Landscape Conservation Forecasting

Great Smoky Mountains National Park

Happy Valley Ridge Wildfire, September 2016. *(photo by Greg Salansky)*

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September, 2017

Front cover photo: *Happy Valley Ridge Wildfire, September 2016, by Greg Salansky.*

Despite control efforts which limited its size, this fire burned for nearly a month during 2016 through an outstanding remnant of low elevation pine woodland. The effects of this fire will provide important clues about the ecology and restoration of this important ecological system.

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Preface

In the autumn of 2016 the Southeastern United States experienced an extraordinary number of wildfires, including a tragic fire event the likes of which had not occurred for at least a century in the deciduous hardwood forests of the Southern Appalachians. The Chimney Tops 2 fire that originated in Great Smoky Mountains National Park shocked the nation and devastated local communities, as is the case with many natural disasters. While we rebuild our communities and mourn our losses, we must also study the ecological implications of this fire and learn more about the role of fire in our forests. We hope that the information contained within this report and the associated maps and models will contribute to our understanding of fire and how to use fire constructively as a management tool.

Introduction

Stretching over 500,000 acres in the heart of the Southern Blue Ridge, the Great Smoky Mountains National Park (GRSM) is widely considered among the most important natural areas in the eastern United States. However, GRSM is experiencing significant effects from long-time fire suppression/exclusion. Numerous studies and peer-reviewed papers have documented losses in ecosystem function and diversity resulting from the exclusion of fire.

Developing a vision for management actions to address the losses due to fire exclusion requires a carefully considered approach. Landscape Conservation Forecasting (LCF) is a management decision-making support tool that has been successfully used by public agencies in numerous landscapes across the United States. Examples include the adjacent Cherokee National Forest as well as the Great Basin National Park in Nevada. Benefits of using LCF include:

- Uses the best available science to develop reference conditions that describe a Natural Range of Variability (NRV) for each ecological system modeled
- Uses remote sensing to assess the health of existing ecological systems
- Employs predictive ecological models to demonstrate how those ecosystems will change over time
- Utilizes computer simulations to assess how alternative management actions can influence those changes
- Customizes management actions based on agency mandates or local constraints
- Provides a cost/benefit analysis for management actions

In 2015, the National Park Service and The Nature Conservancy entered into an agreement to collaborate on Landscape Conservation Forecasting, with a primary focus on the fire-maintained forests of GRSM. The LCF project proceeded in two stages. Stage one processed and optimized existing park vegetation data, ecological zone data and LiDAR data for use in LCF. Stage two included four workshops in 2016 that engaged park staff and others to develop state-

and-transition models for historical vegetation, complete the ecological departure analysis, and compare potential future management scenarios.

Objectives for Great Smoky Mountains National Park Landscape Conservation Forecasting

- Engage NPS Resource Management staff and regional experts to conduct highly credible research that contributes to the establishment of meaningful landscape-scale objectives, effective prioritization, and shared ownership of future fire management direction.
- Synthesize research findings, remote sensing, and spatial data to inform a more complete understanding of past, current, and desired future conditions for fire-maintained forests.
- Use state-and-transition modeling to develop pre-settlement reference conditions for structure and composition of fire-maintained forests in GRSM.
- Complete an ecological departure analysis to highlight the greatest priorities for management action, and provide insight into fuels treatment objectives and effectiveness.
- Produce a final set of management scenarios for a 20-40 year time horizon to serve as a planning guide for future fire management plans, 5-year fuels treatment plans, and prescribed burn plans.

Process and Methodologies

LCF has built upon and modified methodologies developed under the national interagency LANDFIRE program -- including mapping, models, and metrics -- to assess a landscape's ecological condition. The essence of LCF is a measure of ecological departure. Ecological departure is an integrated, landscape-level estimate of the ecological condition of terrestrial and riparian ecological systems. Ecological departure incorporates species composition, vegetation structure, and disturbance regimes to estimate an ecological system's departure from its natural range of variability (NRV). NRV is the percentage of each vegetation succession class that would be expected under a natural disturbance regime. Ecological departure is measured using a scale of 0 to 100 where higher numbers indicate higher departure from NRV.

The LCF project completed the following tasks that were reviewed and revised at the workshops with GRSM's natural resource managers:

- Datasets. Reviewed and processed existing datasets, including historic and existing vegetation mapping, Ecological Zone mapping, disturbance history, and fire history.
- Potential Natural Vegetation. Worked with Steve Simon (Ecological Mapping and Fire Ecology, Inc.) to develop a map of GRSM's potential natural vegetation (the dominant vegetation types expected in the physical environment under a natural disturbance regime). The final "hybrid" map included the best elements from the existing Park vegetation map (1:15,000 scale) (2003), Simon's 10 meter resolution Ecological Zone maps, and a collaboratively developed cross-walk / rule set that defined ecological systems.
- Existing Vegetation. The current/existing ecological systems were largely identified from the 173 dominant vegetation types defined in the 2003 Park map following the same logic and groupings used to identify potential natural vegetation types. Ecological Zone maps were also used to approximate a small number of ecological systems and to help identify 'highly departed vegetation' classes.

- Vegetation Succession Classes. LiDAR remote sensing data for GRSM was processed at 3 meter resolution and used along with disturbance data and a set of decision rules to interpret and map current ecological systems' succession classes.
- Ecological Models. Reviewed and refined state-and-transition ecological models for nine ecological systems, using reference condition models initially developed for the Cherokee National Forest and the Nantahala-Pisgah National Forests based upon the LANDFIRE methodology. Special attention was directed towards refining the models for seven oak and pine-dominated systems, several of which are highly fire-dependent.
- Current Ecological Departure. For each ecological system, compared current vegetation class distributions with the potential natural vegetation and calculated each system's ecological departure from its NRV. Each ecological system was assessed an ecological departure score (0% to 100% departure from NRV).
- Forecast Ecological Departure. Forecasted the future condition of each ecological system over the next 20 - 40 years without active management, based on computer simulations using ST-Sim software incorporating the predictive ecological models.
- Landscape Restoration Objectives. At the May 2016 workshop, GRSM's natural resources managers confirmed a set of overall landscape restoration objectives for GRSM, as follows:

Landscape Restoration Objectives

- Restore fire as a key ecological process in oak and pine ecosystems where practical and most needed.
- Restore more open canopy conditions in dry oak and pine ecosystems to more closely approximate reference conditions/NRV.
- Restore early and mid-succession vegetation in dry oak and pine ecosystems to more closely approximate reference conditions/NRV.
- Manage fire appropriately to protect life and human & cultural resources within and adjoining GRSM.

- Focal Ecological Systems. Five fire-maintained ecological systems were selected for active management using prescribed fire, based upon their high departure from NRV and likelihood of continued future departure. The five focal systems for active management included: Dry Oak forest; Dry-Mesic Oak Forest; Low Elevation Pine Forest; Low Elevation Pine-Oak Heath; and Montane Pine-Oak Heath.
- Management Models. Reference condition models were modified to incorporate prescribed burning as a management action, as well as reflect current levels of fire exclusion in GRSM. With assistance from TNC's LANDFIRE program, expert assistance was secured to develop ST-Sim models that incorporated three prescribed fire "passes" in simulated non-spatial burn units, designed to achieve positive ecological outcomes.
- Management Scenarios. At and between workshops, prescribed fire management strategies were explored to achieve the objectives for these focal systems. Predictive ST-

Sim computer models were used to simulate conditions under alternative future management scenarios. All scenarios assume current levels of fire exclusion will continue in GRSM. The likely future condition of the five focal systems was assessed after 20 and 40 years under four primary scenarios: No Action, Maximum Management, Current Management, and Preferred Management.

- Return on Investment. Return on investment was calculated to compare ecological benefits to management costs.
- Limitations of LCF. LCF is a landscape-scale planning tool, and thus has some inherent limitations in its applications. The LCF maps, models and metrics for GRSM primarily focused on ecosystem structure and disturbances, and were not able to assess the desired *composition* of a given vegetation succession class for a given ecological system. LCF also does not assess the desired size of forest openings or other stand-level treatments.

Key Findings

The primary findings of the landscape conservation forecasting are summarized as follows:

The Landscape's Current Condition

- **The 515,000 acres of Park vegetation support a diversity of Southern Appalachian ecological systems**, ranging from lower elevation pine woodland to large cove forests to higher elevation spruce-fir forests. Eleven major ecological system types in GRSM were identified from the vegetation data, including seven oak and pine systems.
- **Three xeric oak and pine systems constituting 21% of GRSM show high ecological departure** – Dry Oak Forest, Low Elevation Pine Forest and Low Elevation Pine-Oak Heath.
- **Three other oak and pine systems – constituting another 21% of GRSM – are moderately departed from NRV** – Dry-Mesic Oak Forest, High Elevation Red Oak Forest, and Montane Pine-Oak Heath.
- **Three systems that are more mesic show low departure**, including the Cove Forest (itself almost one-fourth of GRSM), Northern Hardwood Forest and Mesic Oak Forest.
- **The primary reason for ecological departure across the landscape is due to overly closed canopy structure in the oak and pine systems**, as compared to more open structure under natural conditions. Across all systems, LIDAR data showed over 80% of GRSM's vegetation structure was closed canopy.
- **There is also a substantial shortfall of early succession and mid succession classes** in the forest as compared to natural conditions.
- **A century of fire suppression and exclusion in GRSM has been a primary cause** of these altered conditions.

The Landscape's Future Condition – Without Management

- **After 20 years, five oak and pine systems remain substantially departed from NRV (~50% or higher), and there is little improvement over the following 20 years.** Somewhat counter-intuitively, these systems do show some slight improvement over their current condition with No Action. A modest increase in early succession and open canopy occurs due to varied disturbances (insects, weather, and some fire) in the models, and over time, some early succession moves to mid succession.
    - Note: this "improvement" only represents improvement to structural classes; it does not account for continued detrimental changes that would likely occur to forest composition during these time periods.
- **Without prescribed fire, five fire-maintained ecosystems comprising almost 40% of GRSM will remain substantially departed from NRV.**

Future Condition – With Prescribed Fire

- **Maximum Management levels of prescribed fire (24,000 acres/year) essentially restore the oak and pine systems to low ecological departure.** The large amount of prescribed fire in these simulations approximates the natural fire regime and serves to open up the canopy and create early/mid succession classes that are much closer to NRV.
- **Current Management levels of prescribed fire (1,500 acres/year) achieve modest improvement in ecological departure scores.** After 40 years, the current level of prescribed fire achieves the greatest improvement in low elevation pine and low elevation pine-oak heath as compared to the No Action scenario. *Note: GRSM's ecological departure scores are based fundamentally on forest structure; current levels of prescribed fire are expected to improve vegetation composition for the managed systems, but this improvement is not accounted for in GRSM's ecological departure scores.*
- **Preferred Management levels of prescribed fire (5,000 acres/year) achieve continued, meaningful improvement over 20 and 40 years (see following table).**

Departure from Natural Range of Variability		
Ecological System	**No Action Ecological Departure 40 Yrs**	**Proposed Restore & Maintain (5K/Yr) Ecological Departure 40 Yrs**
Dry Oak Forest	**51**	**42**
Dry Mesic Oak Forest	**45**	**38**
Low Elevation Pine	**64**	**49**
Low Elev Pine-Oak Heath	**51**	**29**
Montane Pine-Oak Heath	**45**	**36**

- **GRSM's current and proposed allocation of prescribed fire among the ecological systems is reflective of their sizes and fire regimes and is achieving desirable results**.
- **Return on Investment (ROI) analysis also confirmed the allocations of prescribed fire among the systems.** There were very small differences in ROI across the five focal systems when their respective size in acres was taken into account.
- **The average annual cost of the Preferred Management prescribed fire is approximately $250,000 per year,** as compared to approximately $75,000 per year currently.
- **Reducing fire suppression/exclusion in GRSM would also improve ecological departure – recognizing, however, the many difficulties of implementing this strategy.** Current fire management practice allows approximately 7.5% of "natural" fire to occur; increasing this level to 15% would improve average ecological departure scores by 4 points over 40 years.

Preface

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Introduction

Stretching over 500,000 acres in the heart of the Southern Blue Ridge, the Great Smoky Mountains National Park (GRSM) represents a major North American refuge for temperate zone flora and fauna. GRSM is home to over 1,600 species of flowering plants, including 100 native tree species and over 100 native shrub species, as well as many rare or endemic plants and animals. It is widely considered among the most important natural areas in the eastern U.S. and is a designated World Heritage Site. However, GRSM is experiencing significant negative impacts from disruption of natural disturbances regimes – most notably the long-term exclusion of fire. Numerous studies and peer-reviewed papers have documented losses in ecosystem function and diversity resulting from the exclusion of fire (Flatley and others 2015, Harrod and others 2000, Harrod and others 1998, Turrill and others 1995, Harmon and others 1983, Dimmick and others 1980).

Determining the appropriate role of fire on any modern landscape is not a simple task. While fire exclusion has social and ecological costs, determining the need for management actions requires a carefully considered approach. Landscape Conservation Forecasting (LCF) is a management decision-making support tool that has been successfully used by public agencies in numerous landscapes across the United States (Low et al. 2010). Examples include the adjacent Cherokee National Forest (Medlock et al. 2012) as well as the Great Basin National Park in Nevada (Provencher et al. 2013). Benefits of using LCF include:

- Uses the best available science to develop and use reference conditions that describe a Natural Range of Variability (NRV) for each natural community (or *ecological system*) modeled
- Uses remote-sensing to assess the health of existing ecological systems
- Employs predictive ecological models to demonstrate how those ecosystems will change over time
- Utilizes computer simulations to assess how alternative management actions can influence those changes

- Measures success by calculating an ecosystem's departure from its NRV, on a scale of 1 to 100, with and without various management actions
- Uses local or expert derived knowledge
- Customizes management actions based on agency mandates or local constraints
- Provides a cost benefit analysis for management actions

In 2015, the National Park Service (NPS) and The Nature Conservancy (TNC) entered into an agreement to collaborate on landscape conservation forecasting for each of GRSM's ecological systems, with a focus on the fire-maintained forests of GRSM. The LCF project proceeded in two stages. Stage one processed and optimized existing park vegetation data, ecological zone data and LiDAR data for use in LCF. Stage two included four workshops in 2016 that engaged park staff and others to develop state-and-transition models for historical vegetation, complete the ecological departure analysis, and compare potential future management scenarios.

Project Area

Great Smoky Mountains National Park (GRSM) straddles the border between North Carolina and Tennessee (Figure 1). It encompasses over 500,000 acres, making it one of the largest protected areas in the eastern United States. The main park entrances are located along U.S. Highway 441 (Newfound Gap Road) at the towns of Gatlinburg, Tennessee, and Cherokee, North Carolina. It is the most visited national park in the United States.

The Great Smoky Mountains (also known as the Smokies) are a portion of the Appalachian Mountain range, among the oldest mountain ranges in the world. The Smokies are among the tallest mountains in the Appalachian chain. Within GRSM, elevations range from about 875' to 6,643', with sixteen peaks rising more than 5,000 feet. Mount Le Conte rises to 6,593' from a base of 1,292', making it the tallest (but not the highest), mountain in the Eastern United States. The GRSM's highest summit, Clingmans Dome, is the third tallest peak east of the Mississippi River (NPS 2016).

This range in altitude mimics the climate and habitat changes a person would experience driving north or south across the eastern United States. Plants and animals common in the southern United States thrive in the lowlands of the GRSM while species common in the northern states find suitable habitat at the higher elevations. The north-south orientation of the Appalachian chain allowed the Smokies to become a refuge for many species of plants and animals that were displaced from their northern homes by glaciers in the last ice age around 10,000 years ago.

In terms of weather, GRSM's abundant rainfall and high summertime humidity provide excellent growing conditions. In the Smokies, the average annual rainfall varies from approximately 55 inches in the valleys to over 85 inches on some peaks. The relative humidity in GRSM during the growing season is about twice that of the Rocky Mountain region.

Environmental conditions range from xeric (dry) ridgetops and rock outcroppings to very mesic (moist) coves and mountaintops that are often enveloped in low-lying clouds. Forest composition varies continually with differing combinations of elevation and exposure. Major forest community types include oak-hickory forest, hemlock forest, pine-oak forest, cove-hardwood forest, northern hardwood forest and spruce-fir forest (White and others 2004). Almost 95% of GRSM is forested, and about 20% of that area is old-growth forest.

GRSM is one of the most biodiverse parks in the National Park system. Biological diversity, or 'biodiversity', means the number and variety of different types of animals, plants, fungi, and other organisms in a location or habitat. No other area of equal size in a temperate climate can match GRSM's amazing diversity. Some 100 species of native trees find homes in GRSM, more than in any other North American national park. Over 1,500 additional flowering plant species have been identified in GRSM. GRSM is also the center of diversity for salamanders and is home to more than 200 species of birds, 68 species of mammals, 67 native fish species, 39 species of reptiles, and 43 species of amphibians. Mollusks, millipedes, and mushrooms reach record diversity there. All told, over 19,000 species have been documented within GRSM and scientists believe an additional 80,000-100,000 species may live there (NPS 2016).

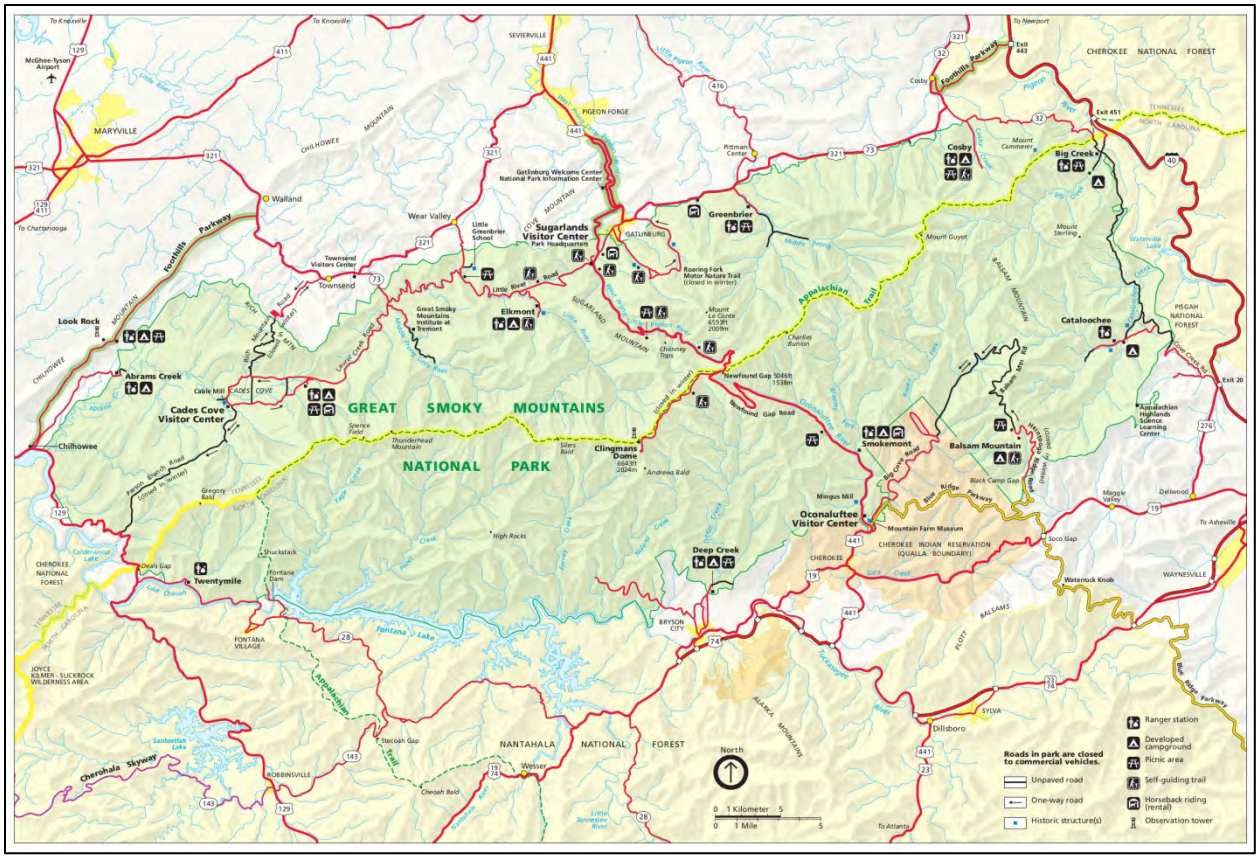

Figure 1. Great Smoky Mountains National Park.

Humans and the Landscape

The interaction between humans and the Great Smoky Mountains landscape has had a major impact on the vegetation and wildlife of the area for the past 10,000 years. The nature of these interactions and their effects on the natural landscape and biota have been studied by numerous authors, and no understanding of past or present vegetation can be complete without acknowledging humans as principal agents of disturbance and change.

The first humans to inhabit the area were very likely Paleo-Indians who arrived over 10,000 years ago. These people are known to have lived in small, multi-family bands that were a migratory, hunting and gathering society. The earliest physical evidence of human use of the Smokies landscape dates to the later Archaic Period, approximately 8000 years ago (Bass 1977). Societies during the Archaic Period were still mostly comprised of small, migratory groups that relied on hunting and gathering subsistence methods, though by the Late Archaic around 4000 years ago, humans had started to develop agricultural systems.

These trends toward plant domestication and larger, more complex and sedentary societies continued into the Woodland and Mississippian Periods, which began around 3000 and 1000 years ago, respectively. These larger societies were found in the river valleys and foothills surrounding GRSM - at sites along the Little Tennessee River, and in places like

modern-day Sevierville, Townsend, and Bryson City. Though these populations were centered in locations outside the modern-day Park, the GRSM landscape was continually utilized for hunting, collection of plant resources, and travel. Paleoecological evidence suggests that long-term, widespread use of fire by Woodland and Mississippian people had substantial impacts to the Southern Appalachian landscape, favoring forests dominated by fire-adapted species like oak, chestnut, and pine (Delcourt and Delcourt 1998). After the 16th century, Native American culture began to be heavily influenced by the European presence in North America, and resulted in the Cherokee culture that dominated the area when the first European settlers arrived.

The GRSM area was permanently settled in the late 1700s/early 1800s by pioneers of European descent. In the 1880s, the invention of the band saw and the logging railroad led to a boom in the lumber industry. As forests throughout the Southeastern United States were harvested, lumber companies pushed deeper into the mountain areas of the Appalachian highlands, including GRSM. The GRSM area was heavily logged in the early 1900s. Between 1910 and 1920, corporate lumbermen built railroads into the most remote watersheds and removed more than 60 percent of the old-growth forest (Brown 2000).

Extensive and intensive human-related disturbances in the pre-Park era were carefully chronicled in a 1985 Park research report by Charlotte Pyle (Pyle 1985). Pyle reported that logging occurred to some degree on approximately 70% of GRSM. Mechanized corporate logging occurred on 40% of GRSM, often followed by intensive fires. Diffuse disturbance occurred on 29% of GRSM (large tracts with patches of intensive logging; smaller forest stands with small logging operations, livestock grazing and frequent, non-intensive fires; and disturbed tracts where some big trees remained). Concentrated human settlement occurred on an additional 9% of GRSM. Conversely, 20% of GRSM was found to have little or no record of major disturbance from logging or settlement (Pyle 1988).

As a response to societal concerns about the rapidly vanishing wilderness, GRSM was chartered by the United States Congress in 1934. The mission of the National Park Service is "...to promote and regulate the use of ...national parks... to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations" (National Park Service Organic Act, 16 U.S.C.1.**).**

The human relationship to this landscape endures today in the conservation and protection of GRSM. The NPS Foundation Document for the GRSM (2016) (see excerpt below) serves as a guide for planning and decision-making to “protect resources and values that are integral to park purpose and identity.” The purpose statement and the values listed in the Foundation Document reflect the GRSM enabling legislation and the legislative history that accompanied the GRSM development.

Great Smoky Mountain National Park Foundation Document (2016) Purpose Statement :

Great Smoky Mountains National Park preserves a vast expanse of the southern Appalachian Mountains ecosystem including it scenic beauty, extraordinary diversity of natural resources, and rich human history, and provides opportunities for the enjoyment and inspiration of present and future generations.

https://www.nps.gov/grsm/learn/management/upload/GRSM_FD_SP.pdf

Fire in Great Smoky Mountains National Park

For thousands of years, wildland fires have been a common and repeated natural event in the Southern Appalachian region, including the area that is now called the Great Smoky Mountains (Underwood 2013, Flatley and others 2013, Laforest 2012, Fesenmyer and Christensen 2010, Delcourt and Delcourt 1998, Harmon 1982). The countless interactions between these frequent fires and weather, topography, and vegetation have played a critical role in the development of several of the widespread natural communities that are found in the Great Smoky Mountains.

Pine woodlands, oak forests, and chestnut forests (prior to the introduction of chestnut blight) were all expanded and maintained on the landscape by various regimes of recurring fire that resulted from both human ignitions and lightning (Flatley and others 2015, Delcourt and Delcourt 1998). Natural communities that are rare in the Southern Appalachian landscape, such as meadows and heath balds, were also very likely created or maintained by fire (Langdon 2005). Numerous other species - from grasses to birds to reptiles to insects - were able to thrive in the unique habitats that resulted from burning, thus increasing the genetic, species, and landscape diversity found throughout the region.

A primary goal of the National Park Service is to preserve native plants and animals inGRSM, as well as the natural processes which perpetuate them. Fire history and ecology research have clearly established wildland fire as one of the natural processes upon which many plants and animals depend. However, when the Great Smoky Mountains National Park was established in 1934, fire was seen as only a destructive force by park managers, and a policy of fire exclusion was instituted. This policy sought to prevent all wildland fires, and used people and tools to suppress any wildland fires that were started, whether by humans or lightning. This disruption of the thousands-year-old disturbance regime had many unforeseen impacts to GRSM ecology, and some of those impacts are still being discovered today - over 80 years after fire exclusion policies were originally put in place.

Historical Role of Fire

Studies of soil and pond charcoal provide direct evidence that wildland fires have occurred on the Southern Appalachian landscape for nearly 10,000 years (Underwood 2013, Fesenmyer and Christensen 2010, Delcourt and Delcourt 1998). Additionally, these paleoecology studies have used fossil pollen and species identification of charcoal fragments to show that prehistoric fires were associated with expanding forests of pine, oak, and chestnut. Though no direct evidence of ignition source exists for these ancient fires, Delcourt and Delcourt (2004) have developed a compelling body of work suggesting that: 1) use of fire by Native American populations was pervasive in the Southern Appalachian region, particularly during the Woodland and Mississippian cultural Periods, and 2) this pervasive use of fire was associated with “profound” impacts to vegetation composition and structure.

In addition to the prehistoric fire history developed from paleoecology, dendrochronology offers a higher-resolution picture of fire history over the past several centuries. Dendrochronology is the study of growth rings and fire scars from trees, and such research can provide data as to the specific year, season, associated climate, and specific fire frequency for a given site. Several dendrochronology studies have been completed within GRSM, with the focus on the pine and oak-dominated western end. These studies have demonstrated that for numerous sites in GRSM’s western end, fire was occurring quite frequently for the 100-200 years prior to GRSM establishment (Flatley and others 2013, Laforest 2012, Harmon 1982). When the results from these studies are viewed collectively, we have strong evidence that fires burned, on average, every 5-15 years through lower-elevation pine and oak forests in GRSM. Other studies and observations suggest that more remote or higher-elevation pine and oak sites may have burned less frequently (Brose and Waldrop 2006, Armbrister 2002, Harmon 1982).

These frequent fires acted in conjunction with climatic and soil factors to favor the widespread development and maintenance of disturbance-dependent woodlands and forests across the lower and middle elevations of GRSM. The specific roles that fire played in the GRSM landscape and within these natural communities include:

- Maintenance of structural heterogeneity (stand, watershed, and landscape scales)

- Selection of fire-adapted and sun-loving plant species
- Creation/maintenance of wildlife habitat
- Enhancement of biodiversity (genetic, species, community)
- Building resilience (by maintaining healthy populations of fire and drought tolerant species).

Consistent with the pattern of fine-scale vegetation diversity across the Southern Appalachian Mountains, numerous natural communities developed within the footprints of repeated fires. These natural communities included a wide array of woodlands and open forests dominated principally by a variety of yellow pines, oaks, and American chestnut. The sunny, open conditions resulting from frequent fire acted to favor regeneration of these species and to increase the cover and diversity of sun-loving grasses and forbs relative to the more shade-tolerant trees and shrubs that dominate the forest understory today (Harrod et al 2000). The structure and food resources (foliage, nectar, seeds, etc.) associated with these herb-dominated woodlands, in turn, provided the foundation for a rich ecological web that was essentially dependent on the occurrence of frequent fire.

Ecological Impacts of Fire Exclusion

The establishment of Great Smoky Mountains National Park in 1934 heralded a dramatic shift in the role of fire in the southern appalachian mountains. Concerns about damage to forest resources, impacts to scenic values, and protection of life and property led to policies of complete fire exclusion from the landscape. The prevention of wildland fires became a core goal, and when fires were started (by lightning or humans), GRSM managers acted to suppress the fire as quickly as possible. This focus on prevention, detection, and suppression resulted in a dramatic change to the fire regime that had acted on the GRSM landscape for thousands of years. The resultant decrease in fire frequency in the 20th century was recorded by the same dendrochronology studies that showed how fires were occurring frequently for centuries prior to park establishment (Flatley and others 2015, Laforest 2012, Harmon 1982).

This long-term exclusion of fire from GRSM forests has been a major factor driving changes to forest structure, function, and composition, particularly among forest types dominated by yellow pines (shortleaf, pitch, table mountain, and Virginia) and oaks. The ecological impacts of fire exclusion from GRSM include:

- Native pine and oak species have been greatly diminished, while fire sensitive trees and shrubs have proliferated. This has rendered many areas more vulnerable to wildfires, and changed vegetation to species poorly adapted to drought and a changing climate

- Wildland fuels - particularly duff, woody debris, and evergreen shrubs – have accumulated substantially, leading to a higher risk of more severe wildfires

- Sun-loving grasses and forbs, which are the foundation of biodiversity in dry forest communities, have been shaded out and reduced across the landscape

- Table mountain pine, which needs fire to release its seeds, has declined dramatically
- Unique 200-400 year old Shortleaf pine forests are threatened by forest pests and lack of regeneration.
- The federally endangered red-cockaded woodpecker, which depends upon fire- maintained mature pine forests for its habitat, was extirpated from GRSM in the 1980s
- Loss of habitat for a unique set of plants, insects, and wildlife that are not found in other parts of GRSM.

All of these changes are the direct result of long-term suppression and exclusion of fire, and they have been documented by GRSM scientists and managers over the past 40 years. These are only the most obvious impacts of fire exclusion in the most fire-prone portion of the GRSM landscape. In the longer term, the continued lack of fire will result in widespread declines in plant and animal diversity, increased difficulty in controlling unwanted wildfires, and will lead to dominance by species that are poorly adapted to drought, fire, and changing climatic conditions. These changes over such a substantial portion of the GRSM land base are believed to pose a serious threat to GRSM's ability to achieve its goals for protection of life and property and preservation of a diverse, resilient, and naturally functioning ecosystem.

Current Fire Management

The Fire Management Plan (FMP) of 1996 was developed as a response to direction in the GRSM General Management Plan, Resource Management Plan, and National Park Service policy to take action in order to prevent and reverse these negative impacts. The 2015 FMP provides the most current update to NPS policy and park direction for the management of fire, and includes the following goals:

GRSM Fire Management Goals

- Protect human life, communities, and resources from the adverse effects of wildfire without compromising safety
- Maintain and restore fire adapted ecosystems using appropriate tools and techniques in a manner that will provide sustainable, ecological and social benefits
- Integrate knowledge generated through fire and natural resource research into fire management priorities, decisions and actions
- Integrate fire as a natural process into GRSM's ecosystem to the fullest extent possible
- Communicate and coordinate with interagency organizations and other stakeholders to pursue common goals, programs and projects

- Build and promote organizational effectiveness by building program capacity, leadership, and effective management practices.

The protection of human life, property and resources from the adverse effects of wildfires remains the most important goal for fire management at GRSM. While the complete exclusion of fire was the policy until 1996, wildfires have still occurred. Over 900 wildfires have been recorded in GRSM between 1942 and 2016. There have been an average of approximately 13 wildfires per year in that time span, and over 70,000 total acres have burned. The vast majority (70%) of wildfires has been 10-acres or less in size, and nearly half (46%) have been 1-acre or less. Fires greater than 1000-acres have been very rare (1% of total), and the largest wildfire in GRSM history was the 17,140-acre (10,964 in Park) Chimney Tops 2 wildfire of November 2016.

Aside from re-emphasizing the primary objective of wildfire protection, the 1996 FMP recognized the importance of using fire to reverse the decades of fuel buildup and ecosystem decline. One of the tools identified as appropriate to achieve these objectives was the management of selected natural (lightning-caused) wildfires for resource benefits. Lightning ignitions have been recorded in GRSM since at least 1942, with over 144 total occurrences, or an average of 2 per year. Prior to 1996, the average size of these fires was 16 acres, and after 1996, the average size was 72 acres – the largest being the Chilly Spring Knob Fire of 2006 (913 acres). The total number of acres burned by managed lightning fires since 1996 is 2,949.

The other tools that were identified in the 1996 FMP were manual thinning of fuels and prescribed burning. Since 1996, manual thinning of fuels has occurred along the GRSM Wildland-Urban-Interface at several locations in Sevier and Blount Counties in Tennessee. These fuel reduction efforts have been accompanied by both pile-burning and broadcast-prescribed burning, with the primary goal to remove large numbers of evergreen shrub stems and heavy fuel accumulations from the GRSM boundary with private residences.

In areas of GRSM that could benefit from fire, the Park Service has conducted prescribed burns. Prescribed fire is a planned fire (also sometimes called a “controlled burn” or “prescribed burn”) and is used to meet management objectives. A prescription is a set of conditions that considers the safety of the public and fire staff, weather, and probability of meeting the burn objectives. Such fires have pre-determined boundaries and are ignited only under very specific conditions. Limiting conditions include weather, fuel moisture, soil moisture, availability of trained fire-fighting personnel, and air quality conditions.

GRSM has conducted 106 prescribed burns since 1996 for a total of nearly 20,000 acres, or an average of about 1000 acres per year. Some focal areas for the prescribed burns have included Cades Cove, Tabcat Creek, the landscape just west of Cades Cove known as “North of Abrams”, and the forests around Cataloochee Valley. Scientific monitoring is conducted before and after the burns to make sure the fires achieve the desired results. This monitoring has

shown that prescribed burns can successfully reduce fuels and restore fire-adapted species (Jenkins et al 2011), though multiple burns may be required to effectively achieve long-term objectives. The important work of fuels reduction and fire restoration will continue. In 2016, Great Smoky Mountains National Park produced a *Foundation Document* that reemphasized the important role of fire and prescribed burning in effectively managing GRSM resources into the future (see excerpt below).

Great Smoky Mountain National Park Foundation Document (2016)
Fire Management Excerpts :

*In "**Threats to Ancient Mountain Ecosystems:**"*

"Alteration of the natural fire regime is creating uncharacteristically dense forests or converting them to mixed mesophytic community types."

*In "**Trends of Biodiversity – Wondrous Variety of Life:**"*

"While the number of known species is increasing, overall biodiversity is decreasing due to the lack of natural disturbance (namely natural fire regimes)."

*In "**Threats to Biodiversity:**"*

"Climate change may reduce the range and distribution of some vegetation communities and amplify invasive species, diseases and pests, and possibly fire."

*In "**Opportunities for Biodiversity:**"*

"Prescribed and natural fire will continue to restore fire-adapted ecosystems including both open meadow and forest areas where fuel loads are high and increasing. Increased funding through federal or private sources is needed to expand this effort."

Finally, in the ***Wilderness Character Narrative***, the need for responsible fire management is summarized in the context of the "Natural" qualities of GRSM's wilderness:

"Restoration of some semblance of natural fire regimes would help to maintain the ecological integrity of fire-adapted habitats and associated wildlife species, while enhancing the diversity of vegetation in the wilderness."

https://www.nps.gov/grsm/learn/management/upload/GRSM_FD_SP.pdf

Objectives

The Great Smoky Mountains National Park's large landscape, with its legacy of decades of fire suppression, along with the promising more recent use of prescribed fire, now provide opportunities to improve the ecological condition of the fire-maintained ecosystems. The Landscape Conservation Forecasting project aimed to help make this happen.

The specific objectives for GRSM Landscape Conservation Forecasting project were as follows:

- Engage NPS Resource Management staff and regional experts to conduct highly credible research that contributes to the establishment of meaningful landscape-scale objectives, effective prioritization, and shared ownership of future fire management direction.
- Synthesize past and current research findings, remote sensing, and spatial data to inform a more complete understanding of past, current, and desired future conditions for fire-maintained forests.
- Use state-and-transition modeling to develop pre-settlement reference conditions for structure and composition of fire maintained forests in GRSM.
- Complete an ecological departure analysis that will highlight the greatest priorities for management action, and provide insight into fuels treatment objectives and effectiveness.
- Produce a final set of management scenarios for a 20-50 year time horizon to serve as a planning guide for future fire management plans, 5-year fuels treatment plans, and prescribed burn plans.

Process and Methods

Landscape Conservation Forecasting (LCF) has built upon and modified methodologies developed under the national interagency LANDFIRE program (Rollins 2009, LANDFIRE 2016) -- including mapping, models, and metrics -- to assess a landscape's ecological condition. The LCF process used for GRSM consisted of six primary components or steps, as follows:

1. Develop maps of potential vegetation types, called ecological systems, and current vegetation succession classes (s-classes) within ecological systems.
2. Refine computerized predictive state-and-transition ecological models for the ecological systems by updating previously developed models, or developing new models as needed.
3. Determine current condition of all ecological systems (a broad-scale measure of their "health"), using the ecological departure metric. Ecological departure is measured by comparing the current condition of vegetation with the Natural Range of Variability (NRV), which represents the reference condition for the ecological systems.
4. Use computerized ecological models to forecast anticipated future condition of ecological systems with no management action.
5. Use the computerized ecological models to forecast anticipated future condition of ecological systems under alternative management strategies and scenarios.
6. Use return-on-investment analysis to assess which strategies for which ecological systems yield the most advantageous results.

A schematic diagram that displays the relationship of these components to each other is presented below (Figure 2):

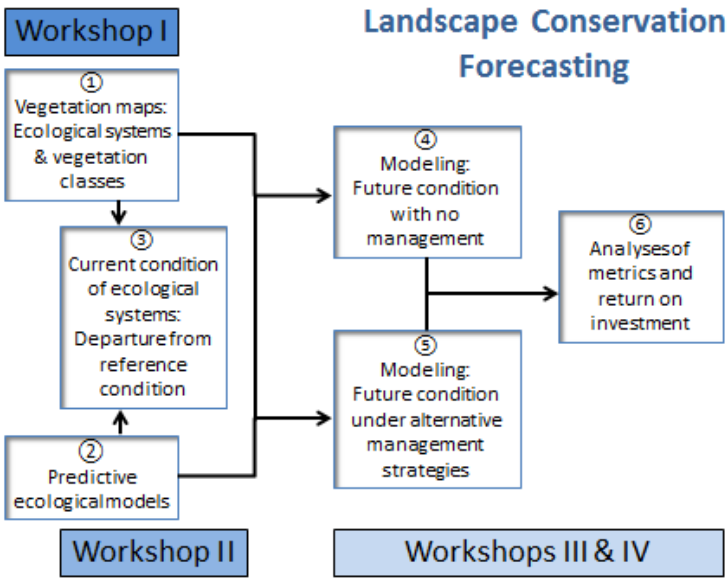

Figure 2. LCF Process Diagram.

The LCF project at GRSM proceeded in two stages. Stage one processed and optimized existing park vegetation data, ecological zone data and LiDAR data for use in LCF. Stage two included four workshops in 2016 that engaged park staff and others to develop state-and-transition models for historical vegetation, complete the ecological departure analysis, and compare potential future management scenarios.

Detailed descriptions of methods used in each of the project's component steps are presented in the following subsections.

Vegetation Data

The fundamental elements of LCF's ecological departure analysis include: 1) mapping the distribution of ecological systems as potential natural vegetation – i.e., the dominant vegetation types expected in the physical environment under a natural disturbance regime; 2) mapping current vegetation succession classes of each ecological system; and 3) for each ecological system, comparing the current structural class distribution with the expected "natural" distribution and calculating each system's departure from its NRV. NRV is the percentage of each vegetation succession class that would be expected under a natural disturbance regime.

Steve Simon (Ecological Mapping and Fire Ecology, Inc.) was engaged to develop a map of GRSM potential natural vegetation and integrate this map with current vegetation data. Existing datasets were reviewed and processed, including current and historic vegetation mapping, ecological zone mapping, disturbance history, and fire history. A set of crosswalks and decision rules were applied as needed to conform with the LANDFIRE-based vegetation data classification methods used by LCF.

Spatially referenced data is necessary for determining composition and structure parameters and for evaluating LCF results at a given project area. The following vegetation data were spatially defined in a Geographic Information System (GIS) for GRSM. These data were grouped within NatureServe's Ecological Systems classification approach (Comer et al. 2003) which is deployed by LANDFIRE and LCF:

1. Potential Natural Vegetation, defined as either -
    a. Biophysical Settings (BpS): 'the vegetation that may have been dominant on the landscape prior to Euro-American settlement based on both the current biophysical environment and an approximation of the historical disturbance regime' (LANDFIRE 2016), or
    b. Ecological Zones: 'units of land that delineate the environment that can support a specific plant community or plant community group under historical disturbance regimes that may or may not represent current vegetation composition' (Simon 2011).

2. Current/Existing Vegetation, as determined by existing vegetation mapping geospatial data, generally created through interpretation of aerial photography or remotely-sensed data.
3. Succession Classes, identified primarily by –
    a. canopy height, and
    b. canopy gaps and/or dNBR (pre- and post-fire Landsat imagery radiance and reflectance values), and
    c. canopy cover (tree and evergreen shrub)

The following sub-sections providing details on the mapping of potential natural vegetation, current vegetation and succession classes are extracted from Simon's report.

Potential Natural Vegetation

Three primary data sources were available for developing a map of potential natural vegetation suitable for NRV measurements at GRSM:

1) An existing vegetation map produced in 2003 (1:15,000 scale) that included 173 dominant vegetation types and two companion documents that, in combination, provided a rough cross-walk between the dominant vegetation types and ecological systems:
    a. Final Report May 2003: 'Vegetation classification of Great Smoky Mountains National Park': Unpublished report submitted to BRDNPS Vegetation Mapping Program. NatureServe: Durham, NC. (White, R.D., K.D. Patterson, A. Weakley, C.J. Ulrey, and J.Drake. 2003)
    b. Draft Report May 2004: Vegetation Classification System Outline for Mapping Great Smoky Mountain National Park (Center for Remote Sensing and Mapping Science (CRMS) Department of Geography, the University of Georgia & NatureServe-Durham Office.
2) A preliminary grouping of the 173 dominant vegetation types by reference and current condition, Great Smoky Mountains Park Ecological Systems, and LANDFIRE Ecological Systems (GRSM staff - Rob Klein), and
3) An Ecological Zone map (10 meter resolution) produced in 2011 that included 21 Zones and 12 Ecological Systems and a companion document that described these types (Ecological Zones in the Southern Blue Ridge 3rd Approximation, S.Simon, 2011: Unpublished report submitted to the National Forests in North Carolina).

GIS map representations of these data were produced for ecological systems from both intersected and independent data coverages; these GIS map data were then evaluated at both broad and local landscape levels. Some relatively minor map unit errors in both mapped data sources were evident. For example, for the Cades Cove and Mount Guyot USGS quads, data reflected different photo interpreter's judgment of existing vegetation classes. However, these errors were very localized.

Based upon these observations, a "hybrid" map of potential natural vegetation was produced that included the best elements from the existing vegetation and ecological zone

maps, along with a collaborative effort at developing a crosswalk / rule set that defined ecological systems. The final ecological system "rules" are included in Appendix 1.

The hybrid map included some minor adjustments of polygons based upon an analysis of over 300 field reference plots that were used in both the existing vegetation and ecological zone map development. Approximately 620 acres, primarily at higher elevations, were adjusted to better reflect ecological systems where reference plots were not in agreement with existing vegetation map units.

The hybrid map was created to allow flexibility for different types of ecosystem evaluation, i.e., types were split as much as the data would allow but could be easily aggregated. For example, Spruce and Fir types were identified separately, but combined for the LCF ecological system analysis. On the other hand, some ecological systems were split into elevation or moisture-temperature gradients to reflect major types that were evident in the field and for which differences existed in disturbance regimes. For example, the oak types were split into four systems - Dry Oak Forest, Dry-Mesic Oak Forest, Mesic Oak Forest, and High Elevation Red Oak Forest based on differences in composition and fire regime. A total of eleven ecological systems were identified in the final map (Table 1).

Other highlights of the final hybrid map of potential natural vegetation include:

- Low Elevation Pine-Oak ecological system split into: (1) Low Elevation Pine-Oak Heath at elevations < 2,300' and within the Pine-Oak Heath Ecological Zone, and (2) Low Elevation Pine = other Pine-Oak existing vegetation < 2,300' (all Yellow Pine-Oak > 2,300 = Montane Pine-Oak Heath),
- Identified Northern Hardwood, Hemlock-Northern Hardwood, and Beech Gaps but aggregated these into the Northern Hardwood ecological system,
- Identified Hemlock and Hemlock-White Pine but these aggregated to Acidic Cove,
- Identified Acidic Cove and Rich Cove but aggregated these types to the Cove Forest ecological system, and
- Split White Pine-Oak into either Dry Oak or the ecological zone model prediction.

Approximately 90% of the final hybrid map area was derived by grouping existing vegetation map units into logical ecological systems; approximately 10% of the area was derived from ecological zone models.

Table 1: Ecological systems identified by the hybrid map. Original LANDFIRE-based system names were shortened for naming GRSM systems for LCF

LANDFIRE Ecological System Name	System Name for GRSM LCF	Acres
Central and Southern Appalachian Spruce-Fir Forest	Spruce-Fir Forest	40,830

Southern Appalachian Northern Hardwood Forest	Northern Hardwood Forest	67,830
Southern and Central Appalachian Cove Forest	Cove Forest	123,900
Central Interior and Appalachian Riparian and Floodplain Systems	Montane Alluvial	7,920
Central and Southern Appalachian Montane Oak	High Elevation Red Oak Forest	22,410
Central and Southern Appalachian Northern Red Oak-Chestnut Oak	Mesic Oak Forest	60,560
Southern Appalachian Oak Forest – dry type Southern Appalachian Oak Forest – dry-mesic type	Dry Oak Forest Dry-Mesic Oak Forest	80,370 65,850
Southern Appalachian Montane Pine Forest and Woodland - high elevation type Southern Appalachian Montane Pine Forest and Woodland - low elevation type	Montane Pine-Oak Heath Low Elevation Pine-Oak Heath	18,760 8,760
Southern Appalachian Low-Elevation Pine Forest	Low Elevation Pine Forest	17,870
Not included in LCF evaluation (developed areas, roads, balds, water, fields, etc.)		29,130
TOTAL		544,190

Current (Existing) Vegetation

Ecological departure analysis requires that both the potential and existing vegetation are defined as ecological systems map units. The GRSM existing vegetation map produced in 2003 clearly defined vegetation composition at that time; this map was used to define current vegetation types. The significant but highly localized forest disturbances that have occurred since the 2003 map was produced have been documented and were included in the evaluation of vegetation succession classes for the LCF analysis.

For approximately 90% of GRSM, the current/existing ecological systems were identified from the 173 dominant vegetation types defined in the 2003 map following the same logic and groupings used to identify potential natural vegetation types.

The other 10% of the area (52,260 acres) included the following more generalized “types” that could not be accurately placed within an ecological system using the dominant vegetation type classification:

- Southern Appalachian Early Successional Hardwoods (19,710 ac.),
- Southern Appalachian Mixed Hardwood Forest (Acidic) (23,355 ac.),
- High Elevation Xeric Woodlands (885 ac.),
- Eastern White Pine and Mixed Eastern White Pine-Dry Oak (7,027 ac),
- Eastern White Pine-Mesic Oak Forest (548 ac.), and

- Chestnut Oak/Hardwoods with White Pine (735 ac).

Ecological zone maps were used to approximate where these types fit within ecological systems (Table 2).

Table 2: Ecological systems used in the LCF identified by ecological zone in the hybrid model

LANDFIRE Ecological System Name	System Name for GRSM LCF	Acres
Central and Southern Appalachian Spruce-Fir Forest	Spruce-Fir Forest	1,470
Southern Appalachian Northern Hardwood Forest	Northern Hardwood Forest	2,640
Southern and Central Appalachian Cove Forest	Cove Forest	25,990
Central Interior and Appalachian Riparian and Floodplain Systems	Montane Alluvial	1,010
Central and Southern Appalachian Montane Oak	High Elevation Red Oak Forest	2,210
Central and Southern Appalachian Northern Red Oak-Chestnut Oak	Mesic Oak Forest	8,870
Southern Appalachian Oak Forest Southern Appalachian Oak Forest	Dry Oak Forest Dry-Mesic Oak Forest	680 5,150
Southern Appalachian Montane Pine Forest and Woodland - high elevation type	Montane Pine-Oak Heath	3,210
Southern Appalachian Low-Elevation Pine Forest	Low Elevation Pine Forest	900
Not included in LCF evaluation (developed areas, roads, balds, water, fields, etc.)		140
TOTAL		52,260

Ecological zone maps were also used in combination with GRSM existing vegetation map to identify "highly departed vegetation" (i.e., uncharacteristic) classes. LANDFIRE describes a vegetation class that is outside the historic range of variability in vegetation composition and structure as "uncharacteristic" – either uncharacteristic native vegetation or uncharacteristic exotic vegetation. For example, cheatgrass (an exotic annual grass) that occurs in sagebrush ecological systems in the Western U.S. is often used to characterize an 'uncharacteristic exotic' LANDFIRE condition. The extent and severity of this type of uncharacteristic condition does not occur in ecological systems within GRSM. However, uncharacteristic classes can also include native vegetation when the vegetation structure or composition would not have been expected to occur on the ecological system during the reference condition period. Within GRSM, only 5,475 acres were found to be of this uncharacteristic type, which were labeled as "highly departed vegetation"; they include stands where tulip poplar is dominant in Oak ecological systems or where white pine or oak is dominant in Low Elevation Pine or Pine-Oak Heath ecological systems.

Succession Classes (s-classes)

Seral Stages

Forest seral stages are most easily categorized by stand age. Stand age is used in the 5-box LANDFIRE ecological models (see following section) to define early, mid, and late succession classes. Stand age, however, is not available spatially for GRSM and consequently a combination of factors was needed to estimate seral stages for the GRSM ecological systems.

At the time of GRSM establishment in 1934, over half of the total area of GRSM had been cut over by large corporately owned logging companies, and pioneers had settled and farmed in some areas for 100 years (Pyle, 1985). Most of the logging occurred between 1910 and 1930 (Brown, 2001) which would suggest an average current age of 86 to 106 years for over half of GRSM, i.e., at or near late seral condition for most ecological systems. Pyle (1985) also identified and mapped over 110,000 acres as "undisturbed" at the time of park establishment. This would suggest that much of these areas are likely in late seral "old growth" condition because there has been no extensive logging or widespread natural stand-replacing disturbance since park establishment.

Although disturbance history data would indicate that most forests in GRSM are late successional, natural disturbances (e.g., wind and fire) have occurred since park establishment that have caused localized stand replacement and more widespread canopy gaps. These disturbances have either reset succession to early seral stages or maintained mid-successional conditions, but not all of these disturbances have been documented or mapped. In order to estimate where these conditions might occur, tree canopy height and canopy gap size were considered to be suitable surrogates or indicators of stand age and therefore seral condition. LiDAR (Light Detection and Ranging) data were available across GRSM and were used to spatially measure canopy height. The LiDAR data were processed at 3 meter resolution.

Early succession vegetation was defined as forests where canopy height is less than 20' in canopy gaps greater than 1/20 of an acre in size, regardless of ecological system. A similar method was applied and field reviewed on the adjacent Nantahala-Pisgah National Forests and proved reasonably accurate (Josh Kelly, personal communication). In addition, early succession was evaluated from 12 documented disturbance events (wildfire, prescribed fire, and a tornado), three of which occurred after the 2009 acquisition of LiDAR data. The relationship between LiDAR early succession estimates and dNBR (the difference in pre- and post-disturbance vegetation radiance and reflectance values) were evaluated to estimate early succession in the largest of these disturbance events, the 2011 tornado concentrated in the Calderwood USGS quad. A dNBR score of > 270 was considered indicative of significant canopy mortality and found to correlate well with LiDAR early succession estimates for disturbance events documented from 1986 to 2009 (pre LiDAR acquisition).

Determining mid-succession forest was also accomplished using canopy height (although with somewhat less confidence for this hard-to-determine seral stage, which GRSM staff have found to be much less prevalent in the GRSM current vegetation structure). Height growth rates for different species on different sites were considered and the following "rules" established to identify mid-successional classes:

- canopy height > 20’ but < 60’ in Low Elevation Pine, Dry-Mesic Oak, Mesic Oak, Cove Forest, Northern Hardwood Forest, Spruce-Fir, and Alluvial Forest ecological systems, and
- canopy height > 20’ but < 30’ in Montane Oak, Low Elevation Pine-Oak Heath, Montane Pine-Oak Heath, and Dry Oak ecological systems.

All other areas within GRSM, except those excluded from the LCF analysis (developed areas, roads, balds, water, and fields*)* were considered late-succession vegetation. Areas mapped as “undisturbed” by Pyle (1985) were separately identified as “old growth,” which could be used as a potential “Late 2” seral stage in the ecological models.

Canopy Cover

In addition to seral stages, canopy cover is the other key component of identifying vegetation s-classes in the LANDFIRE methodology. LANDFIRE models typically include both Open and Closed canopy cover for the Mid and Late seral stages. Early succession is typically classified as Open canopy structure.

Due to the high degree of competition and shading that can result in areas of GRSM that have dense evergreen shrub cover, shrub cover was included as a factor in the determination of canopy cover. The LiDAR data were used to estimate both canopy cover and evergreen shrub cover. The following rules were used to define open and closed canopy classes within different succession classes in the ecological models:

- mid-succession open canopy class =
    - canopy cover < 60% and shrub cover < 75% (all ecological systems)
- mid-succession closed canopy class =
    - canopy cover ≥ 60% or shrub cover > 75% (all ecological systems)
- late-succession open canopy class =
    - canopy cover < 80% in the Cove Forest ecological system
    - canopy cover < 80% and shrub cover < 75% in the Mesic Oak ecological system
    - canopy cover < 60% and shrub cover < 75% in all other Oak ecological systems
    - canopy cover < 60% and shrub cover < 75% in all Pine-Oak ecological systems
    - canopy cover < 60% in Northern Hardwood, Spruce-Fir, and Alluvial Forest systems
    - dNBR > 270 within the 2011 tornado disturbance area
- late-succession closed canopy class =
    - canopy cover ≥ 80% in the Cove Forest ecological system
    - canopy cover ≥ 80% or < 80% and shrub cover > 75% in the Mesic Oak ecological system
    - canopy cover ≥ 60% or < 60% and shrub cover > 75% in all other Oak ecological systems
    - canopy cover ≥ 60% or < 60% and shrub cover > 75% in all Pine-Oak ecological systems
    - canopy cover ≥ 60% in Northern Hardwood, Spruce-Fir, and Alluvial systems

Ecological Models

Landscape Conservation Forecasting uses state-and-transition models to estimate vegetation succession class distributions for reference conditions and to simulate future management scenarios. A state-and-transition model is a discrete non-spatial, box-and-arrow representation of the continuous variation in vegetation composition and structure of an ecological system (Bestelmeyer et al. 2004). The LANDFIRE program worked with hundreds of experts to develop state-and-transition model descriptions for every terrestrial ecological system in the United States. These descriptive models are accompanied by quantitative models that can be viewed and manipulated in ST-Sim State-and-Transition Simulation Model (hereafter ST-Sim), computer-based simulation software developed with LANDFIRE support by Apex Resource Management Solutions. ST-Sim is a successor program to the Vegetation Dynamics Development Tool (VDDT) used in earlier LCF applications. LANDFIRE used the computer models to estimate reference conditions (also referred to as "Natural Range of Variability" or NRV) for each ecological system, which are then used to help evaluate ecosystem health through the ecological departure metric (Low et al. 2010; LANDFIRE 2016).

At their core, LANDFIRE models have the reference condition represented by some variation around succession classes labeled by five “boxes” (Figure 3). Each box represents a distinct developmental stage of forest growth, usually from early succession herbaceous vegetation to increasing woody species dominance where the dominant woody vegetation might be shrubs or trees. Two classes (boxes) typically represent mid-succession seral stages, and two classes (boxes) represent late-succession stages. Each Class is also considered to be either Open or Closed canopy. Therefore the 5th box for a forest system might represent Late-succession (e.g., age 71+), Open-canopy condition (Figure 3).

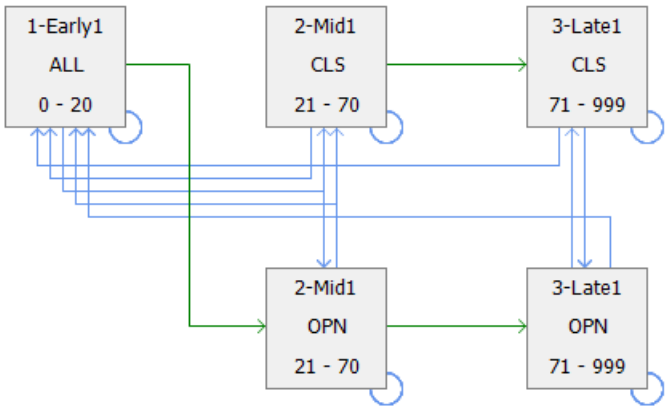

Figure 3. S-classes with age ranges and transition pathways for Dry Oak Forest model in ST-Sim. Green lines represent primary succession pathways. Blue lines represent transitions due to disturbances.

The models all incorporate the relevant natural disturbances that influence each ecological system. Disturbances for forest systems might include fire, insects, disease, wind, and weather events. These disturbances may be further sub-divided – fire typically includes surface fire, mixed fire and replacement fire. Each disturbance has an average return interval under natural conditions (e.g. 100 year return interval for replacement fire); these return

intervals for disturbances are converted into probabilities for a given year in the ST-Sim software (i.e., a 100 year return interval equals a .01 probability that replacement fire will occur in any given year). The replacement fire would typically convert a mid-succession or late-succession class back to an early succession state in the ST-Sim software.

In addition to modeling reference conditions, the predictive models allow for addition of management actions to allow managers to simulate future conditions under alternative management strategies and scenarios (Low et al. 2010; TNC 2009).

Models and Descriptions

State-and-transition models were reviewed and refined for nine ecological systems within GRSM. These systems included: Dry Oak Forest, Dry-Mesic Oak Forest, Mesic Oak Forest, High Elevation Red Oak Forest, Low Elevation Pine Forest, Low Elevation Pine-Oak Heath, Montane Pine-Oak Heath, Cove Forest, and Northern Hardwood Forest.

Most of these models had a long "lineage" going back to original LANDFIRE models, and many were subsequently refined for LCF application in the Cherokee National Forest Landscape Restoration Initiative (Medlock 2012). Additional refinements were made for the Nantahala-Pisgah National Forest by Gary Kauffman, USFS Botanist, and Kori Blankenship with the TNC-LANDFIRE program. These latter models were used as the starting point for refinements and modifications for LCF models at GRSM. An entirely new model was developed for one system, the Low Elevation Pine-Oak Heath, building off the model parameters for similar systems.

Special attention was directed towards refining the models for the seven oak and pine-dominated systems, several of which are highly fire-dependent. In particular, the fire return intervals (FRI) for all three types of fire (surface, mixed and replacement) were compared across all of the oak and pine systems, and refinements made by GRSM resources staff based upon their experience in GRSM, knowledge of the systems, and available scientific literature. The fire return intervals for the reference condition models of the oak and pine systems are displayed in Table 3 below. The shortest FRI is 8 years for surface fire in Early and Mid-Open classes of Low Elevation Pine. The longest FRI is 333 years for replacement fire for Mid-Open and Late-Open classes in Mesic Oak. A discussion of the fire regime and development of model parameters is included in the descriptions of ecological systems (Appendix 2).

Other relatively minor adjustments and refinements were made to the Kaufmann model parameters in the process of comparing age ranges for the succession classes, other disturbances (e.g., insects, weather) and alternative succession (i.e., conversion Open to Closed condition in absence of fire) across systems. These changes are documented in the ST-Sim model database descriptions.

Kaufmann's revised LANDFIRE models for Cove Forest and Northern Hardwood Forest at the Nantahala-Pisgah National Forest were used to assess conditions for these two systems at GRSM. The FRIs in the models for these two mesic systems were very long, with replacement

fire occurring every 1000 years for Cove Forest and every 667 years for Northern Hardwood, as well as infrequent Surface and Mixed fire. These two systems account for approximately 38% of the vegetation in GRSM, but represent a very small fraction of the fire across all systems within GRSM in the reference condition models (see Appendix 6).

The LANDFIRE-based models for two other ecological systems – Montane Alluvial and Spruce-Fir Forest – were not reflective of these systems within GRSM. Trying to refine or rebuild these models had issues going beyond the project team's expertise and the scope of the project; accordingly, these models were not used for the LCF project.

Table 3. Fire return intervals, by s-class, for GRSM 9 modeled ecological systems. The shaded bars for each system display the average FRI for all 5 s-classes.

	Type of Fire		
	Surface	Mixed	Replacement
Dry Mesic Oak	**28**	**127**	**224**
Early	29	50	83
Mid-Closed	29	83	200
Mid-Open	20	200	303
Late-Closed	32	100	200
Late-Open	22	200	333
Dry Oak	**17**	**73**	**136**
Early	15	22	67
Mid-Closed	18	56	100
Mid-Open	12	100	200
Late-Closed	20	77	111
Late-Open	13	111	200
High Elevation Red Oak	**33**	**102**	**163**
Early	25	50	67
Mid-Closed	37	91	100
Mid-Open	25	125	200
Late-Closed	40	100	200
Late-Open	28	143	250
Low Elevation Pine	**10**	**74**	**145**
Early	8	20	100
Mid-Closed	10	50	100
Mid-Open	8	100	200
Late-Closed	11	77	125
Late-Open	9	125	200
Low Elev Pine-Oak Heath	**14**	**55**	**115**
Early	12	15	50
Mid-Closed	15	34	75
Mid-Open	12	75	149
Late-Closed	17	50	100
Late-Open	13	100	200
Mesic Oak	**37**	**175**	**243**
Early	33	67	100
Mid-Closed	37	143	200
Mid-Open	33	250	333
Late-Closed	40	167	250
Late-Open	37	250	333
Montane Pine-Oak Heath	**22**	**60**	**97**
Early	20	25	50
Mid-Closed	22	50	75
Mid-Open	20	75	125
Late-Closed	25	67	83
Late-Open	22	83	149

	Surface	Mixed	Replacement
Cove Forest	**100**	**500**	**1000**
Early	100	500	1000
Mid-Closed	100	500	1000
Mid-Open	100	500	1000
Late-Closed	100	500	1000
Late-Open	100	500	1000
Northern Hardwood	**333**	**667**	**667**
Early	333	500	667
Mid-Closed	333	667	667
Mid-Open	333	500	667
Late-Closed	333	667	667
Late-Open	333	1000	667

"Back tests" were conducted on the models of two representative fire-dependent systems – Dry Oak Forest and Low Elevation Pine Forest – to help confirm the validity of the fire-return intervals and other key variables in the models. These tests were designed to roughly mimic the major human-caused disturbances in GRSM over the last century and see if the models would generate results that approximate actual current conditions. Using ST-Sim, the back tests populated the reference condition s-classes as the Initial Conditions for these two systems as of 1910. It then simulated heavy logging (50% clearcut) over a 20 year period, and recorded the s-class outcomes after those simulations as new Initial Conditions as of 1930. It then simulated 85 years of 98% fire suppression and recorded the s-class outcomes after those simulations. The final simulated 2015 results for both systems very closely tracked actual current conditions with only about 10% overall variance (Appendix 3).

The project team considered and tested both 5-box and 7-box models for GRSM's ecological systems. 7-box models had been developed for several ecological systems in the Cherokee National Forest in order to account specifically for old-growth forest, which was determined to need special attention in regard to National Forest management decisions. "Late 2" classes were added for both Open and Closed old-growth condition, thereby creating 7-box models. This approach was continued for the Nantahala-Pisgah models.

However, after reviewing simulations for both 5-box and 7-box models at GRSM, it was determined that the 5-box models provided sufficient, simpler and clearer information. This was the case for several reasons: (1) GRSM manages for overall natural conditions and does not need to focus special attention on managing for old growth forest, unlike the National Forests which manage for multiple use including timber harvest; (2) GRSM has abundant old growth forest – approximately 20% – due to an absence of logging since GRSM park establishment; (3) much of GRSM's current late-succession forest that is not *now* old growth will soon *become* old growth due to natural aging of the forest, which was heavily logged about a century ago; and (4) the disturbance parameters for the old-growth classes in the 7-box models were identical to the late-succession classes in the 5-box models, thereby providing no distinction in the combined late-class outcomes in simulations.

Descriptions of all ecological systems are provided in Appendix 2. Model parameter values for the age ranges of classes (deterministic transitions) are provided in Appendix 4. Model parameter values for all disturbances (probabilistic transitions) are provided in Appendix 5. The ST-Sim model databases, including outcomes of all simulations, are available online at https://tnc.app.box.com/s/489f7i45kmbjkskgc0tsd4wrcq2c4a9t/1/8487753965. They will also be made available on the NPS Date Store.

Natural Range of Variability

The vegetation composition and structure prior to European settlement was considered to be each ecological system's reference condition or natural range of variability (NRV). ST-Sim model runs were conducted to re-simulate NRV, using 10 simulations over a 1,000 year time horizon. The mean natural range of variability for each ecological system is listed below in Table 4.

The project team considered and tested using a *range* for the frequency of each disturbance regime (as was included in the Nantahala-Pisgah models) to estimate NRV (Blankenship 2015). For example, instead of a surface fire return interval of 17 years for the Dry Oak system, the *range* may be 5-20 years. This approach calculates a *range* of NRV for each s-class, in addition to a *mean* score. [While the mean NRV provides a useful benchmark, land managers and researchers are often interested in knowing the range of variability around the mean.] However, this methodology requires determining not only an *average* return interval for each disturbance in the models, but also a *minimum* and a *maximum* return interval for each disturbance. The GRSM LCF project team did not feel there was sufficient science information to establish these minimum and maximum return intervals with confidence, and therefore used the traditional LANDFIRE methodology with stochastic variance in ST-Sim for determining mean-based NRV.

Table 4. The natural range of variability for the GRSM nine modeled systems.

Ecological System	Vegetation S-Class				
	Early	Mid-Closed	Mid-Open	Late-Closed	Late-Open
Dry Oak Forest	17%	9%	21%	24%	29%
Dry-Mesic Oak Forest	9%	9%	18%	32%	31%
Mesic Oak Forest	6%	17%	14%	46%	17%
High Elevation Red Oak Forest	14%	14%	12%	37%	23%
Low Elevation Pine Woodland	13%	10%	30%	12%	35%
Low Elevation Pine-Oak Heath	21%	13%	30%	15%	21%
Montane Pine-Oak Heath	25%	16%	25%	15%	19%
Cove Forest	4%	24%	4%	57%	11%
Northern Hardwood Forest	6%	22%	1%	59%	12%

Assessment of Ecological Condition - Metrics

Ecological Departure

The ecological departure methodology was used to assess the overall ecological condition of each of the modeled systems. Ecological departure is a broad-scale measure of ecosystem "health" – an integrated, landscape-level estimate of the ecological condition of terrestrial and riparian ecological systems. Ecological departure estimates an ecological system's *departure* from its NRV. The level of departure, or dis-similarity, from NRV for each ecological system was calculated by comparing the current vegetation succession-class distribution with the expected "natural" distribution (see Dry Oak example in Table 5).

Ecological departure (Low et al. 2010) – currently known in LANDFIRE as Vegetation Departure or VDEP (LANDFIRE 2016) – is scored on a scale of 0% to 100% departure from reference conditions: Zero percent represents NRV while 100% represents total departure from NRV [i.e., the higher the number, the greater the departure]. Originally In LANDFIRE, a coarser-scale metric known as Fire Regime Condition Class (FRCC) was used by federal agencies to group ecological departure scores into three classes (FRCC Guidebook 2010): FRCC 1 represents ecological systems with low (<34%) departure, which is color coded green; FRCC 2 indicates ecological systems with moderate (34 to 66%) departure, which is color coded yellow; and FRCC 3 indicates ecological systems with high (>66) departure, which is color coded red. The new VDEP-based metric in LANDFIRE is called Vegetation Condition Class (VCC) rather than FRCC. VCC now provides a six-category classification system in addition to the original three class-FRCC system. The LCF scorecard at GRSM therefore uses six color shades (two red shades for >66, orange for >50, yellow for > 33, and two green shades for <33). An example of ecological departure scoring is shown in Table 5.

Table 5. Calculation of Ecological Departure for Dry Oak at GRSM

Dry Oak Forest				
Vegetation Class	**NRV** Mean	**Current %**	Current Acres	Delta vs Mean NRV
Early	17%	2%	1,600	-15%
Mid-Closed	9%	0%	0	-9%
Mid-Open	21%	0%	100	-21%
Late-Closed	24%	90%	72,300	66%
Late-Open	29%	8%	6,200	-21%
Highly Departed Composition	0%	0%	100	0%
Totals	100%	100%	80,300	0
Ecological Departure		**66**		

Ecological Departure = 100% – $\sum_{i=1}^{n} \min\{Current_i, NRV_i\}$

Other Metrics Considered

Ecological departure can be caused by two factors: departure from the expected natural seral stage structure and/or departure from the expected natural canopy structure. For LCF at GRSM, a new *Open Canopy Departure* metric was used as a working metric by the project team to quickly assess the departure from historical open canopy conditions. This metric proved to be a useful analysis tool since much of the ecological departure of the fire-dependent systems was often accounted for by the forest's overly closed canopy conditions due to long-time fire suppression. The calculation was derived by adding the total percentage of Mid-Closed and Late-Closed classes, and then subtracting the combined NRV percentages for these two classes. In the Dry Oak example, as shown in Table 6 below, total current Closed canopy is 90% as compared to NRV closed canopy of only 33%; the difference is 57%. As with the Ecological Departure metric, a score of 0 would represent no departure from historic open conditions, whereas higher scores would indicate more overly closed forest conditions. For the Dry Oak system, Open Canopy Departure was 57% as compared to the 66% overall Ecological Departure, meaning that much of the ecological departure was attributable to departure in canopy structure (versus changes in seral stage).

Table 6. Calculation of Open Canopy Departure for Dry Oak at GRSM

Dry Oak Forest				
Vegetation Class	**NRV** Mean	**Current %**	Current Acres	Delta Mean
Early	17%	2%	1,600	-15%
Mid-Closed	9%	0%	0	-9%
Mid-Open	21%	0%	100	-21%
Late-Closed	24%	90%	72,300	66%
Late-Open	29%	8%	6,200	-21%
Highly Departed Composition	0%	0%	100	0%
Totals	100%	100%	80,300	0
Total Closed	33%	90%	72,300	57%
Ecological Departure		**66**		
Open Canopy Departure		**57**		

The project team also tested and temporarily deployed a new metric to assess departure from the *range* of NRV as was calculated in the Nantahala-Pisgah models, but discarded this metric when it decided that the ranges for the disturbance return intervals could not be scientifically established at GRSM (see Natural Range of Variability section above).

Management Objectives

At the May 2016 workshop, after reviewing the initial ecological departure scores for current condition, GRSM natural resources managers developed a set of overall landscape restoration objectives for GRSM, as follows:

- Restore fire as a key ecological process in oak and pine ecosystems where practical and most needed.
- Restore more open canopy conditions in dry oak and pine ecosystems to more closely approximate reference conditions/NRV.
- Restore early and mid-succession vegetation in dry oak and pine ecosystems to more closely approximate reference conditions/NRV.
- Manage fire and fuels appropriately to protect life and human & cultural resources in and adjoining the park.

Five fire-maintained ecological systems were selected for active management using prescribed fire, based upon their high departure from NRV and likelihood of continued future departure. The five focal systems for active management included: Dry Oak Forest; Dry-Mesic Oak Forest; Low Elevation Pine Forest; Low Elevation Pine-Oak Heath; and Montane Pine-Oak Heath.

Assessment of Future Ecological Condition – Alternative Management Scenarios

Predictive state-and-transition computer models are a valuable tool for assessing future condition because they can simulate management actions. A fundamental purpose of LCF is to identify specific, cost-effective vegetation management strategies to maintain, enhance or restore the desired more natural conditions. The assessment of current ecological condition is merely a precursor to this ultimate endpoint.

Fire in the Management Models

Reference condition models for the five focal systems were modified to incorporate prescribed burning as a management action, as well as reflect current levels of fire exclusion in GRSM. These models are considered to be management models. In order to conduct simulations of future management scenarios (in contrast to the historical NRV simulations described previously), it was necessary to determine the amount of fire that would occur in the management models. Two types of fire were built into the management models – the *suppressed reference condition fire* and the *prescribed fire that is added* as a management action. [Note: Reference condition fire was based on the modeled fire return intervals as shown previously in Table 3.]

Fire Suppression/Exclusion

Two factors were considered in accounting for fire activity in GRSM models: the amount and type of total fire activity in the GRSM over its recent history, and the virtual certainty of substantially continued fire suppression/exclusion as an overarching management activity (see Introduction) in the foreseeable future.

Fire history data for GRSM was analyzed for the period from 1920 to 2012 and compared to the amount of "natural" fire that was predicted in the NRV simulations for the models (Appendix 6). During the decades from the 1930s to the 1990s, GRSM's fire management policy was essentially complete fire suppression – i.e., "out by 10am" the following morning after a fire was reported. Data show approximately 98% fire suppression over these decades as compared to the amount of fire that occurs during reference conditions in the models. In 1996, Park management changed from its previous policy of near-total suppression to provide for the addition of some prescribed fire, as well as some limited "wildland fire use." From 2000 to 2012 data show that wildfire equaled approximately 7.5% of the predicted reference condition fire in the models, which converts to approximately 92.5% suppression on average. Prescribed fire equaled an additional 5.5% of the predicted reference condition fire.

It is relatively straightforward to model fire suppression in ST-Sim, using transition multipliers. A transition multiplier is a number that multiplies a base disturbance rate in the ST-Sim models: e.g., for a given year, a transition multiplier of 1.0 creates no change in a disturbance rate, whereas a multiplier of 0 is a complete suppression of the disturbance rate, and a multiplier of 0.50 halves the disturbance rate. For GRSM, a transition multiplier of .075 (1.00 - .925) was applied for all three types of fire to reflect the rate of fire suppression/ exclusion as compared to fire during reference conditions, based on the analysis described above.

Prescribed Fire

Adding prescribed fire to ecological models is typically a relatively straightforward modeling task that has been applied during many LCF applications. The ecological effects of the prescribed fire are determined for each s-class in which it might occur. Then the management action is added as a new Transition type in the ST-Sim models (e.g., RxFire). The modeler then determines the number of acres and years they wish to simulate prescribed burning for a given ecological system or set of systems, and conducts a simulation computer run (TNC 2009).

However, this modeling task was more complex for GRSM. Prescribed burning in GRSM is not a one-off event to achieve the desired outcomes. Rather, fire managers typically define a burn unit and apply prescribed fire within that unit in a number of "passes" over a number of years. This approach is necessary to achieve the desired ecological effects; trying to achieve the effects with a one-time burn has been found to produce results which are undesirable over large spatial scales. Accordingly, with assistance from TNC's LANDFIRE program, expert assistance was secured from the developers of ST-Sim to develop models that incorporated

three prescribed fire "passes" in simulated non-spatial burn units, designed to achieve the desired ecological outcomes. Each pass was modeled to occur within 10 years after the previous pass.

Collectively, the three passes of prescribed fire were considered to be *restoration burning*. The ecological effects were programmed to occur upon the completion of the 3rd pass. Based upon knowledge of previous control burns in GRSM, the effects were deemed to be different for Closed versus Open canopy classes of the fire-maintained systems, with the bigger impacts occurring in the Closed canopy classes, as follows:

- In Closed canopy
  - 20% converts to Early succession
  - 60% converts to Open canopy
  - 20% remains Closed canopy (i.e., no change in class)
- In Open canopy
  - 10% converts to Early succession
  - 90% remains Open canopy (i.e., no change in class)

For the second 20-year period in the models (i.e., years 21-40), the allocation of prescribed fire was modified to include *maintenance* burning in addition to the restoration burning used exclusively in the first 20 years. Maintenance burning was programmed to occur in forest patches that were in Open condition as a result of previous prescribed burns or otherwise. Maintenance burning is intended to retain the Open canopy structure, versus converting Closed canopy to Open. The effects of the maintenance fire are the same as described for Open canopy above (i.e., 90% remains Open and 10% converts to Early succession). In the management scenario modeling, fifty percent of the prescribed burning during years 21-40 was allocated to maintenance burning and fifty percent to restoration burning.

Allocation of Prescribed Fire Across Systems

The ecological systems within GRSM are frequently arrayed in a mosaic pattern, and prescribed burns are not directed towards one single ecosystem, but rather to multiple ecological systems within a functional burn unit. Therefore it was necessary to determine how the controlled burning in the non-spatial ST-Sim models would be allocated among the five focal systems, along with other ecological systems in GRSM that receive burning as a result of the functional design of burn units on the ground.

The models deployed an allocation ratio based largely upon the recent allocation of prescribed fire among the ecological systems during controlled burns, based upon an assessment by GRSM staff. This allocation is shown in Table 7 below. Thus if 1000 acres of prescribed burning were to occur in a given year across GRSM, 300 acres (30%) would be allocated to Dry Oak Forest, and so on. The 25% of prescribed burning allocated to Cove Forest and all other systems represents the less fire-prone portions of functional burn units. These areas are not the focal point for fire restoration and they often do not burn under controlled-burning conditions, and so were not accounted for in the ST-Sim models.

Table 7. Allocation of Prescribed Fire Across Ecological Systems

Ecological System	% of Rx Fire
Dry Oak Forest	30%
Dry Mesic Oak Forest	15%
Low Elevation Pine Woodland	12%
Low Elevation Pine-Oak Heath	10%
Montane Pine-Oak Heath	8%
Cove Forest/All Others	25%
Total	100%

Management Scenarios

At and between workshops, prescribed fire management strategies were explored to achieve the objectives for the focal systems. ST-Sim computer models were used to simulate conditions under alternative future management scenarios. All scenarios assume current levels of wildfire exclusion will continue in GRSM. The likely future condition of the five focal systems was assessed after 20 and 40 years under four primary scenarios:

1. No Action – i.e., no prescribed fire.
2. Maximum Management – use of prescribed fire to restore ecological departure to the lowest possible level, regardless of budget or practicality.
3. Current Management – prescribed fire at current levels -- approximately 1,500 acres/year average parkwide.
4. Preferred Management – prescribed fire at proposed levels – 5,000 acres/year average parkwide.

Computer Simulations and Reporting Variables

ST-Sim computer simulations were used to test the scenarios for each of the focal ecological systems over a 20-year and 40-year time horizon. Five replicates were run for each scenario to capture some degree of stochastic variability in fire activity and other natural disturbances. The mean of the five replicates was used for reporting.

The primary reporting variables for simulations were: (1) ecological departure score, (2) total acres treated with prescribed fire, and (3) total cost. Results were tallied in an Excel-based Model Runs Workbook.

Reducing Levels of Fire Suppression/Exclusion

ST-Sim computer simulations were also used to test the effect of reducing the degree of fire suppression/exclusion in GRSM, which as reported previously was set at a rate of 92.5% suppression of reference condition fire in the models. Rates of 85% exclusion and 77.5% exclusion were tested (i.e., allowing additional increments of 7.5% of natural wildland fire to occur in GRSM), using the No Action scenario as the baseline. The reporting variable for this exercise was the ecological departure score.

Return on Investment (ROI) Analysis

The final step in the LCF process was the calculation of benefits (magnitude of ecological improvement) as compared to the costs of management. Two ROI metrics were used to determine which of the five focal systems received the greatest ecological benefits per dollar invested, independent of their size (absolute) and reflecting their varying acreage (systemwide). The two ROI metrics calculated were:

(1) Absolute ROI. The change of ecological departure between the NO ACTION scenario and an ALTERNATIVE MANAGEMENT scenario for a given ecological system in year 20 or year 40, divided by total cost of the scenario over the period of years. Correction factors were used to bring all measures to a common order of magnitude.

(2) Systemwide ROI. The change of ecological departure between the NO ACTION scenario and an ALTERNATIVE MANAGEMENT scenario for a given ecological system in year 20 or year 40, *multiplied by total area of the ecological system*, divided by total cost of the scenario over the period of years. Correction factors were used to bring all measures to a common order of magnitude.

If ROI values differ substantially, they are sometimes a useful tool for land managers to decide where to allocate scarce management resources among many possible choices on lands that they administer. Of course, managers also select final strategies or treatment areas based upon a variety of additional factors, such as availability of financial resources, policy constraints, and other societal objectives.

LCF Benefits and Limitations

By developing a decision support tool to assess alternative management strategies, LCF provides many benefits to natural resource managers. Among the key benefits are the answers that LCF provides to the following questions:

- What is the current condition of each ecological system in the landscape
- What systems are likely to change in condition, and how much
- Which management treatments, and how much, will improve altered ecosystems
- What degree of improvement can be feasibly achieved
- Where to place treatments on the landscape, by ecological system
- Which management treatments produce the most cost effective results

The models used to help develop the answers to these questions are relatively simple, transparent and easily adaptable, thereby providing a solid framework for adaptive ecosystem management.

Some additional LCF benefits include:

- Scorecards of current & future condition
- Scientific documentation for Fire Planning and National Environmental Policy Act (NEPA) documents
- Help attract funding for implementation
- Help build collaborative learning and consensus among resource managers and stakeholders

Landscape Conservation Forecasting has some limitations in its applications. Some constraints were overcome by adaptations for the Great Smoky Mountain National Park project, such as revising LANDFIRE ecological models based upon local expertise and substituting higher resolution local vegetation data for national LANDFIRE data. The following general constraints and challenges were inherent in the LCF methods used at GRSM.

- Maps and Data. The assessment of current condition is only as good as the vegetation data that supports it. High-resolution and well-interpreted geospatial data is best for understanding current conditions and was used at GRSM; nevertheless a number of crosswalks, assumptions and rules were required to interpret that data and apply it for LCF.
- Models. "All models are wrong, but some are useful," said prominent statistician George Box. A well-developed predictive model can provide a reasonable approximation of reality. LANDFIRE was designed to use relatively simple, peer-reviewed, consistent, and repeatable scientific methods in developing ecological models. However, many standard LANDFIRE models do not accurately reflect local conditions, and therefore require local, expert-based modifications, as was done with all models for GRSM.

Incorporating management actions into models also requires expert-based judgments on their ecological effects and probability of success.

- Metrics. While ecological departure is a powerful, unified metric of overall ecological "health" – generally incorporating vegetation structure, composition, and all relevant ecological processes – it does not fully account for all impairments to ecosystems or all improvements in ecological health from potential management actions. Ecological departure typically is based upon the NRV for the reference conditions of an ecosystem. NRV reflects many elements of what is typically desired for a given ecosystem, such as the amount of early succession habitat and the degree of open canopy structure. However, its application at GRSM generally does not capture the desired vegetation *composition* within a given succession class, other than the designation of "highly altered vegetation" found within some ecological systems.
- Perceived Precision. The 0-100 ecological departure scores and other related metrics may suggest a high level of precision to some readers (e.g. a departure score of 53), whereas the scores should be more appropriately viewed as approximations that reflect ranges of outcomes. A small percentage difference in scores (e.g. 52 vs. 55) is not meaningful, given the inherent imprecision of the underlying models and/or data.
- Climate Change. LCF has addressed climate change effects in a few projects, but it is complex and challenging to do so and with a high confidence level in the models. LCF climate change forecasting in the northern Sierra Nevada found that effects were not occurring at a significant level until 40 years out. Two important findings were that management actions taken to restore ecosystems closer to NRV helped to improve future condition in the face of climate change, and the sooner these restoration actions were taken, the better the long-term outcome.
- Non-Spatial. While LCF can be assessed with spatial models, spatial modeling is very complex, time-intensive and expensive. The more common non-spatial application of LCF using ST-Sim models does not address the *pattern* of vegetation and succession classes across the landscape. Addressing vegetation heterogeneity and fragmentation requires the addition of complex and more expensive spatial modeling tools and metrics.
- Stand-level Dynamics and Treatments. LCF is a landscape-scale planning tool. The non-spatial application of LCF does not address vegetation patch size, openings, or stand-level treatments. Qualitative management treatment guidelines cannot be simulated because quantitative rules are required by all simulation platforms.
- Vegetation Composition. The LCF maps, models and metrics for GRSM primarily focused on ecosystem *structure* and *disturbances*, and generally were not able to reflect or assess the desired *composition* of a given vegetation succession class for a given ecological system. However, the Ecological System Descriptions found in Appendix 2 provide an account of the dominant vegetation expected for each succession class in a given ecological system.
- Aquatics. LCF does not address aquatic ecosystems.

Findings

Current Ecological Condition

Ecological Systems

The 515,000 acres of Park vegetation supports a diversity of Southern Appalachian ecological systems, ranging from low-elevation pine woodland to large cove forests to higher elevation spruce-fir forests. Eleven major ecological system types in GRSM were identified from the vegetation data, including seven oak and pine systems. These systems and the acreage of each system (rounded) are as follows:

Ecological System	% of Acres	Acres
Dry Oak Forest	16%	80,300
Dry Mesic Oak Forest	13%	66,000
Mesic Oak Forest	12%	60,500
High Elevation Red Oak Forest	4%	22,300
Low Elevation Pine Forest	3%	17,800
Low Elevation Pine-Oak Heath	2%	8,800
Montane Pine-Oak Heath	4%	18,800
Cove Forest	24%	123,800
Northern Hardwood Forest	13%	67,800
Spruce-Fir Forest	8%	40,900
Montane Alluvial	2%	7,900
Total Acres		514,900

Cove Forest is the largest ecological system in GRSM; at approximately 124,000 acres it comprises almost one-fourth of the GRSM's total vegetation. Four oak systems collectively constitute approximately 229,000 acres, or 45% of GRSM's vegetation. Three pine-dominated systems equal approximately 45,000 acres, or almost 10% of the vegetation. Three other systems (Northern Hardwood Forest, Spruce-Fir Forest, and Montane Alluvial) make up the remainder of the vegetation. All of the ecological systems are described in Appendix 2.

Ecological Departure

The current condition of GRSM's varied ecological systems ranges from good (low ecological departure) to relatively poor (high ecological departure) – see Table 8. Three xeric oak and pine systems constituting 21% of GRSM show *high* ecological departure – Dry Oak Forest, Low Elevation Pine Forest and Low Elevation Pine-Oak Heath. Three other oak and pine systems – constituting another 21% of GRSM are *moderately* departed from NRV – Dry-Mesic Oak Forest, High Elevation Red Oak Forest and Montane Pine-Oak Heath. Three systems that are more mesic show *low* departure, including the Cove Forest, Northern Hardwood Forest and Mesic Oak Forest.

The primary reason for ecological departure across the landscape is due to overly closed canopy structure in the oak and pine systems, as compared to more open structure under reference conditions (Table 9). Across all systems, LIDAR data showed over 80% of GRSM vegetation was closed canopy. There is also a substantial shortfall of early succession and mid succession classes in the most-departed systems as compared to reference conditions. The large-scale logging operations prior to the Park's establishment, followed by a century of fire suppression and exclusion, have been the primary causes of the currently altered conditions, most notably in the drier oak and pine systems. In contrast, the more closed-canopy conditions within mesic systems − including Cove Forest, Northern Hardwood Forest and Mesic Oak Forest − which are much less influenced by fire, show low departure from reference conditions.

Table 8. Current Ecological Departure of GRSM's ecological systems. The measure of Ecological Departure is scored on a scale of 0% to 100% departure from NRV: 0% represents NRV while 100% represents total departure. Departure was not calculated for the two systems that were not modeled.

Ecological System	Acres	Current Ecological Departure
Dry Oak Forest	80,300	**66**
Dry-Mesic Oak Forest	66,000	**57**
Mesic Oak Forest	60,500	**32**
High Elevation Red Oak Forest	22,300	**59**
Low Elevation Pine Forest	17,800	**66**
Low Elevation Pine-Oak Heath	8,800	**70**
Montane Pine-Oak Heath	18,800	**64**
Cove Forest	123,800	**30**
Northern Hardwood Forest	67,800	**25**

Table 9. Acres, percentages and NRV for all S-classes, including totals for 7 oak and pine systems.

Dry Oak Forest							
Class	**Early**	**Mid-Closed**	**Mid-Open**	**Late-Closed**	**Late-Open**	**Highly Departed**	**Total**
Acres in Class	1,600	-	100	72,300	6,200	100	80,300
NRV %	17%	9%	21%	24%	29%	0%	100%
Current % in Class	2%	0%	0%	90%	8%	0%	100%
Ecological Departure							**66**
Dry-Mesic Oak Forest							
Class	**Early**	**Mid-Closed**	**Mid-Open**	**Late-Closed**	**Late-Open**	**Highly Departed**	**Total**
Acres in Class	500	4,500	500	56,300	1,500	2,700	66,000
NRV %	9%	9%	18%	32%	31%	0%	99%
Current % in Class	1%	7%	1%	85%	2%	4%	100%
Ecological Departure							**57**
Mesic Oak Forest							
Class	**Early**	**Mid-Closed**	**Mid-Open**	**Late-Closed**	**Late-Open**	**Highly Departed**	**Total**
Acres in Class	400	2,300	400	39,700	15,900	1,800	60,500
NRV %	6%	17%	14%	46%	17%	0%	100%
Current % in Class	1%	4%	1%	66%	26%	3%	100%
Ecological Departure							**32**
High Elevation Red Oak Forest							
Class	**Early**	**Mid-Closed**	**Mid-Open**	**Late-Closed**	**Late-Open**	**Highly Departed**	**Total**
Acres in Class	300	10	10	21,400	600	-	22,320
NRV %	14%	14%	12%	37%	23%	0%	100%
Current % in Class	1%	0%	0%	96%	3%	0%	100%
Ecological Departure							**59**
Low Elevation Pine Forest							
Class	**Early**	**Mid-Closed**	**Mid-Open**	**Late-Closed**	**Late-Open**	**Highly Departed**	**Total**
Acres in Class	500	2,200	700	12,900	900	600	17,800
NRV %	13%	10%	30%	12%	35%	0%	100%
Current % in Class	3%	12%	4%	72%	5%	3%	100%
Ecological Departure							**66**
Low Elevation Pine-Oak Heath							
Class	**Early**	**Mid-Closed**	**Mid-Open**	**Late-Closed**	**Late-Open**	**Highly Departed**	**Total**
Acres in Class	190	-	-	7,370	1,100	100	8,760
NRV %	21%	13%	30%	15%	21%	0%	100%
Current % in Class	2%	0%	0%	84%	13%	1%	100%
Ecological Departure							**70**
Montane Pine-Oak Heath							
Class	**Early**	**Mid-Closed**	**Mid-Open**	**Late-Closed**	**Late-Open**	**Highly Departed**	**Total**
Acres in Class	1,100	100	100	14,700	2,600	200	18,800
NRV %	25%	16%	25%	15%	19%	0%	100%
Current % in Class	6%	1%	1%	78%	14%	1%	100%
Ecological Departure							**64**
Cove Forest							
Class	**Early**	**Mid-Closed**	**Mid-Open**	**Late-Closed**	**Late-Open**	**Highly Departed**	**Total**
Acres in Class	900	1,500	200	84,500	36,700	-	123,800
NRV %	4%	24%	4%	57%	11%	0%	100%
Current % in Class	1%	1%	0%	68%	30%	0%	100%
Ecological Departure							**30**
Northern Hardwood Forest							
Class	**Early**	**Mid-Closed**	**Mid-Open**	**Late-Closed**	**Late-Open**	**Highly Departed**	**Total**
Acres in Class	1,200	7,000	700	56,900	2,000	-	67,800
NRV %	6%	22%	1%	59%	12%	0%	100%
Current % in Class	2%	10%	1%	84%	3%	0%	100%
Ecological Departure							**25**
All Oak & Pine Systems (7)							
Class	**Early**	**Mid-Closed**	**Mid-Open**	**Late-Closed**	**Late-Open**	**Highly Departed**	**Total**
Acres in Class	4,590	9,110	1,810	224,670	28,800	5,500	274,480
Simple Ave NRV %	15%	13%	21%	26%	25%	0%	100%
Current % in Class	2%	3%	1%	82%	10%	2%	100%

Future Condition Without Management

Using ST-Sim, the future condition of each modeled system was simulated after 20 years and 40 years, assuming no active management action to restore ecological condition. This essentially represents a "no action" scenario – other than the continuation of current levels of fire exclusion.

20 Year Forecast

After 20 years, five oak and pine systems remain substantially departed from NRV (~50% or higher): Dry Oak Forest (56% departure), Dry-Mesic Oak Forest (48% departure), Low Elevation Pine Forest (63% departure), Low Elevation Pine-Oak Heath (57% departure), and Montane Pine-Oak Heath (51% departure) – see Table 10. These five ecological systems are the most fire-dependent systems in GRSM. High Elevation Red Oak, which has a longer fire return interval, remains moderately departed but shows substantial improvement without management. The three more mesic systems that are currently low departure remain in low departure.

Table 10. Forecasted Ecological Departure summary after 20 Years

Ecological System	Acres	Current Ecological Departure	No Action Ecological Departure 20 Yrs
Dry Oak Forest	80,300	66	56
Dry-Mesic Oak Forest	66,000	57	48
Mesic Oak Forest	60,500	32	30
High Elevation Red Oak Forest	22,300	59	44
Low Elevation Pine Forest	17,800	66	63
Low Elevation Pine-Oak Heath	8,800	70	57
Montane Pine-Oak Heath	18,800	64	51
Cove Forest	123,800	30	22
Northern Hardwood Forest	67,800	25	14

Somewhat counter-intuitively, the fire-maintained systems do show some improvement over their current condition without management. Over the 20 years, a modest increase in early succession and open canopy occurs due to varied disturbances (insects, weather, and some fire) in the models, and over time, some early succession moves to mid succession. Departure analysis for each of the five focal systems is summarized in Tables 11-15 below:

Table 11. Forecasted Ecological Departure after 20 Years – Dry Oak Forest

Vegetation Class	NRV Mean	Current %	No Action - 20 Yrs
Early	17%	2%	6%
Mid-Closed	9%	0%	2%
Mid-Open	21%	0%	0%
Late-Closed	24%	90%	80%
Late-Open	29%	8%	12%
Highly Departed Composition	0%	0%	0%
Totals	100%	100%	100%
Total Early/Open			
Total Closed	33%	90%	82%
Ecological Departure		66	56
Open Canopy Departure		57	49

- 2nd largest system
- Modest improvement with No Action – a little more Early & Open
- Still highly Closed canopy after 20 years
- Still large shortfall in Early & Mid succession

Table 12. Forecasted Ecological Departure after 20 Years – Dry-Mesic Oak Forest

Vegetation Class	NRV Mean	Current %	No Action - 20 Yrs
Early	9%	1%	3%
Mid-Closed	9%	7%	5%
Mid-Open	18%	1%	2%
Late-Closed	32%	85%	76%
Late-Open	31%	2%	10%
Highly Departed Composition	0%	4%	4%
Totals	99%	100%	100%
Total Early/Open			
Total Closed	41%	92%	81%
Ecological Departure		57	48
Open Canopy Departure		51	40

- Same overall story as Dry Oak, but slightly better condition
- 4% highly departed vegetation -tulip poplar
- Modest improvement with No Action – more Open canopy
- Still highly Closed canopy after 20 years
- Still large shortfall in Early & Mid succession

Table 13. Forecasted Ecological Departure after 20 Years – Low Elevation Pine Forest

Vegetation Class	NRV Mean	Current %	No Action - 20 Yrs
Early	13%	3%	5%
Mid-Closed	10%	12%	16%
Mid-Open	30%	4%	2%
Late-Closed	12%	72%	66%
Late-Open	35%	5%	8%
Highly Departed Composition	0%	3%	3%
Totals	100%	100%	100%
Total Early/Open			
Total Closed	22%	85%	82%
Ecological Departure		66	63
Open Canopy Departure		63	60

- Highly departed system
- Virtually no improvement with No Action
- Still very Closed canopy
- Large shortfall in Early & Mid succession (but more in Mid classes than other systems)
- 3% highly departed vegetation- white pine

Table 14. Forecasted Ecological Departure after 20 Years – Low Elevation Pine-Oak Heath

Vegetation Class	NRV Mean	Current %	No Action - 20 Yrs
Early	21%	2%	9%
Mid-Closed	13%	0%	7%
Mid-Open	30%	0%	1%
Late-Closed	15%	84%	71%
Late-Open	21%	13%	11%
Highly Departed Composition		1%	1%
Totals	100%	100%	100%
Total Early/Open			
Total Closed	28%	84%	78%
Ecological Departure		70	57
Open Canopy Departure		56	50

- Some improvement with No Action – more Early & Mid succession
- But still large shortfall in Early & Mid
- Still overly Closed canopy
- 1% highly departed vegetation- oak species

Table 15. Forecasted Ecological Departure after 20 Years – Montane Pine-Oak Heath

Vegetation Class	NRV Mean	Current %	No Action - 20 Yrs
Early	25%	6%	10%
Mid-Closed	16%	1%	9%
Mid-Open	25%	1%	1%
Late-Closed	15%	78%	65%
Late-Open	19%	14%	13%
Highly Departed Composition	0%	1%	1%
Totals	100%	100%	99%
Total Early/Open			
Total Closed	31%	79%	74%
Ecological Departure		**64**	**51**
Open Canopy Departure		**48**	**43**

- Similar to LEPOH but slightly less departed
- Some improvement with No Action – more Early & Mid succession
- But still large shortfall in Early & Mid
- Still overly Closed canopy
- 1% highly departed vegetation- oak species

The four other modeled systems in GRSM, which are less fire dependent, also show improvement over their current condition without management. Over 20 years, varied disturbances (e.g., insects, weather, and some fire) and/or natural age succession in the models bring all of these systems closer to their NRV. The departure analysis for the other systems is summarized in Table 16.

Table 16. Forecasted Ecological Departure Summary over 20 Years for Other Modeled Systems

	Mesic Oak Forest			High Elevation Red Oak			Cove Forest			Northern Hardwood		
Vegetation Class	**NRV**	**Current %**	**No Action - 20 Yrs**	**NRV**	**Current %**	**No Action - 20 Yrs**	**NRV**	**Current %**	**No Action - 20 Yrs**	**NRV**	**Current %**	**No Action - 20 Yrs**
Early	6%	1%	2%	14%	1%	5%	4%	1%	4%	6%	2%	5%
Mid-Closed	17%	4%	2%	14%	0%	2%	24%	1%	5%	22%	10%	10%
Mid-Open	14%	1%	3%	12%	0%	0%	4%	0%	0%	1%	1%	1%
Late-Closed	46%	66%	57%	37%	96%	81%	57%	68%	76%	59%	84%	73%
Late-Open	17%	26%	33%	23%	3%	12%	11%	30%	14%	12%	3%	12%
Highly Departed Composition	0%	3%	3%									
Totals	100%	100%	100%	100%	100%	100%	100%	100%	99%	100%	100%	101%
Total Early/Open	37%	28%	38%	49%	4%	17%	19%	31%	18%	19%	6%	18%
Total Closed	63%	69%	59%	51%	96%	83%	81%	69%	81%	81%	94%	83%
Ecological Departure		**32**	**30**		**59**	**44**		**30**	**22**		**25**	**14**
Open Canopy Departure		**6**	**-4**		**45**	**32**		**-12**	**0**		**13**	**2**

40 Year Forecast

Without active management, there is little improvement in ecological departure forecasts over the second 20 years (Table 17). Without management (i.e., prescribed burning), all five fire-dependent ecosystems comprising almost 40% of GRSM will remain substantially departed from NRV after 40 years: Dry Oak Forest (51% departure), Dry-Mesic Oak Forest (45% departure), Low Elevation Pine Forest (64% departure), Low Elevation Pine-Oak Heath (51% departure), and Montane Pine-Oak Heath (45% departure)

Table 17. Forecasted Ecological Departure Summary after 40 Years

Ecological System	Acres	No Action Ecological Departure 20 Yrs	No Action Ecological Departure 40 Yrs
Dry Oak Forest	80,300	**56**	**51**
Dry-Mesic Oak Forest	66,000	**48**	**45**
Mesic Oak Forest	60,500	**30**	**34**
High Elevation Red Oak Forest	22,300	**44**	**40**
Low Elevation Pine Forest	17,800	**63**	**64**
Low Elevation Pine-Oak Heath	8,800	**57**	**51**
Montane Pine-Oak Heath	18,800	**51**	**45**
Cove Forest	123,800	**22**	**16**
Northern Hardwood Forest	67,800	**14**	**12**

Management Scenarios Forecasts

Using ST-Sim, the future condition of the five focal fire-maintained systems (Dry Oak Forest, Dry-Mesic Oak Forest, Low Elevation Pine Forest, Low Elevation Pine-Oak Heath, and Montane Pine-Oak Heath) was simulated after 20 years and 40 years under three different management scenarios to restore ecological condition. The three management scenarios deployed different levels of prescribed fire. The average annual amount of prescribed fire, parkwide, in the scenarios was:

MAXIMUM MANAGEMENT 24,000 acres

CURRENT MANAGEMENT 1,500 acres

PREFERRED MANAGEMENT 5,000 acres

A summary of the outcomes for all scenarios is shown in Appendix 7. Detailed outcomes for all scenarios for the five focal systems are shown in the Excel Model Runs Worksheets in Appendices 7-11.

Maximum Management

Maximum Management is typically run in LCF as a "bookend" scenario to determine how much ecological improvement is possible, regardless of cost or feasibility. At GRSM, Maximum Management restores the five oak and pine systems to low ecological departure (Table 18). After just 20 years, the large amount of prescribed fire in the Maximum Management simulations, which approximates the natural fire regime for these systems, serves to open up the canopy and create early succession and mid succession classes that are much closer to NRV.

Table 18. Forecasted Ecological Departure with Maximum Management as Compared to No Action – 20 & 40 Years

Ecological System	Acres	No Action Ecological Departure 20 Yrs	No Action Ecological Departure 40 Yrs	Max Mgmt Ecological Departure 20 Yrs	Max Mgmt Ecological Departure 40 Yrs
Dry Oak Forest	80,300	56	51	28	20
Dry-Mesic Oak Forest	66,000	48	45	32	21
Low Elevation Pine Forest	17,800	63	64	28	26
Low Elevation Pine-Oak Heath	8,800	57	51	34	21
Montane Pine-Oak Heath	18,800	51	45	32	17

Current Management

Current Management levels of prescribed fire (1,500 acres/year average parkwide) achieve modest improvement in ecological departure scores after 20 and 40 years, as compared to the No Action scenario (Table 19). After 40 years, the current level of prescribed fire achieves the greatest improvement in Low Elevation Pine Forest and Low Elevation Pine-Oak Heath as compared to No Action. Departure scores for all systems, except for Low Elevation Pine, fall below 50% after 40 years under current management.

It should be noted that ecological departure scores for GRSM are based fundamentally on forest structure; current levels of prescribed fire are expected to improve vegetation composition for the managed systems, but this improvement is not accounted for in GRSM's ecological departure scores.

Table 19. Forecasted Ecological Departure with Current Management as Compared to No Action – 20 & 40 Years

Ecological System	Acres	No Action Ecological Departure 20 Yrs	No Action Ecological Departure 40 Yrs	Current Mgmt (1500 Ac/Yr) Ecological Departure 20 Yrs	Current Mgmt Restore & Maintain (1500 Ac/Yr) 40 Yrs
Dry Oak Forest	80,300	56	51	54	48
Dry-Mesic Oak Forest	66,000	48	45	47	43
Low Elevation Pine Forest	17,800	63	64	60	58
Low Elevation Pine-Oak Heath	8,800	57	51	52	43
Montane Pine-Oak Heath	18,800	51	45	50	42

Preferred Management

The Preferred Management levels of prescribed fire (5,000 acres/year average parkwide) achieve continued, meaningful improvement in ecological departure for all five systems over 20 and 40 years (Table 20). As with the Current Management scenario, the greatest 40-year improvements as compared to No Action occur in in Low Elevation Pine Forest and Low Elevation Pine-Oak Heath (which actually falls into the low departure category after 40 years).

Table 20. Forecasted Ecological Departure with Preferred Management as Compared to No Action – 20 & 40 Years

Ecological System	Acres	No Action Ecological Departure 20 Yrs	No Action Ecological Departure 40 Yrs	Preferred Mgmt (5000 Ac/Yr) Ecological Departure 20 Yrs	Preferred Restore & Maintain (5000 Ac/Yr) Ecological Departure 40 Yrs
Dry Oak Forest	80,300	56	51	50	42
Dry-Mesic Oak Forest	66,000	48	45	45	38
Low Elevation Pine Forest	17,800	63	64	52	49
Low Elevation Pine-Oak Heath	8,800	57	51	43	29
Montane Pine-Oak Heath	18,800	51	45	46	36

Allocation of Fire in Management Scenarios

The management models assigned the amount of prescribed fire to each system based largely upon the ratio of prescribed fire among GRSM's ecological systems during actual controlled burns. The relative amount of modeled prescribed fire the management models matched up closely with the relative amount of modeled natural fire in the reference models

(Table 21). For example, Montane Pine-Oak Heath accounts for approximately 4% of the vegetated acres in GRSM but 8% of the total natural fire in the reference model simulations. Accordingly, it has an approximately 2 to 1 ratio of fire to system acres. The amount of prescribed fire in the management models almost exactly replicated this 2 to 1 ratio. The comparative ratios were very close for four of the five focal systems, with the only exception being Low Elevation Pine-Oak Heath. Low Elevation Pine-Oak Heath received the highest comparative ratio of prescribed fire in the management models, comprising about twice as much relative fire as the other four systems. Therefore, not surprisingly, as reported in the previous section, this system had the lowest of all departure scores (29) after 40 years.

Table 21. Percentages of Fire as Compared to Park Acres in Reference Models and Management Models for Focal Systems

Natural Fire in Reference Model Simulations

Ecological System	% ot Total Acres	% ot Total Fire	Ratio
Dry Oak	15%	38%	2.4
Dry-Mesic Oak	12%	16%	1.4
Low Elevation Pine	3%	11%	3.4
Low Elev Pine-Oak Heath	2%	5%	3.0
Montane Pine-Oak Heath	4%	8%	2.1

Prescribed Fire in Management Models

Ecological System	**% of Park Acres**	**% of Rx Fire**	**Ratio**
Dry Oak Forest	16%	30%	1.9
Dry Mesic Oak Forest	13%	15%	1.2
Low Elevation Pine	3%	12%	3.5
Low Elev Pine-Oak Heath	2%	10%	5.9
Montane Pine-Oak Heath	4%	8%	2.2

Alternative Levels of Fire Exclusion

The effect of reducing the degree of fire suppression/exclusion in GRSM was also tested using ST-Sim. Just as adding prescribed fire improves ecological departure, reducing fire suppression/ exclusion in GRSM would also improve ecological departure – recognizing, however, the many challenges, risks and difficulties of implementing this strategy, especially in the light of the recent deadly wildfires in and around GRSM. Current fire management practice allows approximately 7.5% of "natural" wildfire to occur (i.e., 92.5% suppression) ; increasing this level to 15% (i.e., 85% suppression) would improve average ecological departure scores for the five focal systems by an average of 4 points over 40 years (Table 22).

Table 22. Ecological Departure Scores with Alternative Level of Fire Suppression/Exclusion – No Action Scenario - 40 Years

Ecological Departure with Alternative Fire Suppression Levels				
"No Action" Scenarios				
Year	40			
		Fire Suppression		
Row Labels	**77.5%**	**85.0%**	**92.5%**	
DryMesicOak	39	41	45	
DryOak	43	46	51	
LowElevationPine	55	59	64	
LowElevPineOakHeath	43	48	52	
MontanePineOakHeath	38	42	45	

Management Budgets & Return-on-Investment

The final step in the LCF process was calculating the cost of proposed management actions and the benefits (magnitude of ecological improvement) as compared to costs of management. Two return-on-investment (ROI) metrics were used to determine which of the systems received the greatest ecological benefits per dollar invested.

Budgets

The *average* cost of implementing prescribed fire was estimated at $50 per acre by GRSM's fire management staff. Actual cost on the ground for a given prescribed burn will vary depending upon many circumstances, but it was felt that $50 per acre represented a reasonable average cost. These costs do *not* include the regularly scheduled time of Park staff.

Based upon the current level of prescribed burning (1,500 acres/year), the average annual cost is $75,000 per year. The proposed level of burning to achieve the desired ecological outcomes (5,000 acres/year) would cost approximately $250,000 per year. These are *average* estimated costs; actual costs will vary depending upon actual acres burned in a given year, as well as other variables.

Return-on-Investment

Two ROI metrics were used to determine which of the five focal systems received the greatest ecological benefits per dollar invested, independent of their size (absolute) and reflecting their varying acreage (systemwide). Overall, there were not dramatic differences in the results among the five focal systems that might influence management decisions.

The "absolute" return on investment (Table 23) was highest for the Low Elevation Pine-Oak Heath (8.8), followed by Low Elevation Pine (5.0) and Montane Pine-Oak Heath (4.5), as

compared to the two larger oak systems. This is not a surprising outcome, as the three high ROI systems are all small in size and cost less to burn to achieve the desired results.

On the other hand the "systemwide" ROI, which takes the relative sizes of the systems into account, showed roughly equivalent results across all five ecological systems. With this metric the two larger oak systems actually achieved the highest scores.

Table 23. Absolute and Systemwide Return-on-Investment over 40 Years (ROI calculations are multiplied by constants)

	Total Acres	RxFire Acres / Year	Ecological Improvement vs No Action	Annual Cost	Absoute ROI 40 Years	Systemwide ROI 40 Years
Dry Oak	80,300	1,500	9	$ 75,000	1.2	2.4
Dry-Mesic Oak	66,000	750	7	$ 37,500	1.9	3.1
Low Elevation Pine	17,800	600	15	$ 30,000	5.0	2.2
Low Elevation Pine-Oak Heath	8,800	500	22	$ 25,000	8.8	1.9
Montane Pine-Oak Heath	18,800	400	9	$ 20,000	4.5	2.1

Acknowledgements

The Landscape Conservation Forecasting process is a collaborative one, so, first and foremost we'd like to acknowledge all the participants in the four workshops. Participation by National Park Service staff and partners created a rich dialogue that resulted in a robust product. Special thanks go to the Great Smoky Mountain National Park staff: Chris Corrigan, Katie Corrigan, Troy Evans, Kristine Johnson, Shane Paxton, Wylie Paxton, Tom Remaley, Greg Salansky, Jeff Troutman, Jesse Webster, and Matt Wood, as well as Missy Forder from the NPS Atlanta Regional Office. Other partners participating in workshops included Margit Bucher, Gary Kauffman, Josh Kelly, Steve Simon, Rob Sutter, Megan Sutton and Alex Wyss. Thanks also to Jim Smith with TNC-LANDFIRE, Leonardo Frid with Apex Resources Management Solutions, and Gary Kauffman with National Forests of North Carolina for their assistance with modeling.

Rob Klein, Great Smoky Mountains National Park Fire Ecologist, served as the NPS project leader. Greg Low with Applied Conservation LLC led the overall LCF process and model simulations. Steve Simon, Josh Kelly and Jess Riddle with Ecological Mapping and Fire Ecology Inc. led the vegetation mapping work. Katherine Medlock with The Nature Conservancy served as project leader and facilitator.

Very special thanks go to our funders, the Tallassee Fund and the National Park Service fire program.

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Appendix 1. "Rules" for Vegetation Mapping at Great Smoky Mountains National Park.

Ecological System 'RULES' ***2nd Approximation Hybrid Ecological System Model***

GRSM Ecological Systems - - Ecological Zone	***Landfire Ecological System***	***"DOMINANT VE" Classes Reference Condition (original grouping unless indicated)***	***Approx. extent 1/ acres***	***Hybrid Model Comments***	***"DOMINANT VE" Classes Current Condition 2/***
Southern Appalachian Low Elevation Pine-Oak Forest - - Shortleaf Pine-Oak	Southern Appalachian Low Elevation Pine Forest	PI, PIp, PIr, PIv, PI-OzH, PI/OmH, PI/OzH, PIp-OzH, PIp/OzH, PIv-OzH, PIv/OzH ---------- **Oak/Pine and Oak-Pine that intersect with Miller YPH?** OzH/PI, OzH-PI, OzH/PIp, OzH/PIv, OzH/PIr	*17,850 total*	all classes included < 2300' RULE ---------- all classes included < 2300' RULE includes ≈ 15 acres from reference plot analysis	PI, PIp, PIr, PIv, PI-OzH, PI/OmH, PI/OzH, PIp-OzH, PIp/OzH, PIv-OzH, PIv/OzH
Original Comments: This system contains much greater amounts of PINRIG than PINECH. Not sure PINECH types can be separated out, but would like to do that.					
Montane Pine-Oak-Heath - - Pine-Oak Heath	Southern Appalachian Montane Pine Forest and Woodland	Same as Low-Elev Pine RULE = > 2300'	*18,775 total*	 includes ≈ 265 acres from reference plot analysis	Same as Low-Elev Pine
Low Elevation Pine-Oak Heath - - Pine-Oak Heath	not defined	Same as Low-Elev Pine	*8,775 total*	Same as Low-Elev Pine **and** Ecological Zone = Pine-Oak Heath includes ≈ 100 acres from reference plot analysis	Same as Low-Elev Pine
Low Elevation Dry to Xeric Oak - - Dry Oak	Southern Appalachian Oak Forest	OzH, OzHf, OzHfA < 2300' ---------- Och < 2300' ---------- OzH-PIs, OzH/PIs, OzHF/PIs **(that does not intersect with Miller WPH)** < 2300' ---------- **Oak/Pine and Oak-Pine that do not intersect with Miller YPH?** < 2300' OzH-PI, OzH/PIp, OzH/PIv, OzH/PIr, OzH/PI ----------	*79,144 total*	all units included regardless of Elevation Rule ---------- moved to Dry-Mesic Oak regardless of Elev. Rule ---------- all classes included < 2300' per RULE ---------- all classes included < 2300' per RULE ---------- PIs/OzH added (Rob-March 2016), was described as 'uncharacteristic' originally. At Feb 22nd mtg. it was decided that White Pine is not 'uncharacteristic' in oak types	OzH, OzHf, OzH/PI, OzH-PI, OcH, OzHfA, OzH/PIp, OzH/PIv, OzH/PIr
Original Comments: For all oak types that would have had chestnut as a dominant/codominant, we have decided to pretend chestnut never existed. This because is it functionally gone and has no known chance of returning at any appreciable scale.					

GRSM Ecological Systems - - Ecological Zone	*Landfire Ecological System*	*"DOMINANT VE" Classes Reference Condition (original grouping unless indicated)*	*Approx. extent acres*	*Hybrid Model Comments*	*"DOMINANT VE" Classes Current Condition*
Dry-Mesic Oak-Hickory - -	Southern Appalachian Oak Forest	OmHA, OmHA-PI, OmHA/PI, OmHA/PIs **(That does not intersect with Miller WPH)** OmHA/T --- OmH --- **Should this group be its own Mixed Hardwood system?** HxA, HxBl, HxBI/R, HxAz, HxA/T --- Dry-Mesic Oak	*60,233 total* 15,283	split from Dry-Mesic to Mesic Oak Hickory original group --- split by elevation (< 2300' to Dry-Mesic Oak) --- HxBI moved to CoveForest HxA, HxBI/R, HxAz, HxA/T: moved to 'use Ecological Zones to define' --- Och added (Rob-March 2016, all elevations) --- includes ≈ 130 acres from reference plot analysis	OmH, OmHA, OmHr, OmHR, OmHp/R, OmHL, OmH/T, OmHA/T, OmHA/PI, OmHA-PI
Mesic Oak-Hickory - - Montane Oak Cove&Slope	Montane Red Oak-Chestnut Oak	OmHr, OmHR, OmHL, OmH/T, OmHr/PIs OmH	*60,431 total* 20,996	split by elevation (> 2300' to Mesic Oak) includes ≈ 87 acres from reference plot analysis	
Original comments: This one is tough! Should probably be divided according to landform. OmHA and associated variants have a different disturbance ecology than many of the "Om" types, but may not rise to the same regime as "Oz" types.					
Montane Oak - - High Elev. Red Oak		MOz/K, MOa/K --- MOz, MOa, MOr/Sb, MOr, MOr/R-K, MOr/G, MOr/K, MOr/R, MOr/T --- **At elevations > 2300'**: OzH, OzHf, OzHfA --- Och		not in GIS, but listed in Draft Report (May 2004) --- all classes included as the 'core' --- moved to Dry Oak (Rob-March 2016) --- moved to Dry-Mesic Oak (Rob-March 2016) --- includes ≈ 247 acres from reference plot analysis	MOz, MOz/K, MOa, MOa/K, MOr/Sb, MOr, MOr/R-K, MOr/G, MOr/K, MOr/R, MOr/T **At elevations > 2300':** OzH, OzHf, OzH/PI, OzH-PI,OcH, OzHfA, OzH/PIp, OzH/PIv, OzH/PIr
Original comments: Treatment of elevations based on higher frequency of fire at lower elevations.					
Southern Appalachian Spruce-Fir - - Spruce-Fir	Central & Southern Appalachian Spruce-Forests	Fir & Spruce-Fir = (F), (F)S, F, F/S, S(F), S-F, S-F/Sb, S/F, S/R, S/Sb: Spruce =S, S-NHx, S-NHxB, S-R, S-T, S-TR, S/NHx, S/NHxA, S/NHxB, S/T	*40,490 total*	added to original grouping: NHxS, NHxB/S, NHxE, T/S --- includes ≈ 13 acres from reference plot analysis	S/NHxB, S, S/NHx, S/T, S/R, S/F, S(F), F, S-NHxB, S/HNxA, S-T, S/Sb, F/S, S-F, S-F/Sb , S-NHx, (F), (F)S, S-R
Original comments: Park interest in capturing change in areal extent of Spruce and Spruce-Fir. Hypothesize that area is less today than in the ref. condition (Beyond just loss from BWA). Don't know how best to capture this spatially? Are changes due to BWA best captured by canopy ht. changes, or should we look for a better way to deal with this loss? The veg map uses (F) for former fir sites.					
GRSM Ecological Systems – Ecological Zone	*Landfire Ecological System*	*"DOMINANT VE" Classes Reference Condition (original grouping unless indicated)*	*Approx. extent acres*	*Hybrid Model Comments*	*"DOMINANT VE" Classes Current Condition*
Hemlock and Hemlock/White Pine Forest - -	None	T/HxA, T/OmH, T/OmHA, OmHA-T, T/PIs, PIs-T, PIs/T, T/CHxA, T/HxL, T/CHx, T/CHxR, T/MAL, T, T/R, T/K --- MAL-T, MALc-T --- T/NHxA, T/NHx, T/NHxB, NHxA-T, T/NHxR, NHxR-T --- T/S --- HxA-T	*0 total*	moved to Cove Forest --- moved to Alluvial Forest --- moved to Hemlock-Northern Hardwood --- moved to Spruce-Fir --- moved to 'use Ecological Zones to define'	T, T/R, T/CHxA, T/CHx, T/NHxA, T/HxA, T/PIs, PIs-T, MAL-T, NHxR-T, NHxA-T, HxA-T, T/NHx, T/OmH, PIs/T, T/OmHA, T/S, T/NHxR, T/NHxB, T/K , OmHA-T, MALc-T, T/HxBI, T/CHxR, T/HxL, T/MAL
Original comments: Significant Hemlock also exists in Acid Cove, Acidic NH, and Spruce. How to deal with loss of hemlock? "Treated" Hemlock is a Vegetation Management geodatabase.					

White Pine - Oak		None	PIs/OzH ---------- OmHA/PIs ---------- PIs, PIs/OmHA, PIs/OzHf, PIs/OmH, OzH-PIs, OzHf/PIs, OzH/PIs	*0 total*	moved to Dry Oak (Rob-March 2016) ---------- All in DMoak because none = Miller WPH moved to 'use Ecological Zones to define' **Note Original Rules for classes:** WP-Oak, = intersects with Miller WPH (2,700 acres) Uncharacteristic = not Miller as above (6,156 acres)	PIs, PIs/OzH, OzH-PIs, OzHf/PIs, OzH/PIs, OmHA/PIs, OmHr/PIs, PIs/OmHA, PIs/OzHf, PIs/OmH **(that intersects with Miller WPH)**
Cove Forests - - Rich & Acidic Cove	Rich Cove Acidic Cove Oak/ Rhodo	Southern and Central Appalachian Cove Forest	CHx, CHxR, CHxL, CHxO, CHxR/T, CHxR-T, HxF, HxF/T CHxA, CHxA-T, CHx-T, CHx/T, CHxA/T, CHxL/T, HxL, Hx, HxL/T, HxL-T ---------- not in original grouping ----------	*128,859 total*	all classes included all **but** highlighted classes included ---------- added to the original group: HxBI T/HxA, T/OmH, T/OmHA, OmHA-T, T/PIs, PIs-T, PIs/T, T/CHxA, T/HxL, T/CHx, T/CHxR, T/MAL, T/HxF (T & T/R & T/K) may include Northern Hardwood - Hemlock on S-facing slopes at higher elevations. ---------- OmHp/R ---------- HxL, Hx, HxL-T, HxL/T = use Ecological Zones ---------- includes ≈ 254 acres from reference plot analysis	CHx, CHxR, CHxL, CHxO, CHxR/T, CHxR-T, CHxA, CHxA-T, CHx-T, CHx/T, CHxA/T, CHxL/T
Original Comments: Could inform the best placement of HxL (successional LIRTUL) with Miller or Simon model? Is there a way to capture the loss of hemlock in Acid Cove? For example, the veg map distinguishes acid cove with hemlock (CHxA-T, CHx-T). Could we simply call these types "uncharacteristic" in the current veg? (unless they are in a "treated" polygon).						
GRSM Ecological Systems - - Ecological Zone	***Landfire Ecological System***	***"DOMINANT VE" Classes Reference Condition (original grouping unless indicated)***	***Approx. extent acres***	***Hybrid Model Comments***	***"DOMINANT VE" Classes Current Condition***	
Northern Hardwood - - Northern Hardwood Slope and Cove	Appalachian Northern Hardwood	Nothern Hardwood: NHx, NHxR, NHxB, NHxY, NHxR/T, NHxB/S, NHxBe, NHxE, NHxY-T ---------- Hemlock Northern Hardwood: NHx-T, NHx/T, NHxB/T, T/NHxAz ---------- Beech Gaps: NHxBe, NHxBe/Hb, NHxBE/G ---------- ---------- NHxA, NHxA/T, NHxBl/R, NHxAz, NHxAz/T	*67,329 total*	all classes included ---------- all classes included ---------- Beech Gaps lumped with Northern Hardwood ---------- added to the original group: Hemlock-Northern Hardwood = T/NHxA, T/NHx, T/NHxB, NHxB-T, NHxA-T, T/NHxR, NHxR-T moved out of this System: approx. 250 acres in 13 polygons based upon Ecological Zone ref. plots ---------- defined by Ecological Zones	NHx, NHxR, NHxB, NHx-T, NHxY, NHxA/T, NHx/T, NHxBl/R, NHxR/T, NHxB/S, NHxAz, NHxBe, NHxB/T, NHxE NHxA (acidic)	
Original Comments: Ditto the comment on hemlock loss in Acid Cove.						
Montane Alluvial Forest - - Alluvial Forest	Central Interior and Appalachian Riparian and Floodplain	MAL, MALc, MALt, MALj, MAL/T, HxJ	*7,850 total*	added to the original group: MAL-T, MALc-T includes ≈ 3 acres from reference plot analysis	MAL, MALc, MALt, MALj, MAL/T	
Balds		Hth		not included in LCF	Hth	
Beech Gaps?				lumped with Northern Hardwood		

GRSM Ecological Systems - - Ecological Zone	*Landfire Ecological System*	*"DOMINANT VE" Classes Reference Condition (original grouping unless indicated)*	*Approx. extent acres*	*Hybrid Model Comments: Description of DOMINANTVE Classes*	*"DOMINANT VE" Classes Current Condition*
			52,260 total 10.1 % of LCF area		use the original Rules or new Rules
Use Ecological Zones to define: Variable Systems	Variable	Hx, HxL, HxL/T, HxL-T	19,710	Southern App. Early Successional Hardwoods	
		HxA-T, HxA, HxBl/R, HxAz, HxA/T, NHxA, NHxA/T, NHxBl/R	23,355	Southern App. Mixed Hardwood Forest, Acidic	
		NHxAz , NHxAz/T	885	High Elevation Xeric Woodlands	
		PIs, PIs/OzHf	7,027	Eastern White Pine and Mixed Eastern White Pine - Dry Oak	
		PIs/OmHA, PIs/OmH	548	Eastern White Pine Mesic Oak Forest	
		OzH-PIs[1/], OzHf/PIs, OzH/PIs	735	Chestnut Oak/Hardwoods with White Pine	
		[1/] not listed in 2004 Report but is a GIS mapunit			
Uncharacteristic **ORIGINAL GROUPING**				Mixed Hardwoods (Hx) should maybe not be considered uncharacteristic? Though some of these sites may have been logged or dominated by chestnut, this does seem to be a distinct veg type?	PIs,PIs/OzH, OzH-PIs, OzHf/PIs, OzH/PIs, OmHA/PIs, OmHr/PIs, PIs/OmHA, PIs/OzHf PIs/OmH **(that does not intersect with Miller WPH)** HxL, HxL/T, HxL-T, Hx, HxF, HxF/T **(successional LIRTUL)** HxA, HxBl, HxBl/R, HxAz, HxA/T? **(former Chestnut forest?)** HxJ **(old homesites along streams - former Montane Alluvial?)** **"Untreated"** T, T/R, T/CHxA, T/CHx, T/NHxA, T/HxA, T/PIs, PIs-T, MAL-T, NHxR-T, NHxA-T, HxA-T, T/NHx, T/OmH, PIs/T, T/OmHA, T/S,

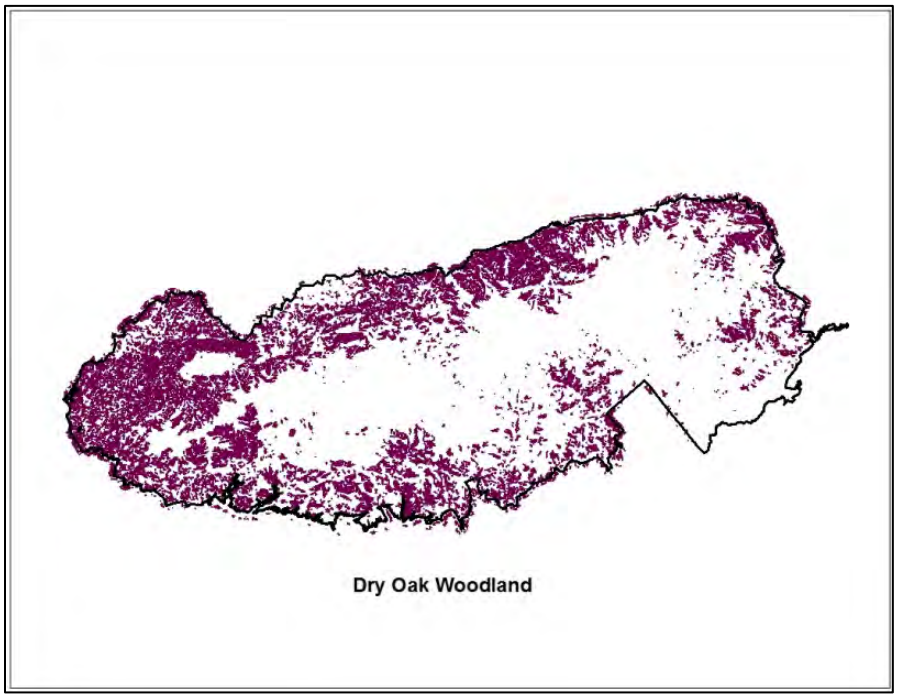
Appendix 2. Description of fire-maintained ecological systems in Great Smoky Mountains National Park.

Dry Oak Woodland

Dominant Species (Reference Condition): *Quercus montana, Q. coccinea, Q. velutina, Q. falcata, Carya glabra*

Dominant Species (Current Condition): *Quercus montana, Q. coccinea, Acer rubrum, Pinus strobus*

LCF Mapping Rules (Reference Condition): All occurrences of included vegetation map codes; all occurrences of veg map codes with codominant white pine; all occurrences of veg map codes with codominant yellow pine ***if*** they do not intersect with Miller "YPH"



NVCS Classes and GRSM Veg Map Codes:

- 56% is 6271 – Chestnut oak forest (xeric ridge type); veg map codes OzH
- 36% is 7267 – Appalachian montane oak-hickory forest (Chestnut oak type); veg map code OzHf
- 3% is 7230 – Appalachian montane oak-hickory forest (Typic acidic type); veg map code OzHfA
- 3% is 7519 – Appalachian white pine – xeric oak forest; veg map codes PIs/OzHf, PIs-OzHf
- Concept also includes 7691 – Appalachian oak-hickory forest (low elevation xeric type)
    - ❖ 7691 was apparently not included in the 2004 veg map; not sure why, but this association would have probably been 10-20% of the Dry Oak type parkwide, with a distribution related to that of shortleaf pine. It is prominent in the Community Classification document.

S-Class Comparison:

- Landfire BPS 5713150 Southern Appalachian Oak Forest
  - Early 5%
  - Mid closed 25%
  - Mid open 35%
  - Late open 26%
  - Late closed 9%

- GRSM LCF Model - Reference Conditions:
  - Early 17%
  - Mid closed 9%
  - Mid open 21%
  - Late open 29%
  - Late closed 24%

- GRSM LCF Model - Current:
  - Early 2%
  - Mid closed 0%
  - Mid open 0%
  - Late open 8%
  - Late closed 90%

Physical Description (Geology, Soils, Topography):

Geology – Metasedimentary and sedimentary rocks of the Great Smoky, Snowbird, Walden Creek, and Chilhowee Groups

Mountains: Metasedimentary geology - Metasandstone, metasiltstone, metagraywacke, metaconglomerate, phyllite, slate, shale

Western Foothills (Beard Cane to Chilhowee): "diverse" Sedimentary/metasedimentary geology: sandstone, shale, slate, siltstone, quartzite (which is metamorphic), isolated dolomite

Soils - Dystrudepts of the Ditney-Unicoi and Soco-Stecoah series; Hapludults of the Junaluska-Tsali series. These soils are generally nutrient-poor, well-drained, rocky, and strongly acidic.

Topography – Ridgetops and convex middle to upper slopes. Slopes have primarily south and west aspects. Elevations range from 900' to 4000', though this is primarily a low elevation type. Most occurrences are below 3000'.

Vegetation Description:

Vegetation ranges from oak and oak-pine woodlands with shrub layers dominated by ericaceous species to stands with more open understories dominated by a diverse set of dry-site herbs and grasses. Chestnut oak and scarlet oak are the characteristic trees, with black oak, white oak, and southern red oak co-occurring or becoming dominant on lower elevation sites. Blackjack oak and post oak are infrequent and localized, but are strong indicators of low-elevation dry oak woodlands. Other associated tree species include shortleaf pine, Virginia pine, pitch pine, pignut hickory, red maple, and black gum. Under current conditions, red maple, black gum, and white pine may have high densities in all size classes except the largest tree classes.

Typical understory trees include sourwood, dogwood, sassafras, and black locust. The density of the shrub layer can be highly variable. Under reference conditions, shrubs have moderate to sparse cover, but shrubs like mountain laurel and bear huckleberry could become well-established and dense in stands where the fire-return interval exceeds the historical average. High cover of these shrubs is very common in contemporary, unburned stands. *Vaccinium pallidum, V. stamineum, V. arboreum*, and *V. hirsutum* are other common shrubs and are good indicators of low-elevation dry oak forests.

The herb layer is also variable, ranging from sparse-to-moderate coverage by waxy-leaved evergreen subshrubs like *Gaultheria procumbens, Epigaea repens*, and *Galax urceolata* to high coverage by a diverse set of herbs and grasses that includes *Schizachyrium scoparium, Danthonia sericea, Piptochaetium avenaceum, Dichanthelium commutatum, Eurybia surculosa, Coreopsis major*, *Sericocarpus asteroides*, and *Baptisia tinctoria*. The vine species *Smilax rotundifolia* and *Smilax glauca* are also common.

Fire Regime:

Comparison with Landfire:

LCF	**Landfire (BPS 5713150)**
Surface fire – 17 year MFI	Surface Fire – 16 year
Mixed Fire – 73 year MFI	Mixed Fire – 139 year
Replacement – 136 years MFI	Replacement – 602 year

Description:

Frequent, low severity fires are the norm, with mean fire-free intervals (MFI) of 12-18 years, on average. This system is included in Landfire Fire Regime Group 1. Fires can occur virtually any time of year, but most commonly occur during the dormant season, between November and May. Fires in the winter

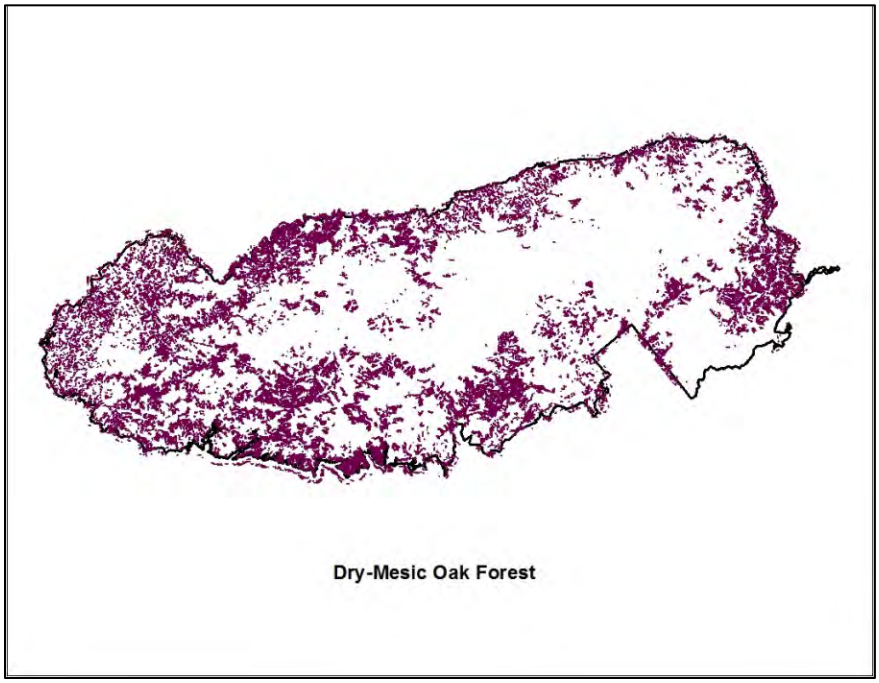
months of December and January are rare. Mixed severity fires, where fires top-kill 25-75% of the dominant vegetation (Landfire definition), are much less common, occurring every 50-100 years. Replacement fires (>75% top-kill) are rare events that occur every 100-200 years in an average stand. Both mixed severity and replacement fires are most likely to occur during the growing season and they are typically associated with extreme droughts. High severity fires may also be associated with extreme wind events during any time of year.

Dry Mesic Oak Forest

Dominant Species (Reference Condition): *Quercus alba, Q. montana, Castanea dentata, Q. rubra, Carya glabra*

Dominant Species (Current Condition): *Quercus alba, Q. montana, Q. rubra, Carya glabra, Acer rubrum, Carya alba, Pinus strobus, Liriodendron tulipifera*

LCF Mapping Rules (Reference Conditions): All occurrences of included vegetation map codes, except for OmH, for which occurrences below 2300' elevation were mapped as Dry-Mesic Oak (above 2300' were mapped as mesic oak).



NVCS Classes and GRSM Veg Map Codes:

- 47% is 7230 – Appalachian montane oak-hickory forest (Typic acidic type); veg map code OmHA
- 23% is 6192 – Appalachian montane oak-hickory forest (Red Oak Type); veg map code OmH < 2300'
- 14% is 7267/7230 – Appalachian montane oak-hickory forest (Typic acidic type); veg map code OcH. Appalachian montane oak-hickory forest (Chestnut oak type) ; veg map code OcH
- 8% is 6286 – Chestnut Oak Forest (Mesic Slope Heath Type); veg map code OmHp/R
- 4% is 7219 - Early Successional Appalachian Hardwood Forest; veg map code HxL
- Trace of 7100, 7944, 7519, 8558, 6271, 7517

S-Class Comparison:

- Landfire BPS 5713150 Southern Appalachian Oak Forest
  - Early 5%
  - Mid closed 25%
  - Mid open 35%
  - Late open 26%
  - Late closed 9%

- GRSM LCF Model - Reference Conditions:
  - Early 9%
  - Mid closed 9%
  - Mid open 18%
  - Late open 31%
  - Late closed 32%

- GRSM LCF Model - Current:
  - Early 1%
  - Mid closed 7%
  - Mid open 1%
  - Late open 2%
  - Late closed 85%

Physical Description (Geology, Soils, Topography):

Geology – Metasedimentary and sedimentary rocks of the Great Smoky, Snowbird, Walden Creek, and Chilhowee Groups

Mountains: Metasedimentary geology - Metasandstone, metasiltstone, metagraywacke, metaconglomerate, phyllite, slate, shale

Western Foothills (Beard Cane to Chilhowee): "diverse" Sedimentary/metasedimentary geology: sandstone, shale, slate, siltstone, quartzite (which is metamorphic), isolated dolomite

Soils - Dystrudepts of the Soco-Stecoah and Ditney-Unicoi series; Hapludults of the Junaluska-Tsali series. These soils are good to nutrient-poor, well-drained, rocky, and strongly acidic.

Topography – Protected ridgetops and saddles. South and west-facing low slopes and concave slopes. Upper north and east-facing slopes. Elevations range from 1200' to 4500'.

Vegetation Description:

Vegetation ranges from open oak-hickory forests to oak woodlands. The shrub layer can moderately dense and dominated by a single ericaceous species, but is most often sparse to moderate with several deciduous species and no clear dominant. White oak and chestnut oak are the characteristic species, though they often occur separately with other species such as northern red oak, black oak, mockernut hickory, and pignut hickory. White pine, red maple or tulip poplar may be much more important in current forests than they were in reference-condition forests. American chestnut was likely very important in reference-condition forests, though it is relegated to the shrub layer in current forests.

Typical understory trees include sourwood, dogwood, Fraser magnolia, and black gum. White pine and (now dead) hemlock saplings may occur at high densities. The density and composition of the shrub layer can be highly variable. Under reference conditions in typical sites, a wide variety of shrubs (including *Acer pensylvanicum, Rhododendron calendulaceum, Castanea dentata, and Pyrularia pubera*) can occur at moderate to sparse cover, but shrubs like great rhododendron or bear huckleberry can become well-established and dense in stands where the fire-return interval exceeds the historical average.

The herb layer can range from sparse with species such as *Galax urceolata, Chimaphila maculata, and Goodyera pubescens* to high coverage by a diverse set of herbs and ferns that includes *Amphicarpa bracteata, Desmodium nudiflorum, Polystichum acrosticoides, Maianthemum racemosum, Eurybia divaricata, Dennstaedtia punctilobula, and Dichanthelium spp.*

Fire Regime:

Comparison with Landfire:

LCF	Landfire (BPS 5713150)
Surface fire – 28 year MFI	Surface Fire – 16 year
Mixed Fire – 127 year MFI	Mixed Fire – 139 year
Replacement – 224 years MFI	Replacement – 602 year

Description:

In the Dry-Mesic Oak system, low severity fires are the norm. Mean fire-free intervals (MFI) for surface fires can be long (20-32 years), but are still classified as Fire Regime Group 1 by Landfire. Surface fires occur more frequently in the open s-classes and less frequently in the closed s-classes due to subtle differences in fuel composition, site exposure, and hence fuel moisture/availability. These fires can occur virtually any time of year, but most commonly occur during the dormant season, between November and May. Fires in the winter months of December and January are rare. Mixed severity fires, where fires top-kill 25-75% of the dominant vegetation (Landfire definition), are much less

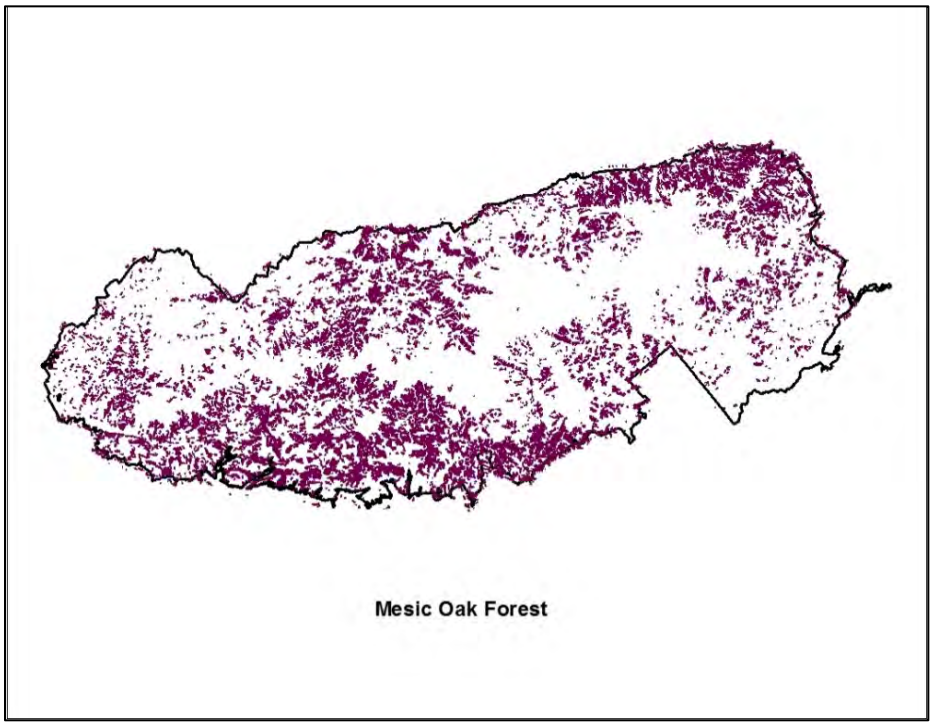
common, occurring every 100-200 years. Replacement fires (>75% top-kill) are rare events that may occur every 200-400 years in an average stand. Both mixed severity and replacement fires are most likely to occur during the growing season and they are typically associated with extreme droughts. High severity fires may also be associated with extreme wind events during any time of year.

Mesic Oak Forest

Dominant Species (Reference Condition): *Quercus rubra, Q. alba, Catanea dentata, Carya alba, Acer rubrum, Liriodendron tulipifera, Q. montana*

Dominant Species (Current Condition): *Quercus rubra, Q. alba, Acer rubrum, Carya alba, Liriodendron tulipifera, Q. montana*

LCF Mapping Rules: All occurrences of OmH above 2300' elevation. All occurrences of OmHr, OmHL, OmH/T, or OmH/PIs. All current occurrences of HxA and NxA were included in this concept because these areas were historically believed to be dominated by Chestnut or oak that failed to regenerate following logging or fire.



NVCS Classes and GRSM Veg Map Codes:

- 75% is 6192 – Appalachian montane oak-hickory forest (Red Oak Type); veg map codes OmH > 2300', OmHr, OmHL, OmH/T, OmH/PIs
- 11% is 7692 – Appalachian montane oak-hickory forest (Rich Type); veg map code OmHr
- 10% is 8558 – Southern Appalachian Mixed Hardwood Forest; veg map code HxA, NxA
- 3% is 7219 – Early Successional Appalachian Hardwood Forest; veg map code HxL
- Trace of 7100, 7944, 7519, 6271, 7517, 7267

S-Class Comparison:

- Landfire BPS 5713150 Southern Appalachian Oak Forest
  - Early 5%
  - Mid closed 25%
  - Mid open 35%
  - Late open 26%
  - Late closed 9%

- GRSM LCF Model - Reference Conditions:
  - Early 6%
  - Mid closed 17%
  - Mid open 14%
  - Late open 17%
  - Late closed 46%

- GRSM LCF Model - Current:
  - Early 1%
  - Mid closed 4%
  - Mid open 1%
  - Late open 26%
  - Late closed 66%

Physical Description (Geology, Soils, Topography):

Geology – Metasedimentary and sedimentary rocks of the Great Smoky, Snowbird, Walden Creek, and Chilhowee Groups

Mountains: Metasedimentary geology - Metasandstone, metasiltstone, metagraywacke, metaconglomerate, phyllite, slate, shale

Western Foothills (Beard Cane to Chilhowee): "diverse" Sedimentary/metasedimentary geology: sandstone, shale, slate, siltstone, quartzite (which is metamorphic), isolated dolomite

Soils - Primarily Dystrudepts of the Soco-Stecoah and Ditney-Unicoi series; some occurrence on Hapludults of the Junaluska-Tsali series. These soils are good to nutrient-poor, well-drained, rocky, and circumneutral to strongly acidic.

Topography – Typically on protected slopes with northern, eastern, southeastern aspect. Some occurrences have been documented on western slopes. Typical elevations range from 2000' to 4500', though small examples of this system can occur at elevations down to 1000' in GRSM's western end.

Vegetation Description:

Vegetation is oak, oak-hickory, and oak-mixed hardwood closed forest. Well-developed subcanopies, shrub layers, and herb layers are typical, though open s-classes may approach open forest conditions. Red oak is the characteristic species of the mesic oak system, though white oak or chestnut oak may also dominate or share dominance. Red maple, tulip poplar, mockernut hickory, and/or pignut hickory may be locally important, and red maple may be codominant. Under current conditions, red maple is the most abundant species in the subcanopy, and (now dead) eastern hemlock may be abundant in the understory. American chestnut was likely very important in reference-condition forests, though it is relegated to the shrub layer in current forests.

Typical understory trees include sourwood, silverbell, and dogwood. Shrub coverage is moderate to high and includes the following species: *Gaylussacia ursina, Calycanthus floridus, Castanea dentata, Pyrularia pubera, and Acer pensylvanicum*. *Rhododendron maximum* can be present and may be abundant.

The herb layer is typically very diverse and can range from sparse to high cover, with species such as *Galax urceolata,Thelypteris noveboracensis, Eurybia divaricata*, several *Carex spp., Polygonatum biflorum, Houstonia purpurea,Lysimachia quadrifolia*, and *Dioscorea quaternata*. The richest, closed forests within this system may approach cove forest in species diversity and composition. These stands may include: *Cimicifuga racemosa, Adiantum pedatum, Dryopteris intermedia, Collinsonia Canadensis, Caulophyllum thalictroides, Amphicarpa bracteata, and Athyrium filix-femina,* among many others.

Fire Regime:

Comparison with Landfire:

LCF	**Landfire (BPS 5713150)**
Surface fire – 37 year MFI	Surface Fire – 16 year
Mixed Fire – 175 year MFI	Mixed Fire – 139 year
Replacement – 243 years MFI	Replacement – 602 year

Description:

The fire regime of the Mesic Oak system represents the lowest frequency among the oak forest systems, with mean fire-free intervals (MFI) for surface fires between 33-40 years. This fire regime falls within the Landfire Fire Regime Group III. Low severity surface fires are the norm, and like the dry-mesic oak system, fires occur most frequently in the early and mid- s-classes due to subtle differences in fuel composition, site exposure, and hence fuel moisture/availability. These fires can occur virtually any time

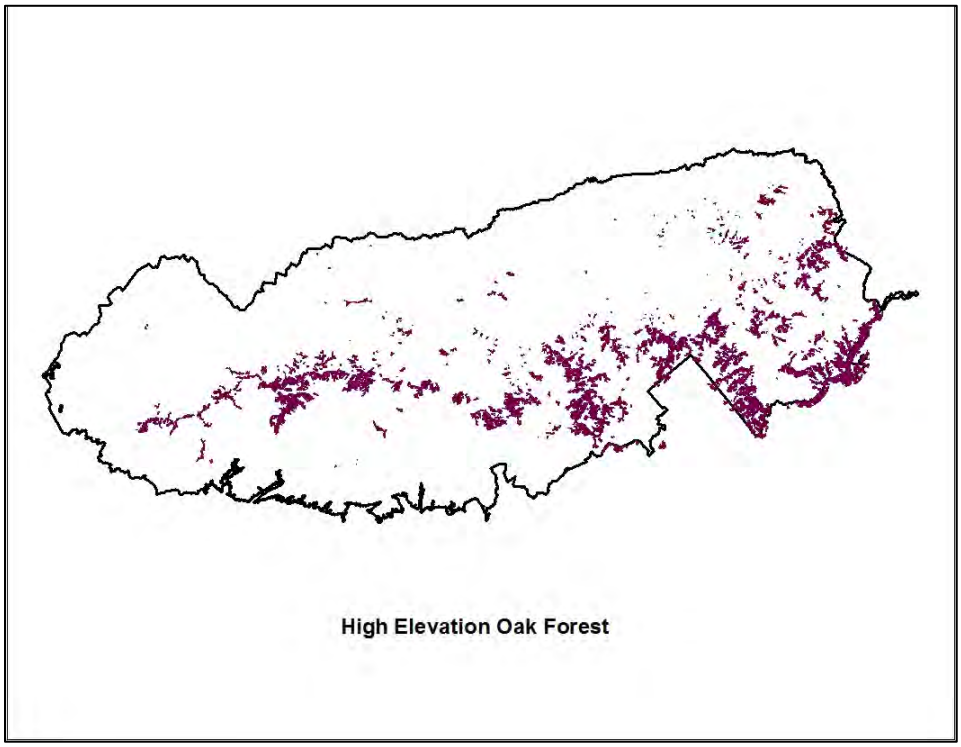
of year, but most commonly occur during the dormant season, between November and May. Fires in the winter months of December and January are rare. Mixed severity fires, where fires top-kill 25-75% of the dominant vegetation (Landfire definition), are much less common, occurring every 150-250 years. Replacement fires (>75% top-kill) are very rare events that may occur every 250-400 years in an average stand. Both mixed severity and replacement fires are most likely to occur during the growing season and they are typically associated with extreme droughts. High severity fires may also be associated with extreme wind events during any time of year.

High Elevation Oak Forest

Dominant Species (Reference Condition): *Castanea dentata, Quercus rubra, Quercus alba,*

Dominant Species (Current Condition): *Quercus rubra, Q. alba, Acer rubrum, Prunus serotina, Betula alleghaniensis*

LCF Mapping Rules: All occurrences of veg map codes listed below.



NVCS Classes and GRSM Veg Map Codes:

- 34% is 7300 – High-Elevation Red Oak Forest (Deciduous Shrub Type); veg map code MOr/Sb
- 31% is undifferentiated 7298, 7299, 7300 – High Elevation Red Oak Forest; veg map code MOr
- 21% is 7299 – High-Elevation Red Oak Forest (Evergreen Shrub Type); veg map code MOr/K, MOr/R, MOz
- 5% is 8558 – Southern Appalachian Mixed Hardwood Forest; veg map code HxA, NxA
- 5% is 7298 – High-Elevation Red Oak Forest (Tall Herb Type); veg map code MOr/G
- 4% is 7295 – Southern Blue Ridge High Elevation White Oak Forest; veg map code MOa
- Trace of 7230, 7517, 4973, 7219, 6192

S-Class Comparison:

- Landfire BPS 5713200 Central and Southern Appalachian Montane Oak Forest

(Note: This BPS is narrowly-defined as stunted talus-slope woodlands)

  - Early 2%
  - Mid closed 21%
  - Mid open 77%
  - Late open 0% *(not used)*
  - Late closed 0% *(not used)*

- GRSM LCF Model - Reference Conditions:
  - Early 14%
  - Mid closed 14%
  - Mid open 12%
  - Late open 38%
  - Late closed 22%

- GRSM LCF Model - Current:
  - Early 1%
  - Mid closed 0%
  - Mid open 0%
  - Late open 3%
  - Late closed 96%

Physical Description (Geology, Soils, Topography):

Geology – Predominantly found on metasedimentary rocks of the Great Smoky Group, with some occurrence on Snowbird Group geology, and on the small areas of Biotite augen gneiss found in the Balsam Mountains.

Soils - Primarily Dystrudepts of the Soco-Stecoah series; some occurrence on Dystrudepts of Cataska-Sylco, Hapludults of Evard-Cowee, and Humudepts of Breakneck-Pullback soils. These soils range from good to nutrient-poor, are well-drained, stony, and strongly acidic.

Topography – High ridges, mid- to upper slopes of all aspects, but primarily south and southeast-facing. This is a high-elevation system that occurs between 3500' – 5000'.

Vegetation Description:

Vegetation includes high-elevation forests and woodlands strongly dominated by northern red oak, with a small percentage of stands dominated by white oak. The upper canopy oak trees may be stunted and

gnarled by exposure to wind and ice. Other tree species include: yellow birch, red maple, and cherry. The subcanopy is typically open to poorly developed. American chestnut was very important in reference-condition forests, though it is relegated to the shrub layer in current forests.

There are four distinct associations within this system, and these associations are largely distinguished by differences in the structure of the understory. Most stands in this system have a very dense shrub layer, which may be dominated by evergreen or deciduous species. Stands with evergreen shrubs typically have a high cover of *Rhododendron maximum*, though *Kalmia latifolia* can be present. Stands dominated by white oak more often have a shrub layer dominated by *Kalmia*. These forests have low herbaceous cover and diversity, typically dominated by *Galax urceolata*.

Forests in this system that are dominated by deciduous shrubs may include the following species in the understory: *Ilex montana, Rhodendron calendulaceum, Castanea dentata, Rubus canadensis, Vaccinium erythrocarpum, or V. corymbosum*. These stands often have a high coverage of diverse herbs that is dominated by the ferns Dennstaedtia puntilobula and Thelypteris noveboracensis. The final montane oak association has a sparse, open shrub layer and an herb layer that is strongly dominated by Carex pensylvanica, which can appear a dense carpet. Other herbs may include: *Angelica triquinata, Eurybia chlorolepis, Cuscuta rostrate, Dryopteris intermedia, Prenanthes altissima,* and *Lilium superbum*, among others.

Fire Regime:

Comparison with Landfire:

LCF	**Landfire (BPS 5713200)**
Surface fire – 33 year MFI	Surface Fire – 13 year
Mixed Fire – 102 year MFI	Mixed Fire – none
Replacement – 163 years MFI	Replacement – none

Description:

The fire regime of the High Elevation Oak Forest is not well understood. It is generally thought to be a frequent, low severity regime due to its woodland-like structure and the exposed nature of its high-elevation sites; however, due to the isolation of most stands and the higher moisture levels that are present at higher elevations, it is likely a much longer mean fire-free interval than lower-elevation dry oak stands. This project maintained this system in the Landfire Fire Regime Group I, but used a relatively long MFI of 25-40 years (average 33 years). Due to the high moisture conditions at high elevations in GRSM, fires likely occurred most frequently in the early and open s-classes, and this is reflected in the modelled fire regime. Low severity fires are the norm, however mixed severity (MFI 100

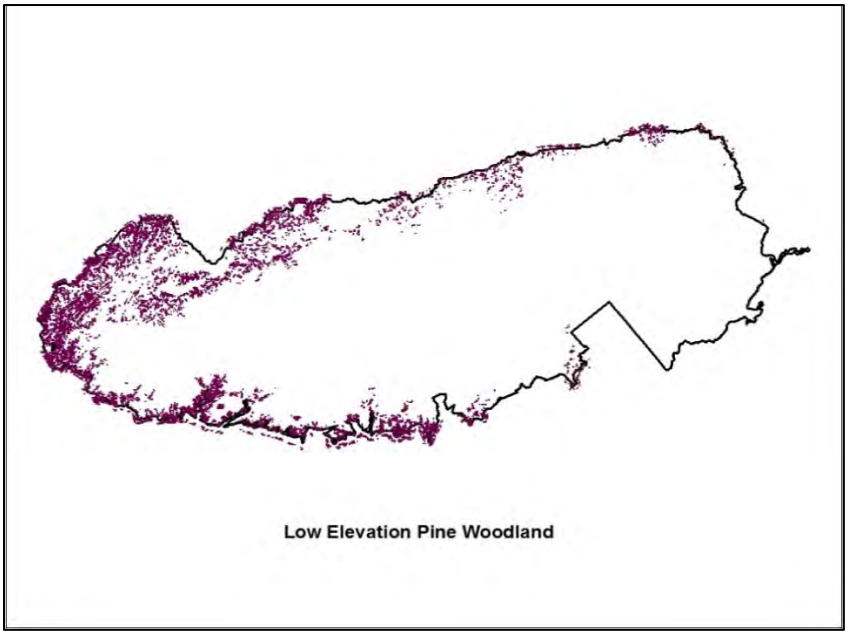
years) and replacement fires (160 years) likely occurred more frequently than in lower-elevation mesic oak forests due to topographic features such as exposure and slope. Fires can occur virtually any time of year, but most commonly occur during the dormant season, between November and May. Fires in the winter months of December and January are rare. Both mixed severity and replacement fires are most likely to occur during extreme droughts. High severity fires may also be associated with extreme wind events during any time of year.

Low Elevation Pine Woodland

Dominant Species (Reference Condition): *Pinus echinata, Pinus virginiana, Quercus coccinea,Q. falcata, Q. montana, Q. velutina, Q. stellata*

Dominant Species (Current Condition): *Pinus echinata, P. rigida, P. virginiana, P. strobus, Quercus coccinea, Q. falcata, Q. montana, Q. velutina, Acer rubrum*

LCF Mapping Rules: The two low-elevation pine types presented here are not distinguished by the current GRSM veg map. These systems were mapped using our pine map units (<2300' elevation) intersected with Simon's Low Elevation Pine system model. For reference conditions mapping, if current oak-pine types intersected with areas mapped as "Yellow Pine" by Miller in 1938, they were included as pine map units. Of those, the areas that intersected Simon's Low-Elevation Pine model were included here as Low-Elevation Pine. If our pine units (again, only those less than 2300') ***did not*** intersect with Simon's Low-Elevation Pine model, they were placed in our Low-Elevation Pine-Oak-Heath.



NVCS Classes and GRSM Veg Map Codes:

- 40% has no CEGL code –veg map codes are PI, PIr
  The most likely CEGL is currently: 7493 – SBR Escarpment Shortleaf Pine – Oak Forest
- 26% is undifferentiated 7119, 7078, 2591, 3560; veg map code PI/OzH
- 16% is undifferentiated 7097, 7119; veg map code PI-OzH
- 9% is 6271 – Chestnut Oak Forest (Xeric Ridge); veg map codes OzH/PI, OzH/PIv, OzH-PIs, OzH
- 3% is 7097 – Blue Ridge Table Mt. Pine – Pitch Pine Woodland (Typic Type); veg map code PIp, PIp/OzH, PIp-OzH
- 3% is undifferentiated 7100, 7944, 7519 – various White Pine types; veg map code PIs, PIs/OzHf
- Trace of 2591, 7219, 7517, 8558, 6192

S-Class Comparison:

- Landfire BPS 5713530 - Southern Appalachian Low-Elevation Pine Forest
  - Early 32%
  - Mid closed 2%
  - Mid open 32%
  - Late open 33%
  - Late closed 1%

- GRSM LCF Model – Reference Conditions:
  - Early 13%
  - Mid closed 10%
  - Mid open 30%
  - Late open 35%
  - Late closed 12%

- GRSM LCF Model - Current:
  - Early 3%
  - Mid closed 12%
  - Mid open 4%
  - Late open 5%
  - Late closed 72%

Physical Description (Geology, Soils, Topography):

Geology – Metasedimentary and sedimentary rocks of the Walden Creek, Chilhowee, Great Smoky, and Snowbird, Groups

Mountains: Metasedimentary geology - Metasandstone, metasiltstone, metagraywacke, metaconglomerate, phyllite, slate, shale, -

Western Foothills (Beard Cane to Chilhowee): "diverse" Sedimentary/metasedimentary geology: sandstone, shale, slate, siltstone, quartzite (which is metamorphic), isolated dolomite

Soils - Dystrudepts of the Ditney-Unicoi, Soco-Stecoah and Cataska-Sylco series; Hapludults of the Junaluska-Tsali series. These soils are generally nutrient-poor, well-drained, rocky to stony, and strongly acidic.

Topography – Low ridges and summits. Convex, low to middle slopes, and some upper slopes. Slopes have primarily south and west aspects. Elevations range from 900' to 2300'. This system is primarily limited to the lowest elevations in GRSM, and is distributed largely along the park boundary and in the western end of GRSM.

Vegetation Description:

The low-elevation pine system is rare in the Southern Appalachians, and it is one of the most departed from its reference conditions. Few good examples of the system remain within GRSM, but there remain exceptional stands of shortleaf pine, some of which have been aged at 200-300 years old. There also remain vital remnants of the diverse herb layer of xeric grasses and forbs, though these are largely relegated to trail-sides, roadsides, and burned areas that intersect areas where this system formerly existed.

Much of this system is thought to have existed as Shortleaf Pine/Little Bluestem Appalachian Woodland (CEGL 3560) under reference conditions (roughly pre-Columbian), though this association is not mapped in GRSM's vegetation map. Most of the shortleaf stands are better described today as CEGL 7078 or 7493, and this is likely due to homogenization and degradation of the low elevation pine system due to fire exclusion. The presence of Shortleaf Pine and a more abundant and diverse herb layer are the two things that differentiate this system from the related Low-Elevation Pine-Oak-Heath. Subtle differences in site conditions (topography, solar exposure, moisture index) are some of the primary factors separating the two low elevation pine types, and these site differences in turn contribute to a different disturbance ecology and differences in species dominance. Southern pine beetle has hastened the loss of shortleaf pine in many areas, but several sites have been partially restored by fire, and show great promise for further restoration.

Reference conditions were primarily pine to pine-oak woodlands with open subcanopies and shrub layers. Herb layers were diverse and had moderate to high cover. Dominant trees included shortleaf pine, Virginia pine, and various species of dry-site oaks, and these species accounted for most of the trees in the subcanopy and seedling layer. Shrub layers were open and included species such as *Vaccinium pallidum, V. hirsutum, V. stamineum, V. arboreum, Lyonia ligustrina, and Kalmia latifolia*. The herb layer was very diverse, and included dominants such as: *Schizachyrium scoparium, Danthonia sericea, Piptochaetium avenaceum, Pityopsis graminifolia, Baptisia tinctoria, Coreopsis major, Pteridium aquilinum, Solidago odora, and Eurybia surculosa*.

Current conditions range from reasonable remnants with canopy dominance or codominance by shortleaf pine to highly degraded examples with few of the characteristic herbs remaining and very little shortleaf pine. All of these current stands have advanced succession to a variety of hardwoods or white pine. Canopy hardwoods include the dry oaks, but subcanopies are dominated by red maple, black gum, and white pine. Numerous other species crowd the midstory, including sourwood, sassafras, and mountain laurel. Shrub layers include the characteristic *Vaccinium* spp., and herb layers are sparse.

Fire Regime:

Comparison with Landfire:

LCF	Landfire (BPS 5713530)
Surface fire – 10 year MFI	Surface Fire – 4 year
Mixed Fire – 74 year MFI	Mixed Fire – 145 year
Replacement – 145 years MFI	Replacement – 25 year

Description:

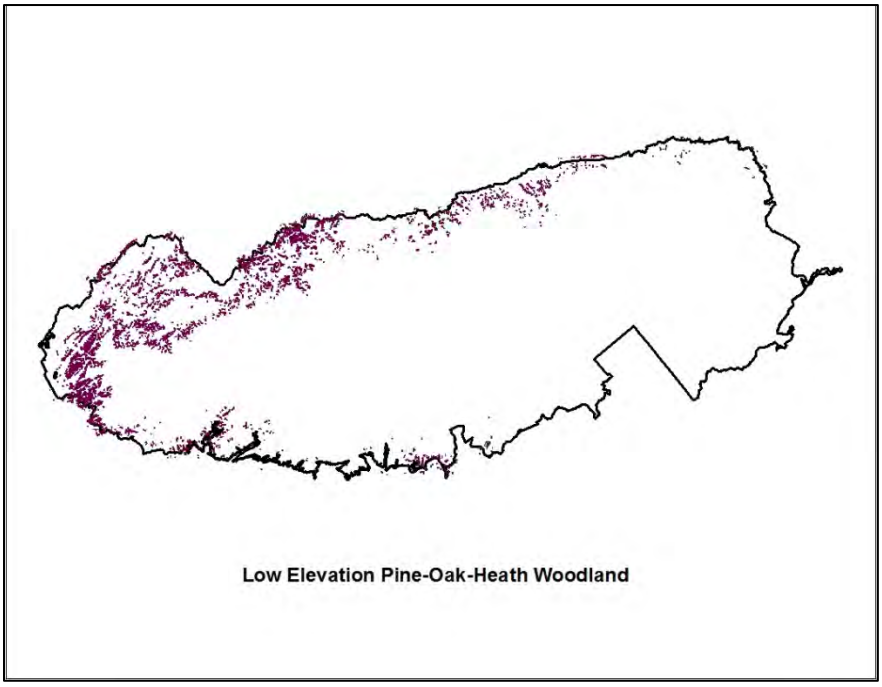
Under reference conditions, the low-elevation pine system experienced the most frequent fire of any system in the Great Smoky Mountains. Frequent, low severity fires are the norm, with mean fire-free intervals (MFI) of 8-11 years, on average. This system is included in Landfire Fire Regime Group 1. Fires can occur virtually any time of year, but most commonly occur during the dormant season, between November and May. Fires in the winter months of December and January are rare. Mixed severity fires, where fires top-kill 25-75% of the dominant vegetation (Landfire definition), are much less common, occurring every 50-125 years. Replacement fires (>75% top-kill) are rare events that occur every 100-200 years in an average stand. Both mixed severity and replacement fires are most likely to occur during the growing season and they are typically associated with several missed fire rotations and extreme droughts. High severity fires may also be associated with extreme wind events during any time of year.

Low Elevation Pine-Oak-Heath

Dominant Species (Reference Condition): *Pinus rigida, P. virginiana, Quercus coccinea, Kalmia latifolia*

Dominant Species (Current Condition): *P. rigida, P. virginiana, P. strobus, Quercus coccinea, Q. montana, Acer rubrum*

LCF Mapping Rules: The two low-elevation pine types presented here are not distinguished by the current GRSM veg map. These systems were mapped using our pine map units (<2300' elevation) intersected with Simon's Low Elevation Pine system model. For reference conditions mapping, if current oak-pine types intersected with areas mapped as "Yellow Pine" by Miller in 1938, they were included as "pine" map units. Of those, the areas that intersected Simon's Low-Elevation Pine model were included in the Low-Elevation Pine system. Those pine units that ***did not*** intersect with Simon's Low-Elevation Pine model (again, only those less than 2300'), were placed in this Low-Elevation Pine-Oak-Heath ecological system.



NVCS Classes and GRSM Veg Map Codes:

- 34% is undifferentiated 7119, 7078, 2591, 3560; veg map code PI/OzH
- 29% has no defined CEGL; veg map codes are PI and PIr
  The most likely CEGL is currently: 7119 – Appalachian Low Elevation Mixed Pine Forest
- 18% is undifferentiated 7097, 7119; veg map code PI-OzH
- 12% is 6271 – Chestnut Oak Forest (Xeric Ridge Type); veg map codes OzH, OzH/PI, OzH/PIv, OzH-PIs
- 4% is 7219 – Early Successional Appalachian Hardwood Forest: veg map code Hx, HxL, /T-T
- Trace of 2591, 7097, 8558, 7267

S-Class Comparison:

- Landfire BPS 5713520 - Southern Appalachian Montane Pine Forest and Woodland
  - Early 12%
  - Mid closed 3%
  - Mid open 25%
  - Late open 55%
  - Late closed 5%

- GRSM LCF Model - Reference Conditions:
  - Early 21%
  - Mid closed 13%
  - Mid open 30%
  - Late open 21%
  - Late closed 15%

- GRSM LCF Model - Current:
  - Early 2%
  - Mid closed 0%
  - Mid open 0%
  - Late open 13%
  - Late closed 84%

Physical Description (Geology, Soils, Topography):

Geology – Metasedimentary and sedimentary rocks of the Walden Creek, Chilhowee, Great Smoky, and Snowbird Groups

Mountains: Metasedimentary geology - Metasandstone, metasiltstone, metagraywacke, metaconglomerate, phyllite, slate, shale

Western Foothills (Beard Cane to Chilhowee): "diverse" Sedimentary/metasedimentary geology: sandstone, shale, slate, siltstone, quartzite (which is metamorphic), isolated dolomite

Soils - Dystrudepts of the Ditney-Unicoi, Soco-Stecoah and Cataska-Sylco series; Hapludults of the Junaluska-Tsali series. These soils are generally nutrient-poor, well-drained, rocky to stony, and strongly acidic.

Topography – Ridgetops and convex, steep middle to upper slopes. Slopes have primarily south and west aspects. Elevations range from 900' to 2300'.

Vegetation Description:

Vegetation is pine woodlands with a high percentage of early and mid-successional stand classes. Under reference conditions, most stands are open in the canopy and subcanopy, but have a moderate to high density of stems in the shrub layer. The herb layer is sparse to moderate in cover, depending on stand conditions. Pitch pine and Virginia pine are the characteristic trees, with scarlet oak, black oak, and blackjack oak frequently present. Under current conditions, red maple, black gum, white pine, and the dry oak spp. may have high densities in all size classes except the largest tree classes. Southern pine beetle has hastened the loss of the yellow pines in many areas, and most stands have at least some large standing dead or fallen pine trees.

Typical understory trees include sourwood, sassafras, and black locust. The density of the shrub layer is typically high, with high cover values for *Kalmia latifolia, Gaylussacia baccata, G. ursina, Vaccinium stamineum*, and *V. pallidum*. Under reference conditions, shrubs may have been shorter in stature and had more moderate cover, but the shrub *Kalmia latifolia* could become well-established and dense in stands where the fire-return interval exceeded the historical average. High cover of these shrubs is very common in contemporary, unburned stands.

The herb layer is also variable, ranging from sparse-to-moderate coverage by waxy-leaved evergreen subshrubs like *Gaultheria procumbens, Epigaea repens*, and *Galax urceolata* to sparse coverage by grasses and forbs including: S*chizachyrium scoparium, Dichanthelium commutatum, Pteridium aquilinum and Chimaphila maculata*. The vine species *Smilax rotundifolia* and *Smilax glauca* are also common.

Low Elevation Pine-Oak Heath is perhaps most closely related to Montane Pine-Oak-Heath (TMP/Pitch Pine), with which it shares a fire regime that is more mixed-severity than that of the Low Elevation Pine system. However, the species composition of the vegetation is transitional between Low Elevation Pine and the Montane Pine systems. It differs from Montane pine-oak-heath by occurring in less mountainous and isolated terrain and by the general absence of TMP.

Fire Regime:

Comparison with Landfire:

LCF	**Landfire (BPS 5713520)**
Surface fire – 14 year MFI	Surface Fire – 5 year
Mixed Fire – 55 year MFI	Mixed Fire – 101 year
Replacement – 115 years MFI	Replacement – 88 year

Description:

Low Elevation Pine-Oak-Heath has a mixed-severity fire regime, which contrasts with the geographically-related Low Elevation Pine system. This difference is due to the greater extremes of topographic exposure of the POH system, and the tendency of POH to occur in locations that are slightly more rugged and isolated than the Low Elevation Pine Woodlands. These more rugged, isolated landscapes have had a greater average distance from prehistoric and historic human use (thus less prone to be impacted by anthropogenic fire regimes) and smaller fire compartments. The effect of the greater isolation is less frequent fire and corresponding fuel buildup that tends to increase fire severity when fires do occur.

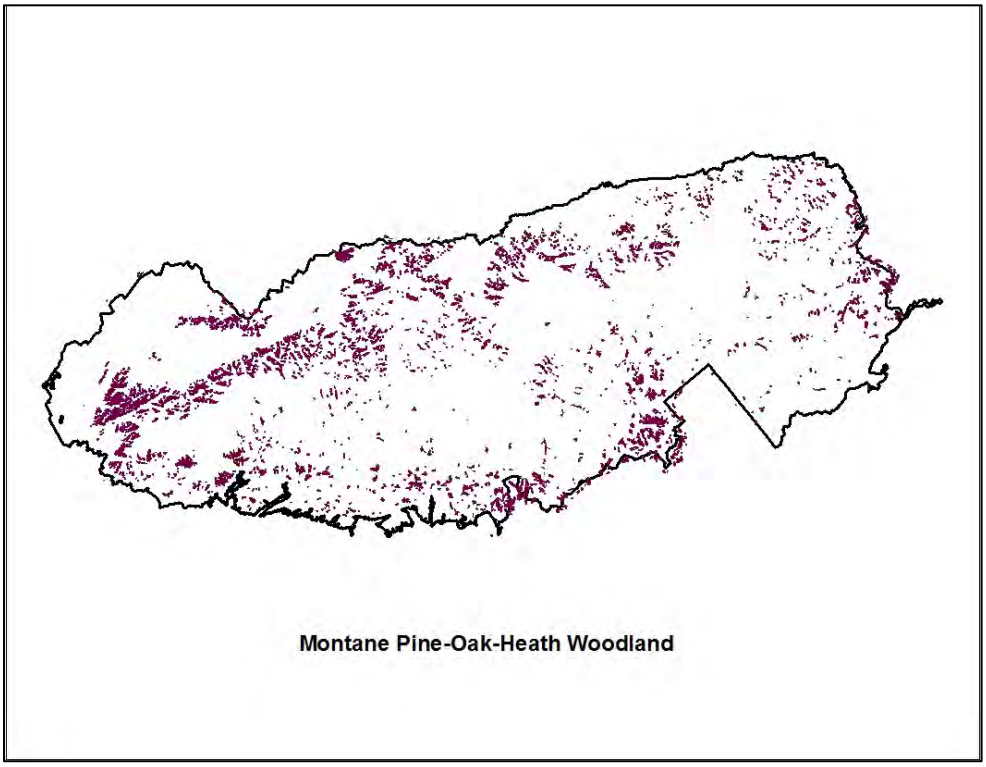
Surface fires occurred on average every 12-17 years, and mixed severity fires occur every 55 years on average. Due to fuel buildup processes, mixed severity fires are more likely to occur in closed s-classes that have missed one or more fire rotations. The relatively high frequency of these mixed severity fires best places this system into the Landfire Fire Regime Group III, though some stands in the system operate more as Fire Regime Group I. Fires can occur virtually any time of year, but most commonly occur during the dormant season, between November and May. Fires in the winter months of December and January are rare. Replacement fires (>75% top-kill) are more uncommon, but still occur on an average of every 115 years. Replacement fires are typically associated with several missed fire rotations and extreme droughts. High severity fires may also be associated with extreme wind events during any time of year.

Montane Pine-Oak-Heath

Dominant Species (Reference Condition): *Pinus pungens, Pinus rigida, Quercus montana, Kalmia latifolia*

Dominant Species (Current Condition): *Pinus pungens, Pinus rigida, Quercus montana, Q. coccinea, Kalmia latifolia, Acer rubrum, Oxydendrum arboreum, Nyssa sylvatica*

LCF Mapping Rules: All mapped Yellow Pine stands above 2300' elevation. For reference conditions mapping, if current oak-pine types intersected with areas mapped as "Yellow Pine" by Miller in 1938, they were included as pine map units.



NVCS Classes and GRSM Veg Map Codes:

- 35% has no defined CEGL; veg map codes are PI and PIr
  The most likely CEGL is currently: 7097 – Blue Ridge Table Mountain Pine-Pitch Pine Woodland
- 25% is undifferentiated 7119, 7078, 2591, 3560; veg map code PI/OzH
- 12% is 8558; veg map code HxA, NxA, NHxAz
- 12% is undifferentiated 7097 and 7119; veg map code PI-OzH
- 8% is 6271 – Chestnut Oak Forest (Xeric Ridge); veg map codes OzH/PI, OzH/PIv, OzH-PIs, OzH
- 7% is 7097 – Blue Ridge Table Mountain Pine-Pitch Pine Woodland; veg map codes PIp, PIp/OzH, PIp-OzH

S-Class Comparison:

- Landfire BPS 5713520 - Southern Appalachian Montane Pine Forest and Woodland
  - Early 12%
  - Mid closed 3%
  - Mid open 25%
  - Late open 55%
  - Late closed 5%

- GRSM LCF Model - Reference Conditions:
  - Early 25%
  - Mid closed 16%
  - Mid open 25%
  - Late open 19%
  - Late closed 15%

- GRSM LCF Model - Current:
  - Early 6%
  - Mid closed 1%
  - Mid open 1%
  - Late open 14%
  - Late closed 78%

Physical Description (Geology, Soils, Topography):

Geology – Metasedimentary Great Smoky and Snowbird Groups

Mountains: Metasedimentary geology - Metasandstone, metasiltstone, metagraywacke, metaconglomerate, phyllite, slate, shale

Soils - Dystrudepts of the Ditney-Unicoi, Soco-Stecoah and Cataska-Sylco series; Hapludults of the Junaluska-Tsali series. These soils are generally nutrient-poor, well-drained, rocky to stony, and strongly acidic.

Topography – Exposed ridgetops and steep middle to upper slopes. Slopes are convex to flat. Slopes have primarily south and west aspects. Elevations mostly 2300' – 4000', with a few stands to 5000'.

Vegetation Description:

Vegetation is pine woodlands with a high percentage of early and mid-successional stand classes. Under reference conditions, most stands are open in the canopy and subcanopy, but have a moderate to high density of stems in the shrub layer. The herb layer is sparse to moderate in cover, depending on stand

conditions. Table-mountain and pitch pine are the characteristic trees, with chestnut oak and scarlet oak frequently present. Under current conditions, red maple, black gum, white pine, and the dry oak spp. may have high densities in all size classes except the largest tree classes. Southern pine beetle has hastened the loss of the yellow pines in many areas, and most stands have at least some large standing dead or fallen pine trees.

Typical understory trees include sourwood, service berry, Fraser magnolia, and black locust. The density of the shrub layer is typically high, with high cover values for *Kalmia latifolia, Gaylussacia baccata, G. ursina, Vaccinium stamineum*, and *V. pallidum*. At elevations around 4000', *Pieris floribunda* can become a dominant shrub. Under reference conditions, shrubs may have been shorter in stature and had more moderate cover, but the shrub *Kalmia latifolia* could become well-established and dense in stands where the fire-return interval exceeded the historical average. High cover and high height (8'-10') of these shrubs is very common in contemporary, unburned stands.

The herb layer is also variable, ranging from sparse-to-moderate coverage by waxy-leaved evergreen subshrubs like *Gaultheria procumbens, Epigaea repens*, and *Galax urceolata* to sparse coverage by grasses and forbs including: S*chizachyrium scoparium, Dichanthelium commutatum, Pteridium aquilinum, Chimaphila maculata, Cleistesiopsis bifaria, and Cypripedium acuale*. The vine species *Smilax rotundifolia* and *Smilax glauca* are also common.

Fire Regime:

Comparison with Landfire:

LCF	Landfire (BPS 5713520)
Surface fire – 22 year MFI	Surface Fire – 5 year
Mixed Fire – 60 year MFI	Mixed Fire – 101 year
Replacement – 97 years MFI	Replacement – 88 year

Description:

Montane Pine-Oak-Heath has a mixed-severity fire regime. The system generally occurs on the most exposed, rugged, and isolated landscapes, which have had a greater average distance from prehistoric and historic human use (thus less prone to be impacted by anthropogenic fire regimes) and smaller fire compartments. The effect of the greater isolation is less frequent fire and corresponding fuel buildup that tends to increase fire severity when fires do occur.

Surface fires occurred on average every 20-25 years, and mixed severity fires occur every 60 years on average. Due to fuel buildup processes, mixed severity fires are more likely to occur in closed s-classes

that have missed one or more fire rotations. The relatively high frequency of these mixed severity fires best places this system into the Landfire Fire Regime Group III, though some stands in the system operate more as Fire Regime Group I, with much more frequent surface fires. Fires can occur virtually any time of year, but most commonly occur during the dormant season, between November and May. Fires in the winter months of December and January are rare. Replacement fires (>75% top-kill) are more uncommon, but still occur on an average of every 97 years, making this system the most likely in GRSM to experience high-intensity stand replacement fires. Replacement fires are typically associated with several missed fire rotations and extreme droughts. High severity fires may also be associated with extreme wind events during any time of year.

Appendix 3. Back Test of Models for Dry Oak and Low Elevation Pine

"Back tests" were conducted on the models of two representative fire-dependent systems – Dry Oak Forest and Low Elevation Pine Forest – to help confirm the validity of the fire-return intervals and other key variables in the models. These tests were designed to roughly mimic the major human-caused disturbances in GRSM over the last century and see if the models would generate results that approximate actual current conditions.

Using ST-Sim, the back tests populated the reference condition s-classes as the Initial Conditions for these two systems as of 1910. It then simulated heavy logging (50% clearcut) over a 20 year period, and recorded the s-class outcomes after those simulations as new Initial Conditions as of 1930. It then simulated 85 years of 98% fire suppression and recorded the s-class outcomes after those simulations at the end of 85 years (i.e., 2015).

The table below shows the Actual Current % for each s-class as compared to the simulated current results (1910-2015 Back Test Model Run Outcomes) for both systems. A "departure score" was calculated to compare current to simulated outcomes. The comparison of results by s-class within the table and low "departure scores" of 12 for each of the two systems demonstrated that their models very closely predicted actual current conditions.

	Dry Oak Forest			Low Elevation Pine	
Vegetation Class	**Current %**	**1910-2015 BackTest Model Run Outcomes**		**Current %**	**1910-2015 BackTest Model Run Outcomes**
Early	2%	5%		3%	5%
Mid-Closed	0%	6%		12%	22%
Mid-Open	0%	0%		4%	1%
Late-Closed	90%	78%		72%	67%
Late-Open	8%	11%		5%	5%
Highly Departed Composition	0%	0%		3%	0%
Total Early/Open	10%	16%		12%	11%
Total Closed	90%	84%		85%	89%
"Departure" from Current		**12**			**12**

Appendix 4. Deterministic Transitions for ST-Sim ecological models.

Vegetation Type	From Class	To Class	Age Min	Age Max
RichAcidicCove	1-Early1:ALL	2-Mid1:CLS	0	10
RichAcidicCove	2-Mid1:CLS	3-Late1:CLS	11	80
RichAcidicCove	2-Mid1:OPN	3-Late1:CLS	11	80
RichAcidicCove	3-Late1:CLS	3-Late1:CLS	81	999
RichAcidicCove	3-Late1:OPN	3-Late1:OPN	81	999
DryMesicOak	1-Early1:ALL	2-Mid1:OPN	0	15
DryMesicOak	2-Mid1:CLS	3-Late1:CLS	16	75
DryMesicOak	2-Mid1:OPN	3-Late1:OPN	16	75
DryMesicOak	3-Late1:CLS	3-Late1:CLS	76	999
DryMesicOak	3-Late1:OPN	3-Late1:OPN	76	999
DryOak	1-Early1:ALL	2-Mid1:OPN	0	20
DryOak	2-Mid1:CLS	3-Late1:CLS	21	70
DryOak	2-Mid1:OPN	3-Late1:OPN	21	70
DryOak	3-Late1:CLS	3-Late1:CLS	71	999
DryOak	3-Late1:OPN	3-Late1:OPN	71	999
HighElevRedOak	1-Early1:ALL	2-Mid1:OPN	0	20
HighElevRedOak	2-Mid1:CLS	3-Late1:CLS	21	70
HighElevRedOak	2-Mid1:OPN	3-Late1:OPN	21	70
HighElevRedOak	3-Late1:CLS	3-Late1:CLS	71	999
HighElevRedOak	3-Late1:OPN	3-Late1:OPN	71	999
LowElevPineOakHeath	1-Early1:ALL	2-Mid1:OPN	0	17
LowElevPineOakHeath	2-Mid1:CLS	3-Late1:CLS	18	70
LowElevPineOakHeath	2-Mid1:OPN	3-Late1:OPN	18	70
LowElevPineOakHeath	3-Late1:CLS	3-Late1:CLS	71	999
LowElevPineOakHeath	3-Late1:OPN	3-Late1:OPN	71	999
LowElevationPine	1-Early1:ALL	2-Mid1:OPN	0	15
LowElevationPine	2-Mid1:CLS	3-Late1:CLS	16	70
LowElevationPine	2-Mid1:OPN	3-Late1:OPN	16	70
LowElevationPine	3-Late1:CLS	3-Late1:CLS	71	999
LowElevationPine	3-Late1:OPN	3-Late1:OPN	71	999
MesicOak	1-Early1:ALL	2-Mid1:OPN	0	10
MesicOak	2-Mid1:CLS	3-Late1:CLS	11	80
MesicOak	2-Mid1:OPN	3-Late1:OPN	11	80
MesicOak	3-Late1:CLS	3-Late1:CLS	81	999
MesicOak	3-Late1:OPN	3-Late1:OPN	81	999
MontanePineOakHeath	1-Early1:ALL	2-Mid1:OPN	0	20
MontanePineOakHeath	2-Mid1:CLS	3-Late1:CLS	21	70
MontanePineOakHeath	2-Mid1:OPN	3-Late1:OPN	21	70
MontanePineOakHeath	3-Late1:CLS	3-Late1:CLS	71	999
MontanePineOakHeath	3-Late1:OPN	3-Late1:OPN	71	999
NorthernHardwood	1-Early1:ALL	2-Mid1:CLS	0	15
NorthernHardwood	2-Mid1:CLS	3-Late1:CLS	16	75
NorthernHardwood	2-Mid1:OPN	3-Late1:OPN	16	75
NorthernHardwood	3-Late1:CLS	3-Late1:CLS	76	999
NorthernHardwood	Late1:OPN	3-Late1:OPN	76	999

Appendix 5. Probabilistic Transitions for ST-Sim ecological models.

Vegetation Type	From Class	To Class	Transition Type	Prob	Propr	Age Reset	TST Min
DryMesicOak	1-Early1:ALL	2-Mid1:CLS	AltSuccession	1.0000	1.0000	Yes	18
DryMesicOak	2-Mid1:OPN	2-Mid1:CLS	AltSuccession	1.0000	1.0000	No	25
DryMesicOak	3-Late1:OPN	3-Late1:CLS	AltSuccession	1.0000	1.0000	No	25
DryMesicOak	3-Late1:CLS	3-Late1:OPN	Insect/Disease	0.0025	1.0000	No	
DryMesicOak	3-Late1:OPN	3-Late1:OPN	Insect/Disease	0.0025	1.0000	No	
DryMesicOak	1-Early1:ALL	1-Early1:ALL	MixedFire	0.0200	1.0000	No	
DryMesicOak	2-Mid1:CLS	2-Mid1:OPN	MixedFire	0.0120	1.0000	No	
DryMesicOak	2-Mid1:OPN	2-Mid1:OPN	MixedFire	0.0050	1.0000	No	
DryMesicOak	3-Late1:CLS	3-Late1:OPN	MixedFire	0.0100	1.0000	No	
DryMesicOak	3-Late1:OPN	3-Late1:OPN	MixedFire	0.0050	1.0000	No	
DryMesicOak	1-Early1:ALL	1-Early1:ALL	ReplacementFire	0.0120	1.0000	Yes	
DryMesicOak	2-Mid1:CLS	1-Early1:ALL	ReplacementFire	0.0050	1.0000	Yes	
DryMesicOak	2-Mid1:OPN	1-Early1:ALL	ReplacementFire	0.0033	1.0000	Yes	
DryMesicOak	3-Late1:CLS	1-Early1:ALL	ReplacementFire	0.0050	1.0000	Yes	
DryMesicOak	3-Late1:OPN	1-Early1:ALL	ReplacementFire	0.0030	1.0000	Yes	
DryMesicOak	1-Early1:ALL	1-Early1:ALL	SurfaceFire	0.0340	1.0000	No	
DryMesicOak	2-Mid1:CLS	2-Mid1:CLS	SurfaceFire	0.0340	0.9500	No	
DryMesicOak	2-Mid1:CLS	2-Mid1:OPN	SurfaceFire	0.0340	0.0500	No	
DryMesicOak	2-Mid1:OPN	2-Mid1:OPN	SurfaceFire	0.0500	1.0000	No	
DryMesicOak	3-Late1:CLS	3-Late1:CLS	SurfaceFire	0.0310	0.9500	No	
DryMesicOak	3-Late1:CLS	3-Late1:OPN	SurfaceFire	0.0310	0.0500	No	
DryMesicOak	3-Late1:OPN	3-Late1:OPN	SurfaceFire	0.0450	1.0000	No	
DryMesicOak	2-Mid1:CLS	1-Early1:ALL	Wind/Weather/Stress	0.0020	1.0000	Yes	
DryMesicOak	2-Mid1:CLS	2-Mid1:OPN	Wind/Weather/Stress	0.0025	1.0000	No	
DryMesicOak	2-Mid1:OPN	1-Early1:ALL	Wind/Weather/Stress	0.0025	1.0000	Yes	
DryMesicOak	2-Mid1:OPN	2-Mid1:OPN	Wind/Weather/Stress	0.0025	1.0000	No	
DryMesicOak	3-Late1:CLS	1-Early1:ALL	Wind/Weather/Stress	0.0020	1.0000	Yes	
DryMesicOak	3-Late1:CLS	3-Late1:OPN	Wind/Weather/Stress	0.0025	1.0000	No	
DryMesicOak	3-Late1:OPN	1-Early1:ALL	Wind/Weather/Stress	0.0020	1.0000	Yes	
DryMesicOak	3-Late1:OPN	3-Late1:OPN	Wind/Weather/Stress	0.0025	1.0000	No	

DryOak	Early1:ALL	2-Mid1:CLS	AltSuccession	1.0000	1.0000	Yes	19
DryOak	2-Mid1:OPN	2-Mid1:CLS	AltSuccession	1.0000	1.0000	No	18
DryOak	3-Late1:OPN	3-Late1:CLS	AltSuccession	1.0000	1.0000	No	18
DryOak	2-Mid1:CLS	2-Mid1:CLS	Insect/Disease	0.0033	1.0000	No	
DryOak	2-Mid1:OPN	2-Mid1:OPN	Insect/Disease	0.0033	1.0000	No	
DryOak	3-Late1:CLS	3-Late1:OPN	Insect/Disease	0.0033	1.0000	No	
DryOak	3-Late1:OPN	3-Late1:OPN	Insect/Disease	0.0033	1.0000	No	
DryOak	1-Early1:ALL	1-Early1:ALL	MixedFire	0.0450	1.0000	No	
DryOak	2-Mid1:CLS	2-Mid1:OPN	MixedFire	0.0180	1.0000	No	
DryOak	2-Mid1:OPN	2-Mid1:OPN	MixedFire	0.0100	1.0000	No	
DryOak	3-Late1:CLS	3-Late1:OPN	MixedFire	0.0130	1.0000	No	
DryOak	3-Late1:OPN	3-Late1:OPN	MixedFire	0.0090	1.0000	No	
DryOak	1-Early1:ALL	1-Early1:ALL	ReplacementFire	0.0150	1.0000	Yes	
DryOak	2-Mid1:CLS	1-Early1:ALL	ReplacementFire	0.0100	1.0000	Yes	
DryOak	2-Mid1:OPN	1-Early1:ALL	ReplacementFire	0.0050	1.0000	Yes	
DryOak	3-Late1:CLS	1-Early1:ALL	ReplacementFire	0.0090	1.0000	Yes	
DryOak	3-Late1:OPN	1-Early1:ALL	ReplacementFire	0.0050	1.0000	Yes	
DryOak	1-Early1:ALL	1-Early1:ALL	SurfaceFire	0.0667	1.0000	No	
DryOak	2-Mid1:CLS	2-Mid1:CLS	SurfaceFire	0.0560	0.9500	No	
DryOak	2-Mid1:CLS	2-Mid1:OPN	SurfaceFire	0.0560	0.0500	No	
DryOak	2-Mid1:OPN	2-Mid1:OPN	SurfaceFire	0.0830	1.0000	No	
DryOak	3-Late1:CLS	3-Late1:CLS	SurfaceFire	0.0500	0.9500	No	
DryOak	3-Late1:CLS	3-Late1:OPN	SurfaceFire	0.0500	0.0500	No	
DryOak	3-Late1:OPN	3-Late1:OPN	SurfaceFire	0.0770	1.0000	No	
DryOak	2-Mid1:CLS	2-Mid1:OPN	Wind/Weather/Stress	0.0033	1.0000	No	
DryOak	2-Mid1:OPN	2-Mid1:OPN	Wind/Weather/Stress	0.0033	1.0000	No	
DryOak	3-Late1:CLS	1-Early1:ALL	Wind/Weather/Stress	0.0025	1.0000	Yes	
DryOak	3-Late1:CLS	3-Late1:OPN	Wind/Weather/Stress	0.0033	1.0000	No	
DryOak	3-Late1:OPN	1-Early1:ALL	Wind/Weather/Stress	0.0025	1.0000	Yes	
DryOak	3-Late1:OPN	3-Late1:OPN	Wind/Weather/Stress	0.0033	1.0000	No	

HighElevRedOak	Early1:ALL	2-Mid1:CLS	AltSuccession	1.0000	1.0000	Yes	19
HighElevRedOak	2-Mid1:OPN	2-Mid1:CLS	AltSuccession	1.0000	1.0000	No	20
HighElevRedOak	3-Late1:OPN	3-Late1:CLS	AltSuccession	1.0000	1.0000	No	20
HighElevRedOak	3-Late1:CLS	3-Late1:OPN	Insect/Disease	0.0033	1.0000	No	
HighElevRedOak	3-Late1:OPN	3-Late1:OPN	Insect/Disease	0.0033	1.0000	No	
HighElevRedOak	1-Early1:ALL	1-Early1:ALL	MixedFire	0.0200	1.0000	No	
HighElevRedOak	2-Mid1:CLS	2-Mid1:OPN	MixedFire	0.0110	1.0000	No	
HighElevRedOak	2-Mid1:OPN	2-Mid1:OPN	MixedFire	0.0080	1.0000	No	
HighElevRedOak	3-Late1:CLS	3-Late1:OPN	MixedFire	0.0100	1.0000	No	
HighElevRedOak	3-Late1:OPN	3-Late1:OPN	MixedFire	0.0070	1.0000	No	
HighElevRedOak	1-Early1:ALL	1-Early1:ALL	ReplacementFire	0.0150	1.0000	Yes	
HighElevRedOak	2-Mid1:CLS	1-Early1:ALL	ReplacementFire	0.0100	1.0000	Yes	
HighElevRedOak	2-Mid1:OPN	1-Early1:ALL	ReplacementFire	0.0050	1.0000	Yes	
HighElevRedOak	3-Late1:CLS	1-Early1:ALL	ReplacementFire	0.0050	1.0000	Yes	
HighElevRedOak	3-Late1:OPN	1-Early1:ALL	ReplacementFire	0.0040	1.0000	Yes	
HighElevRedOak	1-Early1:ALL	1-Early1:ALL	SurfaceFire	0.0400	1.0000	No	
HighElevRedOak	2-Mid1:CLS	2-Mid1:CLS	SurfaceFire	0.0270	0.9500	No	
HighElevRedOak	2-Mid1:CLS	2-Mid1:OPN	SurfaceFire	0.0270	0.0500	No	
HighElevRedOak	2-Mid1:OPN	2-Mid1:OPN	SurfaceFire	0.0400	1.0000	No	
HighElevRedOak	3-Late1:CLS	3-Late1:CLS	SurfaceFire	0.0250	0.9500	No	
HighElevRedOak	3-Late1:CLS	3-Late1:OPN	SurfaceFire	0.0250	0.0500	No	
HighElevRedOak	3-Late1:OPN	3-Late1:OPN	SurfaceFire	0.0360	1.0000	No	
HighElevRedOak	2-Mid1:CLS	2-Mid1:OPN	Wind/Weather/Stress	0.0025	1.0000	No	
HighElevRedOak	2-Mid1:OPN	2-Mid1:OPN	Wind/Weather/Stress	0.0025	1.0000	No	
HighElevRedOak	3-Late1:CLS	1-Early1:ALL	Wind/Weather/Stress	0.0025	1.0000	Yes	
HighElevRedOak	3-Late1:CLS	3-Late1:OPN	Wind/Weather/Stress	0.0025	1.0000	No	
HighElevRedOak	3-Late1:OPN	1-Early1:ALL	Wind/Weather/Stress	0.0025	1.0000	Yes	
HighElevRedOak	3-Late1:OPN	3-Late1:OPN	Wind/Weather/Stress	0.0025	1.0000	No	

LowElevationPine	Early1:ALL	2-Mid1:CLS	AltSuccession	1.0000	1.0000	Yes	9
LowElevationPine	2-Mid1:OPN	2-Mid1:CLS	AltSuccession	1.0000	1.0000	No	20
LowElevationPine	3-Late1:OPN	3-Late1:CLS	AltSuccession	1.0000	1.0000	No	20
LowElevationPine	2-Mid1:CLS	1-Early1:ALL	Insect/Disease	0.0033	1.0000	Yes	
LowElevationPine	2-Mid1:OPN	1-Early1:ALL	Insect/Disease	0.0033	1.0000	Yes	
LowElevationPine	3-Late1:CLS	1-Early1:ALL	Insect/Disease	0.0033	1.0000	Yes	
LowElevationPine	3-Late1:OPN	1-Early1:ALL	Insect/Disease	0.0033	1.0000	Yes	
LowElevationPine	1-Early1:ALL	1-Early1:ALL	MixedFire	0.0500	1.0000	No	
LowElevationPine	2-Mid1:CLS	2-Mid1:OPN	MixedFire	0.0200	1.0000	No	
LowElevationPine	2-Mid1:OPN	2-Mid1:OPN	MixedFire	0.0100	1.0000	No	
LowElevationPine	3-Late1:CLS	3-Late1:OPN	MixedFire	0.0130	1.0000	No	
LowElevationPine	3-Late1:OPN	3-Late1:OPN	MixedFire	0.0080	1.0000	No	
LowElevationPine	1-Early1:ALL	1-Early1:ALL	ReplacementFire	0.0100	1.0000	Yes	
LowElevationPine	2-Mid1:CLS	1-Early1:ALL	ReplacementFire	0.0100	1.0000	Yes	
LowElevationPine	2-Mid1:OPN	1-Early1:ALL	ReplacementFire	0.0050	1.0000	Yes	
LowElevationPine	3-Late1:CLS	1-Early1:ALL	ReplacementFire	0.0080	1.0000	Yes	
LowElevationPine	3-Late1:OPN	1-Early1:ALL	ReplacementFire	0.0050	1.0000	Yes	
LowElevationPine	1-Early1:ALL	1-Early1:ALL	SurfaceFire	0.1250	1.0000	No	
LowElevationPine	2-Mid1:CLS	2-Mid1:CLS	SurfaceFire	0.1000	0.9000	No	
LowElevationPine	2-Mid1:CLS	2-Mid1:OPN	SurfaceFire	0.1000	0.1000	No	
LowElevationPine	2-Mid1:OPN	2-Mid1:OPN	SurfaceFire	0.1250	1.0000	No	
LowElevationPine	3-Late1:CLS	3-Late1:CLS	SurfaceFire	0.0910	0.9000	No	
LowElevationPine	3-Late1:CLS	3-Late1:OPN	SurfaceFire	0.0910	0.1000	No	
LowElevationPine	3-Late1:OPN	3-Late1:OPN	SurfaceFire	0.1110	1.0000	No	
LowElevationPine	2-Mid1:CLS	2-Mid1:OPN	Wind/Weather/Stress	0.0033	1.0000	No	
LowElevationPine	2-Mid1:OPN	2-Mid1:OPN	Wind/Weather/Stress	0.0033	1.0000	No	
LowElevationPine	3-Late1:CLS	1-Early1:ALL	Wind/Weather/Stress	0.0025	1.0000	Yes	
LowElevationPine	3-Late1:CLS	3-Late1:OPN	Wind/Weather/Stress	0.0033	1.0000	No	
LowElevationPine	3-Late1:OPN	1-Early1:ALL	Wind/Weather/Stress	0.0025	1.0000	Yes	
LowElevationPine	3-Late1:OPN	3-Late1:OPN	Wind/Weather/Stress	0.0033	1.0000	No	

LowElevPineOakHeath	Early1:ALL	2-Mid1:CLS	AltSuccession	1.0000	1.0000	Yes	11
LowElevPineOakHeath	2-Mid1:OPN	2-Mid1:CLS	AltSuccession	1.0000	1.0000	No	16
LowElevPineOakHeath	3-Late1:OPN	3-Late1:CLS	AltSuccession	1.0000	1.0000	No	16
LowElevPineOakHeath	2-Mid1:CLS	1-Early1:ALL	Insect/Disease	0.0050	1.0000	Yes	
LowElevPineOakHeath	2-Mid1:OPN	1-Early1:ALL	Insect/Disease	0.0050	1.0000	Yes	
LowElevPineOakHeath	3-Late1:CLS	1-Early1:ALL	Insect/Disease	0.0050	1.0000	Yes	
LowElevPineOakHeath	3-Late1:OPN	1-Early1:ALL	Insect/Disease	0.0050	1.0000	Yes	
LowElevPineOakHeath	1-Early1:ALL	1-Early1:ALL	MixedFire	0.0667	1.0000	No	
LowElevPineOakHeath	2-Mid1:CLS	2-Mid1:OPN	MixedFire	0.0290	1.0000	No	
LowElevPineOakHeath	2-Mid1:OPN	2-Mid1:OPN	MixedFire	0.0133	1.0000	No	
LowElevPineOakHeath	3-Late1:CLS	3-Late1:OPN	MixedFire	0.0200	1.0000	No	
LowElevPineOakHeath	3-Late1:OPN	3-Late1:OPN	MixedFire	0.0100	1.0000	No	
LowElevPineOakHeath	2-Mid1:CLS	2-Mid1:OPN	Optional1	0.0040	1.0000	No	
LowElevPineOakHeath	3-Late1:CLS	3-Late1:OPN	Optional1	0.0040	1.0000	No	
LowElevPineOakHeath	1-Early1:ALL	1-Early1:ALL	ReplacementFire	0.0200	1.0000	Yes	
LowElevPineOakHeath	2-Mid1:CLS	1-Early1:ALL	ReplacementFire	0.0133	1.0000	Yes	
LowElevPineOakHeath	2-Mid1:OPN	1-Early1:ALL	ReplacementFire	0.0067	1.0000	Yes	
LowElevPineOakHeath	3-Late1:CLS	1-Early1:ALL	ReplacementFire	0.0100	1.0000	Yes	
LowElevPineOakHeath	3-Late1:OPN	1-Early1:ALL	ReplacementFire	0.0050	1.0000	Yes	
LowElevPineOakHeath	1-Early1:ALL	1-Early1:ALL	SurfaceFire	0.0830	1.0000	No	
LowElevPineOakHeath	2-Mid1:CLS	2-Mid1:CLS	SurfaceFire	0.0667	0.9000	No	
LowElevPineOakHeath	2-Mid1:CLS	2-Mid1:OPN	SurfaceFire	0.0667	0.1000	No	
LowElevPineOakHeath	2-Mid1:OPN	2-Mid1:OPN	SurfaceFire	0.0830	1.0000	No	
LowElevPineOakHeath	3-Late1:CLS	3-Late1:CLS	SurfaceFire	0.0590	0.9000	No	
LowElevPineOakHeath	3-Late1:CLS	3-Late1:OPN	SurfaceFire	0.0590	0.1000	No	
LowElevPineOakHeath	3-Late1:OPN	3-Late1:OPN	SurfaceFire	0.0770	1.0000	No	
LowElevPineOakHeath	2-Mid1:CLS	2-Mid1:OPN	Wind/Weather/Stress	0.0033	1.0000	No	
LowElevPineOakHeath	2-Mid1:OPN	2-Mid1:OPN	Wind/Weather/Stress	0.0033	1.0000	No	
LowElevPineOakHeath	3-Late1:CLS	1-Early1:ALL	Wind/Weather/Stress	0.0025	1.0000	Yes	
LowElevPineOakHeath	3-Late1:CLS	3-Late1:OPN	Wind/Weather/Stress	0.0033	1.0000	No	
LowElevPineOakHeath	3-Late1:OPN	1-Early1:ALL	Wind/Weather/Stress	0.0025	1.0000	Yes	
LowElevPineOakHeath	3-Late1:OPN	3-Late1:OPN	Wind/Weather/Stress	0.0033	1.0000	No	

MesicOak	Early1:ALL	2-Mid1:CLS	AltSuccession	1.0000	1.0000	Yes	20
MesicOak	2-Mid1:OPN	2-Mid1:CLS	AltSuccession	1.0000	1.0000	No	20
MesicOak	3-Late1:OPN	3-Late1:CLS	AltSuccession	1.0000	1.0000	No	20
MesicOak	3-Late1:CLS	3-Late1:OPN	Insect/Disease	0.0025	1.0000	No	
MesicOak	3-Late1:OPN	3-Late1:OPN	Insect/Disease	0.0025	1.0000	No	
MesicOak	1-Early1:ALL	1-Early1:ALL	MixedFire	0.0150	1.0000	No	
MesicOak	2-Mid1:CLS	2-Mid1:OPN	MixedFire	0.0070	1.0000	No	
MesicOak	2-Mid1:OPN	2-Mid1:OPN	MixedFire	0.0040	1.0000	No	
MesicOak	3-Late1:CLS	3-Late1:OPN	MixedFire	0.0060	1.0000	No	
MesicOak	3-Late1:OPN	3-Late1:OPN	MixedFire	0.0040	1.0000	No	
MesicOak	1-Early1:ALL	1-Early1:ALL	ReplacementFire	0.0100	1.0000	Yes	
MesicOak	2-Mid1:CLS	1-Early1:ALL	ReplacementFire	0.0050	1.0000	Yes	
MesicOak	2-Mid1:OPN	1-Early1:ALL	ReplacementFire	0.0030	1.0000	Yes	
MesicOak	3-Late1:CLS	1-Early1:ALL	ReplacementFire	0.0040	1.0000	Yes	
MesicOak	3-Late1:OPN	1-Early1:ALL	ReplacementFire	0.0030	1.0000	Yes	
MesicOak	1-Early1:ALL	1-Early1:ALL	SurfaceFire	0.0300	1.0000	No	
MesicOak	2-Mid1:CLS	2-Mid1:CLS	SurfaceFire	0.0270	0.9500	No	
MesicOak	2-Mid1:CLS	2-Mid1:OPN	SurfaceFire	0.0270	0.0500	No	
MesicOak	2-Mid1:OPN	2-Mid1:OPN	SurfaceFire	0.0300	1.0000	No	
MesicOak	3-Late1:CLS	3-Late1:CLS	SurfaceFire	0.0250	0.9500	No	
MesicOak	3-Late1:CLS	3-Late1:OPN	SurfaceFire	0.0250	0.0500	No	
MesicOak	3-Late1:OPN	3-Late1:OPN	SurfaceFire	0.0270	1.0000	No	
MesicOak	2-Mid1:CLS	1-Early1:ALL	Wind/Weather/Stress	0.0020	1.0000	Yes	
MesicOak	2-Mid1:CLS	2-Mid1:OPN	Wind/Weather/Stress	0.0025	1.0000	No	
MesicOak	2-Mid1:OPN	1-Early1:ALL	Wind/Weather/Stress	0.0020	1.0000	Yes	
MesicOak	2-Mid1:OPN	2-Mid1:OPN	Wind/Weather/Stress	0.0025	1.0000	No	
MesicOak	3-Late1:CLS	1-Early1:ALL	Wind/Weather/Stress	0.0020	1.0000	Yes	
MesicOak	3-Late1:CLS	3-Late1:OPN	Wind/Weather/Stress	0.0025	1.0000	No	
MesicOak	3-Late1:OPN	1-Early1:ALL	Wind/Weather/Stress	0.0020	1.0000	Yes	
MesicOak	3-Late1:OPN	3-Late1:OPN	Wind/Weather/Stress	0.0025	1.0000	No	

MontanePineOakHeath	Early1:ALL	2-Mid1:CLS	AltSuccession	1.0000	1.0000	Yes	14
MontanePineOakHeath	2-Mid1:OPN	2-Mid1:CLS	AltSuccession	1.0000	1.0000	No	20
MontanePineOakHeath	3-Late1:OPN	3-Late1:CLS	AltSuccession	1.0000	1.0000	No	20
MontanePineOakHeath	2-Mid1:CLS	1-Early1:ALL	Insect/Disease	0.0050	1.0000	Yes	
MontanePineOakHeath	2-Mid1:OPN	1-Early1:ALL	Insect/Disease	0.0050	1.0000	Yes	
MontanePineOakHeath	3-Late1:CLS	1-Early1:ALL	Insect/Disease	0.0050	1.0000	Yes	
MontanePineOakHeath	3-Late1:OPN	1-Early1:ALL	Insect/Disease	0.0050	1.0000	Yes	
MontanePineOakHeath	1-Early1:ALL	1-Early1:ALL	MixedFire	0.0400	1.0000	No	
MontanePineOakHeath	2-Mid1:CLS	2-Mid1:OPN	MixedFire	0.0200	1.0000	No	
MontanePineOakHeath	2-Mid1:OPN	2-Mid1:OPN	MixedFire	0.0133	1.0000	No	
MontanePineOakHeath	3-Late1:CLS	3-Late1:OPN	MixedFire	0.0150	1.0000	No	
MontanePineOakHeath	3-Late1:OPN	3-Late1:OPN	MixedFire	0.0120	1.0000	No	
MontanePineOakHeath	2-Mid1:CLS	2-Mid1:OPN	Optional1	0.0040	1.0000	No	
MontanePineOakHeath	3-Late1:CLS	3-Late1:OPN	Optional1	0.0040	1.0000	No	
MontanePineOakHeath	1-Early1:ALL	1-Early1:ALL	ReplacementFire	0.0200	1.0000	Yes	
MontanePineOakHeath	2-Mid1:CLS	1-Early1:ALL	ReplacementFire	0.0133	1.0000	Yes	
MontanePineOakHeath	2-Mid1:OPN	1-Early1:ALL	ReplacementFire	0.0080	1.0000	Yes	
MontanePineOakHeath	3-Late1:CLS	1-Early1:ALL	ReplacementFire	0.0120	1.0000	Yes	
MontanePineOakHeath	3-Late1:OPN	1-Early1:ALL	ReplacementFire	0.0067	1.0000	Yes	
MontanePineOakHeath	1-Early1:ALL	1-Early1:ALL	SurfaceFire	0.0500	1.0000	No	
MontanePineOakHeath	2-Mid1:CLS	2-Mid1:CLS	SurfaceFire	0.0450	0.9000	No	
MontanePineOakHeath	2-Mid1:CLS	2-Mid1:OPN	SurfaceFire	0.0450	0.1000	No	
MontanePineOakHeath	2-Mid1:OPN	2-Mid1:OPN	SurfaceFire	0.0500	1.0000	No	
MontanePineOakHeath	3-Late1:CLS	3-Late1:CLS	SurfaceFire	0.0400	0.9000	No	
MontanePineOakHeath	3-Late1:CLS	3-Late1:OPN	SurfaceFire	0.0400	0.1000	No	
MontanePineOakHeath	3-Late1:OPN	3-Late1:OPN	SurfaceFire	0.0450	1.0000	No	
MontanePineOakHeath	2-Mid1:CLS	2-Mid1:OPN	Wind/Weather/Stress	0.0033	1.0000	No	
MontanePineOakHeath	2-Mid1:OPN	2-Mid1:OPN	Wind/Weather/Stress	0.0033	1.0000	No	
MontanePineOakHeath	3-Late1:CLS	1-Early1:ALL	Wind/Weather/Stress	0.0025	1.0000	Yes	
MontanePineOakHeath	3-Late1:CLS	3-Late1:OPN	Wind/Weather/Stress	0.0033	1.0000	No	
MontanePineOakHeath	3-Late1:OPN	1-Early1:ALL	Wind/Weather/Stress	0.0025	1.0000	Yes	
MontanePineOakHeath	3-Late1:OPN	3-Late1:OPN	Wind/Weather/Stress	0.0033	1.0000	No	

NorthernHardwood	Mid1:OPN	2-Mid1:CLS	AltSuccession	1.0000	1.0000	No	25
NorthernHardwood	3-Late1:OPN	3-Late1:CLS	AltSuccession	1.0000	1.0000	No	25
NorthernHardwood	3-Late1:CLS	3-Late1:OPN	Insect/Disease	0.0050	1.0000	No	
NorthernHardwood	3-Late1:OPN	3-Late1:OPN	Insect/Disease	0.0050	1.0000	No	
NorthernHardwood	1-Early1:ALL	2-Mid1:OPN	MixedFire	0.0020	1.0000	Yes	
NorthernHardwood	2-Mid1:CLS	2-Mid1:OPN	MixedFire	0.0015	1.0000	No	
NorthernHardwood	2-Mid1:OPN	2-Mid1:OPN	MixedFire	0.0020	1.0000	No	
NorthernHardwood	3-Late1:CLS	3-Late1:OPN	MixedFire	0.0015	1.0000	No	
NorthernHardwood	3-Late1:OPN	3-Late1:OPN	MixedFire	0.0010	1.0000	No	
NorthernHardwood	2-Mid1:CLS	1-Early1:ALL	Optional1	0.0030	1.0000	Yes	
NorthernHardwood	2-Mid1:OPN	1-Early1:ALL	Optional1	0.0030	1.0000	Yes	
NorthernHardwood	3-Late1:CLS	1-Early1:ALL	Optional1	0.0030	1.0000	Yes	
NorthernHardwood	3-Late1:OPN	1-Early1:ALL	Optional1	0.0030	1.0000	Yes	
NorthernHardwood	1-Early1:ALL	1-Early1:ALL	ReplacementFire	0.0015	1.0000	Yes	
NorthernHardwood	2-Mid1:CLS	1-Early1:ALL	ReplacementFire	0.0015	1.0000	Yes	
NorthernHardwood	2-Mid1:OPN	1-Early1:ALL	ReplacementFire	0.0015	1.0000	Yes	
NorthernHardwood	3-Late1:CLS	1-Early1:ALL	ReplacementFire	0.0015	1.0000	Yes	
NorthernHardwood	3-Late1:OPN	1-Early1:ALL	ReplacementFire	0.0015	1.0000	Yes	
NorthernHardwood	1-Early1:ALL	1-Early1:ALL	SurfaceFire	0.0030	1.0000	No	
NorthernHardwood	2-Mid1:CLS	2-Mid1:CLS	SurfaceFire	0.0030	1.0000	No	
NorthernHardwood	2-Mid1:OPN	2-Mid1:OPN	SurfaceFire	0.0030	1.0000	No	
NorthernHardwood	3-Late1:CLS	3-Late1:CLS	SurfaceFire	0.0030	1.0000	No	
NorthernHardwood	3-Late1:OPN	3-Late1:OPN	SurfaceFire	0.0030	1.0000	No	
NorthernHardwood	2-Mid1:CLS	2-Mid1:OPN	Wind/Weather/Stress	0.0025	1.0000	No	
NorthernHardwood	2-Mid1:OPN	2-Mid1:OPN	Wind/Weather/Stress	0.0070	1.0000	No	
NorthernHardwood	3-Late1:CLS	3-Late1:OPN	Wind/Weather/Stress	0.0025	1.0000	No	
NorthernHardwood	3-Late1:OPN	3-Late1:OPN	Wind/Weather/Stress	0.0070	1.0000	No	

RichAcidicCove	Mid1:OPN	2-Mid1:CLS	AltSuccession	1.0000	1.0000	No	20
RichAcidicCove	3-Late1:OPN	3-Late1:CLS	AltSuccession	1.0000	1.0000	No	20
RichAcidicCove	2-Mid1:CLS	2-Mid1:OPN	Insect/Disease	0.0040	1.0000	No	
RichAcidicCove	2-Mid1:OPN	2-Mid1:OPN	Insect/Disease	0.0040	1.0000	No	
RichAcidicCove	3-Late1:CLS	3-Late1:OPN	Insect/Disease	0.0040	1.0000	No	
RichAcidicCove	3-Late1:OPN	3-Late1:OPN	Insect/Disease	0.0040	1.0000	No	
RichAcidicCove	1-Early1:ALL	1-Early1:ALL	MixedFire	0.0020	1.0000	No	
RichAcidicCove	2-Mid1:CLS	2-Mid1:OPN	MixedFire	0.0020	1.0000	No	
RichAcidicCove	2-Mid1:OPN	2-Mid1:OPN	MixedFire	0.0020	1.0000	No	
RichAcidicCove	3-Late1:CLS	3-Late1:OPN	MixedFire	0.0020	1.0000	No	
RichAcidicCove	3-Late1:OPN	3-Late1:OPN	MixedFire	0.0020	1.0000	No	
RichAcidicCove	2-Mid1:CLS	1-Early1:ALL	Optional1	0.0020	1.0000	Yes	
RichAcidicCove	2-Mid1:OPN	1-Early1:ALL	Optional1	0.0020	1.0000	Yes	
RichAcidicCove	3-Late1:CLS	1-Early1:ALL	Optional1	0.0020	1.0000	Yes	
RichAcidicCove	3-Late1:OPN	1-Early1:ALL	Optional1	0.0020	1.0000	Yes	
RichAcidicCove	1-Early1:ALL	1-Early1:ALL	ReplacementFire	0.0010	1.0000	Yes	
RichAcidicCove	2-Mid1:CLS	1-Early1:ALL	ReplacementFire	0.0010	1.0000	Yes	
RichAcidicCove	2-Mid1:OPN	1-Early1:ALL	ReplacementFire	0.0010	1.0000	Yes	
RichAcidicCove	3-Late1:CLS	1-Early1:ALL	ReplacementFire	0.0010	1.0000	Yes	
RichAcidicCove	3-Late1:OPN	1-Early1:ALL	ReplacementFire	0.0010	1.0000	Yes	
RichAcidicCove	1-Early1:ALL	1-Early1:ALL	SurfaceFire	0.0100	1.0000	No	
RichAcidicCove	2-Mid1:CLS	2-Mid1:CLS	SurfaceFire	0.0100	1.0000	No	
RichAcidicCove	2-Mid1:OPN	2-Mid1:OPN	SurfaceFire	0.0100	1.0000	No	
RichAcidicCove	3-Late1:CLS	3-Late1:CLS	SurfaceFire	0.0100	1.0000	No	
RichAcidicCove	3-Late1:OPN	3-Late1:OPN	SurfaceFire	0.0100	1.0000	No	
RichAcidicCove	2-Mid1:CLS	1-Early1:ALL	Wind/Weather/Stress	0.0020	1.0000	Yes	
RichAcidicCove	2-Mid1:CLS	2-Mid1:OPN	Wind/Weather/Stress	0.0030	1.0000	No	
RichAcidicCove	2-Mid1:OPN	2-Mid1:OPN	Wind/Weather/Stress	0.0030	1.0000	No	
RichAcidicCove	3-Late1:CLS	1-Early1:ALL	Wind/Weather/Stress	0.0020	1.0000	Yes	
RichAcidicCove	3-Late1:CLS	3-Late1:OPN	Wind/Weather/Stress	0.0030	1.0000	No	
RichAcidicCove	3-Late1:OPN	1-Early1:ALL	Wind/Weather/Stress	0.0020	1.0000	Yes	

Appendix 6. Fire in Reference Condition Models and Park Fire History Summary -- Annual average total acres burned by decade.

Modeled Fire in ST-Sim - Reference Conditions (NRV)				
Ecological System	**Estimated Acres**	**% ot Total Acres**	**AllFire Probability**	**Est. Acres/Yr Burned**
Dry Oak	78,800	15%	0.094	7,400
Dry-Mesic Oak	59,600	12%	0.053	3,200
Mesic Oak	60,400	12%	0.036	2,200
High Elev Red Oak	23,400	5%	0.049	1,100
Low Elevation Pine	17,100	3%	0.130	2,200
Low Elev Pine-Oak Heath	8,800	2%	0.116	1,000
Montane Pine-Oak Heath	18,700	4%	0.080	1,500
Cove	128,300	25%	0.006	800
No. Hardwoods	66,800	13%	0.002	100
Spruce-Fir	40,800	8%	0.001	40
Alluvial (use Cove FRI)	7,800	2%	0.006	50
Ave/Weighted Ave	510,500	100%	0.038	**19,600**
5 Focal Oak & Pine Systems	**183,000**	**36%**	0.084	**15,300**

Fire History in Park: Annual Average Acres by Decade 1920-2000				
Ave. 1920s				1,100
Ave. 1930s				300
Ave. 1940s				600
Ave. 1950s				200
Ave. 1960s				100
Ave. 1970s				400
Ave. 1980s				1,000
Ave. 1990s				400
1920-2000 Annual Average				**513**
Ave. % of Reference Condition Fire				**2.6%**

Fire History in Park: Annual Average Acres 2000 - 2012				
Prescribed Fire			1,075	5.5%
All Other Fire			1,460	7.4%
2000-2012 Annual Average				**2,535**
Ave. % of Reference Condition Fire				**12.9%**

Appendix 7. Excel model runs worksheet – summary all systems and scenarios.

Great Smoky Mountains National Park

Departure from Natural Range of Variability

Ecological System	% of Acres	Acres	Current Ecological Departure	No Action Ecological Departure 20 Yrs	No Action Ecological Departure 40 Yrs	Max Mgmt Ecological Departure 20 Yrs	Current Mgmt (1500 Ac/Yr) Ecological Departure 20 Yrs	Preferred Mgmt (5000 Ac/Yr) Ecological Departure 20 Yrs	Preferred Restore & Maintain (5000 Ac/Yr) Ecological Departure 40 Yrs	Current Mgmt Restore & Maintain (1500 Ac/Yr) 40 Yrs	Max Mgmt Ecological Departure 40 Yrs
Dry Oak Forest	16%	80,300	66	56	51	28	54	50	42	48	20
Dry-Mesic Oak Forest	13%	66,000	57	48	45	32	47	45	38	43	21
Mesic Oak Forest	12%	60,500	32	30	34	26					
High Elevation Red Oak Forest	4%	22,300	59	44	40	24					
Low Elevation Pine Forest	3%	17,800	66	63	64	28	60	52	49	58	26
Low Elevation Pine-Oak Heath	2%	8,800	70	57	51	34	52	43	29	43	21
Montane Pine-Oak Heath	4%	18,800	64	51	45	32	50	46	36	42	17
Cove Forest	24%	123,800	30	22	16						
Northern Hardwood Forest	13%	67,800	25	14	12						
Spruce-Fir Forest	8%	40,900									
Montane Alluvial	2%	7,900									
Total Acres		514,900									
		Total Acres				RxFire Acres / Year	RxFire Acres / Year	RxFire Acres / Year	RxFire Acres / Year	RxFire Acres / Year	RxFire Acres / Year
Dry Oak		80,300				9,000	450	1,500	1,500	450	9,000
Dry-Mesic Oak		66,000				3,750	225	750	750	225	3,750
Mesic Oak		60,500				3,000	-	-	-	-	3,000
High Elevation Red Oak		22,300				1,800	-	-	-	-	1,800
Low Elevation Pine		17,800				2,400	180	600	600	180	2,400
Low Elevation Pine-Oak Heath		8,800				1,500	150	500	500	150	1,500
Montane Pine-Oak Heath		18,800				2,700	120	400	400	120	2,700
All Other Systems		240,400				-	375	1,250	1,250	375	-
Total Acres Rx Fire						**24,150**	**1,500**	**5,000**	**5,000**	1,500	24,150
Ave. Annual Cost All RxFire	*$ 50*	*per acre*				**$1,208,000**	**$ 75,000**	**$ 250,000**	**$ 250,000**	**$ 75,000**	**$1,208,000**

Appendix 8. Excel model runs worksheet – Dry Oak Forest

Dry Oak Forest										
Vegetation Class	**NRV** Mean	**Current %**	**No Action - 20 Yrs**	**No Action 40 Yrs**	**Max Mgmt 20 Yrs**	**Current Mgmt 1.5K Parkwide - 20 Yrs**	**Preferred Mgmt 5K Parkwide - 20 Yrs**	**Restore-Maintain 40 Yrs**	**Current Level 40 Yrs**	**Max Mgmt 20 Yrs**
Early	17%	2%	6%	6%	17%	6%	8%	9%	6%	25%
Mid-Closed	9%	0%	2%	7%	1%	2%	2%	7%	7%	7%
Mid-Open	21%	0%	0%	0%	1%	0%	0%	2%	1%	4%
Late-Closed	24%	90%	80%	75%	46%	78%	74%	66%	72%	31%
Late-Open	29%	8%	12%	12%	35%	13%	16%	16%	14%	34%
Highly Departed Composition	0%	0%	0%	0%					0%	0%
Totals	100%	100%	100%	100%	100%	99%	100%	100%	100%	101%
Total Early/Open										
Total Closed	33%	90%	82%	82%	47%	80%	76%	73%	79%	38%
Ecological Departure		**66**	**56**	**51**	**28**	**54**	**50**	**42**	**48**	**20**
Open Canopy Departure		**57**	**49**	**49**	**14**	**47**	**43**	**40**	**46**	**5**
Total Management Cost					$ 9,000,000	$ 450,000	$ 1,500,000	$ 3,000,000	$ 900,000	###########
ROI					2.6	3.6	3.2	2.4	7.1	1.7

Treatments			**Max Mgmt 20 Yrs**	**Current Mgmt 1.5K Parkwide**	**Proposed Mgmt 5K Parkwide**	**Restore-Maintain 40 Yrs**	**Current Level 40 Yrs**	**Max Mgmt 40 Yrs**
RxFire-Restore (Realized Acres)			60,000	3,000	10,000	10,000	3,000	60,000
Acres/Yr Burned			9,000	450	1,500	1,500	450	9,000
Cost/Acre			$ 50	$ 50	$ 50	$ 50	$ 50	$ 50
# Years			20	20	20	20	20	20
RxFire-Restore (Realized Acres)						6,000	1,800	36,000
2nd 20 years						900	270	5,400
						$ 50	$ 50	$ 50
						20	20	20
Rx-Maintenance								
2nd 20 years						600	180	3,600
						$ 50	$ 50	$ 50
						20	20	20

Appendix 9. Excel model runs worksheet – Dry-Mesic Oak Forest.

Dry-Mesic Oak Forest										
Vegetation Class	**NRV** Mean	**Current %**	**No Action - 20 Yrs**	**No Action 40 Yrs**	**Max Mgmt 20 Yrs**	**Current Mgmt 1.5K Parkwide - 20 Yrs**	**Preferred Mgmt 5K Parkwide - 20 Yrs**	**Restore-Maintain 40 Yrs**	**Current Level 40 Yrs**	**Max Mgmt 40 Yrs**
Early	9%	1%	3%	3%	9%	4%	5%	5%	4%	11%
Mid-Closed	9%	7%	5%	5%	4%	5%	4%	5%	5%	4%
Mid-Open	18%	1%	2%	3%	2%	2%	2%	4%	3%	8%
Late-Closed	32%	85%	76%	73%	60%	75%	73%	66%	71%	47%
Late-Open	31%	2%	10%	12%	20%	11%	12%	16%	13%	26%
Highly Departed Composition	0%	4%	4%	4%	4%	4%	4%	4%	4%	4%
Totals	99%	100%	100%	100%	99%	101%	100%	100%	100%	100%
Total Early/Open										
Total Closed	41%	92%	81%	78%	64%	80%	77%	71%	76%	51%
Ecological Departure		**57**	**48**	**45**	**32**	**47**	**45**	**38**	**43**	**21**
Open Canopy Departure		**51**	**40**	**37**	**23**	**39**	**36**	**30**	**35**	**10**
Total Management Cost					$3,750,000	$ 225,000	$ 750,000	$ 1,500,000	$ 450,000	$ 7,500,000
ROI					2.8	2.9	2.6	3.1	7.3	2.5
Treatments					**Max Mgmt 20 Yrs**	**Current Mgmt 1.5K Parkwide**	**Proposed Mgmt 5K Parkwide**	**Restore-Maintain 40 Yrs**	**Current Level 40 Yrs**	**Max Mgmt 40 Yrs**
RxFire-Restore (Realized Acres)					25,000	1,500	5,000	5,000	1,500	25,000
Acres/Yr Burned					3,750	225	750	750	225	3,750
Cost/Acre					$ 50	$ 50	$ 50	$ 50	$ 50	$ 50
# Years					20	20	20	20	20	20
RxFire-Restore (Realized Acres)								3,000	900	15,000
2nd 20 years								450	135	2,250
								$ 50	$ 50	$ 50
								20	20	20
Rx-Maintenance										
2nd 20 years								300	90	1,500
								$ 50	$ 50	$ 50
								20	20	20

Appendix 10. Excel model runs worksheet – Low Elevation Pine Forest.

Low Elevation Pine Forest										
Vegetation Class	**NRV** Mean	**Current %**	**No Action - 20 Yrs**	**No Action 40 Yrs**	**Max Mgmt 20 Yrs**	**Current Mgmt 1.5K Parkwide - 20 Yrs**	**Preferred Mgmt 5K Parkwide - 20 Yrs**	**Restore-Maintain 40 Yrs**	**Current Level 40 Yrs**	**Max Mgmt 40 Yrs**
Early	13%	3%	5%	5%	17%	6%	9%	9%	6%	20%
Mid-Closed	10%	12%	16%	20%	12%	16%	15%	19%	19%	20%
Mid-Open	30%	4%	2%	2%	7%	2%	3%	4%	3%	11%
Late-Closed	12%	72%	66%	63%	31%	63%	56%	49%	58%	18%
Late-Open	35%	5%	8%	7%	31%	10%	14%	15%	10%	28%
Highly Departed Composition	0%	3%	3%	3%	3%	3%	3%	3%	3%	3%
Totals	100%	100%	100%	100%	101%	100%	100%	99%	99%	100%
Total Early/Open										
Total Closed	22%	85%	82%	83%	43%	79%	71%	68%	77%	38%
Ecological Departure		**66**	**63**	**64**	**28**	**60**	**52**	**49**	**58**	**26**
Open Canopy Departure		**63**	**60**	**61**	**21**	**57**	**49**	**46**	**55**	**16**
Total Management Cost					$2,400,000	$ 180,000	$ 600,000	$ 1,200,000	$ 360,000	$ 4,800,000
ROI					2.7	3.0	3.3	2.2	3.0	1.4

Treatments			**Max Mgmt 20 Yrs**	**Current Mgmt 1.5K Parkwide**	**Proposed Mgmt 5K Parkwide**	**Restore-Maintain 40 Yrs**	**Current Level 40 Yrs**	**Max Mgmt 40 Yrs**
RxFire-Restore (Realized Acres)			16,000	1,200	4,000	4,000	1,200	16,000
Acres/Yr Burned			2,400	180	600	600	180	2,400
Cost/Acre			$ 50	$ 50	$ 50	$ 50	$ 50	$ 50
# Years			20	20	20	20	20	20
RxFire-Restore (Realized Acres)						2,400	720	9,600
2nd 20 years						360	108	1,440
						$ 50	$ 50	$ 50
						20	20	20
Rx-Maintenance						1,600	480	6,400
2nd 20 years						240	72	960
						$ 50	$ 50	$ 50
						20	20	20

Appendix 11. Excel model runs worksheet – Low Elevation Pine-Oak Heath.

Low Elevation Pine-Oak Heath										
Vegetation Class	**NRV** Mean	**Current %**	**No Action - 20 Yrs**	**No Action 40 Yrs**	**Max Mgmt 20 Yrs**	**Current Mgmt 1.5K Parkwide - 20 Yrs**	**Preferred Mgmt 5K Parkwide - 20 Yrs**	**Restore-Maintain 40 Yrs**	**Current Level 40 Years**	**Max Mgmt 40 Yrs**
Early	21%	2%	9%	7%	25%	10%	13%	15%	11%	27%
Mid-Closed	13%	0%	7%	18%	7%	7%	7%	17%	18%	16%
Mid-Open	30%	0%	1%	3%	1%	1%	1%	7%	4%	13%
Late-Closed	15%	84%	71%	60%	24%	66%	54%	39%	52%	11%
Late-Open	21%	13%	11%	10%	41%	15%	24%	21%	13%	32%
Highly Departed Composition		1%	1%	1%	1%	1%	1%	1%	1%	1%
Totals	100%	100%	100%	99%	99%	100%	100%	100%	99%	100%
Total Early/Open										
Total Closed	28%	84%	78%	78%	31%	73%	61%	56%	70%	27%
Ecological Departure		**70**	**57**	**51**	**34**	**52**	**43**	**29**	**43**	**21**
Open Canopy Departure		**56**	**50**	**50**	**3**	**45**	**33**	**28**	**42**	**-1**
Total Management Cost					$1,500,000	$ 150,000	$ 499,950	$ 999,950	$ 300,000	$ 3,000,000
ROI					1.5	2.9	3.0	1.9	5.0	1.2
Treatments					**Max Mgmt 20 Yrs**	**Current Mgmt 1.5K Parkwide**	**Proposed Mgmt 5K Parkwide**	**Restore-Maintain 40 Yrs**	**Current Level 40 Years**	**Max Mgmt 40 Yrs**
RxFire-Restore (Realized Acres)					10,000	1,000	3,333	3,333	1,000	10,000
Acres/Yr Burned					1,500	150	500	500	150	1,500
Cost/Acre					$ 50	$ 50	$ 50	$ 50	$ 50	$ 50
# Years					20	20	20	20	20	20
RxFire-Restore (Realized Acres)								2,000	600	6,000
2nd 20 years								300	90	900
								$ 50	$ 50	$ 50
								20	20	20
Rx-Maintenance										
2nd 20 years								200	60	600
								$ 50	$ 50	$ 50
								20	20	20

Appendix 12. Excel model runs worksheet – Montane Pine-Oak Heath.

Montane Pine-Oak Heath										
Vegetation Class	**NRV** Mean	**Current %**	**No Action - 20 Yrs**	**No Action 40 Yrs**	**Max Mgmt 20 Yrs**	**Current Mgmt 1.5K Parkwide - 20 Yrs**	**Preferred Mgmt 5K Parkwide - 20 Yrs**	**Restore-Maintain 40 Yrs**	**Current Level 40 Yrs**	**Max Mgmt 40 Yrs**
Early	25%	6%	10%	10%	24%	12%	13%	14%	12%	29%
Mid-Closed	16%	1%	9%	19%	6%	9%	8%	18%	20%	14%
Mid-Open	25%	1%	1%	3%	3%	1%	1%	4%	4%	12%
Late-Closed	15%	78%	65%	56%	26%	64%	60%	48%	52%	13%
Late-Open	19%	14%	13%	11%	39%	14%	17%	14%	12%	31%
Highly Departed Composition	0%	1%	1%	1%	1%	1%	1%	1%	1%	1%
Totals	100%	100%	99%	100%	99%	101%	100%	99%	101%	100%
Total Early/Open										
Total Closed	31%	79%	74%	75%	32%	73%	68%	66%	72%	27%
Ecological Departure		**64**	**51**	**45**	**32**	**50**	**46**	**36**	**42**	**17**
Open Canopy Departure		**48**	**43**	**44**	**1**	**42**	**37**	**35**	**41**	**-4**
Total Management Cost					$2,700,000	$ 120,000	$ 400,050	$ 800,050	$ 240,000	$ 5,400,000
ROI					1.5	1.6	2.3	2.1	8.6	1.3

Treatments			**Max Mgmt 20 Yrs**	**Current Mgmt 1.5K Parkwide**	**Proposed Mgmt 5K Parkwide**	**Restore-Maintain 40 Yrs**	**Current Level 40 Yrs**	**Max Mgmt 40 Yrs**
RxFire-Restore (Realized Acres)			18,000	800	2,667	2,667	800	18,000
Acres/Yr Burned			2,700	120	400	400	120	2,700
Cost/Acre			$ 50	$ 50	$ 50	$ 50	$ 50	$ 50
# Years			20	20	20	20	20	20
RxFire-Restore (Realized Acres)						1,600	480	10,800
2nd 20 years						240	72	1,620
						$ 50	$ 50	$ 50
						20	20	20
Rx-Maintenance								
2nd 20 years						160	48	1,080
						$ 50	$ 50	$ 50
						20	20	20