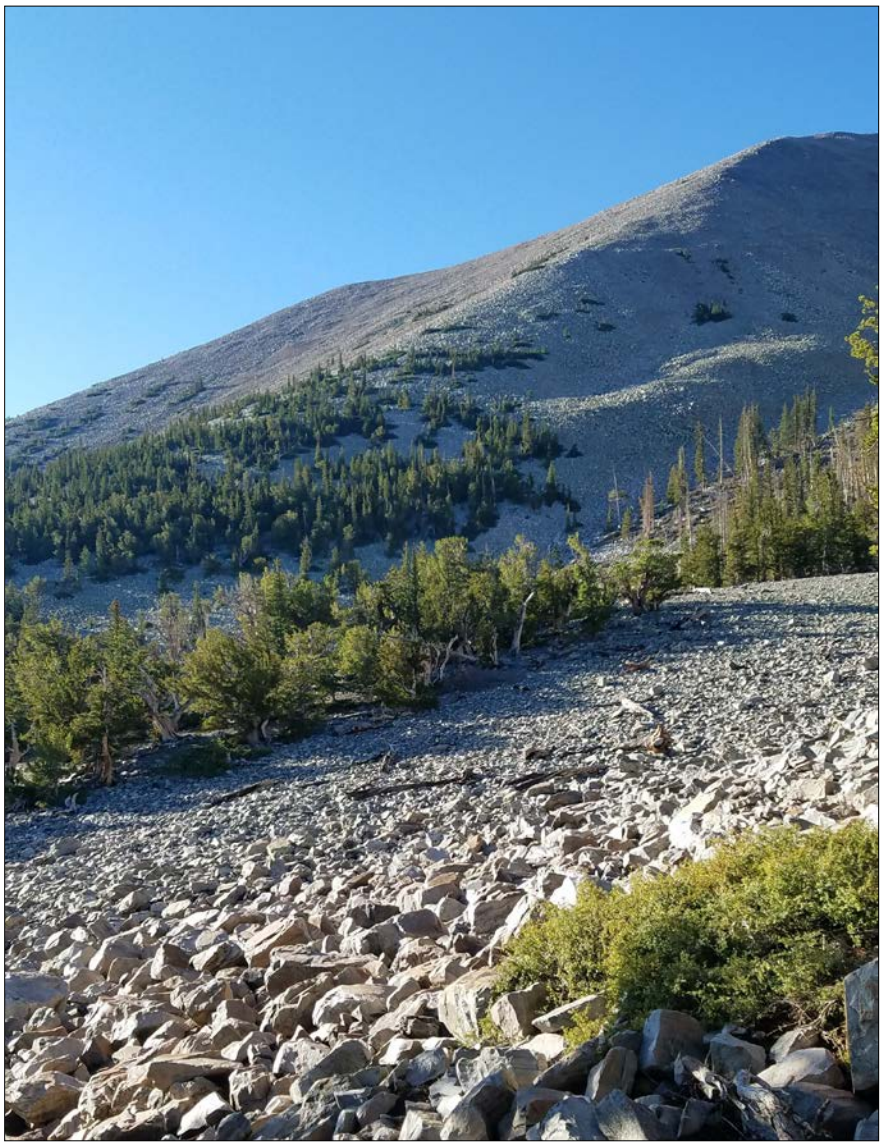
National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

# Protocol Implementation Plan for Monitoring White Pine in Great Basin National Park

*Narrative Version 1.0*

Natural Resource Report NPS/MOJN/NRR—2018/1759



**ON THE COVER**

Photo of *Pinus flexilis* and *P. longaeva* in Great Basin National Park, summer 2017.
Photograph courtesy of the National Park Service (Nicole Hupp)

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# Executive Summary

This Protocol Implementation Plan (PIP) was written through a collaborative effort between two National Park Service Inventory and Monitoring Programs, the Mojave Desert Network (MOJN) and the Upper Columbia Basin Network (UCBN). In 2013, UCBN, the Sierra Nevada Network (SIEN), and the Klamath Network (KLMN) worked together to create a detailed and rigorous long-term monitoring protocol for three white pine species in the West: whitebark, limber, and foxtail pines (McKinney et al. 2013). In this PIP, MOJN and UCBN worked together to apply the objectives and methods of McKinney et al. (2013) to Great Basin National Park (GRBA). Unlike Mckinney et al. (2013), whitebark and foxtail pines are not monitored in this PIP because these species are not present in MOJN parks. However, a different species of white pine, Great Basin bristlecone pine, is present; this PIP is written specifically to monitor limber pine and Great Basin bristlecone in GRBA. This PIP freely uses, without in-line citations, the direct text, ideas, and some products from the protocol on which it is based, McKinney et al. (2013). Funding for this project was provided through the National Park Service Natural Resource Challenge (NPS 1999) and the Service-wide Inventory and Monitoring Program.

White pines are not currently monitored in MOJN parks, yet Great Basin National Park (GRBA) contains over ten thousand acres of bristlecone pine and limber pine forest (Cogan et al. 2012). As of December 2017, GRBA included Great Basin bristlecone pine in their Species of Management Concern document (SOMC 2014) due to its vulnerability to climate change, white pine blister rust (WPBR), and possible mountain pine beetle outbreaks. This monitoring PIP will add valuable information to better understand the dynamics of forest ecosystems under modern perturbations in GRBA. The monitoring will add to a growing body of information on WPBR spread and epidemiology within white pine forest communities in a variety of biophysical settings.

The objectives of this PIP are to determine status and trends in bristlecone and limber pine forests at Great Basin National Park by measuring:

1. Forest or community composition and structure
2. Tree species birth, death, and growth rates
3. Incidence of white pine blister rust (WPBR) and level of crown kill
4. Incidence of pine beetle and severity of tree damage
5. Incidence of dwarf mistletoe and severity of tree damage
6. Cone production of white pine species

As recommended by Oakley et al. (2003), this PIP consists of a narrative and a set of standard operating procedures (SOPs; all SOPs are in Hupp et al. 2018) which detail the steps required to collect, manage, and disseminate the data representing the status and trend of white pine community dynamics and the condition of associated communities in GRBA. The intent of this PIP is to ensure that a scientifically credible story about the ecological condition of white pine communities and their

responses to invasive pathogens, park management actions, changing climate patterns, and other stressors can be shared with park visitors and managers alike. Long-term data sets can contribute to the development of informative models of relationships between white pine community dynamics and key environmental factors and management actions specific to each park.

## Acknowledgments

This Protocol Implementation Plan (PIP) includes large amounts of text, without in-line citation, from the white-pine long-term monitoring protocol (McKinney et al. 2013) implemented in three other Pacific West Region networks (Upper Columbia Basin Network, Sierra Nevada Network, and Klamath Network). Park staff at Great Basin National Park, particularly Ben Roberts, Gretchen Baker, Meg Horner, and Julie Long, contributed many hours to visiting sites, refining goals, and proofreading many versions of this PIP. Additionally, staff at the UCBN contributed ideas and time to this document. Mojave Desert Network personnel also contributed time to site visits, document edits, and development of methods.

## List of Acronyms and Glossary of Terms

**ANOVA:** In statistics, analysis of variance (ANOVA) is a collection of statistical models, and their associated procedures, in which the observed variance is partitioned into components due to different explanatory variables.

**BLM:** Bureau of Land Management

**DEM:** Digital Elevation Model (DEM); a digital model made from terrain elevation data used in our sample selection process.

**DEVA:** Death Valley National Park

**GRBA:** Great Basin National Park

**GRYN:** Greater Yellowstone Inventory & Monitoring Program

**I&M:** Inventory and Monitoring

**IPSED:** Invasive Plant Species Early Detection

**JOTR:** Joshua Tree National Park

**KLMN:** Klamath Network Inventory and Monitoring Program

**LAKE:** Lake Mead National Recreation Area

**LAKE-EPMT:** Lake Mead Exotic Pest Management Team

**MANZ:** Manzanar National Historic Site

**MOJA:** Mojave National Preserve

**MOJN:** Mojave Desert Network Inventory and Monitoring Program

**NPS:** National Park Service

**PARA:** Grand Canyon- Parashant National Monument

**PIP:** Protocol Implementation Plan

**SOP:** Standard Operating Procedure

**TTCSM:** Travel Time Cost Surface Model; this is a model that calculates travel time from defined point and/or linear locations to other locations within a user-defined area of interest. It is designed to model travel time in national parks using readily available geospatial products such as road, trail, and stream networks, digital elevation models and land cover data.

**TUSK:** Tule Springs Fossil Beds National Monument

**US EPA:** United States Environmental Protection Agency

**UCBN:** Upper Columbia Basin Network Inventory and Monitoring Program

**USGS:** United States Geological Survey

**Vital Signs:** A subset of physical, chemical, and biological elements and processes of park ecosystems that were selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values. The elements and processes that are monitored are a subset of the total suite of natural resources that park managers are directed to preserve "unimpaired for future generations," including water, air, geological resources, plants and animals, and the various ecological, biological, and physical processes that act on those resources. Vital signs may occur at any level of organization including landscape, community, population, or genetic level, and may be compositional (referring to the variety of elements in the system), structural (referring to the organization or pattern of the system), or functional (referring to ecological processes).

**WPBR:** White pine blister rust, a disease that affects white pine species. It is caused by *Cronartium ribicola*, a non-native pathogen.

# Background, Rationale, and Objectives

## Rationale for Monitoring White Pine Species in the Pacific West Region

Western North American coniferous forests are currently facing unprecedented health challenges, including upsurges of native pests and pathogens, invasive species, and altered disturbance regimes. Increased atmospheric warming, carbon dioxide concentration, and nitrogen deposition, as well as changes in precipitation patterns (i.e., timing, magnitude, and type) pose short-term and long-term threats. Each factor alone can alter forest ecosystem structure, function, and species composition, and those effects are magnified when multiple agents act jointly. These modern perturbations will affect forest ecosystems, however the magnitude of change in structure and composition, and the resulting effects on key ecological processes, are uncertain. Increased tree mortality rates over the last several decades have recently been documented across a broad range of latitudes and forest types in western North America (van Mantgem et al. 2009). Global studies of tree mortality due to drought and heat stress have identified that there is a strong need for large-scale monitoring of tree health and response to threats (Allen et al. 2010, Allen et al. 2015).

Five-needle white pines (Family Pinaceae, Genus *Pinus*, Subgenus *Strobus*) are foundation species (Tomback and Achuff 2010) in upper subalpine and treeline forests of several National Park Service (NPS) Pacific West Region (PWR) parks. Declines of foundation tree species pose a compelling problem because these species provide fundamental structure to their ecosystems and are thereby irreplaceable (Ellison et al. 2005). Foundation species generally occupy low trophic levels, create locally stable conditions required by many other species, and stabilize fundamental ecosystem processes (Ellison et al. 2005). In temperate zone forests (e.g., western North America), there are often only one or two foundation tree species, and therefore little functional redundancy is present in the system. If a foundation tree species is lost from these systems, it will likely lead to a cascade of secondary losses, shifts in biological diversity, and ultimately affect the function and stability of the community (Ebenman and Jonsson 2005). Because of these concerns, three species of white pine, limber pine (*P. flexilis)*, foxtail pine (*P. balfouriana*), and whitebark pine (*P. albicaulis*), are currently monitored in several parks in the west (Tables 1 and 2; McKinney et al. 2013).

Limber pine and Great Basin bristlecone pines (*P. longaeva*) are the only two five-needle white pine species occurring in Great Basin National Park (GRBA), and they are the focus of this monitoring Protocol Implementation Plan (PIP; Tables 1 and 2). While limber and Great Basin bristlecone pines have different ecological requirements, they both often occupy environments too harsh for other tree species to thrive. They both frequently occur in proximity to other tree species and then transition into nearly, or entirely, monospecific stands. Limber pine occupies a wide elevation range and occurs in upper-montane, subalpine, and lower-treeline habitats. Bristlecone pine is found in a narrow elevational band in subalpine and treeline zones. By virtue of their status as dominant components of forest stands, these two species can have a large influence on key ecosystem processes and community dynamics, such as influencing snowmelt and stream flow, moderating local environments by allowing for establishment of shade-tolerant plants, and providing habitat and food resources for birds and mammals.

**Table 1.** In the West, four Inventory and Monitoring networks are monitoring white pines. These monitoring programs include four total species of white pines, though not every network is monitoring every tree species.

| Network | Tree Species | Associated White Pine Monitoring Protocol |
|---|---|---|
| Upper Columbia Basin Network (UCBN) | Limber pine (*P. flexilis*) | McKinney et al. 2013. |
| Sierra Nevada Network (SEIN) | Limber pine (*P. flexilis*)<br>Whitebark pine (*P. albicaulis*)<br>Foxtail pine (*P. balfouriana*) | McKinney et al. 2013. |
| Klamath Network (KLMN) | Whitebark pine (*P. albicaulis*) | McKinney et al. 2013. |
| Mojave Desert Network (MOJN) | Limber pine (*P. flexilis*)<br>Great Basin bristlecone pine (*P. longaeva*) | Hupp et al. 2018 (this document, which is designed after McKinney et al. 2013) |

**Table 2.** Estimated extent in hectares of white pine species by network and by park. Total area of each of the white pine species included in this PIP and in McKinney et al. 2013 is of nearly 75,000 hectares.

| | | White Pine Species | | | | |
|---|---|---|---|---|---|---|
| Network | Park | Whitebark Pine | Limber Pine | Foxtail Pine | Great Basin Bristlecone Pine | Total |
| SIEN | SEKI | 18,312 | 221 | 24,056 | 0 | 42,590 |
| | YOSE | 18,089 | 0 | 0 | 0 | 18,089 |
| KLMN | CRLA | 1,526 | 0 | 0 | 0 | 1526 |
| | LAVO | 257 | 0 | 0 | 0 | 257 |
| UCBN | CRMO | 0 | 9,244 | 0 | 0 | 9,244 |
| | CIRO | 0 | 35 | 0 | 0 | 35 |
| MOJN | GRBA | 0 | 2609 | 0 | 608 | 3,217 |
| | Total | 38,184 | 12,109 | 24,056 | 608 | 74,958 |

## Potential Threats to Bristlecone Pine and Limber Pine

### *White Pine Blister Rust (WPBR)*

A particularly pernicious threat to many western forest ecosystems is the exotic fungal pathogen *Cronartium ribicola* (Division Basidiomycota, Order Pucciniales), which causes WPBR in five-needle white pines. Native to Asia, the fungus exhibits a complex life cycle that includes five different spore types alternating between five-needle white pines and plants of the genera *Ribes*, *Pedicularis*, and *Castilleja* (Hummer 2000, McDonald and Hoff 2001, McDonald et al. 2006). Basidiospores are produced on alternate host leaves and enter white pine needles through stomata. Mycelium forms and grows down vascular bundles and into branches and boles (McDonald and Hoff 2001), forming a sporulating canker after two to three years of growth. WPBR ultimately damages and kills host five-needle white pines by girdling branches and boles, thereby reducing cone seed

production, and altering successional processes, species composition, structure, and function of white pine forests (McDonald and Hoff 2001).

Geils et al. (2010) estimate that *C. ribicola* was introduced to western North America several times and in multiple locations prior to 1910. Since its introduction, the fungus has spread across western North American forests. Previous attempts to control WPBR, including elimination of its main alternate host *Ribes*, have been unsuccessful (McDonald and Hoff 2001). Low levels of genetic resistance in North American five-needle white pines, and favorable habitat and climatic conditions, have allowed for rapid advance of WPBR. Indeed, all North American five-needle white pine species are susceptible to WPBR infection. Great Basin bristlecone pine is susceptive to WPBR, yet it is the only North American white pine not yet found with WPBR in its native habitat. Limber pine is declining rapidly throughout most of its range from WPBR-induced mortality.

#### *Mountain Pine Beetle*

Limber pine is also declining from large outbreaks of mountain pine beetle (*Dendroctonus ponderosae*). Mountain pine beetle is one of a handful of bark beetle species that kills its host during reproduction (Heavilin et al. 2007). Mountain pine beetle is a native species and natural disturbance factor in western forest ecosystems and has had an important influence on the process of forest succession. Although a large mountain pine beetle outbreak affected whitebark (*P. albicaulis*) pine forests in the 1930s, high-elevation pines appear to have had less interaction historically with the beetle (Logan et al. 2010). This lack of association could be the result of cold temperatures limiting beetle spread at high elevations. Mountain pine beetle outbreaks are cyclical, yet the recent epidemic in high-elevation forests of western North America are considered unprecedented in duration and magnitude over the past 200 years (Logan et al. 2010). Mountain pine beetle outbreaks subside after the most susceptible trees are killed (Millar et al. 2007), leaving a heterogeneous pattern of dead trees and survivors (Rocca and Romme 2009), and lower density forests than would develop in the absence of the beetle.

Remarkably, bristlecone pine (unlike limber pine) does not appear to be at risk of mortality from mountain pine beetle, due to an impressive suite of defense traits (Bentz et al. 2017).

#### *Dwarf Mistletoe*

In Nevada, there are 14 native species of dwarf mistletoe (genus *Arceuthobium)*; together these 14 species infect all coniferous tree species in Nevada (except incense cedar and junipers). These parasitic pests are ubiquitous in Nevada and are host-species specific (Hawksworth and Wiens 1998). In other words, there is often one dwarf mistletoe species associated with a specific tree species, although there are cases of a dwarf mistletoe species using alternate hosts. For example, the primary host of limber pine dwarf mistletoe (*Arceuthobium cyanocarpum*) is limber pine, but Mathiasen and Daughtery (2010) reported recent infections on sugar pine (*Pinus lambertiana*) in California. Dwarf mistletoe hosts in GRBA include limber pine, ponderosa pine (*Pinus ponderosa*), Engelmann spruce (*Picea englemannii*), Great Basin bristlecone pine, single leaf pinon pine (*Pinus monosperma*), and Douglas-fir (*Pseudotsuga menziesii*).

## Taxonomy, Distribution, and Ecology of Great Basin Bristlecone and Limber Pines

### *Bristlecone Pine Natural History*

Great Basin bristlecone pine is classified within the bristlecone-foxtail pine complex (*Pinus*, subgenus *Strobus*, section Parrya, subsection Balfourianae). Bristlecone pines are closely related to Rocky Mountain bristlecone pine (*P. aristata*) and foxtail pine (*P. balfouriana*) but are distinguished by growth form, bark, and differences in chemical defense composition. Great Basin bristlecone pine occurs in a relatively narrow latitudinal range in California, Nevada, and Utah, usually between 8,000 and 10,000 feet.

Pure Great Basin bristlecone pine stands at high elevations may be species-poor. For example, a Great Basin bristlecone pine community located between 8,900 and 10,000 feet (2,700 and 3,200 m) elevation in Cedar Breaks National Monument (southern Utah) is composed of monospecific stands of Great Basin bristlecone pine and a dwarfed paintbrush (*Castilleja* spp.), but the understory is otherwise bare. In contrast, Great Basin bristlecone pine-limber pine communities on the plateaus of southern Utah typically have a diverse understory. A full description of the GRBA plant communities associated with Great Basin bristlecone pine is provided below in the *Sampling Design- Target Population, Sampling Frames, and Location of Plots* section.

In the United States, Great Basin bristlecone pines are a cherished tree. The oldest known living non-clonal tree in the world is a Great Basin bristlecone, and these trees are famous for their age, shape, and habitat preference. Great Basin bristlecone pine is a native conifer of highly variable growth form. Low-elevation trees are typically tall and upright. At high elevations, Great Basin bristlecone pine becomes twisted and contorted. For botanists in the West, the type locality for Great Basin bristlecone pine is Wheeler Peak in GRBA, although the bedrock type (quartzite) is an outlier as most stands are found in carbonate derived rock or soils. Great Basin bristlecone pine is rarely shrubby and often has a gnarled appearance. It does not always form timberline krummholz (e.g., the White Mountains), but high-elevation sites in eastern Nevada and Utah, including GRBA, support Great Basin bristlecone pine krummholz. Trees are typically 30 feet (9.1 m) or less in height. Trees on mesic, low-elevation sites may reach 60 feet (18 m) in height and 5 feet (1.5 m) in diameter. Great Basin bristlecone pine may have single or multiple trunks. Downed wood may persist for thousands of years on high-elevation sites. These trees disperse pollen and seeds by wind, and through the tightly evolved relationship with Clark's nutcrackers (*Nucifraga columbiana*), particularly at high elevations (Lanner 1988).

As of December 2017, GRBA included Great Basin bristlecone pine in their Species of Management Concern document (SOMC 2014) due to its vulnerability to climate change, white pine blister rust, and possible mountain pine beetle outbreaks. It is not listed by the Nevada Natural Heritage Program.

### *Limber Pine Natural History*

Limber pine is classified into the Genus *Pinus*, subgenus Strobus, Section Quinquefoliae, Subsection Strobus, and is a relatively small tree; it may attain a height of about 65 feet (20 m) and grows as krummholz in treeline environments. Limber pine ranges widely from 34° to 53° N latitude and from 104° to 108° W longitude (Little 1980). It occurs from the Rocky Mountains of southeast British Columbia and southwest Alberta into the United States through northeast Oregon, Idaho, Montana,

North Dakota, South Dakota, Nebraska, Wyoming, Colorado, Utah, Nevada, and into northern New Mexico and Arizona, the southern Sierra Nevada and White-Inyo range of California (Little 1980). Limber pine occupies the broadest elevational distribution, from lower elevation sites to timberline, of all North American white pines (1,300–3,700 m range wide). It occurs in a wide range of environments, but is often found on dry, rocky slopes (Schuster et al. 1995). In MOJN, limber pine occupies a large portion of Great Basin National Park (GRBA) and a smaller area in Death Valley National Park (DEVA).

Limber pine is a pioneer species of severe sites, moderating local environments and facilitating establishment of other species (Baumeister and Callaway 2006). Limber pine cones open when seeds are ripe; some seeds remain within cones, while others fall to the ground. The seeds of limber pine are large, have rudimentary wings, and are preferred by numerous birds and mammals. Its seeds are dispersed by Clark's nutcrackers (*Nucifraga columbiana*; Lanner and Vander Wall 1980, Tomback and Kramer 1980, Vander Wall 1988) and small mammals (Tomback et al. 2005). A full description of the GRBA plant communities associated with limber pine is provided below in the *Sampling Design- Target Population, Sampling Frames, and Location of Plots* section.

### Fire History in Great Basin National Park

Fire history of an area can have a large impact on forest species composition, particularly in places such as GRBA where the modern fire regime has been dominated by fire suppression, yet the history was complex before 1860. A United States Forest Service (USFS) fire scar study (Gruel et al 1999) estimated that before 1800, Snake Creek and Strawberry Creek drainages likely burned every 15-20 years, and attributed those fires to lightning and Native American ignitions. Post Euro-American colonization, fire suppression became common. Of 35 fire scars studied in pinyon-juniper forests, 3% were from the 1900s, 76% occurred in the 1800s, and 21% were from the 1700s or earlier. On rocky slopes, fires were generally less common, and scars indicate a 50-100 year or longer fire return interval. The same report indicates that from 1959 to 1988, 83 fires were suppressed in the Snake Range; all but three were less than 1 ha (the remaining three were between 4 and 24 ha).

The regime changes in the 1800s created shifts in composition and structure on a local-level and homogenization at the landscape scale. However, if park managers are interested in re-creating the mosaic the park once had, increasing fire frequency should not be used in a one-size-fits-all approach. Without frequent fires in pinyon-sagebrush communities, pinyon pine tends to replace sagebrush. However, macroscopic charcoal research in sagebrush dominated lowlands show that fires were not historically as common as in the pinyon-sagebrush alliance, and increasing the fire frequency could damage those communities (Mensing et al 2016). In other words, the fire regimes in GRBA were varied both spatially and temporally across the park.

In recent history, GRBA has had few large fires. Notably, the Strawberry Creek fire (2016) burned 1907 ha and is considered the most destructive fire in the park's history. Prior to that, historical records indicate that largest fire in the South Snake Range in modern times occurred between 1908-1910 and covered 80-120 ha.

While such large fires have benefits, planned disturbances with differing levels of severity can restore the vegetative mosaics that GRBA once had (Kitchen 2012) without the collateral destruction large wildfires pose. In an effort to restore fire as a tool for maintaining healthy ecosystems, the Park has undertaken several fuels reduction and restoration projects. GRBA is currently conducting post-fire restoration from the Strawberry Creek Fire and fuels reduction elsewhere in the Park. In 2005, Grey Cliffs Campground underwent fuels reduction and plant community restoration. Park data indicated that Grey Cliffs formerly supported a big sagebrush plant community but has converted to a pinyon-juniper woodland since the 1900s. Park managers worked to recreate the historical ecological site description by seeding, selectively cutting trees, and chipping and spreading slash. To match historical records, aspen, ponderosa pine, mountain mahogany, white fir, and old growth pinyon pine were not removed (NPS 2018). White pine species are not currently targeted for any fire treatments at this time in GRBA.

### Rationale for Monitoring Bristlecone Pine and Limber Pine at GRBA

White pines are not currently monitored in MOJN parks, yet Great Basin National Park contains over 4,000 ha of bristlecone pine and limber pine forests (Cogan et al. 2012). This monitoring PIP will provide valuable information about the dynamics of forest ecosystems under modern perturbations in GRBA. The monitoring will add to a growing body of information on WPBR spread and epidemiology within white pine forest communities in a variety of biophysical settings. Monitoring of other white pine populations in the NPS North Coast and Cascades Network (NCCN), and in the Greater Yellowstone Network (GRYN) is also ongoing (GYWPMWG 2007, Rochefort 2008) and presents an important opportunity for data sharing and regional synthesis of status and trends. At a broad level, this long-term monitoring program can show how mortality events, and possibly even local extirpations of foundation species, influence rates and trajectories of succession, leading to novel forest types with unexpected dynamics (Ellison et al. 2005). This information can help management adapt to anticipated short- and long-term changes in ecosystem structure and function that follow the loss of a foundation species (Ebenman and Jonsson 2005).

In GRBA, there is a unique opportunity to study two foundation tree species that may be subject to high mortality rates in parts of their range but have so far not been affected in MOJN parks. If introduced, WPBR and mountain pine beetle could pose significant risks to white pines in GRBA, particularly considering that climate change may exacerbate plant-insect and plant-disease interactions (e.g., Vogler and Charlet 2004, Kearns and Jacobi 2007).

### Project Goal and Problem Statements

The purpose of this monitoring project is to document and interpret changes in community dynamics in forests containing two white pine species (*P. longaeva* and *P. flexilis*). To achieve this goal we ask the following questions: (1) Are white pine forests changing in structure and species composition? (2) Are rates of tree mortality increasing, are rates of recruitment from the seedling class (<137 cm height) into the tree class (≥137 cm height) decreasing, and are there declines in seedling regeneration (<137 cm height; seedlings/$m^2$)? (3) Are the key disturbance species—the invasive *Cronartium ribicola* and native mountain pine beetle and dwarf mistletoe—increasing in incidence and severity?

## Hypothesized Relationships

We anticipate an increase in the incidence of WPBR and mountain pine beetle in GRBA and parks in other networks implementing McKinney et al. (2013). We therefore predict an increase in the number of trees infected with WPBR and infested with mountain pine beetle over time. Crown kill and tree mortality associated with these species will subsequently increase. As crown kill and tree mortality increase, we predict that cone production will decrease. Decreasing cone production will lead, over time, to a decrease in regeneration (seedlings/$m^2$). Since WPBR only affects white pines (subgenus Strobus) and mountain pine beetles only attack *Pinus* species, this hypothesized mortality will be disproportionate with respect to subgenus and genus, respectively. Therefore, we also predict that over time, forest community composition will change with a decrease in the relative proportion of trees that are white pines and an increase in the relative proportion of trees that are non-*Pinus* genera (e.g., *Abies, Juniperus, Tsuga*). An alternative hypothesis is that the absolute number of white pine trees will decrease but with no subsequent replacement by other non-*Pinus* species owing to the inability of other species to establish in these harsh environments.

## Long-Term Monitoring Objectives

White pine monitoring objectives in MOJN match the collaboratively identified goals identified in McKinney et al. (2013) for KLMN, SIEN, and UCBN. The objectives were developed by network ecologists and program managers and informed by the vital signs scoping process in each network, as documented in network monitoring plans (Garrett et al. 2007, Sarr et al. 2007, Mutch et al. 2008). The anticipated impacts of WPBR, mountain pine beetle, mistletoe, and climate change on high-elevation white pines based on published scientific literature and expert-opinion influenced the objective selection process. By monitoring individual trees within plots, we will be able to estimate key demographic parameters and adequately address our objectives.

For white pine (*P. flexilis* and *P. longaeva*) forest communities in MOJN, with constraints based on safety and accessibility, we will determine the status and trends in the following variables (see Table 4 for details on the relationship between the six objectives and measured variables):

1. Tree species composition and structure
2. Forest birth, death, and growth rates
3. Incidence of WBPR and level of associated crown kill
4. Incidence of mountain pine beetle and severity of tree damage
5. Incidence of dwarf mistletoe and severity of tree damage
6. Cone production of white pine species

## Management Actions

The overall, range-wide recovery strategy for limber pine and bristlecone pine is largely based on increasing the frequency of WPBR-resistant alleles within populations (Schoettle et al. 2014), reducing impacts from mountain pine beetle, and restoring fire to the landscape to promote seedling regeneration. Managers have a suite of tools available to protect and restore these forests, including using natural or artificial regeneration, to increase WPBR resistance. For artificial regeneration,

phenotypically WPBR-resistant trees are identified, their cones are protected from vertebrate seed predators with wire cages in early summer, and then their seeds collected later in the summer when mature. Prescribed burning can be used to prepare sites prior to planting nursery-grown seedlings or used as a tool to reduce competing shade-tolerant species and attract Clark's nutcracker seed caching. Wildland fire for resource benefit can also be used which entails allowing lightning-ignited fires to burn in remote areas. Individual trees can be protected from mountain pine beetle by placing verbenone (a synthetically-produced chemical to mimic beetle pheromones) patches on trees or by spraying trees with contact insecticide. All of these tools are now employed in various locations in the Rocky Mountains (Keane et al. 2012) where severe tree declines are occurring.

GRBA is actively investigating genetic resistance of *P. flexilis* and *P. longaeva* to WPBR through a task agreement with the USFS (Schoettle 2017). Currently in GRBA, collaborators are working to conduct ex situ genetic conservation, disease resistance testing, and in situ genetic conservation (NPS 2017). In these studies, cones are collected from the Park, seedlings are grown in a nursery, and seedlings are inoculated with WPBR to test for resistance. After three to four years, WPBR-resistant seedlings can be out-planted in suitable habitat.

Understanding the health of individual trees is crucial for appropriately managing a forest. The most common way to identify health of plants is to use a "score card" rating system; this is challenging because of the general lack of detailed information about the forest communities. The score card rating system is a means to report the health of various biological systems to park managers and the public and follows the convention of *green = good, yellow = caution*, and *red = concern*. We propose the following relationships determined by McKinney et al. (2013) with the caveat that these relationships must be revisited and further refined following several years of data collection and analyses. Pine beetle infestation of 5% and dwarf mistletoe infection of 10% should warrant a caution rating, while values greater than these should result in a rating of concern. Since WPBR has not been detected in GRBA to date, any occurrence of this pest will be immediately reported to the Park and will warrant a caution rating. MOJN will work with park staff and the USFS to determine what type of management action will be needed. If established, WPBR infection of 1% will be of concern. A specific mortality threshold is more difficult to identify and would likely be spurious and potentially misleading. For example, it will be important to explore mortality rates by tree size class, species, and genus to fully comprehend the trajectory in forest community dynamics and thus, the overall "health" of these systems. However, we do know that a sustained doubling of mortality rates (e.g., from 1-2% year-1) would lead to a 50% decline in average tree age and likely a corresponding decline in tree size (van Mantgem et al. 2009).Therefore, a doubling in overall mortality rate would be cause for concern, and less than that, caution. Furthermore, it will be important to identify whether tree recruitment rates and regeneration densities are declining or increasing over time. If mortality is increasing, and recruitment and regeneration are decreasing, a rating of concern would be warranted.

### Monitoring Locations

Presently, this document focuses on one MOJN park, GRBA. The option to include additional parks in the future is available but is dependent on the use of vegetation maps, which are in development. MOJN plans to include *P. longaeva* and *P. flexilis* monitoring in DEVA. While there are additional

parks in MOJN, other parks are not suitable for monitoring using the approach outlined in this protocol.

***Great Basin National Park (GRBA)*** is located in east central Nevada near Baker and less than 18 kilometers from the Nevada-Utah state border (Figure 1). The Park's history goes back to 1922, when Lehman Caves National Monument was established by Presidential Proclamation (No. 1618; 42 Stat. 2260), signed by President Warren G. Harding. Lehman Caves is the longest limestone cave in Nevada, and the National Monument was a 240 ha (593 ac) parcel surrounding the entrance to Lehman Caves, carved out from the then Nevada National Forest. Lehman Caves National Monument was initially administered by the USFS and transferred to the NPS in 1933, during a major federal government reorganization effort. Lehman Caves National Monument and much of the surrounding South Snake Range were designated as Great Basin National Park in 1986, the nation's 49$^{th}$ national park, when President Ronald W. Reagan signed Public Law 99-565 (100 Stat. 3181), the "Great Basin National Park Act of 1986" (Unrau 1990). The purpose of the Park was "to preserve for the benefit and inspiration of the people a representative segment of the Great Basin of the Western United States possessing outstanding resources and significant geological and scenic values." Park visitation in 2016 was 144,846 people (highest year on record; data sourced from National Park Service Visitor Use Statistics website, https://irma.nps.gov/Stats/, as of November 2017).

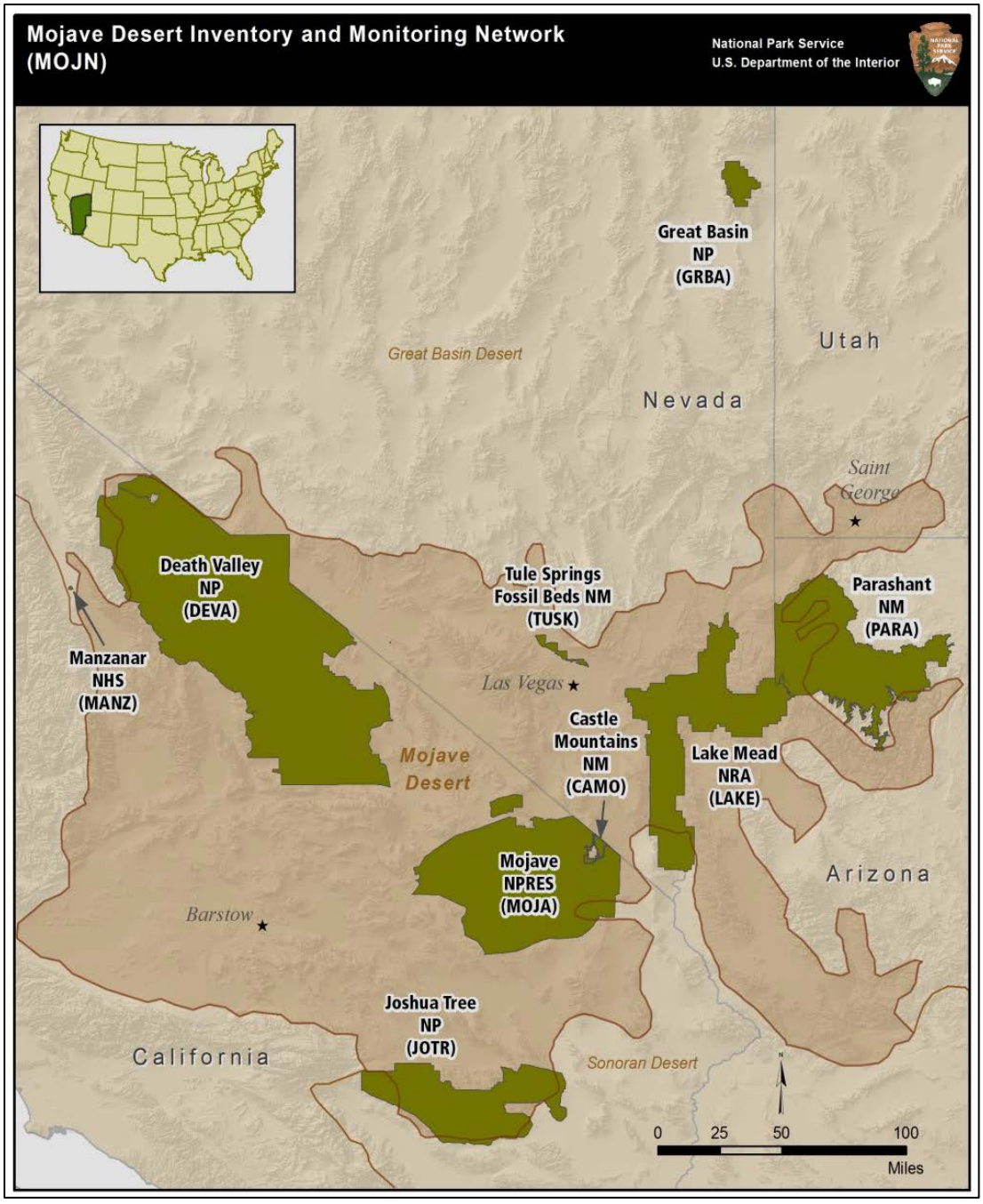



**Figure 1.** Map of the Mojave Desert Network parks where the dark brown coloration denotes the Mojave Desert geographically.

Unlike other MOJN parks, GRBA lies wholly in the Great Basin Desert region. It is a mountainous park as its 31,161 ha (77,000 ac) encompass the rugged South Snake Range, an elongated north-south oriented range bounded on the west by Spring Valley and on the east by Snake Valley. The boundaries of GRBA are contiguous with Bureau of Land Management (BLM) lands managed by the Ely, Nevada district office and by private lands. Besides Lehman Caves, another major feature of GRBA is Wheeler Peak (3,982 m), the highest point in the Snake Range and second highest peak in

Nevada, where the only glacier in Nevada is found. Elevations in GRBA range from 1,615 m in the sagebrush foothills to 3,982 m at the top of Wheeler Peak.

The extreme elevational gradient in GRBA leads to a variety of different habitats, ranging from sagebrush communities at lower elevations to alpine/subalpine communities at high elevations. GRBA has a variety of habitats including sagebrush steppe (*Artemisia* spp.), grasslands, aspen/conifer woodlands, ponderosa pine woodlands, limber pine-bristlecone pine forests, pinyon/juniper forests, mountain mahogany woodlands (*Cercocarpus ledifolius*), riparian shrubs, and wet meadows. Great Basin bristlecone pines and limber pines are found associated with other conifer species such as white fir (*Abies concolor),* Douglas-fir, and Engelmann spruce. A full description of other plant species associated with Great Basin bristlecone and limber pines is provided in Table 3.

**Table 3.** All monitoring locations are located within three vegetation classes in GRBA identified, described, and mapped in Cogan et al. (2012). These communities are comprised of similar but distinct vegetation associations.

| **Community Type** | **Common Species** |
|---|---|
| Great Basin Bristlecone Pine Subalpine Woodland | Great Basin bristlecone pine (*Pinus longaeva*)<br>White fir (*Abies concolor*)<br>Engelmann spruce (*Picea engelmannii*)<br>Limber pine (*Pinus flexilis*)<br>Common juniper (*Juniperus communis*)<br>Gooseberry currant (*Ribes montigenum*)<br>Hollyleaf clover (*Trifolium gymnocarpon*)<br>Ross' sedge (*Carex rossii*)<br>Dwarf alpine Indian paintbrush (*Castilleja nana*)<br>Snowline springparsley (*Cymopterus nivalis*)<br>Whitestem goldenbush (*Ericameria discoidea*) |
| Great Basin Bristlecone Pine Montane Woodland | Great Basin bristlecone pine (*Pinus longaeva*)<br>Limber pine (*Pinus flexilis*)<br>Mountain snowberry (*Symphoricarpos oreophilus*)<br>Greenleaf manzanita (*Arctostaphylos patula*)<br>Wax currant (*Ribes cereum*)<br>Muttongrass (*Poa fendleriana*)<br>Ross' sedge (*Carex rossii*) |
| Great Basin Limber Pine Woodland Alliance | Limber pine (*Pinus flexilis*)<br>White fir (*Abies concolor*)<br>Engelmann spruce (*Picea engelmannii*)<br>Limber pine (*Pinus flexilis*)<br>Douglas-fir (*Pseudotsuga menziesii*)<br>Mountain snowberry (*Symphoricarpos oreophilus*)<br>Greenleaf manzanita (*Arctostaphylos patula*)<br>Muttongrass (*Poa fendleriana*)<br>Ross' sedge (*Carex rossii*) |

# Sampling Design

## Sampling Design Rationale

Monitoring large landscapes poses unique challenges that require compromises among the following: 1) the accuracy and precision of measurements needed to detect meaningful change, 2) the large sample sizes and extensive sampling required to reflect the high natural variability found across park ecosystems, and 3) the logistical constraints posed by rugged and often inaccessible terrain, especially given the limitations of staffing and financial resources. We considered many cost-benefit trade-offs when developing this sampling design, and our decisions reflect a consideration of our objectives to detect both the status and trends in white pine community dynamics and detection of disease and insect infestations, and the travel costs associated with accessing these habitats.

We placed a premium on obtaining substantial information from large, intensively measured, permanent plots, and accepted the limits to sample size, spatial extent, and subsequent scope of inference that necessarily come from this decision. Peet et al. (1998) identified additional sampling design decision criteria that we subscribe to, including one of open architecture, involving a design that can be easily added to or modified without compromising the utility of earlier data. We think this approach is particularly important for long-term studies subject to unanticipated future uses and modifications, and is critical to accommodate the needs and constraints of regional studies. Finally, this PIP and its parent protocol (McKinney et al. 2013) closely follow the *Interagency Whitebark Pine Monitoring Protocol for the Greater Yellowstone Ecosystem* (GYWPMWG 2007). We modeled this protocol to benefit from the collective experience and expertise represented in that document and to facilitate regional syntheses of status and trends in white pine ecosystems across the western US and Canada. This PIP addresses a broader set of objectives but overlaps substantially with the Yellowstone protocol.

## Target Population, Sampling Frames, and Location of Plots

Target populations addressed in this PIP include white pine (*P. flexilis* and *P. longaeva*) forest and woodland communities in MOJN parks, with sampling frame constraints based primarily on safety and accessibility (Figure 2). The sampling frame constructed for GRBA used all available information such as park vegetation maps and road networks as described in the following subsections. We adopted a common sampling design to allocate permanent plots to random locations with an unstructured, equal-probability, spatially-balanced approach using the Generalized Random Tessellation Stratified (GRTS) algorithm (Stevens and Olsen 2004). The GRTS design has been successfully applied in many NPS I&M monitoring protocols and is a flexible, efficient, and statistically robust approach that accommodates many of the difficulties commonly encountered in field sampling (e.g., sampling frame errors, inaccessibility) and allows inclusion of new or replacement sites as necessary (Stevens and Olsen 2004). Spatial point locations obtained from GRTS sample draws are used as plot locations. The sampling employs a 3-year rotating panel design with a third of the total sample allocated to each panel. One panel of plots is surveyed each year.

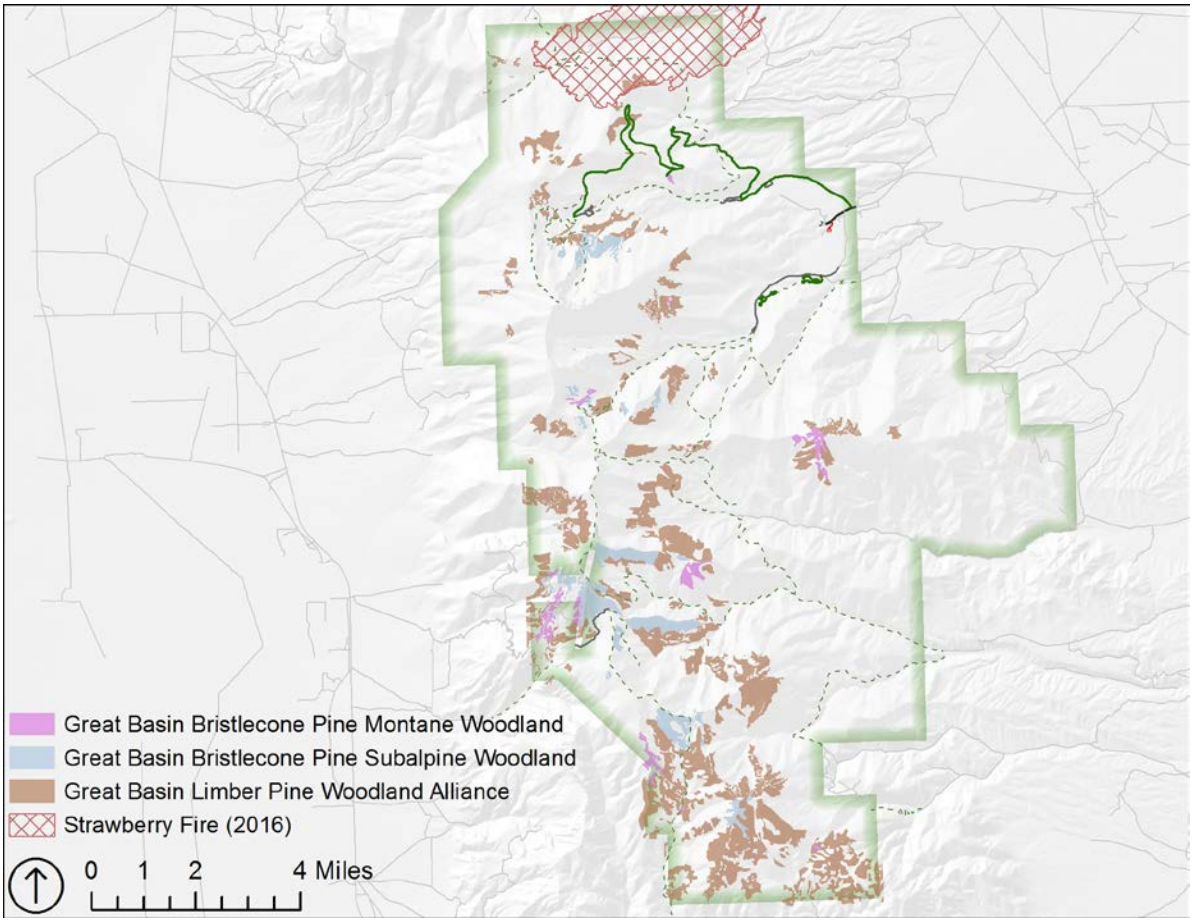



**Figure 2.** Great Basin National Park vegetation alliances that contain the two species of interest and are included in our sample design.

The two species of interest (*P. flexilis* and *P. longaeva*) are present in three vegetation alliances, according to the GRBA vegetation map created in 2012 (Cogan et al. 2012): Great Basin Bristlecone Pine Subalpine Woodland, Great Basin Bristlecone Pine Montane Woodland, and Great Basin Limber Pine Woodland Alliance. Each of these community types are briefly described below, following Cogan et al. (2012). The descriptions are explained in further detail in Cogan et al. (2012) and elucidated in the associated vegetation map.

The Great Basin Bristlecone Pine Subalpine Woodland community type is dominated by subalpine bristlecone pine trees and is common throughout the higher elevation areas of GRBA. These communities contain moderate to sparse stands of tall conifer trees (>15 m) with sparse evergreen and deciduous shrubs and some occasional alpine herbaceous vegetation in the understory. Overall, the vegetation mapping team considers this community in "Good" condition. Localized patches are often in steep exposed sites and likely prone to rock slide and avalanche events. Common species in this community are listed in Table 3.

Great Basin Bristlecone Pine Montane Woodland communities are located in the montane region and comprised of bristlecone pine trees; this community type is rare throughout the entire GRBA area. In

the vegetation map, polygons of this community type contain moderate to sparse stands of tall conifer trees (>15 m) with sparse evergreen and deciduous shrubs and some occasional herbaceous vegetation in the understory. This community's general health is considered "Good – Fair" by the vegetation mapping team. Montane bristlecone pine trees are rare at GRBA, and the cause of their rarity is unknown. Stands of this type contain different understory species, and the trees are not as old as the higher elevation Great Basin Bristlecone Pine Subalpine Woodland described above. Common species in this community are listed in Table 3.

Great Basin Limber Pine Woodland Alliance is a common plant community throughout the upper montane and subalpine areas of GRBA. In the vegetation map, polygons of this community contain moderate to dense stands of tall conifer trees (>15 m) with sparse evergreen and deciduous shrubs and some occasional herbaceous vegetation in the understory. The vegetation mapping team considers this community in "Good" health. The limber pine trees in GRBA are widespread and appear disease-free at this time. Common species in this community are listed in Table 3.

For safety and efficiency reasons, slopes steeper than 30° were excluded from the sampling frame using GIS. GIS data layers that included roads, trails, lakes and a digital elevation model (DEM) were obtained from MOJN. These layers were used to create a travel time cost surface model (TTCSM; Frakes et al. 2015) for GRBA using nine predetermined starting locations which consisted of campgrounds, field offices, and trailheads. Stands further than two hours from these sites were excluded from the sample frame. Stands smaller than 5,000 $m^2$ were also excluded. This sample frame was then stratified into three classes: Great Basin Bristlecone Pine Subalpine Woodland, Great Basin Bristlecone Pine Montane Woodland, and Great Basin Limber Pine Woodland Alliance. A set of GRTS points was drawn using the previously described strata. For our pilot analysis, we looked at the first ten plots within each stratum for thirty potential plots. Plot locations were initially evaluated using GIS and aerial imagery in an attempt to visually eliminate plots without trees and plots located in steep or inaccessible locations. We excluded woodlands beyond an estimated 2-hour travel time to manage travel costs, reduce safety concerns, and enable desired sample sizes to be achieved within each season.

The final sample frame is restricted to the three vegetation classes and confined by the TTCSM (Table 4, Figure 3). Approximately 37.6% (982.2 ha) of the limber pine woodland target population occurs within this frame, representing a substantial and representative proportion of *P. flexilis* woodlands in the park. Bristlecone pine associations are also well represented in the sample frame; it captures 27.8% (35.6 ha) of the bristlecone pine montane woodland alliance and 55.5% (266.5 ha) of the bristlecone pine subalpine alliance (Table 4). The sampling frame captures a substantial portion of the biophysical gradient; elevations in the frame range from 2,565-3,437 m (for reference, the highest point in GRBA is 3,982 m at Wheeler Peak and lowest point is 1,615 m). Elevation can be used as a proxy for temperature and precipitation (Körner 2007), and the elevational gradient captured by the sample will enable hypotheses about the effects of climate on limber pine demography and WPBR infection dynamics to be addressed. Particularly in GRBA, aspect is a relevant factor and will be considered in analyses.

**Table 4.** Sample frame areas for each of the three vegetation classes. “Percent Included” is the percent of the total area of each alliance that is included in the sample frame. Note that more than 40% of each alliance had to be excluded due to the results of the TTCSM.

| Vegetation Alliance Name | Total Area ($m^2$) | Total Area (ha) | Sample Frame Area ($m^2$) | Sample Frame Area (ha) | Percent Included | Total Area | | Sample Frame | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Lowest Elevation (m) | Highest Elevation (m) | Lowest Elevation (m) | Highest Elevation (m) |
| Great Basin Bristlecone Pine Montane Woodland | 3,555,926 | 35.6 | 1,278,750 | 127.9 | 27.8 | 2,784 | 3,406 | 2,814 | 3,283 |
| Great Basin Bristlecone Pine Subalpine Woodland | 4,801,500 | 480.2 | 2,664,630 | 266.5 | 55.5 | 2,773 | 3,550 | 2,926 | 3,437 |
| Great Basin Limber Pine Woodland Alliance | 26,092,000 | 2,609.2 | 9,821,640 | 982.2 | 37.6 | 2,367 | 3,477 | 2,565 | 3,431 |

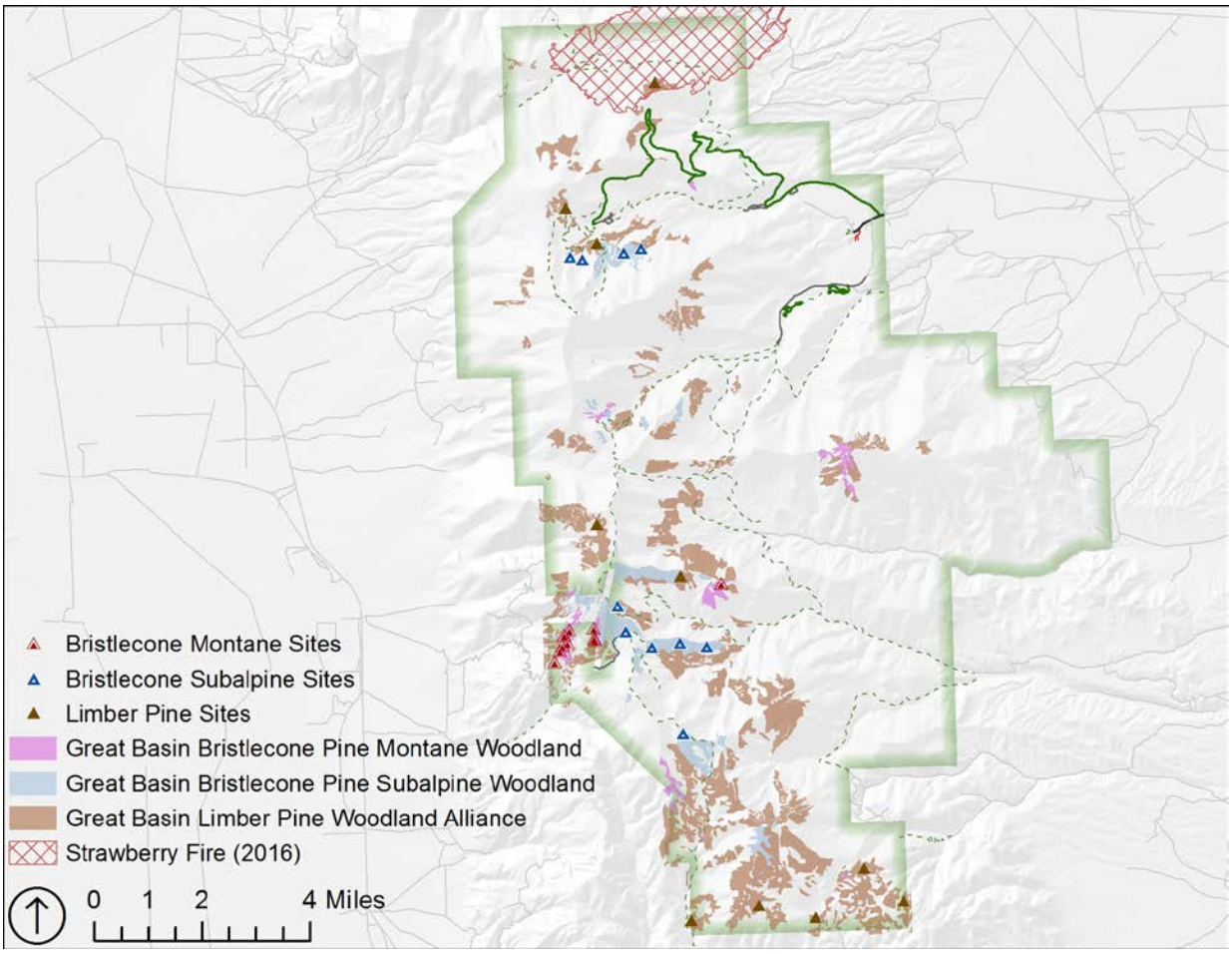



**Figure 3.** The top ten sample locations for each strata are shown here throughout GRBA. If plots must be rejected (e.g., due to inaccessibility, etc.), additional plots will be added from the oversample.

## Revisit Design

Plots will be revisited once every 3 years, starting in 2018 (Table 5). Each year, one panel will be visited, and each panel includes 10 plots (Figure 3; refer to Appendix A of the SOPs [Hupp et al. 2018] for the list of sample locations). The panel is comprised of plots from within each of the three sample strata (i.e., panels include three plots in Stratum 1, three plots in Stratum 2, and four plots in Stratum 3). Once all the plots in each panel have been established, the panels will be revisited in order.

**Table 5.** Revisit design for monitoring white pine species in the Mojave Desert Network.

| Panel | Year | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **2018** | **2019** | **2020** | **2021** | **2022** | **2023** | **2024** | **2025** | **2026** | **2027** | **2028** | **2029** | **2030** |
| 1 ($n_1$ = 10) | X | – | – | X | – | – | X | – | – | X | – | – | X |
| 2 ($n_2$ = 10) | – | X | – | – | X | – | – | X | – | – | X | – | – |
| 3 ($n_3$ = 10) | – | – | X | – | – | X | – | – | X | – | – | X | – |

## Sample Size Calculations

In this PIP, we applied the sample size requirements that KLMN and UCBN estimated from their 2009 pilot data (included in McKinney et al. 2013). Using these data, those networks determined the approximate number of macroplots needed to yield a given margin of error for a 90% confidence interval for status estimates of total live basal area ($m^2$/ha), proportion of infected trees with WPBR, and number of seedlings/ha. To determine the appropriate sample size, McKinney et al. (2013) used formulas for simple random sampling (SRS) which are statistically conservative. In other words, SRS estimates tend to overestimate the number of samples needed to achieve certain confidence level. The SRS formulas are useful for estimating status of these variables within the proposed GRTS sampling design (Stevens and Olsen 2003, Theobald et al. 2007). The SRS formula for sample size is based on a given margin of error ($e$ = confidence interval half-width), estimated sample variance ($S^2$), and 1.64 for the 5% z-quantile ($z$) from a standard normal distribution is $n = ( zS / e )^2$. Note that McKinney et al. (2013) used different estimates of standard deviation ($S$) for KLMN and UCBN based on the available pilot data.

McKinney et al (2013) proposed that sample sizes of 10 macroplots per year (panel) for KLMN and 30 macroplots per year for UCBN were sufficient to support precise estimates of annual status. In this PIP, we will sample 10 plots per year (panel; Table 3); this sample size should be revisited in future power analyses. For seedlings/ha, the estimates for KLMN were based on live whitebark pine <1.37 m, whereas for UCBN the estimates were for limber pine seedlings/saplings <1.37 m, scaled to seedlings/ha for both networks. The required sample size for high precision estimates of seedlings is much higher than that for basal area because of the inherently greater spatial variability in seedlings compared to mature trees. However, we note that seedling subsampling procedures followed in the 2009 pilot surveys differ from those developed and described in this current protocol. Preliminary analyses of 2011 surveys results in Craters of the Moon (CRMO) and SIEN indicate that the proposed methodology, which uses larger regeneration plots, will result in lower variability for seedling density than that employed in the pilot effort (Stucki et al. 2012, Stucki and Rodhouse 2012). In 2009 and 2011, UCBN did not find WPBR on limber pine trees (Stucki et al. 2012, Stucki and Rodhouse 2012). KLMN found between 0 and 35% of whitebark pine trees infected with WPBR in macroplots during 2009.

## Response Design

### *Sample Unit*

Macroplots, consisting of five subplots and nine regeneration plots, are used to measure and track forest demographic parameters, disease and insect occurrence, and magnitude of their impact through time. The response design for this protocol closely matches the *Interagency Whitebark Pine Monitoring Protocol for the Greater Yellowstone Ecosystem* (GYWPMWG 2007) but differs in some respects, most notably, macroplot size. The 10 x 50 m plot size from the Yellowstone protocol has been increased by five times to accommodate the often sparse distribution of white pines in some of our parks and to adequately address forest demographic objectives.

Following McKinney et al. (2013), nine square regeneration plots (3 x 3 m) are established within each 50 x 50 m macroplot to measure seedling regeneration (Figure 4). Regeneration plots are located at each corner (4), at each midpoint between corners (4), and in the middle (1) of the macroplot (Figure 4). We consulted multiple sources, including the USFS Forest Inventory and Analysis design (Bechtold and Patterson 2005) and forest ecologists from other agencies and universities to help inform the decision on regeneration plot size and number. The current design was chosen because it provides a reasonable balance among observer accuracy and precision, sampling time constraints, and total area sampled.

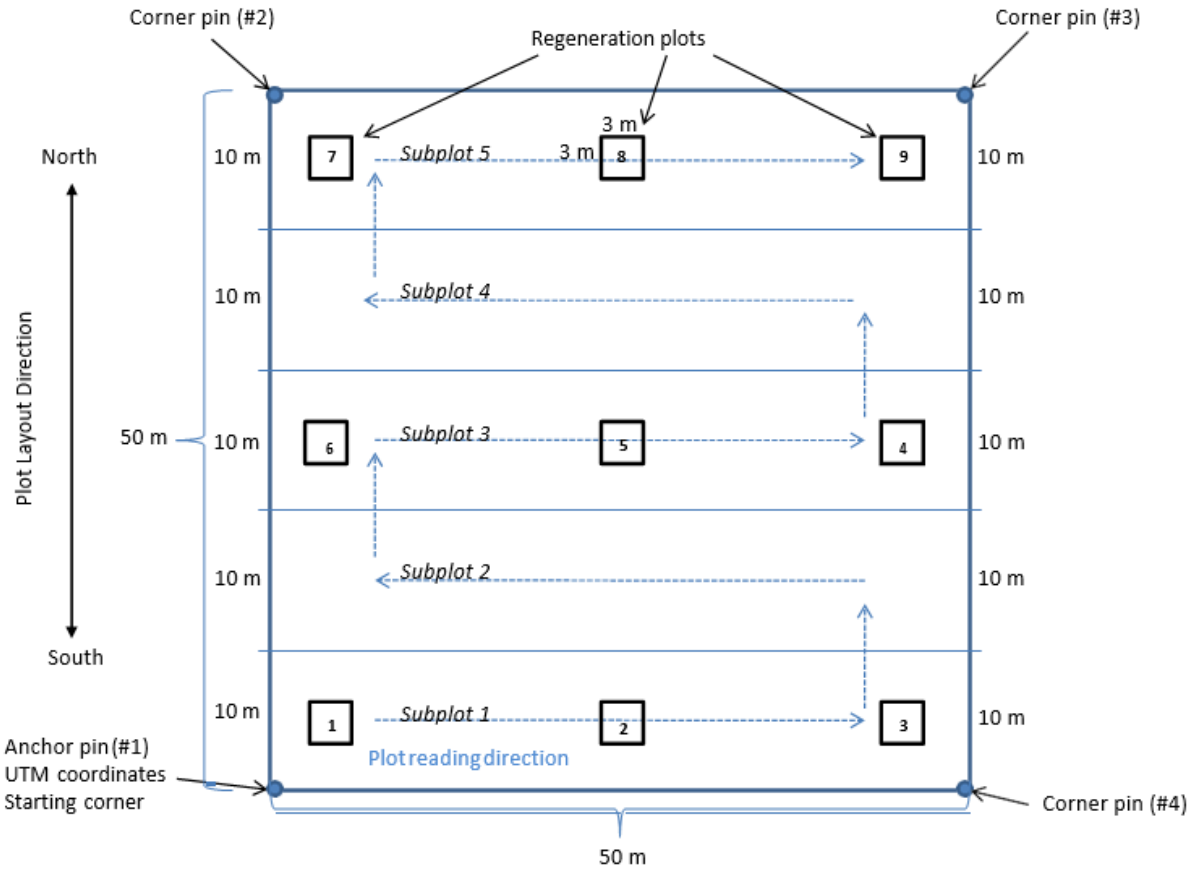



**Figure 4.** Plot layout for GRBA white pine monitoring. This design follows SIEN, UCBN, and KLMN white pine monitoring protocol.

### *Plot Measurements*

The response design for this PIP and its parent document closely match the *Interagency Whitebark Pine Monitoring Protocol for the Greater Yellowstone Ecosystem* (GYWPMWG 2007) but differ in that all tree species (i.e., regardless of genus and species) are evaluated in this protocol whereas the Yellowstone protocol only considers whitebark pine. Table 6 outlines the relationship among the variables, raw data, summarized data, and monitoring objectives. Detailed instructions on response design measurements are provided in SOP 4 and only a general overview is described here.

Each tree in the plot that is at least 1.37 m in height, live or dead, is uniquely tagged. For each tagged tree, the species is identified, diameter at breast height (DBH; 1.37 m) is measured, and height is measured. Dead, non-target species trees with a DBH <5cm or dead trees that may pose a safety risk to the observer while tagging will not be tagged or measured. Dead trees of all species are distinguished between recently dead and dead (recently dead trees have red needles present and dead trees have no needles present). A tree may also be identified as live or dead krummholz if it shows such characteristics (short and stunted growth with many crowded stems, on high-elevation or exposed site).

WPBR infection is assessed for all living white pine trees. The bole of white pine trees are each vertically divided into thirds (upper, middle, and bottom). Each third is assigned one of three WPBR condition classes: 1) absent (no sign of WPBR infection), 2) aeciospores present, or 3) no active cankers, but the presence of three of the following six indicators of infection: rodent chewing, flagging, swelling, roughened bark, old aecia, and oozing sap. The level of crown kill in live white pine trees is determined by dividing the tree's crown (all the main branches that begin as bifurcations off the bole, encompassing all foliage and supporting twigs and side branches) into thirds and visually estimating the percentage of each third that is dead.

Mountain pine beetle occurrence is recorded for all pine trees using three indicators of beetle activity: pitch tubes, frass, and J-shaped galleries. The galleries are monitored by inspecting bark that is sloughed by the trees when possible to avoid damaging the tree by removing bark.

Dwarf mistletoe infection presence or absence is recorded for all living trees. Cone production is recorded, noting presence or absence of female cones on each white pine tree.

Each live seedling found within regeneration plots has a uniquely numbered metal tag attached to it, and seedlings are tallied by species and height class for each of the nine regeneration plots. Height classes are 1) 20 to <50 cm; 2) 50 to <100 cm; and 3) 100 to <137 cm. Seedlings <20 cm in height were excluded because of the extremely high annual mortality rate of newly established seedlings as well as the sensitivity of expected seedling density to the date when sampling occurs. In addition, inter-annual variation in newly established seedling density can be extremely high and would therefore require extensive sampling to accurately estimate population trends for this size class.

**Table 6**. Relationship among measured variables, data, and objectives for long-term monitoring of white pine communities in GRBA. This design follows SIEN, UCBN, and KLMN white pine monitoring protocol. (p/a) indicates presence/absence.

| Variable | Raw Data | Summarized Data | Objectives Addressed |
|---|---|---|---|
| Species | Tree (nominal) | Trees per hectare (TPH); all spp., each spp., proportion of total by spp. | 1. composition & structure |
| Diameter | Tree (cm) | Basal area ($m^2$/ha); all spp., each spp., proportion of total by spp.<br>Mean diameter (cm) by spp. Diameter classes (5 cm); proportion and TPH by spp. | 1. composition & structure<br>2. growth rate |
| Height | Tree (m) | Mean ht. (m); all spp. and by each spp.<br>Height classes (3 m); proportion and TPH by spp. | 1. composition & structure<br>2. growth rate |
| Status | Tree (live or dead) | Proportion live and dead; all sp. and by each sp. TPH and proportion by 5 cm diameter classes in each condition; all sp. and by each sp. | 2. birth and death rates |
| Crown kill | Each of three parts of a tree (%) | Mean (%); individual white pine trees infected with WPBR. | 3. level of crown kill |
| Aecia observed | Each of three parts of a tree (p/a) | Proportion and TPH with active cankers by each white pine sp. | 3. WPBR infection incidence |
| Indicators of WPBR | Each of three parts of a tree (p/a) | Proportion and TPH with inactive cankers by each white pine sp. | 3. WPBR infection incidence |
| WPBR infection | Tree (p/a of active or inactive canker) | Proportion and TPH infected and healthy by each white pine sp.<br>TPH by 5 cm diameter classes in each condition by each white pine sp. | 3. WPBR infection incidence |
| Bark beetle | Tree (p/a) | Proportion and TPH with beetle sign; all sp. and each sp. | 4. incidence of mountain pine beetle |
| Dwarf mistletoe | Tree (p/a) | Proportion and TPH with mistletoe sign; all sp. and each sp. | 5. incidence of dwarf mistletoe |
| Female cones | Tree (p/a) | Proportion and TPH with cones by each white pine sp. | 6. cone production |
| Seedlings | 9 $m^2$ plot; number of each of three size classes by species | Mean (number per $m^2$); all sp. and each spp. for each size class. | 1. composition & structure<br>2. birth rates |

# Field Methods

## Field Season Preparations

The protocol, including all SOPs, is reviewed by the Protocol Lead to ensure that any changes to sampling procedures have been updated prior to start of the field season. Specific park applications for research permits are required for monitoring in GRBA and are available at the Research Permit and Reporting website (https://irma.nps.gov/rprs/). Wilderness compliance, minimum tool analyses, safety documents (including field itinerary and readiness review), and park housing (camping) or access key requests are completed and submitted to the proper divisions well in advance of the field season. Global Positioning System (GPS) devices are loaded with locations of all plots to be visited in the coming field season. Electronic field data collection devices (usually tablets), if available, will be loaded with a portable version of the database. Hardcopy paper field data sheets will be printed on regular paper and on Rite-in-the-Rain waterproof paper and used either as a backup in the event of tablet failure or as the primary data collection method if tablets are not available. Equipment is checked against the equipment list (SOP 1) and repairs or purchases are made as needed to complete the list. Biological technicians are hired either as park service employees or through cooperating organizations. In either case, the hiring process is initiated well in advance of the field season (i.e., by January).

## Training, Calibration, and Consistency

Proper training is paramount to the success of the project, and therefore, field crews receive thorough training each year with a combination of indoor and outdoor instruction. Training will be conducted by the Protocol Lead and the MOJN Data Management Team, or other appropriate staff members. All crew members will review the protocol narrative and SOPs independently, then the training staff will give detailed instruction on how to use sampling and navigation equipment, methodologies for data collection, tree species identification, and identifying symptoms of WPBR infection, beetle attacks, and dwarf mistletoe infection. An assessment of crew competencies will be made toward the end of training to identify and correct errors in technique, approach, or understanding. The assessment tests both understanding of material and field methodology. Values for variables that are estimated rather than directly measured (e.g., crown kill) are compared among crew members and any broad deviations discussed and corrected. Training will be completed within one week (five days) at the start of each season and is described in SOP 2.

## Locating and Establishing Plots

Driving directions to Park study areas are discussed in SOP 3. Once on site, access to sampling areas will require hiking across rugged terrain and backcountry camping; field crews must be prepared for challenging weather conditions such as extreme heat, cold, rain, and snow. Each crew member should maintain a supply of warm clothes, rain gear, sun protection, sturdy boots, and plenty of water. Safety procedures are provided in detail in the *Mojave Desert Network Inventory & Monitoring Field Safety Plan* (Tallent et al. 2017). Field crews are required to maintain close communication with office-based Park points-of-contact, such as Park resource managers, regarding field schedules and check-in/check-out times. Park hazards, including emerging threats such as extreme weather or fire hazards, should be discussed with Park staff during a briefing prior to

initiation of fieldwork and as necessary throughout the duration of sampling. Field crews will carry a first aid kit, and each MOJN vehicle is equipped with a larger first aid kit and other safety equipment.

Plots are located using GPS, following procedures outlined in MOJN general SOP *Using GPS Devices* (Lehman 2017). Plots to be visited in the coming season are organized into groups by geographic proximity. These groups are further divided into specific trips, or hitches, during which field crews visit and sample a set of plots. Plot locations and trip routes are printed on hard copy maps and entered into GPS units. The crew and the appropriate staff members review trip routes and discuss potential dangers (e.g., river crossings, impassable terrain), contingency plans, and, in the case of plot revisits, notes and experiences from previous trips. This is a good time to check that each crew member's compass is adjusted to the correct declination.

Crew members navigate to plot locations using map, compass, and GPS. As the plot location is approached, the GPS is used to hone in on the exact location by following the direction indicated on the unit until the coordinates have been reached. At this point, the observer immediately stops and temporarily marks that location with a metal pin flag or surveyor's pin. If this is the first time the plot is visited (i.e., plot establishment), procedures for monumenting the plot are followed (see SOP 3). There must be at least one live white pine tree of the target species ≥137 cm tall within the plot boundaries or steps must be taken to relocate the plot. The plot location will be rejected if relocation is unsuccessful (see Plot Offsetting and Replacement in SOP 3). If this is a revisit, the plot monument marker (e.g., metal rebar or metal tag) is found by searching the area around the pin flag. If this fails, a metal detector can be used to find the marker. Notes from previous visits and plot photographs should be consulted.

The plot boundaries follow cardinal directions, making plot setup uniform between sites. Each plot corner is marked with metal rebar sticking 5 cm above the ground. Once the plot corners and center are established, regeneration plots for sampling seedlings (i.e., individuals <1.37 m height) are laid out. Regeneration plots are 3 x 3 m, with nine regeneration plots per macroplot. SOP 3 details the procedure for laying out the plot and establishing regeneration plots.

All trees ≥1.37 m height in plots are marked with small steel tags with unique numeric identifiers (except dead non-target species trees <5 cm diameter). Tags are attached at 1.37 m height on the north side of the tree to aid in relocation. Trees may be tagged on a different side (e.g., east side) to limit visibility when plot is in close proximity to roads or trails. Metal wiring is used to secure tags to trees <5 cm DBH, and nails are used to attach tags to trees ≥5 cm DBH with the nail head pointing slightly downward so that moisture runs away from the bole. Nails are inserted into the tree only as far as needed to secure the tag, and at least 2 cm should be left to allow for the growth of the tree. SOP 3 provides detailed instruction on how to tag and number trees including what to do when tree clusters (groups of tree stems) are encountered. Once plot and subplot boundaries are established (or located for revisits) and all trees ≥1.37 m in height are tagged, the plot can be sampled.

### Measuring Response Variables

A series of digital photographs are taken at the beginning of each plot visit (see SOP 3 for detailed instruction on taking and recording photos). Macroplots are sampled by locating the origin and

moving east across the subplot until the other side of the macroplot is reached (Figure 4). Once the far side is reached, crew members turn 90°, move into the adjacent 10 x 50 m subplot, and begin reading the plot in the opposite direction (west). SOP 3 provides detailed instructions on how to work from the starting point to the ending point through the macroplot. Trees are numbered consecutively in the order of sampling (see SOPs 3 and 4 for instructions and diagrams). When plots are revisited, field data sheets from the previous visit indicate which 10 x 50 m subplot a tree is located in to serve as a check during sampling.

Tree- and plot-level data are collected for each plot. Once a tree is encountered on a revisit, its tag number is checked and recorded and the appropriate suite of measurements and assessments are made. Tags are attached to all new trees ≥1.37 m height found without tags. Tag number and measurements for the same complement of variables are recorded. These individuals may represent seedlings recruiting into the next size class or could be trees missed during plot establishment. Any pertinent information about new trees is recorded in field notes. If a previously tagged tree cannot be found, the ground is searched for the tag or for a downed tree still holding the tag. Detailed notes are taken describing what was done to locate the tag and whether the tag was found (Tree Level Data section of SOP 4).

### Data Entry and Management

This protocol includes an option for collecting data on paper field data sheets or electronically using tablets. Field data sheets are located in Appendix B of the SOPs (Hupp et al. 2018). If electronic data collection devices are used, the data must be backed up daily using a portable USB flash drive (thumb drive). Field crews should also carry paper field data sheets as a backup, so that data collection can continue in the unlikely event of tablet malfunction.

Site information sheets are made for each plot and are given to crews prior to leaving for a hitch. These include information on plots (e.g., azimuths for plot boundaries from the plot center) and notes on important information from previous sampling events (e.g., tree tags that were not found). Information included in site information sheets is archived in the white pine project database.

Field data sheets and/or electronically recorded data are inspected by crew members and any discrepancies resolved while still at the plot. This is a key step in the quality assurance and quality control process (QA/QC). When crews return from the field after a hitch, the Protocol Lead reviews the data and discusses with the crew to ensure further QA/QC. Data from paper field data sheets are entered into the white pine project database, a Microsoft Access application used by MOJN and the Networks implementing the McKinney et al (2012) protocol, SEIN, KLMN, and UCBN. Validation rules programmed into the database help detect logical inconsistencies.

### After the Field Season

Equipment is compared against the equipment checklist to make sure it is all accounted for. Equipment is inspected for damage and a decision is made whether to repair or replace damaged equipment. Repairs and replacements should be made as soon as possible and the equipment list updated with this information. Batteries are taken out of all electronic devices prior to storage.

Diameter tapes are cleaned with rubbing alcohol or another solvent, and other equipment is cleaned of dirt and grime. A final check of the equipment against the equipment list is made, and the list annotated as necessary. All sampling gear is stored in the MOJN Ready-Room in Boulder City, Nevada.

# Data Management

Effective data management is critical to ensuring the quality, interpretability, security, longevity and discoverability of the data produced by our monitoring efforts. The principles of sound data management as they apply to I&M networks are defined in the national data management plan (NPS 2008). This narrative will describe in general terms how these principles will be applied to the white pine monitoring effort at MOJN. A detailed set of procedures for all data management tasks can be found in SOP 5.

## Database Design

The MOJN white pine data will be stored in a MOJN-hosted copy of the Microsoft Access database that is used by UCBN, SIEN, and KLMN to store their white pine data. The database structure consists of a user interface or "front-end" (forms for data entry, review, and export) that is linked to a "back-end" database file (core data tables). Network-specific components of the database such as equipment lookup tables will be populated with information relevant to MOJN. SOP 5 provides additional details about the database, including a model of table relationships and a data dictionary. The database will track the QA/QC processes (data processing level) that have been applied to each site visit activity and will store a "line of sight" to the full package of protocol materials that were in place at the time that the data were collected.

Any time a revision of the protocol requires a revision to the database, a complete copy of the database will be made and stored in a read-only archive directory.

## Data Entry, Verification, and Validation

### *Data Entry*

The primary goal of data entry is to transfer the data from paper field data sheets into the database with 100% accuracy. Ideally, this should be undertaken during the field season in order to provide the best opportunity to correct data omissions or ambiguities. When this is not practical, it should occur as soon after the field season as possible. Data entry should be completed by someone who participated in data collection or is familiar with the project and data. Database backups will occur regularly to maximize the ability to recover from any irreversible errors or problems that occur during the data entry session.

### *Data Verification*

The white pine database application will incorporate QA/QC strategies to ensure data quality. The database design and the allowable value ranges assigned to individual fields within the data tables help to minimize the potential for data entry errors and/or the transcription of erroneously recorded data.

SOP 5 describes the steps that the Protocol Lead and data management staff will take to ensure that the data for a given season are verified (i.e., database values are compared against hard-copy datasheets). The goal is to check 100% of records and correct and track any errors discovered. Errors and inconsistencies that cannot be corrected will be documented and included in the metadata and

certification report. The completion of data verification and other QA processes will be tracked in the database.

The Protocol Lead or Data Manager will verify the geospatial component of the white pine database each field season.

When data verification is complete, the dataset has reached the "provisional" data processing level. The data processing levels referred to in this document are more fully described in *Certification Guidelines for Inventory and Monitoring Data Products* (National Park Service 2016).

#### *Data Validation*

The Protocol Lead and data management staff collaboratively validate a given season's dataset (i.e., ensure that the data make sense). Some validation procedures that check for outliers, missing values, and illogical values have been incorporated into the database. Other, more specific, validation routines are developed in collaboration with the Protocol Lead and will be incorporated into the database as appropriate. Data management staff will work closely with the Protocol Lead to provide any needed database queries, reports, graphs, or export file formats to assist with the overall validation.

### Data Certification and Documentation

Once the data are validated, the Data Manager and Protocol Lead will complete the necessary accompanying metadata. Metadata are structured information about the content, quality, condition, and other characteristics of a given dataset. Additionally, metadata provide the means to catalog and search among datasets, thus making them available to a broad range of potential users. Any records that did not meet the documented quality standards in the validation process must be clearly identified in the metadata.

When this process is complete, the dataset has reached the "accepted" data processing level and is suitable for reporting and distribution.

### Data Distribution

Prior to publication of any reports or data, MOJN staff will work with a staff member from GRBA to complete a data sensitivity assessment form. The results of this assessment will dictate the appropriate audience for the data: Park only, NPS only, or Public. Redacted datasets and reports may be created when it is deemed that sensitive information should be obscured for one or more of these audiences. The sensitivity or "protected status" of species and location data will be tracked in the database following the guidance in the IMD document *Minimum Standards for Network Projects* (Frakes and Kingston 2017).

As part of the reporting cycle, summary reports and derived data products will be made available on the Integrated Resource Management Application (IRMA) Data Store (http://irma.nps.gov/DataStore/). Additionally, pertinent species data will be uploaded to the National Invasive Species Information Management System (NISIMS) and NPSpecies.

### Data Maintenance and Archiving

Secure data archiving is essential for protecting data files from loss or corruption. Once the master project dataset and metadata are considered certified for a field season, the Data Manager will place a copy of the dataset and the metadata record into the appropriate folder within the archive directory on the MOJN M drive (a shared network server), which is backed up to a remote location. These archived files will be stored in read-only format. Any subsequent changes made to this database must be documented in an edit log and in the metadata. In addition to the database copy in its native format, all tables will be archived in a comma-delimited ASCII format that is platform-independent. A full copy of the project master dataset will be uploaded to the IRMA Data Store on an annual basis.

Additional digital files to be archived include all digital photos associated with that field season and any digital files associated with data analysis products and project reporting. Hard-copy materials (e.g., datasheets, field notebooks) are currently stored in the network office but will eventually be moved to an NPS-approved repository for permanent storage.

# Data Summary, Analysis, and Reporting

## Data Analysis

Data collection for this PIP includes one Network, MOJN, and one Park, GRBA. Yet, since this protocol is a direct extension of other white pine monitoring in the West (McKinney et al. 2013), this Data Analysis section includes instructions for how to utilize data collected in other networks and parks. This section includes modeling techniques to conduct trend analyses across parks and across networks (e.g., the linear equations have variables to include networks and parks in the models). In other words, the statistical models below can be used for park-level analysis but also include the flexibility to conduct regional-scale assessments of white pine conditions.

### *Data Analysis for Status Estimation and Protocol Review*

SOP 6 describes the procedures for data summary, analysis, and reporting. Each sampling year, the Protocol Lead will create an annual report which will summarize each year of data collection. Data are summarized by species and park. Exploratory data analyses are included in annual reports, including graphical analyses of plots and maps. These procedures are important in avoiding violations of underlying assumptions of statistical techniques, in reducing type I and II errors, and therefore, in minimizing the risk of formulating incorrect ecological conclusions. Exploratory data analyses will also aid in the refinement of existing hypotheses and can help generate new hypotheses about pattern and process.

The R package used for generating the GRTS sample points, *spsurvey* (Kincaid et al. 2011; R version 2.11.0, 2010; R Development Core Team, Vienna, Austria), is useful for analyzing data as well as sampling design. For status estimation, the neighborhood variance estimator (Stevens and Olsen 2003) is used for confidence interval computation and hypothesis testing. Note that the current version of *spsurvey* does not support use of ratio estimators (newer tools for conducting GRTS draws, such as the NPS package, SDrawNPS, provide additional functionality but were not used in this protocol). Further, *spsurvey* provides tools for the analysis of data collected from a GRTS sampling design using the function `total.est`. Estimates of means, totals, and proportions may be obtained with this function.

### *Trend Estimation and Hypothesis Testing*

Analyses of trends are conducted after completion of three full panel rotations (9 years). Trend estimation, and the testing of other outcomes of interest, such as counts and proportions, will incorporate the appropriate models. These models may include Poisson models for counts, net odds models for relative proportions, and logistic regression models for monitoring the incidence of disease.

Trend for real-valued outcomes is estimated using a linear mixed model developed by VanLeeuwen et al. (1999) and Piepho and Ogutu (2002) for correlated data. Data transformations will be examined if untransformed outcomes do not meet model assumptions. Significance testing of the linear trend coefficient employs the null hypothesis of no trend in a given variable ($H_0$: $\beta_1 = 0$) at the park level (i.e. GRBA) against its two-sided alternative with $\alpha = 0.10$, and $\beta = 0.2$ (i.e., Power = 0.8). The mixed model allows for consideration of both fixed and random effects where fixed effects

contribute to the mean of the outcome and random effects contribute to the variance. Given replication at the appropriate levels, random effects modeling allows estimation of components of year-to-year variation (as well as site-to-site variation, variation in trends across sites, and site-by-year variation if using the GRBA data alongside other parks or networks included in McKinney et al 2013). This way, the power to detect trends may be accurately calculated, and survey resources may be allocated to optimize power to detect trend.

The linear mixed model provides a flexible approach for trend analysis by combining terms for fixed linear trend with random effects to account for year-to-year variation, site-to-site variation, and variation among site-level trends (VanLeeuwen et al. 1996, Piepho and Ogutu 2002). This model-based approach does not incorporate aspects of the survey design. Given that an equal- probability sample is used, the spatial balance is not expected to adversely affect estimates of trend.

For inference at the park-level, the following mixed model for the white pine protocol was derived from the approach proposed by Piepho and Ogutu (2002). (See SOP 6 for a definition of terms):

$$y_{ijk} = \mu + w_j \beta_i + a_{k(i)} + b_{j(ik)} + \gamma_i + w_j t_{k(i)} + e_{j(ik)} \qquad (1)$$

If the GRBA data are used alongside other parks or networks included in McKinney et al 2013, for regional inference, a single overall fixed slope is estimated across all parks using the following model:

$$y_{ijk} = \mu + w_j \beta + a_{k(i)} + b_{j(ik)} + \gamma_i + w_j t_{k(i)} + e_{j(ik)}. \qquad (2)$$

If there is appropriate replication in parks over time, analyze the site-level means of response variables (e.g. DBH) outcomes with the linear mixed model given above in R using the *lme4* R package. Data analysis will require a data set formatted with columns for Year, WYear ($w_j$), Site, Park, Species, and the site-level means, Y. Note that the Site variable must be unique across all parks and that Site, Year, and Park must be defined as factors.

Estimate trend within a Park:

```
trendfit.ByPark<-lmer(Y ~ WYear * Park + (-1+Park +
Park:WYear|Site) + (-1+ Park|Year), data= DBHmean)
summary(trendfit.ByPark)
```

Estimate trend across parks (MOJN parks and others in other Networks where McKinney et al 2013 is applied):

```
trendfit.Regional <-lmer(Y ~ WYear + Park + (-1+Park +
Park:WYear|Site) + (-1+ Park|Year), data= DBHmean)
summary(trendfit.Regional)
```

The first model provides R code to estimate trends in time within each park as well as to measure components of variation such as site-to-site variation, year-to-year variation, and variation among site-level trends. Output from the second model will provide an estimate of the regional trend across all parks.

### *Reporting*

MOJN will produce an Annual Report as desired by the Park and a Comprehensive Report after each full panel rotation. The Annual Reports will contain basic summary information such as:

- Summary history of the samples taken during each year of the study, tabulating numbers of samples for each sampling frame and showing these locations on maps of GRBA.
- Summary status statistics of the results relative to management goals.
- Summary table for use in park reporting and resource stewardship strategies.
- Evaluate data quality and identify any data quality concerns and/or deviations from the protocol that affect data quality and interpretation.
- Evaluate and identify suggested changes to the protocol.

The 2011 annual reports developed for the UCBN and SIEN provide good examples of annual report content (Stucki et al. 2012, Stucki and Rodhouse 2012). A 1–2 page resource brief may also be prepared from the annual report that will be provided to superintendents, park interpretive staff, and resource managers. MOJN will create a Comprehensive Report once all plots have been installed to summarize the full panel data.

Comprehensive Reports will include a summary of the data over the full panel and a trend analysis using the methods described above when adequate data are available (i.e., after three full panel rotations [9 years]). Comprehensive Reports will provide greater analytical and interpretive detail than the Annual Reports and will evaluate the relevance of findings to long-term management and restoration goals. The report will evaluate operational aspects of the monitoring program, such as whether sample frame boundaries need to be changed or whether the sampling period remains appropriate (the optimal sampling season could conceivably change over time in response to climate change). The report will also evaluate the monitoring protocol. For instance, does allocation of samples among vegetation alliances appear to be adequate or are there new management concerns that might dictate some reallocation of effort or additions to the indicator metrics that are monitored annually. If feasible, all four associated networks, may collaborate to create a regional synthesis report.

Current versions of the protocol, resource briefs, Annual Reports, Comprehensive Reports, and regional synthesis reports will be made available on individual network websites. The protocol will also be available from the national NRPM website (https://www.nps.gov/im/publication-series.htm).

## Protocol Testing and Revision

A draft version of this protocol was tested in 2017 and 2018 in GRBA. These field experiences and the analysis of data collected were useful in forming recommendations for training, database design,

measurement calibration, sample sizes, power analyses, and trend analyses that are specific to GRBA. Subsequent protocol testing will occur during each field season, and evaluation of existing protocols and recommended revisions will be documented in Annual Reports and during season close-out. Revisions to this protocol and the SOPs are expected. We anticipate possible revisions to the detailed instructions to field crews, the number of plots sampled each field season, and the frequency of sampling. Population boundaries should be revised only if management priorities shift significantly and should be done only in consultation with park management and careful consideration of statistical consequences. A protocol revision history log will be updated for each portion of the protocol, including the narrative and SOPs. SOP 5 describes procedures for protocol revision.

# Personnel Requirements and Training

## Personnel Requirements

MOJN will have a Field Crew of 3-4 biological technicians during initial plot establishment and then scale back to a Field Crew of two biological technicians and/or the MOJN Ecologist during plot revisits. Technicians collecting data for this protocol will have substantial college-level training in biology or related subjects. A botany, forestry, or closely related degree is desired but not necessary. Technicians will be carefully trained in the sampling techniques and in the identification of tree species and the incidence of WPBR, mountain pine beetle, and dwarf mistletoe as described in SOP 2. This protocol requires a capable Protocol Lead who will train the technicians, oversee their work, and verify, summarize, analyze, and interpret data each year. The Protocol Lead may also double as one of the two Field Crew members. The Network Ecologist and/or Program Manager may serve as the Protocol Lead in the absence of the MOJN Ecologist.

The Field Crew is able to effectively sample approximately one plot per day (once plots have been established), with 10 plots per sampling year. Thus, MOJN will require approximately two to three weeks of post-training sampling time to complete each season's fieldwork. This number will yield an accurate statistical sample of the sample frame and provide ample time to accommodate travel, foul weather delays, and unanticipated contingencies.

## Roles and Responsibilities

Table 7 provides a general outline for the roles and responsibilities of personnel involved in this monitoring protocol.

**Table 7.** Roles and responsibilities for implementing the white pine monitoring program in MOJN.

| Role | Responsibilities | Name/Position |
|---|---|---|
| Protocol Lead | • Project oversight and administration.<br>• Track project objectives, budget, requirements, and progress toward meeting objectives.<br>• Facilitate communications between NPS and cooperator(s).<br>• Coordinate and ratify changes to protocol.<br>• Acquire and maintain field equipment.<br>• Assist in training field teams.<br>• Perform data summaries and analyses.<br>• Maintain and archive project records.<br>• Oversee project operations and implementation.<br>• Certify each season's data for quality and completeness.<br>• Complete reports, metadata, and other products according to schedule. | MOJN Ecologist |

**Table 7 (continued).** Roles and responsibilities for implementing the white pine monitoring program in MOJN.

| Role | Responsibilities | Name/Position |
|---|---|---|
| Field Leader | • Direct training and safety of field teams.<br>• Plan and execute field visits.<br>• Oversee data collection and entry; verify accurate data transcription into database.<br>• Complete a field season report. | MOJN Biological Technician or other staff |
| Technicians (2–4) | • Collect, record, enter and verify data. | MOJN Biological Technician or seasonal employees or interns (e.g., SCA) |
| Data Management Team | • Consultant on data management activities.<br>• Facilitate check-in, review and posting of data, metadata, reports, and other products to national databases and clearinghouses according to schedule.<br>• Maintain and update database application.<br>• Provide database training as needed.<br>• Consultant on GPS use and data collection tools.<br>• Work with Protocol Lead to analyze spatial data and develop metadata for spatial data products.<br>• Primary steward of Access database and GIS data and products. | Data Manager and Assistant Data Manager |
| Program Manager | • Protocol Lead oversight<br>• Administration and budget<br>• Consultant on all phases of protocol review and implementation<br>• Review of annual and comprehensive reports | Network Program Manager |
| Park Resource Managers | • Consultant on all phases of protocol implementation.<br>• Facilitate logistics planning and coordination.<br>• Communicate management and restoration plans and associated information to Protocol Lead.<br>• Review reports, data and other project deliverables. | Park Resource Managers |

## Qualifications, Training, and Calibration

The technicians must become adept at all aspects of the sampling procedures and must be able and willing to travel and work independently at the parks where the white pine protocol will be implemented. The technicians must know or be able to learn quickly the principal tree species that will be encountered. Field work in white pine habitat involves traversing rough terrain, working in inclement weather (particularly in GRBA where summer monsoon storms are common), and carrying backpacks for several miles. Technicians also must be conscientious and organized, giving attention to accurate sampling site location, sampling documentation, accurate identification of the source of tree damage, and oversight of data recording for accuracy, thoroughness, and clarity.

The Field Lead must have a thorough understanding of sampling design and data management and analysis. Field Lead must also have knowledge of the woodland flora and ability to identify tree

species and the insects and pathogens that cause damage to white pine species. Protocol Lead will supervise training of the technicians and must be available for consultation and oversight of their work during the sampling season.

The most important protocol specific training elements are the use of sampling and navigation equipment, methods for data collection, tree species identification, and identifying symptoms of WPBR infection, mountain pine beetle occurrence, and dwarf mistletoe infection.

# Operational Requirements

### Annual Workload and Field Schedule

The phenological window for yearly sampling spans the entire snow-free season, roughly five months. The annual workload for field personnel ranges from 8-14 weeks, depending on weather and logistical constraints in GRBA. This period includes 1-2 weeks of training and field preparation, 2-3 weeks of field sampling, and 1-2 weeks of data entry, validation, miscellaneous administrative duties, and close-out. Additional weeks of field season preparation and analysis and reporting will be required from the Protocol Lead and field leaders. Table 8 details the annual workload and schedule.

**Table 8.** Annual schedule of major tasks and events for the white pine monitoring protocol.

| Month | Administration | Field | Data Management/Reporting |
|---|---|---|---|
| January | Network annual report and work plan complete<br>Begin recruiting and hiring seasonal personnel | Begin process for hiring seasonal staff and scheduling field visits, housing, and vehicles | – |
| February | Administer and modify existing agreements, if necessary | – | – |
| March | – | Organize sample sites into hitches, prepare maps and field data sheets | – |
| April | – | Prepare field and GPS equipment and training manuals and conduct associated training with network and park staff as needed | – |
| May | – | Begin training (weather permitting) | – |
| June | – | Potentially start field work at lowest elevation sites | – |
| July | – | Continue field work (if needed based on weather) | – |
| August | – | Continue field work (if needed based on weather) | – |
| September | Close-out of fiscal year | – | Data entry and verification<br>Preliminary analysis of current year's results, Annual resource brief prepared for network meetings |
| October | Prepare & submit budget estimate for fiscal year<br>Draft network annual report and work plan | Complete field work<br>Clean and store equipment | Metadata production, quality review Data certification complete<br>Data archival and posting<br>Field season report complete |

## Facilities and Equipment Needs

For all field work in GRBA, crews will travel from the MOJN office to GRBA for the field week and will return to MOJN at the end of a hitch. Crews will be camping, and campsite reservation should be coordinated with Park staff. One dedicated field vehicle per team, preferably 4-wheel drive, will be required each field season.

## Equipment Lists

### *Measuring Equipment*

- Four 50-m reel tapes
- Wire pin flags for temporary plot boundary markers (approx. 30)
- 2 small tape measures for assessing seedling/sapling height classes
- Surveyor's pins for temporarily anchoring corners
- Compass with inclinometer for estimating slopes
- Laser rangefinder with capacity for measuring tree height
- Diameter tape
- Small hatchet
- Yellow crayon for temporarily marking seedlings during counts
- Plant ID references (e.g. regional floras and photographic tree guides)
- 10x Binoculars for looking into tall trees for WPBR, cone production, etc.

### *Plot marking and Tree Tagging Equipment*

- Short (e.g., 8-10 inches) ½ rebar
- Aluminum rebar caps ½ in dia. (pre-stamped if possible with basic plot information such as "MOJN White Pine Monitoring")
- 1 ¼ in round aluminum or brass tree tags consecutively numbered in sets of 500
- Wood siding sinker head style galvanized aluminum nails, 2 ¼ in length
- Steel wire for securing tags to small trees
- Pliers with wire cutter
- Small mallet suitable for driving rebar and tag nails

### *Navigation and Recording Equipment*

- GPS unit with pre-loaded sampling location waypoints (MOJN supplied, or comparable unit)
- Tablet with field data sheet (if used by this team) + AC/DC converter for charging batteries
- Weatherized field data sheets
- Backup copies of data entry forms
- Mechanical pencils and clip boards
- Field reference maps identifying clusters of proximal sample points, access locations, and other key travel information

### *Communication and Safety*

- Cell phone
- InReach satellite locator device (pre-programmed)

- Park 2-way radios
- Emergency contact information
- Fire extinguisher, shovel, and other park-specific vehicle safety equipment required
- Sunscreen
- Water cube (don't forget to fill)
- First Aid kit

### *Miscellaneous Field Equipment*

- Digital camera
- Spare batteries for GPS, Tablet, camera, laser range finder
- Field-relevant SOPs (SOP 1–5)
- Plastic file box for storage of field data sheets (in vehicle) with folders and extra forms, mechanical pencils, and Rite-in-the-Rain paper
- Wire brush for cleaning tires, boots, and trousers of weed seeds, and for exposing discolored bark on trees infected with WPBR
- Small spray bottle for wetting tree bark to help identify WPBR symptoms
- Solvent for cleaning pitch off of tapes and other equipment
- Daypack and overnight backpack

## Budget

The annual operating budget for this protocol includes permanent staff salaries, seasonal staff salaries, and field operations costs such as seasonal employee housing, field equipment, and travel and vehicle costs. Total annual cost and individual line items are listed in Table 9 and can vary year-to-year due to differences in the allocation of duties among staff, field crew sizes, lengths of sampling season, and field operation requirements.

**Table 9**. The approximate annual budget for Pine monitoring in the MOJN. This budget does not include equipment costs because existing equipment will be used.

| **Personnel Type** | **Position** | **Time Allotted (Cost in Dollars** |
|---|---|---|
| Permanent NPS Personnel | Network Program Manager (GS13) | 1 week report review, hiring, and training (2,360) |
| | Data Manager (GS11) | 1 week database maintenance and preparing field data collection device (1,600) |
| | Ecologist (GS11) | 1 week field season prep (1,600)<br>1 week QA/QC, data archiving and closeout (1,600)<br><br>1 week hiring and training (1,600)<br>1 week sampling (1,600)<br>1 week analyzing data and report writing (1,600) |
| | Crew Lead and Logistics Coordinator (GS07) | 1 week preparing and training (1,120)<br>3 weeks field work (3,360)<br>1 week season closure (1,120) |

**Table 9 (continued)**. The approximate annual budget for Pine monitoring in the MOJN. This budget does not include equipment costs because existing equipment will be used.

| **Personnel Type** | **Position** | **Time Allotted (Cost in Dollars** |
|---|---|---|
| Seasonal Personnel | Field Technician 1 (GS05) | 3 week sampling (2,400)<br>1 week data input and QA/QC (800) |
| | Field Technician 2 (GS05) | 3 week sampling (2,400)<br>1 week data input and QA/QC (800) |
| **Total Cost** | – | $23,960 |

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