34	0.22	0.01
	10-20,000	48.93	4.21	0.28	0.02	56.12	31.85	2.97	0.01
GRSM002	100-800	25.38	1.30	0.17	0.02	17.29	0.48	0.15	0.01
	10-20,000	48.00	2.49	0.38	0.02	41.14	8.97	1.39	0.00

Table 4.10.4 (continued). Winter percent time above metrics.

Site	Frequency (Hz)	% Time Above Sound Level: 0700 to 1900				% Time Above Sound Level: 1900 to 0700			
		35 dBA	45 dBA	52 dBA	60 dBA	35 dBA	45 dBA	52 dBA	60 dBA
GRSM003	100-800	11.32	0.99	0.19	0.01	12.28	0.17	0.02	0.01
	10-20,000	22.94	1.42	0.35	0.00	28.11	1.61	0.06	0.00
GRSM004	100-800	36.12	3.75	0.07	0.00	36.12	4.27	0.07	0.00
	10-20,000	45.86	4.98	0.10	0.00	39.16	6.38	0.58	0.02
GRSM005	100-800	11.39	1.00	0.20	0.01	13.61	0.61	0.04	0.01
	10-20,000	25.19	2.30	0.34	0.01	39.92	7.00	0.95	0.00
GRSM006	100-800	19.07	1.63	0.20	0.01	8.89	0.52	0.06	0.01
	10-20,000	51.39	3.68	0.52	0.03	18.90	3.83	0.16	0.00
GRSM007	100-800	45.70	3.43	0.15	0.00	54.87	12.07	0.86	0.00
	10-20,000	69.66	15.45	1.34	0.02	69.45	23.86	4.00	0.04

Table 4.10.5. Summer percent time above metrics.

Site	Frequency (Hz)	% Time Above Sound Level: 0700 to 1900				% Time Above Sound Level: 1900 to 0700			
		35 dBA	45 dBA	52 dBA	60 dBA	35 dBA	45 dBA	52 dBA	60 dBA
GRSM001	100-800	6.73	0.56	0.09	0.01	1.85	0.13	0.01	0.01
	10-20,000	19.77	1.17	0.20	0.01	8.91	0.50	0.06	0.00
GRSM002	100-800	7.02	0.81	0.15	0.01	2.69	0.16	0.01	0.01
	10-20,000	17.60	1.74	0.20	0.00	7.76	0.43	0.05	0.00
GRSM003	100-800	3.22	0.32	0.07	0.00	2.52	0.19	0.03	0.00
	10-20,000	40.07	1.17	0.11	0.00	40.68	0.54	0.05	0.00
GRSM004	100-800	10.15	0.33	0.02	0.00	10.25	0.13	0.02	0.00
	10-20,000	22.54	5.13	0.34	0.02	20.64	5.20	0.16	0.00
GRSM005	100-800	5.19	0.83	0.17	0.01	2.38	0.24	0.03	0.01
	10-20,000	19.94	2.20	0.28	0.01	11.13	0.74	0.13	0.00
GRSM006	100-800	12.26	1.06	0.25	0.04	2.65	0.20	0.01	0.00
	10-20,000	84.45	41.34	8.66	0.06	91.49	42.20	0.56	0.00
GRSM007	100-800	6.48	0.34	0.06	0.01	3.45	0.13	0.02	0.01
	10-20,000	14.62	1.57	0.12	0.00	14.05	0.77	0.08	0.00

Exceedence levels (L_x) are metrics used to describe acoustical data. They represent the dBA exceeded x percent of the time during the given measurement period (e.g., L_{90} is the dBA that has been exceeded 90% of the time). Tables 4.10.6 and 4.10.7 report the L_{90}, L_{50}, and L_{10} values for the sites measured in GSRM. The top value in each cell focuses on frequencies affected by transportation noise, whereas the lower values use the conventional full frequency range.

Table 4.10.6. Winter exceedence levels for existing conditions.

Site	**Frequency (Hz)**	**Exceedence Levels (dBA): 0700 to 1900**			**Exceedence Levels (dBA): 1900 to 0700**		
		L_{90}	**L_{50}**	**L_{10}**	**L_{90}**	**L_{50}**	**L_{10}**
GRSM001	100-800	27.5	31.1	36.1	30.1	33.9	39.0
	10-20,000	30.5	34.2	38.9	32.1	36.8	41.9
GRSM002	100-800	24.3	29.2	35.3	19.7	22.3	30.5
	10-20,000	28.1	32.9	39.0	24.4	29.5	34.4
GRSM003	100-800	29.2	30.5	34.2	30.1	31.3	33.0
	10-20,000	30.5	32.0	35.8	31.1	32.5	34.7
GRSM004	100-800	23.6	29.3	34.7	23.0	27.3	32.6
	10-20,000	26.3	31.3	37.5	26.0	29.2	34.5
GRSM005	100-800	25.1	27.2	33.6	24.3	25.7	28.8
	10-20,000	27.0	29.1	35.4	26.1	27.5	31.4
GRSM006	100-800	28.2	30.9	36.6	25.9	27.3	31.5
	10-20,000	31.7	33.7	39.2	30.4	31.6	34.2
GRSM007	100-800	29.5	34.1	39.8	30.6	35.2	40.9
	10-20,000	32.2	36.9	43.8	32.9	37.8	44.5

Table 4.10.7. Summer exceedance levels for existing conditions.

Site	**Frequency (Hz)**	**Exceedence Levels (dBA): 0700 to 1900**			**Exceedence Levels (dBA): 1900 to 0700**		
		L_{90}	**L_{50}**	**L_{10}**	**L_{90}**	**L_{50}**	**L_{10}**
GRSM001	100-800	21.1	24.2	31.5	17.5	21.6	27.8
	10-20,000	24.9	28.6	35.5	21.6	25.3	32.3
GRSM002	100-800	21.3	24.6	32.5	16.9	19.1	26.6
	10-20,000	25.5	28.9	36.3	21.9	23.6	30.8
GRSM003	100-800	28.2	29.1	31.6	29.5	30.3	31.8
	10-20,000	32.8	34.4	38.0	33.1	34.3	36.8
GRSM004	100-800	20.8	23.8	32.6	19.1	23.7	30.5
	10-20,000	25.6	30.8	40.6	25.7	30.8	39.6
GRSM005	100-800	23.9	25.8	31.0	23.0	24.9	27.8
	10-20,000	27.8	31.0	36.5	26.5	28.5	33.2
GRSM006	100-800	26.3	29.3	35.3	24.7	26.4	29.9
	10-20,000	39.0	42.6	47.3	42.6	44.5	46.1
GRSM007	100-800	21.4	23.9	30.0	19.6	22.5	27.6
	10-20,000	25.0	27.6	33.4	23.1	26.3	31.9

Fig. 4.10.2 – 4.10.15 plot the dB levels for 33 one-third octave band frequencies over the day and night periods at each site. The grayed area represents sound levels outside of the typical range of

human hearing. The typical frequency levels for transportation, conversation, and songbirds are presented on the Figure as examples for interpretation of the data. These ranges are estimates and are not vehicle-, species-, or habitat-specific.

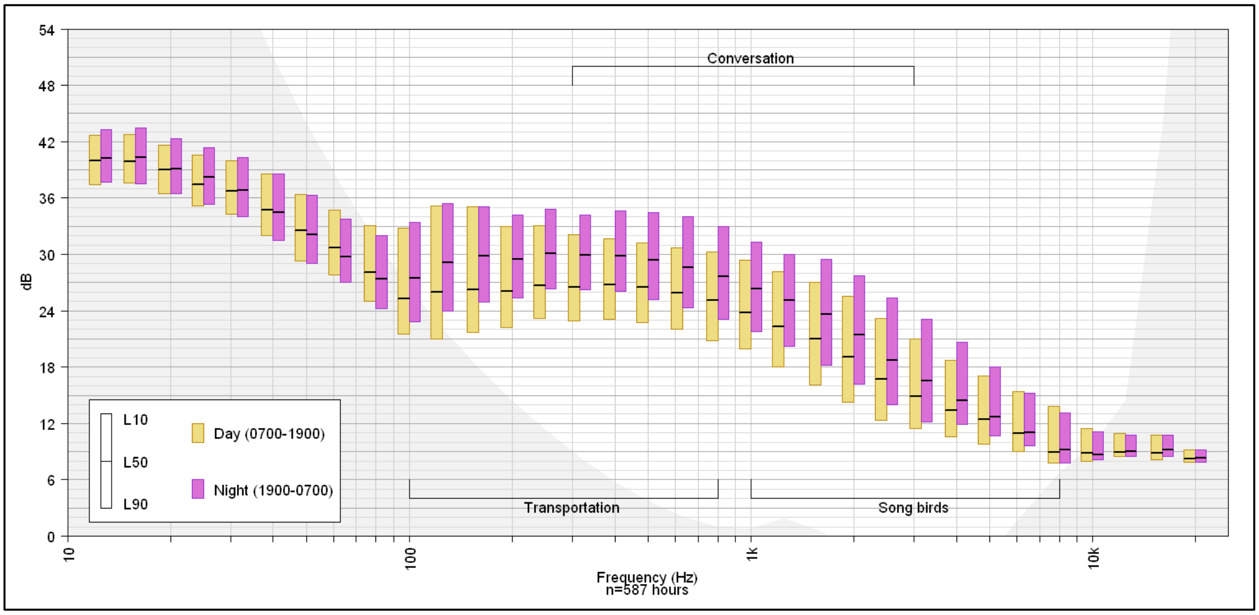

Figure 4.10.2. Winter day and night dB levels for 33 one-third octave bands at GRSM001.

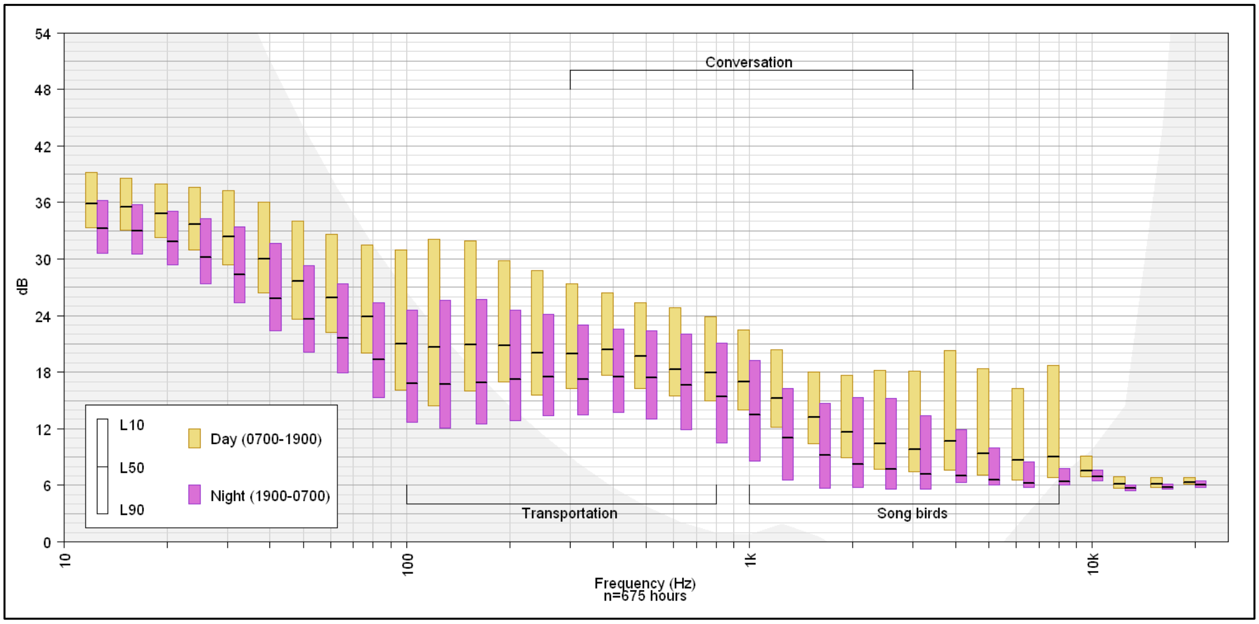

Figure 4.10.3. Summer day and night dB levels for 33 one-third octave bands at GRSM001.

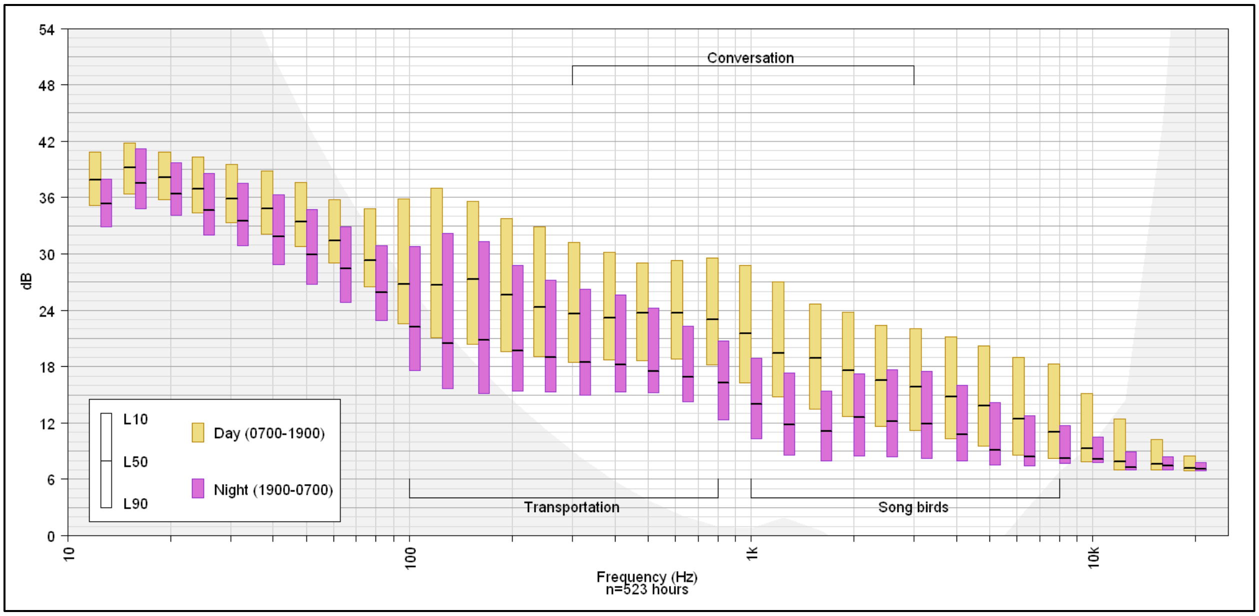

Figure 4.10.4. Winter day and night dB levels for 33 one-third octave bands at GRSM002.

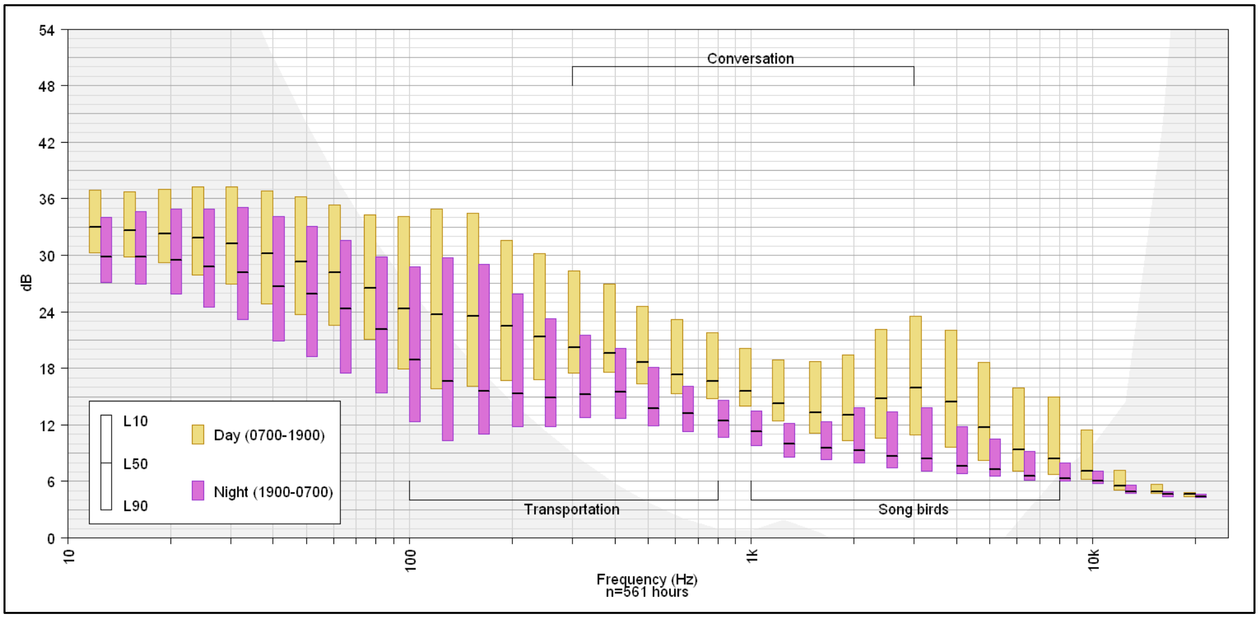

Figure 4.10.5. Summer day and night dB levels for 33 one-third octave bands at GRSM002.

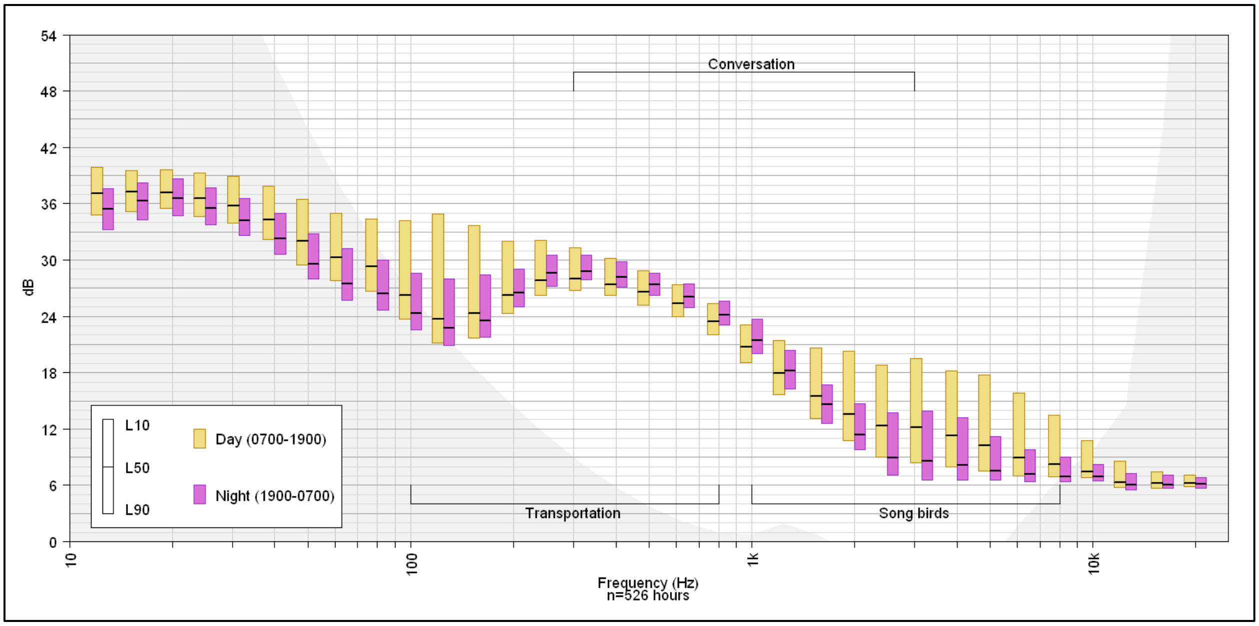

Figure 4.10.6. Winter day and night dB levels for 33 one-third octave bands at GRSM003.

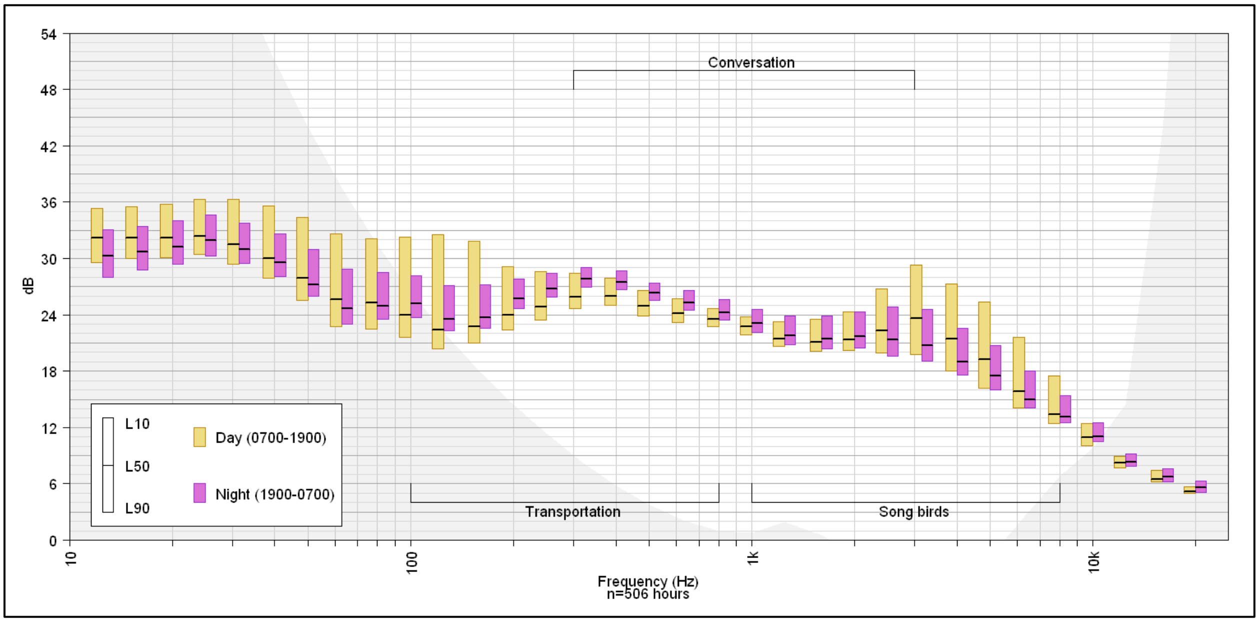

Figure 4.10.7. Summer day and night dB levels for 33 one-third octave bands at GRSM003.

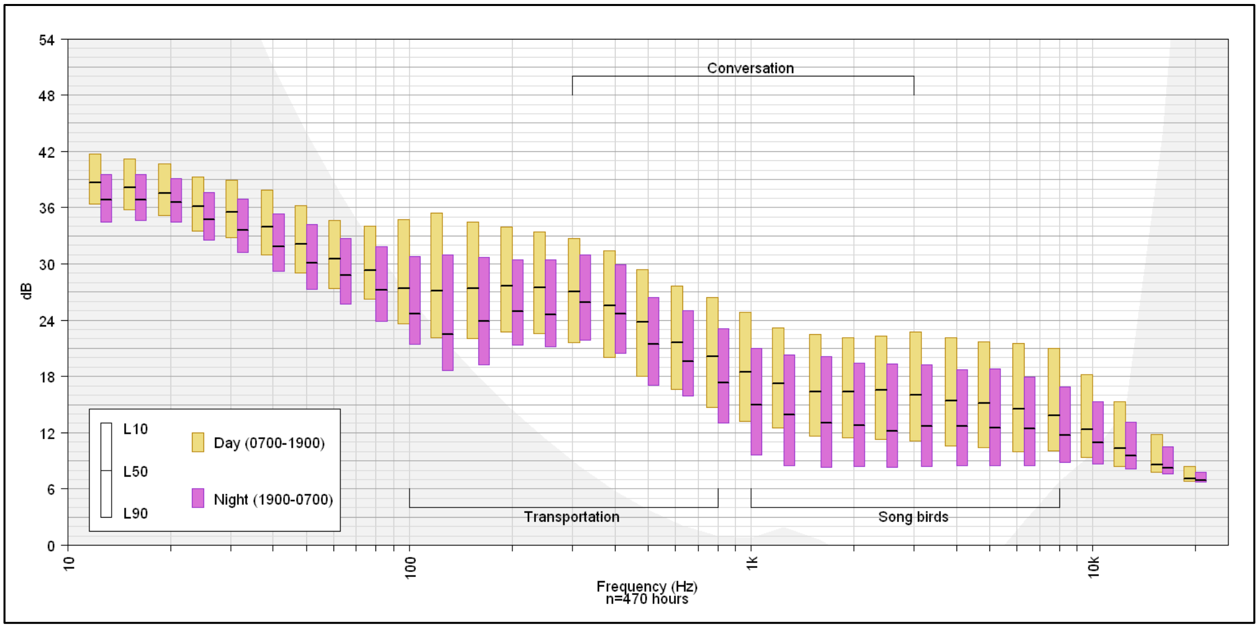

Figure 4.10.8. Winter day and night dB levels for 33 one-third octave bands at GRSM004.

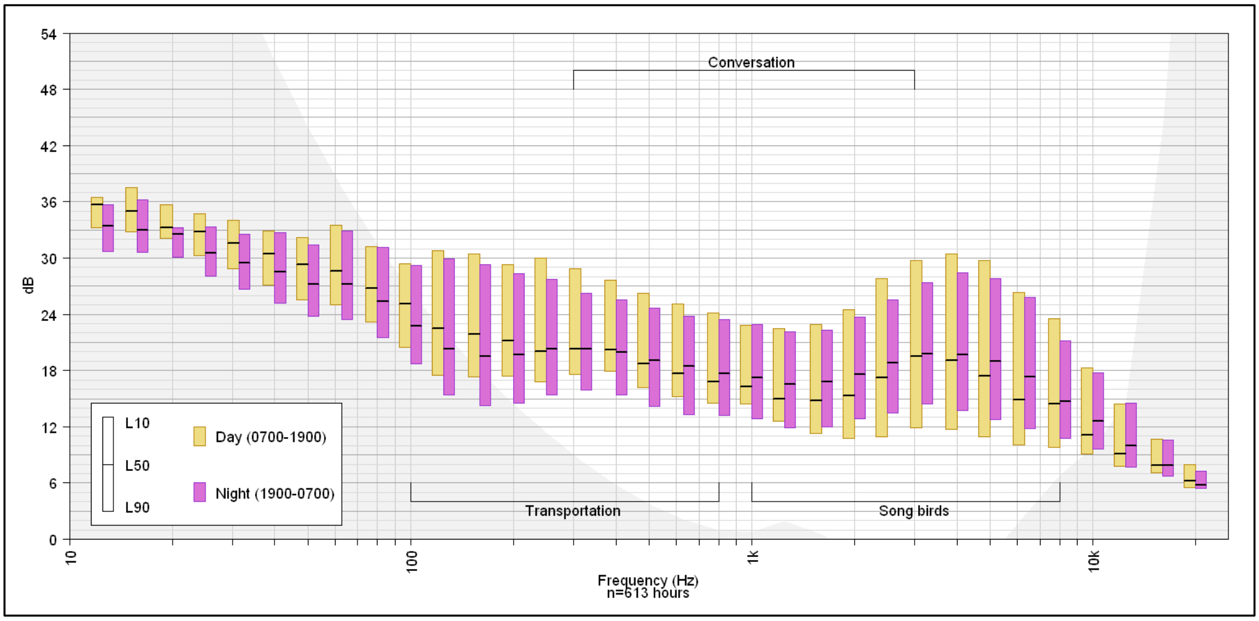

Figure 4.10.9. Summer day and night dB levels for 33 one-third octave bands at GRSM004.

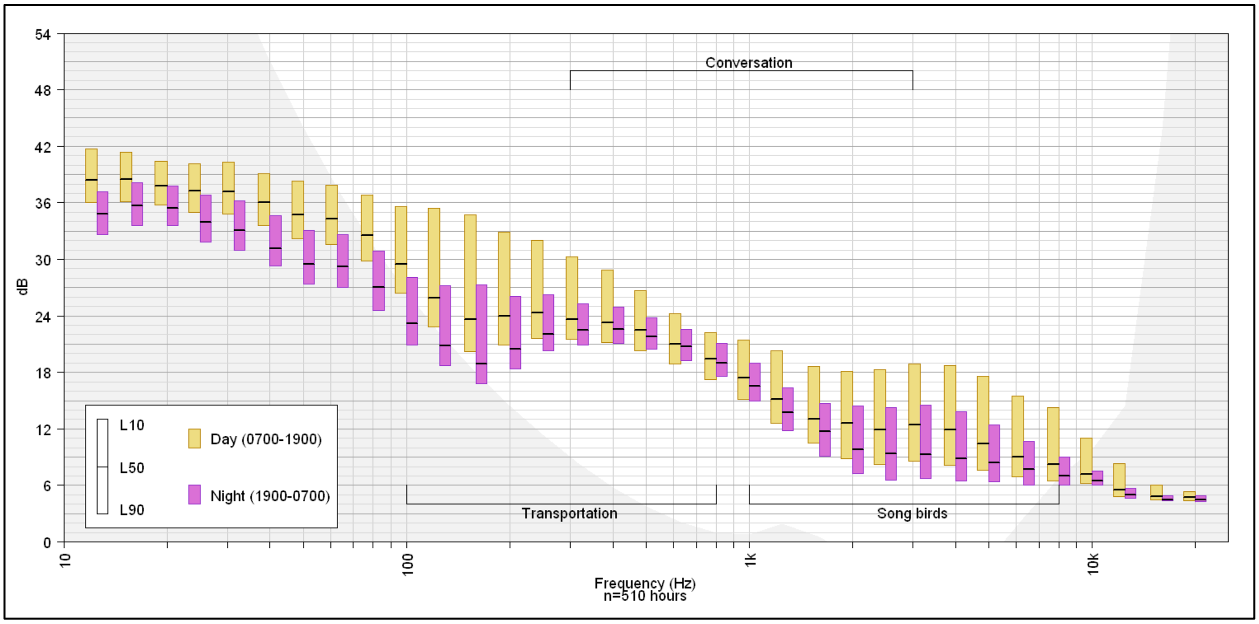

Figure 4.10.10. Winter day and night dB levels for 33 one-third octave bands at GRSM005.

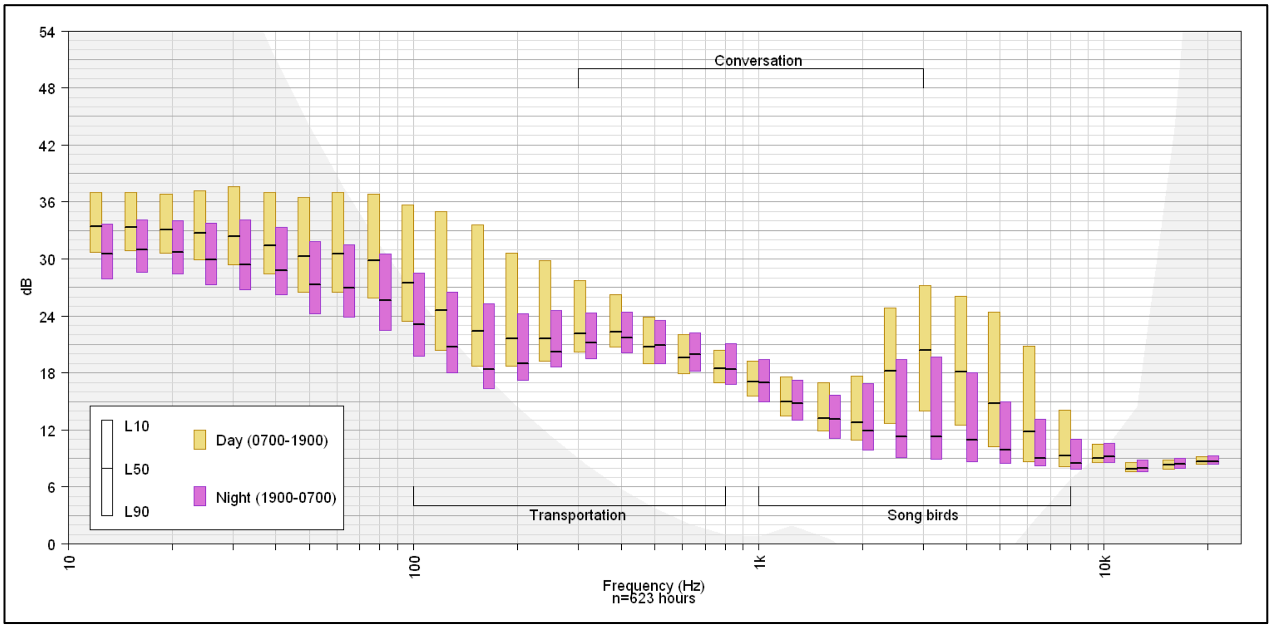

Figure 4.10.11. Summer day and night dB levels for 33 one-third octave bands at GRSM005.

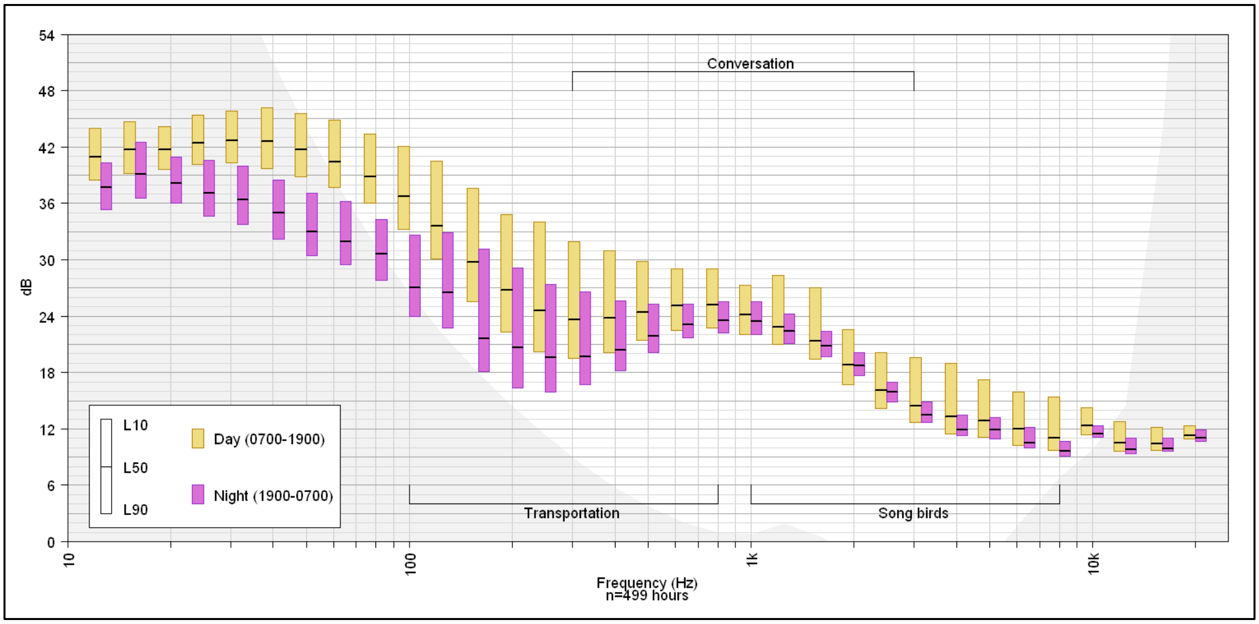

Figure 4.10.12. Winter day and night dB levels for 33 one-third octave bands at GRSM006.

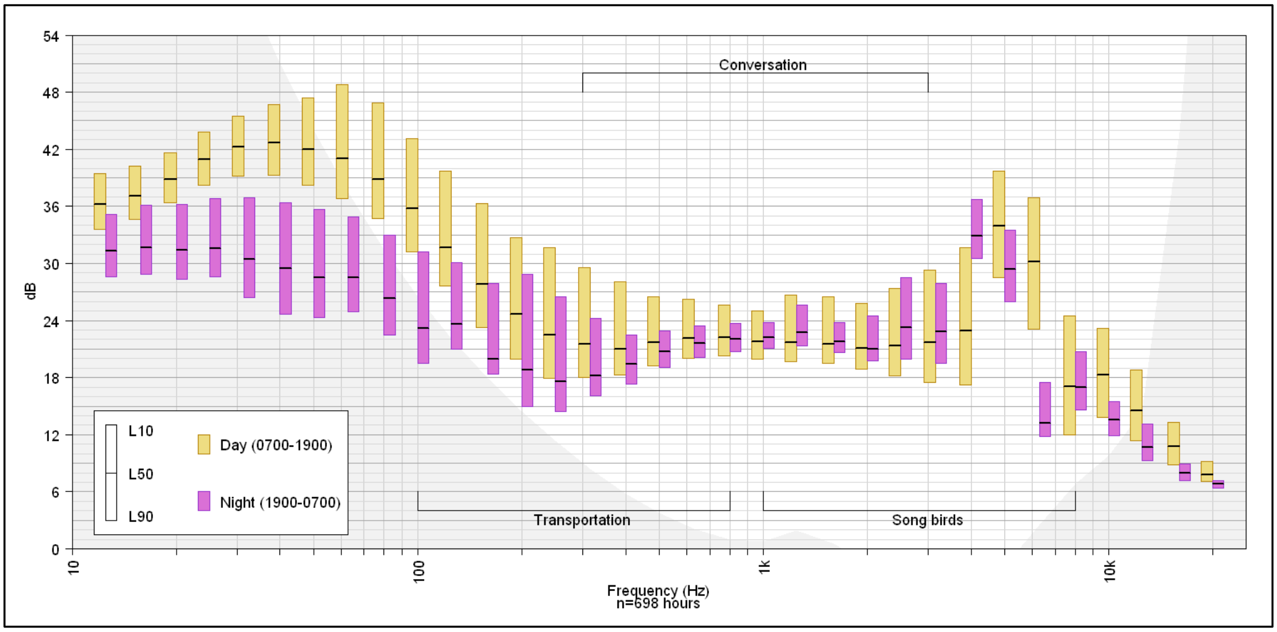

Figure 4.10.13. Summer day and night dB levels for 33 one-third octave bands at GRSM006.

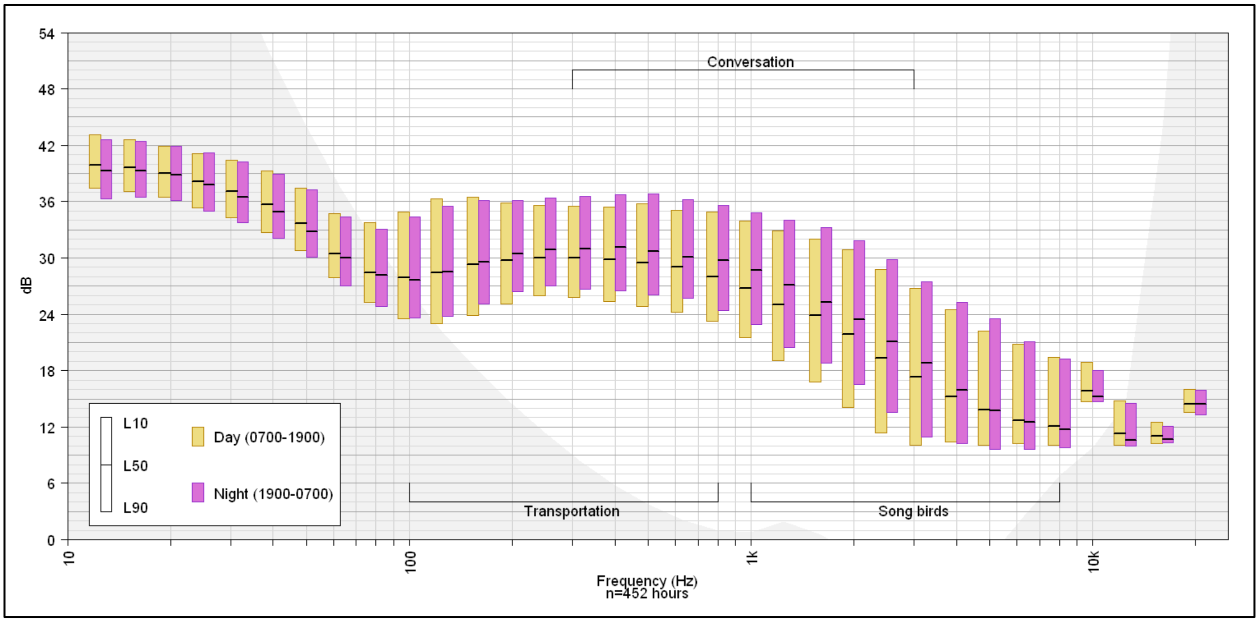

Figure 4.10.14. Winter day and night dB levels for 33 one-third octave bands at GRSM007.

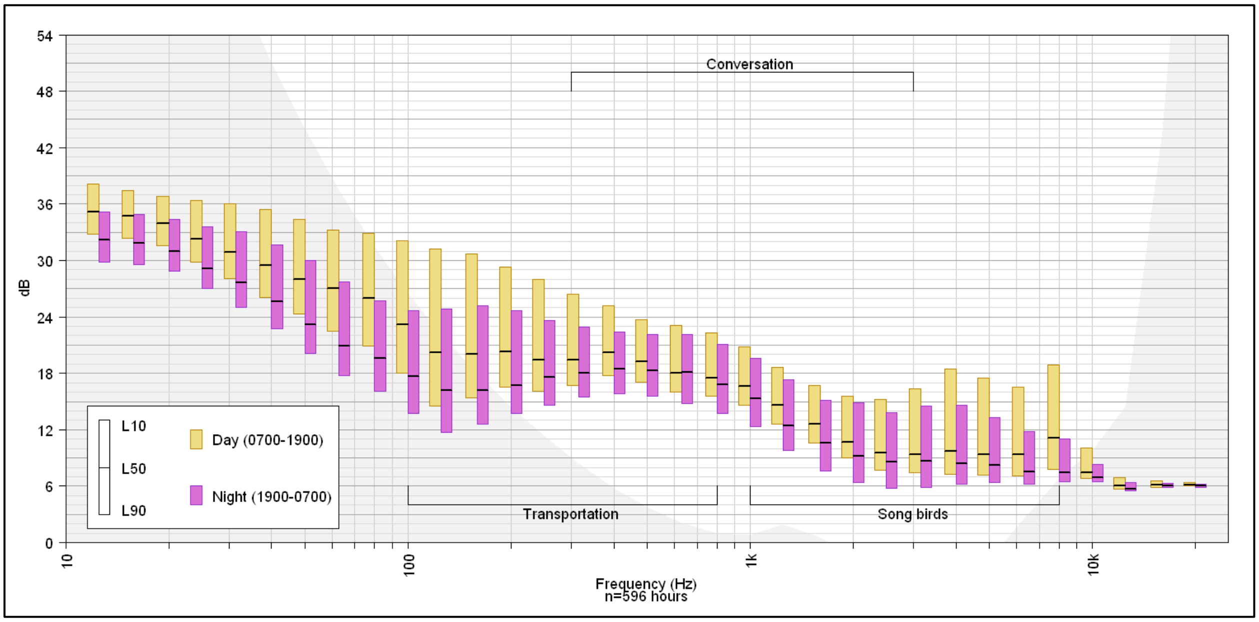

Figure 4.10.15. Summer day and night dB levels for 33 one-third octave bands at GRSM007.

At the time of the 2005-2006 monitoring effort, the technology to collect and store continuous audio data was very limited. Therefore, audio data was only collected at GRSM004 and is very limited in nature. Due to this limitation, percent time audible for anthropogenic sound sources and Lnat within the park were not calculated.

In cases where the ability to collect acoustic data on site is limited or has not yet been collected, alternatives for assessing condition and trend are also available. Using acoustic data collected at 244 sites and 109 spatial explanatory layers (such as location, landcover, hydrology, wind speed, and proximity to noise sources such as roads, railroads, and airports), the NPS Natural Sounds and Night Skies Division (NSNSD) has developed a geospatial sound model which predicts natural and existing sound levels with 270 m resolution (Fig. 4.10.16) (Mennitt et al. 2013). In addition to predicting these two ambient sound levels, the model also calculates the difference between the two metrics, providing a measure of impact to the natural acoustic environment from anthropogenic sources. The resulting metric (L_{50} dBA impact) indicates how much anthropogenic noise raises the existing sound pressure levels in a given location.

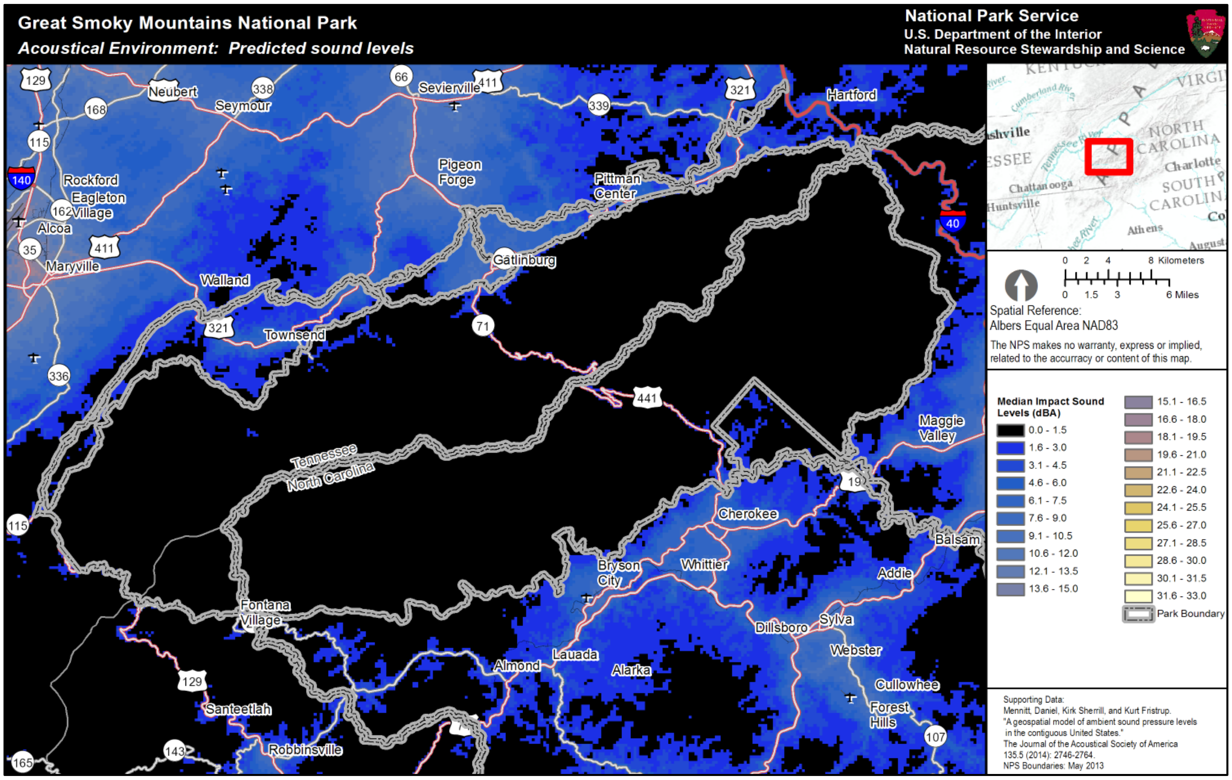

Figure 4.10.16. Map displaying modeled L_{50} dBA impact levels in GRSM. Source: Mennitt et al. 2013

To gain insight into the condition of the acoustic environment in parks where acoustic data have not been collected, it is also useful to have an inventory of audible sounds. The important variables to track are what sounds are audible, how often they are audible, and how many times they are audible. These data are best collected by a single, focused listener in calm weather conditions during a series of listening sessions. It is advisable to conduct the sound inventory in a number of different locations and across different times of day to capture spatial and temporal variation in acoustic conditions. A listening session of this nature can be conducted with tools as simple as a pen, paper, and stopwatch, or with custom software produced by the NSNSD which runs on most Apple iOS products. The ultimate goal of the inventory is to gather information about what sounds presently contribute to the acoustic environment, which are the most common, and which could possibly threaten the quality of the acoustic environment.

To assess the condition of the acoustic environment, it is also useful to consider the functional effects that increases in sound level might produce. For instance, the *listening area*, the area in which a sound can be perceived by an organism, will be reduced when background sound levels increase. The failure to perceive a sound because other sounds are present is called *masking*. Masking interferes with wildlife communication, reproductive and territorial advertisement, and acoustic location of prey or predators (Barber, Crooks, and Fristrup 2010). However, the effects of masking are not limited to wildlife. Masking also inhibits human communication and visitor detection of wildlife sounds. In urban settings, masking can prevent people from hearing important sounds like approaching people or vehicles, and interfere with the way visitors experience cultural sounds or interpretive programs. Keep in mind that seemingly small increases in sound level can have substantial effects, particularly when quantified in terms of loss of listening area (Payne and Webb 1971, Barber et al. 2010). Each 3 dB increase in the background sound level will reduce a given listening area by half. See Table 4.10.8 for additional information.

Table 4.10.8. Increases in background sound level (dB) with resulting decreases in listening area.

Increase in Background Sound Level (dB)	Decrease in Listening Area
1	21%
2	37%
3	50%
4	60%
5	68%
6	75%
7	80%
8	84%
9	87%
10	90%

Trends

Evaluating trends in condition is straightforward for parks where repeated measurements have been conducted because measurements can be compared. But inferences can also be made for parks where fewer data points exist. Nationwide trends indicate that prominent sources of noise in parks (namely vehicular traffic and aircraft) are increasing. However, it is possible that conditions in specific parks differ from national trends. The following events might contribute to a declining trend in the quality of the acoustic environment: expansion of traffic corridors nearby, increases in traffic due to industry, changes in zoning or leases on adjacent lands, changes in land use, planned construction in or near the park, increases in population, and changes to airspace (particularly those which bring more aircraft closer to the park). Most states post data on traffic counts on department of transportation websites, and these can be a good resource for assessing trends in vehicular traffic. Changes to airport operations, air space, and land use will generally be publicized and evaluated through the National Environmental Policy Act (NEPA) process.

Conversely, the following events may signal improvements in trend: installation of quiet pavement in or near parks, use of quiet technology for recreation in parks, decrease in vehicle traffic, use of quiet shuttle systems instead of passenger cars, building utility retrofits (e.g., replacing a generator with solar array), or installation of "quiet zone" signage.

There is an ongoing effort to assess condition and trend of acoustic resources for the state of the parks (SOP) project, and although SOPs generally report one metric per resource (while NRCAs often incorporate multiple metrics), it may serve as a useful template (see this link for more information: https://irma.nps.gov/App/Reference/Profile/2206094). Table 4.10.9 reports suggested thresholds for the mean L_{50} impact, which is a measure of the impact of anthropogenic sources on the acoustic environment. Because the National Park System is comprised of a wide variety of park units, two threshold categories are considered (urban and non-urban), based on proximity to urban areas (U.S. Census Bureau 2010). The urban criteria are applied to park units that have at least 90% of the park property within an urban area. The non-urban criteria were applied to units that have at least 90% of the park property outside an urban area. Parks that are distant from urban areas possess lower sound levels, and they exhibit less divergence between existing sound levels and predicted natural sound levels. These quiet areas are more susceptible to subtle noise intrusions than urban areas, and visitors and wildlife have a greater expectation for noise-free environments. Accordingly, the thresholds for the amber and red condition ratings are lower for these park units than for units near urban areas. Urban areas tend to have higher ambient sound levels than non-urban areas (EPA 1971, Schomer et al. 2011), and therefore, higher thresholds are used for parks in urban areas. However, acoustic environments are important in all parks: units in urban areas may seek to preserve or restore low ambient sound levels to offer respite for visitors. GRSM is considered a non-urban park under this model and a preliminary acoustic impact level of 0.2 dBA across GRSM has been calculated (Table 4.10.9).

Table 4.10.9. Example condition thresholds for non-urban and urban parks.

Indicator	Condition Level	Threshold for Non-urban Parks (dBA)	Threshold for Urban Parks (dBA)
Mean L_{50} impact (dBA)	Resource is in good condition	Threshold ≤ 1.5 *Listening area reduced by ≤30%*	Threshold ≤ 6.0 *Listening area reduced by ≤75%*
Mean L_{50} impact (dBA)	Warrants moderate concern	1.5 < Threshold ≤ 3.0 *Listening area reduced by 30 - 50%*	6.0 < Threshold ≤ 12 *Listening area reduced by 75 - 94%*
Mean L_{50} impact (dBA)	Warrants significant concern	3.0 < Threshold *Listening area reduced by >50%*	12 < Threshold *Listening area reduced by >94%*

Summary Condition

Table 4.10.10. Summary condition and trend graphic for acoustic environment in GRSM (non-urban park).

Resource	Indicator	Status and Trend	Rationale
Acoustic Environment	Acoustic impact level, which is a modeled measure of the noise (in dBA) contributed to the acoustic environment by man-made sources.	⇩	The condition of the acoustic environment is assessed by determining how much noise man-made sources contribute to the environment through the use of a national noise pollution model. The mean acoustic impact level at the park is 0.2 dBA, meaning that the condition of the acoustic environment is good. Overall, long-term projected increases in ground-based (U.S. Federal Highway Administration 2013) and aircraft traffic (Federal Aviation Administration 2010) indicate a deteriorating trend in the quality of acoustic resources at this location.

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4.11. Night Skies

4.11.1 Overview

Relevance

The loss of dark night skies has obvious impacts to star-gazing, but influences on nocturnal wildlife behavior (Longcore and Rich 2004) and adverse effects on human health (Bogard 2013) have also been documented. Two-thirds of Americans can't see the Milky Way from their backyard, and 99% of Americans live in areas considered to be light polluted (Cinzano et al. 2001). At the rate light pollution is currently increasing, there will be almost no dark skies in the contiguous U.S. by 2025 (J. Renfro, pers. comm.). Ecological impacts on wildlife include degradation of habitat quality for birds, terrestrial and marine mammals, fish, and sea turtles, as well as changes in migration patterns, predator-prey interactions, and activity and behavior of nocturnal wildlife (Longcore and Rich 2004). Physiological impacts on the human body include sleep disorders, disruption of circadian rhythms, and disruption of melatonin production (Bogard 2013). Regulations that limit the intensity of night light are necessary to minimize the negative effects of artificial lighting on park resources and ecosystems.

Natural dark skies are a valued resource within the NPS, reflected in NPS management policies (NPS 2006) which highlight the importance of a natural photic environment to ecosystem function, and the importance of the natural lightscape for aesthetics. The preservation of natural lightscapes (the intensity and distribution of light on the landscape at night) will keep the nocturnal photopic environment within the range of natural variability. Excursions outside this natural range may result in an alteration to natural ecosystem function, especially to systems involving the behavior and survival of nocturnal animals. The natural night sky is therefore one of the physical resources under which natural ecosystems have evolved.

The "scenery" or viewshed of national park areas do not just include the daytime hours. A natural starry sky absent of anthropogenic light is one of their key scenic resources, especially large wilderness parks remote from major cities. Further, the history and culture of many civilizations are steeped in interpretations of night sky observations, whether for scientific, religious, or time-keeping purposes. As such, the natural night sky may be a very important cultural resource, especially in areas where evidence of aboriginal cultures is present. Recreational value of dark night skies is important to campers and backpackers, allowing the experience of having a campfire or "sleeping under the stars." It follows that a natural night sky is an important wilderness value, contributing to the ability to experience a feeling of solitude in a landscape free from signs of human occupation and technology.

Data and Methods

Data used in this assessment consisted of sky brightness values (magnitudes/square arc second [mag/arcsec^2]) measured within the park at Clingmans Dome (October 26 2008) and at Cades Cove (October 29 2008) through a process known as astronomical photometry (Duriscoe et al. 2007), and provided by J. Renfro, GRSM. These data represent a one-time analysis of night sky brightness in and around GRSM. Relative night sky brightness is compared with measured and modeled data from across the U.S. to provide a national and regional context for night sky brightness at GRSM (NPS 2013).

Sky brightness may be presented as a map of the entire hemisphere of the night sky. As an example, light domes from many cities, as they appear from various locations and representing a wide range of sky quality, are shown in Figs. 4.11.1-4.11.4. These graphics demonstrate that the core of the light dome may be tens or hundreds of times brighter than the extremities and that using a logarithmic scale for sky brightness and false color for skies with a very large dynamic range easily reveals these details at a glance. These sky brightness maps are used extensively in reports by the National Park Service Night Skies Program (NPS-NSP), Natural Resource Stewardship and Science Directorate.

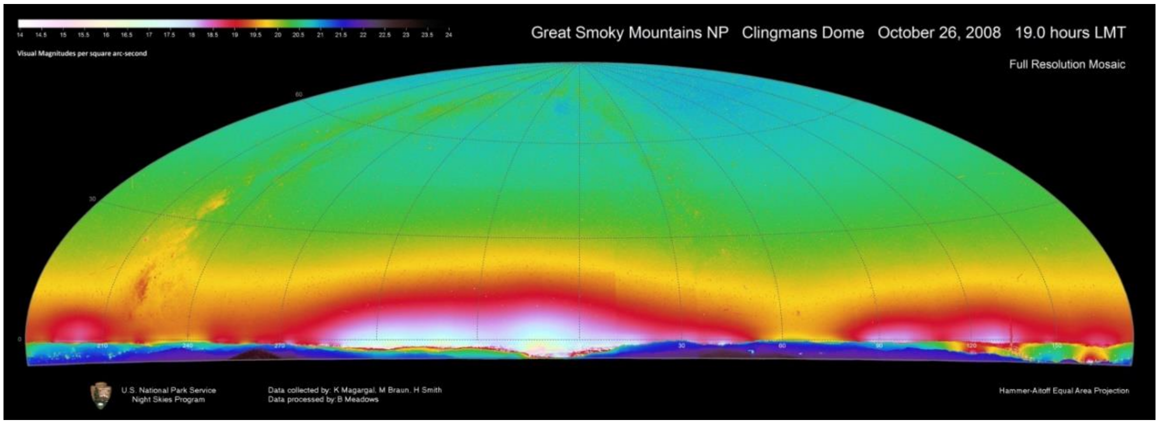

Figure 4.11.1. All-sky full resolution mosaic of the dataset's images from Clingmans Dome on October 26, 2008, rendered in false color. The false color scheme reveals a wide dynamic range of sky brightness values in a logarithmic scale from 14 to 23 mag/arcsec^2. The all-sky image mosaic (zenith to 6 degrees below the level horizon) contains about 34 million pixels.

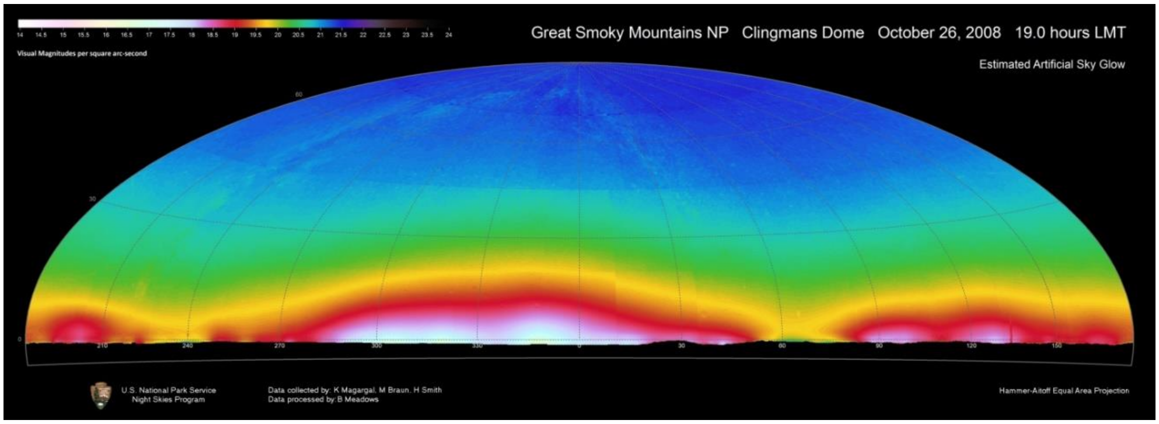

Figure 4.11.2. Sky glow mosaic from Clingmans Dome October 26, 2008. The sky glow or anthropogenic mosaic is the sky brightness mosaic subjected to pixel by pixel subtraction of a registered natural sky model mosaic, rendered in the same false color scale as the full resolution mosaic. The resolution is 0.05 degrees per pixel. The natural sky model is not shown as a graphic in this report.

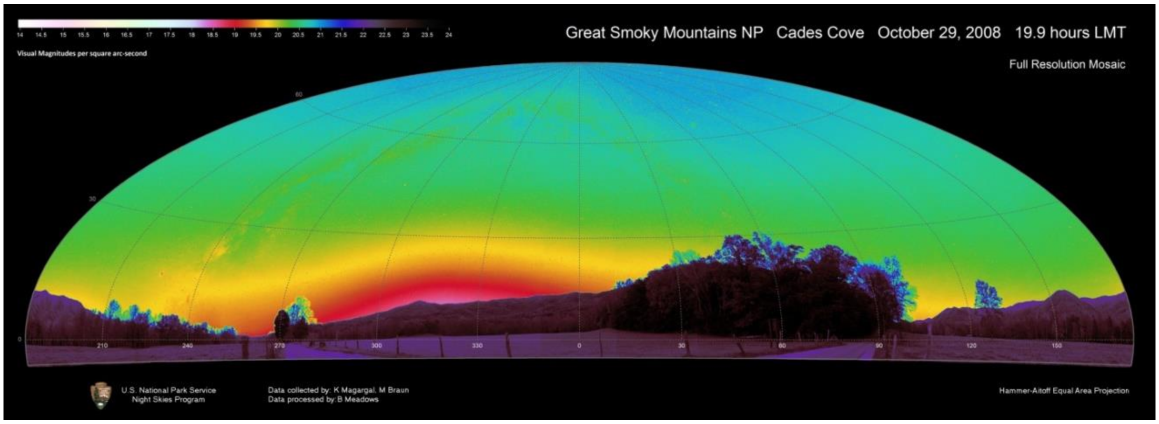

Figure 4.11.3. All sky full resolution mosaic of the data set's images from Cades Cove on October 29, 2008, rendered in false color. The false color scheme reveals a wide dynamic range of sky brightness values in a logarithmic scale from 14 to 23 mag/arcsec^2. The all-sky image mosaic (zenith to 6 degrees below the level horizon) contains about 34 million pixels.

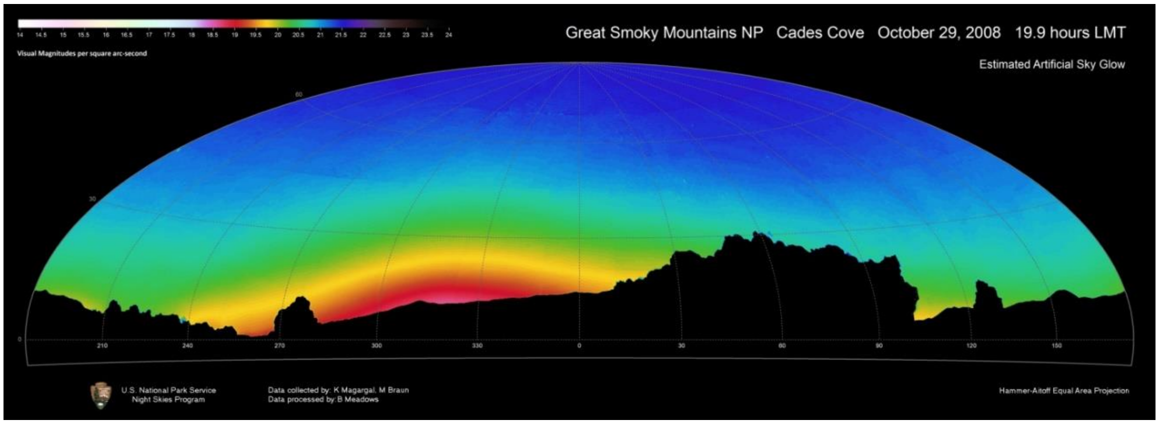

Figure 4.11.4. Sky glow mosaic from Cades Cover on October 29, 2008. The sky glow or anthropogenic mosaic is the sky brightness mosaic subjected to pixel by pixel subtraction of a registered natural sky model mosaic rendered in the same false color scale as the full resolution mosaic. The resolution is 0.05 degrees per pixel. The natural sky model is not shown as a graphic in this report.

The brightness (or luminance) of the sky in the region of the light domes may be measured as the number of photons per second reaching the observer for a given viewing angle, or area of the sky (such as a square degree, square arc minute, or square arc second). The NSP utilizes a digital camera with a large dynamic range monochromatic CCD detector and an extensive system of data collection, calibration, and analysis procedures (Duriscoe et al. 2007). This system allows for the accurate measurement of both luminance and illuminance, since it is calibrated on standard stars that appear in the same images as the data, and the image scale in arc seconds per pixel is accurately known. Sky luminance may be reported in astronomical units of V-magnitudes per square arc second, and in engineering units of nano-Lamberts (nL) or milli-Candela (mcd) per square meter. The V-magnitude is a broadband photometric term in astronomy, meaning the total flux from a source striking a detector after passing through a "Johnson-Cousins V" filter (Bessell 1990). It is similar to the "CIE photopic" broadband function for wavelengths of light to which the human eye is sensitive, and a formula is used to convert quantities in the V-magnitude system to nano-Lamberts. High resolution imagery of the entire night sky reveals details of individual light domes that may be attributed to anthropogenic light from distant cities or nearby individual sources. These data sets may be used for both resource condition assessment and long-term monitoring.

The natural night sky is luminous from sources such as the Milky Way, Zodiacal Light, and the natural atmospheric airglow. The appearance of the natural night sky may be modeled and predicted in terms of sky luminance and illuminance over the hemisphere, given the location, date and time, and the relative brightness of the natural airglow, or the so-called “permanent aurora,” which varies in intensity over time periods as short as minutes, but usually on the scale of hours (Roach and Gordon 1973). The NSP has constructed such a model and it is used in analysis of data sets to remove the natural components, resulting in a more accurate measure of anthropogenic sky glow. Fig. 4.11.1 represents “total sky brightness” while Fig. 4.11.2 displays “anthropogenic sky glow” or “sky glow.” This is an important distinction, especially in areas where anthropogenic sky glow is of relatively low intensity.

The accurate measurement of both anthropogenic light in the night sky and the accurate prediction of the brightness and distribution of natural sources of light allows for the use of a very intuitive metric of the resource condition--a ratio of anthropogenic to natural light. Both luminance and illuminance for the entire sky, or a given area of the sky, may be described in this manner (Hollan 2009). This so-called *light pollution ratio* is unitless and is always referenced to the brightness of a natural moonless sky under average atmospheric conditions, or, in the case of the NSP data, the atmospheric conditions determined from each individual data set.

Reference Conditions

The reference condition for natural sky brightness is necessary to maintain natural and cultural components of the special places harbored within national parks. Natural lightscapes are not only critical for nighttime park activities such as star-gazing, but also for maintaining nocturnal wildlife habitats (NPS 2013). Reference conditions are described below for each metric derived from all sky measures. For more information on natural reference conditions see Duriscoe et al. 2013.

Zenith

Perhaps the most often reported sky quality indicator in the astronomical literature, this measure is calculated from the median pixel value of an approximately one-degree diameter circle centered on the zenith.

Mean all-sky

This is an important statistic describing the photic environment. It is reported in logarithmic units of mag/arcsec^2 and linear units of µcd/m^2. The natural moonless reference condition is set at 21.6 mag/arcsec^2 or 250 µcd/m^2. This is an unbiased measure of the amount of light reaching the observer from sky luminance.

Brightest

The brightest part of the sky is an important indicator because the human eye's ability to dark-adapt will be impaired by the brightest part of the visual scene, and because bright parts of the sky may cast shadows from 3D objects on the land surface, giving depth to an otherwise uniformly lit natural landscape. The brightest part of the Milky Way is 19.6 mag/arcsec^2, or 1500 µcd/m^2. Brighter values will begin to impair dark adaptation, as values brighter than 17.0 mag/arcsec^2 can cast shadows. The Light Pollution Ratio is scaled to 22.0 mag/arcsec^2, or 172 µcd/m^2.

Darkest

The darkest part of the sky is an indicator of the ability to see faint objects anywhere in the night sky. The darkest part of a pristine sky during times of low solar activity is generally represented at 22.0 mag/arcsec^2, or 172 µcd/m^2, and any value lower (brighter) than 21.3 mag/arcsec^2 usually indicates significantly degraded sky quality. The Light Pollution Ratio is scaled to this value.

Median

The median is the middle sky brightness value over the whole sky. A view of the whole sky reveals that most areas will be near this value. The Light Pollution Ratio is scaled to the mean all-sky reference condition of 21.6 mag/arcsec^2, or 250 µcd/m^2.

Horizontal and Maximum Vertical Illuminance

Vertical illuminance is an important measure of the amount of light striking the ground (horizontal) or a vertical plane (vertical). Units are millilux (mlx), and natural reference condition for moonless nights is 0.8 mlx for horizontal and 0.4 mlx for vertical. The maximum vertical illuminance is for a vertical plane facing the brightest part of the sky near the horizon.

Conditions and Trends

Night sky quality was measured by NPS-NSP at GRSM in 2008 from Clingmans Dome (October 26) and Cades Cove (October 29). The all-sky light pollution ratio (ALR), a measure of light pollution calculated as the ratio of anthropogenic sky glow to average natural sky luminance, and other sky quality metrics were recorded for both sites (Tables 4.11.1). Also recorded were the all-sky and sky-glow mosaics from the same nights and locations, respectively (Figures. 4.11.1-4.11.4). All-sky measurements were 4.50 and 2.59 as measured from Clingmans Dome and Cades Cove, respectively, and indicate that GRSM is impacted by several population centers, or sources of light pollution: Sevier County, TN (26 km [16 mi]), metro Knoxville, TN (61 km [38 mi]), Asheville, NC (80 km [50 mi]), Greenville, SC (130 km [81 mi]), and Atlanta, GA (217 km [135 mi]). These findings indicate poor conditions, and warrant significant concern for darkness of night skies at GRSM. This condition is based on NPS-NSP benchmarks and other sky quality metrics, discussed in more detail below.

Table 4.11.1. Photometric sky luminance indicators measured from Clingmans Dome, October 26, 2008.

Measure	Indicator	Observed mag/arcsec^2	Observed µcd/m^2	Estimated Artificial mag/arcsec^2	Estimated Artificial µcd/m^2	Light Pollution Ratio (Artificial/Natural)
Sky Luminance	Zenith	20.98	441	21.36	305	1.78
	Mean all-sky	19.72	1,406	19.95	1,118	4.50

Table 4.11.1 (continued). Photometric sky luminance indicators measured from Clingmans Dome, October 26, 2008.

Measure	Indicator	Observed mag/arcsec^2	Observed µcd/m^2	Estimated Artificial mag/arcsec^2	Estimated Artificial µcd/m^2	Light Pollution Ratio (Artificial/Natural)
Sky Luminance (continued)	Brightest	16.62	24,155	16.63	23,957	140.10
	Darkest	20.84	492	21.42	290	1.69
	Median	20.18	904	20.61	609	2.44

Table 4.11.2. Photometric illuminance indicators measured from Clingmans Dome, October 26, 2008.

Measure	Indicator	Observed mags	Observed millilux	Estimated Artificial mags	Estimated Artificial millilux	Light Pollution Ratio (Artificial/Natural)
Illuminance	Horizontal	-7.55	2.65	-7.13	1.80	2.25
	Max Vertical	-8.11	4.45	-7.72	3.11	7.78

Table 4.11.3. Sky quality luminance metrics from Cades Cove, October 29, 2008.

Measure	Indicator	Observed mag/arcsec^2	Observed µcd/m^2	Estimated Artificial mag/arcsec^2	Estimated Artificial µcd/m^2	Light Pollution Ratio (Artificial/Natural)
Sky Luminance	Zenith	20.93	460	21.50	268	1.57
	Mean all-sky	20.22	882	20.59	619	2.49
	Brightest	18.52	4,202	18.59	3,906	22.84
	Darkest	20.93	453	21.54	259	1.51
	Median	20.41	736	20.88	474	1.90

Table 4.11.4. Sky quality illuminance metrics from Cades Cove, October 29, 2008.

Measure	Indicator	Observed mags	Observed millilux	Estimated Artificial mags	Estimated Artificial millilux	Light Pollution Ratio (Artificial/Natural)
Illuminance	Horizontal	-7.35	2.21	-6.89	1.45	1.81
	Max Vertical	-7.04	1.66	-6.72	1.24	3.10

Clingmans Dome

When considering the entire sky, measurements from Clingmans Dome indicate the sky to be 450% brighter than average natural conditions. At zenith, or directly overhead, the sky is 178% brighter than average natural conditions. Measurements from the darkest part of the sky as observed from Clingmans Dome are 169% brighter than average natural conditions. At these light levels the Milky Way may be visible when it is directly overhead, otherwise it is not apparent. The Andromeda

Galaxy M31 may be barely visible. Little sense of naturalness remains in the night sky, and the landscape is clearly shadowed or illuminated. The horizon may appear aglow with anthropogenic light, and substantial glare may be present. In these conditions, full dark adaptation is not possible and circadian rhythms in wildlife may be disrupted.

Cades Cove

When considering the entire sky, measurements from Cades Cove indicate the sky to be 249% brighter than average natural conditions. At zenith, or directly overhead, the sky is 157% brighter than average natural conditions.

Overall, only one year of monitoring is reported, so no actual trend data are available. However, NPS-NSP uses the last five years of population growth of large cities or metro areas within 161 km (100 mi) of parks to estimate trend, with <10% growth indicating a neutral trend and >10% growth representing negative trend in sky quality. As such, the trend for GRSM is static based on the slow to moderate population growth (2.5%) of the Knoxville-Morristown-Sevierville combined statistical area (U.S. Census Bureau 2014).

Confidence and Data Gaps

Great Smoky Mountains National Park has only recently been included in the national assessment of park units for night sky brightness by NPS, and this monitoring will fill an important data gap. Confidence in the current assessment of condition was high, but the current assessment of trend was limited (Table 4.11.2).

Sources of Expertise

- Kate Magargal, Night Skies Program, National Park Service
- Jeremy White, Night Skies Program, National Park Service

Summary Condition

Table 4.11.2. Summary condition and trend graphic for night skies in GRSM.

Resource	Indicator	Status and Trend	Rationale and Reference Conditions
Night Skies	Anthropogenic light (all-sky light pollution ratio [ALR])	↔	The all-sky light pollution ratio (ALR), a measure of light pollution calculated as the ratio of anthropogenic sky glow to average natural sky luminance, was 4.50 and 2.59 as measured from Clingmans Dome and Cades Cove, respectively. These are considered poor conditions (Moore et al. 2013). Trend is static based on slow to moderate population growth of the Knoxville-Morristown-Sevierville combined statistical area (2.5% growth). (U.S. Census Bureau 2014).

4.11.2 Literature Cited

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Chapter 5. Natural Resource Conditions Summary

5.1. NRCA Overview

Great Smoky Mountains National Park comprises approximately 2,000 km^2 (772 mi^2) of almost entirely forested land in the southern Appalachian Mountains, and is characterized by rugged terrain, large elevation gradients, and highly varied aspects. The varied topography combined with complex geology and some of the highest precipitation levels in North America have helped create one of the most biodiverse regions in the world. GRSM is designated both as an International Biosphere Reserve and a World Heritage Site, and is an important refuge for rare species. This NRCA describes the current conditions and trends for the park's natural resources. These resource assessments were largely based on summarizing existing data in combination with expert judgement from NPS scientists and project collaborators. The primary goals of the NRCA were to (1) document the current conditions and trends for important park natural resources, (2) list critical data and knowledge gaps, and (3) identify some of the factors that are influencing park natural resource conditions. The information delivered in this NRCA can be used to communicate current resource conditions to park stakeholders. It will also be used to support park managers in the implementation of their integrated and strategic approach to the management of park resources.

5.2. Key Resource Summaries Affecting Management

Great Smoky Mountains National Park is responsible for the management and conservation of its natural resources as mandated by the National Park Service Organic Act of 1916. In 2011, GRSM staff identified and prioritized critical natural resource management issues when designing the park's vital signs monitoring program. This NRCA built on that work and identified four resource areas where management and monitoring are particularly important to achieving the park's mission. These are (1) air quality, (2) water quality, (3) non-native plants, animals, and diseases, and (4) biodiversity, particularly as reflected in rare plants and animals. These resource areas largely overlap with the top vital signs identified by park staff as most indicative of the park's overall health.

5.2.1. Air Quality

Great Smoky Mountains National Park experiences some of the highest measured air pollution of any national park in the U.S. This is likely because the park is located downwind of many sources of air pollution including fossil fuel burning power plants, industry, and automobiles. Some of these sources are nearby, while others are transported from industrial cities of the Southeast and Midwest. Air pollution from acid deposition has been shown to cause measureable effects on ecosystem structure and function. Sulfate and nitrate wet deposition values recorded in GRSM indicate levels are high, easily exceeding ecological thresholds and warranting significant concern. Atmospheric deposition of mercury can lead to contamination of aquatic systems as well, which can ultimately result in human health issues. Total mercury wet deposition in GRSM has been well above natural background levels since monitoring began in 2002. Ozone has been recognized as the most widespread air pollutant in eastern North America, causing impacts to human health. It is concentrated in mountainous regions like the Smoky Mountains, and although ozone levels exceed reference conditions, long-term trends suggest they are improving. Particle pollution represents one of the most widespread human health threats, possibly greater than ozone because it can occur year-round. Most recent data for particle pollution show it below ecological thresholds, but there are insufficient long-term data to suggest this trend will continue, and thus particle pollution still warrants significant concern. Haze is a general term for one of the most basic forms of air pollution that degrades visibility across the landscape, and GRSM has consistently experienced values well in excess of estimated natural conditions. While most air quality indicators have improved in recent years (with the exception of wet nitrogen deposition) all indicators still exceed ecological and national standards and are of significant concern.

5.2.2. Water Quality

On a park-wide basis, stream water acidification resulting primarily from the atmospheric deposition of sulfur and nitrogen compounds is likely to pose the most significant threat to water quality and aquatic biota within the park. GRSM is particularly sensitive to atmospheric deposition due to the low natural buffing capacity of its soils and waters. At a finer resolution, acidification differs between sites and events, and is not only due to the influx of sulfate and nitrate associated with acid deposition, but the input of organic acids to stream waters. Higher elevation watersheds, subjected to higher atmospheric depositional fluxes of nitrate and sulfate, exhibit lower pH values (higher acidity) than lower elevation stream reaches. Both pH and acid neutralizing capacity (ANC) typically decline during rainfall events in response to the flushing of sulfate, nitrate, and dissolved organic carbon (organic acids) into streams, and the degree of alteration to stream water chemistry during stormflow is controlled in part by the hydraulic conductivity of the soil. Watersheds characterized by highly conductive soils exhibit lower base cation concentrations and higher nitrate and sulfate concentrations than watersheds possessing poorly conductive soils. Presumably, conductive soils allow acid deposition during rainfall events to pass quickly through to the stream channel. Neither nitrate nor sulfate concentrations have significantly declined in river waters over the monitoring period in spite of the notable decrease in acidic deposition in recent years. The lack of improved water quality is likely due to biogeochemical processes operating within upland soils and suggests that it will take decades for watersheds to recover from acidic deposition.

Stream water acidification is known to enhance the dispersal and bioavailability of metal cations. Dissolved aluminum, which is strongly correlated with pH and ANC, appears to have a significant negative effect on aquatic biota, which is a concern in GRSM. Its potential effects are unlikely to change until stream waters recover from acidification. Concentrations of other metals including copper, iron, manganese, and zinc are generally below threshold toxicity criteria. Data pertaining to mercury, as well as dissolved organic carbon, organic acids, and other contaminants are currently limited within GRSM. These parameters represent a gap in the current monitoring program.

5.2.3. Non-native plants, animals, insects, and diseases

Approximately 380, or 20%, of the vascular plant species found in the park are non-native. Many of these plants are found in disturbed areas, such as roadsides, areas of past wildfire, construction sites, and old home sites. The park has identified 53 non-native invasive plant species (NNIP) and is actively managing 28 species that are believed capable of displacing native plant communities, hybridizing with native plants, or interfering with cultural landscapes. Currently, there are over 900 treatment locations across the park, with some in remote and rugged areas. Treatment is extremely labor intensive and requires many hours from both paid staff and volunteers. Past and current efforts have successfully managed or even eliminated some invasive populations; however, the need to monitor and treat these species will continue indefinitely due to continuous entry from adjacent properties, park visitors, animals, or a myriad other human or natural mechanisms.

Non-native insects and diseases introduced from Europe and Asia are having devastating impacts on several keystone species within the park. Perhaps most reflective of these are the chestnut blight, balsam woolly adelgid, and hemlock woolly adelgid, which have largely eliminated American chestnut and Fraser fir from the forest overstory throughout the park. Only a small fraction of the park's hemlock trees have been treated, and these are surviving while many others have perished. Numerous other non-native insect and disease pests, such as dogwood anthracnose, gypsy moth, emerald ash borer, and thousand cankers disease will continue to threaten the park's forests. To date, there are few effective treatments to combat widespread infestations, leaving continuous monitoring and aggressive containment and elimination as perhaps the best strategy for preventing future outbreaks.

There are many exotic animal species documented in the Smokies landscape, but only a few are considered invasive. Considerable study and effort has been expended in recent decades on managing several invasive vertebrates, including feral hogs, rainbow trout, and brown trout. In addition to the non-native forest pests described above, several invertebrate species from other continents are having a deleterious impact on park resources. These include European honey bees, Chinese jumping earth worms, multicolored Asian lady beetles, and perhaps the Japanese rock-hole mosquito. Impacts of these invasive invertebrates can be locally intensive, and in some instances have resulted in park-wide extirpations of native species.

Some diseases in mammals, such as rabies, pseudorabies, hantavirus, and epizootic hemorrhagic disease have been relatively well-documented in the park and are episodic. Hantavirus variants are naturally found in a number of native park rodent species. Humans may be at risk of respiratory infection by this virus if inhaled in closed spaces where dry rodent feces are concentrated. White-nose syndrome (WNS) in bats is much more worrisome, and has been documented as causing serious losses in several rare bat species in the park. On-going park studies are a critical part of the nationwide research and monitoring efforts needed to develop strategies for the eventual recovery from WNS. The park's world-renowned amphibian fauna, especially salamanders, are reported to have undergone a significant loss in the past few decades. However this is still controversial within the scientific community since salamanders in particular, are very difficult to quantitatively monitor. The situation is unclear at present but is concerning to the park. Similarly, chytrid fungal infections have been confirmed in the park's anurans, but the long-term impacts are unclear at present.

5.2.4. Rare plants and animals (biodiversity)

Many parks and reserves have documented rare species occurrences, but the Smokies are demonstrably different. First, the park is a large (2,000 km^2 [772 mi^2]) area that has more elevational relief and geologic complexity than almost any other similar-sized area in eastern North America. This allows populations of native species that are subjected to environmental stressors, including acidic deposition, contaminant pollution, climate change, invasive species, and habitat conversion, to migrate within the park along a wide spectrum of moisture, temperature, topographic, geochemical, vegetation, and other gradients. Because they remain in the park, they are still protected. Second, as is true for the southern Appalachians in general, the park's many mountain peaks are archipelagos of biological islands. This means that evolutionary isolation between and among these cool, moist peaks has caused speciation of many new taxa. Thus, the park is a large, stable stronghold for rare, widely ranging species, and the only home for a number of unique species endemic to the region.

Park staff actively monitor populations of 36 rare plant species to ensure population survival. These species were selected based on potential or documented disturbances, federal and state listing, and park rarity. The types of disturbances impacting these species are both human-induced and naturally occurring, and include road and trail maintenance, wild hog rooting, deer browsing, forest succession, trampling, vandalism, poaching, and non-native plant invasions. However, most rare plant populations in the park have an unknown status, and are therefore not included in the long-term monitoring program. Among the park's animals, 38 vertebrates and at least 52 invertebrates (species groups like mollusks, aquatic insects, crustaceans, moths, bees) are listed by either North Carolina, Tennessee, or the U.S. Fish and Wildlife Service as threatened or endangered, or have been designated by NatureServe as G1 (critically imperiled globally) or G2 (imperiled globally). Some of the fish and bats, and almost all of the invertebrates that are listed are endemic to the region, if not the park itself. While the park has been actively restoring a few rare vertebrates like peregrine falcons, red wolves, and several fishes, clearly these efforts need to be expanded to many other creatures.

5.3. Compiled Resource Assessment Summary Condition

Table 5.3.1 contains the resource condition summary tables for each Level 3 resource assessed in this NRCA. These provide a snapshot of the current condition and trend for park resources.

Table 5.3.1. Resource condition summaries for Level 3 resources assessed in this NRCA.

Resource	Indicator	Status and Trend	Rationale and Reference Conditions
Air Quality	Sulfur deposition (kg/ha/yr)	⇧	Values have declined since 1981 but still exceed the NPS ARD "significant concern" level of >3 kg/ha/yr wet deposition; 5-yr annual average wet S deposition: 3.33 kg/ha/yr. Data source: NADP Elkmont (Site TN11).
	Nitrogen deposition (kg/ha/yr)	⇔	Total wet N deposition trend is unchanging from 2004-2013. Nitrate values have declined since 1981 but ammonium values have increased; levels still exceed the NPS ARD "significant concern" level of >3 kg/ha/yr wet deposition; 5-yr annual average wet N deposition: 3.79 kg/ha/yr. Data source: NADP Elkmont (Site TN11).
	Mercury (µg/l)	⇧	Based on data from 2003-2012, the condition level is of high concern but the trend has been improving (see Fig. 4.1.2.3). Five-yr annual average wet Hg deposition: 14.08 µg/m^3, and Hg in precipitation: 8.52 µg/l. Data source: MDN Elkmont (Site TN11).

Table 5.3.1 (continued). Resource condition summaries for Level 3 resources assessed in this NRCA.

Resource	Indicator	Status and Trend	Rationale and Reference Conditions
Air Quality	Sulfur deposition (kg/ha/yr)	⇧	Values have declined since 1981 but still exceed the NPS ARD “significant concern” level of >3 kg/ha/yr wet deposition; 5-yr annual average wet S deposition: 3.33 kg/ha/yr. Data source: NADP Elkmont (Site TN11).
	Ozone (ppb)	⇧	Values have declined since 1990; levels at all monitors still exceed NPS ARD “moderate/significant concern” levels of 60 ppb; 5-yr average of 4th highest 8-hr average: 74 ppb. None of the park’s O_3 monitors exceed 2008 NAAQS of 75 ppb; “non-attainment.” Data source: NPS park monitors.
	Particulate matter$_{2.5}$ (µg/m^3)	⇧	Values have declined since 1999; most recent levels at all monitors except Knox Co, TN have fallen below the annual standard of ≤12 µg/m^3. Five-yr average of PM$_{2.5}$ concentration (at Look Rock): 7.06 µg/m^3; “non-attainment.” Data sources: EPA NAAQS, IMPROVE.
	Visibility (deciviews)	⇧	Values have improved since the late 1990s; levels exceed the NPS ARD “significant concern” level of >8 dv above natural conditions; 5-yr average of 20% haziest days is 22.5 dv (11.2 dv over natural conditions). Data sources: IMPROVE and NPS.
Soil Quality	Soil pH	⇩	Soil and water exposure to acids via atmospheric deposition and hematite exposure reduce soil pH. Forested soil pH conditions typically range from 4.0 to 6.5, but can be as basic as 9.0 in the case of soils derived from basic substrates. Soil pH in peer-reviewed literature in high-elevation southern Appalachian forest systems ranged from 3.8 to 5.2 (Taylor 2008), 4.0 to 4.5 (Cai et al. 2010), and 4.17 to 4.61 (Neff et al. 2013).
	Soil acid neutralizing capacity	⇩	Soil is exposed to continual atmospheric deposition and cation leaching.
	Soil cation exchange capacity	⇩	Declining as a result of leaching impacts from low pH precipitation (less than 4% of GRSM soils are assessed for CEC).
	Soil base saturation	◌	Continued leaching of base cations as a result of acidic atmospheric inputs lower base saturation and increase soil water acidity. There is a lack of data from GRSM on this topic.
	Soil Ca:Al ratio	⇔	Low calcium mineralization rates and high soil leaching of calcium, coupled with decreasing soil pH, results in aluminum toxicity.

Table 5.3.1 (continued). Resource condition summaries for Level 3 resources assessed in this NRCA.

Resource	Indicator	Status and Trend	Rationale and Reference Conditions
Soil Quality (continued)	Soil organic layer and soil C	🟡⇧	Forested regions continue to accumulate organic matter and soil carbon as they recover from earlier logging disturbances and areas that had previous agricultural impacts.
	Soil C:N ratio	🟡⇧	Soil carbon is increasing, but soil nitrogen is variable across elevational gradients, due to plant uptake and atmospheric deposition.
Water Quality	Hydrogen (H^+) concentration (pH)	🔴⇔	There is high spatial variability between watersheds, but base- and stormflows are often below a pH 6.0 and/or exhibit a pH change over one unit within 24 h. Temporal trends are also variable across the park, but significant recovery of pH to meet acceptable targets will likely take decades to centuries. Reference condition: Tennessee State Water Quality Standard for fish and aquatic life.
	ANC, Difference between proton acceptors and donors in stream water (µeq/L)	🔴⇔	There is high spatial variability between watersheds, but base- and stormflows are often below the reference target of 50 µeq/l; significant recovery to reasonable declines in atmospheric sulfate and nitrate deposition will likely generate mixed responses between watersheds within the park. Reference condition: Tennessee State ANC TMDL default target set for the GRSM (TDEC 2010).
	Concentration of sulfate (µeq/L)	🔴⇔	Sulfate concentrations are well above the 12 µeq/l proposed as a general reference target. Reference condition: based on estimated pre-industrial concentrations and values measured at Coweeta Hydrologic Laboratory.
	Concentration of nitrate (µeq/L)	🔴⇔	Nitrate concentrations are well above the 5 µeq/l proposed as a general reference target. Reference condition: based on estimated pre-industrial concentrations and values measured at Coweeta Hydrological Laboratory.
	Stream water temperature (°C)	🟢⇔	Temperatures of headwater streams are consistently below reference standard; higher-order streams may occasionally exceed reference standard by ~1 °C during summer months. Reference condition: based on North Carolina and Tennessee standards for aquatic life.
	Specific conductivity of water (µS/cm)	🟢⇔	Conductivity values of stream waters are consistently below reference standard. Reference condition: based on regional data collected from "reference" basins.

Table 5.3.1 (continued). Resource condition summaries for Level 3 resources assessed in this NRCA.

Resource	Indicator	Status and Trend	Rationale and Reference Conditions
Water Quality (continued)	Organic acids, charge balance discrepancy (µeq/L)	◌	Limited data both within the park and nationally.
	Dissolved organic carbon, carbon content in water passing through 0.45 µm filter (mg/L)	◌	Limited data collected during base and storm-flows suggest values are similar to those measured in relatively undisturbed basins. Reference condition: based on national data.
	Dissolved aluminum concentration, aluminum in water passing through 0.45 µm filter (µg/L)	🔴↔	Concentrations of dissolved aluminum frequently exceed the 200 µg/l reference value. Reference condition: based on review of toxic effects to biota by Cai et al. (2012).
	As, Cu, Mn, Fe, Zn Concentration, total and/or dissolved concentrations (µg/L)	🟢↔	Concentrations of these metals rarely exceed the reference values. Reference condition: based on EPA and/or state guidelines.
	Hg concentration, total and/or dissolved Hg (µg/L)	◌	Data within the park are limited. Reference condition: based on EPA guidelines.
	Various chemicals, dissolved concentration (µg/L)	◌	Data within the park are lacking. Reference condition: EPA and/or Tennessee guidelines exist for a few contaminants in this class; no guidelines exist for a majority.
Invasive Species	Presence of non-native invasive plant species	🟡↓	Reference condition is defined as maintaining NNIP species at manageable and non-damaging levels. There are serious challenges to preventing the introduction of NNIP species into the park, and identifying and treating all existing populations.
	Invasive/exotic animals	🟡↓	Invasive hogs and trout numbers are reduced, but Eurasian insects and earthworms and rusty crayfish are generally increasing. Other exotic invasives are approaching this region. Future increased hobbyist animal trade and accidental introductions are very unpredictable.

Table 5.3.1 (continued). Resource condition summaries for Level 3 resources assessed in this NRCA.

Resource	Indicator	Status and Trend	Rationale and Reference Conditions
Focal Species or Communities	Oak-Hickory Forests	🟡⇔	Reference condition is a mosaic of stands ranging from open woodlands to closed forests. Oaks and hickories are represented in all canopy layers, with minimal amounts of non-native insects, diseases, and plants. Threats include shifts in species composition and a more closed forest canopy due to fire suppression, infestations of non-native insects and diseases, and climate change.
	Pine-Oak Forests	🟡⇩	Reference condition is a mosaic of open woodlands and closed canopy forests dominated by pine species and some oak species, especially chestnut and scarlet oaks, with a rich herbaceous layer. Concerns include reductions in pine and oak regeneration, increased litter and duff thickness, exacerbated southern pine beetle outbreaks, increased mountain laurel density, and decreased overall herb abundance and diversity.
	High-elevation Hardwood Forests	🟡⇩	Reference conditions include a mosaic of stands with a high component of northern hardwood species, intact and undisturbed soils, and a dense and diverse herbaceous layer in most areas. Impacts include disease, wild hogs, acidic deposition, and climate change, causing reductions in basal area and density of key species, soil acidification and physical disturbances, reductions in herbaceous vegetation and soil fauna.
	Cove Hardwood Forests	🟢⇩	Reference conditions for Cove Hardwood Forests consist of a mosaic of uneven-aged forests with dense tree canopies and rich herbaceous layers. They typically occur in protected positions on some of the most productive soils in the park and support a large number of mesic tree, shrub, and herbaceous species.
	High-elevation Spruce-Fir Forests	🔴⇔	Reference conditions consist of uneven-aged forests dominated by a dense, healthy overstory dominated by red spruce, Fraser fir, and yellow birch growing on a well-developed organic soil layer. Impacts include Balsam wooly adelgid and acid deposition.
	Early Successional Forests	🟢⇔	Reference conditions consist of communities comprised of native, early successional species that are resilient following future disturbances, or if left undisturbed, would develop into Montane Alluvial, Cove Hardwood, or other native forest communities. Impacts include southern pine beetle, thousand cankers disease, butternut canker, and other insects and diseases, ozone climate change, and invasion by non-native exotic plants.

Table 5.3.1 (continued). Resource condition summaries for Level 3 resources assessed in this NRCA.

Resource	Indicator	Status and Trend	Rationale and Reference Conditions
Focal Species or Communities (continued)	Hemlock Forests	🔴↔	The reference condition for Hemlock Forests consists of having 50% or more of the canopy dominated by hemlock trees in a mesic environment, and an undergrowth consisting of acid-tolerant species with low species richness. Trees in developed areas and selected stands have been treated for hemlock woolly adelgid and many have survived, but outside treatment areas, high mortality has occurred. However, until there is a permanent solution, the cost of treatment programs brings into question the sustainability of such efforts.
	Montane Alluvial Forests	🔴↔	Reference conditions consist of forests dominated similar to what would be found in Cove Hardwood Forests, though also containing American sycamore (*Platanus occidentalis*), river birch (*Betula nigra*), and smooth alder (*Alnus serrulata*), and butternut (*Juglans cinerea*) growing on fertile alluvial soils that are periodically flooded. Impacts of historical land use, non-native exotic plants, and climate change.
	Heath Balds	🟢↔	Reference condition for Heath Balds are dense stands of ericaceous shrubs with few to no trees and little to no herb layer growing on acidic, organic soils. With the exception of landslides, there are no major stressors.
	Grassy Balds	🔴↔	Reference conditions include natural, or apparently natural, non-forested high mountain complexes dominated by grasses and sedges. Impacts of plant succession, non-native invasive plants, horses, and wild hog. Most areas that were grassy balds have either reverted back to forest or are in a state of transition to forest.
	Wetlands	🔴↔	Reference conditions include plant communities dominated by native, hydrophytic vegetation growing in areas where soils are saturated throughout much of the growing season. Impacts include hydrologic alterations, non-native invasive plant species, and wild hog rooting. There is a need for more surveying.
	Freshwater invertebrates	🟢↔	The NCBI was used to assess status and trends using the guidelines established by NCDENR. Confidence in the assessment is based on many years of bioclassification scores.
	Pollinators	🔴↓	The best reference data for pollinators are the systematic Malaise trap collections of the ATBI that occurred from 1999 to 2002 at 11 sites (Parker and Bernard 2006). Threats include pesticide overuse, habitat destruction, and climate change.

Table 5.3.1 (continued). Resource condition summaries for Level 3 resources assessed in this NRCA.

Resource	Indicator	Status and Trend	Rationale and Reference Conditions
Focal Species or Communities (continued)	Endemic invertebrates	🔴⇩	The 60 plots surveyed by Keller (2012) are the reference for endemic land snails, and other high-elevation endemic invertebrates. Air quality issues and the loss of three dominant tree species are the major threats to these species.
	High elevation fishes	🟢⇔	Brook trout density trends and professional opinion were used to assess status and trends. Abundances were variable, but there were no obvious upward or downward trends.
	Low elevation fishes	🟢⇔	Historic large-stream sampling and professional opinion plus recent IBI scores were used to assess status and trends. Lower confidence is based on the small number of IBI scores currently available.
	Extirpated and reintroduced species	🟢⇧	Densities and evidence of reproduction of three re-introduced species were used to assess status and trends.
	Amphibians	🟡⇩	Ideal reference condition would be the pre-settlement condition. Amphibians generally may be declining. Ranavirus, Bd, invasive species, and climate change are the major concerns.
	Reptiles	🟢⇔	Ideal reference condition would be the pre-settlement condition. Reptiles will likely increase as prescribed fire is increased. Closed canopies, lack of fire, and emerging diseases are the major concerns.
	Birds	🟢⇔	There is little or no scientific data on which to base a reference condition. However, generally the condition of birds in the park is stable.
	Mammals	🟡⇩	No previous reference thresholds. Nearly half of park's bat species are in serious, rapid decline. There have been recent re-patriations, but other single-species losses. Many small species with no recent data.
At-risk Biota	Threatened and endangered plants	🔴⇔	The reference condition is considered to be viable populations of all threatened and endangered plant species currently existing in the park. The stressors that negatively impact these species, such as road and trail maintenance, wild hog rooting, deer browsing, forest succession, trampling by park visitors, poaching, decline of associated species, and non-native plant invasions are well documented throughout the park.
	Threatened and endangered animals	🔴⇩	No previous reference thresholds; in current weighted analysis of 92 rarest animals, nearly 1/2 indicated high influence from at least one stressor.

Table 5.3.1 (continued). Resource condition summaries for Level 3 resources assessed in this NRCA.

Resource	Indicator	Status and Trend	Rationale and Reference Conditions
Consumptive Use	Ginseng and ramps	🔴 ⇩	The reference condition includes viable populations that will sustain themselves into the foreseeable future throughout their native habitats. It is inferred that this condition will require little to no illegal harvesting. Ginseng populations in the park are just barely regenerating enough to replace lost plants and cannot tolerate illegal harvesting. Ramp popularity remains extremely high and it is highly likely that illegal harvesting of ramps is occurring at unsustainable levels.
	All other species	◌	The reference condition is viable populations that will sustain themselves into the foreseeable future throughout their native habitats. It is inferred that this condition will require little to no illegal harvesting. Because there is no formal monitoring program, we have no information on the current condition or trend for these plants.
Landscape Condition	Forest loss & fragmentation (Trends from 1992-2011)	🟡 ⇩	Trends in all indicators show a loss of forest and an increase in fragmentation adjacent to GRSM. LULC changes inside the park may have stabilized, although the potential impacts of adjacent LULC changes in nearby areas are of concern.
	Historic soil disturbance (Relative severity and potential duration of impacts.)	🟢 ⇔	While some areas were heavily impacted, historic impacts occurred prior to park establishment and many areas are assumed to have recovered. Trend is assumed given the protected status of these areas now.
Extreme Disturbance Events	Wind and wind throw	◌	Potential loss of human life warrants significant concern. Due to infrequent nature of events, and their inherent natural occurrence, assessment of both condition and trend is not applicable.
Acoustic Environment	Acoustic impact level, a modeled measure of the noise (in dBA) contributed to the acoustic environment by man-made sources.	🟢 ⇩	The condition of the acoustic environment is assessed by determining how much noise man-made sources contribute to the environment through the use of a national noise pollution model. The mean acoustic impact level at the park is 0.2 dBA, meaning that the condition of the acoustic environment is good. Overall, long-term projected increases in ground-based (U.S. Federal Highway Administration 2013) and aircraft traffic (Federal Aviation Administration, 2010) indicate a deteriorating trend in the quality of acoustic resources at this location.

Table 5.3.1 (continued). Resource condition summaries for Level 3 resources assessed in this NRCA.

Resource	**Indicator**	**Status and Trend**	**Rationale and Reference Conditions**
Night Sky Quality	Anthropogenic light (All-sky Light Pollution Ratio (ALR))	↔	The all-sky light pollution ratio (ALR), a measure of light pollution calculated as the ratio of anthropogenic sky glow to average natural sky luminance, was 4.50 and 2.59 as measured from Clingmans Dome and Cades Cove, respectively. These are considered poor conditions (Moore et al. 2013). Trend is static based on slow to moderate population growth of the Knoxville-Morristown-Sevierville combined statistical area (2.5% growth). (U.S. Census Bureau 2014).

Appendix: Notes on the Status of Rare Animal Species, and Possible Stressors

Species	Common Name	Notes on status in park and possible stressors (various sources)
Mammals	Rafinesque's big-eared bat	One of largest hibernacula in GRSM; WNS not acute.
	Carolina northern flying squirrel	Sub-species largest population is in GRSM; high-elevation acid inputs may be affecting fungal food sources.
	Southern rock vole	Mostly obligate to rock talus sites.
	Gray bat	Documented on park boundaries. One sight report in GRSM. WNS and cave disturbances are possible stressors.
	Small-footed bat	Few records available. Roosts in buildings in GRSM.
	Northern long-eared bat	Records over creeks in GRSM; 94% decline post WNS in park, prescribed burns may be beneficial.
	Indiana bat	Lower elevations; critical habitat hibernacula in GRSM; 99% decline, post WNS.
	Southern water shrew	Few records; mid-elevation streams; poorly known, aquatic insect prey may be affected by acid deposition.
	Appalachian cottontail	Few, higher elevation records; declining in north; may be impacted by recently invading coyotes.
Birds	Saw-whet owl	Southern Appalachian population is most genetically diverse population of this species; may be linked to spruce-fir habitat status.
	Golden eagle	Legacy and very recent documentation; found at high elevations, especially open areas; may not breed in GRSM.
	Common raven	Low to high elevations, congregates in winter; increasing in northeast U.S. recently.
	Peregrine falcon	Recently de-listed federally, impacted by disturbance of cliff sites, recovering but periodic monitoring required.
	Bald eagle	Recently de-listed federally; breeding activity observed in GRSM; pesticide bio-magnification was an issue in the past.
	Southern Appalachian red crossbill	This sub-specific taxon may require a mixture of stands of different conifer species, erratic migration between regions.
	Red-cockaded woodpecker	Was found in western GRSM pinelands, but last seen 1980s before fire management; needs sparse shrub layer, old pines to nest.
	Southern Appalachian black-capped chickadee	Upper elevation, breeding distribution well mapped; susceptible to acid deposition-snail (calcium) loss.
	Cerulean warbler	Several breeding season records from ~CY2000, tall hardwoods on steep slopes may be required. No recent data.
	Southern Appalachian bewick's wren	Last records in 1950s, may no longer breed in eastern U.S. perhaps due to house wren competition.

Species	**Common Name**	**Notes on status in park and possible stressors (various sources)**
Birds (continued)	Golden-winged warbler	Higher elevation, requires early successional vegetation to breed.
Reptiles	Northern pine snake	Several lower elevation records in areas with sandy soils/dry pinelands; may benefit from fire management.
Amphibians	Green salamander	1930 specimen, recent unconfirmed report; may be linked to old-growth.
	Hellbender	Known in several watersheds but only one thriving population, though it is unclear why.
	Southern pygmy salamander	High elevations and moist aspect mid elevations; susceptible to disease and acid deposition.
	Seepage salamander	Found in seepage areas, and wet leaf litter in SW quarter of park; susceptible to hog disturbance and disease.
	Junaluska salamander	Found in west end at lower elevations in larger creeks and adjacent woods. Low populations.
Fish	"Smoky dace"	Unclear taxon; sub-specific differentiation unresolved; may be stable.
	Spot-fin chub	Extirpated by1957 piscicide event, repatriation apparently not successful.
	Banded sculpin	Little River, Middle Prong Little Pigeon River, moderate to high densities; may be fairly stable.
	Tuckaseegee darter	Known from boundary area creeks mostly on NC side; unclear status in park.
	Citico darter	Extirpated from Abrams Creek in 1957; re-patriated and apparently stable.
	Wounded darter	Lower Little River, low densities, status unclear.
	American brook lamprey	Mostly TN-side streams, low elevations; peripheral distribution, algae/detritus feeder.
	"Sicklefin redhorse"	Larger creeks, relegated to tributaries of Fontana Reservoir; taxonomy unresolved.
	Smoky madtom	Extirpated by 1957 piscicide event, repatriation apparently successful, recovering.
	Yellowfin madtom	Extirpated by 1957 piscicide event, repatriation apparently successful, recovering.
	Blotchside logperch	Believed extirpated by Abrams Creek 1957 piscicide and reservoir event.
	Logperch	Found in Abrams and Tabcat Creeks in low densities.
	Olive darter	Found in low elevation, reservoir truncated streams in Swain County, NC.
Bivalves	Tennessee clubshell	Two TN-side streams; exotic mollusk competition; reservoir; requires certain fish species to reproduce.
	Mountain creekshell	Little River at FH Parkway-Walland; exotic mollusks, requires certain fish species to reproduce.

Species	**Common Name**	**Notes on status in park and possible stressors (various sources)**
Bivalves (continued)	Tennessee pigtoe	Abrams creek; reservoir habitat loss, exotic mollusks; requires certain fish species to reproduce.
Land Snails	Rustic tigersnail	Blount County, TN, GRSM lower elevations; calcareous slopes, status unclear.
	Summit covert	Endemic to Clingmans Dome area, GRSM; impacted by acidic deposition, requires calcium for shell.
	Clifty covert	Old-growth cove forest, TN side (only), impacted by acidic deposition, requires calcium for shell.
	Big tooth covert	GRSM endemic, declining, now mostly below a roadside where calcium available.
	Light glyph	Found in upland mixed hardwood litter, lower elevation NC side.
	Pink glyph	Found in rich forests and limestone areas at low elevation, TN side.
	Blue-footed lancetooth	Found in high and mid elevation mixed forests/gorges; some acid deposition influence expected.
	Smoky Mountain covert	GRSM near endemic; rock talus, mid to high elevations; declining due to acidic deposition influence.
	Fuzzy covert	Mid elevations in rock talus, mostly east end of GRSM; some acidic dep influence expected.
	Wandering globe	Found in high-elevation spruce/fir, northern hardwoods; impacted by acidic deposition, believed declining.
	High mountain supercoil	Found in upper Cataloochee watershed; impacted by acidic deposition.
	Mirey ridge supercoil	Found at high elevations, burrows into rock talus; impacted by acidic deposition.
	Lamellate supercoil	Found at higher elevations, mixed hardwoods in talus; impacted by acidic deposition.
	Open supercoil	Found mostly at lower elevations, in western and southern sides.
	Great Smoky slitmouth	Found in rich hardwood litter at high elevations; impacted by acidic deposition.
Arachnids	"Surprizing" daddy-long legs	Unusual opilionid, found in rich forests, poorly known but associated w/decaying hemlock logs.
	Spruce-fir moss spider	Found at very high elevation, windward sites; microhabitat easily dessicated, highly impacted by acidic deposition.
Crustaceans	French Broad crayfish	Found in lower Hazel Creek; narrow endemic; population truncated by reservoir.
	Tuckaseegee crayfish	Found in Oconoluftee River up to Bradley Fork; narrow endemic; habitat extends outside park in urban corridor.
	Gregorys cave amphipod	Found in ephemeral rimstone pools, Gregorys Cave, adequate water is essential.
	Sparse bristle amphipod	Found in ephemeral rimstone pools, Gregorys Cave, adequate water is essential.
Springtails	Copelands springtail	Reported for GRSM, currently no issues known.

Species	**Common Name**	**Notes on status in park and possible stressors (various sources)**
Mayflies	"Pale" epeorus mayfly	Reported for GRSM, currently no issues known.
	Sinclair's mayfly	Found in Blount County, TN portion of GRSM, currently no issues known.
Stoneflies	Smokies snowfly	Found in high elevations in east end of GRSM.
	Georgia snowfly	Found in low to mid elevations.
	Mountain needlefly	Found in springs, taxonomic status unclear.
	Smokies' needlefly	Rare, found in high elevation springs, impacted by acidic deposition; status unclear.
	Hairy springfly	Found in seeps and springs at scattered locations.
	NFG tiny winter black stonefly	Found at higher elevations, 1st order streams near Newfound Gap; may be impacted by acidic deposition. Status unclear.
Caddisflies	“Flint's” caddisfly	Found in high elevation streams; may be impacted by acidic deposition.
	“Chattanooga” caddisfly	Reported on Abrams Falls trail.
	“Excavating” caddisfly	Found at high elevations, reported at Indian Gap.
	“Lobate” caddisfly	Found at higher elevations.
	“Stylis” caddisfly	Found from low to high elevations, GRSM.
	Kolodski's caddisfly	Found in tributaries of the Middle Prong Little River; endemic to this area.
	“Singular” caddisfly	Found in seepage areas.
	"Neighbor" caddisfly	Found in small streams and springs at low elevation, Smokemont.
	"Friendship" caddisfly	Found in streams at several locales in GRSM.
	Celadon caddisfly	Found at mid elevations, Little Pigeon River, may be impacted by acid deposition.
	Mohr's caddisfly	Found at lower elevations.
Dragonflies	Mountain river cruiser	Found in Middle Prong Little Pigeon River, only population known in park.
Moths/Butterflies	Southern Appalachian Bates crescent	1930s specimens, recently reported in Haywood County, GRSM; larval host (aster) uncommon.
	"Milne's" looper moth	Widespread but very rare globally; one GRSM record at lower elevations in Swain County.
	Yellow stoneroot moth	Decline in NE U.S. due to deer herbivory on host (*Collinsonia*) of local distribution.
Bees	Rusty-patched bumble bee	Extreme decline most likely caused by introduced *Microsporidium* infection.

Species	**Common Name**	**Notes on status in park and possible stressors (various sources)**
Bees (continued)	Yellow-banded bumble bee	Extreme decline most likely caused by introduced *Microsporidium* infection.
Grasshoppers	Cherokee spur-throat	Found in GRSM at mid-elevations; requires open woodlands.
	Deceptive spur-throat	Found in higher elevation openings; Haywood County section, GRSM.
	Lobecercus short-wing	Requires open, high elevations, grassy balds.

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