National Park Service
U.S. Department of the Interior

Northeast Region
Philadelphia, Pennsylvania

A Natural Resource Assessment for Shenandoah National Park

Technical Report NPS/NER/NRTR—2006/071

ON THE COVER
Black bear: Shenandoah National Park (SHEN) supports the largest population of black bears (*Ursus americanus*) in Virginia, with 300-800 bears present in the park. This regionally significant wildlife resource may act as a source population of black bears for the Blue Ridge Mountains. NPS photo.

Greenstone cliffs: These greenstone rock cliffs at SHEN support a globally rare vegetation community—the high-elevation greenstone barren alliance. This plant community is endemic to the park and is represented by such species as Rand's goldenrod (*Solidago simplex* var. *randii*) and hemlock parsley (*Conioselinum chinense*). NPS photo.

Big Meadows: Big Meadows is a 49-ha (121-ac) ridge-top meadow located at an elevation of 1,067 m (3,500 ft) along Skyline Drive in SHEN. This high-elevation meadow supports the globally rare Blue Ridge mafic fen plant alliance. Big Meadows has probably persisted in its open state for the apst 10,000 years and is a haven for plants and wildlife that need open meadow habitat. NPS photo.

Shenandoah salamander: The Shenandoah salamander (*Plethodon shenandoah*) is a federally endangered species that is endemic to SHEN. This species, which closely resembles the more common red-backed salamander (*Plethodon cinereus*), is confined to three talus slopes within the park. Virginia Department of Game and Inland Fisheries photo.

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Executive Summary

This report provides an assessment of the currently available natural resource knowledge relating to Shenandoah National Park (SHEN). This report provides usable, understandable, and transferable information about the current status and significance of, threats to, and gaps in knowledge about the natural resources at SHEN. In addition, this report presents suggested management recommendations to help ensure proper stewardship of natural resources at SHEN. The knowledge contained in this report was translated into a natural resources report card so that current resource conditions and trends can be immediately understood by legislators, park managers, and the general public.

In order to conduct this assessment, all relevant reports, publications, and data files pertinent to natural resources in the park were synthesized and summarized. In addition, two workshops related to specific natural resources (geology and animal resources) were conducted and attended by park resource managers, academic, non-governmental (e.g., The Nature Conservancy) and governmental researchers, and research technicians. Workshop attendees helped summarize past and ongoing natural resource studies, identified gaps in knowledge about the resources, and suggested desired conditions and management prescriptions for natural resources at SHEN. In addition, participants provided their collective opinions regarding the significance of these natural resources. Key researchers and managers who could not attend the workshops were met with on an individual basis to obtain their input. Workshops were not held for other natural resource groups (e.g., air, water, plants) because technical summary reports or assessments had been prepared for these groups within the last three years.

A combination of high elevation, ancient geology, topographic variation, and natural- and human-caused disturbance regimes shaped the natural resource condition at SHEN today. Within this recovering, largely forested landscape, a variety of natural resources are intrinsically significant on a global, national, regional, or state (local) level, and are summarized below.

Level of Significance	Natural Resource
Global	Large expanse of mature and botanically diverse Northern Blue Ridge forest including 32,204 ha of designated wilderness.
	Globally rare and endemic High Elevation Greenstone Barren and Northern Blue Ridge Mafic Fen plant alliances.
	Abundant and diverse breeding populations of neotropical migratory birds, including cerulean warblers (*Dendroica cerulea*).
	Federally endangered and endemic population of Shenandoah salamander (*Plethodon shenandoah*).
National	Scenic vistas of Shenandoah Valley and the Virginia Piedmont
	High density of native brook trout (*Salvelinus fontinalis*).
	Federally endangered small-whorled pogonia (*Isotria medeoloides*) populations.
	Peregrine falcons (*Falco peregrinus*) nesting in their natural and historic habitat.
Regional	Catoctin Greenstone rock type.
	Old Rag Mountain grantie intrusion and granitic block fields.
	Rock outcrops that provide habitat for diverse plants and animals.

Reginal (cont'd)	Clear and cold headwater streams of three major river networks that have provided recreational opportunities for prominent U.S. leaders. Highest population of black bears (*Ursus americanus*) in Virginia; may be a source population for Blue Ridge Mountains. Diverse stream-side salamander assemblage.
State and Local	Burrowing worm trace fossil, *Skolithos*. Variety of state species and communities (e.g., Allegheny woodrats [*Neotoma magister*], Shenandoah Valley Sinkhole Ponds) of special concern. Variety of more-typically northern species of plants and animals including balsam fir (*Abies balsamea*), red spruce (*Picea rubens*), Canada yew (*Taxus canadensis*), red-breasted nuthatch (*Sitta canadensis*), and winter wren (*Troglodytes troglodytes*). Type locality for the Swift Run Rock Formation.

Although the aforementioned resources were identified as having global, national, regional, or state and local significance, many other natural resource elements were examined in the natural resource assessment. For example, this report provides an assessment of air resources (including a description of pollution, visibility, and soundscape issues) and recreational impacts to resources at SHEN.

A range of potential management recommendations to ensure the goal of protection of natural resources at SHEN were formulated and are presented in this report. A partial list is presented below.

Proposed Management Goal	Proposed Management Recommendations
Because the expanse of mixed deciduous forest in SHEN is a globally significant representative of the Northern Blue Ridge ecosystem, the diverse plant communities found within the park should be protected.	Minimize development of fragmenting landscape features within large, continuous forest blocks at SHEN. Maintain forest components that are currently declining such as oak-hickory forest and pine communities where they historically occurred. Maintain natural gap dynamics so that small, early successional patches of habitat that support associated bird species can persist. Protect park endemic plant communities (High Elevation Greenstone Barren and Northern Blue Ridge Mafic Fen) from visitor disturbance and maintain disturbance regimes, where appropriate, to ensure their persistence in the park.
Because SHEN supports an endemic species of salamander, *Plethodon shenandoahii*, and other populations of regionally significant salamander assemblages, habitat that support these species should be protected.	Initiate a population monitoring and life history study of the Shenandoah salamander to determine the status of each of the three isolated populations. Protect the talus slopes on which they are found from disturbance from development and visitor impacts. The small number of vernal pools that occur in SHEN provide valuable salamander breeding habitat and should be protected. Roads and other barriers should not be permitted in migration routes to these pools.

Because the streams of SHEN form the headwaters of three major rivers and support a high density of native brook trout, the water quality in these streams should be maintained and, if possible, restored from the effects of acid deposition, and threats to native brook trout should be removed.	Remove nonnative brown (*Salmo trutta*) and rainbow trout (*Oncorhynchus mykiss*) from native brook trout streams. Maintain connectivity in stream channels by clearing culverts and other in-stream barriers to fish movement. Maintain and enforce strict fishing regulations for brook trout in SHEN. Maintain sewage facilities so that fecal coliform does not enter stream waters. Work with Virginia's Department of Environmental Quality on Virginia's State Implementation Plan for air quality. These plans must be submitted to the EPA and document the rate of progress needed to achieve specific CAA Class 1 attainment goals. These plans could help achieve further reductions in acid deposition in Virginia.

An 80-year history of natural resource management at SHEN has permitted this forest landscape to recover from intensive resource use and change. Continued stewardship of the park's natural resources will require resource managers to cooperate with local, regional, and national officials and communities.

Furthermore, proper planning will ensure that human impacts to natural resources at SHEN are limited and the park will remain an outstanding example of the Blue Ridge Mountain ecosystem.

Acknowledgments

The natural resource assessment for Shenandoah National Park (SHEN) could not have been undertaken and completed without the help of many people. I wish to thank the National Park Service staff who assisted in many aspects of this effort. John Karish, Terrence Moore, and Bob McIntosh provided funding and contract management. Patricia Iolavera assisted with initial project planning. The staff at SHEN, including Gordon Olson, Wendy Cass, Alan Williams, Shane Spitzer, Dan Hurlbert, Steve Bair, Mary Bair, Rolf Gubler, Jim Atkinson, KellyAnn Gorman, and Eric Butler, provided oversight, review, comment, and invaluable support throughout the project.

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For professional assistance on individual resource topics, via their attendance at workshops, meeting with me personally, providing data analyses, or reviewing earlier drafts of this report, I thank Gary Fleming, Bruce Heise, Tim Connors, Carol McCoy, Bob Higgins, Jim Comiskey, John Young, Scott Southworth, Allen Belden, Joe Mitchell, Bill Witt, Joseph Weber, Larry Mohn, Scott Eaton, Dick Tollo, Steve Kite, Chuck Bailey, Kevin Heffernan, Robin Jung, Jeff Marion, Rick Webb, Andy Dolloff, Craig Snyder, Michael Vaughan, Michael Mengak, Mike Wilson, Dave DeSante, Phil Nott, Bryan Watts, Denny Martin, Nelson Lafor, Matt Knox, Alan Ellsworth, Holly Salazer, and Tonnie Maniero. As previously stated, many of these professionals, including the SHEN park staff, reviewed earlier versions of this report. Any errors found in this final document are my own.

Introduction

Each unit of the National Park Service (NPS) must maintain an up-to-date General Management Plan (GMP) (NPS 2001). The purpose of a GMP is to ensure that each park has a clearly defined direction for resource preservation and visitor use (NPS 2001). A park's GMP should be based on current scientific and scholarly understanding of park ecosystems and help to ensure that decisions are consistent with park purposes (NPS 2001).

Unfortunately, the information needed for developing a useful GMP usually has not been synthesized to provide a collective description of the status and significance of park natural resources. In addition, park staff turnover reduces institutional knowledge of the content of past studies and data collection efforts. Past research, therefore, becomes a matter of historical record and copies of most documents frequently are located only in the park. Information requirements often are overlooked or unknown early in the planning process. In many cases potentially usable data have not been systematically identified and mapped using Geographic Information Systems (GIS). Without GIS, the information is not readily available for use in general management or facilities planning.

In 1999, the NPS announced the Natural Resource Challenge, a 5-year program to strengthen natural resource management (Engquist 2001). The NPS strategy to meet the challenge identified the need for a new planning framework which ensures that available natural resource information is synthesized and interpreted for planning purposes, with information gaps and the significance of the natural resources (in a global, national, regional, and state [local] context) analyzed.

Shenandoah National Park (SHEN) is scheduled to begin its GMP process within the next few years. Therefore, the purpose of this report is to provide usable, understandable, and transferable information about the current status and significance, threats, and gaps in knowledge for the natural resources found in SHEN. In addition, suggested management recommendations are provided that aim to assist resource managers in the stewardship of the natural resources at the park. The information provided in this report will ensure that up-to-date and relevant natural resource data will be incorporated into the planning process at SHEN.

Study Area

Shenandoah National Park (SHEN) was authorized by an Act of Congress on May 22, 1926 (44 Stat. 616) and established on December 26, 1935 for "the preservation from injury or spoliation of all timber, mineral deposits, natural curiosities, or wonderful objects within said park, and for the protection of the animals and birds in the park from capture or destruction, and to prevent their being frightened or driven from said park." The authorization of SHEN directed the NPS to administer, protect, and develop SHEN in accordance with the NPS Organic Act (39 Stat. 535). In addition, the designation of 40% of the park as wilderness in 1976 obligated SHEN to administer these lands "in accordance with the applicable provisions of the Wilderness Act" (Public Law [PL] 04-567). SHEN also contains a portion of the Appalachian Trail, the nation's longest marked footpath (3,500 km [2,175 mi]), and must administer this section of the trail as a National Scenic Trail "to provide for maximum outdoor recreation potential and for the conservation and enjoyment of the nationally significant scenic, historic, natural, or cultural qualities of the areas through which such trails may pass" (PL 90-543). The Appalachian Trail was the first national scenic trail, designated in 1968. Finally, Camp Hoover, the Rapidan Camp of President H. C. Hoover, is a National Historic Landmark and adds a significant cultural element to the landscape.

SHEN is located along the narrow Blue Ridge Mountains in northwestern Virginia and lies closer to more people than any other park in the country (Conners 1988). The Blue Ridge Mountains are the eastern-most remnant of the ancient Appalachian mountain chain. There are 79,899.76 ha (197,411.6 ac) in the park, including 32,204.53 ha (79,579 ac) of designated wilderness. The park is divided into three management districts: North, Central, and South (Figures 1a., 1b., and 1c.). Elevations in the park range from 181 m (595 ft) at Front Royal to 1,234 m (4,049 ft) at the top of Hawksbill Summit. One notable aspect of the park is its 167-km (105-mi) Skyline Drive, which runs the entire length of the park and was one of the first recreational highways of its type in the United States when it was opened to the public in 1934 (Conners 1988). Part of SHEN's purpose is to maintain the Skyline Drive.

The Southern Appalachian National Park Commission (SANPC) was established in 1924 to recommend national park sites in the southern Appalachians. In its report to Congress it highlighted outstanding park features of what is now SHEN that included: " … mountain scenery with inspiring perspectives and delightful details … … forests, shrubs, flowers, and mountain streams with picturesque cascades and waterfalls overhung with foliage … ... " (SANPC 1933). Furthermore, the park's mission involves protecting the ecological integrity of the Blue Ridge/Central Appalachian biome, cultural resources, views of the Shenandoah Valley and Piedmont Plain, recreational opportunities, and "stories" of the park. Today, many of these park features and resources are threatened by poor air quality (which decreases visibility of vistas), acid precipitation (which degrades water quality), and invasive plants and pests (which threaten forest health). Because of these and other threats the National Parks Conservation Association (NPCA) designated SHEN as one of the country's most endangered National Parks in 2003 (NPCA 2003).

Figure 1. Maps depicting the North, Central, and South Districts of Shenandoah National Park, Virginia.

Figure 1a. North District, Shenandoah National Park, Virginia.

Figure 1b. Central District, Shenandoah National Park, Virginia.

Figure 1c. South District, Shenandoah National Park, Virginia.

Figure 1a. North District, Shenandoah National Park, Virginia.

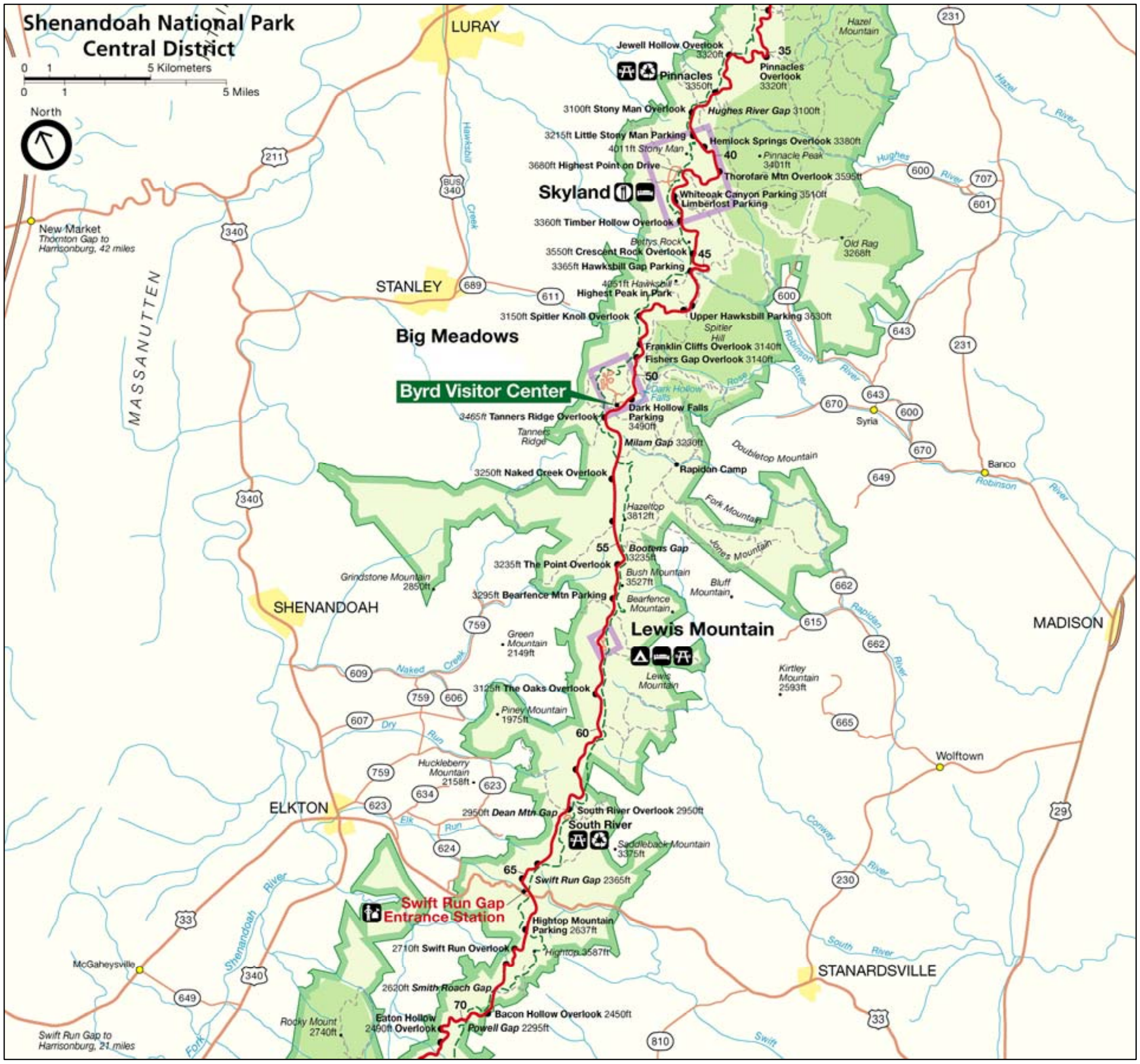

Figure 1b. Central District, Shenandoah National Park, Virginia.

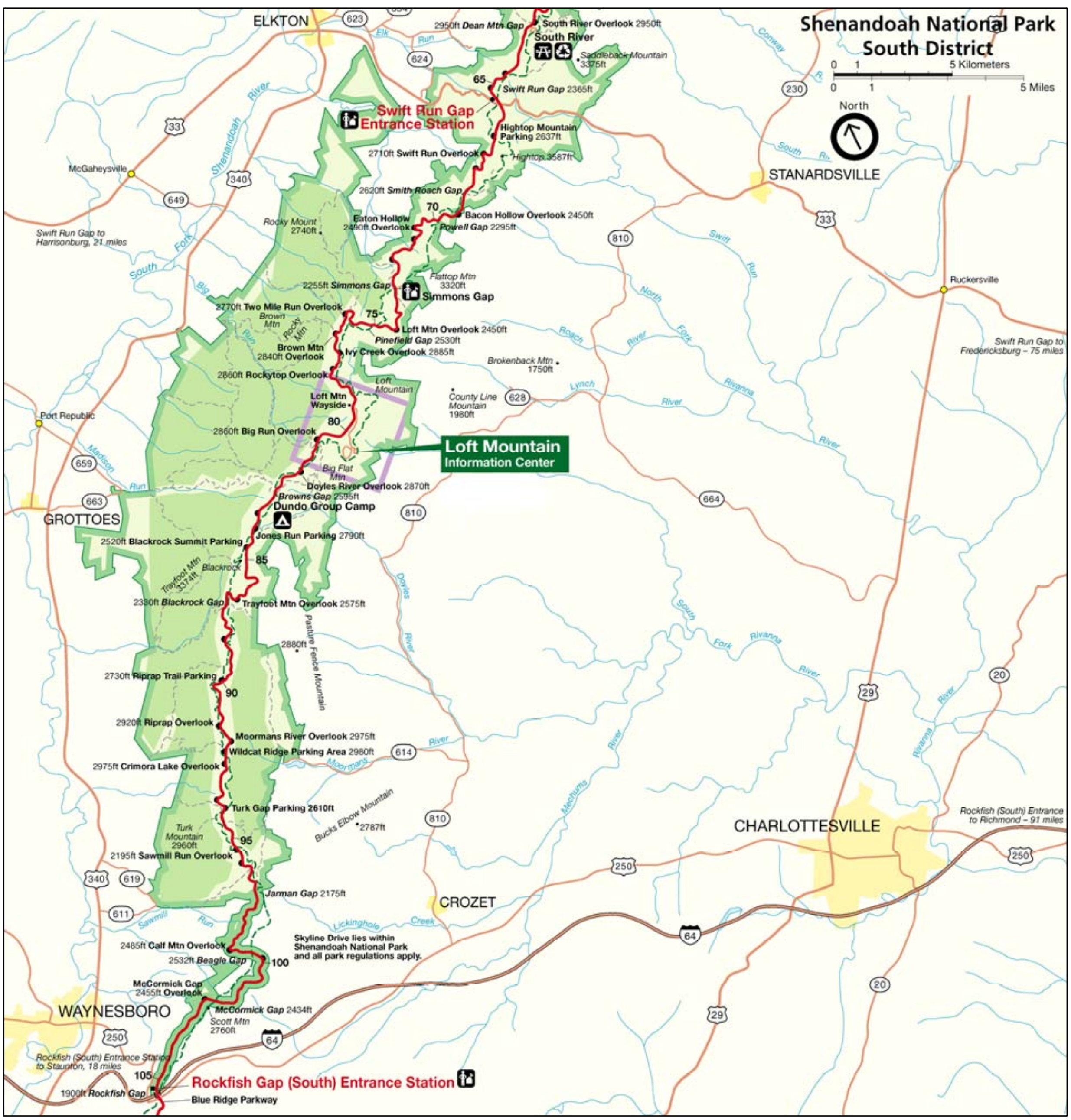

Figure 1c. South District, Shenandoah National Park, Virginia.

Due to its linear shape, SHEN also is threatened by encroachment from surrounding land use. SHEN is located in parts of eight counties in Virginia: Albemarle, Augusta, Greene, Madison, Page, Rappahannock, Rockingham, and Warren. During the period 2000–2004, populations in these counties increased an average of 5.6%, slightly higher than the state's average increase of 5.4%. Green and Warren counties exhibited the greatest change, with population increases of 11.7% and 8.9%, respectively (U.S. Census Bureau 2005).

Approximately 93% of SHEN is dominated by forested land cover, 2% is covered by wetland communities, and about 3% of the area is occupied by other natural communities such as barrens. Roughly 2% of SHEN is developed or disturbed by humans and includes drivable roads, parking lots, powerline rights-of-way, and buildings (Young et al. 2005).

The mean annual temperature in the lowland portion of the park near Luray, VA is 12°C (53.6°F) and average annual precipitation is 91 cm (36 in) with 43 cm (17 in) of snow. Mean annual temperature in higher elevations of the park is, on average, 3–6 °F cooler and average annual precipitation is 132 cm (52 in) with 94 cm (37 in) of snow (Sullivan et al. 2003a).

SHEN is a prototype park of the NPS's Natural Resource Inventory and Monitoring Program (NPS 2000). SHEN represents the deciduous forest biome and monitoring of air quality, water quality, plants, aquatic macroinvertebrates, and fish is conducted under their Long-term Inventory and Monitoring (LTEM) Program (NPS 2000). Very detailed, long-term trend data are available regarding the physical environment at SHEN. However, less is understood about the terrestrial biotic communities of the park. The park maintains limited reference and museum collections of primarily fish and botanical specimens. However, these collections are incomplete and efforts are underway to improve accessioning and cataloging.

A variety of recent assessment and natural resource plans have been completed at the park. For example, a Draft Fire Management plan is currently under review and will be completed in 2006. A vegetation cover type map and report also is under review and will be completed in 2006. A comprehensive Air Quality Assessment was completed in 2003 and a Water Resources Scoping Report was completed in 2004. A Resource Management Plan and a Wilderness and Backcountry Plan were both completed in 1998. Several plans, however, are greater than ten years old and these include management plans for black bear (*Ursus americanus* [1990]), white-tailed deer (*Odocoileus virginianus* [1986 draft only]), fisheries (1987), Big Meadows (1985), and several pests (cockroaches, flies, gypsy moths [*Lymantria dispar*], and hemlock woolly adelgid [*Adelges tsugae*] [NPS 1998]). Although specific management plans may not exist for all natural resources, park managers still incorporate recent research findings into their resource stewardship. For example, a rotation of fire, herbicide application, and mowing is being used to maintain the herbaceous plant communities at Big Meadows, a 49-ha (121-ac) ridge-top meadow located along Skyline Drive (Cass 1999).

Methods

Literature and Database Review and Workshops

In order to conduct the assessment of natural resources at SHEN all relevant reports and publications were identified by using NatureBIB®, searching park libraries, meeting with resource managers, and directly contacting researchers who have conducted projects pertinent to natural resources in the park. In addition, a literature search was conducted for articles based on natural resource research conducted in and around SHEN. For the literature search, I used electronic databases, referenced proceedings of conferences, meetings, and workshops, United States Department of Agriculture (USDA) and NPS technical bulletins, journal articles, and Web sites. Electronic databases included Agricola®, Biological Abstracts®, and Biological and Agricultural Index®.

After an initial review of natural resource literature and meeting with resource managers, general natural resource topics of particular relevance to SHEN, and for which no recent management plans or assessments existed, were identified. These topics, animal resources (terrestrial and aquatic animals) and geologic resources (soil and rock), then became the focus topics for two workshops held in Virginia during February and March of 2005. I did not hold focused workshops for air, water, or plant resources because detailed assessments or analyses of these resources had been completed within the past two years. Workshops were attended by invited resource managers, academic and governmental researchers, and research technicians. The purposes of the workshops were to identify all past and ongoing natural resource studies, recognize gaps in knowledge about the resources, and suggest desired conditions and management prescriptions (recommendations) for natural resources (Appendix A). In addition, the participants gave their collective opinion on what were the intrinsically significant natural resources found in SHEN. Attendees at these workshops also became the source of a cadre of knowledgeable natural resource professionals who could aid in the GMP process (Appendix B).

After workshops were conducted, a thorough review of all identified reports and publications was conducted. The information contained in the reports and publications then was consolidated, summarized, and synthesized in a manner that portrays historical and existing park ecosystems and identifies the inherently significant natural resources of the park. For each resource identified, current status, threats, gaps in knowledge, and suggested management recommendations for the resource were described and formulated.

Subcontractors and GIS

Due primarily to time constraints, I negotiated subcontracts with three research professionals to assist with the assessment. Dr. Joseph Mitchell of Mitchell Ecological Research, LLC, and the University of Richmond were asked to compete an assessment of terrestrial vertebrates; Dr. Scott Eaton of James Madison University was asked to complete an assessment of geologic resources; and Mr. John Young of the U.S. Geological Survey, Leetown Science Center, was asked to perform a Geographic Information Systems (GIS) analysis that would identify the regions of the park that contained forests with a diversity of habitat types and minimal fragmentation. Aside from this forest block analysis, GIS data sets are available for many natural resources at SHEN and were used in this assessment as needed (Appendix C). GIS data sets are becoming more prevalent as researchers provide georeferenced data points as part of their deliverables.

NPS Synthesis Information Management System

In order to provide an organized database containing the majority of the reports and documents cited in this natural resource assessment report, a Synthesis (information management system) database was created by the Synthesis Regional Support Center at James Madison University (JMU) in Harrisonburg, Virginia. Synthesis is an information management system for efficiently locating, organizing, integrating, and disseminating data and information. Synthesis presents the user with a simple, graphical user interface that functions as a gateway to information that may be stored on local computers, networks, intranets, or the Internet. From this single gateway, a user may view and integrate many types of information, including text-based documents, photographic libraries, databases, spreadsheets, presentation graphics, GIS data, bibliographies, Internet-based information, and decision support systems. Synthesis provides a means to link and share data, information, and applications. It does not replace existing databases or dictate the structure or function of other databases. Rather, it provides a set of pathways that link various sources of information.

The SHEN Synthesis database contains 434 full-text searchable documents cited in this natural resource assessment. Due to time constraints, not all documents cited in this assessment report are contained in the SHEN Synthesis database, but Synthesis can be updated continually. This report contains two Synthesis discs. The first, a CD, contains the executable files to run Synthesis and the second, a DVD, contains SHEN-specific data files. Additional copies of these discs are available from the Synthesis Regional Support Center (synthesis@jmu.edu). The data-file DVD can be continually updated so that an electronic version of all significant natural resource documents is always available for the park. Instructions for installing Synthesis are available in Appendix C.

Pre-European Settlement Natural Resource Conditions and Effects of Native Americans (pre-1750)

The human history in and surrounding what is now SHEN has been described and documented by many sources (e.g., Bruce 1895; Conners 1988; Lambert 1989; Moore 2003). This portion of Virginia was inhabited by people for the past 12,000 years and perhaps longer (Lambert 1989). The people that were encountered when the first European explorers arrived were the Woodland Indians and, more specifically, the Mannahoaks, as documented by Captain John Smith (Bruce 1895; Conners 1988; Lambert 1989). These native Americans were highly dependent on the plants and animals of the Blue Ridge Mountains, relying especially on white-tailed deer, black bear, and a variety of native plants, including cultivated tobacco (*Nicotiana tobacum*) and corn (*Zea mays*) (Bruce 1895; Lambert 1989). In order to increase the productivity of the plants and animals, low intensity fire was regularly used by the Woodland Indians to clear land for agriculture, assist in the management of favored vegetation, clear routes of travel, herd game, and even wage war on neighboring tribes (Lambert 1989; Abrams 1992; Brose et al. 2001). These fires probably varied in intensity and exerted a considerable influence upon vegetation composition. Early accounts from Virginia describe the landscape as consisting of open woodlands and grasslands resulting from the effects of these fires (Tigner 1998). Species, such as various oaks (*Quercus* spp.), pines (*Pinus* spp.), and American chestnut (*Castanea dentata*), would have benefited and, perhaps, spread their distribution due to these fires.

These fires also may have helped maintain Big Meadows in its open state. However, there is some archeological evidence that Big Meadows may have existed as open land since the archaic period of mountain tundra (10,000 years ago) (Lambert 1989; Moore 2003). This *in situ* archeological evidence helps explain the long (10,000+ year) history of human habitation in the northern Blue Ridge Mountains and has been identified as a globally significant cultural resource in the park's resource management plan (NPS 1998).

The pre-European forests were dominated by old-growth hardwood tree species such as white oak (*Q. alba*), red oak (*Q. rubra*), tulip poplar (*Liriodendron tulipifera*), and American chestnut (Braun 1950). American chestnut was the most widely dispersed and most commonly occurring tree in the Blue Ridge Mountains of Virginia during this time period. This species comprised 20–30% of all tree species, and in some stands may have comprised 50–80% of the overstory (Braun 1950; Conners 1988; Stephenson 1986; Stephenson and Adams 1989; NPS 1998; Moore 2003). The northern Blue Ridge Mountains also contained patches of old-growth red spruce (*Picea rubens*)/eastern hemlock(*Tsuga canadensis*)/balsam fir (*Abies balsamea*) forests at high elevations. These high-elevation forest tree species remain in small, scattered stands at SHEN and are remnants from the Wisconsin glaciation. Although glaciers never reached SHEN, their existence as far south as northern Pennsylvania modified the climate so that the Blue Ridge Mountains supported tundra and boreal forests (Bruce 1895; Crandall 1975). Another historic forest community that still persists in the park is the fire-dependent xeric pine community. Mature stands of xeric pines are characterized by trees that are 150–200 years old and 30–38 cm (12–15 in) in diameter at breast height (dbh) (Murphy and Nowacki 1997).

Although oak/chestnut forests dominated the historic landscape, old-growth, mixed-mesic stands of poplar and maple occurred in cool, moist ravines. The old-growth tree species in these mesic stands included white ash (*Fraxinus americana*), tulip poplar, sugar maples (*Acer saccharum*), and basswood (*Tilia americana*) and ranged in age from 150–400 years old (depending on species and forest community) and ranged in size from 76–114 cm (30–45 in) in dbh (Greenberg et al. 1997). Characteristics of all old-growth forest stands of the Blue Ridge Mountains were the presence of large trees for that species and that site (e.g., dbh >76 cm [30 in]), wide variation in tree size and spacing, accumulation of large dead (standing and fallen) trees, decadence in the form of decayed tops and boles and root decay, multiple canopy layers, and the occurrence of canopy gaps and understory patchiness. The lack of thick undergrowth in most old-growth stands was a notable feature of early Virginia's forest, perhaps due to intentional burning and the deep shade created by the closed canopy of the mature forests (Bruce 1895; Tigner 1998).

This old-growth forest landscape was interspersed with younger (second-growth) stands of oaks, hickory (*Carya* spp.), chestnut, and pine forest types due to the effects of burning and other natural disturbances, such as blow downs caused by storm events and individual tree falls (Brose et al. 2001). Severe storms and hurricanes are part of the normal disturbance regime in the Blue Ridge Mountains with storms containing hurricane-force winds and heavy, driving rains occurring every 80 years on average (Brinkman 1975). These storms and resulting tree falls probably contributed to the historic forest structure and composition at SHEN. In addition, open meadows, varying in size from 0.5–21 ha (1–52 ac), may have been scattered throughout the forest landscape due to repeated burning and clearing for agriculture. Therefore, the early explorers encountered a forest landscape with considerable species, community, and structural diversity.

Prior to 1750, wildlife in what is now SHEN included some species of birds and mammals currently extirpated from the area. For example, mountain lions (*Felis concolor*), elk (*Cervus elaphus*), bison (*Bison bison*), passenger pigeons (*Ectopistes migratorius*), Carolina parakeets (*Conuropsis carolinensis*) (on lower slopes), and gray wolves (*Canis lupus*) historically were found throughout the Appalachians and Blue Ridge Mountains (Bruce 1895; Weidensaul 1994). In addition, fishers (*Martes pennanti*) and porcupines (*Erethizon dorsatum*) may have occurred in SHEN, and the eastern subspecies of peregrine falcon (*Falco peregrinus anatum*) probably nested on the cliffs at Stony Man (NPS 1998). Also, northern flying squirrel (*Glaucomys sabrinus*), never documented in the park, may have occurred (or may still occur) in the high elevation, mixed spruce/hemlock/fir forests. Mountain lions, bobcats (*Lynx rufus*), black bears, and wolves would have preyed upon white-tailed deer and may have accounted for half of the annual deer mortality (after Redding 1995). This predation, coupled with predation by native Americans, would have resulted in a deer herd of about 4–8 deer/km^2 (10–20 deer/mi^2) in SHEN (Seton 1909, 1929). Diverse assemblages of neotropical migratory birds inhabited the mountain forests and populations of native brook trout (*Salvelinus fontinalis*) and stream salamanders occurred in headwater streams.

European fur traders and explorers had a limited effect on the wildlife of the Blue Ridge Mountains prior to permanent European settlement. Fur trading began in the mid-1550s and continued through the 1700s. The primary species targeted by these early traders (who often bought furs directly from native Americans) were deer, beaver (*Castor canadensis*), northern river otter (*Lontra canadensis*), bobcat, gray fox (*Urocyon cinereoargenteus*), and raccoon (*Procyon lotor*) (Lambert 1989).

Effects of European Settlement on Natural Resources (1750–1925)

Permanent settlement of the Blue Ridge Mountains in Virginia by Europeans began in the mid-1700s (Moore 2003). These settlers came to the Piedmont and Shenandoah Valley first, then moved up into the hollows and mountains. The earliest European settlers often did not own the land, but rather the land was owned by wealthy British landowners (Lambert 1989). The soil in the mountains was very thin, but due to the greenstone geology it was also very rich and fertile. Often, settlers would graze their livestock in the mountains during the spring and summer and bring the livestock to the valley during the colder months. These livestock may have played a role in maintaining Big Meadows in its open state.

By the late 1700s and throughout the 1800s, a variety of small homestead farms and larger plantations (commercial farms of 162 ha [400 ac] or more) were established in what is now SHEN (Lambert 1989). The establishment of these settlements had a variety of effects on the natural resources of the region. First, land clearing intensified. Forests were initially harvested for their lumber value. The cleared lands were then maintained in their open state to support agriculture, both subsistence and commercial. In addition, a variety of nonnative plants and animals were introduced by these settlers (Mazzeo 1966a). These nonnative plants can be broken down into two groups: 1) ornamentals that were used to landscape the homesites, and 2) trees or other plants that either produced fruit or were sold as a cash-crop in the nearby towns (Mazzeo 1966a). Mazzeo (1966a) provides a complete list of nonnative plants documented in SHEN. The most conspicuous, however, include tree-of-heaven (*Ailanthus altissima*), paulownia (*Paulownia tomentosa*), Norway spruce (*Picea abies*), and lily-of-the-valley (*Convallaria majalis*). These early settlers also planted native plant species. Some of these native plants persisting at old homesites include balsam fir, red spruce, eastern cottonwood (*Populus deltoides*), and osage-orange (*Maclura pomifera*) (Mazzeo 1966a).

The construction of roads, coupled with forest clearing by the early European settlers, lead to a fragmentation of the original Blue Ridge forest. Aside from logging to clear land for agriculture, commercial logging occurred throughout the Blue Ridge Mountains. By 1914, fewer than 4,047 ha (10,000 ac) of virgin timber remained in Virginia's Blue Ridge Mountains (Moore 2003). Lumber production increased rapidly in Virginia in the early 1900s, reaching its peak by 1909 (Wisdom and Hudspeth 1978). Deforestation may have acerbated soil erosion along the steep slopes of the Blue Ridge. Periodic, intense storm events (Brinkman 1975) also may have acerbated this soil erosion and had negative siltation effects on headwater streams.

Aside from logging and agriculture, limited industrial development, including charcoal making, iron production, and manganese and copper mining, occurred in and around what is now SHEN (Conners 1988; Lambert 1989). For example, copper mines were present near Stony Man and Dark Hollow Falls. Manganese mines and the associated ponds are still evident on the western slopes of the park. There is some evidence that the proposed park boundary was modified to leave out this historic source of manganese (Lambert 1989). These industrial activities and associated roads and railroads probably affected the intensity and frequency of fires in the northern Blue Ridge. In 1917, for example, there were 1,460 recorded fires in Virginia and most were attributed to lumbering (18%) and railroads (19%) (Virginia Department of Forestry 2002). These fires led to conditions in the Blue Ridge that were conducive to oak and xeric pine forest regeneration and allowed their increase in importance in the eastern mountains (Williams 1991).

These industrial activities, although never widespread, began to decline during the early 1900s and may have ceased altogether by 1920, leading to the initial recovery of the future park and laying the groundwork for its eventual conservation (Conners 1988). According to Conners (1988), roughly half the mountain people had left the northern Blue Ridge by 1925 and moves were underway to turn a portion of the Blue Ridge Mountains into a national park. Much of the exodus from the northern Blue Ridge was probably due to the depletion of valuable timber species, such as chestnut oak (*Quercus prinus*) (harvested for tannin) and American chestnut, and depleted agricultural soils.

During this period of European settlement and industrialization, species such as wolves, mountain lions, elk, bison, and passenger pigeon were extirpated throughout much of the eastern United States (Matthiessen 1987; NPS 1998). Other populations of wildlife, although not extirpated from the eastern United States, declined dramatically during this period or disappeared from the park. For example, beaver and river otter disappeared in the late 1800s and white-tailed deer were eliminated in the park by 1920 (NPS 1998). Elk and bison were extirpated by 1798 and 1855, respectively. The major predators, wolves and mountain lions, persisted in the area until 1912. Black bear, bobcats, and wild turkey (*Meleagris gallopavo*) populations declined severely due to habitat destruction and market hunting in the early 1900s (Kallman 1987).

The most significant alteration to the forests of the Blue Ridge, the loss of the American chestnut, also occurred during this time. In the late 1800s tree hybridizers sought to breed a new variety of chestnut that would combine the large size of the American chestnut with the larger nut of the Chinese specimens (Moore 2003). The Asian trees they imported, however, contained a fungus that was deadly to the native chestnut. This fungus, chestnut blight (*Cryphonectria parasitica*), was first identified at the New York Zoological Gardens in 1904 and by the 1920s it had reached SHEN (Johnson and Ware 1982; Moore 2003). The chestnut trees of SHEN, the most common tree species, died in place, leaving pale-gray, lifeless snags throughout the Blue Ridge Mountains (Moore 2003). The loss of the chestnut probably had secondary impacts to the forest wildlife, especially to those mast-dependent species such as deer, bear, turkey, and passenger pigeons.

Park Establishment: Resource Restoration, Protection, and Recovery (1926–present)

The impetus, history, controversy, and human conflict associated with the establishment of SHEN as a national park has been well documented by a variety of authors (e.g., Conners 1988; Lambert 1989; Moore 2003), but the park’s existence and subsequent resource conservation has had profound impacts on the natural resources of the northern Blue Ridge Mountains. The park was established by an act of Congress in 1926. This act, however, provided no expenditure of federal funds for land purchase (Conners 1988). A series of private land donations and expenditures by the Commonwealth of Virginia lead to the official establishment of the park by 1935 (Conners 1988; Lambert 1989; Moore 2003). One of these land donations was the Rapidan River Camp (Camp Hoover). President Hoover built his presidential retreat in 1929 near the headwaters of the Rapidan River. He donated the 66-ha (164-ac) complex to SHEN when he left office. In addition, the Civilian Conservation Corps (CCC), which had established six camps within the park boundary, was restoring nature to SHEN by planting trees, many of which were not native to the Blue Ridge (e.g., Norway spruce) (Mazzeo 1966b). The CCC camps became the foundation of visitor facilities, but a variety of private concessionaires also were establishing new recreational facilities and restoring older facilities (e.g., Skyland) inside the park. Today, there are almost 79,899.76 ha (197,411.6 ac) within the authorized boundary of SHEN, 40% of which is designated as wilderness.

During and after park establishment, Skyline Drive was constructed and funded as a drought-relief measure (Lambert 1989). This road allowed visitors to view the recovering landscape of SHEN, but it also facilitated the spread of nonnative plants to the summits of the park, including introducing these nonnatives to sensitive habitats such as at Big Meadows. The road is also a landscape fragmenting feature in a now mature deciduous forest habitat.

At the time of park establishment, 98% of SHEN's forests were second growth or had been removed entirely (Conners 1988; Lambert 1989; Fievet et al. 2003). The establishment of SHEN has permitted these forests to regenerate and now forests occupy 93% of the park's landscape (Young et al. 2005). The loss of the American chestnut greatly changed the composition and structure of the forest communities of the Blue Ridge. Forest succession in SHEN following the elimination of the American chestnut has been described as "simple replacement" of chestnut by former associated species, such as the oaks, hickories, and tulip poplar, depending on topographic and edaphic conditions (Johnson and Ware 1982; Stephenson 1986; Eshleman et al. 2001). For example, Johnson and Ware (1982) found that the post-chestnut forest of the central Blue Ridge in Virginia are now dominated by chestnut oak, especially at lower elevations and in less mesic sites (Stephenson 1986). The post-chestnut forests are dominated by red oak at higher elevations and more mesic sites (Fievet et al. 2003). The coves and draws of the post-chestnut forest in the Blue Ridge now support a mixed assemblage of more mesic species such as tulip poplar, yellow birch, and sugar maple (Johnson and Ware 1982). These mesic species are increasing in SHEN and throughout Virginia as fire suppression and rapid expansion of deer populations have greatly reduced the amount of oak regeneration at the same time that age, drought, and defoliation due to gypsy moth removed much of the oak overstory (Tigner 1998). The species composition of Virginia's hardwood forests, therefore, is shifting away from oak towards species such as tulip poplar and maple (Tigner 1998).

The forests that have recovered since park establishment represent one of the largest, unfragmented expanses of eastern deciduous forest in the northern Blue Ridge. Today these forests support, as they did during pre-European settlement, diverse assemblages of neotropical migratory birds, including healthy populations of the cerulean warbler (*Dendroica cerulea*), a species that is declining in other parts of its range (Rosenberg et al. 2000).

Several species of wildlife were re-established at SHEN during this time period. For example, 13 white-tailed deer were released along Big Run in the park in 1934 (NPS 1998). Today, there are approximately 6,000 white-tailed deer in the park, or 10–12 deer/km^2 (25–30 deer/mile^2) on average (NPS 1998). Also in 1934, several turkeys from George Washington's Birthplace were released in the park; today, SHEN supports healthy populations of this game bird, in part due to introductions of subsequent flocks on private lands adjacent to SHEN (NPS 1998). Black bears naturally re-established themselves at SHEN and today there is a stable population of 300–800 black bears in the park (Carney et al. 1987). Bobcats are common in the park today and undocumented cougar sightings have recently occurred in the park, although the source population of these sightings (if substantiated) is unknown (NPS 1998). Coyotes (*Canis latrans*), not a species of wildlife original to the Blue Ridge, have now established themselves within the park boundaries.

As exemplified by the chestnut blight, nonnative pests remain one of the most troubling threats to the forest communities at SHEN. For example, the oak forests that replaced American chestnut sustained major defoliation by the caterpillar of the nonnative gypsy moth. This insect, accidentally released in Medford, MA in 1869, first began defoliating oaks throughout the park in 1986 and, by 1989, over 16,187 ha (40,000 ac) of oak forest were defoliated (Kasbohm 1994). This defoliation, coupled with drought, caused widespread oak mortality (18%) in SHEN in the early 1990s and resulted in a 99% reduction in acorn production in defoliated stands (Kasbohm 1994). Defoliation attributed to gypsy moth has declined dramatically over the last decade due to the application of a lethal bacteria, *Bacillus thuriengensis*. Occasional outbreaks of gypsy moth populations are still possible, however. The most xeric sites in the park with a significant oak component have the potential for being most affected by this nonnative pest. Natural resource managers at SHEN continue to monitor the park for the presence of gypsy moth (Ravlin et al. 1990).

Several virgin forest stands that persisted at SHEN since the pre-European settlement period are threatened today by a variety of introduced insect pests. For example, the hemlock woolly adelgid has caused the decline of eastern hemlock, the most common component of old-growth forests in the park (Winstead 1995). The glacial remnant, balsam fir, is threatened by the balsam wooly adelgid (Mazzeo 1996b). Red spruce is infested by the eastern spruce gall aphid (*Adelges abietis*), and the rare plant communities of Big Meadows are threatened by incursion of nonnative plants.

Historical suppression of fire at SHEN also altered the park’s forests from their pre-European condition. This fire suppression, coupled with gypsy moth defoliation and deer browsing of oak seedlings, may be contributing to a forest that contains fewer oaks and a greater mix of more mesic tree species. At Big Meadows, natural plant succession from an open meadow to a more shrubby habitat in the absence of fire has prompted resource managers to use prescribed fire and mowing in an effort to keep this community open as it has been for the past 10,000 years (Cass 1999). Furthermore, effective fire suppression slowed or reversed xeric pine forest expansion throughout the Appalachian Mountains, with remaining stands on more mesic sites becoming reproductively stagnant and succeeding to oak dominance (Willams 1991). The suppression of natural disturbances, coupled with nonnative plants, continue to alter plant communities at the park.

Other natural disturbances continue to occur within the park. For example, in 1995 a widespread debris flow and flooding event took place that reflects the once-in-80-years natural occurrence of such events within the southern Appalachian Mountains (Brinkman 1975; Eaton and McGeehin 1997). In addition, period ice storms often damage overstory trees, especially at high elevations, causing canopy openings in the forest.

Natural resource challenges that have arisen since park establishment include declining visibility and air quality and increasing acid deposition (NPS 2003). For example, SHEN's average visibility is 20% of its natural range. Declining air quality, and especially the increase of ground-level ozone, may further stress the forest community at SHEN. In addition, due to human industrial activities that occur outside of park boundaries, the area in and around SHEN has among the highest concentrations of airborne sulfates in the U.S. (NPS 2003). These airborne sulfates impair visibility, contribute to acidic deposition, and degrade water resources in the park (Burks 1994; NPS 2003). Reflecting the numerous adverse impacts to its natural resources, the U.S. Department of the Interior published a preliminary notice of adverse impact on SHEN's visibility, streams, and vegetation in the Federal Register in 1990 (http://www.gpoaccess.gov/fr/index.html).

Today, 1.8 million people visit SHEN annually, down from the peak visitation of over 3 million visitors in 1977, and recreational activities that currently occur within the park also have the potential to affect natural resources (Conners 1988). For example, rock climbing threatens the fragile plants associated with cliff communities; heavy use of hiking and horseback riding trails and backcountry campsites can contribute to soil erosion; and concession-supported activities like permanent campgrounds that require infrastructure, such as wells, may alter hydrologic regimes and threaten water quality in the park (Bain 1988).

Geologic and Geomorphologic Resources

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Physiography and Bedrock Geology

Current Status and Significance: The vast majority of Shenandoah National Park (SHEN) resides in the central Blue Ridge Mountains, the easternmost prominent range in the Appalachian Mountains of Virginia. As pictured from above, the Blue Ridge is neither linear nor sinuous, but is extremely irregular with numerous outlying ridges, promontories, and recesses. Streams on the eastern flank have cut deep ravines into the ridge and drain into narrow, alluvium-floored valleys. Major recesses on the western flank are covered with thick alluvial accumulations of sand and gravel. Depending on the extent of outlying ridges, the Blue Ridge in SHEN varies in width from 5 km (3 mi) near Waynesboro, to 31 km (19 mi) near Stanley. The relative elevation difference, or relief, between the ridge tops and valley floor is always in excess of 305 m (1,000 ft) and can be as much as 1,006 m (3,300 ft).

Overall, the geology of this area represents the western limb of a major fold structure that extends from southernmost Pennsylvania to central Virginia (Espenshade 1970; Mitra and Lukert 1982).

The eastern flank of the Blue Ridge is underlain by granite and gneissic rocks (granite/charnockite) of the Mesoproterozoic Era of the Proterozoic Eon (1600 to 1000 million years ago; Figure 2). The granite associated with Old Rag Mountain, part of this association, is regionally significant because it is one of the four places in the eastern United States where an intact, ancient, igneous (e.g., rock that is derived from magma [liquid rock]) intrusion is visible and creates a major landscape feature.

Aside from Old Rag, the majority of summits of the Blue Ridge are underlain by metamorphosed basalts, designated as the Catoctin (greenstone) Formation of Neoprecambrian age (570-565 million years ago) (Gathright 1976; Figure 2). The type locality for one of these basalts, the Swift Run Formation, is from SHEN and therefore is significant to geologists.

The western flank and some summits of the Blue Ridge are underlain by siliciclastic rocks (quartzites and phyllites), which are metamorphosed sedimentary rocks of the Weverton, Harpers, and Antietam Formations (Chilhowee Group) of early Cambrian age (570–545 million years ago) (Gathright 1976, Figure 2). To the west, the lowlands that comprise the Shenandoah and Page Valleys are underlain by limestones, dolomites, and shales (e.g., Tomstown Formation) of early Cambrian age (Baedke and Fichter 2000; Figure 2).

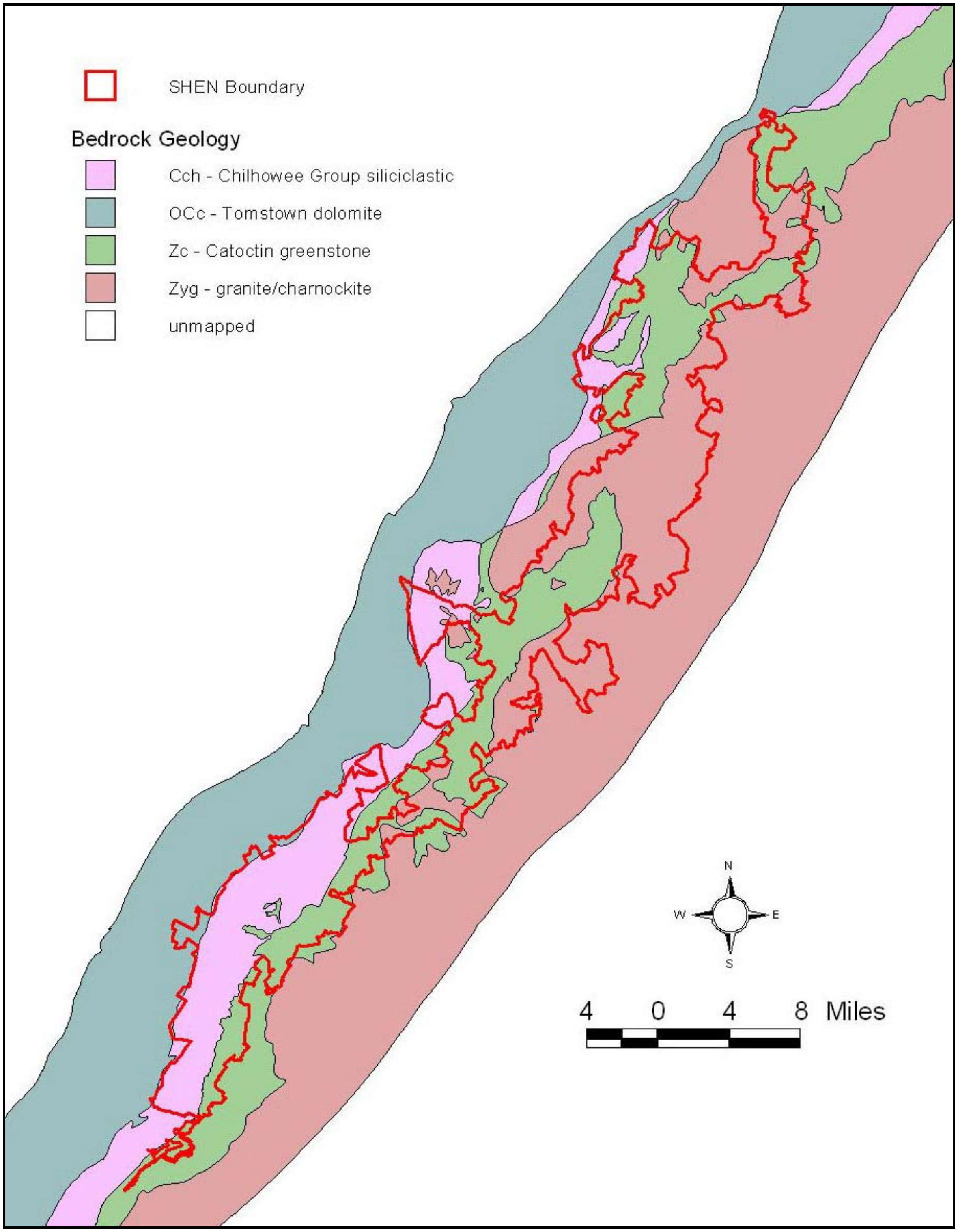

Figure 2. Bedrock geology of Shenandoah National Park (SHEN), Virginia (after Gathright 1976).

The Catoctin greenstone formation rests unconformably on a basement of granitic rock with bedding locally dipping gently to the southeast. The Catoctin Formation rock type is regionally significant because it is one of the few places in the mid-Atlantic where volcanic rocks are found at the surface. The siliciclastic rock rests on the Catoctin Formation, but is sharply overturned on the west flank, resulting in bedding that dips steeply to the southeast (Gathright 1976). The siliciclastic rocks form the flatiron and hogback ridges prominent along the western margins of SHEN.

The oldest evidence of animal life in SHEN is preserved within the geology of the park. A burrowing worm trace fossil (*Skolithos*) found in early Cambrian rock provides this evidence. These trace fossils were caused by phoronid worms, a phylum of marine invertebrates with an elongated, nonsegmented body that burrow in the sand or mud.

The soils and rubble formed from the natural weathering of rocks throughout SHEN provide a partial record of the most recent 500,000 years of Virginia history. Over the last decade geologists have begun to examine these sediments for changes in the SHEN flora and climate during the past 30,000 years (Litwin et al. 2004). These initial findings show past climates that were warmer and drier than current conditions, as well as colder, tundra-type environments similar to present day central Canada (Litwin et al. 2004). As development covers and consumes more private holdings it becomes increasingly important to preserve these geologic resources that provide the data to unravel Earth's history.

Threats: Bedrock outcrops are numerous throughout the park. However, those present at overlooks along Skyline Drive and along hiking trails have the potential for overuse, including erosion created from repeated foot traffic and rock climbing.

Vandalism is a problem in nearly all national parks, and graffiti is one of the threats that could impact the natural character of rock outcrops. Additionally, open fires constructed beneath rock ledges blacken the outcrops and pose an additional threat to interpreting the rock history.

Gaps in Knowledge: Much still is unknown of the depositional environments of the rocks present in SHEN. Each rock has the potential to reveal part of Earth's history, and only a small part of the outcrops within the park have been studied. The composite bedrock map for SHEN that was prepared by Gathright (1976) is inadequate and needs revision. More detailed studies are needed to unravel the depositional environments of the rocks present in SHEN, which will give visitors insight to the geologic environments (e.g., volcanoes, vast sandy beaches, and carbonate reefs) that existed at the time these rocks were formed. In addition, these studies will determine the age and origin of all rocks and surficial deposits, when they were metamorphosed and deformed, when they tectonically evolved and got here, and how and why the landscape has evolved (USGS, S. Southworth, pers. comm., 2006).

Historically, no baseline data exist that quantifies the relationship between rock climbing frequency and impact on geologic outcrops. However, current research efforts have identified sites that serve as rock climbing loci and have measured anthropogenic impacts (e.g., erosion and degradation of outcrops) (NPS 2005h).

Little is known about the rockfall hazard potential along Skyline Drive, most of which was created from the road's construction. No inventories of the overhangs and slopes along the Drive currently exist. There are no studies that document the rockfall hazards at other locations in the park.

No map or literature exists detailing moderate-to-small structural features within the park, including fractures and small faults. From a practical stance, these fractures control much of the subsurface waterflow in the local bedrock and serve as local aquifers for most of the developed areas of the park. The importance of documenting the location and aerial extent of these features cannot be understated, especially when the location of potential septic drain fields and other sources of water pollution are considered. In extreme cases, lubrication via water injection of these structures could potentially trigger rockfalls, as the recent lawsuit case in Yosemite National Park illustrates (Watts 2001). As park personnel continue to examine possibilities for future development, the location of these features should be considered.

Suggested Management Recommendations:

- Conduct detailed bedrock mapping on a 1:24,000 scale and incorporate these data into a GIS system. Initiate separate studies that map rock fractures and faults in areas that have development or have the potential for development.
- Most of the potential hazard from rockfalls exists along Skyline Drive. Although signage alerts motorists to areas that are susceptible to rockfalls, no known scientific study has examined which sites have the greatest potential for this hazard. Several methodologies exist for assessing the degree of risk (e.g., National Highway Institute 1994), one of which is currently being used to document potential rockfall and debris flow hazard sites along the Blue Ridge Parkway in North Carolina (North Carolina Geologic Survey, Rick Wooten, pers. comm., 2005). From a liability standpoint it would be wise to conduct a phase one rockfall hazard assessment survey along Skyline Drive. These hazards are also present along hiking and horse trails, but appear to be only a nominal risk.
- Continue a scientific investigation of the impacts of climbing and foot traffic on the weathering of rock outcrops and develop a plan where compromise is found between the needs of the park and park users. The impact of foot traffic can be altered by systematically moving trail access points to overlooks, or in extreme cases, limiting access to outcrops. In areas where rock climbing is suspected to have impacted outcrops, a morphological comparison that documents degradation of these sites should be made to proximal sites that have received little or no human impact. At a minimum, physical documentation of these sites is necessary for long-term monitoring of outcrop durability and associated rare plant communities.
- The proliferation of graffiti is usually a function of intensity of site use, and the distance from the highway. Most vandals will choose to display their work on rock outcrops on or near roads, rather than 5 km (3 mi) into the backcountry. Adequate highway patrolling and education are likely the best deterrents.

<u>Surficial Deposits</u>

Current Status and Significance: The summits of the Blue Ridge have extensive areas of rock outcrop as well as mountain-top detritus and shallow colluvial (gravity-derived) deposits. The detritus is most likely a product of degradation of bedrock by action of ice wedging in the subsurface and other periglacial (cold) processes during colder climatic periods in the Late Pleistocene (100,000 to 10,000 years ago) (Eaton et al. 2003a). The detritus is most conspicuous in sparsely vegetated block fields and talus sheets underlain by quartzites of the Antietam and Harpers Formations and is best seen on the west flanks of the Blue Ridge in the southern section of SHEN. These quartzites produce extensive block fields that grade into slope and talus deposits, rock streams, and clusters or jumbles of balanced rocks, present as tors (isolated bedrock outcrops) along ridge crests and summits. These features are also widespread in areas underlain by the Catoctin Formation and by granitic rock and are prominent along slopes to the east of Skyline Drive. For example, occurrences of extensive block fields and talus composed of Catoctin Formation boulders are found in the upper headwaters of the Rapidan River (Eaton et al. 2001b). Tors, balanced rocks, block fields, and talus composed of granitic rock are found on Old Rag Mountain. A few of the block fields and talus sheets are as much as 500 m (1,640 ft) in longest dimension, but most block fields and talus rarely exceed a few acres in area (Morgan et al. 2004). These block fields are geologically uncommon and are, therefore, a regionally significant resource, especially as they reflect past, near-glacial history.

Colluvial deposits of slope wash occur throughout the area and are usually several meters thick in outcrops along banks of streams. The slope wash is interpreted to be the result of solifluction of soils and weathered bedrock during periglacial conditions (Eaton et al. 2003a; Smoot 2004). Solifluction is a form of creep in which soil, water, and ice flow downslope at slow rates (a process that primarily occurs in permafrost regions), this occurred at SHEN under periglacial conditions (100,000–10,000 years ago). The brief warmth of summer thaws only the upper meter or two of the soil, which becomes waterlogged because the underlying ground remains frozen and therefore inhibits water drainage. The result is the flowing of the thawed layer that can produce multiple terraces or lobes. In SHEN these deposits contain charcoal with radiocarbon ages that range from approximately 13,000 to greater than 50,000 years old (Eaton and McGeehin 1997). Overall, outcrops of these deposits are difficult to find due to the combination of winter frost action and vegetation cover. However, the meadow clearing below the visitor center at Big Meadows shows subtle terracing, and may be the result of past movement and deposition of solifluction lobes (USGS, Joe Smoot, pers. comm., 2002).

The recognition of these colluvial deposits in SHEN has regional significance for at least two reasons. First, radiocarbon dating and examination of pollen from these periglacial landforms described above indicate that 20,000 years ago SHEN was dominated by a climate similar to present day central Canada. Work by Litwin et al. (2004) indicates that permafrost conditions were prevalent and that much of the summits of the park at that time were habitats for tundra grasses and shrubs. Secondly, the story revealed by these deposits indicates that the park is not a static environment, but one that is continually changing. The landscape within SHEN today is quite different from the landscape at the time of the park's inception ~85 years ago, and is nearly alien to the environment that existed 20,000 years ago. This revelation should be disseminated to not only those interested in SHEN's history, but to the larger public who has an interest in natural history; as these conditions may have affected the highlands of most of the eastern seaboard south of the glacial border in Pennsylvania.

Downslope of these periglacial landforms are equally curious deposits. The transition from the upland hillslopes to the river environments are marked by a decrease in slope, as well as a different type of deposits. The eastern flank of the park is largely dominated by debris flow deposits intermingled with fluvial (water-derived) sediments. Debris flow activity within the park, although rare (only one recorded event since the park's inception), is usually triggered by prolonged, intense rainfall (Jacobson et al. 1989; Wieczorek et al. 2000; Eaton et al. 2003a). One event occurred on June 27, 1995, and was centered over the Rapidan River basin in western Madison County, Virginia. The storm developed from the combination of a stalled cold front and westward-flowing, moisture-laden air moving toward the eastern slopes of the Blue Ridge Mountains (Smith et al. 1996). Maximum rainfall totals for the storm system reached 775 mm (30.5 in) during a 16-hour period. The deluge triggered more than 1,000 debris flows, several dozen originating from SHEN, and flooding in the region was catastrophic and locally significant. Many of the debris flows left the park property and traveled into private holdings creating destruction to property and casualties to livestock.

Debris flow frequency for small (<5 km^2 [<2 mi^2]) river basins in the Blue Ridge Mountains is once every few thousand years (Eaton et al. 2003b). However, frequency of activity increases with area, where one event has impacted central and western Virginia every decade and the southern Appalachians once every 80 years (Eaton et al. 2003b). Most of the flatlands residing in the eastern side of the park are composed of debris fans, some of which were incised by the previously-mentioned debris flows in 1995 (Wieczorek et al. 2000; Eaton et al. 2001a).

The western side of the park is largely devoid of debris flow activity, except where outcrops of granite and greenstone provide detritus to the basins (e.g., the region around Stanley). The western slopes are largely underlain by siliciclastic rocks. These basins tend to be larger than those on the east side of the Park, and produce water-derived deposits rather than debris flows. Despite the local severity of floods and resulting debris flows, they do not produce prominent and persistent geomorphic features in the landscape of the Blue Ridge (Jacobson et al. 1989).

Threats: Many locations throughout the park have boulders that are detached from bedrock outcrops and are perched or balanced in a quasi-stable state. These locations have the potential for dangerous rockfalls; high-foot-traffic areas (e.g., Old Rag, Black Rock, and Bear Church Rock) have the greatest potential for hazards to park visitors.

The flood of 1995 demonstrated the force of water and rock on the landscape within the park. The Rapidan River region received up to 76.2 cm (30 in) of rainfall in less than a day, resulting in numerous landslides and flooding of the Rapidan, Robinson, and Conway rivers, and their tributaries (Wieczorek et al. 2000; Eaton et al. 2003b). The park should consider these threats when planning for future backcountry campsites or other permanent activities that may occur in the eastern flank lowlands. Although the probability of having additional debris flows in the affected basins in the near future is small, other areas of the park still remain at risk. Finally, the scoured tributaries impacted by the debris flows lack the capacity to slowly store and transmit rainwaters due to the full removal of the soils and rubble from the channels via the debris flows. These sediments act as a sponge, thereby slowly releasing the captured rain water during precipitation events. This problem will continue until the impacted stream channels revegetate and develop the soil mantle.

Gaps in Knowledge: The vast majority of the park lacks documentation of surficial deposits and landforms. However, a recent mapping project in Paine Run (S. Eaton, James Madison

University, 2005, unpublished data) revealed several flights of river terraces, each with its own set of distinctive vegetation and probable hydrologic regime.

Until recently it was thought that the effects of glaciation beyond the limits of the ice sheets in northern Pennsylvania were limited to high peaks within and outside the Blue Ridge. However, ongoing research by geologists has identified numerous periglacial deposits throughout the park. Studies of the processes that emplaced the deposits in conjunction with research on pollen and plant fossils will help elucidate the climatic history of the central Blue Ridge for the past 30,000 years.

Suggested Management Recommendations:

- Purchase LiDAR imagery for the entire park. This tool provides a base map of centimeter scale resolution and is a vital resource for documenting not only the geology, but habitat for endangered flora, topography of stream channels, potential hazard sites, and other resources.
- Establish a surficial geologic map at 1:24,000 scale.
- Develop a debris-flow and flooding hazard map for the park. The final product should be GIS based, thus allowing for modeling of areas prone to potential threats.
- Support studies that investigate the history and climatic conditions of surficial deposits, as they give insight to the timing and frequency of past events.

<u>Soils</u>

Current Status and Significance: Eaton et al. (2001a, 2003c) show two variables that affect the character and nature of the soils within SHEN. First, the local topography greatly influences soil profile thickness. Soils on steep slopes tend to be thin (and lack the B horizon associated with well-developed profiles), whereas flat summits, gently-sloping mountain hollows, debris and alluvial fans, and flood plains have thicker profiles. The summits are usually the more stable of the group and are not subjected to the frequent burial by fresh sediment associated with fans and flood plains, thereby allowing a stable and mature soil profile to develop.

Second, parent bedrock types found at SHEN greatly influence soil properties. The bedrock and associated soils greatly affect the terrestrial vegetation communities and the aquatic resources in the park. For example, the effect of acid deposition on aquatic fauna varies depending upon which rock type a particular stream is located. Streams located on the siliciclastic rock type at SHEN experience significantly lower pH and acid-neutralizing capacity (ANC) than those located on other rock types (Galloway et al. 1999). In general, soils derived from the quartzites and sandstones (siliciclastic rock) tend to produce sandy, low-fertility soils. Profiles are typically thin, and distinct flora concentrate in these conditions, including chestnut oaks and huckleberries (*Vaccinium* spp.). When disturbed from fire or clear cutting, sandy soils have a moderate susceptibility to erosion. In contrast, the Catoctin greenstones weather to soils that have a high clay content and thick B horizon. Due to the high cohesion of these soils, their susceptibility to erosion is minimal. Flora requiring high fertility, including some globally rare plant communities (e.g., the High Elevation Greenstone Outcrop Barren), prefer the greenstone soils due to the calcium and magnesium released during the weathering process. Finally, the granites and gneisses initially weather to sandy soils and are comprised primarily of quartz and feldspar. With time, the feldspars (initially sand sized) weather to clay minerals, thereby decreasing the amount of sand while increasing the percentage of clay. In one study by Eaton et al. (2001b) granite soils that were dated 500,000 years old were comprised of over 80% clay, whereas fresh granitic sediment from the flood plain contained only 5% clay. In general, stable landforms composed of weathered granite and gneiss material also develop thick soil horizons and are only moderately susceptible to erosion. These materials produce soil that has moderate fertility, yielding a variety of flora.

Threats: Due to the steep slopes of the Blue Ridge Mountains and periodic flood disturbance regimes the soils at SHEN have severe erosion potential.

Gaps in Knowledge: Soils maps are primarily in the form of county soil survey reports, and information is very general in areas within SHEN. For example, the small scale is insufficient for detailed mapping of surficial deposits or delineation of endangered flora habitat. Furthermore, there is no single document that describes and delineates the soils that mantle SHEN.

Earlier mapping of the park by geologists revealed that the underlying bedrock geology may be quite different than the overlying surficial materials, often derived from gravity or flooding activity. The mineralogy of the rocks comprising the surficial cover influences soil fertility and acidity, thus affecting the flora present within the park. A detailed surficial map may provide insight on possible localities of particular flora that may be threatened or endangered.

Suggested Management Recommendations:

- Develop a parkwide soils map of a scale no smaller than 1:12,000.

Air Resources

The effects and types of human-made air pollution on natural resources at SHEN have been well studied, especially compared to other national parks in the mid-Atlantic. Under the Clean Air Act (CAA) Amendments of 1977, all national parks over 6,000 acres that were in existence as of August 7, 1977, were designated as federal Class I areas. Therefore, SHEN, as a Class I area, is afforded the greatest degree of air quality protection under the CAA (Sullivan et al. 2003a). Under the CAA, air pollution concentrations at SHEN may not violate any of the National Ambient Air Quality Standards (NAAQS) set by the EPA to protect human health and welfare (Bunyak 1993). Additionally, because SHEN is a Class I area, federal land managers may assume an aggressive role in protecting the air quality related values, including recommending denial for a Prevention of Significant Deterioration (PSD) permit for any new pollution sources (Sullivan et al. 2003a). The 1990 CAA amendments provided additional tools to accomplish the protection of Class I areas including acid rain reduction provisions (Sullivan et al. 2003a).

In order to effectively monitor air quality, it is necessary to both monitor the concentrations of pollutants in the air and assess the effects of those pollutants on park resources (NPS 2001). The SHEN air quality monitoring and research program has acquired information about key pollutants that can degrade visibility, impact growth and vitality of plant species, acidify streams, impact aquatic biota, leach nutrients from soils, erode buildings and materials, or harm human health.

SHEN participates in a number of national and state programs that monitor air pollutants of primary concern to the NPS. These programs are: 1) the National Atmospheric Deposition Program/National Trends Network (NADP/NTN), a nationwide network of precipitation chemistry monitoring sites; 2) the Clean Air Status and Trends Network (CASTNet), the nation's primary source for atmospheric data to estimate dry acidic deposition (this program used to be called the National Dry Deposition Network [NDDN]); 3) the Mercury Deposition Network (NADP/MDN); 4) state and federally operated ozone and particulate matter monitors, and 5) the Interagency Monitoring of Protected Visual Environments (IMPROVE) program. Data collected from these programs at SHEN have or currently include:

- visibility and particulate matter via 35-mm camera, transmissometer, nephelometer, stacked filter units, and IMPROVE samplers;
- ozone via a continuous monitor;
- sulfur dioxide, carbon monoxide, volatile organic compounds (VOCs), nitrogen oxide, chlorofluorocarbons, ultraviolet radiation, wet deposition, dry deposition, mercury in precipitation, sulfur isotopes in precipitation, and meteorological data via a variety of instrumentation.

Data collected from these programs have been analyzed, synthesized, and summarized in SHEN's Air Quality Assessment Report (Sullivan et al. 2003a).

SHEN is located within the Chesapeake Bay Airshed that contains numerous sources of air pollution, including vehicular emissions and emissions from fossil-fuel-burning power plants. However, many of the pollutants of concern at SHEN are generated outside of the park's airshed and transported many hundreds of kilometers (km) by prevailing winds before reaching the Blue Ridge Mountains of Virginia. Based on a variety of models and programs, the air pollutants, primarily sulfates, nitrates, and volatile organic compounds (VOCs), that affect the natural resources at SHEN are generated in a 160 x 160 km^2 (62 x 62 mi^2) area centered on the joining of the state boundaries of West Virginia, Kentucky, and Ohio in the Ohio River Valley (Ferman et al. 1981; Sullivan et al. 2003a). Coal combustion in this valley seems to be the primary source of the pollutants or their precursors. The reach of sulfur-containing pollutants is farther than for nitrate-containing pollutants. Therefore, it is likely that Virginia is the top contributor of nitrate-containing pollutants at SHEN, and West Virginia and Ohio are the top contributors of sulfur-containing pollutants at the park (Ferman et al. 1981). Overall, pollution emission sources located within 200 km (125 mi) of SHEN contribute more to declining visibility and acid deposition at the park, on a per ton basis, than more distant sources. Within the park, prescribed burning, campfires, fireplaces, and mobile sources are the largest contributors to air pollution (Sullivan et al. 2003a). However, for all air pollutants, SHEN contributed less than 1% to the emissions generated from counties in which the park is located (Sullivan et al. 2003a).

<u>Air Quality (Including Acid Deposition)</u>

Current Status and Significance: Four main categories of gaseous pollutants have been recognized as potential threats to the natural resources at SHEN. These pollutants, ground-level ozone, sulfur-containing pollutants (e.g., sulfur dioxide), volatile organic compounds (VOCs), and nitrogen oxides, are all monitored within and/or around SHEN. These pollutants may be harmful on their own or contribute to the formation of other pollutants. For example, sulfur dioxide and nitrogen oxides cause acid deposition, and VOCs contribute to ground-level ozone formation. Naturally occurring stratospheric ozone also may contribute to levels of ground-level ozone at high elevations. Stratospheric ozone may mix with tropospheric (ground-level) ozone and increase background ozone values, especially following cold fronts (Cooper and Moody 2000).

Ground-level ozone primarily is a secondary pollutant formed by the photo-oxidation of nitrogen oxides (NO_x) and VOCs. Ozone generation generally requires sunlight; therefore, ozone typically shows a strong diurnal and seasonal pattern, being of greatest concern in warmer months; i.e., May–September (Musselman and Massman 1999).

At SHEN, ground-level ozone has been monitored periodically at three sites (Dickey Ridge [North District], Big Meadows [Central District], and Sawmill Run [South District]) from 1983–1994. Since 1994, however, only the Big Meadows ozone monitoring site remains active. At the Big Meadows site, the SUM06 exposure index indicated that ozone concentrations averaged 46.9 ppm/hr during May–September 1990–2000 (Table 1). The SUM06 index is calculated by summing the absolute value of the hourly average concentrations of ozone concentrations that are equal to or above 0.06 ppm over a 3-month period. While there is no NAAQS for SUM06, 46.9 ppm-hr far exceeds concentrations most experts believe can harm sensitive vegetation; i.e., 10–15 ppm/hr.

Table 1. The mean, minimum, and maximum SUM06 exposure index (ppm/hr) for ground-level ozone measured at three sites at Shenandoah National Park (after Sullivan et al. 2003a).

Site and collection dates	Mean	Minimum	Maximum
Big Meadows 1990-2000	46.9	31.1	83.4
Dickey Ridge 1989-1994	27.3	16.2	41.8
Sawmill Run 1989-1994	25.5	13.2	36.4

There were periodic events when the ground-level ozone at Big Meadows exceeded the daily maximum NAAQS for ozone of 85 ppb. For example, an analysis of the Big Meadows monitoring data showed that the number of times per year daily maximum 8-hour ozone concentrations exceeded 85 ppb were 6, 22, and 15, respectively, during 1997, 1998, and 1999 (Sullivan et al. 2003a).

The Big Meadows ground-level ozone monitoring site generally recorded the highest values when compared to other ozone monitoring sites in counties located near SHEN (e.g., Fauquier and Frederick counties). In addition, SHEN has among the highest concentration of ground-level ozone of all national parks monitored and, in 2004, a portion of the park was designated by the state of Virginia and the EPA as a non-attainment area for ozone (Sullivan et al. 2003a). However, in 2005, the park was re-designated as an attainment area of the ozone standard due to monitoring data showing improvement in ozone levels since 2002 (NPS, H. Salazar, pers. comm., 2006).

Despite these recent improvements, ground-level ozone pollution at SHEN has been relatively constant over the past decade, as no statistically significant increasing or decreasing trends in ground-level ozone could be detected in and around the park from 1989–2000 (Sullivan et al. 2003a). However, background (or historic) concentrations for ground-level ozone in the U.S. were much lower than they are now. For example, ground-level ozone levels were probably 5–10 ppb in the nineteenth century in contrast to 10–25 ppb in pristine areas of the U.S. today (Beck and Grenfelt 1994; Altshuller and Lefohn 1996; Cooper and Peterson 2000).

As previously mentioned, ground-level ozone is generated, in part, by VOCs and nitrogen oxides. VOCs are primarily natural in origin and are emitted by soils and vegetation; trees, in particular, emit the highly reactive VOCs isoprene and terpene. However, there also are anthropogenic sources of VOCs, including motor vehicle exhaust, gasoline vapors, and stationary fuel combustion (Smith 1990). Automobiles, fossil fuel burning stations, soils, wildfire, and lightening are sources of nitrogen oxides. Based on the Shenandoah Cloud and Photochemistry Experiment, ozone-formation at SHEN is driven by nitrogen oxide concentrations in the summer and driven by VOC concentrations in the winter (Jacob et al. 1995; Keene at al. 1995; Munger et al. 1995). Computer models that examined the effects of VOC concentrations at SHEN on the local production of ozone indicate that, due to the highly vegetated condition of the park and its elevation, reducing anthropogenic VOC emissions within the park will not reduce ozone concentration at the park (Sullivan et al. 2003a).

Ozone generation from power plants may increase in the future as permits for two power plants that would generate ozone precursors recently were approved. One of these proposed power plants is a coal-powered plant located in West Virginia (Longview; proposed permit approved 2004), approximately 193 km (120 mi) from SHEN. The other, a natural gas power plant, would be located near Front Royal, Virginia, approximately 7 km (4 mi)from SHEN (CPV-Warren; proposed permit approved 2003) (Sullivan et al. 2003a). In 2004, SHEN completed a mitigation plan in concert with Virginia Electric Power Company (VEPCO) which generated $1,000,000 in restoration funds that are being used to reduce emissions from mobile sources within the park. For example, SHEN will attempt to target and reduce NPS vehicle-related emissions in the park through the purchase of hybrid vehicles and EPA-compliant Heavy-Duty Diesel vehicles. Also in 2004, the park launched the Clean Air Restoration Effort (CARE) aimed at making park operational changes that will reduce air pollution, including ozone generation (NPS 2005a). Despite the link between power plant emissions and ozone generation, automobile exhaust is the primary generator of ozone precursors. Therefore, these park programs set examples of good natural resource stewardship. Due to sheer volume, automobiles driven outside the park generate the most ozone; consequently, increasing the traffic capacity of I-81 poses a greater threat of ozone generation than in-park sources or power plants (NPCA 2003).

Sulfur dioxide and nitrogen oxide are air pollutants that are products of fossil fuel, primarily coals and oil, combustion. These pollutants are a concern especially in the eastern United States where they are precursor pollutants of acid deposition. Acidic conditions develop when these sulfur- and nitrogen-containing pollutants react with water, oxygen, and other chemicals in the atmosphere to produce various acidic components (Sullivan et al. 2003b).

The estimation of acid deposition at SHEN is difficult because there are so many components that have to be measured concurrently. For example, rain, snow, cloudwater, dryfall, and particular gases all contribute to acid deposition. Monitoring at SHEN, however, does provide some insight into overall trends in acid deposition. The chemical components of precipitation are measured at three monitoring locations at SHEN: Big Meadows (1981–present), White Oak Run (1980–2000), and North Fork Dry Run (1987–2000). Compared with other locations in the eastern United States, SHEN receives relatively high wet deposition of sulfate and moderately high wet deposition of nitrate (NPS 2005a). Among Class I national parks, SHEN and Great Smoky Mountains National Parks receive the highest sulfate and nitrate deposition (Sullivan et al. 2003a). Over the approximately 20-year monitoring period at Big Meadows, wet deposition of sulfur averaged 6.7 kg/ha/year and total wet deposition of nitrogen averaged 4.6 kg/ha/year. Dry deposition of sulfur and nitrogen averaged 4.9 kg/ha/yr and 3.2 kg/ha/yr, respectively, at Big Meadows during the period 1991–1998. Cloud deposition does not likely contribute a significant amount of sulfur or nitrogen at SHEN due to the park's elevation of <1,500 m (<4,921 ft) (Sullivan et al. 2003a).

Enforcement of the CAA regulations has contributed to reduced emissions of sulfate and nitrate pollutants over the past 30 years and these trends are apparent when examining deposition data at SHEN. Despite high year-to-year variability, wet deposition of sulfate and nitrate has generally declined at SHEN, especially in the last five years. For example, Galloway et al. (1999) found statistically significant declines in SO_4^{2-} and NO^{3-} from 1980–1993.

The positive effects of the CAA on improving air quality at SHEN also are supported by the Regional Acid Deposition Model (RADM). This model predicts a 10–44% decline in ozone, sulfate, and nitrate pollutants by 2007 as compared to 1996 levels (Sullivan et al. 2003a).

Another source of air pollution at SHEN is fine mass particulates. These fine mass particulates, typically those less than 2.5 μm in diameter ($PM_{2.5}$), are associated with fossil fuel combustion and industrial development, and may vary in their chemical constituency. Industrial development in western Virginia and the Ohio River Valley produces pollutants that often reach SHEN as fine mass particulates (Ferman et al. 1981; Sullivan et al. 2003a). These fine mass particulates contribute to human health hazards and visibility impairment.

Fine mass particulate matter averaged 10.5 μg/m^3/yr at Big Meadows during the 12-year period of 1988–2000 (Table 2). Chemical components of the fine mass particulates included ammonium sulfate, ammonium nitrate, organics, light-absorbing carbon, and fine soil (Sullivan

Table 2. Natural annual background and current (1988–2000) annual fine mass particulate matter concentrations (ug/m^3/yr) and concentrations of chemical components (ug/m^3/yr) of fine mass particulates measured at Shenandoah National Park (after Sullivan et al. 2003a).

	All fine-mass particulates	Ammonium Sulfate	Ammonium Nitrate	Organics	Light-absorbing Carbon	Fine Soil
Natural background (reference) condition	2.3	0.23	0.1	1.4	0.02	0.5
Current condition (1988–2000)	10.5	6.8	0.5	2.4	0.4	0.5

et al. 2003a; Table 2). Current levels of fine mass particulate matter and its chemical components greatly exceed natural background (reference) conditions (Sullivan et al. 2003a; Table 2). The highest fine mass particulate concentration occurred during summer and most of the contribution was from ammonia sulfate. Course mass particulate matter (particulates ≥2.5 μg in diameter) averaged 4.7 $\mu g/m^3/yr$ at Big Meadows from 1988–2000 and the highest concentration occurred during the summer.

Atmospheric deposition of mercury and subsequent contamination of aquatic ecosystems has become a national and global pollution problem (Vana-Miller and Weeks 2004). For example, in the U.S., mercury makes more surface waters impaired for fishing than any other contaminant (Vana-Miller and Weeks 2004). Most mercury is emitted into the air from fossil fuel combustion, but there are natural sources (e.g., volcanic eruptions). Levels of mercury in fish tissue tend to be higher in more acidic waters, indicating a link between acid deposition and mercury contamination (Richardson et al. 1995). A study to determine the distribution, abundance, and variability of mercury in fish within SHEN was initiated in 2004 (Snyder et al. 2003). This project will help park managers understand the level of mercury contamination in brook trout.

Threats of Air Pollutants to Natural Resources at SHEN: Ground-level ozone, a component of smog, is injurious to human health as well as to vegetation. It is an eye, nose, and lung irritant, and because ozone concentrations are higher at high elevations, it is especially deleterious to high-elevation plant species. Eleven ozone-sensitive plant species at SHEN (NPS 2004). Ground-level ozone interferes with the ability of plants to produce and store food ,which makes them more susceptible to disease, insects, other pollutants, and pathogens (Skelly and Hildebrand 1992).

Ground-level ozone may cause visible foliar injury and early senescence to plants at concentrations as low as 25–38 ppb (Skelly and Hildebrand 1992). Among mature trees, black cherry (*Prunus serotina*) seems to be the most sensitive to foliar injury, with injury also occurring on mature tulip poplar, red maple (*Acer rubrum*), sassafras (*Sassafras albidum*), and white ash at SHEN (Chappelka and Chevone 1992; Hildebrand et al. 1996; Skelly et al. 2001). In seedlings, tulip poplar, green ash (*Fraxinus pennsylvanica*), and sweetgum (*Liquidambar styraciflua*) exhibited foliar injury due to ambient ground-level ozone at Big Meadows. In addition, the average height growth of seedlings of tulip poplar, green ash, black locust (*Robinia pseudoacacia*), Virginia pine (*Pinus virginiana*), eastern white pine (*Pinus strobus*), table mountain pine (*Pinus pungens*), and eastern hemlock was reduced due to ambient ground-level ozone at Big Meadows (Duchelle et al. 1982; Sanchini 1988). Furthermore, virgin's bower (*Clematis virginiana*), black locust, milkweed (*Asclepias* spp.), and wild grape (*Vitis* spp.) display increased foliar injury due to ground-level ozone at SHEN (Bennett 1984; Winner et al. 1989).

In order to determine the potential effects of current and projected levels of ground-level ozone on forest health at SHEN two models, ZELIG (a model of forest stand dynamics and succession) and TREGRO (a physiologically based model of the growth of individual trees), were used to predict potential changes in forest stand composition (Sullivan et al. 2003a). Based on these models, it seems likely that, among mature trees, only the growth of white ash is significantly affected by ground-level ozone at the present time. Any increases in ozone exposure, however, may negatively affect the growth of tulip poplar as well. In contrast, Bennett (1985) could find no support for hypotheses that predicted measurable declines in forest communities due to ozone exposure at SHEN. He found that overall patterns of forest composition, structure, reproduction, and mortality appear to be within normal ranges for eastern deciduous forest—no evidence of forest decline was recorded.

Like ground-level ozone, sulfur dioxide can cause foliar injury in plants, and prolonged exposure can weaken plants, making them susceptible to pathogens. Sensitive plant species, such as high-elevation red spruce at SHEN, may show foliar injury at sulfur dioxide exposures as low as 25 ppb (Treshow and Anderson 1989). Plants generally take up sulfur as SO_4^{2-} from the soil, not in the gaseous sulfur dioxide form. If sulfur dioxide does enter the stomata of plant leaves it is converted to SO_4^{2-}, and sulfite, a compound highly toxic to plants, is produced, causing foliar injury.

Sulfate- and nitrate-containing pollutants acidify forest soils and may cause leaching of base cations (Ca^{2+}, Mg^{2+}, K^+, and H^+) from soils (Webb et al. 1995). In addition, increased acidity of soils leads to increased dissolved aluminum in soils. This aqueous aluminum is toxic to tree roots. Plants affected by high levels of soil aluminum typically exhibit reduced root growth. To date, however, the forests at SHEN have not experienced substantial adverse acidification-related impacts. This low impact is, in part, due to the relatively young age of the forest and the fact that most of SHEN lies in an altitude below which deleterious cloud acid deposition occurs (Sullivan et al. 2003a).

Acid deposition is damaging to water resources at SHEN and has resulted in acid-neutralizing capacity (ANC) values that are lower than levels that can support brook trout in parts of the park ($\geq$50μeq/L) (Webb et al. 2004). The median historic loss of ANC in SHEN streams is estimated to be 20 ueq/L (Sullivan et al. 2003a). Acid deposition is particularly deleterious during high flow events. During these episodes, ANC values are generally 20% lower than baseflow values (Eshleman et al. 1999). Furthermore, acid deposition leads to increased leaching of base cations into streams, decreased pH, and increased concentrations of dissolved aluminum in streams (Webb et al. 1995). These effects are especially harmful to fish populations in streams located in areas of siliciclastic bedrock (Galloway et al. 1999). These siliciclastic streams have naturally poor ANC and, therefore, are not able to buffer the effects of acid deposition. Acid deposition has probably contributed to declines in fish and macroinvertebrate diversity in streams at SHEN. For example, Model of Acidification of Groundwater in Catchments (MAGIC) predicts that there are fewer fish species in all streams at SHEN due to the effects of acidic deposition on water chemistry (Vana-Miller and Weeks 2004).

Fine mass particulates are a leading cause of human respiratory illness and present a serious danger to human health (Environment Canada 1998). For example, fine particles are easily inhaled deeply into the lungs where they can remain embedded for long periods of time or be absorbed into the bloodstream. Particulates are especially harmful to people with lung disease, such as asthma, chronic bronchitis, and emphysema, as well as people with heart disease. Exposure to particulates can trigger asthma attacks and cause wheezing, coughing, and respiratory irritation in individuals with sensitive airways.

Gaps in Knowledge: At SHEN, elevation and local topography contribute to the effects of air-borne pollutants on natural resources. For example, high elevation sites may be more susceptible to the effects of certain pollutants, and air turbidity created by local topography may influence how pollutants are transmitted and deposited at the park (Arritt 1988). However, due to cost, there are a limited number of air quality monitoring sites at SHEN and the local effects of topography on pollution is not well understood.

In contrast to the relatively well-studied effects of sulfate-containing pollutants on natural resources at SHEN, little is known about the effects of nitrate pollution at the park. In addition, the contribution of dry deposition to overall acid-deposition rates is not well understood.

Due to a relative lack of knowledge about soils parkwide, little is known about the cumulative impacts of air pollution on soils, and hence, plant communities, at SHEN.

There is still little known about the sources of mercury and deposition rates in SHEN. For example, the fate and transport of mercury in the terrestrial and aquatic environments of SHEN is unknown. In particular the generation of methylmercury (CH_3Hg^+), a neurotoxin, and the form of mercury that is most easily bioaccumulated in organisms, has not been studied at SHEN. Methylmercury is formed in the environment primarily by a process called biomethylation that carried out by sulfate-reducing bacteria that live in anoxic (low dissolved oxygen) environments, such stream sediments.

Suggested Management Recommendations:

- Due to the severity of the air-quality deterioration in and around SHEN, and now that approval has been granted, the air resource specialist position should be refilled.
- Improve estimates of dry deposition in the park.
- Determine rates of nitrogen fixation and denitrification to more completely understand the potential for long-term effects of nitrogen deposition on forest health.
- Quantify current base cation status of SHEN soils and determine how leaching of cations from soils at SHEN are affected by acid deposition, forest disturbance, land use history, and forest regeneration.
- Determine nitrogen retention capacity, sinks, and flowpaths in SHEN's watersheds.
- Continue trends analyses of collected air-quality data to ensure that air-quality trends can be detected under the current monitoring program.
- Work with Virginia's Department of Environmental Quality on Virginia's State Implementation Plan for air quality. This plan must be submitted to the EPA in 2008 and document the rate of progress needed to achieve specific CAA Class I attainment goals.
- Determine the rate of mercury methylation and the processes/ecosystem characteristics that enhance methylation at SHEN.

<u>Visibility (Haze and Dark Night Skies)</u>

Current Status and Significance: SHEN's estimated natural (background) visual range is approximately 185 km (115 mi). Visibility in the park has been severely degraded, so that today the annual standard visible range (SVR) at SHEN averages 36.8 km (23 mi [only 20% of the park's natural visual range]). During summer, SVR decreases to an average of 20 km (12 mi) and increases to an average of 64 km (40 mi) during winter (Sullivan et al. 2003a).

The decline in visibility at SHEN is especially apparent from scenic overlooks located along Skyline Drive. SHEN's Skyline Drive is on the National Register of Historic Places and is designated as a Virginia Scenic Highway. SHEN is also considered a "regionally representative park" where visibility is considered an important preservation value by the public (Chestnut and Rowe 1990). Skyline Drive features 69 overlooks that provide expansive views of mountains, valleys, and unique geologic features. In 1924, surveyors noted that the park's "greatest single feature" was a commanding view of the Piedmont Plain stretching east to Washington (NPCA 2003). Because of these regionally and nationally significant values, haze is an important issue for the NPS. With the signing of the 1999 Regional Haze Rule, federal land managers are working with state and other federal officials to improve visibility in national parks.

In 1977, Congress established a national goal of no human-caused visibility impairment in Class I areas, and in 1999 instituted a rule requiring states to develop and implement plans to make progress towards that goal (Sullivan et al. 2003a). In order to determine how states are progressing toward the goal, the IMPROVE Program was developed as a cooperative monitoring effort. There are three IMPROVE monitoring sites located at SHEN: Big Meadows, Skyland, and Dickey Ridge. At these sites, depending on location, fine mass particulates (the main contributor to visibility impairment), visibility conditions, and viewsheds are monitored. Details of IMPROVE visibility monitoring within SHEN include:

- Particulate monitoring samples the fine mass and course mass particulates directly and occurs only at Big Meadows. Particulate monitoring has occurred to some degree at SHEN since 1982.
- Optical monitoring measures light extinction using transmissometers or nephelometers and occurs only at Big Meadows. Light extinction coefficient is used to determine the light lost per unit length along a sight path due to scattering and absorption by gases. An increase in extinction is equivalent to a decrease in visual range. Therefore, improved visibility is associated with decreasing extinction and increasing visual range. Optical monitoring has occurred at Big Meadows since 1991.
- Viewshed monitoring uses automated 35-mm or digital camera systems to provide a photographic record of visibility conditions and occurs at Skyland (WNW Vista) and Dickey Ridge (SW Vista). Viewshed monitoring occurred at Dickey Ridge only in 1991 and at Skyland from 1991–1995.

Fine particles in the air are the main contributor to human-caused visibility impairment. Ferman et al. (1981) estimated that 78–86% of total light extinction in the Blue Ridge Mountains was caused by anthropogenic fine mass particles. Visibility degradation results from scattering and absorption of visible light by these fine mass particles in the atmosphere. Fine mass particulate matter, typically those less than 2.5 micrometers in diameter ($PM_{2.5}$), has a greater scattering efficiency on a per mass basis than coarse particles (particles between 2.5 and 10.0 μm in diameter). These fine mass particulates create haze and, not only decrease the distance one can see, also reduce the colors and clarity of scenic vistas. Moisture in the air enhances the impact, so areas in the eastern U.S. with higher relative humidity have worse visibility than areas in the arid west. The chemical composition of the fine mass particulates also influences their effect on visibility. $PM_{2.5}$ that contains sulfate and nitrate are particularly deleterious to visibility because they absorb water at higher relative humidity conditions.

SHEN experiences the highest extinction in summer (195 Mm^{-1}) and lowest in winter (61 Mm^{-1}). These trends in extinction rate reflect trends in particulate matter deposition at SHEN. Seasonal differences are driven largely by summer increases in ammonia sulfate. In general, extinction declined at SHEN from 1988–2000 during spring and summer, but remained relatively constant during autumn and winter. The analyses of the speciated particulate data that cause extinction revealed the following:

- Ammonium sulfate is the largest contributor to extinction (51–72%) at SHEN.
- Organic mass is generally the second largest contributor to extinction (20–26%) at SHEN.
- Ammonia nitrate contribute 2–12% to extinction at SHEN.
- Soil and light absorbing carbon contribute 6% or less to total extinction at SHEN.

Automated cameras at Dickey Ridge and Skyland were programmed to take photographs three times each day (at 0900, 1200, and 1500 local time) to determine the visibility of the selected vista. Representative photographs from this sampling are available in SHEN's Air Quality Assessment Report and show a distinct seasonal pattern (Sullivan et al. 2003a; Figures 3a, b). Summer exhibited the poorest visibility at both sites with a visual range of 20–25 km (12–15 mi), and extinction of 156–196 Mm^{-1}, and a haziness of 28–30 deciviews (dv). Winter had the best visibility with a visual range of 275–325 km (170–200 mi), extinction of 14–12 Mm^{-1}, and a relative haziness of 4–2 dv. SHEN's estimated natural (background) haziness is approximately 7.5 dv averaged over the year.

In 1999, the Environmental Protection Agency (EPA) enacted visibility protection regulations that require states to put in place cost-effective emission reductions with the goal of returning to natural visibility conditions in 60 years. Based on emission control scenarios modeled in SHEN's Air Quality Assessment Report, visibility is not expected to improve dramatically at the park (Sullivan et al. 2003a). For example, an 85% improvement in current visibility is needed to restore estimated natural background conditions at SHEN during summer. If maximally feasible controls were applied to all emission sources (electric generating units, non-electric generating units, and mobile sources) by CAA or state-based restrictions SHEN would only achieve a 52.4% improvement in visibility during the summer.

The visual environment of dark night skies has not been studied at the park. However, the NPS is obligated to preserve, to the greatest extent possible, the natural landscape and dark night skies of parks, which are natural resources and values that exist in the absence of human-caused light (NPS 2001). Aside from affecting the visibility of night skies, recent studies indicate that light pollution may adversely affect water quality, salamander foraging, bird migration, and turtle breeding (Duriscoe 2001; Harder 2004). Alverez del Castillo and Crawford (2001) suggest

a) View on clear day.

b) View on hazy day.

Figure 3. View from Shenandoah National Park from the same vista on two different visibility conditions: a) clear day, and b) hazy day (Shenandoah National Park photos).

several approaches to achieving "good" lighting in national parks that will reduce the risk to dark night skies.

Threats: The primary contributor to visibility impairment in the eastern U.S. is sulfate particulates which are emitted by coal-fired power plants, electricity-generating facilities, and other industrial sources. Other contributors to visibility impairment are particulates from nitrates (from fossil fuel combustion), organics (from automobiles and manufacturing facilities), and light-absorbing carbon (from burning wood). Soil from windblown dust is a relatively small contributor to visibility impairment in the eastern U.S.

The primary threat to dark night skies at SHEN is the use of artificial light in and around the park. Artificial lighting is associated with roads, buildings, and signage.

Gaps in Knowledge: No studies on the effects of artificial light on the natural landscapes of SHEN have been conducted.

Until fall 2003, SHEN was a major participant in the Visibility Improvement State and Tribal Association of the Southeast (VISTAS), a regional planning organization that is dealing with air quality issues related to regional haze. However, in fall 2003, the park's air resource specialist position was vacated and has not been refilled. Therefore, the park's continued knowledge of regional haze issues and air quality issues in general has been compromised. In 2006, approval was granted to refill the air resource specialist position.

Suggested Management Recommendations:

- Continue participation in VISTAS when the air resource specialist position is refilled.
- Much of the ambient light that affects visibility of night skies at SHEN is generated outside the park; therefore, a cooperative effort between NPS officials and local and regional planners should be established to help protect dark night skies. One cooperative effort may be to work lighting restrictions into land development proposals that occur within a particular distance of the park.
- Conduct an inventory and assessment of the prevalence and effects of artificial lighting within the park and utilize the keys to good lighting as outlined in Alvarez del Castillo and Crawford (2001). In particular, all night lighting should be directed downward, unobstrusive, activated by motion sensors, and lighting should eliminate glare.

Natural Sounds

Current Status and Significance: The NPS is obligated to preserve, to the greatest extent possible, the natural soundscapes of parks. Natural soundscapes exist in the absence of human-caused sound. The natural soundscape is the aggregation of all natural sounds that occur in parks, together with the physical capacity for transmitting natural sound. Natural sounds occur within and beyond the range of sounds that humans can perceive, and can be transmitted through air, water, or solid materials (NPS 2001).

Threats: Noise from construction practices, traffic, logging, and human aggregation all are potential threats to the natural sounds of SHEN.

Gaps in Knowledge: No research on the natural soundscape of SHEN has been conducted.

Suggested Management Recommendations:

- Determine sources of threats to the natural soundscape of SHEN.
- In accordance with normal construction practice, noise-generating construction equipment should be equipped with effective noise-control devices (e.g., mufflers, lagging, and/or engine closures). All equipment should be properly maintained to ensure that no additional noise will be generated.
- Noise from construction activities should be limited according to the appropriate sections of local ordinances.
- SHEN should further prevent and/or minimize construction noise by managing its intensity, frequency, magnitude, and duration in any one place on any particular day.

Water Resources

A variety of the water resources at SHEN have been studied for 30 years or more. In 2004, a Water Resources Scoping Report (WRSR) was prepared that synthesized the results of this body of research (Vana-Miller and Weeks 2004). The WRSR also provided an overview of state and federal water-related legislation, summarized the ecological setting and hydrological environment of the park, identified significant water-related issues and informational needs, and presented recommendations for management consideration (Vana-Miller and Weeks 2004). Many of the findings of the WRSR are excerpted here.

Streams

Current Status and Significance: SHEN streams are regionally significant because they comprise the headwaters of three major river drainages: the Shenandoah River to the west and the Rappahannock and James rivers to the east (Vana-Miller and Weeks 2004). There are 42 watersheds that contain perennial streams located on the west side of SHEN and 28 on the east side of the park (Vana-Miller and Weeks 2004). Of these 70 watersheds, 44 are actively sampled for water quality and other parameters. Watersheds are relatively small at SHEN, ranging in size from 0.5 km^2 (0.2 mi^2 [Dry Run]) to 31 km^2 (12.1 mi^2 [Big Run]). Most watersheds, however, are 2.5–5 km^2 (1–2 mi^2) in size (Vana-Miller and Weeks 2004). The eastern slope streams in SHEN tend to be larger and are fed by more tributaries and springs than those on the western slopes, which tend to be more linear and have lower flows (Vana-Miller and Weeks 2004). All streams in SHEN, due to relatively high elevation and steep slopes, contain pools interspersed with riffles, rapids, and locally significant waterfalls, some up to 26 m (85 ft) in length. The bottom reaches of streams in the park are strewn with large gravel, rubble, boulder, and bedrock, and are well-shaded, cool, and clear (Vana-Miller and Weeks 2004). These streams support nationally significant populations of native brook trout and have attracted recreational anglers for almost a century.

The headwaters of the park's streams are affected by processes that may differ from those that affect the stream network further downslope. For example, the headwaters (located closest to the crest of the Blue Ridge) may experience greater or more frequent precipitation, snow accumulation, canopy coverage, discharge volume variation, and debris flows than downslope streams. In addition, headwater streams tend to contain less nutrients and are more influenced by groundwater flow than downslope streams (Vana-Miller and Weeks 2004). Despite the differences between headwater and downslope stream dynamics, it is critical to maintain connectivity between them in order to preserve in-stream habitat, species migration, and flux of organic matter and nutrients (Vana-Miller and Weeks 2004).

Flow rates in streams at SHEN are largely influenced by precipitation, although groundwater levels and soil moisture also affect waterflow (Lynch 1987). Most peak stream flows occur during spring when soils are saturated. However, some peak stream flows occur in summer due to intense thunderstorm activity. For example, in 1995 up to 61 cm (24 in) of rain fell in localized areas in and around SHEN in less than 10 hours (Smith et al. 1996; Karish et al. 1997; Demarest 2005). This severe flooding event removed soil, boulders, and vegetation from a 75–100 m (246–328 ft) swath along the stream corridors of the Stauton River, the Rapidan River, and the north fork of Moorman's River (Demarest 2005).

Physical characteristics of the watershed also influence flow rate in streams. For instance, Lynch (1987) found that variation in low-flow rates were largely due to the size of the drainage basin, bedrock geology, topography, the thickness of loose rock, local climate, and vegetative cover. A bedrock geology that contains inclined rocks (e.g., on the eastern side of the Blue Ridge) stores large quantities of groundwater that sustain stream flow during dry periods. In contrast, stream watersheds that contain sedimentary rocks (in the southwestern portion of the park) have little groundwater infiltration, resulting in low flow rates during dry periods.

Water quality and quantity is monitored in SHEN's streams by a variety of programs. The most comprehensive, the Shenandoah Watershed Study (SWAS), is a cooperative program of the NPS and the Department of Environmental Sciences at The University of Virginia (Galloway et al. 1999). This program is the longest running research cooperative in the NPS. SWAS was initiated in 1979 with the establishment of water-quality monitoring on two streams at SHEN; White Oak Run and Deep Run (Vana-Miller and Weeks 2004). SWAS was established to determine biogeochemical conditions in forested, mountain watersheds of SHEN and their responses to anthropogenic perturbations (Hendrey et al. 1980; Vana-Miller and Weeks 2004). Currently, SWAS technicians conduct weekly sampling in six watersheds and quarterly sampling in eight additional watersheds within SHEN. These watersheds represent the range and distribution of streams in the park. Streamwater acidification, sulfur retention, and overall streamwater composition are examined as part of the SWAS study. SWAS was first able to document the acid-sensitive nature of SHEN streams in the late 1970s (Hendrey et al. 1980).

Another water quality monitoring program, the Virginia Trout Stream Sensitivity Study (VTSS), was initiated in 1987 by the Virginia Department of Game and Inland Fisheries. VTSS data collection became a partnership with SWAS and primarily focuses on sampling water quality mainly on national forest lands, thus providing a regional perspective on water quality.

Galloway et al. (1999) assessed the data collected as part of the SWAS study and found that statistically significant trends in certain water-chemistry parameters could be detected in White Oak Run and Deep Run. These trends reflected those of Ryan et al. (1989) and included declining ANC, increasing SO_4^{2-}, and increased leaching of Mg^{2+} (a base cation) from 1982–1990. After 1990, however, declining trends in ANC and increasing trends in SO_4^{2-} did not continue, perhaps due to declines in atmospheric deposition of sulfates and nitrates due to the implementation of CAA emission controls. For example, for the period 1988–2001, there were statistically significant increases in ANC and significant decreases in sulfate in SHEN streams (Webb et al. 2004; Table 3). In addition, nitrates, and base cations (sum of calcium, magnesium, potassium, and sodium) concentration also declined in SHEN streams during this time period (Webb et al. 2004; Table 3). These changes over the past decade reflect some regional recovery from acidic deposition in park streams. However, during the same time period there was also a slight increase in hydrogen ion concentration in study streams.

Table 3. Linear regression trends in constituent solute concentrations in study streams at Shenandoah National Park, Virginia 1988–2001 (*n*= 14 streams). Streams are part of the Shenandoah Watershed Study (SWAS) lead by the University of Virginia (after Webb et al. 2004).

Constituent solute	Concentration trend1988-2001 (μeq/l)
ANC	0.168*
Sulfate	-0.229*
Nitrate	-0.298
Base cations	0.072
Hydrogen ion	0.007*

*Statistically significant trend ($P < 0.05$)

Deviney and Webb (2005) provide ranking categories for SHEN streams (Table 4). These rankings were elicited from questionnaires that were completed by both SHEN and University of Virginia (UVA) staff. Eighty streams were ranked into 1 of 4 categories: impaired (303d), exceptional waters, suspected-impaired, and other. Twelve impaired streams, based on 303(d) criteria of the Clean Water Act, were noted. Six streams were categorized as exceptional and 15 were listed as suspected impaired. The primary impairment was due to acidification and fecal coliform contamination (Deviney and Webb 2005).

Threats: Acid deposition, caused by sulfate and nitrate pollutants, is the major threat to water quality of SHEN's streams. Western and central Virginia consistently receives among the highest level of sulfate (acid-causing) deposition in the United States. Despite this threat, there may be some regional recovery occurring in SHEN streams. A variety of long-term studies conducted at SHEN, including the Shenandoah Watershed Study (SWAS), the Virginia Trout Stream Sensitivity Survey (VTSSS), and individual research projects, document decreasing trends in streamwater pH and ANC consistent with acidification of the streams due to acid deposition during the period 1980–1987 (Ryan et al. 1989; Webb et al. 1993; Underwood and Dolloff 1996; Galloway et al. 1999). However, Webb et al. (2004) noted some recovery in ANC and sulfate concentrations in study streams (Table 3). Despite this recovery in constituent solute values, water quality in SHEN streams is still degraded compared to historic levels. For example, sulfate concentrations in SHEN streams have increased 2.5–7.5 times from historic levels (Webb et al. 2004). In addition, the median historical loss of ANC in park streams has been estimated to be 20 μeq/L (Sullivan et al. 2003b).

The ANC and pH of the streams at SHEN are influenced primarily by the geology underlying the streams. Streams located in basaltic geology (Catoctin greenstone) have highest ANC (>75

Table 4. Streams located in Shenandoah National Park, Virginia and their rank status based on questionnaire completed by park staff and researchers at University of Virginia (after Deviney and Webb 2005).

Stream name	Status
Paine Run	Impaired-low pH due to acid deposition
Hawksbill Creek	Impaired-fecal coliform bacteria
North Fork Moormans Creek	Impaired-low dissolved oxygen
Meadow Run	Impaired-low pH due to acid deposition
Rocky Branch	Impaired-low pH due to acid deposition
Swift Run	Impaired- fecal coliform bacteria
Deep Run	Impaired-fecal coliform bacteria
Jeremy's Run	Impaired-low pH due to acid deposition
Naked Creek	Impaired-fecal coliform bacteria
Flint Run	Impaired-fecal coliform bacteria
Pass Run	Impaired-fecal coliform bacteria
Happy Creek	Impaired-fecal coliform bacteria
Lower Lewis Run	Suspected impaired
Fultz Run	Suspected impaired
North Fork Dry Run	Suspected impaired
One Mile Run	Suspected impaired
Big Ugly Run	Suspected impaired
Overall Run	Suspected impaired
Two Mile Run	Suspected impaired
Lands Run	Suspected impaired
Shenk Hollow	Suspected impaired
Sawmill Run	Suspected impaired
Little Hawksbill Creek	Suspected impaired
East Fork	Suspected impaired
Madison Run	Suspected impaired
South Fork Dry Run	Suspected impaired
Whiteoak Canyon Run	Suspected impaired
Doyles River/Jones Falls	Exceptional quality
Piney River	Exceptional quality
East Branch Naked Creek	Exceptional quality
Big Run	Exceptional quality
East Hawksbill Creek	Exceptional quality
North Fork Thornton River	Exceptional quality
Brokenback Run	Other
South Fork Thornton River	Other
Berry Hollow	Other
Pocosin River	Other
Hughes River	Other
Hazel River	Other
Cedar Run	Other
South River	Other
Rose River	Other
Broad Hollow	Other
Rapidan River	Other
Ivy Creek	Other
South Fork Moormans River	Other
Hannah Run	Other
Staunton River	Other
Bolton Branch	Other
Ragged Run	Other
Conway River	Other

μeq/L), streams located in granitic geology have intermediate ANC (25–75 μeq/L), and streams located in siliciclastic geology have lowest ANC (<25 μeq/L) (Herlihy et al. 1993). Streams underlain by the siliciclastic geology are located on the western slopes of the Blue Ridge and have the highest risk of adverse effects due to acid precipitation (Vana-Miller and Weeks 2004). Approximately half of the streams associated with siliciclastic bedrock had ANC in the chronically acidic range (<0 μeq/L) in which lethal effects to brook trout are probable (Galloway et al. 1999).

The major dissolved ion in low-ANC streams is atmospherically derived sulfate (Webb et al. 1989), although nitrate may also play a role in stream acidification (Baker et al. 1990). The effects of bedrock on ANC in streams may be due, in part, to variation in sulfate retention by soils associated with different bedrock types. Although acid deposition is relatively consistent across the park, sulfate retention rates in soil range from 45–66%, with siliciclastic soils retaining sulfate at higher rates than basaltic (greenstone) soils (Ryan et al. 1989; Galloway et al. 1993; Herlihy et al. 1993). Even though SHEN's soils retain up to two-thirds of the deposited sulfate, the streamwater sulfate concentrations are increasing as the retention capacity of the soils is depleted, and stream acidity may continue to increase for decades (Ryan et al. 1989). For example, Cosby et al. (1991) estimated that sulfate concentrations have apparently increased over background levels at SHEN by a factor of 4.4 in streams associated with siliciclastic bedrock, 1.7 in streams associated with basaltic bedrock, and 2.8 in streams associated with granitic bedrock.

Aside from the effects of bedrock on stream acidity, ANC of streams in SHEN appears to vary with season and flow rate. ANC is generally lower in the winter during high-flow rates than in the summer during low flow (Hyer et al. 1995; Eshleman et al. 1999). However, some streams contain carbonic and organic acids, products of microbial and root respiration in soils (Castelle and Galloway 1990). Carbonic acid is derived from soil carbon dioxide and, at SHEN, soil carbon dioxide increases during late summer (Castelle and Galloway 1990). Therefore, in these streams, ANC is lowest during warm months and low flows (Webb 2004). In contrast, in streams with naturally low ANC, dissolved aluminum, a primary cause of fish mortality, is mobilized during high-flow events (Burns 1989; Wigington et al. 1993; Hyer et al. 1995). For example, in Paine Run, a high-flow event in 1992 caused a depression of ANC to less than 0 μeq/L and a corresponding increase in aluminum to almost 100 μeq/L, well above the threshold for adverse biotic effects (Vana-Miller and Weeks 2004). Similar trends in dissolved aluminum were noted in the White Oak Run watershed during high-flow events in 1980 (Burns 1989).

The threats to water quality by acidification may be declining, albeit slightly, due to decreasing atmospheric emissions of sulfur dioxide following implementation of Title IV of the CAA Amendments of 1990 (Webb et al. 2004). As state previously, monitoring indicates that sulfate deposition in the region declined 40% between 1985 and 2000 (Webb et al. 2004). Corresponding with this decrease in deposition, ANC increased in 14 streams in SHEN an average of 0.17 μeq/L/yr, and the sulfate concentration in these streams declined at 0.229 μeq/L/yr (Webb et al. 2004). This degree of recovery is small compared to other regions of the United States, and the low rate of recovery may be attributed to differences in soil sulfate retention due to different underlying bedrock geology (Webb et al. 2004). In addition, this recovery may not be entirely related to decreasing sulfur-dioxide emissions, but rather to recovery of the streams from the effects of gypsy moth defoliation in the watersheds. When defoliation due to gypsy moth caterpillars peaked at SHEN, nitrate levels rose and ANC decreased in SHEN streams (Eshleman et al. 1995; Webb et al. 1995). For instance, episodic depressions in ANC increased by nearly a factor of two in White Oak Run during the first outbreak of forest defoliation by the gypsy moth caterpillar during summer 1990 (Eshleman et al. 1995). After this nitrate pulse, stream ANC gradually increased due to forest regeneration and re-foliation of watersheds. The slight "recovery" of streams from acidification at SHEN may, therefore, be due to the short-term response to the effects of gypsy moth defoliation rather than to reductions of sulfur-dioxide emissions.

The short-term pulse in lowered ANC and increased nitrates in streamwaters at SHEN due to gypsy moth defoliation events also resulted in the leaching of many base cations (Ca^{2+}, Mg^{2+}, K^{+}, and H^{+}) from park soils into park streams. Therefore, the long-term effects of gypsy moth defoliation include reduction of base-cation supplies in park soils (Webb et al. 1995; Sullivan et al. 2003b; Webb et al. 2004;). In addition, the depletion of base cations from soils due to long-term exposure to acid deposition and historic land use practices may make it difficult for SHEN streams to recover as quickly as other regions of the country.

Overall, alkalinity of surface waters in some watersheds at SHEN may have been reduced by as much as 50% over the past 140 years (Cosby et al. 1985). In order to begin restoring streams to historic alkalinity and to prevent any further acidification, there would need to be a 70–100% reduction in atmospheric acid deposition rates (Cosby et al. 1985; Sullivan et al. 2003b; Webb et al. 1994). Based on modeling performed by Webb et al. (1994) and Sullivan et al. (2003b) as part of the VTSS study, the number of streams with pH <5 (the approximate minimum for the most acid-tolerant fish species present in VA mountain streams) will increase despite anticipated reductions in sulfate deposition due to CAA amendments.

Fecal coliform contamination has been noted at Pass Run and Hawksbill Creek in SHEN (Deviney and Webb 2005). The fecal coliform most likely originates from wildlife and human sources (recreational use) near streams.

Gaps in Knowledge: The effects of acid deposition on SHEN's streams needs to be placed in the larger context of climate change. Weather models predict that the climate of the mid-Atlantic will become warmer and wetter, and these climatic conditions could affect the occurrence and severity of acid deposition (Vana-Miller and Weeks 2004). For example, analyses, experimental designs, and aquatic indicators (perhaps headwater stream-flow rate) need to be developed that distinguish between climatic and anthropogenic effects on SHEN's streams.

The knowledge of soil chemistry and type is poor at SHEN, and that limits the ability to understand the response of park ecosystems to acid deposition (Galloway et al. 1999).

Although much research has been conducted on the effects of sulfate-containing pollutants on watersheds, a more thorough understanding of nitrogen cycling in SHEN watersheds is necessary (Galloway et al. 1999).

Suggested Management Recommendations

- Reevaluate and revise (if needed) existing water-quality monitoring programs. The water-quality monitoring program at SHEN should establish clear, statistically relevant monitoring objectives so that trends in water quality in SHEN's streams can be detected. Specifically, the ongoing trend analysis of SWAS data on streamwater chemistry and a more thorough analysis of the controls on episodic stream responses are needed (Galloway et al. 1999).
- Continue to partner with the University of Virginia's SWAS study in order to increase the understanding of biogeochemical processes in SHEN's watersheds. As part of this partnership, focus water-quality sampling at headwater and lower stream reaches in the SWAS watersheds.
- Use a combination of pH and benthic macroinvertebrate community assessments to determine the level of impairment of SHEN's streams so that they can be monitored while on Virginia's 303(d) list. Such inclusion provides funds for restoration and rehabilitation of these streams.
- Ensure that sewage facilities are maintained so that fecal coliform does not enter streamwaters.
- Follow best management practices for all stream crossings so that construction-caused soil erosion does not impact streams.
- Collect additional soils data within SHEN watersheds to better understand spatial variation and capacity to respond to acidification.
- Given the documented effects of defoliation on water chemistry, control potential defoliators (including gypsy moth) at SHEN.

<u>Groundwater</u>

Current Status and Significance: In general, groundwater occurs in rock fractures and pore spaces within unconsolidated sediments. Most water-bearing fractures exist in the upper 91 m (300 ft) of bedrock at SHEN (DeKay 1972). These fractures are not interconnected at SHEN and Lynch (1987) describes the park's groundwater as a group of isolated groundwater systems, each made of hydraulically connected fractures and overlying regolith (loose stone). Precipitation is the major source of groundwater recharge at SHEN.

Groundwater reaches the surface by percolating through fractures in the bedrock and occurs as springs and seeps throughout the park. In other words, at springs and seeps the groundwater table coincides with the land surface (Vana-Miller and Weeks 2004). Dekay (1972) identified 854 "surface-water sources" at SHEN. However, he did not specifically identify the locations of these surface-water sources so it is unclear what type of source they are, springs or seeps. Little is known about the springs and seeps at SHEN, and most research to date has focused on those developed springs and seeps located along Skyline Drive (Vana-Miller and Weeks 2004). Springs and seeps are a main source of water supply (along with wells) for human use at the park and often are associated with recreational development (Vana-Miller and Weeks 2004). For example, the Big Meadows, Skyland, and Lewis Mountain campgrounds are all located near developed springs. In addition to their use by humans, springs and seeps provide critical habitat to rare plants and wildlife at SHEN. In particular, breeding amphibians rely on these habitats in the park.

Like streamflow, spring flows are influenced by season, local climate, recharge area (watershed) size, topography, and geology. In general, spring/seep flows are at a maximum in spring and a minimum in late summer (Vana-Miller and Weeks 2004). Springs and seeps occur most commonly in the middle portion of the park and are least common in the southern section of SHEN. Sixty-five springs have been identified and mapped at SHEN. Forty-seven are located in the middle section of the park, and 18 are located in the northern and southern sections, combined (Vana-Miller and Weeks 2004).

The average age of groundwater discharging to springs or seeps at SHEN is less than three years (Plummer et al. 2001). At Lewis Springs, however, the average age of groundwater is 6–7 years (Plummer et al. 2001). These relatively young ages of groundwater discharge are indicative of fast groundwater travel times; therefore, there is a high potential of susceptibility to contamination from polluting events in the recharge area of the aquifer (Martin 2002). Tests indicate that groundwater from wells and springs in and around SHEN is low in dissolved solids and iron, is classified as soft, and concentrations of arsenic, cadmium, chromium, copper, lead, mercury, selenium, and zinc are below EPA limits set for public water supplies (Plummer et al. 2001; Vana-Miller and Weeks 2004).

Threats: Groundwater has primarily been used for local domestic and recreational needs at SHEN and, with the exception of Big Meadows, there have been no long-term negative effects on the groundwater resources at SHEN due to these uses (Lynch 1987). A study conducted at Big Meadows (BM) campground, however, demonstrated that water table declines in the early- to mid-1980s began earlier in the year and were larger than would occur naturally (Lynch 1987). These declines in water table were adversely affecting the adjacent wetland complex of Big Meadows. The decline in the water table was attributed to groundwater pumping at well BM-3. This well was closed to all uses in 1992 and today most potable water for the Big Meadows campground is obtained from Lewis Spring. In addition, three wells were developed in 1989 to provide supplemental/backup water sources when flow from Lewis Spring is insufficient to meet demand at the Big Meadows campground in late summer (Martin 2002).

A complete list of potential point and non-point groundwater contamination sources are provided in Vana-Miller and Weeks (2004) and include: Skyline Drive, sewage pollutants from campgrounds (pit toilets, tertiary sewage treatment plants) and visitor centers (which are all located near the largest springs in the park), underground gasoline tanks (associated with gasoline stations along Skyline Drive), gas lines, pesticide or other chemical spills at ranger stations and maintenance yards, landfills (12 known NPS sanctioned and CCC-era landfills are in SHEN), and chemical spills and road runoff (including deicing salts, heavy metals, and hydrocarbons) along any of the ten state roads found in the park (including routes 211 and 33). Wells near Lewis Spring potentially could be contaminated by pollutants leaking from an abandoned dump located 1.6 km (1 mi) away (Vana-Miller and Weeks 2004). Herbicides used to maintain power line rights-of-way could affect groundwater supplies at SHEN. Furthermore, bacteria from horse (used for trail riding) and human waste (from backcountry waste disposal and potential sewage leaks at developed facilities) may infiltrate groundwater supplies after storm events.

Gaps in Knowledge: The recharge zones and groundwater flow paths have not been determined at SHEN. Therefore, it is difficult to protect water supplies from pollutants that could enter aquifers via conduits in fractured rock (Vana-Miller and Weeks 2004).

Suggested Management Recommendations:

- Update the Spill Prevention and Control Counter Measure Plan and the Well Head Protection Plan to provide protections to SHEN's groundwater supplies.
- Map aquifers at SHEN, including recharge zones and groundwater flow paths.
- Ensure that all park employees are familiar with SHEN's Emergency Operations Plan that includes spill response.
- Initiate a program to periodically test stormflow bacteria levels in SHEN's groundwater to determine potential effects of bacterial (and other pathogen) contamination.

Plant Resources

Most of SHEN is covered by second-growth forest whose composition has been influenced by the topography, climate, geology, and natural disturbance regimes of the northern Blue Ridge Mountains, as well as by historic land use and other anthropogenic disturbances. Braun (1950) defines the Northern Blue Ridge as a forest section of the Oak-Chestnut Forest region. However, the loss of American chestnut in the early 1900s changed the composition of the Oak-Chestnut Forest region. It currently resembles the Oak-Hickory Forest region also described by Braun (1950), and is generally dominated by oaks with hickories as secondary components.

Despite a history of disturbance, SHEN represents one of the nation's most diverse botanical reserves, contains globally rare plant communities, and is an outstanding example of the Northern Blue Ridge Forest (NPS 1998). Braun (1950) considered the forest within SHEN, whose range of elevation is from 170–1,234 m (560–4,050 ft), to be the best representative of the Northern Blue Ridge Oak-Chestnut Forest region.

Although the forests of the Northern Blue Ridge lack the floral diversity that is characteristic of the Southern Blue Ridge forest, the climate, topography, and geology gives rise to an interesting flora, including areas where some typically northern species reach their southern limit (Braun 1950; Mazzeo 1966b; Ludwig et al. 1993). For example, balsam fir, speckled alder (*Alnus incana* ssp. *rugosa*), bearberry (*Arctostaphylos uva-ursi*), Bebb's sedge (*Carex bebbii*), and bunchberry (*Cornus canadensis*) occur at or near their southern or southeastern range limit in SHEN (NPS 1998). In addition, gray birch (*Betula populifolia*), leathery grape-fern (*Botrychium multifidum*), hemlock parsley (*Conioselinum chinense*), highland rush (*Juncus trifidus*), mountain sandwort (*Minuartia groenlandica*), three-toothed cinquefoil (*Sibbaldiopsis tridentata*), white mandarin (*Streptopus amplexifolius*), and narrow false oats (*Trisetum spicatum*) are long-range boreal disjuncts occurring in isolated, high-elevation stations in SHEN. By contrast, catawba rhododendron (*Rhododendron catawbiense*) reaches its northern limit in the park (NPS 1998).

The history of plant collecting in and around SHEN is described in a series of articles published in the journal Castanea and the Journal of the New York Botanical Garden from 1936–1972 (Camp 1936; Fosberg and Walker 1941, 1943; Fosberg 1946, 1947; Fosberg and Walker 1948;

Fosberg 1955; Fosberg and Walker 1955; Patterson 1955; Fosberg 1959; Fosberg and Mazzeo 1965; Mazzeo1966c, 1967, 1972). Furthermore, collections and study by Schnooberger and Wynne (1945) and Mazzeo (1968, 1981) lead to the publication of works about the trees, ferns, and bryophytes of SHEN, respectively. The majority of the specimens collected and described in the park are deposited at the United States National Arboretum Herbarium in the collection of Charles E. Stevens at Longwood University (Longville, VA) and at park headquarters in Luray, VA (Mazzeo collection). NPSpecies documents the occurrence of 1,360 vascular and nonvascular plant species in SHEN (NPSpecies 2005). Ninety-three species that are considered rare or species of special concern have been documented in the park (Table 5; The Virginia Natural Heritage Program [VANHP] 2006).

Young et al. (2005) built upon the earlier work of Berg and Moore (1941), Braun (1950), and Teetor (1988) in mapping and classifying the vegetation communities of SHEN. in relation to physical processes (e.g., climate), landforms (e.g., geology and topography), and disturbance regimes (e.g., fire and prior land use history). Using an approach consistent with the U.S. National Vegetation Classification System (Sneddon and Metzler 1992), Young et al. (2005) completed a mapping and classification study of plant communities of SHEN in relation to landforms and environmental gradients. Their research identified 35 plant communities, including 24 forest and woodland communities, one shrubland community, five wetland/seep communities, and five rock outcrop barren communities. The 24 forest and woodland communities of SHEN include 11 distinct forest types in which oaks are prevalent, four mixed coniferous types (white pine, pitch pine [*Pinus rigida*], and two hemlock forest types), seven mixed mesophytic/cove forest types, and two other forest types. These forest communities ranged from low- (<457 m [1,500 ft]), to mid- (458–913 m [1,500–3,000 ft]), to high- (>914 m [3,000 ft]) elevation sites and are found on acidic and basic soil types (Young et al. 2005). Two of the communities identified by this effort, the High-Elevation Greenstone Barren and the Northern Blue Ridge Mafic Fen, are endemic to SHEN (Young et al. 2005).

Vegetation at SHEN has been monitored since in 1989 as part of the park's Long-term Ecological and Monitoring (LTEM) program (Smith and Torbert 1990). This monitoring is conducted to provide information on how the forests of the park are changing over time. However, an analysis of LTEM forest vegetation data conducted in 1999 indicated that the current program was unable to detect statistically significant and ecologically meaningful trends in many forest species (Gibbs 1998; Diefenbach 2001b; Diefenbach and Mahan 2002). Despite these deficiencies the program did detect a 40% loss of adult chestnut oak following gypsy moth defoliation, the relative stability (no change) of tulip poplar populations in the park, a 90% decline in dogwood (*Cornus florida*), likely due to dogwood anthracnose, and the reduction in pine trees, likely by pine bark beetles followed by the establishment of tree-of-heaven (NPS 2005c).

A revised LTEM forest vegetation monitoring program was initiated in 2003 and implementation was completed in 2005 (Diefenbach and Vreeland 2003). This revised program consists of 160 sampling sites distributed throughout the park according to combinations of elevation, aspect, and bedrock geology. The forest monitoring program is active in alternate years to conserve funds. The program anticipates re-sampling all 160 sample sites in 2007 followed by the establishment of a four-year plot re-sampling cycle beginning in 2009.

Table 5. Virginia Natural Heritage Program (VANHP) list of plant species of special concern in Virginia known to occur in Shenandoah National Park, 2006.

Common Name	Scientific Name	Federal Status	Virginia Status	Virginia Rank	Global Rank
VASCULAR PLANTS:					
balsam fir	*Abies balsamea*			S1	G5
white monkshood	*Aconitum reclinatum*			S3	G3G4
climbing fumitory	*Adlumia fungosa*			S3	G4
speckled alder	*Alnus incana* ssp. *rugosa*			S2	G5T5
roundleaf serviceberry	*Amelanchier sanguinea var. sanguinea*			S3	G5T5
pearly everlasting	*Anaphalis margaritacea*			S1	G5
bristly sarsaparilla	*Aralia hispida*			S2	G5
bearberry	*Arctostaphylos uva-ursi*			S1	G5
Bradley's spleenwort	*Asplenium bradleyi*			S2	G4
mountain paper birch	*Betula cordifolia*			S2	G5T5
gray birch	*Betula populifolia*			S1	G5
lance-leaved grape-fern	*Botrychium lanceolatum* var. *angustisegmentum*			S1	G5T4
leathery grape-fern	*Botrychium multifidum*			S1	G5
blunt-lobe grape-fern	*Botrychium oneidense*			S2	G4Q
least grape-fern	*Botrychium simplex*			S1	G5
fringed brome-grass	*Bromus ciliatus*			S1	G5
bebb's sedge	*Carex bebbii*			S1	G5
buxbaum's sedge	*Carex buxbaumii*			S2	G5
field sedge	*Carex conoidea*			S1S2	G5
finely-nerved sedge	*Carex leptonervia*			S3	G4
variable sedge	*Carex polymorpha*		LE	S2	G3
prairie straw sedge	*Carex suberecta*			S3	G4
giant-seed goosefoot	*Chenopodium simplex*			S3	G5
purple clematis	*Clematis occidentalis* var. *occidentalis*			S2	G5T5
hemlock parsley	*Conioselinum chinense*			S1	G5
western spotted coralroot	*Corallorrhiza maculata* var. *occidentalis*			S1	G5T?
spring coralroot	*Corallorrhiza wisteriana*			S3	G5

Table 5. Virginia Natural Heritage Program (VANHP) list of plant species of special concern in Virginia known to occur in Shenandoah National Park, 2006 (continued).

Common Name	Scientific Name	Federal Status	Virginia Status	Virginia Rank	Global Rank
bunchberry	*Cornus canadensis*			S1	G5
roundleaf dogwood	*Cornus rugosa*			S1	G5
a hawthorn	*Crataegus pruinosa*			S3	G5
fleshy hawthorn	*Crataegus succulenta*			S1	G5
hazel dodder	*Cuscuta coryli*			S2?	G5
beaked dodder	*Cuscuta rostrata*			S2	G5
Houghton's flatsedge	*Cyperus houghtonii*			SH	G4?
slender wheatgrass	*Elymus trachycaulus* ssp. *trachycaulus*			S2	G5T5
linear-leaved willow-herb	*Epilobium leptophyllum*			S2	G5
glade spurge	*Euphorbia purpurea*			S2	G3
rough-leaved aster	*Eurybia radula*			S1	G5
black ash	*Fraxinus nigra*			S3	G5
northern bedstraw	*Galium boreale*			S3	G5
herb-robert	*Geranium robertianum*			S2	G5
yellow avens	*Geum alepiccum*			SH	G5
low cudweed	*Gnaphalium uliginosum*			S1	G5
Appalachian oak fern	*Gymnocarpium appalachianum*			S3	G3
Appalachian fir clubmoss	*Huperzia appalachiana*			S2	G4G5
slender blueflag	*Iris versicolor*			S3	G5
small whorled pogonia	*Isotria medeoloides*	T	LE	S2	G2
butternut	*Juglans cinerea*			S3?	G3G4
highland rush	*Juncus trifidus*			S1	G5
shale-barren blazing-star	*Liatris turgida*			S3	G3
wood lily	*Lilium philadelphicum* var. *philadelphicum*			S3	G5T4T5
grooved yellow flax	*Linum sulcatum* var. *sulcatum*			S3	G5T5
kidneyleaf twayblade	*Listera smallii*			S3	G4
American fly-honeysuckle	*Lonicera canadensis*			S3	G5
stiff clubmoss	*Lycopodium annotinum*			S3?	G5
treelike clubmoss	*Lycopodium dendroideum*			S3?	G5

Table 5. Virginia Natural Heritage Program (VANHP) list of plant species of special concern in Virginia known to occur in Shenandoah National Park, 2006 (continued).

Common Name	Scientific Name	Federal Status	Virginia Status	Virginia Rank	Global Rank
buckbean	*Menyanthes trifoliata*			S1	G5
muskflower	*Mimulus moschatus*			S1	G4G5
mountain sandwort	*Minuartia groenlandica*			S1	G5
sweet pinesap	*Monotropsis odorata*			S3	G3
marsh muhly	*Muhlenbergia glomerata*			S2	G5
stiff goldenrod	*Oligoneuron rigidum* var. *rigidum*			S2	G5T5
balsam ragwort	*Packera paupercula*			S3?	G5
American ginseng	*Panax quinquefolius*		LT	S3S4	G3G4
Canby's mountain-lover	*Paxistima canbyi*			G2	S2
sword-leaved phlox	*Phlox buckleyi*			S2	G2
tubercled rein orchid	*Platanthera flava* var. *herbiola*			S3?	G4T4Q
large purple fringed orchid	*Platanthera grandiflora*			S1	G5
bog bluegrass	*Poa paludigena*			S2	G3
fringed black bindweed	*Polygonum cilinode*			S3	G5
quaking aspen	*Populus tremuloides*			S2	G5
Alleghany plum	*Prunus alleghaniensis* var. *alleghaniensis*			S3	G4T4
Canada plum	*Prunus nigra*			S1	G5
Torrey's mountain mint	*Pycnanthemum torrei*			S2?	G2
greenish-flowered pyrola	*Pyrola chlorantha*			SH	G5
shinleaf	*Pyrola elliptica*			S2	G5
dwarf chinkapin oak	*Quercus prinoides*			S1	G5
alderleaf buckthorn	*Rhamnus alnifolia*			S1	G5
red raspberry	*Rubus idaeus* ssp. *strigosus*			S2	G5T5
Canada burnet	*Sanguisorba canadensis*			S2	G5
large-fruited sanicle	*Sanicula trifoliata*			S3	G4
three-toothed cinquefoil	*Sibbaldiopsis tridentata*			S2	G5
hairy goldenrod	*Solidago hispida* var. *hispida*			S3	G5T5
Rand's goldenrod	*Solidago randii*			S2S3	G5T4
yellow nodding ladies'-tresses	*Spiranthes ochroleuca*			S1	G4

Table 5. Virginia Natural Heritage Program (VANHP) list of plant species of special concern in Virginia known to occur in Shenandoah National Park, 2006 (continued).

Common Name	Scientific Name	Federal Status	Virginia Status	Virginia Rank	Global Rank
white mandarin	*Streptopus amplexifolius*			S1	G5
mountain pimpernel	*Taenidia montana*			S3	G3
Canada yew	*Taxus canadensis*			S3	G5
western poison ivy	*Toxicodendron rydbergii*			S1	G5
narrow false oats	*Trisetum spicatum*			S1	G5
velvetleaf blueberry	*Vaccinium myrtilloides*			S1S2	G5
white camas	*Zigadenus elegans* ssp. *glaucus*			S3	G5T4T5
<u>NON-VASCULAR PLANTS:</u>					
five-rowed peatmoss	*Sphagnum quinquefarium*			S2S3	G5

[1]Federal Status
T=Threatened
[2]State rankings:
LE=Listed Endangered. A taxon threatened with extinction throughout all or a significant portion of its range.
LT=Listed Threatened. A taxon likely to become endangered in the foreseeable future.
[3]NHP Ranking VA:
SH=Historical: Element occurred historically in the state (with expectation that it may be rediscovered), perhaps having not been verified in the past 20 years, and suspected to be still extant. Naturally, an Element would become SH without such a 20-year delay if the only known occurrences in a state were destroyed or if it had been extensively and unsuccessfully looked for. Upon verification of an extant occurrence, SH-ranked Elements would typically receive an S1 rank. The SH rank should be reserved for Elements for which some effort has been made to relocate occurrences, rather than simply ranking all Elements not known from verified extant occurences with this rank.
S1=Critically Imperiled: Critically imperiled in the state because of extreme rarity or because of some factor(s) making it especially vulnerable to extirpation from the state; typically 5 or fewer occurrences or very few remaining individuals or acres.
S2=Imperiled: Imperiled in the state because of rarity or because of some factor(s) making it very vulnerable to extirpation from the state; typically 6 to 20 occurrences or few remaining individuals or acres.
S3=Vulnerable: Vulnerable in the state either because rare and uncommon, or found only in restricted range (even if abundant at some locations), or because of other factors making it vulnerable to
S4=Apparently Secure: Uncommon but not rare, and usually widespread in the state; usually more than 100 occurrences.
SNR=Unranked; state rank not yet assessed.
SU=Unrankable: Currently unrankable due to lack of information or due to substantially conflicting information about status or trends. Note: Whenever possible, the most likely rank is assigned and a question mark added (e.g., S2?) to express uncertaintly, or a range rank (e.g., S2S3) is used to delineate the limits (range) of uncertainty.

[4]Global Rank:
G1=Critically Imperiled=At very high risk of extinction due to extreme rarity (often 5 or fewer populations), very steep declines, or other factors
G2=Imperiled=At moderate risk of extinction due to a restricted range, relatively few populations (often 20 or fewer), steep declines, or other factors.
G3=Vulnerable=At moderate risk of extinction due to a restricted range, relatively few populations (often 80 or fewer), recent and widespread declines, or other factors.
G4=Apparently Secure=Uncommon but not rare; some cause for long-term concern due to declines or other factors.
G5=Secure=Common; widespread and abundant
T#=Infraspecific Taxon (trinomial)=The status of infraspecific taxa (subspecies or varieties) are indicated by a “T-rank” following the species’ global rank. Rules for assigned T-ranks follow the same principles outlined above for global conservation status ranks. For example, the global rank of a critically imperiled subspecies of an otherwise widespread and common species would be G5T1. A T-rank cannot imply the subspecies or variety is more abundant than the species as a whole-for example, a G1T2 cannot occur. A vertebrate animal population, such as those listed as distinct population segments under the U.S. Endangered Species Act, may be considered an infraspecific taxon and assigned a T-rank; in such cases a Q is used after the T-rank to denote the taxon’s informal taxonomic status. At this time, the T-rank is not used for ecological communities.
?=Uncertain ranking within a category.

Approximately 93% of SHEN is covered by upland forests, 2% is covered by wetland communities, and about 3% of the area is occupied by other communities such as barrens. Roughly 2% of SHEN is currently developed or disturbed by humans and includes drivable roads, parking lots, powerline rights-of-way, and buildings (facilities) (Young, USGS, 2006, pers. comm.). The majority of SHEN's vegetation is in a natural state and is unmanaged. However, vegetation around developed areas, along roadsides, at certain cultural areas and historic structures, and at overlooks is managed for a variety of purposes, including safety and visitor enjoyment. For example, road shoulders along Skyline Drive need periodic vegetation removal to maintain lines of sight. Furthermore, the park's many scenic overlooks require periodic maintenance to ensure vista preservation. Roadside vegetation management involves the use of mowing, herbicide application, and manual removal. Vegetation management on vistas is achieved through the application of herbicides or prescribed fire. Removal zones are surveyed for the presence of species of concern prior to vegetation removal activities, and efforts are made to work with the park's maintenance division to ensure that no species of concern will be harmed by vegetation management work (NPS 2005d).

Plant inventory and monitoring efforts at SHEN may benefit by compiling a plant species list that includes species likely to occur in the park but not yet documented (e.g., Norris 2002). One goal of resource managers could be to document 90% of plant species likely to occur in the park. In order to achieve this goal, researchers will have to begin scouting wide areas for the express purpose of creating a complete floristic list (Norris 2002). All floristic lists should be accompanied by vouchered specimens or photographs with locality and surrounding habitat described (Norris 2002).

Unfragmented Forest (Including Wilderness Areas)

Current Status and Significance: Due to the unfragmented and protected forests found in the park, SHEN contains an outstanding example of the Blue Ridge/Central Appalachian biome. Over 28% of the expansive Blue Ridge forestlands in Virginia are in conservation land (DGIF 2005). This high rate of protection is due to the land ownership of SHEN and the George Washington and Jefferson National Forests. In SHEN, approximately 93% of the land cover is forested and 97% of the forestland is classified as interior or core forest based on categories described by Riitters et al. (2000). For comparison, statewide, 71.5% of the forestland is classified as interior or core forest based on the same scale of analysis (J. Weber, Virginia Division of Natural Heritage, 2006, pers. comm.).

SHEN contains 32,204 ha (79,579 ac [40.6% of the park's total acreage]) of federally designated wilderness. This legislative designation occurred in 1976 under the federal Wilderness Act. This designation defines wilderness as follows:

> "… in contrast with those areas where man and his own works dominate the landscape, [wilderness] is hereby recognized as an area where the earth and its community of life are untrammeled by man, where man himself is a visitor who does not remain. An area of wilderness is further defined to mean an area of undeveloped Federal land retaining its primeval character and influence, without permanent improvements or human habitation, which is protected and managed so as to preserve its natural conditions and which (1) generally appears to have

> been affected primarily by the forces of nature, with the imprint of man's work substantially unnoticeable; (2) has outstanding opportunities for solitude or a primitive and unconfined type of recreation; (3) has at least five thousand acres of land or is of sufficient size as to make practicable its preservation and use in an unimpaired condition; and (4) may also contain ecological, geological, or other features of scientific, educational, scenic, or historical value" (Public Law 88-577, 1964).

Most of the park's wilderness experiences low visitor use. Trails in the low-use Wilderness Areas are minimally maintained and no new trails will be constructed (Bair 1998). Some of the designated wilderness in SHEN, however, receives high visitor use. For example, the Ridge Trail on Old Rag Mountain is one of the most frequently used trails within the park (Bair 1998). The only signs permitted in Wilderness Areas are for resource protection or trail direction (Bair 1998). Administrative roads or structures are not permitted in any Wilderness Area; only historic structures are permitted. Motorized vehicle or equipment use within Wilderness Areas also is not permitted, except under emergency conditions. Backcountry permits are required to camp in Wilderness Areas within SHEN and campsites may not exceed 18.6 m^2 (200 ft^2) in size (Bair 1998).

Young (2005) performed a GIS analysis to identify large, unfragmented (roadless) blocks that contain a diversity of vegetation communities in SHEN. These selected blocks represent large, intact natural landscapes that could be targeted for conservation in SHEN, and perhaps future wilderness designation (Figure 4). To select these blocks, Young (2005) considered both primary and secondary sources of habitat fragmentation. The primary fragmenting features of SHEN are highways (Skyline Drive and U.S. routes 211 and 33) and other gravel roads that bisect the park. Secondary fragmentation occurs from other drivable roads and by utility corridors. Blocks were defined and evaluated using digital GIS road and park boundary maps, maps of existing wilderness, and digital aerial photography. Data were augmented using the GIS road layer as needed, and by digitizing a new layer of power and pipeline rights-of-way (Young 2005). Blocks were evaluated based on area (size), and by comparison to maps of current vegetation communities and "ecological land units" recently developed for the park (Young et. al. 2005). Ecological land units combine categories of elevation range (<457 m; 458–914 m; <914 M [<1,500 ft; 1,500–3,000 ft; >3,000 ft]), geologic substrate type (basaltic [greenstone], siliciclastic, granitic), and 14 classes of landform into 126 unique combinations of habitat characteristics (Young et al. 2005). A total of 140 distinct ecological land unit combinations were mapped in the park. Since vegetation and wildlife communities respond to environmental gradients, it is presumed that these ecological land units represent the potential diversity of habitats available. Areas of at least 202 ha (500 ac) were considered for inclusion as an unfragmented forest block.

This analysis resulted in the definition of 33 unfragmented (roadless) blocks within SHEN. Blocks ranged in size from 8,748 ha (21,617 ac) to 240 ha (534 ac), with a mean block size of 2,108 ha (5,208 ac) (Young 2005). According to the analysis, about 85% of the area within the park's boundary is contained within unfragmented blocks greater than 202 ha (500 ac). Fifteen of the 33 blocks were greater than 1,214 ha (3,000 ac) in size (Table 6). Blocks are primarily divided into east and west units bounded by Skyline Drive on the ridge, and then further bounded to the north and south by highways or fire roads traveling from the ridge to either valley. Block

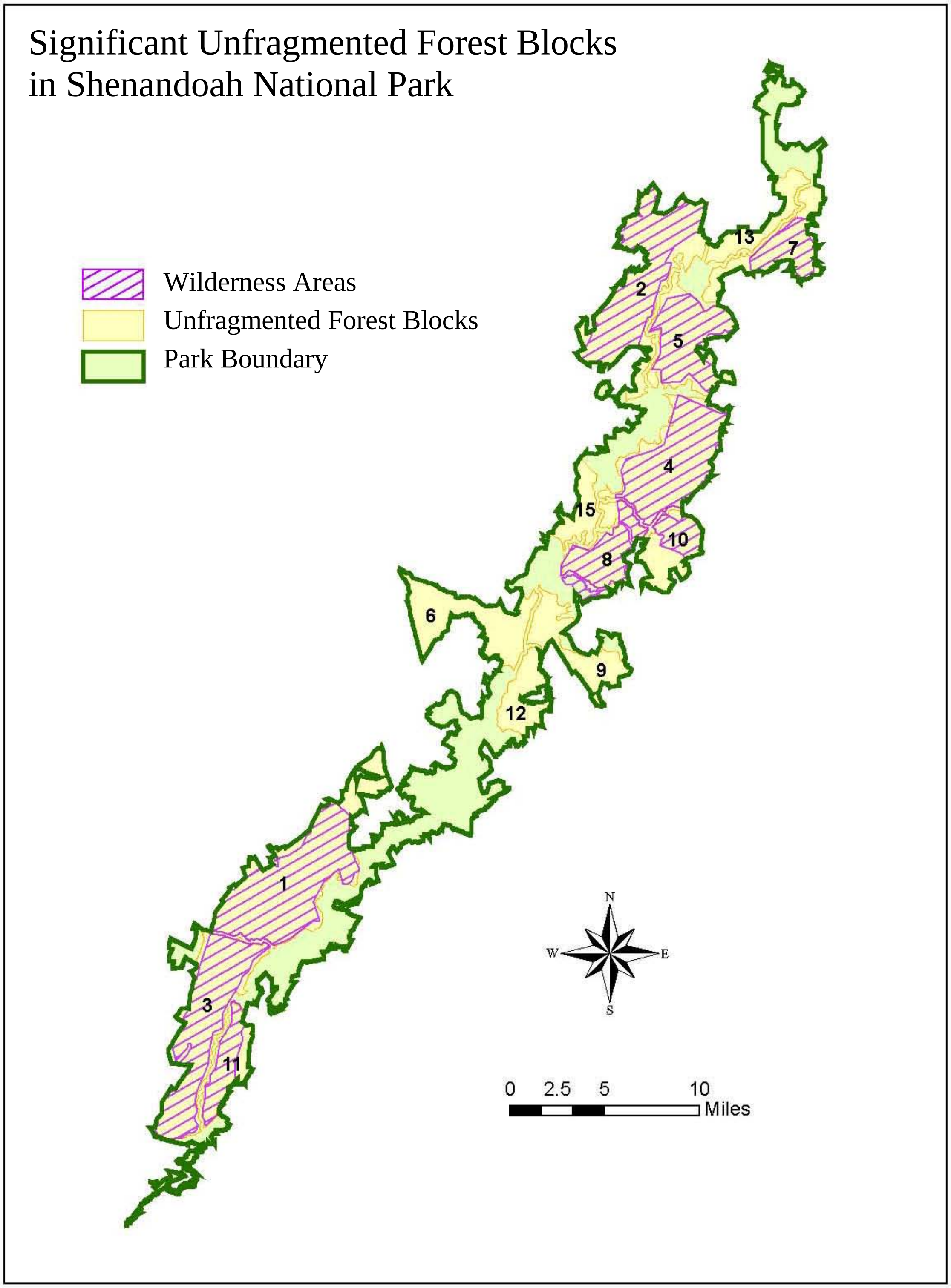

Figure 4. Fifteen unfragmented (roadless) forested blocks (>1,200 ha [3,000 ac]) in Shenandoah National Park, 2005. Blocks are numbered in rank order based on their size. Existing areas of wilderness designation are also shown for comparison.

Table 6. The 15 largest unfragmented (roadless) forest blocks defined in Shenandoah National Park.

Block	Block Name	Hectares	Acres	Perimeter (Mile)	Wilderness Designation?
1	Rocky Mount	8,748.16	21,617.18	44.97	yes
2	Jeremy's Run	7,334.70	18,124.45	52.98	yes
3	Trayfoot Mountain	6,193.79	15,305.19	34.36	yes
4	Nicolson Hollow	5,887.26	14,547.74	29.82	yes
5	Thornton Hollow	4,371.23	10,801.54	29.69	yes
6	Smith Mountain	3,983.12	9,842.50	30.38	no
7	Thoroughfare Gap	2,989.88	7,388.14	30.89	yes (partial)
8	Cedar Run	2,718.07	6,716.50	21.89	yes
9	Jones Mountain	2,535.41	6,265.14	27.00	no
10	Old Rag Mountain	2,410.83	5,957.28	17.10	yes (partial)
11	Moormans River	2,132.47	5,269.44	17.97	yes
12	Lewis Mountain	1,865.08	4,608.71	17.04	no
13	Compton Peak	1,609.29	3,976.65	21.28	no
14	Loft Mountain	1,466.94	3,624.88	19.97	no
15	Hawksbill	1,398.64	3,456.11	18.22	no

boundaries correspond very well with boundaries of Wilderness Areas (Figures 4, 5, and 6) previously designated for the park. For example, blocks 1, 2, 3, 4, 5, 7, 8, 10, and 11 are either wholly or substantially covered by designated Wilderness Areas (Figure 5). Of the ten largest blocks, only blocks 6 and 9 (Smith Mountain and Jones Mountain, respectively) do not contain lands designated as wilderness. Of the 15 largest blocks which are not currently in wilderness designation, blocks 6 (Smith Mountain), 9 (Jones Mountain), 12 (Lewis Mountain), and 15 (Hawksbill) contain significant diversity, capturing 91%, 89%, 86%, and 83% of the park's 35 vegetation communities, respectively (Figure 6).

The four blocks that are larger than 1,214 ha (3,000 ac) in size, contain high plant diversity, and are not currently designated as wilderness, are discussed below. Two of these blocks (block 6 / Smith Mountain and block 9 / Jones Mountain) qualify for wilderness designation because they are larger than 2,024 ha (5,000 ac) in size, contain globally rare ecological features, and have outstanding opportunities for primitive recreation.

- Block 6: Smith Mountain:

This block is approximately 3,966 ha (9,800 ac) and is located on the western flank of the park in the Central District, stretching from the Skyline Drive near Hazeltop Ridge Overlook to the Shenandoah River (Figure 7). Elevations range from 975–305 m (3,200–1,000 ft). No roads and only two trails bisect the area. Vegetation is quite diverse, with montane basic and high elevation seepage swamps at the higher elevations and rich cove and wetland communities along the east and west branches of Naked Creek. Several rare or at-risk herbaceous species occur in

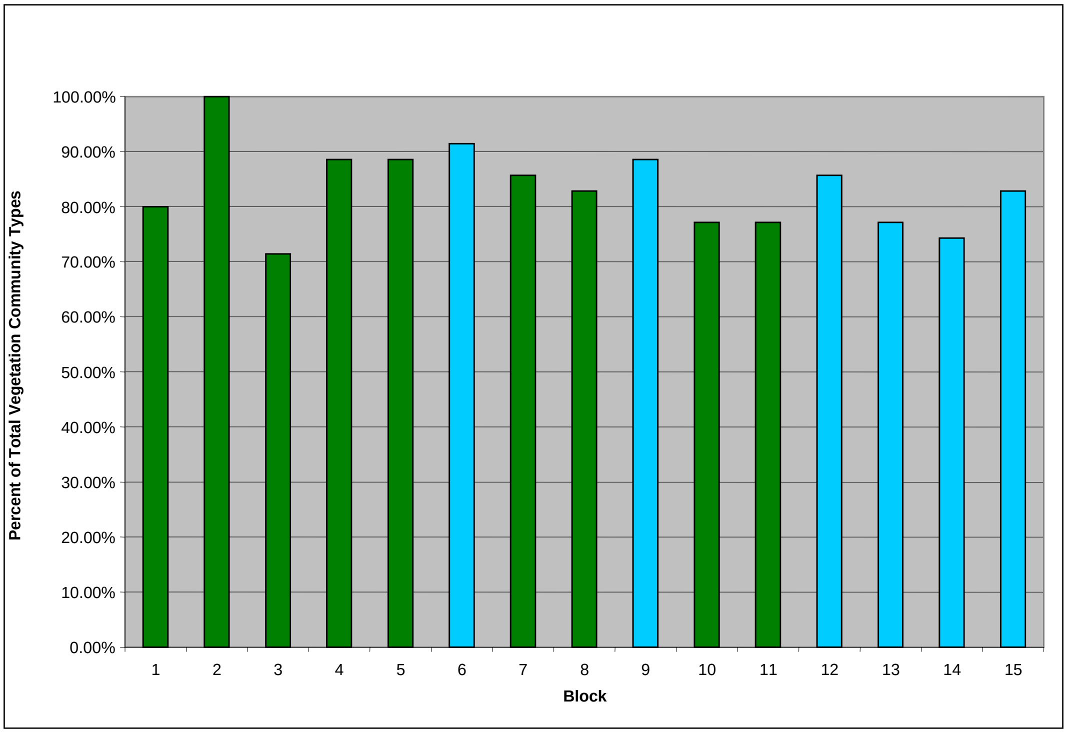

Figure 5. Diversity of vegetation communities in unfragmented (roadless) forest blocks (only the largest 15 are shown). A total of 35 vegetation communities were mapped in the park by Young et al. (2005). Green bars depict blocks completely or partially in wilderness designation.

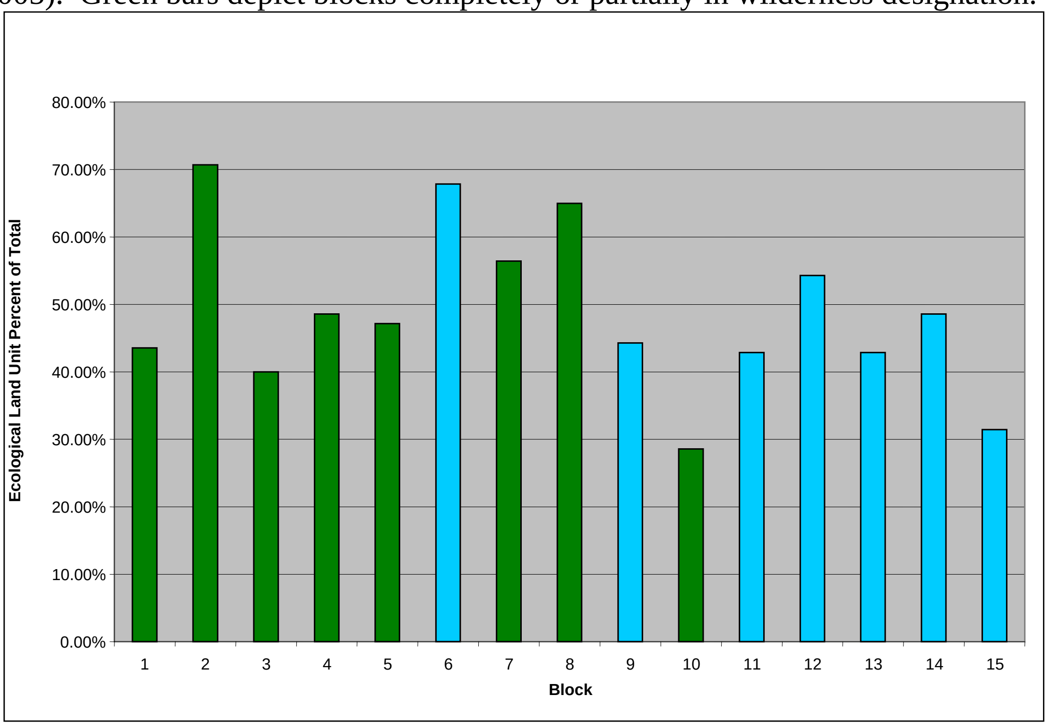

Figure 6. Diversity of ecological land unit (ELU) types (126 ELUs found in the park) contained in each unfragmented (roadless) forest block (only the largest 15 are shown). Ecological land unit types are from Young et al. (2005). Green bars depict blocks completely or partially in wilderness designation.

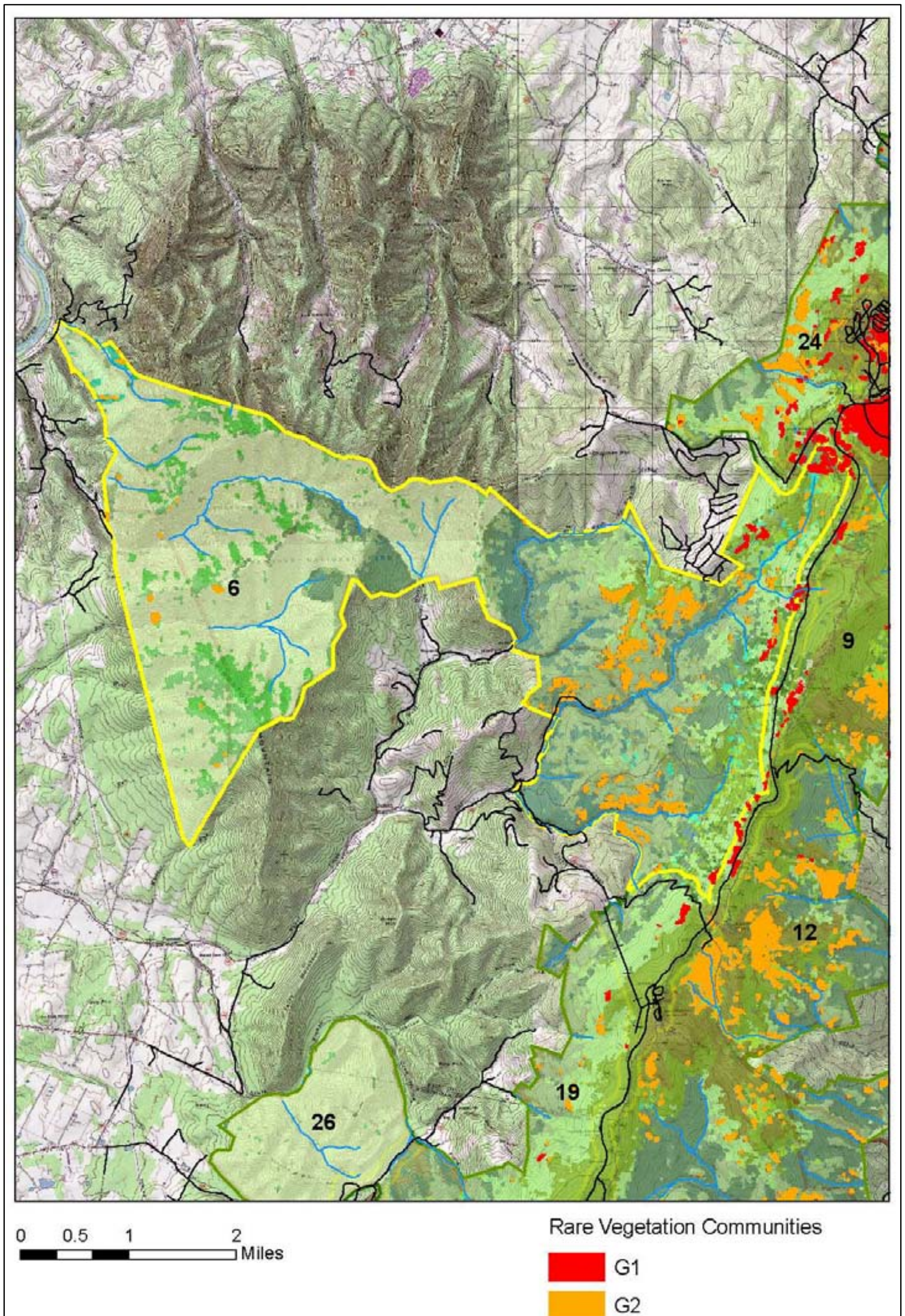

Figure 7. Detail map of unfragmented (roadless) block 6 / Smith Mountain. The G1 communities present in block 6 are the high elevation greenstone barrens, outcrop barrens, and mafic fen. The G2 communities present include high elevation hemlock communities and a variety of barren community types (e.g., heath barrens, mafic barrens).

G1=Critically Imperiled=At very high risk of extinction due to extreme rarity (often 5 or fewer populations), very steep declines, or other factors
G2=Imperiled=At moderate risk of extinction due to a restricted range, relatively few populations (often 20 or fewer), steep declines, or other factors.

these areas. This portion of the park has burned several times since park establishment due to the dry habitat and difficulty in controlling remote natural fire ignitions within this area.

The only known occurrence of American beech (*Fagus grandifolia*) – Tuliptree / Christmas fern (*Polystichum acrostichoides*) Forest in the park occurs in this area near the historic community of Ingram.

- Block 9: Jones Mountain:

This block is approximately 2,509 ha (6,200 ac) and stretches to the south and east of Big Meadows to the confluence of the Staunton and Rapidan rivers (Figure 8). Elevation ranges from 1,158 m (3,800 ft) at Hazeltop to 305 m (1,000 ft) at the park entry point along Route 662. Once an area noted for extensive eastern hemlock stands in the vicinity of Camp Hoover (Rapidan River Camp), this area has seen significant decline of these forests due to the hemlock woolly adelgid. Additionally, the lower stretches of the Staunton River suffered a catastrophic natural flood event in 1995. In spite of this, the area represents significant diversity in vegetation communities and habitat types. Primary communities are rich cove and slope forests, montane oak-hickory forests, and northern red oak forests. Other communities in this block include high elevation seepage swamps, rare mafic fens and seeps (near Big Meadows), woodland seeps, and high elevation boulderfield forests. One negative aspect of this block is its shape, as it narrows significantly where a radio tower service road climbs to the top of Fork Mountain. However, the block is bounded to the south by a State Wildlife Management Area, providing additional roadless area protection.

- Block 12: Lewis Mountain:

This block is 1,861 ha (4,600 ac) and encompasses Bearfence Mountain to the north and Lewis Mountain to the south (Figure 9). This block does not qualify for wilderness designation because it is less than 2,024 ha (5,000 ac) in size. Elevation ranges from 1,037–366 m (3,500–1,200 ft). Pocosin, Devils Ditch, and Bush Mountain streams drain this block. This block has significant area in seepage swamps, rock outcrops, and rich cove forests. The block surrounds a State Wildlife Management Area in the vicinity of Devils Ditch. Almost the entire area is underlain by granitic formations except for Bearfence Mountain and east of Devils Ditch, which are both underlain by the Catoctin greenstone formation.

- Block 15: Hawksbill:

This block is 1,376 ha (3,400 ac) and is located west of Skyline Drive and stretches south of Millers Head near Skyland to the Franklin Cliffs overlook (Figure 10). Like block 12, this block is too small for wilderness designation. This block contains the highest elevation peak in the park (Hawksbill, 1,234 m [4,050 ft]) and includes significant cliff areas and steep terrain. The steep areas falling off to the west are primarily in granitic formations, while the nearly flat lying basalt flows of the Catoctin greenstone form the plateau near the summit of Hawksbill and in the vicinity of Skyline Drive. The cliffs and exposed rock of Millers Head, Bettys Rock, Crescent Rock, Hawksbill, and Franklin Cliffs make this block important for rock outcrop communities.

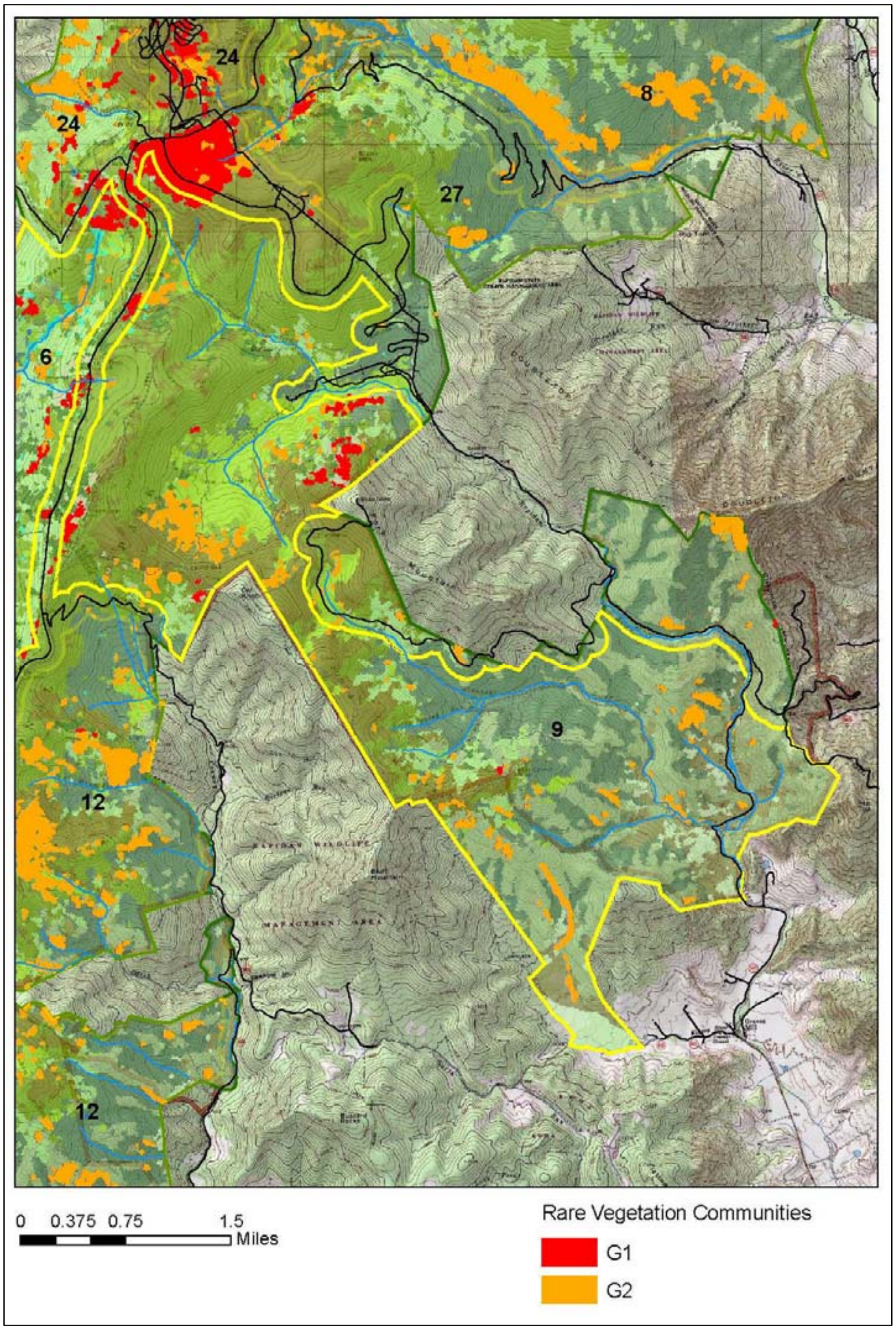

Figure 8. Detail map of unfragmented (roadless) block 9 / Jones Mountain. The G1 communities present in block 9 are the high elevation greenstone barrens, outcrop barrens, and mafic fen. The G2 communities present include high elevation hemlock communities and a variety of barren community types (e.g., heath barrens, mafic barrens).

G1=Critically Imperiled=At very high risk of extinction due to extreme rarity (often 5 or fewer populations), very steep declines, or other factors
G2=Imperiled=At moderate risk of extinction due to a restricted range, relatively few populations (often 20 or fewer), steep declines, or other factors.

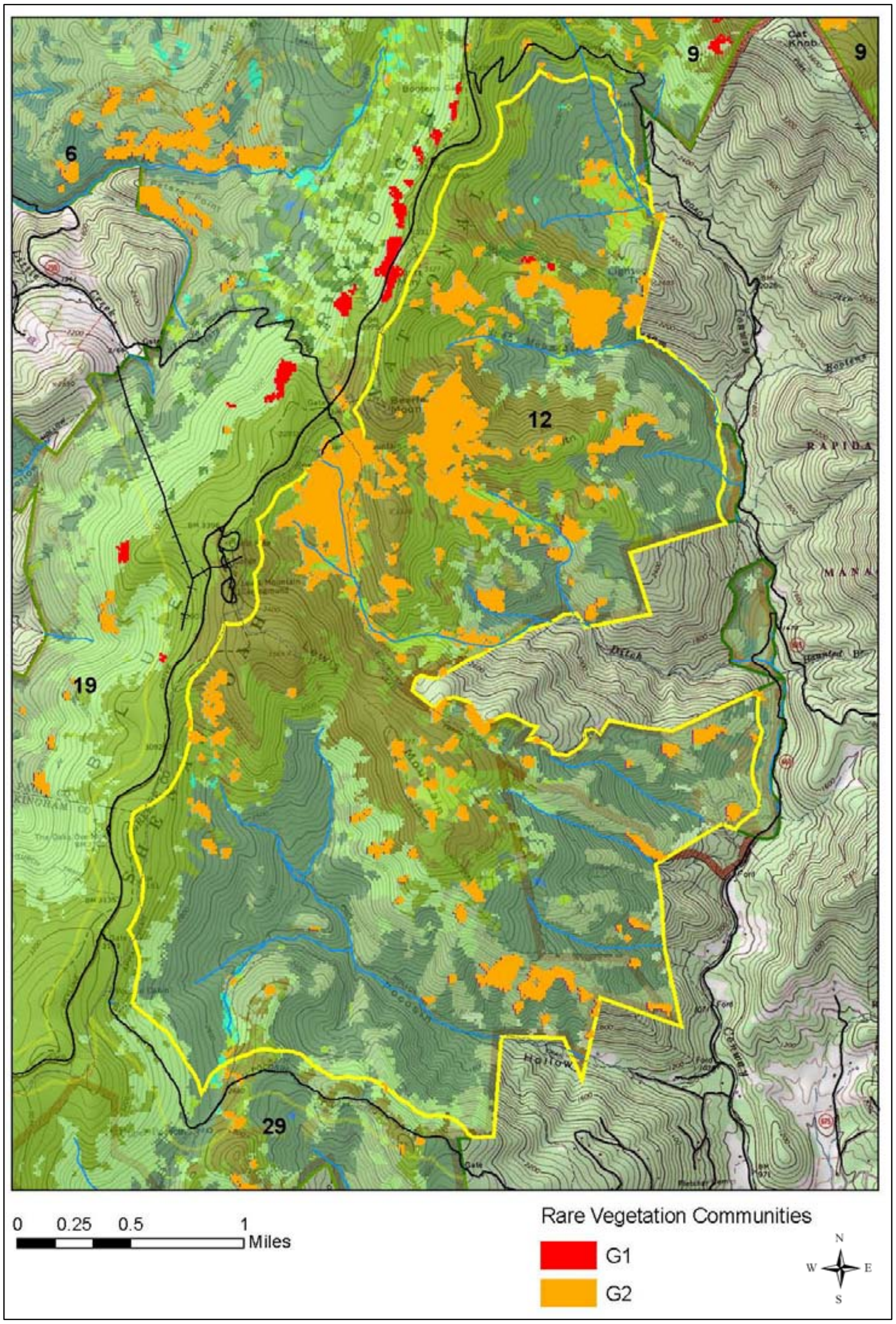

Figure 9. Detail map of unfragmented (roadless) forest block 12 / Lewis Mountain. The G1 communities present in block 12 are the high elevation greenstone barrens, outcrop barrens, and mafic fen. The G2 communities present include high elevation hemlock communities and a variety of barren community types (e.g., heath barrens, mafic barrens).

G1=Critically Imperiled=At very high risk of extinction due to extreme rarity (often 5 or fewer populations), very steep declines, or other factors
G2=Imperiled=At moderate risk of extinction due to a restricted range, relatively few populations (often 20 or fewer), steep declines, or other factors.

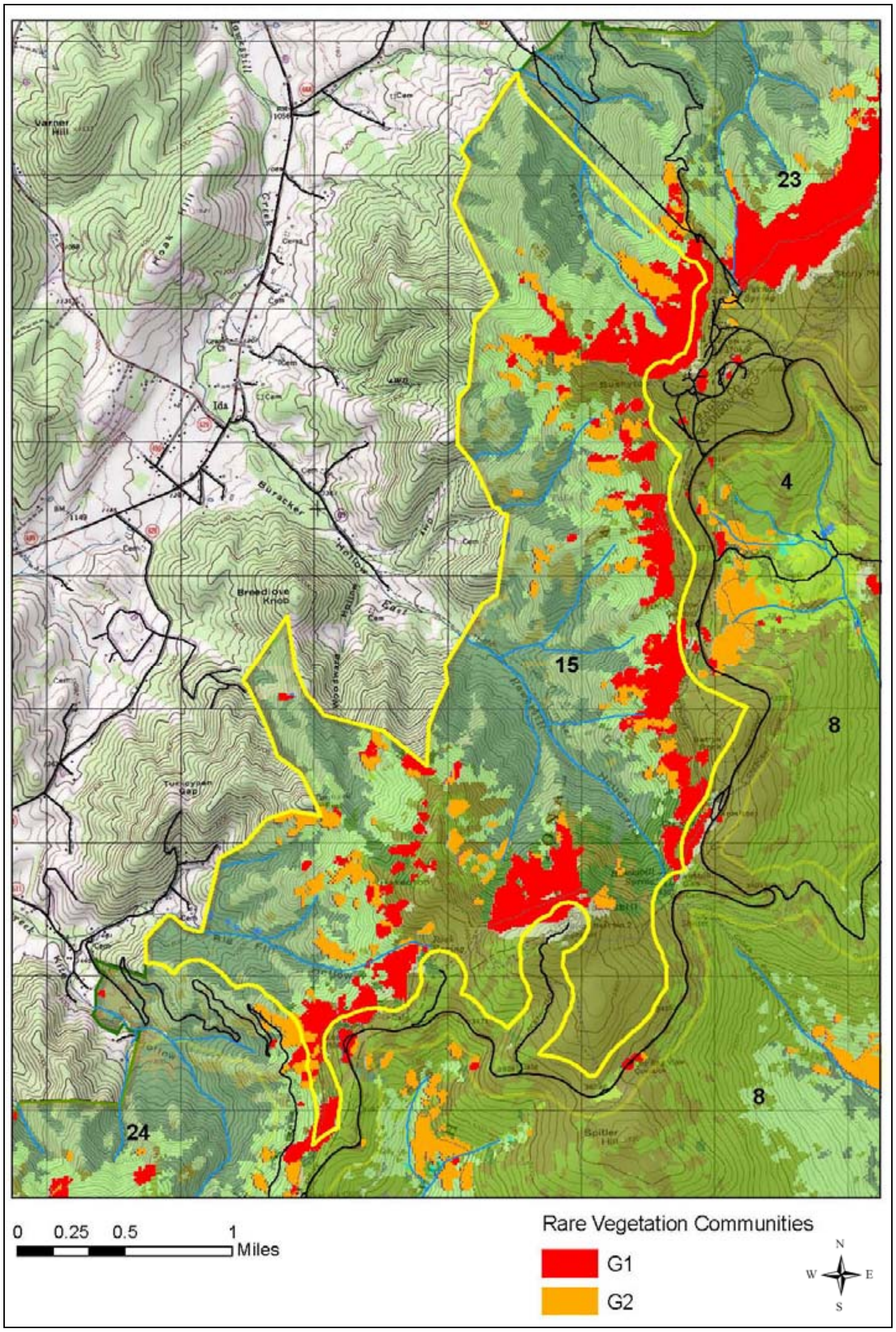

Figure 10. Detail map of unfragmented (roadless) forest block 15 / Hawksbill Mountain. The G1 communities present in block 15 are the high elevation greenstone barrens, outcrop barrens, and mafic fen. The G2 communities present include high elevation hemlock communities and a variety of barren community types (e.g., heath barrens, mafic barrens).

G1=Critically Imperiled=At very high risk of extinction due to extreme rarity (often 5 or fewer populations), very steep declines, or other factors
G2=Imperiled=At moderate risk of extinction due to a restricted range, relatively few populations (often 20 or fewer), steep declines, or other factors.

While this block has a high diversity of vegetation communities, it has significant area in the globally rare high elevation outcrop barren communities on the Greenstone cliff exposures.

Threats: The construction of fragmenting features (such as visitor centers and roads) within large forested blocks that are not under wilderness protection is possible. In addition, the ecological value of the unfragmented forest blocks at SHEN are enhanced by forested areas that are adjacent to, but not owned by, the park. Therefore, road construction and land conversion from forest to residential and other land uses that is occurring outside the park have the potential to diminish the significance of the expansive, unfragmented nature of SHEN's forests.

Gaps in Knowledge: Potential and future land use of properties located outside and adjacent to the park boundary are not being well documented. Development of these forested parcels will fragment the large expansive forests of the northern Blue Ridge Mountains.

Suggested Management Recommendations:

- Potentially seek to extend wilderness protection measures to additional forest blocks at SHEN. At a minimum, do not place fragmenting landscape features within these blocks.
- Work with adjacent landowners and municipalities to suggest appropriate land use practices and/or conservation easements on forested tracks that are adjacent to the largest roadless blocks within the park.
- Inventory and map large (>500 acres) unfragmented forest blocks that lie adjacent to the park boundary.

Oak and Oak-Hickory Forests

Current Status and Significance: Forests that contain oak as a dominant component are the most commonly occurring forest types at SHEN. Representing 11 vegetation associations, oak forests occupy approximately 40,000 ha (98,842 ac [approximately 50% of the land cover]) at SHEN. These oak forest associations are found at all elevations and represent plant communities dominated by northern red oak (*Quercus rubra*), chestnut oak, white oak, black oak (*Q. velutina*), and scarlet oak (*Q. coccinea*), and associated species, primarily, hickories and pines. Some representative associations include Northern Red Oak Forest, Central Appalachian Montane Oak-Hickory Forests (basic and acidic types), Central Appalachian Basic Oak-Hickory Forest, Central Appalachian Acidic Oak-Hickory Forest, Central Appalachian Dry-mesic Chestnut Oak-Northern Red Oak Forest, and Mixed Oak/Heath Forest, among others (Young et al. 2005). The prevalence and persistence of oaks and associated species depend primarily on local soil conditions, moisture gradients, and disturbance history. At least some of the oak and oak-hickory associations found at SHEN today were, historically, the oak-chestnut forest type (Stephenson 1974; Johnson and Ware 1982; Stephenson 1986). American chestnut, however, was eliminated as overstory dominants in SHEN by the 1920s due to the chestnut blight. Over much of the Central Appalachians, black oak, chestnut oak, and white oak seemed to have predominantly replaced the American chestnut on southern exposures, while red oak replaced the American chestnut on northern exposures (Lipford 1984; Stephenson 1986).

During early to late spring a variety of trees and shrubs bloom in association with these oak (and other) communities on the lower and middle slopes of the Blue Ridge Mountains in SHEN.

Perhaps some of the most aesthetic associations are the oak/redbud (Central Appalachian Basic Oak-Hickory Forest and Northern Hardpan Basic Oak-Hickory Forest), the oak/dogwood (Central Appalachian Acidic Oak-Hickory Forest), and the oak/mountain laurel/rhododendron associations (Oak/Heath Forest) (Young et al. 2005).

Variation in the composition of SHEN oak forests is related not only to elevation and topographic factors, but to underlying bedrock parent material and soil chemistry. On the Northern Blue Ridge, true oak-hickory forests (in which hickories are frequently co-dominant) have a strong association with more base-rich soils weathered from granitic rocks and metabasalt, whereas mixed oak and oak/heath communities are prevalent on infertile soils weathered from acidic granites and siliciclastic rocks of the Chilhowee Group (Johnson and Ware 1982; VA Natural Heritage Program, unpublished data). The differences between oak-hickory and oak or oak/heath associations are also reflected by their shrub and herb components, which are generally much lusher and more diverse in oak-hickory forests. Because of the prevalence of metabasalt and base-rich granitic bedrock in SHEN, true oak-hickory forests cover extensive areas in SHEN, which represents one of the finest enclaves of these communities in Virginia's Central Appalachian region.

Threats: Some of the oak associate species, most notably flowering dogwood, are threatened by pathogens at SHEN. The flowering dogwood has declined precipitously at SHEN and elsewhere in Virginia over the past two decades because of the prevalence of dogwood anthracnose, which causes mortality to dogwoods especially during dry years. This disease of flowering dogwood has decimated dogwood populations in the forests of the United States (Anderson et al. 1994). The fungus that causes the disease, *Discula destructiva*, was probably introduced into the U.S. near Connecticut and Washington simultaneously in the mid-1970s. Affected trees may die within one to three years; whereas, saplings may die in the same year they are infected.

Diefenbach (2001b) observed a paucity of oak saplings in LTEM forest vegetation monitoring plots at SHEN suggesting that oak is not regenerating well at SHEN, a trend that may result in expansion of the more mesophytic forest species, especially maples (Stephenson and Adams 1989). However, Stephenson and Adams (1989) predict that red oak will most likely persist at elevations above 900 m (2,953 ft). Oak is regenerating poorly throughout the Appalachians, including the Blue Ridge Mountains (Brose et al. 2001). There may be at least four reasons for the apparent lack of oak regeneration at SHEN.

First, a history of fire suppression probably has limited the regeneration of oak forests at SHEN. Prior to 1750, fires intentionally set by American Indians were used to achieve a variety of results, including clearing land for agriculture, assisting in the management of favored vegetation, clearing routes of travel, herding game, and even waging war on neighboring tribes (Lambert 1989; Abrams 1992; Brose et al. 2001). These fires probably varied in intensity and exerted a considerable influence upon vegetative composition. One effect may have been creating a forested landscape that was dominated by oaks, hickories, and, historically, chestnut. From 1750–1930, increased European settlement augmented the frequency and intensity of disturbances in and around SHEN, maintaining, and perhaps expanding, the oak-hickory component in the forests (Brose et al. 2001). Although 90% of the fires that have been recorded in the park have been the result of human ignitions, natural fires occurred periodically throughout the Appalachians and played a role in shaping the plant communities that historically were present in the park (NPS 2005e). However, natural fires have not been permitted to burn in the park for over 78 years, resulting in conditions different from those that would have resulted if natural fire had been allowed to exert its influence on the landscape (NPS 2005e).

Prescribed fire potentially could be used to maintain an oak component in the park's forests. Without some fire or disturbance management, oaks may decline in SHEN to below pre-European settlement distributions (e.g., Brose et al. 2001). At SHEN, the greatest chance for the use of fire to successfully regenerate oak will occur on xeric sites due to limitations from competing species and more sunlight reaching the forest floor. However, deer herbivory and nonnative species invasion are issues of concern on sites that have been treated by prescribed burning (U.S. Forest Service, T. Shuler, pers. comm., 2003). If prescribed fire is used in oak forests (or if natural fires are permitted to burn in this forest type) an overstory tree mortality rate of 15% (for low-fire intensity) to 67% (for high-fire intensity) can be expected (Regelbrugge and Smith 1994). In addition, data collected after the SHEN Complex Fire of 2000 reveals that low intensity fires killed the above ground portions of most saplings and shrubs, but eventually stimulated understory growth. Blackberries (*Rubus* spp.), mountain laurel (*Kalmia latifolia*), sassafras, and black birch (*Betula lenta*) were the most common seedlings found post-fire. Red oak and black locust saplings also increased post-fire (Cass 2002).

Second, although oaks replaced American chestnut in many of the forests ravaged by the chestnut blight, tuliptree and other mesic, shade-tolerant species replaced chestnut in other areas (Fievet et al. 2003). The species that replaced chestnut were primarily dictated by local topography and geologic conditions (Johnson and Ware 1982; Eshleman et al. 2001). For example, the coves and draws of the post-chestnut forest in the Blue Ridge are now dominated by a mixed assemblage of mesic species such as tulip poplar, yellow birch (*Betula alleghaniensis*), and sugar maple (Johnson and Ware 1982). While these mesic species have probably always been present to some extent on fertile, protected sites, they have increased in SHEN and throughout Virginia, even on more exposed slopes and ridges, as fire suppression and rapid expansion of deer populations have greatly reduced the amount of oak regeneration at the same time that age, drought, and defoliation have removed much of the oak overstory (Tigner 1998). The species composition in many of Virginia's hardwood forests, therefore, is shifting away from oak towards species such as poplar and maple (Tigner 1998).

Third, the large deer population in some areas of the park (e.g., near the Big Meadows and Matthews Arm camping areas) may be limiting the success of oak and other forest regeneration. Without control of the deer herd, no fire or disturbance regime will maintain oak forests in parts of SHEN. Oak is a preferred food of deer, and continued grazing by deer will contribute to the replacement of oak by species such as red maple, that are less palatable to deer (Curtis and Sullivan 2001). Some researchers found that there was a failure in oak regeneration following prescribed fire, attributed primarily to increased herbivory of seedlings and saplings by deer (Schuler and McClain 2003).

Finally, oak mortality caused by gypsy moths may have caused a decline in oak throughout the Appalachians. This nonnative insect pest is a polyphagous defoliator, but prefers oaks and true poplars (Montgomery and Wallner 1988). Although many oaks recover from defoliation caused by gypsy moths, repeated defoliation may lead to tree weakening and death (Schweitzer 2004). Trees weakened by defoliation are more susceptible to attack by secondary organisms such as the shoestring root rot fungus (*Armillariellia mellea*) (Schweitzer 2004). Defoliation attributed to gypsy moth has declined dramatically over the last decade due to the introduction of a fungus (*Entomophaga maimaiga*) that is fatal to the pest and due to the application of a lethal bacteria, *Bacillus thuriengensis*. Outbreaks of gypsy moth populations still occur in the park; however, they are generally highly localized and small in size. The ridges, south-facing aspects, and dry plateau areas with a significant oak component have the potential for being most affected by this nonnative pest. If trees die due to defoliation, hazard tree loadings will increase. In 2002, significant areas of defoliation due to the gypsy moth were observed on dry sites located on the western portion of the park (Bair 2002). In spite of this recent tree defoliation, no suppression activities are recommended under the park's Gypsy Moth Management Plan unless defoliation and corresponding tree mortality threaten visitor safety, cultural resources, or endangered species (Bair 2002). Nonnative plants, red maple, tuliptree, and other opportunistic species may invade gaps created by mortality of oaks. On the other hand, canopy gaps following gypsy moth infestation in some drier Virginia oak forests have also stimulated dense pulses of oak seedling germination (Fleming 2002).

Sudden oak death, caused by the pathogen *Phytophthora ramorum*, potentially threatens oaks at SHEN. Sudden oak death was first reported in California in 1995 and no natural occurrence has been reported in the forests of the eastern U.S. However, there is significant risk that this pathogen could be introduced to eastern oak forests, as it was detected in nursery stock in Florida, North Carolina, and Georgia in 2004 (USFS 2002; Ockels et al. 2004)

Gaps in Knowledge: The natural fire regimes and accompanying forest condition at SHEN need to be determined. A comprehensive fire history for the park needs to be developed to help determine the historic role of fire in maintaining and/or creating selected vegetation communities at SHEN. GIS maps that show the fire history at SHEN are available. However, the cause of the fires (human-caused versus natural) needs to be determined. In addition, more information is needed to determine if fire can be used to successfully regenerate oak-hickory forests in the park.

Suggested Management Recommendations:

- Determine the fire history and natural fire regime at SHEN. Consider using prescribed fire to maintain oak-hickory forests in certain parts of the park.
- Deer removal, perhaps by limited culling or exclosures, should be considered in SHEN to assist with oak regeneration and to help understand how deer may be affecting regeneration at the park.
- Continually monitor for the presence of oak threats such as gypsy moth and sudden oak death.
- Prevent or control the establishment and encroachment of nonnative plant species in the park.

<u>Mesic/Rich Cove Forests</u>

Current Status and Significance: Approximately 8,094 ha (20,000 ac) [approximately 25% of the land cover] at SHEN is in a mesic/rich cove forest vegetation association. Some examples of these forest associations are the Southern Appalachian Cove Forest, the Central Appalachian Cove Forest, the Central Appalachian Acidic Cove Forest, the Mesic Mixed-Hardwood Forest, and the Tuliptree Forest, among others (Young et al. 2005). One mesic type, the Sycamore/Tulip Poplar Forest, is located along flood plains at the lowest elevations in the park. These alliances are the second most common general forest cover types in the park and may be increasing. For example, the Southern Appalachian Cove Forest association is the single most common association found in SHEN, covering 11,827 ha (29,225 ac). Teeter (1988) also listed mesophytic forests as the single most common vegetation cover type in the park.

At SHEN, the mesic/rich cove forest associations are found only at low to middle elevations (<914 m [3000 ft]) and represent plant communities dominated by white ash, tulip popular, sugar maple, basswood, bitternut hickory (*Carya cordiformis*), birches, and, rarely, American beech (*Fagus grandifolia*). Braun (1950) indicated that tuliptree was abundant in the secondary communities of the lower slopes in SHEN, suggesting its future as a now-dominant tree and cover type in the park. Mesic/rich cove forest alliances contain understory and herbaceous plants, including sugar maple, spicebush (*Lindera benzoin*), wood nettle (*Laportea canadensis*), blue cohosh (*Caulophyllum thalictroides*), black cohosh (*Cimicifuga racemosa*), monkshood (*Aconitum* spp.), violets (*Viola* spp.), and many spring ephemerals. In addition, American ginseng (*Panax quinquefolius*), a plant of special concern in Virginia, is often associated with these forest types (Young et al. 2003; Van Manen et al. 2005). Mesic/rich cove forests are maintained by small natural disturbance regimes such as tree-fall gaps, and reflect cool, moist conditions. It is likely that these associations have occupied the park's most mesic and sheltered sites (i.e., coves and ravines) that are naturally protected from fires. However, their composition has changed considerably (e.g., greater dominance of the intolerant tuliptree) and their extent has increased because of logging, secondary succession, fire suppression and exclusion, and other human-caused disturbances.

Threats: Although the mesic forest associations appear to be regenerating at SHEN, threats to this forest type include competition from nonnative species, deer browsing, and fragmentation due to roadways, trails, and land use changes on the lower slopes along the park boundary. In addition, tree species most susceptible to damage by ozone are associated with mesic forests (e.g., tulip poplar, black cherry); therefore, air pollution threatens these forest alliances. The moist, usually fertile soils occupied by these communities make them especially vulnerable to massive invasions of the nonnative herbs garlic-mustard (*Alliaria petiolata*) and Japanese stilt-grass (*Microstegium vimineum*). In addition, beech bark disease may threaten the few mesic forest communities at SHEN where this species occurs. The disease results when bark, attacked and altered by the beech scale (*Cryptococcus fagisuga*), is invaded and killed by fungi, primarily *Nectria coccinea* var. *faginata* and sometimes *N. galligena* (Houston and O'Brien 1983). Beech bark disease primarily kills large, mature trees, and control of this disease is difficult. The disease, although presently not found in SHEN, is present in northwestern Virginia and may arrive at the park and contribute to beech mortality (Mielke et al. 1982, 1985; USFS 2003).

Gaps in Knowledge: The degree to which the mesic forest alliances in SHEN are regenerating, as well as the degree to which they are undergoing successional and composition change, are poorly understood. However, recent revisions to SHEN's LTEM program for forest plants (Cass et al. 2006) should help resource managers better determine trends in forest composition and regeneration.

Suggested Management Recommendations:

- Deer removal, perhaps by limited culling or exclosures, should be considered, at least in certain portions at SHEN, to assist with forest regeneration and to help understand how deer may be affecting regeneration at the park.
- Continually monitor for the presence of threats such as beech bark disease.
- Prevent or control the establishment and encroachment of nonnative plant species in the park.

Barrens, Boulderfields, and Exposed Rock Vegetation Types

Current Status and Significance: Due to the mountainous terrain at SHEN there are distinctive vegetation associations correlated with exposed and/or loose rock, infertile, minimal soils, and low moisture gradients. The plant species that are found on these locations vary depending on elevation, substrate type, soil type, aspect, and degree of exposure, but tend to occur as stunted forests, shrublands, or herbaceous vegetation, and are associated with diverse lichens and high (>50%) surface rock cover. Some examples of these associations present at SHEN include the Central Appalachian High-Elevation Boulderfield Forest, the High-Elevation Outcrop Barren, the High-Elevation Heath Barren, the Central Appalachian Basic Boulderfield Forest, and the globally rare and endemic High-Elevation Greenstone Barren (Young et al. 2005).

The High-Elevation Greenstone Barren vegetation association is endemic to SHEN and is found mostly above 1,000 m (3,281 ft) on exposed metabasalt (greenstone) cliffs and ledges. This vegetation type is listed as a G1 community (critically imperiled globally) by NatureServe and the Natural Heritage network. In addition, some other barren alliances are classified as G2 (imperiled globally) by The Nature Conservancy due to their global rarity (Young et al. 2005). The thin soils present at these habitats support ten state-rare plant species including several long-range boreal disjuncts such as three-toothed cinquefoil, Rand's goldenrod (*Solidago simplex* var. *randii*), and northern bush-honeysuckle (*Diervilla lonicera*) (Heffernan 1999; Young et al. 2005). In addition, the High-Elevation Greenstone Barren vegetation alliance contains the only known Virginia occurrence of hemlock parsley (Heffernan 1999). In general, these communities appear to be relatively stable in the absence of human disturbance and self-maintaining due to harsh edaphic and climatic conditions (Heffernan 1999; Young et al. 2005). A multi-year study to identify and delineate all possible sites of open rock and associated plant communities within the park is ongoing (Cass and Bair 2004, NPS 2005i) The assessment of plant resources and invertebrate assemblages associated with these rock outcrops began in 2005. To date, 30 field sites have been visited. Despite the concern regarding the potential effects of visitor use on plant resources at rock outcrops, this ongoing research indicates that the geology and plant resources at only a few sites are threatened by visitor activities (NPS 2005i).

On lower slopes where massive exposures of Catoctin metabasalt (greenstone) occur at low elevations, eastern red cedar (*Juniperus virginiana*) and white ash are the characteristic trees associated with the Central Appalachian Circumneutral Barren (Massey 1968; Young et al. 2005). This vegetation association is also visible just outside park boundaries on steep or westerly facing slopes.

Threats: Due to harsh conditions and exposure, these vegetation types are slow-growing and vulnerable to disturbance (Heffernan 1999). In addition, the exposed conditions associated with these communities make them popular destinations for hikers seeking scenic vistas and thereby threatening their persistence in the park. Invasive nonnative plants also threaten barren communities, especially on sites that have been disturbed by human activity.

Gaps in Knowledge: Some of these barren communities are relatively well-studied at SHEN, especially the High-Elevation Greenstone Barren vegetation alliance. However, many barren vegetation sites were not identified or studied until recently (NPS 2005f) and potential threats by nonnative plants and human disturbance need to be further evaluated.

Suggested Management Recommendations:

- Close or redirect trails away from barrens, especially those that have globally imperiled plant communities.
- Prohibit rock climbing at sites that contain the critically imperiled High-Elevation Greenstone Barren vegetation type.
- Use environmental education to increase visitor awareness of the sensitive nature of these communities.
- Minimize soil disturbances in barren plant community areas.
- Conduct nonnative plant monitoring and remove nonnative plants in barren plant communities.
- Conduct periodic monitoring of specific species associated with the High-Elevation Greenstone Barren vegetation association, especially hemlock parsley.

<u>Pine Forests and Woodlands</u>

Current Status and Significance: Pine forests and woodlands at SHEN are represented primarily by the Central Appalachian Pine-Oak/Heath Woodland association that is composed of pitch pine, table mountain pine, and scrub oaks (*Quercus ilicifolia*). Virginia pine and, rarely, shortleaf pine (*Pinus echinata*) also dominate early successional forests on dry sites at lower elevations and in the southern portion of the park (Mazzeo 1966b; Young et al. 2005). These pines are all associated with dry, sterile soil and open areas (Mazzeo 1966b). As in other parts of the Appalachians, the pine-oak/heath woodlands at SHEN are associated with xeric, upper slopes, spur ridge crests, and cliffs with westerly aspects and shallow, infertile soils. In addition, pine woodlands occur on sites that are probably the most fire-prone in the park. Both dominant pines have evolved life histories that include production of highly flammable litter, stems, and foliage, as well as specific adaptations to ensure reproductive success in a frequently burned environment. Zobel (1969) found fire scarring almost ubiquitous in stands of table mountain pine that he studied throughout the Appalachians, including the Blue Ridge. Fire contributes to maintenance of these pines by stimulating the opening of serotinous cones, removing litter detrimental to seedling germination, and killing or suppressing competing shrubs and oaks (Zobel 1969; Williams 1991). Table mountain pine is endemic to the Appalachian Mountains, including the Blue Ridge, and is relatively rare (though locally common) throughout its range (Zobel 1969).

Pitch pine and table mountain pine exist as a climax community type on xeric sites along ridge lines throughout the Appalachians. These pines can persist as the dominant tree for several decades; however, fire is necessary for regeneration and recruitment at these sites. Periodic, high-intensity fires will deter hardwood species such as red oak species from invading, while encouraging germination of pine seeds. Futhermore, pine stands may regenerate from adjacent seed sources after fire, although the possibility of post-fire invasion of hardwoods, and subsequent replacement of pine, needs to be considered. Due to the severe conditions at these sites, nonnative plant competition is minimal.

White pine, the only native soft pine in the eastern United States, is found scattered throughout much of the park (Mazzeo 1966b). It is found in association with hardwoods such as red oak, white oak, and tuliptree in the Central Appalachian Acidic Cove Forest community and with drier-site oaks in several oak and oak/heath forests (Young et al. 2005).

Threats: Pitch pine and table mountain pine are declining throughout their range because of the exclusion or suppression of fires (Williams 1991; Welch and Waldrop 2001; NPS 2005e). Zobel (1969) cited fire suppression as the primary reason restricting the establishment of these pines. In addition, the older pine stands in the Appalachians are susceptible to southern pine beetle outbreak (U.S. Forest Service, B. Onken, pers. comm., 2003). At SHEN, a dramatic reduction in pine trees caused by these pine bark beetles has been documented (Cass 2000). Furthermore, tree-of-heaven established itself at several former pine sites (NPS 2005g). White pines are threatened by the white pine blister rust (*Cronartium ribicola*), a fungal disease, and white pine weevil (*Pissodes strobi*), an insect that attacks and kills the uppermost shoots of the tree (Mazzeo 1966b).

Gaps in Knowledge: The periodicity and intensity of fires that will best regenerate pitch pine and table mountain pine at SHEN need to be better understood.

Suggested Management Recommendations:

- Conduct a comprehensive dendroecological analysis for the xeric pine communities so that their ecological history can be better understood.
- Determine the natural fire regime for SHEN (this may vary with site conditions)
- Develop a management plan that includes fire as a tool to assist in the regeneration of pine communities. Proper care and attention should be given to any prescribed burning approach to ensure viable regenerative sources are available for the burned areas.
- Continually monitor and, if possible, treat for threats such as southern pine beetle.

<u>Eastern Hemlock Forests</u>

Current Status and Significance: The Eastern Hemlock – Hardwood Forest association has declined dramatically over the past 10 years at SHEN (Young et al. 2005). Historically, it typically existed on shallow soils and in cool, deep ravines along waterways (Young et al. 2005). The hemlock forests at SHEN also contain yellow birch and other plants with northern affiliation (Braun 1950; Mazzeo 1966b), especially at Limberlost. In addition, hemlocks may be found singly or in groups in mesic cove forests and northern red oak forests at the higher elevations. Hemlock stands provide an important forest cover type throughout the Central and Southern

Appalachians. They provide shade to streams, winter shelter to wildlife, and critical nesting cover to birds such as blackburnian warblers (*Dendroica fusca*) and black-throated blue warblers (*Dendroica caerulenscens*) (Bieri and Anliot 1985; Benzinger 1994; Mahan et al. 2004). In SHEN hemlock forests also provided exclusive habitat for two state-rare plant species, twisted stalk (*Streptopus amlexifolius*) and spotted coral root (*Corallorhiza maculata*).

Threats: Hemlocks are threatened throughout the mid-Atlantic by a nonnative insect pest, the hemlock woolly adelgid, that attacks and kills hemlock trees (McClure 1991). The hemlock woolly adelgid has caused extensive mortality of hemlock in SHEN and this forest type is currently undergoing rapid change as canopy loss and related disturbance potentially affect moisture regimes and plant and nutrient dynamics. For example, 78% of hemlocks that were monitored in forest health plots in 1990 were classified as in "excellent" condition. By 2004, however, 92% of these trees were classified as dead due to extensive feeding by the adelgid (Bair 2005). Furthermore, a dendrochronological study indicated that hemlocks were pre-disposed to rapid mortality by the hemlock wooly adelgid due to drought and exposure to air-born pollutants in years prior to the arrival of this insect pest (Dougherty 2001). As hemlocks continue to decline throughout the mid-Atlantic, they most likely will be replaced by stands of oak, birch, and red maple (Dougherty 2001; Mahan et al. 2004).

At SHEN, dramatic loss of hemlocks due to the hemlock woolly adelgid can be observed at Rapidan Camp (also known as Camp Hoover) and Limberlost, among other sites. Many of the dead hemlocks were removed from Rapidan Camp and Limberlost in 1999 and 2004, respectively, when the trees became hazardous to visitors and historic structures (NPS 2005d).

Gaps in Knowledge: The ecosystem-level effects of the decline of eastern hemlock are not entirely known at SHEN. For example, the effects of hemlock decline on water quality (nutrients, temperature, and aquatic biota) should be studied in the park.

Suggested Management Recommendations

- Perhaps protect isolated hemlock trees at SHEN through intensive pesticide spraying. By saving individual trees, if hemlocks eventually can be restored at the park, the genetic resource of eastern hemlocks associated with the Blue Ridge Mountains will be protected.
- Continue to monitor small stands or individual hemlock trees that still persist in the park. Tree health protocol developed by Onken et al. (1994) can be used to determine the effects of the adelgid on these persistent trees.
- Increase monitoring frequency of rare plant populations within areas previously dominated by hemlocks.

Black Locust Successional Forests

Current Status and Significance: The occurrence of the Black Locust Successional Forest association reflects the past land use history at SHEN, especially the prevalence of small homesites that are now abandoned. This forest association covers 2,261 ha (5,587 ac [2.83%]) of the park and is often dominated by black locust and eastern redbud (*Cercis canadensis*) in the forest canopy. White ash, tuliptree, and other hardwoods are also present in the canopy, and often co-dominate decadent, late-successional phases of this community. Although native to the eastern U.S., black locust has been planted widely and will invade disturbed landscapes, especially abandoned agricultural fields and homesites. This forest type may not persist at the park, as black locust is a relatively short-lived species. This association will likely be replaced initially by alliances containing white ash, tuliptree, and/or white pine, and eventually by red oak and a variety of hickories (Young et al. 2005).

Threats: None kown.

Gaps in Knowledge: None known.

Suggested Management Recommendations:

- Permit succession to progress at these sites.
- Because this forest is associated with past land use disturbance these sites are particularly susceptible to invasion by nonnative plants, especially garlic-mustard and long-bristled smartweed (*Polygonum caespitosum* var. *longisetum*). Nonnative plants should be controlled so that establishment of native plant species is not prevented.

<u>Wetlands, Springs, and Seeps (Including Big Meadows)</u>

Current Status and Significance: The National Wetlands Inventory (NWI) of the U.S. Fish and Wildlife Service (USFWS) shows the location, type, and distribution of wetlands as small as 0.5 ha (1.2 ac) (USFWS 2002). NWI indicates that the most dominant wetland types found in SHEN are riverine wetlands (45%), with palustrine wetlands being the next most common (40%). Riverine wetlands are located in stream channels, contain flowing water, and are bounded by the channel bank (Cowardin et al. 1979). Palustrine wetlands include all nontidal wetlands dominated by vegetation (woody or herbaceous) and also include small, shallow, permanent water bodies (Cowardin et al. 1979). Riverine wetlands may be particularly important at SHEN because these riparian zones are critical for regulating aquatic-terrestrial linkages, controlling mass movements of materials (erosion), shading stream waters, and providing woody debris (Vana-Miller and Weeks 2004). Woody debris dissipate energy, trap moving materials (decrease erosion), and create habitat for aquatic organisms.

Although wetland communities compose <2% of the land cover (1,450.6 ha [3,584.5 ac]) at SHEN, they do represent ecologically significant communities that add diversity to the landscape and provide critical habitat for rare plants, amphibians, and other animals (Young et al. 2005). Young et al. (2005) characterized and mapped six distinct wetland vegetation communities at SHEN. One community alliance, Northern Blue Ridge Mafic Fen, is endemic to SHEN and is classified as a G1 (critically imperiled globally) community by NatureServe and the Natural Heritage network (Heffernan 1999; Young et al. 2005). Another rare wetland community, the Shenandoah Valley Sinkhole Pond, is endemic to a three-county area in Virginia's Shenandoah Valley (Fleming and Van Alstine 1999; Comiskey et al. 2005; Young et al. 2005). Stands of pin oak (*Quercus palustris*) and redtop panic grass (*Panicum rigidulum*), an herbaceous plant, are associated with these ponds that are located along the base of the western Blue Ridge over former karst terrain. These ponds are seasonally flooded and may be particularly important for breeding amphibians (Univ. of Richmond, J. Mitchell, pers. comm., 2005; Young et al. 2005). A single pond is located partly within the western border of SHEN. The remaining wetland plant communities found at SHEN are woodland seeps and swamps that are associated with headwater streams or groundwater-saturated areas. The vegetation associated with these seeps varies depending on soil pH, elevation, and underlying geology, but may be dominated by red maple or eastern hemlock (Young et al. 2005). For example, forested seepage wetlands in the park include the High-Elevation Seepage Swamp and the Central Elevation Basic Seepage Swamp associations. The former is considered globally rare (G2) by NatureServe and the Natural Heritage network and is threatened by the hemlock woolly adelgid. The Central Elevation Basic Seepage Swamp is considered globally uncommon (G3).

Big Meadows is a 53.6-ha (134 -ac), ridge-top meadow located at an elevation of 1,067 m (3,500 ft) along Skyline Drive in SHEN. Rare plant populations, historic settlement sites, and the open character of the landscape impart natural and cultural values to the meadow. As the only large non-forested area in the park, the meadow is also a haven for wildlife and plants that need open habitat. Big Meadows probably persisted in its open state for perhaps the past 10,000 years (Wilhelm 1969 [who also states that it was once 405 ha {1,000 ac} in size.] Lambert 1989; Moore 2003). Big Meadows is only 0.06% of the size of the entire park, but it supports populations of 18% of the state-listed rare plant species in the park. Although not all of Big Meadows is classified as a wetland, the rare Blue Ridge Mafic Fen alliance is located in the lower, groundwater-saturated parts of the meadow on both sides of Skyline Drive. The Mafic Fen contains eight plant species of special concern, including several sedges (Heffernan 1999).

Threats: The mafic fen at Big Meadows is threatened by hydrologic alterations associated with a large well that formerly served the Big Meadows campground, deer browse pressure, invasive nonnative plants, and, perhaps, fire exclusion (Heffernan 1999; Young et al. 2005). Since park establishment, woody vegetation has gradually encroached on the meadow and substantially reduced its size. Cost-effective management of the meadow that maintains the integrity of its natural and cultural resources and its aesthetically pleasing appearance is one of the many challenges of park management. Mowing was the primary means of maintaining Big Meadows in its open state from 1933 until 1972. This approach was followed by other meadow management techniques including a combination of fire, mowing, and herbicide application until 1982. Eighteen years of inactive management followed until a plant inventory of the Meadow was conducted in 1998 and 1999 (Cass 1999).

Combined data from the 1998 and 1999 plant inventories revealed that 17.6% ± 3.6% (SE) of the meadow supported tall-shrub cover (>0.5 m [1.6 ft]). Deerberry (*Vaccinium staminium*) and male-berry (*Lyonia ligustrina*) dominated in the northern, western, and southern sections of the meadow, and panicled dogwood (*Cornus racemosa*) and broad-leaved spiraea (*Spiraea alba* var. *latifolia*) dominated in the wetland center. Low shrubs (< 0.5 m [1.6 ft]) covered 45.8% ± 7.9% (SE) of the meadow, and upland low blueberry (*Vaccinium pallidum*) was the majority of low shrub cover. The central wetland portion of the meadow supported the greatest coverage of high-shrubs. Low shrub cover was high in the central, southern, and northern meadow sections (Cass 1999). Due to these increases in shrub coverage, a new Big Meadows management approach was initiated. The entire meadow was burned in spring 2000 followed by mowing in the fall. This prescribed burning continued annually until 2003 and was successful in reducing the coverage of tall shrubs, and increasing the coverage of herbaceous plants. Currently, Big

Meadows is managed using a rotation of burning, mowing, and fallow treatments with each treatment being applied to one-third of the meadow annually (NPS 2005e).

Nonnative plants threaten native plant communities throughout the park and may be more likely to colonize wetland areas (Vana-Miller and Weeks 2004). At SHEN, small herbs such as Japanese stilt grass and long-bristled smartweed are threats in riparian areas. Furthermore, princess tree (*Paulownia tomentosa*), tree-of-heaven, and oriental bittersweet (*Celastrus orbiculatus*) are great threats in several riparian areas that suffered large land-slides/soil slumps.

Gaps in Knowledge: The National Wetland Inventory (NWI) is based only on aerial photograph interpretation and no field verification has been conducted at SHEN. The current vegetation map (Young et al. 2005) made a special effort to classify and map wetland communities. This map's minimum mapping unit is also 0.5 ha (1.2 ac). In addition, the physiochemical and biological components of wetlands at SHEN are not well understood.

Presently, nothing is known about the structure or function of riverine wetlands at SHEN. Vana-Miller and Weeks (2004) suggest that riverine wetlands may be under-represented in the NWI at SHEN because most streams and their tributaries are not delineated by the NWI at the park due to their small size.

Aside from the gap in knowledge about small wetlands, very little is known about the ephemeral vernal pools found in SHEN. These pools may be rare in the park, but they do provide valuable breeding habitat for amphibians.

Despite several studies and consistent plant monitoring of Big Meadows, the processes that maintain the Blue Ridge Mafic Fen alliance are not well-understood. Recent work by Lee and Hornberger (2006) indicates that Big Meadow does not experience stationary soil moisture conditions, but rather experiences statistically significant bimodality (alternating between preferred states of wetness or dryness) in soil moisture both within the month of August and throughout the year over a 60-year period from 1943–2002. Soil moisture fluctuations have profound consequences in the maintenance of wetland ecosystems (Lee and Hornberger 2006); however, the causes of this bimodality is unknown. Soil moisture bimodality may be attributed to rainfall variability or a soil moisture-precipitation feedback mechanism (Lee and Hornberger 2006).

Suggested Management Recommendations:

- Create a detailed wetland map for SHEN. Most known wet areas, including springs and seeps and vernal pools, are not included on current wetland maps for SHEN.
- Measure the physiochemical and biological characterizations (species present, community structure, and aquifer dynamics) of park wetlands to establish baseline conditions. These baseline conditions could provide the basis for any future wetland monitoring program.
- Do not permit new construction in or near (<30 m [100 ft]) wetland areas of SHEN.
- Limit visitor use and disturbance to wetlands at SHEN.

- Limit the effects of white-tailed deer on wetland plant regeneration through placement of exclosures in rare wetland plant locations, especially at Big Meadows where deer populations are very high.
- Maintain disturbance regimes at Big Meadows through the use of prescribed fire and continue to monitor the response of vegetation to this management approach.
- Prevent the spread of nonnative plants into wetland areas at SHEN and remove any established nonnative plants.

<u>Old-growth Forests</u>

Current Status and Significance: Due to past land-use history, the old-growth (>200 years old) stands that still persist in SHEN are few and small in size. Winstead (1995) described 13 areas in SHEN that may be classified as old-growth stands and 12 stands that may be old-growth or contain individual old-growth trees. Limberlost is perhaps the most famous and most frequently visited old-growth area in SHEN. Unfortunately, most of the old-growth trees in Limberlost died as a result of hemlock woolly adelgid infestation, and most standing dead hemlocks along the trail were removed in 2003. Other stands of old-growth forest are located along the Upper Staunton River and at the headwaters of Pocosin Run (Winstead 1995). The Upper Staunton River site was dominated by hemlocks and has also been decimated by the hemlock woolly adelgid. The Pocosin Run site is unique in that it is dominated by red oak and chestnut oak, rather than the more typical eastern hemlock and tuliptree overstory. Braun (1950) and Fievet et al. (2003) described White Oak Canyon as containing an extensive area of undisturbed forest at the time of park establishment. However, Winstead (1995) noted that no large stands of virgin timber had been identified in the canyon, although large oaks and hemlocks are found scattered along the White Oak Canyon Trail.

Threats: The hemlock woolly adelgid has decimated old-growth hemlock trees in the park. Other tree pathogens, such as sudden oak death and beech bark disease, also potentially threaten old-growth specimens of those species in the park.

Gaps in Knowledge: Although Winstead (1995) documented many individual old-growth trees and stands in the park, he also identified several areas that still need to be visited to confirm the presence of old-growth trees. In addition, the exact age of many of the stands and individual trees is unknown because tree coring is not complete. Most investigation of potential old-growth sites in the park has been driven by the discovery of large trees. Other studies, however, have demonstrated that, on xeric sites, chestnut oaks of pedestrian size (< 40 cm dbh) may be 200–300 years old and that a number of xeric oak stands in the Central Appalachians have never been logged because of the poor growth form of their trees (Fleming and Moorhead 2000).

Suggested Management Recommendations:

- Place old-growth sites identified by Winstead (1995) into GIS. The locations of known individual old-growth trees should be recorded using Global Positioning Systems (GPS).
- It is not clear where tree cores that were taken by Winstead (1995) are located. Ideally, these cores should be located and used to examine the age of trees and the dendrochronology associated with old-growth forest stands at SHEN.
- The possibility that old-growth xeric oak stands exist in SHEN should be investigated.

Plant Species of Special Concern:

Heffernan (1999), Young et al. (2005), and Townsend (2005) provide comprehensive lists of plant species of special concern with habitat associations and locations found within SHEN. Data collected by The VANHP from various sources indicate that 92 vascular plant species and one non-vascular plant species of special concern in Virginia have been reliably reported from SHEN (Table 1).

Three species of plants found in SHEN are listed as threatened or endangered in Virginia, and one of these is also federally listed as threatened (Table 1):

- variable sedge (*Carex polymorpha*) – VA endangered
- small whorled pogonia (*Isotria medeoloides*) – U.S. threatened; VA endangered
- American ginseng (*Panax quinquefolius*) – VA threatened.

Nine additional species are considered globally rare by NatureServe and the Natural Heritage network due to rarity throughout their ranges (Table 1): glade spurge (*Euphorbia purpurea*), Appalachian oak fern (*Gymnocarpium appalachianum*), shale-barren blazing star (*Liatris turgida*), sweet pinesap (*Monotropsis odorata*), Canby's mountain-lover (*Paxistima canbyi*), sword-leaved phlox (*Phlox buckleyi*), bog bluegrass (*Poa paludigena*), Torrey's mountain-mint (*Pycnanthemum torrei*), and mountain pimpernel (*Taenidia montana*). Information on seven of these species that have been studied intensively in the park is provided here.

Variable Sedge:

Current Status and Significance: In the Central Appalachians, variable sedge primarily is found on acidic soils underlain by sandstones. This plant is found in association with both upland and wetland communities, but often grows in the ecotones between them. Two populations of this sedge are known from SHEN, one on a high-elevation ridge underlain by granitic rock, the other on a gentle alluvial fan at low elevation (Heffernan 1999). Both populations occur near the edge of seepage wetlands. Variable sedge is possibly favored by frequent low-level disturbance and is adapted to fire. However, it is capable of persisting and spreading vegetatively by creeping rhizomes, even under adverse conditions.

Threats: Dense canopies (which prevent flowering and fruiting), disturbance suppression, and competition from nonnative plants threaten this species at SHEN.

Gaps in Knowledge: The degree to which fire maintains this species is unknown. However, the largest and most vigorous populations throughout the range of this species occur in habitats with demonstrable histories of recurrent fires.

Suggested Management Recommendations:

- Consider thinning dense canopies at sites where this species persists at the park.
- Study the use of prescribed fire as an appropriate method for maintaining this species.

Small Whorled Pogonia:

Current Status and Significance: Small whorled pogonia is considered threatened under the Federal Endangered Species Act and endangered by the state of Virginia. This delicate orchid generally inhabits open, mesic or dry-mesic, deciduous woods with acidic soil (USFWS 1996; VANHP unpublished data). In SHEN, this species occurs along a trail in a mesophytic cove forest and is closely associated with red maple, white pine, white oak, witch hazel (*Hamamelis virginiana*), anise root (*Osmorhiza longistylis*), white wood aster (*Eurybia divaricata*), partridge berry (*Mitchella repens*), and jewelweed (*Impatiens* spp.) (VANHP, Fleming, pers. comm., 2005).

Gaps in Knowledge: A single plant of this species has been documented in SHEN. However, it grows in pedestrian forest habitats and is extremely difficult to inventory. The full extent of its distribution in the park is therefore uncertain. The plant was only seen and photographed once, almost 10 years ago (NPS, W. Cass, pers. comm., 2006).

Threats: The primary threats to this species at SHEN are herbivory by white-tailed deer, trampling by park visitors, and possibly competition from nonnative plants.

Suggested Management Recommendations:

- In order to maintain small whorled pogonia populations, the surrounding forests should be maintained in a natural condition and protected from disturbance. Removing or reducing associated herbaceous vegetation is not recommended because such manipulations are not likely to enhance populations and may in fact have detrimental consequences (USFWS 1996).
- Monitor the single known SHEN population of small whorled pogonia to document trends in population size and reproductive output, as well as potential disturbances to the habitat.

American Ginseng and Other Species of Economic Importance:

Current Status and Significance: American ginseng is listed as a state threatened species in Virginia due to ongoing pressures related to illegal harvest. However, the VANHP considers American ginseng too common to be ranked as rare and instead it is on their watchlist (VANHP, Fleming, pers. comm., 2005). American ginseng is a slow-growing, long-lived perennial herb native to the eastern United States (Argus and White 1984). Ginseng occurs in closed canopy forested habitats that contain rich soil and ample moisture and organic matter (Argus and White 1984). American ginseng is used as a medicinal herb, and, as such, is highly sought after by collectors. Even though ginseng is classified as threatened in Virginia (Table 1), wild ginseng can still be legally harvested on lands not specifically protected by statute from August 15–December 31 (Cass 2005). Harvesting in national parks is illegal, but still occurs at SHEN (Cass 2005). In fact, 66% of the park's ginseng population is in the relatively young, one- or two-leaf class, indicating poaching pressure (Cass 2005). Black cohosh and bloodroot (*Sanguinaria canadensis*) are vascular plants also targeted by collectors in SHEN, but populations currently seem secure. Due to the threat to these plants by collectors, a habitat model was developed by Young et al. (2003) to predict where ginseng, bloodroot, and cohosh would occur. Their model indicated that 1,821 ha (4,500 ac [2.5%]) of the park are considered most suitable for ginseng, bloodroot, and cohosh (Van Manen et al. 2005).

Threats: Illegal harvest threatens this species and other species of economic importance (e.g., bloodroot and cohosh). In addition, ginseng requires moist, closed-canopy forests; any non-natural, large-scale disturbances (e.g., defoliation due to gypsy moth or other nonnative species) to the overstory may adversely affect ginseng and associated plant species.

Gaps in Knowledge: The degree to which ginseng and other plants of economic importance are harvested illegally at SHEN is unknown.

Suggested Management Recommendations:

- Law enforcement should use the habitat model developed by Young et al. (2003) to identify locales in SHEN where ginseng and black cohosh potentially are found and target these areas for protection via increased patrols, for example.

Glade Spurge:

Current Status and Significance: Glade spurge is characteristically found in seepage swamps or at headwaters of streams and creeks, occasionally ranging into rich, well-drained sites. The two known populations at SHEN occur in association with base-rich soils. This species requires consistent soil saturation, but cannot withstand severe flooding events (Heffernan 1999).

Threats: Hydrologic alteration, canopy defoliation, and competition from nonnative plants threaten this species at SHEN. In addition, because this species is found on base-rich soils, acid precipitation, which tends to leach bases from soils, could adversely affect this species.

Gaps in Knowledge: The effects of water and soil chemistry on glade spurge distribution are unknown.

Suggested Management Recommendations:

- Monitor for presence and change in abundance of nonnative plants near populations of glade spurge. Remove nonnative plants when present.
- Monitor for human impacts and limit visitor use near populations.

Canby’s Mountain Lover:

Current Status and Significance: Canby’s mountain lover is usually found on limestone exposures and occasionally on shale outcrops. Its range is restricted to four southcentral states and this species is only known from one location within the park, on a metabasalt (greenstone) clifftop barren (Heffernan 1999).

Threats: Trampling from visitors and, perhaps, illegal collecting threaten this plant species. Additional threats at SHEN are canopy reductions due to defoliation and human disturbance of soils on exposed sites. As with other species of native plants, competition from nonnative plants may threaten this species.

Gaps in Knowledge: This plant is known from only one site in the park, Although most potential habitats have been inventoried, it could possibly occur at additional sites. The SHEN plants constitute the only known population of the species on metabasalt. Because this species is absent from a large number of similar, low-elevation metabasalt barrens, the reasons for its occurrence at this one site are unknown.

Suggested Management Recommendations:

- The known population of Canby's mountain lover is currently well protected at SHEN. The site is remote and rarely visited. However, the site should be monitored every five to ten years to determine if this species is persisting.

Sword-leaved Phlox:

Current Status and Significance: Sword-leaved phlox is a Central Appalachian (Virginia and West Virginia) endemic that typically occurs in dry, more or less open habitats on shale soils. Most existing occurrences are on forested roadsides in shale districts of the Ridge and Valley province, although a few populations occur in natural, open-canopy forests. Soil disturbance, ill-timed mowing, and shading from adjacent vegetation threaten the survival of this species.

Two populations of sword-leaved phlox occur on roadside banks in SHEN. Underlying bedrock in this area is metashale of the Harpers Formation. Since their discovery in 1990, both populations have been periodically inventoried to monitor survival (Heffernan 1999). In 1998, population 1 consisted of 197 plants, but population 2 could not be found. On 28 April 1999, a wildfire destroyed 99% of the above-ground tissue of population 1. However, regeneration after the fire was excellent. The final census in 1999 revealed 249 plants (about 30% seedlings and 70% non-flowering adult plants), 25% more than in 1998. In addition, three months after the fire, plants were sprouting in areas beyond the 1998 population boundary. The increase in the number of plants and the expansion of the population are attributable to the fire. Fire removed leaf litter and reduced competition from surrounding herbs and grasses. Annual inventory of population 1 from 1999 through 2004 shows that the population is stable to increasing, with 664 plants in the 2004 census (VA Natural Heritage Program, G. Fleming, pers. comm., 2006).

In 2004, VANHP and SHEN biologists discovered that sword-leaved phlox was scattered throughout a dry, open oak-hickory forest on the ridge crest just east of the two roadside populations. The plants were flowering. This woodland population is likely the original source of the roadside populations.

Threats: Suppression of natural disturbance regimes, particularly fire, and competititon from nonnative plants threaten this species at SHEN. Shade from adjacent woody vegetation may also pose a threat to this species.

Gaps in Knowledge: Although fire seems to stimulate regeneration of this species, the appropriate fire regime is not well-understood. In general, little is known about the reproductive strategies or habitat requirements of this species.

Suggested Management Recommendations:

- Fire seems to stimulate regeneration of sword-leaved phlox and, perhaps, should be prescribed to assist in maintaining this species at SHEN.
- Control woody succession to maintain the open character of the phlox habitat at SHEN.
- Protect populations of phlox from roadwork activities.
- Monitor the woodland population to detect population trends.
- Monitor populations for infestation by nonnative vegetation, particularly mile-a-minute weed.
- The recent discovery of a population in a natural woodland habitat argues for additional inventory in similar, metashale oak-hickory forests of the southern portion of the park.

Bog Bluegrass:

Current Status and Significance: Bog bluegrass is a delicate perennial species that is found in spring-fed swamps and hummocks in nutrient-rich seeps. Four populations of this species are known from SHEN. Bog bluegrass is known from 12 states in the northeastern and midwestern U.S.

Threats: Declines in water quantity or quality due to water removal from wells and hydrology altered by construction activities could potentially threaten this species at SHEN. This species seems to require closed canopy; therefore, defoliation of trees or other disturbance to the overstory could have adverse affects.

Gaps in Knowledge: Although a targeted inventory for this species has been conducted in suitable habitats, this species is cryptic, somewhat ephemeral, and extremely difficult to detect. More inventory will be required before the complete distribution of this species at SHEN is confidently known.

Suggested Management Recommendations:

- Protect known sites for this species from changes in hydrology or reduction of canopy cover that could be brought about by road or trail construction.
- Minimize visitation to these sites due to the delicate structure of the plant.

<u>Nonvascular Plants and Fungi</u>

Current Status and Significance: NPSpecies only lists one species of nonvascular plant and two fungi from SHEN (NPSpecies 2005). However, Schnooberger and Wynne (1945) reported the occurrence of 38 species of hepatics and 171 species of mosses from the park. In addition, Patterson (1955) documents 224 bryophytes from the park. The specimens from these collections are deposited at the headquarters of SHEN in Luray, VA, and at the herbarium at the University of Michigan herbarium in Ann Arbor, MI. The collections contain several new records for VA. Patterson (1955) noted that several of the specimens reported by Schnooberger and Wynne (1945) were the first documented in VA and seem to be very rare. The entire Schnooberger and Wynne collection was checked for accuracy and annotated to update taxonomy by a bryophyte specialist in 2004–2005 (Olday 2005). This review revealed a total of 751 specimens representing 266 taxa.

Two-hundred and ten lichen records for SNP are available in the "NPLichen" (http://www.ies.wisc.edu/nplichen/park.php?park=Shenandoah&choice1=species) database compiled by the University of Wisconsin. One of the most comprehensive published lists of lichens dealing specifically with SHEN is by Forman and Sierk (1970). A lichen collection effort was completed in 2005 as part of the Rock Outcrop Management Project (Cass and Bair 2004). To date, 94 species have been identified (Flenniken 2006; Harris 2006), many of which are not listed on NPLichen.

Stevenson (1936, 1937) published preliminary lists of the fungi from SHEN. These two published lists document the occurrence of 405 species of fungi from the park. The specimens were deposited in the Mycological Collections of the Bureau of Plant Industry (Stevenson 1936). An additional unpublished list of 476 species of macro-fungi was generated in 1985 (Simpson 1985).

Threats: Poor air quality may threaten nonvascular plants, lichen, and fungi, especially at exposed, high-elevation sites. Furthermore, bryophytes may be especially sensitive to effects of acid deposition (Hallingbäck 1992). Trampling by high visitation at rocky cliffs may threaten these species in the park. Collecting of edible fungi also may be a threat at SHEN.

Gaps in Knowledge: Despite their importance to terrestrial and freshwater communities, little is known about the nonvascular plants and fungi present at SHEN.

Suggested Management Recommendations:

- Expand the survey effort for lichens, fungi, and nonvascular plants in SHEN, especially on rock outcrops.
- Update NPLichen to include most recent lichen discoveries in the park.

Nonnative Plants

Current Status and Significance: Due to past land use, including European settlement and associated homesites, nonnative plants have been present in SHEN since its establishment as a national park (Mazzeo 1966b). Approximately 23% of known plant species in the park are nonnative or naturalized (Comiskey et al. 2005). Many of the old abandoned homesites and cemeteries can be located in the park by the conspicuous exotic plants that have persisted over the years and are now well-established and spreading in the park. Some of the most conspicuous nonnative plants that persist at old homesites include Norway spruce, lily-of-the-valley, common day lily (*Hemerocallis fulva*), daffodils (*Narcissus pseudo-narcissus*), iris (*Iris germanica*), and white mulberry (*Morus alba*) (Mazzeo 1966b). Some nonnative plants are more recent arrivals and are particularly deleterious to natural forested habitats at SHEN. For example, tree-of-heaven, mile-a-minute weed (*Polygonum perfoliatum*), garlic mustard, Japanese stiltgrass, long-bristled smartweed, Oriental bittersweet, and Japanese honeysuckle (*Lonicera japonica*) threaten natural plant communities throughout the park (NPS 2005g). Disturbances associated with road or trail construction, prescribed fire, or visitor trampling can contribute to the spread and establishment of nonnative plants in the park (NPS 2005g). In addition, use by horses (nonnative plant seeds can be spread in their excrement) and seeds spread by birds may acerbate nonnative plant expansion in SHEN.

SHEN began its invasive nonnative plant management program in 1997. This program established the foundation for what is now the Mid-Atlantic Exotic Plant Management Team (Åkerson 2004; NPS 2005g). This team is stationed at SHEN and provides survey and control assistance to SHEN and other national parks in the region. In addition to the Mid-Atlantic Exotic Plant Management Team, SHEN maintains its own, albeit smaller, park-funded effort to deal with nonnative plants in the park. Surveys conducted by these efforts provide parkwide information on the status of nonnative plants and the general health of native plants. To date, surveys have been conducted at developed areas, along wildfire access roads, along the 350+ miles of park boundary, and at portions of historic developments (Arsenault et al. 2004; NPS 2005g). These surveys have documented the following:

- Nonnative plants penetrate an average of 75 m (246 ft) into the forests along Skyline Drive and about 102 m (335 ft) into the forests surrounding historic (and abandoned) developed areas. Garlic mustard and Japanese stiltgrass are the most problematic invasives. Although mile-a-minute weed and oriental ladysthumb (*Polygonum caespitosum*) are recent serious concerns (Åkerson 2005; VANHP, G. Fleming, pers. com. 2006).
- The North District of the park contains more nonnative plant occurrences than the other two districts. In general, nonnative plants are more prevalent on the eastern slopes of the park than on the west. Skyline Drive, abandoned developed areas, and fire roads are associated with high numbers of nonnative plants; park boundaries are not (NPS 2005g).
- Tree-of-heaven is the most prevalent nonnative tree. Oriental bittersweet, multiflora rose (*Rosa multiflora*), wineberry (*Rubus phoenicolasius*), Japanese honeysuckle, and Japanese barberry (*Berberis thunbergii*) are the most common nonnative shrubs. Garlic mustard, Japanese stiltgrass, and long-bristled smartweed are the most common nonnative forbs in the park.

Since 1997, a total of 504 ha (1,245 ac) have been initially treated (using a variety of methods) and 567 ha (1,401 ac) have been re-treated to control nonnative plants (NPS 2005g). In addition, a draft exotic plant management plan has been prepared for the park. The plan outlines a strategy for targeting the most potentially damaging nonnative plants within the park by employing park personnel, volunteers, Student Conservation Association resource assistants, and park neighbors to achieve nonnative control objectives.

Threats: The proliferation and spread of invasive nonnative plants may be the biggest threat to maintaining native forests and plant communities at SHEN.

Gaps in Knowledge: Due to funding constraints and limited survey efforts the full extent and spread of nonnative plants in the park and “new to the park” is unknown. However, the continuation of these surveys is essential because early detection and rapid response is vital to minimizing the detrimental effects of nonnative plants.

Suggested Management Recommendations:

- Limit the establishment and encroachment of nonnative plants through a variety of control techniques including manual removal, select use of herbicides, and minimizing the establishment of new fragmenting and disturbance features such as roads and trails in the park.
- Finalize the draft exotic plant management plan and begin implementation at SHEN.
- Prioritize natural vegetation communities and rare plant populations in the greatest need of protection from nonnative plants. Control efforts should be focused on these highest value resources.

Animal Resources

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SHEN supports a diverse assembledge of native mammals, neotropical birds, and herptofauna. These resources are not only intrinsically significant, but contribute to the enjoyment of park visitors. The presence of wild animals and birds “adds greatly” to the experience of over 90% of park visitors (Sullivan et al. 1993).

<u>Mammals</u>

There is some disagreement as to the exact number of mammals known from SHEN. Manville (1956) confirmed the presence of 49 mammals from the park but estimated that 10 others occur in the park because they were documented in neighboring counties. Burns et al. (2003) listed 33 species of mammals from SHEN. NPSpecies (2005) documents 53 species of mammals from the park, and the Virginia Gap Analysis Program (2005) predicts SHEN to contain 50% (57 of 114 species) of the mammalian fauna known to occur in Virginia (Linzey 1998). There are no federally listed endangered species of mammals in SHEN, but two that are listed as species of special concern by the Virginia Department of Game and Inland Fisheries have been documented in the park (northern river otter, Allegheny woodrat [*Neotoma magister*], Table 7). Eastern small-footed myotis (*Myotis leibii*) and Appalachian cottontail (*Sylvilagus obscurus*), other species of special concern in Virginia, are predicted to occur in the park but have not been documented (VA Gap 2005).

White-tailed Deer:

Current Status and Significance: The Virginia Department of Game and Inland Fisheries (1999) estimates the state population of white-tailed deer to be 400,000–800,000 individuals. Game Zone 9, in which SHEN is located, contains deer densities of approximately 10–12 deer/total km^2 (25–30 deer/total mi^2) (Lafon, VA FWIS, pers. comm., 2005; VDGIF 1999). Densities vary within the park by location and season. For example, estimates by researchers in 2003 were 69±5 deer/km^2 (176±13 deer/mi^2) in the Big Meadows area, with spring densities of 82±5 deer/km^2 (210±12.5 deer/mi^2), and fall densities of 62±5 deer/km^2 (159±13.1 deer/mi^2) (Gubler 2004). Front country (e.g., areas along Skyline Drive and at major campgrounds and visitor centers) deer densities consistently exceed backcountry densities (Scanlon and Vaughan 1987).

Table 7. Vertebrates of special concern known to occur in Shenandoah National Park, Virginia Natural Heritage Program, 2006.

Common Name	Scientific Name	Federal Status	State Status VA	NHP Ranking VA	Global Rank
Birds					
Cooper's hawk	*Accipiter cooperii*			S3B/S3N*	G5
spotted sandpiper	*Actitis macularia*			S2B/SZN	G5
northern saw-whet owl	*Aegolius acadicus*		SC	S1B/S1N	G5
golden eagle	*Aquila chrysaetos*			SHB/S1N	G5
great blue heron	*Ardea herodias*			S3B/S5N*	G5
short-eared owl	*Asio flammeus*			S1B/S3N	G5
American bittern	*Botaurus lentiginosus*			S1B/S2N	G4
purple finch	*Carpodacus purpureus*		SC	S1B/S5N	G5
hermit thrush	*Catharus guttatus*		SC	S1B/S5N	G5
brown creeper	*Certhia americana*		SC*	S3B/S5N*	G5
northern harrier	*Circus cyaneus*		SC	S1B/S3S4N	G5
cerulean warbler	*Dendroica cerulea*			S3S4/SZN*	G4
blackburnian warbler	*Dendroica fusca*			S2B/SZN	G5
magnolia warbler	*Dendroica magnolia*		SC	S2B/SZN	G5
bobolink	*Dolichonyx oryzivorus*			S1B/SZN*	G5
yellow-bellied flycatcher	*Empidonax flaviventris*		SC	S1B/SZN	G5
least flycatcher	*Empidonax minimus*			S3S4B/SZN*	G5
peregrine falcon	*Falco peregrinus*		LT	S1B/S2N	G4
American coot	*Fulica americana*			S1B/S5N	G5
bald eagle	*Haliaeetus leucocephalus*	T	LT	S2S3B/S3N	G5
red crossbill	*Loxia curvirostra*		SC	S1B/SZN	G5
swamp sparrow	*Melospiza georgiana*			S1B/S4S5N	G5
yellow-crowned night heron	*Nyctanassa violacea (Nycticorax violaceus)*		SC	S2S3B/S3N	G5
mourning warbler	*Oporornis philadelphia*		SC	S1B/SZN	G5
osprey	*Pandion haliaetus*				G5
savannah sparrow	*Passerculus sandwichensis*			S3S4B/S4N*	G5
pied-billed grebe	*Podilymbus podiceps*			S1S2B/S3N	G5
golden-crowned kinglet	*Regulus satrapa*		SC	S2B/S5N	G5
bank swallow	*Riparia riparia*			S3B/SZN*	G5
northern waterthrush	*Seiurus noveboracensis*			S1B/SZN	G5
red-breasted nuthatch	*Sitta canadensis*		SC	S2B/S4N	G5
yellow-bellied sapsucker	*Sphyrapicus varius*			S1B/S4N	G5
winter wren	*Troglodytes troglodytes*		SC	S2B/S4N	G5
Canada warbler	*Wilsonia canadensis*			S3S4B/SZN*	G5
Mammals					
silver-haired bat	*Lasionycteris noctivagans*			SUB/S4N*	G5
hoary bat	*Lasiurus cinereus*			SUB/S4N*	G5
northern river otter	*Lontra canadensis (Lutra)*		SC	S4*	G5
Allegheny woodrat	*Neotoma magister*			S3*	G3G4
Reptiles	None				
wood turtle	*Clemmys insulpta*		LT	S2	G4
pine snake	*Pituophis melanoleucus*		SC	S1/S3	G4

Table 7. Vertebrates of special concern known to occur in Shenandoah National Park, Virginia Natural Heritage Program, 2006 (continued).

Common Name	Scientific Name	Federal Status	State Status VA	NHP Ranking VA	Global Rank
Amphibians					
Shenandoah salamander	*Plethodon shenandoah*	E	LE	S1	G1

[1]Federal Status
E=Endangered
T=Threatened
[2]State rankings:
LE=Listed Endangered
LT=Listed Threatened
SC=Special Concern; animals that merit special concern according to the Virginia Department of Game and Inland Fisheries. This is not a legal category.
[3]NHP Ranking VA:
S1=Critically Imperiled: Critically imperiled in the state because of extreme rarity or because of some factor(s) making it especially vulnerable to extirpation from the state; typically 5 or fewer occurrences or very few remaining individuals or acres.
S2=Imperiled: Imperiled in the state because of rarity or because of some factor(s) making it very vulnerable to extirpation from the state; typically 6 to 20 occurrences or few remaining individuals or acres.
S3=Vulnerable: Vulnerable in the state either because rare and uncommon, or found only in restricted range (even if abundant at some locations), or because of other factors making it vulnerable to
S4=Apparently Secure: Uncommon but not rare, and usually widespread in the state; usually more than 100 occurrences.
SNR=Unranked; state rank not yet assessed.
SU=Unrankable: Currently unrankable due to lack of information or due to substantially conflicting information about status or trends. Note: Whenever possible, the most likely rank is assigned and a question mark added (e.g., S2?) to express uncertaintly, or a range rank (e.g., S2S3) is used to delineate the limits (range) of uncertainty.
*=S rank has been assigned and is under review. Contact the individual state Natural Heritage program for assigned rank.
[4]Global Rank:
G1=Critically Imperiled=At very high risk of extinction due to extreme rarity (often 5 or fewer populations), very steep declines or other factors.
G2=Imperiled=At moderate risk of extinction due to a restricted range, relatively few populations (often 20 or fewer), steep declines, or other factors.
G3=Vulnerable=At moderate risk of extinction due to a restricted range, relatively few populations (often 80 or fewer), recent and widespread declines, or other factors.
G4=Apparently Secure=Uncommon but not rare; some cause for long-term concern due to declines or other factors.
G5=Secure=Common; widespread and abundant
T#=Infraspecific Taxon (trinomial)=The status of infraspecific taxa (subspecies or varieties) are indicated by a “T-rank” following the species’ global rank. Rules for assigned T-ranks follow the same principles outlined above for global conservation status ranks. For example, the global rank of a critically imperiled subspecies of an otherwise widespread and common species would be G5T1. A T-rank cannot imply the subspecies or variety is more abundant than the species as a whole-for example, a G1T2 cannot occur. A vertebrate animal population, such as those listed as distinct population segments under the U.S. Endangered Species Act, may be considered an infraspecific taxon and assigned a T-rank; in such cases a Q is used after the T-rank to denote the taxon’s informal taxonomic status. At this time, the T-rank is not used for ecological communities.

In addition, frontcountry deer densities exhibited a clumped distribution pattern with deer most frequently using areas receiving intense human use (Scanlon and Vaughan 1987). This distribution pattern increases the likelihood of deer-human conflicts within the park. Scanlon and Vaughan (1987) estimated that fawn mortality ranged from 35–55% and was attributed to predation by black bears, dogs, and bobcats. Today, coyotes potentially are another major predator of fawns.

Pre-European settlement deer densities in the Blue Ridge Mountains and in the Shenandoah Valley ranged from 3.1–7.7 deer/km^2 (8–20 deer/mi^2) (Horsely et al. 2003). The Virginia Deer Management Plan (VDGIF 1999) provides deer density and distribution maps for the state from 1938–1988. By 1988, deer density in and around portions of SHEN had exceeded the environmental carrying capacity of 12+ deer/km^2 (30+ deer/mi^2) set by the VDGIF (VDGIF 1999). High densities of white-tailed deer in the eastern United States in the late 20th and early 21st centuries reduced plant diversity, affected forest regeneration, and had indirect effects on game and nongame wildlife communities (McShea and Rappole 1997). Deer consume herbaceous vegetation and much of the shrub layer in hardwood forests, vegetation needed by birds, small mammals, and woodland salamanders (McShea and Rappole 1992a, b; McShea and Schwede 1993). High densities of deer are especially problematic at Big Meadows where deer herbivory negatively affects rare plant communities. The magnitude of the impact is probably larger in the absence of large predators that historically helped regulate deer populations. Active deer management by hunting to control population sizes, and therefore direct and indirect impacts on forest ecosystems, is not legally allowed at SHEN.

According to Hall (2000), 71% of visitors to campgrounds at SHEN feel that wildlife, particularly viewing and interacting with deer, is an important part of their visit to the park. Sixty-three percent of visitors to the Big Meadows campground picnic area fed white-tailed deer and 79% of visitors felt that the tameness of the deer within the campground was an appealing feature of the park (Hall 2000). Feeding wildlife threatens the safety of visitors and wildlife and is therefore not permitted at SHEN. Due to the visitor/deer interactions at Big Meadows, park staff conduct spotlight monitoring counts at the campground in spring and fall. Population densities have exceeded 77 deer/km^2 (200 deer/mi^2) at the campground (Comiskey et al. 2005).

Threats: White-tailed deer are potentially threatened by chronic wasting disease (CWD). CWD is a neurological (brain and nervous system) disease of deer and elk in North America. It belongs to a family of diseases known as transmissible spongiform encephalopathies (TSE) or prion diseases. The disease attacks the brains of infected deer, moose, and elk, resulting in death. Although CWD is similar to mad cow disease and scrapie in sheep, there is no known relationship between this and other TSE in animals or humans. To establish whether CWD occurs in Virginia, the VDGIF initiated a CWD surveillance program in fall 2002. To date, CWD has not been found in Virginia. However, due to the discovery of CWD in Hampshire County, West Virginia (<129 km [<80 mi] from SHEN) in September 2005, the VDGIF increased its surveillance in 2005.

Deer are hit by vehicle each year along Skyline Drive. For example, 33 and 18 deer were hit on the Drive in 2004 and 2005, respectively.

Deer feeding, although not permitted, still occurs in the park and threatens the safety of white-tailed deer.

Gaps in Knowledge: The white-tailed deer population size and distribution in SHEN is not accurately known. Highest concentrations occur in the frontcountry along Skyline Drive. Deer may not be harvested and are not controlled by park management in SHEN. An accurate accounting of white-tailed deer in SHEN is needed, especially in the high-visitor areas and along Skyline Drive as compared to low-visitor areas (backcountry).

The potential effects of CWD on the population of white-tailed deer at SHEN is unknown.

Suggested Management Recommendations:

- Obtain estimates of the deer population and distribution in SHEN. Use multiple methods to obtain accurate numbers.
- Elucidate deer impact on the forest ecosystem and their effects on plant and animal species in SHEN. Determine if and where impacts are undesirable and what deer management actions may be necessary.
- Develop GIS models to allow assessment of primary areas of deer occurrence and problem areas in the park.
- Use GIS models to target illegal hunting operations in and along the park's boundaries for law enforcement operations and allow SHEN officers to assist Virginia game wardens in criminal operations.
- Place signs strategically in all campgrounds and picnic areas at SHEN that explain the moral and hazardous reasons not to feed wildlife.
- Implement research recommendations for white-tailed deer provided by Scanlon and Vaugh (1987). They recommend continuing to monitor deer populations through road counts and implementing other approaches and studying the effects of deer on vegetation in both the backcountry and frontcountry of the park.
- Monitor and control the presence and/or spread of CWD in SHEN.
- When possible, cooperate with VDGIF on achieving goals and objectives of Virginia Deer Management Plan (2005–2015).

Black Bear:

Current Status and Significance: There are 5,000–6,000 black bears in Virginia. Harvest records in Virginia have averaged 1,000 per year for several years (VDGIF, R. Duncan, pers. comm., 2005). The two largest populations in Virginia are in the Great Dismal Swamp National Wildlife Refuge and SHEN, with the latter supporting the largest numbers and perhaps being a source population for the Blue Ridge Mountains. Estimates of the number of bears in SHEN range from about 300–800 (Brown 1985; Carney et al. 1987). Bear harvest in VDGIF Zone 9 surrounding SHEN from 1991–2002 ranged from 176–386 individuals annually, but climbed to 574 in 2003, an increase of 21% that year, likely due to the additional 4-day muzzleloader season (VDGIF, D. E. Steffen, pers. comm., 2005).

Home ranges of black bears in SHEN are larger for males (67–77,000 ha [165–190,270 ac]) than females (374–4,983 ha [924–12,313 ac]), and most home ranges extend well beyond park boundaries (Vaughan 1983). In the 1980s, some bears moved extensively during gypsy moth defoliation and occasionally moved into populated areas. In portions of Virginia, defoliation led to increased hunter harvest due to greater movement, increased number of nuisance bears, loss of dens, and longer times in dens (Kasbohm et al. 1994).

Threats: Black bears in Virginia, and especially around SHEN, are potentially threatened by poachers. Bears are killed illegally and their gall bladders and paws are sold on the international market. However, based on the Cooperative Allegheny Bear Study (CABS) conducted by the Virginia Department of Game and Inland Fisheries and Virginia Tech, the illegal killing of bears appears to be relatively inconsequential for population dynamics. Radio-telemetry monitoring of 399 individual bears between 1994–2003 showed that only one bear was illegally killed (85 others were harvested legally). If the legal:illegal ratio observed in CABS (85:1) holds true for the zone around SHEN, then 4–5 bears might be killed illegally every year (VDGIF, D. E. Steffen, pers. comm., 2005). A few bears are killed each year by vehicles on Skyline Drive. In 2004 and 2005, two and seven bears, respectively, were hit by vehicles along Skyline Drive (NPS, Atkinson, pers. comm., 2006).

Gaps in Knowledge: The black bear population in SHEN has been relatively well studied by Dr. Michael Vaughan and his students at Virginia Tech. Studies of population dynamics, denning ecology, movements, habitat ecology, diet, and the effects of gypsy moth defoliation on bear movement, reproduction, diet, and survival were conducted through the 1990s. Bear predation on deer fawns is known to occur in Pennsylvania and Virginia (Scanlon and Vaughan 1987). The extent to which bear predation of deer occurs in SHEN and its effects on the deer population is unknown.

Despite the potential for high bear/human interactions at SHEN, the cultural carrying capacity of bears in the park is unknown. Bear/human interactions declined, however, from 1970–1987 (Garner 1987).

Suggested Management Recommendations:

- Resource managers and law enforcement officers should continue to monitor bear hunting activities around SHEN to prevent poaching in the park.
- Use GIS models to target illegal hunting operations in and along the park's boundaries for law enforcement operations.
- Determine the importance of SHEN to the black bear population as a source population for other areas in Virginia and as a refugium from legal and illegal hunting.
- Develop and implement an education plan to minimize bear/visitor conflicts (e.g., food storage, trash disposal).
- Develop a GIS model to map bear/human conflicts in the park.
- Determine the current black bear population size in SHEN and compare with previous estimates to determine trends.
- Estimate the cultural carrying capacity of bears in the park.

Allegheny Woodrat:

Current Status and Significance: The Allegheny woodrat is recognized as a species of special concern in Virginia (Table 3). In SHEN, woodrat activitiy was documented at nine sites during 1990–2000 (Mengak 2000). Woodrats are in decline in Virginia and the eastern portion of its range (Balcom and Yahner 1996; Linzey 1998). Because this species is in decline in the eastern United States, populations in SHEN may represent critical source populations and should be protected from disturbance.

Threats: Decline in Allegheny woodrat populations throughout its eastern range is also possible in SHEN. Sources of decline include forest fragmentation, habitat loss, and parasite infection by roundworms (*Strongyloides* spp.) carried by raccoons (Balcom and Yahner 1996).

Gaps in Knowledge: The distribution and population biology, including survivorship rates, of this species needs to be elucidated for park populations. Comparisons among populations studied elsewhere should be conducted to determine if SHEN populations are healthy. Gypsy moth infestations and their effects on acorns may contribute to population declines in SHEN (McShea 2000).

Suggested Management Recommendations:

- All known locations where this species has been recorded should be mapped in a GIS model and these data housed at the park.
- Areas within SHEN with viable populations should be mapped and protected from excessive visitor use and habitat alteration.
- Allegheny woodrat populations in SHEN should be monitored carefully and regularly to detect any declines, should they occur.

Coyote:

Current Status and Significance: The coyote has expanded its former western range all the way to the Atlantic Ocean and now occupies nearly all eastern states due to changes in landscape use by humans (Whitaker and Hamilton 1998). The influx of this North American native predator and scavenger into Virginia has been well documented (Linzey 1998). Its occurrence in SHEN was documented by natural resource manager Jim Atkinson in 2002 by using remote cameras with laser triggers.

Threats: Threats to coyotes are unknown in SHEN.

Gaps in Knowledge: Population size, population growth rate, and impacts on native wildlife by coyotes in SHEN are unknown.

Suggested Management Recommendations:

- Create a GIS model to map all known locations of coyote sightings in SHEN.
- Install a reporting mechanism for field sightings by knowledgeable field personnel and visitors.

- Develop a study plan to evaluate the coyote population and its potential effects on other animal species in SHEN.
- Determine if there are any threats of disease transmission from coyotes to humans or native mammals at SHEN.

Bat Communities:

Current Status and Significance: The status of the bat community in SHEN is unknown. There have been no published studies of this vertebrate group in the park, and NPSpecies (2005) documents six species of bats (big brown bat [*Eptesicus fuscus*], little brown bat [*Myotis lucifugus*], silver-haired bat [*Lasionycteris noctivagens*], eastern red bat [*Lasiurus borealis*], hoary bat [*Lasiurus cinereus*], and eastern pipestrelle [*Pipistrellus subflavus*]) as being confirmed from SHEN. However, Virginia Gap predicts nine species of bats to occur in the park. Three of these predicted species, northern myotis (*Myotis septentrionalis*), eastern small-footed myotis, and evening bat (*Nycticeius humeralis*), have not been documented in the park and are not included in NPSpecies. In addition, two species (Indiana bat [*Myotis sodalis*] and Virginia big-eared bat [*Plecotus townsendii virginianus*]), both federally endangered, are known to occur on the west side of the Shenandoah Valley and may occur in the park (Webster et al. 1985).

Threats: Threats to the bat community in SHEN are unknown, although the conversion of nearby limestone caverns (e.g., Luray Caverns) to visitor attractions may have eliminated roosting and hibernation habitat.

Gaps in Knowledge: Essentially nothing is known about the bat fauna in SHEN. Distribution, habitat use, foraging areas, behavior, diet, and life history characteristics need to be studied in the park. Because bats are long-distance flyers, and two species (Indiana bat and Virginia big-eared bat) that occur in the Allegheny Mountains of Virginia (Terwilliger and Tate 1995) are listed as endangered federally and by the state of Virginia, they should be prime targets of inventories in SHEN.

Suggested Management Recommendations:

- Initiate a series of life history studies on the bat fauna of SHEN, starting with a baseline inventory that targets the two endangered species.
- Develop a GIS model on the distribution, habitat use, and overwintering sites of each species.
- Because some bat species are migrants and use SHEN seasonally, determine the phenological patterns for each species in the park.
- Identify which buildings are used for roosts by which bat species in SHEN and if any of these roosts provide winter shelter.
- Identify the distinctive habitats in SHEN that are used by bats.

Mid-sized and Fur-bearing Mammals:

Current Status and Significance: Fur-bearing mammals include beaver, bobcat, muskrat (*Ondatra zibethicus*), red fox (*Vulpes vulpes*), gray fox, skunks (*Mephitis mephitis*, *Spilogale* *putorius*), woodchuck (*Marmota monax*), eastern cottontail (*Sylvilagus floridanus*), gray squirrel (*Sciurus carolinensis*), mink (*Mustela vision*), northern river otter, and weasels (*Mustela* spp.). Beaver and muskrat are only known from around the periphery of the park boundaries. Formal studies of these species' populations in SHEN have not been conducted. Their interactions with predators and the impact of variation in mast production on squirrel populations can have profound affects on the food web in the park.

Threats: The main threat to these animals is mortality due to vehicular traffic on Skyline Drive. Threats from disease are unknown. Coyote predation on these mammals could be significant, but the incidence and impacts are unknown.

Gaps in Knowledge: There have been no studies of the mid-sized and fur-bearing mammal species in SHEN. Studies on the distribution, habitat use, population dynamics, life histories, and interactions with other species need to be conducted. There are no data on distribution and density of populations of riparian and fur-bearing mammals such as the northern river otter, beaver, mink, weasel, muskrat, and bobcat in the park. It is also not known if trapping occurs along the borders of the park or if illegal trapping occurs in the park.

Suggested Management Recommendations:

- Conduct a parkwide inventory of all mid-sized mammals to determine which species occur in SHEN.
- Develop a GIS model to map all known occurrences of and habitat use by each species.
- Assess populations of mid-sized mammals in selected riparian systems in the park.
- Determine if any mid-sized mammals in SHEN are carriers of rabies or other diseases that can be transmitted to humans and ascertain the risk of such threats.
- Determine if coyotes are impacting mid-sized mammals in SHEN.

Small Mammals:

Current Status and Significance: The small mammal community has been little studied in SHEN. A species list in Webster et al. (1985) suggests that 18 species of native mice, moles, voles, and shrews occur within the park. They include star-nosed mole (*Condylura cristata*), southeastern shrew (*Sorex longirostris*), pygmy shrew (*Sorex hoyi*), southern bog lemming (*Synaptomys cooperi*), white-footed mouse (*Peromyscus leucopus*), southern flying squirrel (*Glaucomys volans*), and the rare Appalachian cottontail. In addition, the southern water shrew (*Sorex palustris punctualatus*) (endangered in Virginia) may occur in the park. These small mammals are prey for numerous reptile, bird, and mammal predators. Small mammal populations fluctuate in size due to changes in rainfall, changes in canopy cover, and other climatic and habitat variables. These fluctuations directly affect predator populations and determine their reproductive capacity and survival rates (Vaughan 1986). Understanding population fluctuations of these animals provides insight into the status of numerous other species. Hantavirus disease was documented for two species of mice (white-footed mouse and deer mouse [*Peromyscus maniculatus*]) in SHEN by Mills et al. (1998).

Threats: Gypsy moth infestations and their effects on acorns have caused declines in native rodent populations in SHEN (McShea 2000). Forest succession may contribute to declines in Appalachian cottontail.

Gaps in Knowledge: There have been no systematic studies of small mammal communities in SHEN. Field research on the distribution, habitat use, population dynamics, and life histories of small mammals needs to be conducted. A complete species list based on systematic inventories needs to be developed. Unfortunately, bears could disrupt most of the typical methods used for such inventories (e.g., live traps, drift fences with bucket traps), so creative methods would have to be employed.

Suggested Management Recommendations:

- Conduct a parkwide inventory of all small mammals to determine which species occur and where they occur in SHEN.
- Document which habitats are preferred by small mammal species in SHEN.
- Develop a GIS model to map all known occurrences of and habitat use by each species.
- Manville (1956) provided information about voucher specimens for various small mammals collected in SHEN. The location of these vouchers should be documented, catalogued, and referenced in NPSpecies.

<u>Birds</u>

Simpson (1992) documents a total of 205 species of birds known to occur in SHEN. However, only 175 species of birds were predicted to occur in and around SHEN by the Virginia Gap Analysis (VA Gap 2005), and only 192 species are listed in NPSpecies for SHEN (NPSpecies 2005). SHEN contains 53% of the 390 species of birds known to occur regularly in Virginia (Johnston 1997). In addition, 33% (17 of 49 species) of the birds of special concern in Virginia occur in the park (Terwilliger and Tate 1995). The bald eagle (*Haliaeetus leucocephalus*) is the only federally listed bird species in SHEN (threatened) (Table 7).

Bird species known to occur in SHEN are derived from lists in Wetmore (1950), Lindsay and Lindsay (1997), park checklists by Wilhelm (1966), Thomas (1987), Simpson (1992), Christmas bird counts 1969–1990, the national Breeding Bird Survey (BBS), Monitoring Avian Productivity and Survivorship (MAPS) Program based on observations made from 1935 to 2003, and NPSpecies (2006).

Neotropical Migrants:

Current Status and Significance: At least 41 species of neotropical migratory birds visit SHEN annually (DeSante et al. 2004). DeSante et al. (2004) indicate that SHEN is globally significant in providing habitat for neotropical migrants, especially wood warblers (Family Parulidae). These species depend on unfragmented mixed-deciduous forests with well-developed canopies and gap dynamics (tree falls) in place. Species of warblers in SHEN include golden-winged warbler (*Vermivora chrysoptera*), pine warbler (*Dendroica pinus*), Swainson's warbler (*Limnothlypis swainsonii*), and Tennessee warbler (*Vermivora peregrina*). Eleven species in this family that occur in SHEN are on the Partners in Flight (PIF) watch list of species of concern for the Appalachian Region. The PIF watch list does not include federally listed species. Instead the list identifies those species that are still relatively common but may become endangered or threatened in the near future (USFWS 1999). Several species on this watch list, including those in SHEN, have declined in the past several decades, occupy habitats that are severely threatened, are found in low numbers, or have restricted ranges. The PIF watch list species at SHEN are: black-and-white warbler (*Mniotilta varia*), worm-eating warbler (*Helmitheros vermivorus*), cerulean warbler, blackburnian warbler, yellow-throated warbler (*Dendroica dominica*), prairie warbler (*Dendroica discolor*), Kentucky warbler (*Oporornis formosus*), hooded warbler (*Wilsonia citrina*), Canada warbler (*Wilsonia canadensis*), Louisiana waterthrush (*Seiurus motacilla*), yellow-breasted chat (*Icteria virens*), eastern meadowlark (*Sturnella magna*), scarlet tanager (*Piranga olivacea*), summer tanager (*Piranga rubra*), indigo bunting (*Passerina cyanea*), grasshopper sparrow (*Ammodramus savannarum*), Henslow's sparrow (*Ammodramus henslowii*), Bachman's sparrow (*Aimophila aestivalis*), field sparrow (*Spizella pusilla*), broad-winged hawk (*Buteo platypterus*), peregrine falcon, ruffed grouse (*Bonasa umbellus*), northern bobwhite (*Colinus virginianus*), northern saw-whet owl (*Aegolius acadicus*), whip-poor-will (*Caprimulgus vociferus*), belted kingfisher (*Ceryle alcyon*), red-headed woodpecker (*Melanerpes erythrocephalus*), downy woodpecker (*Picoides pubescens*), acadian flycatcher (*Empidonax virescens*), eastern wood peewee (*Contopus virens*), olive-sided flycatcher (*Contopus cooperi*), purple martin (*Progne subis*), Carolina chickadee (*Poecile carolinensis*), Bewick's wren (*Thryomanes bewickii*), wood thrush (Hylocichla mustelina), loggerhead shrike (*Lanius ludovicianus*), yellow-throated vireo (*Vireo flavifrons*), and red crossbill (*Loxia curvirostra*). These PIF watch list species represent 19% of the known avifauna in SHEN.

Forest neotropical birds depend on the physical structure of the forest for survival. Some live in hardwoods with canopies, some live along the edge, and some live in forest gaps created by tree falls. This partitioning of the physical habitat supports the high diversity of forest birds in SHEN. Forest gaps contain early successional vegetation and sunlight, two environmental variables needed by several neotropical migrants.

Hemlock stands provide, or at least provided, another important habitat for rare birds in SHEN. The Louisiana waterthrush (a PIF watch list species), for example, nests along streams with high water quality in forests with hemlocks and rhododendrons (O'Connell et al. 2003).

Threats: Potential threats to neotropical migratory birds in SHEN include modification of the park's hardwood forest structure due to loss of oaks from introduced gypsy moths, loss of hemlocks from the introduced hemlock woolly adelgid, lack of regeneration due to deer browsing, and disturbance suppression (e.g., McShea and Rappole 1997). Populations are also compromised by loss of forest habitat and fragmentation from developed sites in the park.

Gaps in Knowledge: More research is needed to better understand neotropical migrant habitat relationships in the changing forests in SHEN. Distribution, abundance, habitat partitioning, foraging strategies, and reproductive success are areas of information needed for all species. The Institute for Bird Populations conducted their Monitoring Avian Productivity and Survivorship (MAPS) Program in SHEN from 1992 through 2003 with six stations monitored annually. A primary result was the documented decline in bird population sizes and productivity indices in SHEN during the greater part of the study (DeSante et al. 2004; NPS 2005h). This comprehensive look at breeding birds was suspended due to budget constraints, so continued understanding of breeding bird trends are unknown.

Suggested Management Recommendations:

- Determine distribution, abundance, habitat partitioning, foraging strategies, and reproductive success for PIF watch list neotropical migrant species in SHEN.
- Minimize fragmenting influences to forest blocks in SHEN.
- Maintain and encourage natural gap dynamics in the park's forests for neotropical migrants and other species (see amphibians and reptiles).
- Develop GIS models to allow assessment of primary areas of occurrence of neotropical migrant bird species in the park.
- Provide educational activities and literature for use by interpreters and visitors.
- Revitalize Christmas Bird Counts and the MAPS program to continue collection of trend data. Determine how bird communities in SHEN have changed over the past several decades and why.

Waterbirds and Waterfowl:

Current Status and Significance: Few waterfowl species occur in SHEN due to the small number of ponds and other open water bodies within park boundaries. However, several species, such as wood duck (*Aix sponsa*), green heron (*Butorides virescens*), great blue heron (*Ardea herodias*), and American bittern (*Botaurus lentiginosus*), use riparian corridors along mountain streams, especially at low elevations. The abundance of each of these species within the park is unknown.

Threats: Threats to these birds are unknown in SHEN.

Gaps in Knowledge: Little is known about the distribution, abundance, and reproductive success of waterbirds in SHEN. Wetmore (1950) and Simpson (1992) list several localities where these species have been observed. Studies of these species in the few open areas with standing water and along riparian corridors are needed.

Suggested Management Recommendations:

- An inventory of waterbirds in SHEN is warranted due to lack of information on this group.
- Determine the abundance, habitat use, foraging needs, and reproductive success for all waterbird species that occur in SHEN.
- Develop GIS models to allow assessment of primary areas of occurrence of all waterbird species in the park so that an effective management plan can be produced.

Raptors and Falcons:

Current Status and Significance: Hawks and falcons are frequent visitors to SHEN. The spine of the Blue Ridge Mountains creates a pathway along which several species of raptors fly during fall migration periods (B. Watts, College of William & Mary, Center for Conservation Biology, pers. comm., 2005). A hawk migration watch station is located at the southern end of SHEN near Waynesboro. At least ten species are known from SHEN (Wetmore 1950; Simpson 1992). Resident species include sharp-shinned hawk (*Accipiter striatus*), Cooper's hawk (*Accipiter cooperii*), broad-winged hawk, northern harrier (*Circus cyaneus*), and rough-legged hawk (*Buteo lagopus*). Bald eagles are seen occasionally in SHEN, but none are known to nest there (College of William & Mary, Center for Conservation Biology, B. Watts, pers. comm., 2005).

The eastern race of the peregrine falcon occurred throughout eastern North Amrica prior to its extirpation in the late 1960s. Nesting by an eastern peregrine on the cliffs at SHEN was documented by Wetmore in 1950. In addition, Watts and Padgett (2002) listed seven historical nesting locations in the park. Repatriation efforts with chicks and fledglings from other races of pergrines, have been attempted at SHEN since 2000. During 2000–2004, 36 of 39 nestlings transferred from coastal Virginia bridge sites have been successfully moved to SHEN sites and fledged (Gubler 2005). SHEN is one of the few places in the country where peregrine falcons can be observed nesting in their natural and historic habitat. In 2006, one mated pair is known to nest in SHEN as a result of hacking efforts at the park. Young falcons that have originated at SHEN are monitored using solar-powered satellite transmitters. First year mortality rates for peregrines are as high as 65% (Byrd et al. 2002).

Two vulture species, black (*Coragyps atratus*) and turkey (*Cathartes aura*), are known residents of the park. The 2004 Christmas Bird count indicates an increase in black vultures and a decrease in turkey vultures in and around the park from 1990–2004 (NPS 2005h). SHEN may provide nesting habitat for these vultures. Black vultures occasionally may prey upon young cattle outside the park (USDA, APHIS 2003).

Threats: Raptors are particularly sensitive to West Nile virus. People outside the park still kill hawks occasionally and nesting raptors are periodically disturbed by park visitors. For example, peregrine falcons nests potentially could be disturbed by rock climbing activity near nest sites.

Gaps in Knowledge: A complete inventory of raptors in SHEN needs to be conducted, especially to determine which species depend on park resources for requirements other than a migration corridor.

Suggested Management Recommendations:

- Determine distribution, abundance, habitat use, foraging needs, and reproductive success for all raptors in SHEN.
- Conduct hawk watch events in the fall to assess numbers and species of migratory raptors that migrate through the park.
- Develop GIS models to allow assessment of primary areas of occurrence of all raptor species in the park.
- Support the continued monitoring of peregrine falcon and report findings on a regular basis.
- Provide educational activities and literature for use by interpreters and visitors.
- Develop a protocol to recognize diseases such as West Nile virus in bird populations at the park.

Game birds:

Current Status and Significance: Wild turkey, ruffed grouse, and American wookcock (*Scolopax minor*) occur in SHEN (Wetmore 1950; Simpson 1992). All game bird populations had declined drastically in Virginia by 1900 (Wetmore 1950). However, following establishment of the park, these populations increased at SHEN. The Virginia turkey populations, estimated at about 120,000 statewide in 2005, appear to be stable, or declining slightly due to several years of low reproductive success (VDGIF, R. Duncan, pers. comm., 2005). The current size of the grouse and woodcock populations in Virginia are unknown, although grouse populations are low compared to levels prior to 2000 (VDGIF, R. Duncan, pers. comm., 2005). Woodcock have been declining at a rate of about two percent annually over the past two decades (VDGIF, R. Duncan, pers. comm., 2005).

Threats: The threats to these three game birds in SHEN are unknown, although American woodcock and ruffed grouse may be losing nesting habitat due to forest succession.

Gaps in Knowledge: Accurate counts of wild turkey, ruffed grouse, and woodcock populations in SHEN are needed to guide resource management. Nothing is known of their reproductive success and annual population recruitment rates. An assessment of the numbers harvested illegally, if any, in the park or along its boundaries would help managers ascertain the size of this threat and direct law enforcement operations.

Suggested Management Recommendations:

- Determine distribution, abundance, habitat use, foraging needs, and reproductive success for wild turkey, ruffed grouse, and woodcock in SHEN.
- Monitor populations in SHEN to determine trends
- Develop GIS models to allow assessment of primary areas of occurrence of turkey, grouse, and woodcock in the park.
- Use GIS models to target illegal hunting operations in and along the park's boundaries for law enforcement operations.

<u>Amphibians</u>

There is disagreement about the number of amphibian species at SHEN. For example, Witt (1993) documented 24 species of amphibians at SHEN. However, NPSpecies (2005) documents only 21 species of amphibians from SHEN, and VA Gap (2005) predicts that 27 species occur in and around the park. One species, the Shenandoah salamander (*Plethodon shenandoah*), is endemic to the park and is federally endangered.

Amphibians are sensitive to environmental changes, pollution, and diseases, particularly since many species have a dual life cycle (aquatic larval stage and a terrestrial adult stage), and all have moist, sensitive, semi-permeable skin (Stebbins and Cohen 1995). Death, malformations, and altered behavior resulting from exposure to environmental perturbations have caused the decline of many species and the complete extinction of others (Carey et al. 2003). Thus far, malformations or die-offs of frog or salamander species in SHEN have not been observed or reported.

Amphibians at SHEN can be classified into three groups: pond-breeding, streamside, and terrestrial. Each has its own life history characteristics and habitat requirements.

Pond-breeding Amphibians:

Current Status and Significance: Amphibians in this group (several frogs and salamanders) use isolated vernal pools for breeding, usually in late winter and spring. Adults migrate to pools from terrestrial refugia in the forest, congregate, breed, and return to the forest within days to weeks. Larvae develop in the pools through metamorphosis, emerge in late spring to summer, and then migrate to their own refugia in the forest. Functional vernal pools with water present from winter to late summer are critical to the survival of these species. Forest conditions also affect pond-breeding amphibians, but it is the vernal breeding pool that is the key to their survival (Mitchell 2000).

At least two groups of isolated vernal pools are known to exist in SHEN. These pools, located at Big Meadows near the weather station and at Hogcamp Swamp, have been studied for several years by the USGS Amphibian Research and Monitoring Initiative (ARMI). Historical presence data from Bill Witt (private citizen) also exist. These pools are the only places where pool-breeding amphibians are known to breed in the Central District. Inventories of additional vernal pools that may be located along park boundaries will be conducted during 2006 by ARMI (L. Bailey; project coordinator ARMI, USGS, pers. comm.).

Threats: Acid precipitation and alteration of the hydrological conditions of ponds constitute the primary threats to these amphibians. Draining and alteration (e.g., prescribed burning near these pools) of any part of the Big Meadows pools may cause several species (particularly Jefferson salamander) to become locally extinct within a short period of time. Many amphibians at SHEN migrate outside of the park boundary to breeding ponds on private lands. Any alterations to these ponds or barriers to migration pose a potentially serious threat to these boundary-line populations. Mortality by vehicles on Skyline Drive potentially is a significant source of mortality for some populations.

Gaps in Knowledge: The basic life history traits of amphibians at SHEN are unknown. For example, annual variation in the timing of migration, breeding period, reproductive characteristics, larval period, size and timing of metamorphosis, and survival are unknown. The status of each vernal pool in SHEN as a functional breeding site, including documenting the hydroperiod for each pool, needs critical evaluation.

Suggested Management Recommendations:

- Conduct a full inventory to document vernal pools in SHEN. Information on hydroperiod and threats to the vernal pools at Big Meadows and Hogcamp Swamp should be collected. Protect these pools from degradation.
- Protect each pool from known threats, including any alteration of the hydroperiod. Work with landowners along the boundary to protect these critical habitats.
- Determine which populations along the SHEN boundary migrate to breeding ponds on private lands and work with landowners to protect these populations.

- Support accumulation of population ecology information that will lead to a better understanding of these species, their use of the isolated pools, and annual variation in timing of migrations of adults and metamorphs. Such information is critical for effective management.
- Determine the effects of Skyline Drive on mortality of pond-breeding amphibians especially during the breeding season. Consider establishing migration corridors or periodic road closings if warranted.

Streamside Salamanders:

Current Status and Significance: The primary habitat of several species of salamanders in SHEN is mountain streams and the springs and seeps that feed them. The abundance and diversity of streamside salamanders is regionally significant and depends entirely on this habitat type. This suite of amphibians includes seal salamanders (*Desmognathus monticola*), northern dusky salamanders (*Desmognathus fuscus*), northern and southern two-lined salamanders (*Eurycea bislineata* and *E. cirrigera*), northern spring salamanders (*Gyrinophilus porphyriticus*), and northern red salamanders (*Pseudotriton ruber*). Cool to cold stream water is a critical element in their survival. Individuals may be found on the nearby forest floor when conditions are particularly wet, but most of their lives are spent in or near the water.

The salamander populations in SHEN streams appear relatively secure at this time, but continued exposure to acid deposition and resulting stream acidification eventually may adversely affect these populations (Mitchell 1998; Grant et al. 2005; Jung et al. 2005). These salamanders are important predators and prey in these habitats, and thus play key roles in the energy dynamics of streamside ecosystems. They most likely occur in every stream and associated springs and seeps in the park.

Threats: Acid precipitation has been viewed as the primary threat to streamside salamanders, but pH levels have apparently not declined enough to cause population decline or wide-spread mortality (Mitchell 1998; Grant et al. 2005).

Gaps in Knowledge: Baseline information on the status of streamside salamanders in SHEN has been accumulated, and techniques for sampling have been outlined by recent research (Jung et al. 2000; Jung et al. 2005). Nine streams in the park were monitored for streamside salamanders from 2000–2004 (Jung et al. 2005). However, there are no plans for long-term monitoring. The life histories of these species are not documented well enough to allow managers to understand how forest alterations or environmental perturbations may affect them. SHEN managers do not know all the locations of the springs and seeps in the park, and thus are not able to provide adequate protective measures for these habitats.

Suggested Management Recommendations:

- Conduct annual to periodic monitoring of streamside salamanders at known locations using established techniques so that comparisons to past studies are valid.
- Maintain a data set of streamside salamander monitoring results for a stratified random subset of streams in SHEN. Stratification could be based on bedrock type, elevation, and stream order.

- Conduct life-history and population studies to obtain information on the timing of major events (e.g., larval period, survival) for each streamside salamander species' effective management.
- Identify and obtain GPS locations and descriptions of all springs and seeps in SHEN, and follow up by evaluating their status and threats for future management.

Terrestrial Salamanders:

Current Status and Significance: Terrestrial salamanders are unique because, unlike all other amphibians, they do not require water in which to breed. These terrestrial, or woodland, salamanders remain in and under the forest floor all their lives. Mating occurs there and eggs are laid under rocks, in logs, and underground. All of the larval development occurs within the egg membranes, and the hatchling looks like a miniature adult. There is no aquatic phase. These animals seldom move more than a few meters on the forest floor their entire lives (Mitchell 2000). Thus, any alteration of the forest and local landscape can have significant impacts on these salamanders. The Shenandoah salamander, endemic to the park, is listed as federally endangered (USFWS 1994) and is highly restricted to three talus areas in the northern section of SHEN. Two non-protected species also occur in the park, red-backed salamander (*Plethodon cinereus*) and white spotted slimy salamander (*Plethodon cylindraceus*).

The status of terrestrial salamanders at SHEN is apparently secure. The forests in SHEN, although changing due to introduced species, remain sufficiently healthy to support these species. The endangered and endemic Shenandoah salamander is apparently limited in its distribution to three talus slopes by behavioral interactions with the more widespread red-backed salamander. A substantial amount of academic research, begun in the 1960s, has elucidated much of the interplay between them (e.g., Jaeger 1972; Wrobel et al. 1980; Griffis 1993).

Terrestrial salamanders play major roles in energy dynamics in forested ecosystems in SHEN and the Appalachian Mountains. Biomass of these amphibians exceeds that of birds and mammals (Burton and Likens 1975). The abundance of the species suggests major roles as predators and prey.

Threats: Acid precipitation can alter the pH of the forest floor and low pH may adversely affect terrestrial salamanders (Frisbie and Wyman 1991). An altered distribution in the forest would affect their availability as prey to a large number of predators in SHEN, so there may be a cascading effect. Changes in forest tree composition as a result of the gypsy moth and hemlock woolly adelgid may have affected these salamanders. Mortality by vehicles on Skyline Drive constitutes an unknown level of threat to these salamanders, which cross this road periodically.

Gaps in Knowledge: The life histories and population ecology of these species have not been studied in SHEN. Terrestrial salamanders, however, were monitored by ARMI at 24 plots from 1998-2004. Microdistribution patterns and survival of age groups within different forest types are unknown for all species, including the Shenandoah salamander. How these patterns and characteristics change among years is also unknown.

Suggested Management Recommendations:

- Initiate a population monitoring and life history study of the Shenandoah salamander to determine the status of each of the three isolates. Determine if their microdistributions change as climatic variables change over time.
- Work with the USFWS and qualified researchers to understand the long-term dynamics of the three Shenandoah salamander populations, their survival potential and population sizes and densities in relation to neighboring red-backed salamander populations.
- Understand the life histories and population characteristics of the other woodland salamanders in the park, especially survivorship of age groups among years and in different habitat types.
- Develop an understanding of the interactions these salamanders have with other animals in SHEN and identify how other species could be affected by declines in salamander populations.

<u>Reptiles</u>

With the exception of a few species of snakes, reptiles are not conspicuous species in SHEN. NPSpecies (2005) lists 27 species as being documented in the park and VA Gap (2005) predicts that 35 species of reptiles may occur in and around SHEN. Of the known species in the park, four are turtles, four are lizards, and 19 are snakes. None is recognized as endangered or threatened at the federal level and only one, the wood turtle (*Glyptemys insculpta*), which was recorded from near the park boundary, is listed as threatened at the state level. Two of the snakes in SHEN are venomous (timber rattlesnake [*Crotalus horridus*] and northern copperhead [*Agkistrodon contortrix mokasen*]), and most encounters between these snakes and visitors and park personnel occur along Skyline Drive and some trails. Bites are rare and when they do occur it is because the visitor or employee attempts to handle or manipulate the snake.

Turtles:

Current Status and Significance: The only turtle that occurs throughout SHEN is the eastern box turtle (*Terrapene carolina*). The wood turtle, a state-threatened species, may occur within the current SHEN boundary, but has not been recorded in the park (Mitchell 1994; Mitchell and Reay 1999). Other turtle species in this region of the mid-Atlantic are semi-aquatic and occur in ponds, lakes, streams, and rivers. Two of these species, the painted turtle (*Chrysemys picta*) and the snapping turtle (*Chelydra serpentina*), may enter the park via streams from populations outside the park. Juveniles of the latter have been found near SHEN (Mitchell, Univ. of Richmond, pers. comm., 2006).

Threats: Mortality by vehicles on Skyline Drive potentially is a major threat to box turtles and other turtle species that cross this road. Removal of individuals for pets is also a threat. The impact of these threats on populations in the park is unknown.

Gaps in Knowledge: Almost nothing is known about the turtle fauna in SHEN. A small radio-telemetry study is currently being conducted in SHEN by Will Brown (private citizen) on high-elevation box turtles. Canopy breaks in the form of treefalls and old cabin sites seem to be important habitat for the turtles, which have rather restricted home ranges with fidelity to specific summering and overwintering areas (W. Brown, pers. comm., 2005).

Suggested Management Recommendations:

- Obtain all known records of turtles in SHEN and conduct a systematic survey of streams and pond environments along the park's boundary.
- Develop a GIS model to map the distribution of all species.
- Assess the frequency and effects of road-killed turtles on Skyline Drive so that highly used sites can be posted with signs and other protective measures can be established.
- Conduct surveys to determine if the state-threatened wood turtle occurs in the park, and, if so, identify measures that can be put in place to protect this species.

Lizards:

Current Status and Significance: Lizards are rarely seen in SHEN. At least four species are known to occur within park boundaries (Witt 1993). These are: northern coal skink (*Eumeces anthracinus*), five-lined skink (*Eumeces fasciatus*), northern fence lizard (*Sceloporus undulates hyacinthinus*), and ground skink (*Scincella lateralis*). Most of the known locations are along the park's boundary and in the rock walls located along Skyline Drive. Little is known about these reptiles in SHEN.

The current status of this group of reptiles is unknown. Lizards are prey of several species of birds, mammals, and snakes. The ecological role they play in the park is unknown.

Threats: Threats to these reptiles are unknown.

Gaps in Knowledge: Except for data on a few locations of lizards, nothing is known of these species in SHEN.

Suggested Management Recommendations:

- Obtain all known records of lizards in SHEN and conduct a systematic survey along the park's boundary to gain a better understanding of their distribution within SHEN.
- Develop a GIS model to map the distribution of all species.

Snakes:

Current Status and Significance: Of the 19 known snake species in the park (NPSpecies 2006), two are venomous: timber rattlesnake and northern copperhead (Witt 1993). Both are occasionally encountered on Skyline Drive, on trails, and in campgrounds. No snake species in SHEN is listed by federal or state authorities, although the decline of the timber rattlesnake throughout the Northeast is of concern (Brown 1993). Two species known to occur in SHEN, the northern pine snake (*Pituophis melanoleucus*) and the smooth greensnake (*Opheodrys vernalis*), have apparently declined dramatically in the Appalachians due to habitat loss, mortality on roads, and killing by humans (Mitchell 1994). The pine snake is considered a species of special concern in Virginia.

There currently is no evidence that any snake species is declining dramatically in SHEN, but the status of the pine snake is unknown and of special interest to state authorities. Snakes are major predators of frogs, small mammals, and some species of birds. They are prey of hawks and some mammals. W. H. Martin (private citizen) has been conducting a mark-recapture study of timber rattlesnakes in several areas in SHEN for over 25 years. He has a wealth of information on den sites, snake ecology, and natural history, and would be a critical collaborator on all management conducted on behalf of this species.

Threats: Road mortality on Skyline Drive and incidental killing by visitors and some park personnel constitute the main threats to snakes from humans (Table 8). Most of the individuals collected along Skyline Drive were the large conspicuous species, such as rat snakes and copperheads Some individuals are undoubtedly removed for the pet trade, but the incidences and threat level are unknown. Ecological succession may be having a negative effect by closing open areas that are used for basking and birthing sites.

Table 8. Snake species killed along Skyline Drive and collected by park rangers in 1975, 1976, and 1983–1990.

Common name	Scientific name	Number
copperhead	*agkistrodon controtrix*	34
black racer	*coluber constrictor*	10
timber rattlesnake	*crotalus horridus*	74
northern ring-necked snake	*diadophis punctatus*	26
corn snake	*elaphe guttata*	2
eastern rat snake	*elaphe alleghaniensis*	39
eastern hog-nosed snake	*heterodon platirhinos*	1
eastern milk snake	*lampropeltis triangulum*	19
northern water snake	*nerodia sipedon*	3
rough green snake	*opheodrys aestivus*	1
smooth green snake	*opheodrys vernalis*	9
red-bellied snake	*storeria occipittomaculata*	2
northern garter snake	*thamnophis sirtalis*	18
total		238

Gaps in Knowledge: Except for the timber rattlesnake studied by W. H. Martin for over 25 years in SHEN (Martin 1992, 1993), there is almost no information on the population ecology, movement and seasonal dynamics, and life histories of the snakes in SHEN. Studies are needed on all species, especially the northern pine snake, a species of special concern in Virginia.

Suggested Management Recommendations:

- Obtain all known records of the snakes in SHEN and conduct a systematic survey along the park's boundary to gain a better understanding of their distribution within SHEN.
- Map all den sites of snake species and ensure that they are protected.
- Develop a GIS model to map the distribution of all species.
- Determine if any species that had been found in SHEN in earlier times have become extinct in the park.

- Work with W. H. Martin to ascertain the locations of all rattlesnake dens in SHEN, especially those near visitor areas. Ensure that their locations are kept secret due to their vulnerability to human presence.
- Ascertain the status of the canopy cover on all den and birthing sites in SHEN and conduct habitat management and restoration to ensure that these areas are able to support snake populations.
- Determine the current status and critical habitat of the northern pine snake in SHEN.
- Initiate studies of the ecology and life histories of all snake species possible in SHEN and identify their distinctive habitats in the park.
- Determine the current effect of traffic on Skyline Drive on timber rattlesnakes and other species in SHEN.

Terrestrial invertebrates

Current Status and Significance: Very little is known about the terrestrial invertebrates of SHEN. NPSpecies (2005) only lists 83 taxa (genera, species, or families) of insects and four spiders/scorpions as being from the park. Many of these 83 taxa are Lepidotera that are in a collection housed at SHEN headquarters outside of Luray, VA. VA Gap (2003) lists 107 species of insects as potentially being found in SHEN. Three species from in and around SHEN, the Appalachian grizzled skipper (*Pygrus wyandot*), the regal fritillary (*Speyeria idalia idalia*), and the Zorro clubtail (*Lanthus parvulus*) are species of special concern (VA Gap 2005).

Mahan et al. (2004) conducted the most extensive survey of terrestrial invertebrates at SHEN. Their surveys were conducted over a 4-day period in August 1997 at a hemlock (Limberlost) and a mixed deciduous forest stand (Matthews Arm). They collected 12,978 invertebrate specimens and identified 27% to the species or morphospecies level. All specimens were identified to the family level. The hemlock forest contained more individuals in the orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Psocoptera (book lice). However, the mixed deciduous forest had higher overall species diversity. Their study also documented one new state record (*Actogeophilus fulvus*) and a new Madison County record (*Stimamia bidens*) for centipedes collected at Limberlost. In addition, they documented a previously undescribed species in the order Homoptera and ten previously undescribed species in the order Diptera (Mahan et al. 2004).

As part of the ongoing Rock Outcrop Management Project, geologists from the Virginia Department of Conservation and Recreation collected invertebrates during summer 2005 and 2006 using sweep nets and light traps at 21 rock outcrops in the park. Identification of these specimens is ongoing.

Threats: Threats to terrestrial invertebrates include the application of pesticides by NPS personnel, concessioners, and adjacent landowners. In addition, invertebrates are potentially threatened as overstory forest tree species such as eastern hemlock decline and ecosystems dynamics are altered.

Gaps in Knowledge: Aside from the surveys conducted by Mahan et al. (2004) and ongoing work at rock outcrops, little to no research has been conducted on the terrestrial invertebrates found within SHEN.

Suggested Management Recommendations:

- Conduct parkwide, but habitat-specific, surveys for terrestrial invertebrates.
- Repeat the 1997 insect inventory at Limberlost to help understand how the hemlock woolly adelgid and resulting hemlock decline affected invertebrates at SHEN.

Fish

The cool mountain streams of SHEN support thirty-seven species of fish including one of the last protected habitats of the native eastern brook trout (NPSpecies 2006; Eastern Brook Trout Joint Venture 2005). The eastern brook trout populations are not only ecologically significant but they are culturally significant as their presence probably influenced the creation of SHEN. For example, President Hoover established his camp on the Rapidan River, in part, based on its access to good trout fishing. The primary threat to the fish of SHEN today is acidification of its waterways by acid deposition.

Brook Trout:

Current Status and Significance: The streams in SHEN offer one of the greatest concentrations of native brook trout in the eastern U.S., making native brook trout a nationally significant resource at the park (Vana-Miller and Weeks 2004; Eastern Brook Trout Joint Venture 2005). Eastern brook trout historically were a dietary component of Native Americans in the Blue Ridge Mountains, and early European settlers harvested brook trout from areas in and around the park (Atkinson 2003). Early park development and the Rapidan River Camp (Camp Hoover) established by President Hoover were predicated on the availability of good sport fishing for brook trout in the Blue Ridge Mountains of Virginia. Prior to the establishment of the park, however, many of the park streams had been abused by over-fishing and habitat alteration, and brook trout populations declined. For example, Brokenback Run was identified in 1936 as only a possible trout stream, but by 1941 it was considered a “good” trout stream, and by 1950 it became one of the most heavily fished streams in the park (Lennon 1961). To augment the natural population, park streams were stocked with hatchery-reared brook trout in the 1940s and 1950s (Lennon 1961).

Reflecting the importance of brook trout in SHEN, objectives of the park’s Fisheries Management Plan, finalized in 1997, were to preserve and perpetuate native brook trout as an integral component of the park’s aquatic ecosystems, and to allow for recreational fishing on those park streams that consistently produce adequate numbers of brook trout (NPS 1997). Trout harvest at SHEN is regulated by limits on creel size and trout size. Of the 50 streams in the park that contain brook trout, there are 22 open for harvest in the park. Two streams, Dry Run and One Mile Run, are currently closed to fishing because they have been designated as long-term inventory and monitoring areas.

The monitoring program for fish indicated that brook trout populations experienced a marked decline in 2003 due to the severe droughts of 2001 and 2002. However, more recent monitoring of brook trout numbers indicate that populations have improved from this population low (Atkinson 2005). LTEM fish monitoring also indicated that Lower Lewis Run in the South

District of SHEN experienced an apparent population collapse of brook trout in 2004, perhaps due to the effects of atmospheric acidification (Atkinson 2005).

An ongoing study to provide a complete genetic profile of the park's brook trout populations indicates that there is a high degree of genetic differentiation in trout among the three main drainages (the Shenandoah, Rappahannock, and James rivers) in SHEN (NPS 2005b). Although 50% of the brook trout of SHEN are native, a regional comparison of brook trout genetics indicates that fish from the Rappahannock River are genetically similar to southern Appalachian brook trout sampled from the Great Smoky Mountains (Comiskey et al. 2005). In addition, brook trout collected from Lower Lewis Run are genetically similar to northern strains of brook trout. This similarity indicates that native brook trout were extirpated from this stream and northern strains of stocked brook trout have replaced them (Deviney and Webb 2005).

Threats: Acid deposition and resulting decreases in the ANC of SHEN's streams, and corresponding increases in toxic aluminum, threaten brook trout. Bulger et al. (1999) and MacAvoy and Bulger (1995) found that mortality of early life stages of brook trout were higher in low-ANC streams. In addition, they found that brook trout density increased significantly and brook trout had higher body condition factors (a length/width relationship) with increasing ANC and pH.

Naturalized populations of brown (*Salmo trutta*) and rainbow trout (*Oncorhynchus mykiss*) are known from five of the 50 trout streams in the park. These nonnative trout have disrupted native brook trout population in streams where they coexist (Vana-Miller and Weeks 2004; Hudy et al. 2006).

The catastrophic flooding event of 1995 had the short-term effect of reducing and de-stabilizing brook trout populations in the Rapidan and Stauton rivers (Atkinson 2003). However, these brook trout populations are expected to stabilize with a recorded 40% recruitment rate. In contrast, severe droughts, as experienced in 2001–2002, are more common than significant floods and probably are a more important threat to brook trout populations (Atkinson 2003; Lennon 1961). Maintaining groundwater levels and recharge rates at springs and seeps is therefore critical in protecting brook trout populations in the park.

Although the effects of legal and illegal fishing pressure are difficult to quantify, illegal harvest should always be considered as a potential threat to the park's brook trout fishery (Atkinson 2003). Streams located along the park boundary are particularly susceptible to illegal trout harvest.

Salmonid whirling disease, caused by a parasite (*Myxobolus cerebralis*), has not been detected in the park but has the potential to negatively affect trout.

Finally, Hudy et al. (2006) found the percentage of human land use in a watershed was a useful predictor of brook trout distribution and status. Therefore, watersheds that contain brook trout must be protected from development and forest fragmentation. Once a watershed reaches 18% human land use, brook trout are at a greater threat of extirpation (Hudy et al. 2006).

Gaps in Knowledge: The effects of legal and illegal fishing pressure on brook trout populations are unknown.

Suggested Management Recommendations:

- Continue electrofishing to remove nonnative brown and rainbow trout from brook trout streams.
- Conduct periodic patrols of streams by park rangers along the boundary of SHEN to help protect brook trout from over-harvest.
- Maintain connectivity in stream channels to permit the reestablishment of brook trout populations after natural disturbances like floods and droughts.
- Examine the population dynamics of brook trout in fished versus unfished streams to ascertain the potential effects of recreational angling on this species.
- Work with landowners that surround the park to protect watersheds from extensive human development and fragmentation.

Other Fish:

Current Status and Significance: Compared to other groups of vertebrates, there has been substantial research on the fish communities at SHEN. Currently, NPSpecies (2005) lists 37 species (including one hybrid trout) of fish known from SHEN, and three of these, bluntnose minnow (*Pimephales notatus*), Potomac sculpin (*Cottus girardi*), and yellow bullhead (*Ameiurus natalis*), were first detected in the past two years by the fish monitoring program. The VA Gap project predicts that 47 species of fish could occur within a 4.8-km (3-mi) radius of SHEN, so more fish species may be detected in park streams in the future (VA Gap 2005). No fish currently found in SHEN are recognized as species of concern either federally or by the state. However, the American eel (*Anguilla rostrata*) is under status review for protection by the U.S. Endangered Species Act (USFWS 2005). Vana-Miller and Weeks (2004) provided a complete list of all fish species known from SHEN and their status within the park (i.e., native, nonnative, rare, and common).

SHEN initiated its fisheries monitoring program in 1982 to study the status and distribution of the fish community. Fish, therefore, have been monitored annually on park streams for over two decades. However, due to budgetary constraints, fish monitoring at SHEN has been reduced to a bi-annual effort beginning in 2005. Until 1994, fish monitoring at SHEN was primarily qualitative. In 1996, fish monitoring became more quantitative in an effort to detect trends in fish populations in the park’s streams. Despite this change, a statistical power analysis performed under the direction of Diefenbach (2001a) indicated that, due to high sampling and fish population variability, statistical trends in fish numbers could not be detected within individual park streams. A more thorough power analysis is needed to determine if statistically significant trends in fish populations can be detected across all park streams when combined (Diefenbach 2001a). For example, a sampling method suggested by Doroazio et al. (2005) may be appropriate at SHEN.

Mohn and Bugas (1979) provided baseline data on the fish in six park streams and found that streams on the eastern slopes contained higher trout and higher fish species diversity than streams on the western slopes due to greater invertebrate productivity, water flow, and pool formation. The SHEN fish monitoring program also documents that streams on the eastern slopes of the park are more diverse than on the western slopes. For example, based on data collected in since 2000, the number of fish species in east slope streams ranges from 1–22 with a mean of 9.6 species. For the west slope streams, the number of species ranges from 1–19 with a mean of 6.8 species

Since 2000, the most common species within SHEN is the brook trout (encountered 94% of the time during surveys), followed by blacknose dace (*Rhinichthys atratulus*) (encountered 92% of the time during surveys), longnose dace (*Rhinichthys cataractae*) (encountered 57% of the time), rosyside dace (*Clinostomus funduloides*) (encountered 55% of the time), and mottled sculpin (*Cottus bairdii*) (encountered 47% of the time). Species that are only encountered rarely (encountered less than 4% of the time during surveys) in the park are satinfin shiner (*Cyprinella analostana*), carp (*Cyprinus carpio*), largemouth bass (*Micropterus salmoides*), redbreast sunfish (*Lepomis auritus*), greenside darter (*Etheostoma blennioides*), Johnny darter (*Etheostoma nigrum*), and Potomac sculpin. All populations of fish, regardless of species, are dynamic in the park (experience year to year population fluctuations) due to variations in water flow, acidity, and recruitment rates (Atkinson 2003, 2005).

A study to determine the distribution, abundance, and variability of mercury in fish within SHEN was initiated in 2004. This study will provide park managers with data to evaluate the potential human-health effects of consuming fish from SHEN, determine the potential for acute or chronic problems with mercury accumulation and toxicity in fish populations, and determine the factors affecting the bioavailability of mercury in mountain streams. To date, 512 fish, including seven fish species, from 17 park streams have been sampled for mercury. The final results will be available in 2006 or 2007 (Snyder et al. 2003).

Threats: Acidification of SHEN's streams threatens to reduce fish species richness by eliminating acid-sensitive species from fish communities. A variety of projects, including VTSSS, have enabled researchers to better understand the response of fish to acidification in SHEN. There is a strong correlation between fish species richness and ANC in park streams (Bulger et al. 1995, 1999). In general, low-ANC (annual ANC from 0–20 μeq/L) streams host fewer species than high-ANC streams (>50 μeq/L). Examples of fish species that may be lost from low-ANC streams are: longnose dace, mottled sculpin, northern hog sucker (*Hypentelium nigricans*), central stoneroller (*Campostoma anomalum*), river chub (*Nocomis micropogon*), and rosyside dace (Bulger et al. 1999). Even relatively acid-tolerant fish like the blacknose dace are being affected by acidification at SHEN. For example, Meadow Run, the most acidified stream within the park (average annual pH <5.5), still supports blacknose dace populations, but at extremely low densities (Atkinson 2003). Blacknose dace found in low-ANC streams had the lowest average weights and lowest condition factors, and dace densities appear limited by acidification stress (Bulger et al. 1995, 1999). ANC and SO_4^{2-} concentrations (derived from acid deposition) explained 84% of the variance in condition factors (e.g., length and weight) in blacknose dace populations at SHEN (Dennis and Bulger 1995). In addition, mean whole-body sodium concentrations in dace were highest in low-ANC streams (Dennis and Bulger 1995). Blacknose dace may maintain high body-sodium concentrations in low-ANC streams to provide a buffer against large episodic pH depressions (Dennis and Bulger 1995). Furthermore, laboratory studies show that fish species such as blacknose dace and brook trout behaviorally avoid water when pH was reduced from 7.5 to 5.1 (Newman and Dolloff 1995).

Aside from the effects of stream acidity, the principle short-term natural factors that have the most pronounced effect on the fishery resources of SHEN are drought and flood events (Lennon

1961; Atkinson 2003). High floods that occur during spawning can disrupt juvenile recruitment rates, while severe droughts result in high fish mortality rates.

As part of the fish monitoring program at SHEN, fish are tested for the presence of the following fish pathogens: enteric redmouth disease caused by bacteria (*Yersinia ruckeri*), bacterial kidney disease caused by bacteria (*Renibacterium salmoninarum*), infectious pancreatic necrosis caused by a virus, and salmonid whirling disease caused by a parasite.

Gaps in Knowledge: Although fish data have been collected as part of the monitoring program at SHEN, the ability of the sampling design to detect statistically relevant trends in population and species richness is unknown. Therefore, the minimum threshold of change detection in fish populations in SHEN's streams is unknown.

Because stream acidification will be a long-term problem at SHEN, a better understanding of the sublethal effects of acidification on fish assemblages is needed. The sublethal and lethal effects of acidification on brook trout and blacknose dace have been studied (Bulger et al. 1999), but the effects on multi-species fish communities are unknown.

Suggested Management Recommendations:

- Conduct a trends analysis on the fish monitoring data that examines population trends in all park streams (after Dorazio et al. 2005). In addition, detailed, statistically relevant sampling objectives need to be generated to evaluate the power of the monitoring program.
- Incorporate biological indicators, including multi-species fish assemblages into the SWAS program in order to better understand the lethal and sublethal effects of acidification on aquatic organisms.
- Maintain connectivity in stream channels in order to permit the reestablishment of fish populations after natural disturbances like floods and droughts.

<u>Aquatic Invertebrates</u>

Current Status and Significance: Aquatic insects, crayfish, molluscs, and a variety of aquatic worms are important components of aquatic environments in SHEN. There are approximately 240 species of aquatic macroinvertebrates known from SHEN, although they currently are not all included in NPSpecies (Vana-Miller and Weeks 2004; NPSpecies 2005).

Stream benthic macroinvertebrates have been inventoried and monitored on certain park streams since 1986 as part of the Long Term Ecological Monitoring (LTEM) program at SHEN (Sullivan et al. 2003b). Seventeen sites on 11 streams have been continually sampled during the past two decades. In 1995, SHEN expanded its sampling effort of macroinvertebrates with the goal of sampling every permanent stream within park boundaries at least one time (Vana-Miller and Weeks 2004).

Moeykins and Voshell (2002) demonstrated that most streams in SHEN contained macroinvertebrate assemblages that represent the best condition of streams in the Blue Ridge Mountains. Based on their work, fire, floods, past land use history, and recreation do not appear to have noticeable long-term effects on macroinvertebrate assemblages in the park. However, streams with low ANC (primarily those found in the siliciclastic bedrock type) contain macroinvertebrate assemblages with lower species richness than streams with high ANC (Moeykins and Voshell 2002). These low-ANC streams may now possess less diverse macroinvertebrate communities than were present in pre-industrial times at SHEN due to the effects of acid deposition (Vana-Miller and Weeks 2004).

The aquatic insects are the most well-studied group of aquatic macroinvertebrate at SHEN. In particular, the Insect Orders of Ephemeroptera (mayflies), Trichoptera (caddisflies), and Plecoptera (stoneflies) are frequently encountered and numerous in the park's streams (Sullivan et al. 2003b). Sullivan et al. (2003b) found more insect families in streams with high ANC. This correlation was especially true for families in the Orders Ephmeratoptera and Trichopetera, indicating that the stream macroinvertebrates at SHEN may be adversely affected by acid deposition in the park. In addition, Feldman and Conner (1992) found a greater abundance and richness of mayfly species in streams with higher ANC.

Johnson and Snyder (2002) found that macroinvertebrate communities were relatively insensitive indicators of biological responses to the flood of 1995. However, flood and associated debris flows did affect production within and among trophic groups of macroinvertebrates (Karish et al. 1997). For example, in the Staunton River, which was severely flood impacted in 1995, macroinvertebrates that feed on leafy material (shredders) declined due to the loss of riparian plant cover. The corresponding increases in light-enhanced algal growth and macroinvertebrates that feed on algae (scrapers) also increased in the river. At the same time, caddisflies and mayflies that are classified as grazers and filter feeders increased in the Staunton River, probably due to increased light reaching the stream. As the Staunton River recovers and is re-vegetated, the macroinvertebrate community will eventually revert to being dominated by shredders.

Voshell and Marshall (1994) detected only subtle changes in macroinvertebrate community structure in watersheds that were defoliated by the gypsy moth caterpillar. However, streams located in defoliated watersheds contained aquatic insect populations that had increased production, probably due to increased terrestrial organic pulses of nitrogen (Voshell and Marshall 1994).

Threats: Acid deposition threatens the diversity of stream macroinvertebrate assemblages at SHEN. In addition, loss of eastern hemlocks may alter macroinvertebrate assemblages in streams that drain former hemlock stands (Snyder et al. 2002).

Gaps in Knowledge: Although macroinvertebrate data have been collected as part of the monitoring program at SHEN, the ability of the sampling design to detect statistically relevant trends in population and species richness is unknown.

Suggested Management Recommendations:

- Conduct a trends analysis on the macroinvertebrate monitoring data. In addition, detailed, statistically relevant sampling objectives need to be generated to evaluate the power of the monitoring program.

- Incorporate biological indicators, including macroinvertebrates, into the SWAS program in order to better understand the lethal and sublethal effects of acidification on aquatic organisms.

Recreational Impacts to Natural Resources at Shenandoah National Park (Including Skyline Drive)

Recreation is a critical consideration in the assessment of natural resources at SHEN. Recreation is often cited as a central purpose for creating and managing our national parks, but recreational activities can inevitably change the parks and may endanger the other goal of resource protection (Williams and Marion 1995). Approximately two million people visit SHEN annually, with visitation peaking in July and October (Bair 1998). In SHEN, day hiking, backcountry camping, campground use, horseback riding, rock climbing, and fishing are commonly occurring recreational activities that potentially affect natural resources. In addition, driving along park roads (e.g, Skyline Drive) may be considered a recreational activity. The effects of driving (e.g., wildlife roadkills) and the ecological effect of roads (e.g., forest fragmentation) may adversely impact natural resources in the park. Furthermore, maintenance activities associated with Skyline Drive, including road repair and roadsalt application, may have adverse effects on natural resources in the park. Automobile pollutants, including contribution to ozone formation, are concentrated along Skyline Drive. Overall, however, SHEN is resistant to long-term recreational impacts due to a moderate climate with ample rainfall and a long growing season that produces vigorous plant communities with good regenerative qualities. However, intense or poorly planned recreational use could exceed the natural ability of natural resources to resist or recover in the park (Bair 1998).

Trail Use

Day use activities accounted for 98% of visitor use in 2002. Examples of specific day-use activities include driving Skyline Drive with stops at scenic overlooks, day hiking, fishing, rock climbing, and horseback riding. With over 800 km (500 mi) of hiking trails, day hiking is probably the most popular off-Skyline Drive activity, and most visitors (71%) visiting SHEN found hiking to be a very important part of their visit (Reid and Teer 1989). Most park trails can be accessed from Skyline Drive, but many visitors also access trails from the park boundary (Bair 1998).

A variety of natural resource impacts are associated with hiking trails. For example, soil erosion and vegetation loss on and around hiking trails is a persistent problem at SHEN (Jewell 2001). In addition, the development, deterioration, and proliferation of visitor-created informal trails, widening of existing trails, root and rock exposure, soil compaction, and spread of nonnative vegetation along trails adversely affect vegetation and contribute to soil erosion at SHEN (Jewell 2001). Without proper trail maintenance, soil erosion may alter natural patterns of water runoff and cause turbidity and soil deposition in streams and other water bodies (Marion et al. 1993; Hammitt and Cole 1998). While some visitor impacts to trails are unavoidable, excessive trail impacts threaten the safety of trail users, the quality of recreational experiences, and natural resource quality (Jewell 2001). Jewell (2001) examined 69.43 km (43.14 mi) or 10.8% of SHEN's formal hiking trail system, including portions of the Appalachian Trail. His findings indicate that the trails at SHEN are in good condition with an average trail width of 65.3 cm (25.7 in) and a grade of 10%. However, he also estimated that an average of 8.9 cm (3.5 in) of soil has been eroded from the tread surface since the trails were constructed. In addition, the trails most heavily used by hikers were 22.6 cm (8.9 in) wider, had 1.4% more informal trails, 11.1% more exposed soil, and 14.3% less organic litter cover, and were incised by 6.1 cm (2.4 in) more than trails in less accessible (less used) portions of SHEN.

One of the most popular and well-known hiking trails in SHEN is the Appalachian Trail (AT). Approximately 150 km (95 mi) of the AT are located within SHEN. Despite its popularity, the AT is in very good condition according to Jewell (2001). For example, the average trail width of the AT is 61 cm vs. 65.3 cm (24 in [vs. 25.7 in]) for all trails combined. In addition, the AT was 40% less incised than other hiking trails in SHEN. The above-average condition of the AT in SHEN is, in part, due to the “single file” style of hiking that this linear trail promotes (Jewell 2001). In addition, the AT receives more trail maintenance than other park trails due to the efforts of the Potomac Appalachian Trail Club.

Although many of the formal hiking trails in SHEN are in good condition, recent studies indicate that day hikers may be negatively affecting soil, plant, and animal resources on and around cliffs and rock outcrops in the park. Cliff and rock outcrops afford hikers with scenic vistas and are often popular destinations of day hikers (NPS, Marion, pers. comm., 2005). Almost all (88%) cliffs and rock outcrops examined for visitor impacts in 2005 contained informal, visitor-created trails, and most recreational impacts occurred at the tops of cliffs, suggesting their use as scenic overlooks by hikers (Marion 2005b). The informal, visitor-created trails that threaten sensitive resources should generally be closed or rehabilitated. In many instances, this rehabilitation may include realigning popular, formal trails away from cliff or rock outcrops. Marion (2005a) outlines several techniques for managing and rehabilitating these informal, visitor-created trail networks.

A thorough investigation of hiking trails at SHEN using well-established assessment techniques (Jewell and Hammitt 2000) may indicate areas where maintenance of formal trails can be improved and where visitor-created trails can be rehabilitated. For example, Jewell (2001) recommends that a comprehensive evaluation of the park’s trail system be conducted, beginning with the resource capabilities and deficiencies of trails to support appropriate types and amounts of use. A variety of other factors, including intended purposes, linkages, existing tread conditions, elevation gain/loss, scenic attractions, and sensitive natural or historic sites, could also be evaluated. In addition, surveys of trail users should be conducted to identify trail maintenance needs, direct on-the-ground maintenance activities, set priorities for apportion funding and staffing among park districts, and justify budget and staffing initiatives for additional trail management activities (Jewell 2001). Raphael (1982) provided a hiking trail system model for the Central District of SHEN. It is unclear whether the proposed system was completely implemented.

Almost 320 km (200 mi) of designated horse trails and administrative roads are available for horse and pack animal use in SHEN (Bair 1998). Currently, horse use on trails in SHEN is relatively low, but may be increasing (Bair 1998). Several studies have demonstrated that horse trails have a more negative impact on natural resources than hiking trails (Nagey and Scotter 1974; Weaver and Dale 1978; Whittaker 1978). For instance, Whittaker (1978) found vegetation cover on horse trails to be churned-up and often cut off at the roots, instead of flattened as on hiking trails. Furthermore, horse hoofs tend to dig up and puncture the soil surface, making horse trails more prone to erosion (McQuaid-Cook 1978). Wilson and Seney (1994) found that the erosional impacts from horses were greater than those from hikers, off-road bicycles, and motorcycles. Due to these effects, caution should be used when considering placement and design of trails that may be used by horses. Biking can also cause vegetation loss, widening, and erosion on trails, but their use in SHEN is prohibited. However, bicyclists often enter SHEN from the park boundary (Bair 1998).

Camping

Most visitors to SHEN view the backcountry as a day-use area, but the park does receive substantial overnight backcountry use (Bair 1998). Backcountry recreation is leisure activity occurring in largely natural, undeveloped, and protected areas or wildlands (Hammitt and Cole 1998). Backcountry overnight visitation in SHEN amounted to 39,960 nights in 2002, representing a 9% decline since 1999 when backcountry overnight visitation was 43,913 nights (Reid and Marion 2004). Backcountry overnight use of natural areas has been declining in SHEN since the 1970s. Despite this decline, SHEN has one of the highest backcountry overnight use densities in the national park system. Thus, a backcountry management plan and program are critical to achieving a balance between park resource protection and recreation provision objectives (Bair 1998; Reid and Marion 2004). Primitive camping is permitted in the backcountry of SHEN by obtaining a free backcountry camping permit. Backcountry primitive camping can negatively affect natural resources, including loss of vegetation, erosion of organic litter, soil exposure, erosion and compaction, exposure of tree roots, and damage to tree trunks (Cole and Marion 1988; Marion and Haskell 1988). In addition, littering and human waste potentially threaten water quality and human health, and may lead to visitor dissatisfaction (Williams and Marion 1995). Furthermore, food and trash storage may attract wildlife and contribute to bear and other wildlife/human interactions in the park.

SHEN originally allowed at-large camping in which visitors could camp anywhere in backcountry areas (Marion and Haskell 1988). In 1972, increased impacts to natural resources prompted resource managers to restrict backcountry camping to 39 locations. By 1974, continued natural resource and social condition degradation at many of these locations led to the adoption of a dispersed camping policy that directed visitors to camp more than 7.6 m (25 ft) from water and out of sight of other trails and other campers and forego campfires (Marion and Haskell 1988). This dispersal policy resulted in the creation of approximately 1,100 campsites by 1983 (Marion and Haskell 1988). However, declining visitation and a park closure and rehabilitation of non-approved campsites reduced the number of campsites to 725 by 1994 (Reid and Marion 2004). Williams and Marion (1995) conducted a comprehensive study and assessment of these remaining backcountry campsites in SHEN and found that they were in good condition with minimal natural resource impacts. For example, 22% of campsites were barely distinguishable and 46% had minimal loss of vegetation, limited exposure and disturbance of organic litter, and no exposure of soil. Another 23% had experienced substantial loss of vegetation and organic litter with exposed soil occurring in the center of the campsite. Only 10% of the campsites had lost most of their vegetation and organic litter cover and exhibit widespread soil exposure (Williams and Marion 1995).

Although these campsites minimally affected natural resources, 68% of them violated the park's camping regulations. Therefore, in 2000, SHEN managers revised their backcountry camping policy and asked visitors to use only well-established campsites in most areas of the backcountry, with designated campsites created near shelters for Appalachian Trail hikers (Reid and Marion 2004). This containment strategy resulted in a reduction in campsite numbers and in the total area of camping disturbance in the park (Reid and Marion 2004). Despite increased visitation at the limited number of established campsites, mean campsite size, area of vegetation loss, and area of exposed soil did not increase significantly (Reid and Marion 2004). Campsite conditions, however, should continually be monitored to ensure that natural resource impacts do not increase significantly. Campsite monitoring following established procedures (Williams and Marion 1995; Reid and Marion 2004) is critical as SHEN implements a Limits-of-Acceptable-Change (LAC) planning and management framework (Stankey et al 1985). Monitoring provides periodic data on campsite conditions for comparison to indicator standards of quality that define minimally acceptable conditions. If standards are violated, then campsite management actions must be identified and implemented. For example, posting "No camping" signs and the placement of natural barriers on non-approved campsites and access trails have been effective in permitting campsites to recover at SHEN (Marion and Haskell 1988).

Aside from backcountry camping, camping also occurs at SHEN in car-accessible campgrounds within the park. These campgrounds include Matthews Arm, Big Meadows, Lewis Mountain, and Loft Mountain, which have similar trampling-related impacts to natural resources within and around the campgrounds. In addition, three of the campgrounds have recreational-vehicle dump stations that must be properly maintained so that sewage does enter groundwater or pollute neighboring water bodies. Furthermore, drainage ditches were constructed in the Big Meadows campground to drain water away from campsites located in the wetland. These drainage ditches may facilitate the movement of pollution (e.g., sewage, garbage, parking lot oil, and sediments) to the Big Meadows wetland and, ultimately, the surface water outlet at Hogcamp Branch or the groundwater outlet at Davids Spring.

Rock Climbing

Recreational rock climbing first occurred in SHEN in the late 1930s (Bair 1998). Rock climbing still occurs in SHEN, but primarily is concentrated at two locations within the park: Little Stony Man Cliffs and Old Rag Mountain (Bair 1998; Marion 2005b). Although rock climbing is not widespread in the park, this activity potentially affects the cliff and rock outcrops of SHEN which are some of the largest in the region and support rare animal and plant communities (Ludwig et al. 1993). Rock climbing is not regulated in the park and has several potential effects on these natural resources (Hilke 2002). These effects include (Bair 1998; Hilke 2002):

- Vegetation loss and soil erosion and compaction at the top and bottom of cliffs.
- Informal, visitor-created trails to climbing areas that impact sensitive or critical habitat for plant and animal species.
- The potential for gymnastic chalk used by climbers to change the chemical balance of soils and impact micro flora and fauna.
- Clearing of dirt, small plants, and lichens from natural cracks in rock faces.
- Alteration of cliff rock by motorized drills, chisels, hammers, and glue.

A cliff management project was initiated at SHEN in 2005 to determine the effects of rock climbing (and other recreational activities) to natural resources associated with cliffs and rock outcrops at SHEN. This 3-year project will assess biological and geological resources and visitor impact and use of cliffs in SHEN. Preliminary results from the recreational impacts' portion of the cliff project indicate that most site impacts were due to day hikers and campers and impacts from rock climbing primarily were limited to cliffs at Little Stony Man Cliffs and Old Rag Mountain (Marion 2005b). The cliff management project will culminate in the development and implementation of a Cliff Management Plan that will direct management, mitigation, monitoring, and restoration efforts at cliff sites in the park. Such a plan should include outreach, climber education, and partnering with climber organizations to help limit the effects of rock climbing to natural resources of SHEN.

Fishing

SHEN's numerous mountain streams provide some of Virginia's finest native brook trout fishing (Bair 1998). Catch-and-release fishing is permitted parkwide, except for two streams designated as "closed to fishing". Twenty-two streams are designated as "regulated open for harvest fishing," from which fish may be kept subject to size and creel limitations (Bair 1998). Visitor-created hiking trails occur along popular fishing streams, and these trails and nearby campsites may contribute to sedimentation of streams in SHEN. Due to strict fishing restrictions that prohibit the use of live bait, the inadvertent introduction of nonnative bait species is not a problem at SHEN, as it is in other national parks.

Other Recreational Activities

Hang gliding and cross-country skiing are other recreational activities that occur in SHEN. However, their effects on natural resources are negligible. Hang gliding occurs at designated launch sites, requires a park-issued permit, and is an activity that occurs infrequently (Bair 1998). The effects of cross-country skiing on natural resources are limited due to the buffering effects of snow cover.

Collecting of seasonal forage for personal consumption may be considered another recreational activity in SHEN. Morel mushroom collecting during April/May is fairly popular, but the effects of this collecting on fungi populations in the park are unknown. Furthermore, medicinal plants such as American ginseng, black cohosh, and bloodroot are collected illegally in the park. The effects of collecting on plant populations are not entirely known, but the frequency of small size-classes of ginseng in the park indicate that plant poaching is having some negative effect on populations (Cass 2005).

Conclusions

SHEN supports a variety of natural resources that are intrinsically significant to the park. The globally significant natural resources found in SHEN include species and communities that can be seen nowhere else in the world. The High-Elevation Greenstone Barren plant alliance and the federally endangered Shenandoah salamander are endemic to the park and are globally-rare. Big Meadows contains a globally-rare wetland plant alliance, the Northern Blue Ridge Mafic Fen, that also is endemic to the park and is, perhaps, the only place in the country where a high-elevation grassland/shrub community has persisted for approximately 10,000 years.

Despite a history of disturbance, SHEN represents one of the nation's most diverse botanical reserves and is an outstanding example of the Northern Blue Ridge Forest, a globally significant resource (Braun 1950; NPS 1998). The federally endangered small whorled pogonia is found in this forest expanse. An abundance and diversity of breeding neotropical migratory birds also contribute to SHEN's globally significant natural resources. In addition, SHEN is one of the few places in the country where peregrine falcons can be observed nesting in their natural habitat. The native brook trout that inhabit the high-elevation streams also can be considered nationally significant, as they have been pursued by presidents and other leaders of our country, and SHEN still contains healthy populations of this fish that has declined dramatically throughout its range. Aside from providing valued fish habitat, the streams of SHEN form the cold, clear headwaters of three major river systems.

Regionally significant resources of the park are an abundance of black bears that may serve as a source population for the Blue Ridge Mountains; an abundance and diversity of streamside salamanders; and the presence of a variety of state plant and animal species of special concern that contribute to the local and state significance of the park.

The combination of high elevation, ancient geology, topographic variation, and natural- and human-caused disturbance regimes shaped the pre-European natural resource condition at SHEN. This historic condition consisted of large expanses of American chestnut and mixed-oak forests interspersed with stands of old-growth mesic forests and smaller barren, pine, hemlock, and riparian forest components. Early successional habitat consisted of forest openings created by periodic disturbances such as natural and native American caused fire, frequent ice storms, and periodic flood and hurricane disturbances.

European settlement, associated land clearing, limited industrialization, and introduced pests and pathogens completely transformed this landscape in the early- to mid-20th century so that today the large expanses of American chestnut are completely missing from SHEN's forests and even oak-hickory forests may be declining. Ecological succession has re-forested the northern Blue Ridge Mountains and many of the park's inherently significant resources, including diverse avian, salamander, and, floral communities, continue to thrive. For example, Big Meadows still supports wetland plant communities, provides breeding ground for amphibians, and contains populations of wetland birds, as it did for perhaps the last 10,000 years. A variety of rock outcrop communities support globally rare plant communities and provide opportunities for geologic study. Despite adverse effects by decades of acid deposition, the high-elevation streams at SHEN still support native fish communities in their pools and riffles.

Most of the threats to SHEN's natural resources are generated outside the park. For instance, nonnative insects such as the gypsy moth and the hemlock woolly adelgid threaten oak and hemlock forest communities, respectively. Hemlocks are all but extirpated from the park and the ecosystem effects of this loss are not well understood. Other nonnative pathogens such as dogwood anthracnose and beech bark disease further threaten the park's native trees. Herbaceous plants are most threatened by competition from nonnative plants, especially the invasive garlic mustard and nonnative honeysuckles. Acid deposition and ground-level ozone degrade water quality and affect the regionally significant scenic vistas that occur along the entire length of Skyline Drive. Finally, encroaching land development threatens the park's dark night skies and the expanse of its continuous forest matrix.

The nature of these threats requires natural resource managers at SHEN to cooperate with local, regional, and national officials and communities. For example, NPS resource managers and administrators need to work with state officials on their State Implementation Plans for air quality that must be submitted to the EPA. These plans will calculate the rate of progress needed to achieve specified attainment goals for each Class I air quality area in the country. In addition, natural resource managers should actively support Clean Air Act amendments that further reduce sulfate deposition in order to prevent further acidification in streams at SHEN. Specifically, for most streams to recover in the park, sulfate deposition should be reduced below 5 kg/ha/year, 40% of the current deposition amount.

Finally, the park must continue to steward its resources from within its boundaries. Recreational and cultural use of the park can be entirely compatible with good natural resource conservation. Proper planning will ensure that the intrinsically significant natural resources of SHEN are protected. For example, development in the park should be planned to minimize fragmentation of all large forest blocks and Wilderness Areas. An assessment of lighting within the park would determine the park's contribution to impairment of dark night skies, and the change to using high-efficiency, low-emissions vehicles sets an example of good resource stewardship.

Natural resource protection and stewardship will enable SHEN to remain an outstanding biological reserve for the next 80 years and beyond. In order to assist in the stewardship of this outstanding park, the findings of this natural resource assessment were used to generate a "report card" of natural resource condisions (Table 9). By providing a concise, color-coded overview of resource conditions, park managers may be better able to set conservation goals and prioritize management actions for SHEN.

Table 9. Status and trends in conditions of natural resources for Shenandoah National Park, Virginia. Trends reflect assessment of conditions over the past 10 years.

Air/Visability/Sound	Geology and Soil	Water	Plants	Terrestrial Vertebrates	Fish	Aquatic Invertebrates	Terrestrial Invertebrates
↔	↓	↔	↓	↔	↔	↔	**?**

Status	
	Significant concern
	Caution: may be a developing concern
	Good: resource in good condition
	Status unknown

Trend	
↑	Increasing
↔	Stable
↓	Declining
?	Unknown

Resource	Status	Trend	Evidence
Air Resources (overall)	Significant concern	Stable	
Ground-level ozone air pollutant levels	Significant concern	Declining; slight reduction in ground-level ozone over the past 10 years	SHEN is a Class 1 park and therefore is afforded the greatest degree of air quality protection under the Clean Air Act. However, air quality is of significant concern in the park. Based upon the SUM06 index, ozone concentrations averaged 46.9 ppm/hr during May–September 1990–2000. While there is no National Ambient Air Quality Standard (NAAQS) for SUM06, 46.9 ppm/hr far exceeds concentrations most experts believe can harm sensitive vegetation, i.e., 10–15 ppm/hr. Furthermore, there were periodic events when the ground-level ozone at Big Meadows exceeded the daily maximum NAAQS for ozone of 85 ppb. For example, an analysis of the Big Meadows monitoring data showed that the number of times per year daily maximum 8-hour ozone concentrations exceeded 85 ppb were 6, 22, and 15, respectively, during 1997, 1998, and 1999. SHEN has among the highest concentration of ground-level ozone of all national parks monitored, and in 2004 a portion of the park was designated by the state of Virginia and the EPA as a non-attainment area for ozone. However, in 2005, the park was re-designated as an attainment area of the ozone standard due to monitoring data showing improvement in ozone levels since 2002.
Acid deposition-sulfate and nitrate pollution	Significant concern	Declining; slight reduction in acid deposition over the past 10 years	Compared with other locations in the eastern United States, SHEN receives relatively high wet deposition of sulfate and moderately high wet deposition of nitrate. Among Class I national parks, SHEN and Great Smoky Mountains National Parks receive the highest sulfate and nitrate deposition—making acid deposition one of the greatest environmental problems facing the park. Over the approximately 20-year monitoring period at Big Meadows, wet deposition of sulfur averaged 6.7 kg/ha/year and total wet deposition of nitrogen averaged 4.6 kg/ha/year. Dry deposition of sulfur and nitrogen averaged 4.9 kg/ha/yr and 3.2 kg/ha/yr, respectively, at Big Meadows during the period 1991–1998. Despite high year-to-year variability, wet deposition of sulfate and nitrate has generally declined at SHEN, especially in the last five years. For example, statistically significant declines in SO_4^{2-} and NO^{3-} were recorded at SHEN from 1980–1993.
$PM_{2.5}$ - Fine mass particulate matter air pollutant levels	Caution	Increasing; fine mass particulates exceeds natural reference conditions	Fine mass particulate matter averaged 10.5 µg/m^3/yr at Big Meadows during the 12-year period of 1988–2000. Chemical components of the fine mass particulates included ammonium sulfate, ammonium nitrate, organics, light absorbing carbon, and fine soil. Current levels of fine mass particulate matter and its chemical components are five times greater than natural background (reference) conditions. The highest fine mass particulate concentration occurred during summer and most of the contribution was from ammonia sulfate.

Visibility	Significant concern	Declining; visibility is only 20% of natural visual range	The scenic vistas of the Shenandoah Valley and the Virginia Piedmont provided justification of park establishment and are, therefore, nationally significant. SHEN's estimated natural (background) visual range is approximately 185 km (115 mi). Visibility in the park has been severely degraded so that today the annual standard visible range (SVR) at SHEN averages 36.8 km (23 mi [only 20% of the park's natural visual range]). During summer, SVR decreases to an average of 20 km (12 mi), and increases to an average of 64 km (40 mi) during winter.
Dark night skies	Unknown	Unknown	The visual environment of dark night skies has not been studied at the park. However, the NPS is obligated to preserve, to the greatest extent possible, the natural landscape and dark night skies of parks, which are natural resources and values that exist in the absence of human-caused light. Aside from affecting the visibility of night skies, recent studies indicate that light pollution may adversely affect water quality, salamander foraging, bird migration, and turtle breeding.
Natural sounds	Unknown	Unknown	No research on the natural soundscape of SHEN has been conducted. However, noise from construction practices, traffic, and human aggregation all are potential threats to the natural sounds of SHEN.

Resource	Status	Trend	Evidence
Geologic Resources (overall)	Cautin	Declining	
Bedrock geology	Caution	Unknown	The Catoctin Formation rock type that is found at SHEN is one of the few places in the mid-Atlantic were volcanic rocks are found at the surface. These bedrock outcrops are numerous throughout the park; however, those present at overlooks along Skyline Drive and along hiking trails have the potential for overuse, including erosion created from repeated foot traffic and rock climbing. Vandalism is a problem in nearly all national parks, and graffiti is one of the larger threats that could impact the natural character of rock outcrops. Additionally, open fires constructed beneath rock ledges blacken the outcrops and pose an additional threat to interpreting the rock history.
Soils	Caution	Declining	Due to the steep slopes of the Blue Ridge Mountains and periodic flood disturbance regimes the soils at SHEN have severe erosion potential. In addition, soils that form from the siliciclastic rock type are adversely affected by acid deposition.
Surficial deposits	Caution	Unknown	Many locations throughout the park have boulders that are detached from bedrock outcrops and are perched or balanced in a quasi stable state. These locations have a high potential for dangerous rockfalls; particularly high foot traffic areas (Old Rag, Black Rock, and Bear Church Rock) have the greatest potential for hazards to park visitors. The flood of 1995 demonstrated the force of water and rock on the landscape within the park. The Rapidan River region received up to 76.2 cm (30 in) of rainfall in less than a day, resulting in numerous landslides and flooding of the Rapidan, Robinson, and Conway rivers and their tributaries. The park should consider these threats from surficial deposits when planning for future backcountry campsites or other permanent activities that may occur in the eastern flank lowlands. Although the probability of having additional debris flows in the affected basins in the near future is small, other areas of the park still remain at risk. Finally, the scoured tributaries impacted by the debris flows lack the capacity to slowly store and transmit rainwaters due to the full removal of the soils and rubble from the channels via the debris flows. These sediments act as a sponge; thereby, slowly releasing the captured rain water during precipitation events. This problem will continue until the impacted stream channels revegetate and develop the soil mantle.

Resource	Status	Trend	Evidence
Water Resources (overall)	Significant concern	Stable	
Streams	Significant concern	Increasing; slight improvement last 10 years	The clear and cold mountain streams of SHEN form the headwaters for three major rivers and contain nationally significant populations of native brook trout. Acid deposition, caused by sulfate and nitrate pollutants, is the major threat to water quality of SHEN's streams. Western and central Virginia consistently receive among the highest level of sulfate (acid-causing) deposition in the United States. SHEN, located in the northern region of the Blue Ridge Mountains, has the greatest known loading of sulfate of any national park in the U.S. Despite this threat, there may be some regional recovery occurring in SHEN streams. A variety of long-term studies conducted at SHEN, including the Shenandoah Watershed Study (SWAS), the Virginia Trout Stream Sensitivity Survey (VTSSS), and individual research projects, document decreasing trends in streamwater pH and ANC consistent with acidification of the streams due to acid deposition during the period 1980–1987. However, in 2004 a slight recovery in ANC and sulfate concentrations was noted in study streams. Despite this recovery in constituent solute values, water quality in SHEN streams is still degraded compared to historic levels. For example, sulfate concentrations in SHEN streams have increased 2.5–7.5 times from historic levels. In addition, the median historical loss of ANC in park streams has been estimated to be 20 ueq/l. Fecal coliform contamination has been noted at Pass Run and Hawksbill Creek in SHEN. The fecal coliform most likely originates from wildlife and human sources (recreational use) near streams.
Groundwater	Caution	Stable	Groundwater pumping at a well in Big Meadows (BM-3) contributed to water table decline in this portion of the park. This well was closed to all uses in 1992 and today most potable water for the Big Meadows campground is obtained from Lewis Spring. Additional wells were developed in 1989 to provide supplemental/backup water sources when flow from Lewis Spring is insufficient to meet demand at the Big Meadows campground in late summer. Groundwater pumping at these wells has the potential to contribute to water table declines in SHEN. A complete list of potential point and non-point groundwater contamination sources are provided in the Water Resources Scoping Report and include: Skyline Drive, sewage pollutants from campgrounds (pit toilets, tertiary sewage treatment plants) and visitor centers (which are all located near the largest springs in the park), underground gasoline tanks (associated with gasoline stations along Skyline Drive), gas lines, pesticide or other chemical spills at ranger stations and maintenance yards, landfills (12 known NPS sanctioned and CCC-era landfills are in SHEN), and chemical spills and road runoff (including deicing salts, heavy metals, and

			hydrocarbons) along any of the ten state roads found in the park (including routes 211 and 33). Wells near Lewis Spring potentially could be contaminated by pollutants leaking from an abandoned dump located 1.6 km (1 mi) away. Herbicides used to maintain power line rights-of-way could affect groundwater supplies at SHEN. Furthermore, bacteria from horse (used for trail riding) and human waste (from backcountry waste disposal and potential sewage leaks at developed facilities) may infiltrate groundwater supplies after storm events.

Resource	Status	Trend	Evidence
Plant Resources (overall)	Caution	Declining	
Unfragmented forest	Good	Stable	Due to the unfragmented and protected forests found in the park, SHEN contains a globally outstanding example of the Blue Ridge/Central Appalachian biome. Approximately 85% of the area within the park's boundary is contained within unfragmented blocks greater than 202 ha (500 ac). The construction of fragmenting features (such as visitor centers and roads) within large forested blocks that are not under wilderness protection is possible. In addition, the ecological value of the unfragmented forest blocks at SHEN are enhanced by forested areas that are adjacent to, but not owned by, the park. Therefore, road construction and land conversion from forest to residential and other land uses that is occurring outside the park have the potential to diminish the significance of the expansive, unfragmented nature of SHEN's forests.
Oak and oak-hickory forests	Caution	Declining	Forests that contain oak as a dominant component are the most commonly occurring forest types at SHEN. Some of the oak associate species, most notably flowering dogwood (*Cornus florida*), are threatened by pathogens at SHEN. The flowering dogwood has declined precipitously at SHEN and elsewhere in Virginia over the past two decades because of the prevalence of dogwood anthracnose, which causes mortality to dogwoods especially during dry years. A history of fire suppression probably has limited the regeneration of oak forests at SHEN. Although 90% of the fires that have been recorded in the park have been the result of human ignitions, natural fires occurred periodically throughout the Appalachians and played a role in shaping the plant communities that historically were present in the park. However, natural fires have not been permitted to burn in the park for over 78 years, resulting in conditions different from those that would have resulted if natural fire had been allowed to exert its influence on the landscape. Mesic species of trees have probably always been present to some extent on fertile, protected sites in the park, but they have increased in SHEN and throughout Virginia, perhaps due to fire suppression. Furthermore, rapid expansion of deer populations have greatly reduced the amount of oak regeneration at the same time that age, drought, and gypsy moth defoliation have removed much of the oak overstory. The species composition in many of Virginia's hardwood forests, therefore, is shifting away from oak towards more mesic species such as poplar and maple. Oak mortality caused by gypsy moths may have caused a decline in oak throughout the Appalachians. The ridges, south-facing aspects, and dry plateau areas with a significant oak component have the potential for being most affected by this nonnative pest. Nonnative plants, red maple, tuliptree, and other opportunistic species may invade gaps created by mortality of oaks. On the other hand, canopy

			gaps following gypsy moth infestation in some drier Virginia oak forests have also stimulated dense pulses of oak seedling germination. Sudden oak death caused by the pathogen, *Phytophthora ramorum*, potentially threatens oaks at SHEN. Sudden oak death was first reported in California in 1995 and no natural occurrence has been reported in the forests of the eastern U.S. However, there is significant risk that this pathogen could be introduced to eastern oak forests, as it was detected in nursery stock in Florida, North Carolina, and Georgia in 2004.
Mesic/rich cove forests	Caution	Increasing	Approximately 25% of the land cover at SHEN is in a mesic/rich cove forest vegetation association. Although the mesic forest associations appear to be regenerating at SHEN, threats to this forest type include competition from nonnative species, deer browsing, and fragmentation due to roadways, trails, and land use changes on the lower slopes along the park boundary. In addition, tree species most susceptible to damage by ozone are associated with mesic forests (e.g., tulip poplar, black cherry) and, therefore, air pollution threatens these forest alliances. The moist, usually fertile soils occupied by these communities make them especially vulnerable to massive invasions of the nonnative herbs garlic-mustard (*Alliaria petiolata*) and Japanese stilt-grass (*Microstegium vimineum*). In addition, beech bark disease may threaten the few mesic forest communities at SHEN where this species occurs. The disease results when bark, attacked and altered by the beech scale (*Cryptococcus fagisuga*), is invaded and killed by fungi, primarily *Nectria coccinea* var. *faginata* and sometimes *N. galligena.* The disease, although presently not found in SHEN, is present in northwestern Virginia and may arrive at the park and contribute to beech mortality.
Barrens, boulderfields, and exposed rock vegetation types	Caution	Declining	Due to the mountainous terrain at SHEN there are distinctive vegetation associations associated with exposed and/or loose rock, infertile, minimal soils, and low moisture gradients. The plant species that are found on these locations vary depending on elevation, substrate type, soil type, aspect, and degree of exposure, but tend to occur as stunted forests, shrublands, or herbaceous vegetation and are associated with diverse lichens and high (>50%) surface rock cover. The globally rare High-Elevation Greenstone Barren vegetation association is endemic to SHEN and is found mostly above 1,000 m (3,281 ft) on exposed metabasalt (greenstone) cliffs and ledges. Due to the harsh conditions and exposure, these vegetation types are slow-growing and vulnerable to disturbance. In addition, the exposed conditions associated with these communities make them popular destinations for hikers seeking scenic vistas and thereby threatening their persistence in the park. Invasive nonnative plants also threaten barren communities, especially on sites that have been disturbed by human activity.

Pine forests and woodlands	Significant concern	Declining	Pine forests and woodlands at SHEN are primarily composed of pitch pine, table mountain pine, scrub oaks, Virginia pine and, rarely, shortleaf pine (*Pinus echinata*). Pitch pine and table mountain pine are declining throughout their range because of the exclusion or suppression of fires. In addition, the older pine stands in the Appalachians are susceptible to southern pine beetle outbreak. At SHEN, a dramatic reduction in pine trees caused by these pine bark beetles has been documented. Furthermore, tree-of-heaven established itself at several former pine sites. White pines are threatened by the white pine blister rust (*Cronartium ribicola*), a fungal disease, and white pine weevil (*Pissodes strobi*), an insect that attacks and kills the uppermost shoots of the tree.
Eastern hemlock forests	Significant concern	Declining	The Eastern Hemlock Forest association has declined dramatically over the past 10 years at SHEN. Historically, it typically existed on shallow soils and in cool, deep ravines along waterways. Hemlocks are threatened throughout the mid-Atlantic by a nonnative insect pest, the hemlock wooly adelgid, that attacks and kills hemlock trees. The hemlock woolly adelgid has caused extensive mortality of hemlock in SHEN and this forest type is currently undergoing rapid change as canopy loss and related disturbance potentially affect moisture regimes and plant and nutrient dynamics. By 2004, 92% of these trees were classified as dead due to extensive feeding by the adelgid. As hemlocks continue to decline throughout the mid-Atlantic they most likely will be replaced by stands of oak, birch, and maple.
Black locust successional forest	Stable	Stable	The occurrence of the Black Locust Successional Forest association reflects past land use history at SHEN, especially the prevalence of small homesites now abandoned. This forest association covers 2,261 ha (5,587 ac [2.83%]) of the park and is often dominated by black locust and redbud (*Cercis canadensis*) in the forest canopy. This association will likely be replaced naturally by alliances containing white ash, tuliptree, and/or white pine, and eventually by red oak and a variety of hickories.
Wetland plant communities	Caution	Declining	Although wetland communities compose <2% of the land cover at SHEN, they do represent ecologically significant communities that add diversity to the landscape and provide critical habitat for rare plants, amphibians, and other animals. Six distinct wetland vegetation communities are found at SHEN. One community alliance, the globally rare Northern Blue Ridge Mafic Fen, is endemic to SHEN. Another rare wetland community, the Shenandoah Valley Sinkhole Pond, is endemic to a three-county area in Virginia's Shenandoah Valley. The mafic fen at Big Meadows is threatened by hydrologic alterations associated with a large well that formerly served the Big Meadows campground, deer browse pressure, invasive nonnative plants, and, perhaps, fire exclusion. Nonnative plants threaten native plant communities throughout the park and may be more likely to colonize wetland areas. At SHEN, small herbs such as Japanese stilt grass and long-bristled smart weed are threats in riparian areas. Furthermore, princess tree, tree-of-heaven, and oriental bittersweet are great threats in several riparian areas that suffered large landslides/soil slumps.

Old-growth forest	Significnat concern	Declining	Due to past land-use history, the old-growth (>200 years old) stands that still persist in SHEN are few and small in size. The Limberlost is perhaps the most famous and most frequently visited old-growth area in SHEN. Unfortunately, hemlock woolly adelgid has decimated old-growth hemlock trees in the park. Other tree pathogens, such as sudden oak death and beech bark disease, also potentially threaten old-growth specimens of those species in the park.
Plant species of special concern	Caution	Declining	Data collected by The Virginia Natural Heritage Program (VANHP) from various sources indicate that 92 vascular plant species and one non-vascular plant species of special concern in Virginia have been reliably reported from SHEN. A variety of threats at SHEN are affecting persistence of these plant species of special concern including disturbance suppression, competition from nonnative plants, hydrologic alteration, canopy defoliation, acid precipitation, illegal collecting, and herbivory by white-tailed deer.
Nonvascular plants, lichens, and fungi	Unknown	Unknown	Despite their importance to terrestrial and freshwater communities, little is known about the distribution and abundance of these species in SHEN. Approximately 100 species of lichens, 400 species of fungi, and 260 species of non-vascular plants are known from SHEN. Poor air quality may threaten nonvascular plants and fungi, especially at exposed, high-elevation sites. Furthermore, bryophytes may be especially sensitive to effects of acid deposition. Trampling by high visitation at rocky cliffs may threaten these species in the park. Collecting of edible fungi also may threaten fungi at SHEN.
Nonnative plants	Significant concern	Increasing (nonnative plants seem to be increasing at SHEN)	The invasion of nonnative plants may be the biggest threat to maintaining native forests and plant communities at SHEN because not all nonnatives can be controlled or removed. Nonnative plants penetrate an average of 75 m (246 ft) into the forests along Skyline Drive and about 102 m (335 ft) into the forests surrounding historic (and abandoned) developed areas. Garlic mustard and Japanese stiltgrass are the most problematic invasives, although mile-a-minute weed and oriental ladysthumb (*Polygonum caespitosum*) are recent serious concerns. The North District of the park contains more nonnative plant occurrences than the other two districts. In general, nonnative plants are more prevalent on the eastern slopes of the park than on the west. Skyline Drive, abandoned developed areas, and fire roads are associated with high numbers of nonnative plants; park boundaries are not. Tree-of-heaven is the most prevalent nonnative tree. Oriental bittersweet, multiflora rose (*Rosa multiflora*), wineberry (*Rubus phoenicolasius*), Japanese honeysuckle, and Japanese barberry (*Berberis thunbergii*) are the most common nonnative shrubs. Garlic mustard, Japanese stiltgrass, and long-bristled smartweed (*Polygonum caespitosum* var. *longisetum*) are the most common nonnative forbs in the park.

Resource	Status	Trend	Evidence
Terrestrial animals-including amphibians (overall)	Good	Stable	
White-tailed deer	Good	Increasing	Populations of white-tailed deer at SHEN are currently higher (25–30 deer/mi^2) than historic levels (8–20 deer/ mi^2). Deer densities are even higher in the front country where deer densities approach 200 deer/ mi^2 at Big Meadows. White-tailed deer are potentially threatened by chronic wasting disease (although this disease has not been detected in Virginia as of 2006).
Black bear	Good	Stable	There are approximately 300–800 black bears in SHEN. The SHEN population may be source population for the Blue Ridge Mountains. Black bears throughout the Appalachians are constantly threatened by poachers who illegally kill black bears in order to sell their gall bladders and paws on the international market. However, in SHEN, the illegal killing of black bears appears to be relatively inconsequential for population dynamics.
Allegheny woodrats	Caution	Stable	This species of special concern is declining throughout the Appalachians. Allegheny woodrats are known from nine sites within SHEN. Ensuring the continued persistence of these populations in the park will assist in the long-term conservation of this species.
Bats	Unknown	Unknown	The status of the bat community in SHEN is unknown. There have been no published studies of this vertebrate group in the park, and NPSpecies documents six species of bats (big brown bat [*Eptesicus fuscus*], little brown bat [*Myotis lucifugus*], silver-haired bat [*Lasionycteris noctivagens*], eastern red bat [*Lasiurus borealis*], hoary bat [*Lasiurus cinereus*], and eastern pipestrelle [*Pipistrellus subflavus*]) as being confirmed from SHEN. However, Virginia Gap predicts nine species of bats to occur in the park. Three of these predicted species, northern myotis (*Myotis septentrionalis*), eastern small-footed myotis, and evening bat (*Nycticeius humeralis*), have not been documented in the park and are not included in NPSpecies. In addition, two species (Indiana bat [*Myotis sodalis*] and Virginia big-eared bat [*Plecotus townsendii virginianus*]), both federally endangered, are known to occur on the west side of the Shenandoah Valley. Threats to the bat community in SHEN are unknown, although the conversion of nearby limestone caverns (e.g., Luray Caverns) to visitor attractions may have eliminated roosting and hibernation habitat.
Small mammals	Unknown	Unknown	The small mammal community has been little studied in SHEN. A species list published in 1985 suggests that 18 species of native mice, moles, voles, and shrews occur within the park. They include star-nosed mole (*Condylura cristata*), southeastern shrew (*Sorex longirostris*), pygmy shrew (*Sorex hoyi*), southern bog lemming (*Synaptomys cooperi*), white-footed mouse (*Peromyscus leucopus*), southern-flying squirrel (*Glaucomys volans*), and the rare Appalachian cottontail (*Sylvilagus obscurus*). In addition, the southern water shrew (*Sorex palustris*

			punctualatus) (endangered in Virginia) may occur in the park. Gypsy moth infestations and their effects on acorns have caused declines in native rodent populations in SHEN. Forest succession may contribute to declines in Appalachian cottontail.
Fur-bearing and other mammals	Unknown	Unknown	Fur-bearing mammals include beaver, bobcat, muskrat (*Ondatra zibethicus*), red fox (*Vulpes vulpes*), gray fox, raccoon, skunks (*Mephitis mephitis*, *Spilogale putorius*), woodchuck (*Marmota monax*), eastern cottontail (*Sylvilagus floridanus*), gray squirrel (*Sciurus carolinensis*), mink (*Mustela vision*), northern river otter, and weasels (*Mustela* spp.). Beaver and muskrat are only known from around the periphery of the park boundaries. Formal studies of these species populations in SHEN have not been conducted. The main threat to these animals is mortality due to vehicular traffic on Skyline Drive. Threats from disease are unknown although rabies could adversely affect these populations.
Neotropical migratory birds	Good	Stable	SHEN is globally significant in providing critical habitat for neotropical migratory birds, especially the wood warblers (Family *Parulidae*). Forest neotropical birds depend on the physical structure of the forest for survival. Some live in hardwoods with canopies, some along the edge, and some in forest gaps created by tree falls. This partitioning of the physical habitat supports the high diversity of forest birds in SHEN. Forest gaps contain early successional vegetation and sunlight, two environmental variables needed by several neotropical migrants. Threats to these birds in SHEN include modification of the park's hardwood forest structure due to loss of oaks from introduced gypsy moths, loss of hemlocks from the introduced hemlock woolly adelgid, lack of regeneration due to deer browsing, and disturbance suppression. Populations are also compromised by loss of forest habitat and fragmentation from developed sites in the park.
Waterbirds and waterfowl	Good	Unknown	Few waterfowl species occur in SHEN due to the small number of ponds and other open water bodies within park boundaries. However, several species, such as wood duck (*Aix sponsa*), green heron (*Butorides virescens*), great blue heron (*Ardea herodias*), and American bittern (*Botaurus lentiginosus*), use riparian corridors along mountain streams, especially at low elevations. The abundance of, and threats to these species within the park are unknown.
Raptors	Good	Stable	Hawks and falcons are frequent visitors to, and residents of SHEN. The spine of the Blue Ridge Mountains creates a pathway along which several species of raptors fly during fall migration periods, and at least ten species are known from SHEN. In addition, SHEN is one of the few places in the country where peregrine falcons can be observed nesting in their natural and historic habitat. Raptors are particularly susceptible to West Nile virus, but this pathogen has the potential to negatively affect various bird species.

Game birds	Good	Stable	Wild turkey, ruffed grouse, and American wookcock (*Scolopax minor*) occur in SHEN. Virginia turkey populations, estimated at about 120,000 statewide in 2005, appear to be stable, or declining slightly due to several years of low reproductive success. The current size of grouse and woodcock populations in Virginia are unknown, although grouse populations are low compared to levels prior to 2000. Woodcock have been declining at a rate of about two percent annually over the past two decades. Threats to these three game birds in SHEN are unknown, although American woodcock and ruffed grouse may be losing nesting habitat due to forest succession.
Turtles	Good	Stable	The only turtle that occurs throughout SHEN, is the eastern box turtle (*Terrapene carolina*). The wood turtle, a state-threatened species, may occur within the current SHEN boundary. Two other species, the painted turtle (*Chrysemys picta*) and the snapping turtle (*Chelydra serpentina*), may enter the park via streams from populations outside the park. Mortality by vehicles on Skyline Drive potentially is a major threat to box turtles and other turtle species that cross this road. Removal of individuals for pets is also a threat.
Lizards and snakes	Good	Stable	At least four species of lizard are known to occur within park boundaries: northern coal skink (*Eumeces anthracinus*), five-lined skink (*Eumeces fasciatus*), northern fence lizard (*Sceloporus undulates hyacinthinus*), and ground skink (*Scincella lateralis*). Most of the known locations are along the park's boundary and in the rock walls located along Skyline Drive. Of the 19 known snake species in the park , three are of conservation concern. Populations of timber rattlesnake are declining throughout the Northeast, and the northern pine snake (*Pituophis melanoleucus*) and the smooth greensnake (*Opheodrys vernalis*) have apparently declined dramatically in the Appalachians due to habitat loss, mortality on roads, and killing by humans. The northern pine snake is considered a species of special concern in Virginia. Road mortality on Skyline Drive and incidental killing constitute the main threats to snakes from humans. Some individuals are undoubtedly removed for the pet trade, but the incidences and threat level are unknown.
Salamanders	Good	Stable	The Shenandoah salamander is listed as federally endangered and is highly restricted to three talus areas in the northern section of SHEN. Primary habitat of several species of salamanders in SHEN is mountain streams and the springs and seeps that feed them. The abundance and diversity of streamside salamanders is regionally significant and depends entirely on this habitat type. Salamander populations in SHEN streams appear relatively secure at this time, but continued exposure to acid deposition and resulting stream and soil acidification eventually may adversely affect these populations.
Frogs and toads	Good	Stable	Little is known about the distribution and abundance of frogs and toads at SHEN; however, they are dependent on isolated vernal pools for breeding. At least two groups of isolated vernal pools are known to exist in SHEN. These pools, located at

			Big Meadows near the weather station and at Hogcamp Swamp, have been studied for several years by the USGS Amphibian Research and Monitoring Initiative (ARMI). Acid precipitation and alteration of the hydrological conditions of ponds constitute the primary threats to these amphibians. Draining and alteration (e.g., prescribed burning near these pools) of any part of the Big Meadows pools may cause several species (particularly Jefferson salamander) to become locally extinct within a short period of time. Many amphibians at SHEN migrate outside of the park boundary to breeding ponds on private lands. Any alterations to these ponds or barriers to migration pose a potentially serious threat to these boundary-line populations. Mortality by vehicles on Skyline Drive potentially is a significant source of mortality for some populations.

Resource	Status	Trend	Evidence
Fish (overall)	Good	Stable	
Brook trout	Good	Stable	The streams in SHEN offer one of the greatest concentrations of native brook trout in the eastern U.S., making native brook trout a nationally significant resource at the park. Acid deposition and resulting decreases in the ANC of SHEN's streams, and corresponding increases in toxic aluminum, threaten brook trout. In addition, the introduction of nonnative trout have disrupted native brook trout population in streams where they coexist. Maintaining groundwater levels and recharge rates at springs and seeps is also critical in protecting brook trout populations in the park. The cool water temperatures upon which trout depend may be adversely affected by the decline of the eastern hemlock that historically shaded headwater streams throughout the park. Although the effects of legal and illegal fishing pressure are difficult to quantify, illegal harvest should be considered a potential threat to the park's brook trout fishery. Streams located along the park boundary are particularly susceptible to illegal trout harvest. Salmonid whirling disease caused by a parasite (*Myxobolus cerebralis*) has not been detected in the park, but has the potential to negatively affect trout.
Fish communities (overall)	Good	Stable	Currently, NPSpecies (2005) lists 37 species (including one hybrid trout) of fish known from SHEN, and three of these, bluntnose minnow (*Pimephales notatus*), Potomac sculpin (*Cottus girardi*), and yellow bullhead (*Ameiurus natalis*), were first detected in the past two years by the fish monitoring program. Streams on the eastern slopes of the park contained higher trout and higher fish species diversity than streams on the western slopes due to greater invertebrate productivity, water flow, and pool formation. All populations of fish, regardless of species, are dynamic in the park (experience year-to-year population fluctuations) due to variations in water flow, acidity, and recruitment rates. Acidification of SHEN's streams threatens to reduce fish species richness by eliminating acid-sensitive species from fish communities. Aside from the effects of stream acidity, the principle short-term natural factors that have the most pronounced effect on the fishery resources of SHEN are drought and flood events. Fish pathogens, such as enteric redmouth disease caused by bacteria (*Yersinia ruckeri*), bacterial kidney disease caused by bacteria (*Renibacterium salmoninarum*), infectious pancreatic necrosis caused by a virus, and salmonid whirling disease caused by a parasite (*Myxobolus cerebralis*), have not been detected in SHEN, but are potential thtreats to fish in the park.

Resource	Status	Trend	Evidence
Aquatic invertebrates (overall)	Good	Stable	
Aquatic invertebrates- aquatic insects, crayfish, molluscs, and aquatic worms	Good	Stable	Most streams in SHEN contain macroinvertebrate assemblages that represent the best condition of streams in the Blue Ridge Mountains. However, acid deposition threatens the diversity of stream macroinvertebrate assemblages at SHEN. For example, streams with low ANC (primarily those found in the siliciclastic bedrock type) contain macroinvertebrate assemblages with lower species richness than streams with high ANC. These low-ANC streams may now possess less diverse macroinvertebrate communities than were present in pre-industrial times at SHEN. In addition, loss of eastern hemlocks may alter macroinvertebrate assemblages in streams that drain former hemlock stands. Little is known about the molluscs found in SHEN's streams.

Resource	Status	Trend	Evidence
Terrestrial invertebrates (overall)	Unknown	Unknown	
Insects and other terrestrial arthropods	Unknown	Unknown	Very little is known about the terrestrial invertebrates of SHEN. The most extensive survey of terrestrial invertebrates at SHEN was conducted at a hemlock (Limberlost) and a mixed deciduous forest stand (Matthews Arm) in 1997. In that study, 12,978 invertebrate specimens were collected. The hemlock forest contained more individuals in the orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Psocoptera (book lice). However, the mixed deciduous forest had higher overall species diversity. Reflecting the potential high diversity of terrestrial invertebrates at the park, that limited study documented one new state record (*Actogeophilus fulvus*) and a new Madison County record (*Stimamia bidens*) for centipedes collected at Limberlost. In addition, a previously undescribed species in the order Homoptera and ten previously undescribed species in the order Diptera were documented. As part of the ongoing Rock Outcrop Management Project, geologists from the Virginia Department of Conservation and Recreation collected invertebrates during summer 2005 and 2006 using sweep nets and light traps at 21 rock outcrops in the park. Terrestrial invertebrates are threated by the application of pesticides by NPS personnel, concessioners, and adjacent landowners. In addition, invertebrates are potentially threatened as overstory forest tree species such as eastern hemlock decline and ecosystems dynamics are altered.

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Appendix A. Suggested desired conditions and management prescriptions for intrinsically significant biotic and abiotic components of aquatic habitats, mammalian resources, avian resources, herpetofaunal resources, and geologic resources at Shenandoah National Park.

The following desired conditions and management prescriptions were formulated for intrinsically significant resources at Shenandoah National Park during two workshops held in February and March of 2005. These workshops were attended by research scientists, technicians, and SHEN resource managers who are familiar with the intrinsically significant resources at the park. These conditions and prescriptions (recommendations) are strictly the collective opinions of the workshop attendees.

Biotic and Abiotic Components of Aquatic Habitats

1. Native aquatic fauna desired condition: Prevent loss from current (2005) level of native diversity (species richness and population density) of macroinvertebrates and fish.

   Management prescriptions:

   a. Quantify faunal diversity (species richness and population density) and productivity (reproduction and biomass) of aquatic habitats with a particular emphasis on macroinvertebrate and fish assemblages in headwater habitats to determine natural fluctuations in population levels.

   b. Conduct parkwide watershed analysis to establish hydrogeomorphic setting of water resources in the park (e.g., describe geology, forest composition, LULC, dispersal barriers, terrain within watersheds) to determine current and natural fluctuations in water resources.

   c. If changes are detected that deviate from natural fluctuations in aquatic resources (biotic and/or abiotic), try to determine causes and ameliorate, if possible. For example, if macroinvertebrate populations are declining due to increased stream sedimentation, stabilize stream banks (via re-vegetation), relocate streamside trails, and/or limit recreational use of the area to reduce soil disturbances.

2. Watershed component connectivity desired condition: Lateral and longitudinal connectivity among watershed components will be maintained at current (2005) levels.

   Management prescriptions:

   a. Identify potential barriers to dispersal of native aquatic fauna.

   b. Remove or modify nonnatural dispersal barriers. For example, at stream road crossings culverts should be kept cleared of debris so that aquatic vertebrates and invertebrates can disperse throughout the waterway.

3. Water quantity and quality desired condition: Water quantity and water quality will be maintained and, in some cases, improved from current (2005) levels. For example, acid precipitation is a potential threat to water quality in the park. However, the acid-neutralizing capacity of streams has prevented acid precipitation from degrading in-stream water quality. Water quality must be continually monitored because this situation could change.

Management prescriptions:

a. Determine the extent to which existing water quality/quantity data represents conditions parkwide and reflects natural fluctuations. Water quality data is currently available for 15 streams in Shenandoah National Park.

b. Develop a list of streams with degraded water quality and/or quantity (if any) and determine causes of degradation.

c. Develop and implement remedial solutions (e.g., increase acid-neutralizing capacity of stream via liming, reduce park water removal if water quantity declines) to restore degraded streams.

4. <u>In-stream habitat desired condition</u>: Natural in-stream habitat components will be maintained and artificial habitat components (e.g., damaging stream crossings, human-made stream pools) will be removed.

Management prescriptions:

a. Determine if specific park management activities (such as fire suppression and trail maintenance) disrupt natural processes of in-stream habitat formation and maintenance. For example, woody debris in streams may increase or decrease due to the type of vegetation removal along streams.

b. Ensure that park management activities do not disrupt natural processes of in-stream habitat formation and maintenance.

c. Do not remove or disturb naturally occurring in-stream woody debris unless it is causing impediments to fish movement or threatening property by damming the watercourse.

5. <u>Exotic and invasive species in aquatic systems desired condition</u>: Aquatic systems will be free of nonnative species.

Management prescriptions:

a. Identify nonnative species populations, map their locations, determine their points of entry, and their effects on native aquatic assemblages.

b. Evaluate potential threat of exotic pathogens and diseases to native aquatic assemblages.

c. Remove nonnative species of fish and macroinvertebrates (e.g., nonnative crayfish species) from watersheds if and when they are detected and prevent further introduction or reintroduction of nonnative species (e.g., do not allow nonnative species to be used as bait).

Mammalian Resources

1. <u>White-tailed deer populations and natural communities desired condition</u>: White-tailed deer populations will reflect high herd health (as measured by parasite/malnutrition index) and will not prevent native vegetation regeneration. Based on data collected by the Virginia Department of Game and Inland Fisheries, the average deer density in SHEN is probably 25–45 deer/mi^2 (2004). Historically, SHEN probably supported 12–15 deer/mi^2. Therefore, there are twice as many deer in SHEN today as compared to initial European settlement.

   Management prescriptions:

   a. Quantify deer herd health using indices taken on incidental road-killed deer.

   b. Determine regeneration of native vegetation by initiating deer exclosure studies parkwide.

   c. Determine the threshold deer population that will promote high herd health and that natural communities can sustain without appreciable degradation.

   d. Initiate hunting or in-park chase activities (if necessary).

2. <u>Native mammalian diversity desired condition</u>: Native mammalian diversity representative of the Blue Ridge ecosystem will be maintained at current (2005) levels. However, as research and management warrant, native mammalian components of the Blue Ridge ecosystem may be restored via re-introduction (e.g., Allegheny woodrat, Appalachian cottontail, spotted skunk, eastern elk).

   Management prescriptions:

   a. Determine composition, distribution, abundance, habitat use, interspecific interactions, and diseases of carnivore populations in the park.

   b. Monitor, map, and protect (e.g., reduce visitor disturbance) woodrat populations in the park.

   c. Determine size of Appalachian cottontail populations in the park.

   d. Determine small mammal assemblage (insectivores, lagomorphs, rodentia) and distribution within the park.

   e. Determine bat assemblage, distribution, and habitat use in the park

   f. Identify and determine distribution of, and provide protection for, rocky outcrops, boreal forests, vernal pools, hibernacula, and early successional habitats in the park.

   g. Construct a chronology of mammalian assemblages and distribution in the park based on on available historical accounts and scientific surveys.

h. Restore, via re-introduction, those mammal species native to the Blue Ridge Mountains that have been extirpated from SHEN, if research and management warrants.

Avian Resources

1. <u>High elevation bird communities desired condition</u>: High elevation bird communities will be maintained at current (2005) levels.

   Management prescriptions:

   a. Inventory, monitor, and map distribution of breeding population of red-breasted nuthatch (*Sitta Canadensis*) and winter wren (*Troglodytes troglodytes*) in park.

   b. If breeding populations decline, restore red spruce as replacement species for lost hemlocks at high elevations in the park.

2. <u>Neotropical migratory bird communities desired condition</u>: Neotropical migratory bird communities will be maintained at current (2005) levels.

   Management prescriptions:

   a. Continue breeding bird surveys in the park.

   b. Re-initiate MAPS program and determine population trends of breeding neotropical migratory species in the park in a local, regional, and national context.

   c. Conduct point counts for cerulean warblers throughout the park (including southern half) and determine number of breeding pairs in the park.

   d. Conduct point counts for veery (*Catharus fuscescens*) throughout the park and determine number of breeding pairs in the park.

   e. Conduct point counts for neotropical migratory birds in areas of forest change (e.g., former hemlock stands [Limberlost, Camp Hoover], post-burn areas).

   f. If point count data suggests decline of species in park, formulate and initiate management actions (e.g., restore red spruce in the park as surrogate for hemlock, reduce fragmenting features of the landscape).

3. Peregrine falcon desired condition: Two or three pairs of peregrine falcons will nest annually in the mountains of Virginia.

   Management prescriptions:

   a. Continue peregrine restoration program until park has two successful nesting pairs annually. Monitor successfully nesting pairs and re-instate restoration program if necessary.

   b. Reduce visitor impacts at current and potential peregrine nesting sites.

4. Hemlock bird communities desired condition: Bird communities that declined or were lost due to mortality of eastern hemlock forests will be restored.

   Management prescriptions:

   a. Encourage red spruce expansion at Limberlost.

   b. Provide assistance to researchers attempting to develop and/or implement controls of hemlock woolly adelgid. If adelgid is successfully controlled, re-establish eastern hemlock in the park.

Herpetofaunal Resources

1. Shenandoah salamander desired condition: Shenandoah salamander populations will be maintained at or above current (2005) levels.

   Management prescriptions:

   a. Monitor Shenandoah salamander populations in park.

   b. Determine population boundaries of Shenandoah salamander populations (e.g., are they dynamic?)

   c. If population declines are found, formulate and initiate management actions (e.g., maintain connectivity among populations, identify and restore critical habitat components).

2. Big Meadows swamp desired condition: Big Meadows swamp habitat will be maintained and/or restored to ensure persistence of herpetofaunal species.

   Management prescriptions:

   a. Study and determine hydrology of Big Meadows swamp.

   b. Identify factors that may be altering hydrology of Big Meadows swamp.

c. Restore hydrology, if necessary, by eliminating or minimizing effects of factors that are altering it.

3. Native herpetofaunal diversity desired condition: Diverse and productive assemblages of native herpetofaunal diversity representative of the Blue Ridge ecosystem will be maintained and/or restored.

Management prescriptions:

a. Identify and map all vernal pools and seepages in the park.

b. Determine amphibian species using vernal pools and seepages in the park.

c. Determine annual variation and turnover in amphibian species that use vernal pools and seepages in the park.

d. Identify and map rock outcrops, talus/scree slopes, xeric ridges, and glades in the park and inventory herpetofaunal communities at these habitats.

e. Identify, map, and maintain all timber rattlesnake dens in the park.

f. Determine effects of Skyline Drive on timber rattlesnake populations that are located near to versus far from this road.

g. Determine the effects of Skyline Drive, habitat alteration, and poaching on herpetofaunal communities of the park.

h. Determine occurrence and extent of herpetofaunal diseases in the park (e.g., chytrid fungus, *Perkinsus* parasite, upper respiratory tract disease in box turtles).

i. Determine the effects of hemlock loss on herpetofaunal presence, use of newly formed gaps, and behavior (e.g., do the newly formed gaps caused by dead hemlocks attract rattlesnakes?).

j. Conduct a parkwide inventory for pine snake, smooth green snake (*Opheodrys vernalis*), rough green snake (*O. aestivus*), corn snake (*Elaphe guttata*), eastern king snake (*Lampropeltis getula*), coal skink, wood turtle, painted turtle, and spotted turtle (*Clemmys guttata*).

Geologic Resources

1. Geologic hazards desired condition: By 2010, identify and limit the effects of recognized geologic hazards (rockfalls, debris flows).

   Management prescriptions:

   a. Identify and map visitor use areas (roads, trails, campgrounds, etc) with susceptibility to geologic hazards.

   b. Communicate information to the public by appropriate educational outlets (e.g., signs posted along Skyline Drive, at cliff faces, along trails).

2. Geologic research desired condition: World class interdisciplinary scientific research/understanding will broaden and continue at SHEN. Interdisciplinary/entire ecosystem level of cooperation and research is high at SHEN and will be highlighted and put on the global "radar." Park currently is destination for world-class geologic research.

   Management prescriptions:

   a. Research will be accessible to scientists, public, and resource mangers/interpreters via the development and implementation of annual reports, conferences, public outreach, and Web sites.

   b. Continue geologic research cooperation with the Geologic Resources Division of the NPS.

   c. Identify, map, and promote with scientists, the outstanding geological research and educational locations within the park.

   d. Prevent theft and vandalism of geologic resources in the park by alerting park law enforcement of their locations and value.

3. Cliff communities desired condition: Ninty-five percent of cliffs (>35 degree slope) are maintained in pristine condition where "pristine" is defined as a cliff that contains a continuous mat of vegetation and lichen with <2% exposed soil, and is located >0.5 mi from a trail/road.

   Management prescriptions:

   a. Identify cliff faces that meet pristine condition and implement management actions to protect them, such as: area closures (limiting climbing on certain cliff faces, for example), visitor education, require and enforce "leave no trace" climbing techniques, restore social trails (remove informal trails), remove illegal campsites, periodically patrol pristine cliffs to enforce regulations.

   b. Create a climbing guide to direct visitors to "sacrificial" cliff areas for climbing and other recreation.

Air Resources

A separate workshop was not held to define suggested desired conditions for air quality. Suggested desired conditions for air quality could be developed based upon the suggested management recommendations listed in the air resources section of this report. Additionally, suggested desired conditions could be developed based upon the management recommendations described in Sullivan et al. (2003).

Appendix B. Names, areas of expertise, and affiliations for professionals with knowledge of the natural resources of Shenandoah National Park.

Name	Area of expertise	Affiliation
DeSante, David	Ornithologist	The Institute for Bird Populations, Point Reyes Station, CA
DeViney, Frank	Aquatic Ecologist	University of Virginia, Charlottesville, VA
Diefenbach, Duane	Ecologist	The Pennsylvania State University, University Park, PA
Dolloff, Andy	Fisheries Biologist	Virginia Tech, Blacksburg, VA
Eaton, L. Scott	Geologist	James Madison University, Harrisonburg, VA
Fleming, Gary	Plant Ecologist	VA Natural Heritage Program, Richmond, VA
Heffernan, Kevin	Plant Ecologist	VA Natural Heritage Program, Richmond, VA
Jung, Robin	Herpetologist	U.S. Geological Survey, Laurel, MD
Kim, K. C.	Entomologist	The Pennsylvania State University, University Park, PA
Knox, Matt	Vertebrate Ecologist/Deer Biologist	VA Department Conservation and Inland Fisheries, Richmond, VA
Lafon, Nelson	Vertebrate Ecologist/Deer Biologist	VA Department Conservation and Inland Fisheries, Richmond, VA
Marion, Jeffrey	Recreation Specialist	Virginia Tech, Blacksburg, VA
Martin, Denny	Vertebrate Ecologist/Bear Biologist	VA Department Conservation and Inland Fisheries, Richmond, VA
Mengak, Mike	Vertebrate Ecologist	University of Georgia, Athens, GA
Mitchell, Joseph	Vertebrate Ecologist/Herpetologist	University of Richmond, Richmond, VA
Mohn, Larry	Vertebrate Ecologist	VA Department Conservation and Inland Fisheries, Richmond, VA
Nott, Philip	Ornithologist	The Institute for Bird Populations, Point Reyes Station, CA
Snyder, Craig	Aquatic Ecologist	U.S. Geological Survey, Kearneyville, WV
Southworth, C. Scott	Geologist	U.S. Geological Survey, Reston, VA
Tollo, Richard	Geologist	George Washington University, Washington, DC
Vaughan, Mike	Vertebrate Ecologist	Virginia Tech, Blacksburg, VA
Watt, Bryan	Ornithologist	College of William & Mary, Williamsburg, VA
Webb, Rick	Aquatic Ecologist	University of Virginia,, Charlottsville, VA
Wilson, Mike	Ornithologist	College of William & Mary, Williamsburg, VA
Young, John	G/S Specialist/Ecologist	U.S. Geological Survey, Kearneyville, WV

Appendix C. Synthesis Instructions.

1. Place “Synthesis Program Installation Disc” CD in CD drive and follow instructions on screen.
2. Remove “Synthesis Program Installation Disc” CD.
3. Place “Synthesis Data Disc” DVD in DVD drive.
4. Go to your Program Files and click on Synthesis.
5. Under “Select Site” click on MAHAN.
6. Document outline will appear. Click on subject material, e.g., Fish, and choose report to read. All reports are full-text searchable and most will open in Adobe Acrobat.
7. Some links (e.g. Water Resources) will direct your computer to a Web site. For example, when you click on Water Quality and then NPS-NatureNet Water Resources, you will be directed to a Web page. Click on Shenandoah National Park report found under Northeast Region. This will access the Water Resource Management Plan.
8. The Synthesis program will not run if it has no data to read, so make sure you have the Synthesis Data Disc DVD in your DVD drive.
9. For help and contact information: www.jmu.edu/synthesis/.

As the nation's primary conservation agency, the Department of the Interior has responsibility for most of our nationally owned public land and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

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U.S. Department of the Interior

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