National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Monitoring White Pine (*Pinus albicaulis, P. balfouriana, P. flexilis*) Community Dynamics in the Pacific West Region - Klamath, Sierra Nevada, and Upper Columbia Basin Networks

Narrative Version 1.0

Natural Resource Report NPS/PWR/NRR—2012/532

ON THE COVER

From left to right, limber pine (*Pinus flexilis*) along the edge of a lava flow, Craters of the Moon National Monument and Preserve, Idaho (NPS photo courtesy D. Stucki); whitebark pine (*P. albicaulis*), Yosemite National Park, California (NPS photo courtesy S. T. McKinney); and foxtail pine (*P. balfouriana*), Sequoia National Park, California (NPS photo courtesy S. T. McKinney).

Monitoring White Pine (*Pinus albicaulis, P. balfouriana, P. flexilis*) Community Dynamics in the Pacific West Region - Klamath, Sierra Nevada, and Upper Columbia Basin Networks

Narrative Version 1.0

Natural Resource Report NPS/PWR/NRR—2012/532

Shawn T. McKinney
National Park Service
Sierra Nevada Network

Tom Rodhouse
National Park Service
Upper Columbia Basin Network

Les Chow
National Park Service
Sierra Nevada Network

Alice Chung-MacCoubrey
National Park Service
Sierra Nevada Network

Gordon Dicus
National Park Service
Upper Columbia Basin Network

Lisa Garrett
National Park Service
Upper Columbia Basin Network

Kathi Irvine
Montana State University
Department of Mathematical Sciences

Sean Mohren
National Park Service
Klamath Network

Dennis Odion
National Park Service
Klamath Network

Daniel Sarr
National Park Service
Klamath Network

Leigh Ann Starcevich
Oregon State University
Department of Statistics

June 2012

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

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado publishes a range of reports that address natural resource topics of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate high-priority, current natural resource management information with managerial application. The series targets a general, diverse audience, and may contain NPS policy considerations or address sensitive issues of management applicability.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner. This report received formal, high-level peer review based on the importance of its content, or its potentially controversial or precedent-setting nature. Peer review was conducted by highly qualified individuals with subject area technical expertise and was overseen by a peer review manager.

This report is available from the Upper Columbia Basin Network website (http://science.nature.nps.gov/im/units/ucbn/), the Sierra Nevada Network website (http://science.nature.nps.gov/im/units/sien/), the Klamath Network website (http://science.nature.nps.gov/im/units/klmn/), and the Natural Resource Publications Management website (http://www.nature.nps.gov/publications/nrpm).

Please cite this publication as:

McKinney, S. T., T. Rodhouse, L. Chow, A. Chung-MacCoubrey, G. Dicus, L. Garrett, K. Irvine, S. Mohren, D. Odion, D. Sarr, and L. A. Starcevich. 2012. Monitoring white pine (*Pinus albicaulis, P. balfouriana, P. flexilis*) community dynamics in the Pacific West Region - Klamath, Sierra Nevada, and Upper Columbia Basin Networks: Narrative version 1.0. Natural Resource Report NPS/PWR/NRR—2012/532. National Park Service, Fort Collins, Colorado.

NPS 963/114718, June 2012

Change History

Original Version #	Date of Revision	Revised By	Changes	Justification	New Version #

1. Version numbers increase incrementally by tenths (e.g., version 1.1, version 1.2, …etc) for minor changes. Major revisions should be designated with the next whole number (e.g., version 2.0, 3.0, 4.0 …). Record the previous version number, date of revision, author of the revision, identify paragraphs and pages where changes are made, and the reason for making the changes along with the new version number.

2. Notify the Network Data Manager of any changes to the Protocol Narrative or SOPs so that the new version number can be incorporated in the Metadata of the project database.

3. Post new versions on the internet and forward copies to all individuals with a previous version of the Protocol Narrative or SOPs. A list will be maintained in an appendix at the end of this document.

Contents

Contents (continued)

Page

Contents (continued)

Page

Contents (continued)

Page

Figures

Page

Tables

Page

Appendix

Page

Executive Summary

The mission of the National Park Service is ―to conserve unimpaired the natural and cultural resources and values of the national park system for the enjoyment of this and future generations" (National Park Service 1999). To uphold this goal, the Director of the NPS approved the Natural Resource Challenge to encourage national parks to focus on the preservation of the nation's natural heritage through science, natural resource inventories, and expanded resource monitoring (National Park Service 1999). Through the Challenge, 270 parks in the national park system were organized into 32 inventory and monitoring networks.

All Inventory and Monitoring (I&M) networks within the National Park Service have identified high priority park vital signs, indicators of ecosystem health, which represent a broad suite of ecological phenomena operating across multiple temporal and spatial scales. Our intent has been to develop a balanced and integrated suite of vital signs that meets the needs of current park management, and that also will accommodate unanticipated environmental conditions and management questions in the future. Three Pacific West Region I&M networks, the Klamath Network (KLMN), Sierra Nevada Network (SIEN), and the Upper Columbia Basin Network (UCBN) have identified a common vital sign: high elevation white pine species. These tree species are vulnerable to invasive pathogens as well as other stressors such as climate-change induced drought, and have been recognized as high priority vital signs for five parks: Crater Lake National Park (CRLA) and Lassen Volcanic National Park (LAVO) in KLMN, Sequoia-Kings Canyon National Park (SEKI) and Yosemite National Park (YOSE) in SIEN, and Craters of the Moon National Monument and Preserve (CRMO) in UCBN. Currently, populations of these white pine species and their respective communities are in better ecological condition within the participating network parks compared to populations elsewhere in the Cascades and Rocky Mountains (e.g., blister rust infection and mountain pine beetle infestation rates are lower). However, the observed steeply declining trends in white pine populations in the northern Cascade and Rocky Mountain ranges, coupled with the identification of blister rust and mountain pine beetle in our parks is a significant cause for concern about the future status of these valuable communities. Monitoring of white pine community dynamics will enable parks the opportunity for early detection of downward trends and perhaps more effective management intervention. Also, monitoring information from these parks will contribute meaningfully to the broader regional assessment of the status and trend of white pine species across western North America.

The objectives of the protocol are to determine the status and trends in:

1. Tree species composition and structure
2. Tree species birth, death, and growth rates
3. Incidence of white pine blister rust 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

Each network will establish a set of randomly selected permanent macroplots 50 m x 50 m in dimension. Plots are divided in five 10 x 50 m subplots, facilitating comparison of results from this protocol with other programs, including the NPS Greater Yellowstone Network, which uses the smaller plot size. Within each plot, trees ≥1.37 m (DBH) in height will be tagged and their status tracked over time. Seedlings and saplings will be monitored in a set of nine 3 m x 3 m regeneration plots systematically arranged within each macroplot. The use of a common database structure by each Network will facilitate combined analyses and reporting.

This protocol details the why, where, how, and when of the PWR's white pine community dynamics monitoring program. As recommended by Oakley et al. (2003), it consists of a protocol narrative and a set of standard operating procedures (SOPs) 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 each of the three networks. The protocol is a —living" document in the sense that it is continually updated as new information acquired through monitoring and evaluation leads to the refinement of program objectives and methodologies. Changes to the protocol are carefully documented in a revision history log. The intent of the protocol 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 precipitation patterns, and other stressors can be told to park visitors and managers alike. These long-term data 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

Funding for this project was provided through the National Park Service Natural Resource Challenge and the Servicewide Inventory and Monitoring Program. We thank the Park superintendents and resource staff who met with us to discuss park management objectives and information needs, and who provided invaluable feedback on this protocol. Penelope Latham first conceived of the idea of a joint-network approach to monitoring high-elevation white pines in the Pacific West Region and organized the first conference calls to discuss this possibility in summer 2009. Many people contributed to the development of this protocol. Their assistance and advice improved the document, while any errors or omissions are solely the responsibility of the authors. Sierra Nevada Network forest workgroup members Nate Stephenson, Gus Smith, Tony Caprio, Adrian Das, and Linda Mutch provided valuable input throughout protocol development and gave constructive comments that improved the document. The fire effects crew from Yosemite National Park donated their time to field-test the protocol and gather valuable data. We are grateful to the following people for their contributions to this document: Tom Philippi, Sandy Graban, Paulina Tobar-Starkey, Devin Stucki, Sean Smith, Dan Duriscoe, Tani Meadows, Jenny Matsumoto, John Apel, and Steven Bekedam. We thank Jason Bennett and two anonymous reviewers for their thoughtful comments that improved the document.

Background and Objectives

Rationale for Monitoring White Pine Species in the Pacific West Region

Many western North American coniferous forests are currently facing unprecedented health challenges, including upsurges of native pests and pathogens, invasive exotic 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 additional short- and long-term threats. Each factor alone can alter forest ecosystem structure, function, and species composition, while additive or synergistic effects are possible if multiple agents act jointly. How forest ecosystems will respond to modern perturbations is uncertain, however the magnitude of change in structure and composition, and key ecological processes will likely be exceptional. Indeed, increased tree mortality rates over the last several decades have recently been documented across a broad range of latitude and forest types in western North America (van Mantgem et al. 2009).

Five-needle white pines (Family Pinaceae, Genus *Pinus*, Subgenus *Strobus*), and in particular whitebark pine (*Pinus albicaulis*), limber pine (*P. flexilis*), and foxtail pine (*P. balfouriana*), are foundational species (Tomback and Achuff 2010) in upper subalpine and treeline forests of several National Park Service (NPS) Pacific West Region (PWR) parks. Ongoing declines of many foundation tree species pose an especially compelling problem because these species provide fundamental structure to a system 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 often are only one or two foundational 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 functioning and stability of the community (Ebenman and Jonsson 2005).

Foxtail, limber, and whitebark pine often occupy environments too harsh for other tree species to thrive, and thus, frequently occur in pure to nearly pure stands. It should be noted that limber pine occupies a wide elevation range (see section on limber pine below), and therefore occurs in lower treeline as well as upper subalpine and treeline habitats. Whitebark pine is found in montane, upper subalpine, and treeline habitats, while foxtail pine is primarily restricted to the upper subalpine and treeline zones. By virtue of their status as dominant components of forest stands, these three species can have a large influence on key ecosystem processes and community dynamics, such as influencing snowmelt and stream flow, moderating local environments allowing for establishment of shade-tolerant plants, and providing habitat and food resources for birds and mammals.

A particularly pernicious threat to many western forest ecosystems is the exotic fungal pathogen *Cronartium ribicola* (Division Basidiomycota, Order Pucciniales), which causes white pine blister rust 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. Blister rust ultimately damages and kills five-needle white pines by girdling branches and boles.

Geils et al. (2010) estimate that *Cronartium 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 blister rust, including elimination of its main alternate host *Ribes*, have been in vain (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 the rust. Indeed, all eight of the western North American five-needle white pines (*P. aristata, P. albicaulis, P. balfouriana, P. flexilis, P. lambertiana, P. longeava, P. monticola,* and *P. strobiformis*) are susceptible to blister rust infection. *C. ribicola* reduces seed production, kills trees, and alters successional processes, species composition, structure, and function of white pine forests (McDonald and Hoff 2001).

Table 1. Susceptibility of wild populations of white pine species to blister rust infection by inoculation. Modified from McDonald and Hoff (2001).

Species	No. of Seedlings	Percent Infected	Spots/m of needle*	Percent Killed
P. albicaulis	207	67	6.7	92
P. flexilis	384	89	9.5	89
P. balfouriana	92	100	84.4	100

*# of blister rust spots per meter-length of needles

Whitebark pine and limber pine are declining rapidly throughout most of their range from blister rust-induced mortality, but also from large outbreaks of mountain pine beetle (*Dendroctonus ponderosae*). Although blister rust-induced declines in foxtail pine have not yet been documented, foxtail pine is susceptible to blister rust, and rust infection of foxtail pine has been found in both its northern (Dunlap 2006) and southern (Duriscoe and Duriscoe 2002) populations. Foxtail pine mortality from mountain pine beetles has only recently been reported (Kliejunas and Dunlap 2007).

Mountain pine beetle is one of a handful of bark beetles that kill their host during reproduction (Heavilin et al. 2007). Mountain pine beetles are a native component and natural disturbance factor in western forest ecosystems, having an important influence on the process of forest succession. Although a large outbreak of mountain pine beetles affected whitebark pine 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 population growth is limited by temperatures of -30 °C for several days, or at least twelve hours of -40°C or lower, that kill most beetles thus preventing multiple reproductive cycles within a given year. Recent warm winters, higher beetle densities, and increased beetle-caused tree mortality could be a prolonged pattern if current warming trends continue. Mountain pine beetle outbreaks may 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 less crowded forests than would develop in the absence of the beetle. Due to our incomplete knowledge of the temporal dynamics of mountain pine beetle outbreaks, it is often unclear to park managers whether they are a severe new threat or a critical process for maintaining forest biodiversity in park landscapes. However, although mountain pine beetle outbreaks are cyclical, 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).

Taxonomy, Distribution, and Ecology of Whitebark, Limber, and Foxtail Pines

Whitebark Pine

Recent phylogenetic work based on chloroplast DNA has resulted in a reclassification of whitebark pine into the Subsection, *Strobus*; which represents a new Subsection within the new Section *Quinquefoliae* (Gernandt et al. 2005). Whitebark pine in the Cascades and Sierra Nevada Mountains, similar to elsewhere, ranges in stature from an upright tree reaching a maximum height of about 15 m in relatively protected sites, to a short tree with a horizontal form shaped by the wind in exposed sites; a growth form referred to as *krummholz* (from the German, meaning crooked, bent, or twisted wood). It has thin bark and short needles that can be densely packed. It is often multi-trunked; either a multi-genet tree clump resulting from multiple individuals growing together from former seed caches, or a single genotype tree cluster.

Whitebark pine occurs across a broad geographic range—the most widespread distribution of all eight western five-needle white pines—from 37° to 55° N latitude and from 107° to 128° W longitude (McCaughey and Schmidt 2001; Figure 1). It occurs in two main subregions: the northern Rocky Mountains from central Alberta and British Columbia south through Montana and Idaho and into western Wyoming; and the Cascade and Coastal Ranges of central British Columbia south through the Cascades and Sierra Nevada. Whitebark pine reaches its southern limit in central California near the Mount Whitney vicinity, and occurs on both the west and the more arid east side of the Sierra Nevada crest.

Throughout its range, whitebark pine can occur in the montane, upper subalpine, and treeline zones (Arno and Hoff 1990; 1,370–3,660 m above sea level [asl] rangewide). It occurs as the only tree species on the coldest and driest sites near timberline and as a seral species on protected, slightly lower sites more favorable for its shade-tolerant competitors (Arno and Weaver 1990). The two prominent shade-tolerant high-elevation species in the Sierra Nevada and Southern Cascades are mountain hemlock (*Tsuga mertensiana*) and red fir (*Abies magnifica*). Other associates of whitebark pine in these mountain ranges include lodgepole pine (*Pinus contorta* ssp. *murrayana*), a shade-intolerant species that is the most prominent host of the current mountain pine beetle outbreak, and occasionally western white pine (*Pinus monticola,* another host for blister rust) and, in the Cascades, subalpine fir (*Abies lasiocarpa*).

In the Pacific West Region, whitebark pine is scattered across tens of thousands of hectares in the high elevations of Sequoia-Kings Canyon (SEKI) and Yosemite National Park (YOSE) (Table 2; Figure 1). It also occurs around the rim at Crater Lake (CRLA) and at scattered upper elevations in Lassen Volcanic National Park (LAVO). Blister rust infections on whitebark pine decrease from north to south in the Pacific West region, reflecting the trend seen in the Rocky Mountains. Blister rust is relatively rare in LAVO, SEKI, and YOSE. Mountain pine beetle is currently abundant in the northern Cascades, but also decreases with latitude (Gibson et al. 2008) in the Pacific west of North America.

Whitebark pine acts as both a foundation and keystone species in high-elevation forest communities by regulating ecosystem processes, community composition and dynamics, and by influencing regional biodiversity (Tomback and Kendall 2001, Ellison et al. 2005). Whitebark pine plays a role in initiating community development after fire, influencing snowmelt and stream flow, and preventing soil erosion at high elevations (Farnes 1990, Tomback et al. 2001). The large, wingless seeds of whitebark pine are high in fat, carbohydrates, and lipids and provide an important food source for many granivorous birds and mammals (Tomback and Kendall 2001). Whitebark pine is a coevolved mutualist with Clark‘s nutcracker (*Nucifraga columbiana*), and is obligately dependent upon nutcrackers for dispersal of its large, wingless seeds (Tomback 1982). Nutcrackers are a facultative mutualist; they favor whitebark pine seeds, but also disperse seeds of other large-seeded conifers (e.g., ponderosa pine [*P. ponderosa*]). Nutcrackers extract seeds from indehiscent cones in late summer and early fall and often cache seeds in recently disturbed sites accounting for the pine‘s early successional status. Whitebark pine also provides important habitat structure for high-elevation vertebrates. For example, white-tailed jackrabbits (*Lepus townsendii*) have been documented using dense, low-growing whitebark pine mats for shelter in the Sierra Nevada. The hare is a species of concern in California and has become uncommon in the Sierra Nevada where its southern range limit coincides with whitebark pine (Storer et al. 2004). The second largest hare in the western hemisphere, white-tailed jackrabbits can be an important prey source for large raptors, mountain lions, and other high-elevation predators.

Limber Pine

Like whitebark pine, 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 20 m, and also grows in *krummholz* in treeline environments. Limber pine ranges widely from 34° to 53° N latitude and from 104° to 108° W longitude (Little 1980; Figure 1). 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 asl rangewide) and occurs in a wide range of environments preferring dry, rocky slopes (Schuster et al. 1995). Limber pine occupies approximately 9,244 ha of the northern, highest elevation portion (>1,600 m) of Craters of the Moon National Monument (CRMO) and approximately 35 ha of mixed conifer stands at City of Rocks National Reserve (CIRO), two parks in southern Idaho within the Upper Columbia Basin Network (UCBN). Limber pine is uncommon in Sierra Nevada Network (SIEN) parks, but extensive stands occur just to the east of both SEKI and YOSE.

Limber pine is a pioneer of severe sites, moderating local environments and facilitating the 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 prized by numerous birds and mammals. Its seeds are dispersed by Clark‘s nutcrackers (Lanner and Vander Wall 1980, Tomback and

Kramer 1980, Vander Wall 1988), and small mammals (Tomback et al. 2005). Limber pine provides many of the same ecological services as described above for whitebark pine.

Foxtail Pine

Foxtail pine is classified into the Genus *Pinus,* Subgenus *Strobus,* Section *Parrya,* Subsection *Balfourinae*. Foxtail pine is limited to high-elevation slopes, ridges, and peaks (1,525–3,650 m asl rangewide) often in pure to nearly pure, open stands with little other vegetation. Its distribution is much smaller than that of whitebark pine and limber pine. It is a California endemic confined to two discrete regions separated by 500 km: the Klamath Mountains of northwestern California (but not known or suspected in any Klamath Network [KLMN] parks), and the southern Sierra Nevada (Figure 1), where it is scattered over a large area of the treeline zone in SEKI. The northern population extends from 40° to 42° N latitude and from 122° to 123° W longitude, and the southern population occupies a range from 36° to 37° N latitude and from 118° to 119° W longitude. Consistent differences between the Klamath (northern) and Sierra Nevada (southern) populations in cone, needle, and bark morphologies have led to their description as distinct allopatric subspecies: *P. balfouriana balfouriana* in the north, and *P. b. austrina* in the south (Mastrogiuseppe and Mastrogiuseppe 1980). However, more recent genetic analysis of allozymes identified greater differentiation among populations within *P. b. balfouriana* than between the two subspecies, likely owing to a mountain island effect limiting gene flow among isolated mountain populations in the Klamath (Oline et al. 2000).

Research on community and population dynamics is lacking for foxtail pine compared to whitebark pine and limber pine. Eckert and Sawyer (2002) did not find differences in stand characteristics between Klamath and Sierra Nevada populations, which is contrary to the genetic (Oline et al. 2000) and morphological (Mastrogiuseppe and Mastrogiuseppe 1980) differentiation identified by other researchers. Foxtail pine occurs in four different forest types: 1) stands dominated by foxtail pine, 2) stands with foxtail pine and whitebark pine, 3) stands with foxtail pine and red fir, and 4) stand with foxtail pine, red fir, and western white pine (Eckert and Sawyer 2002). Foxtail and whitebark pine overlap in some portions of their southern Sierra Nevada distribution (Figure 1). However, in many areas of the southern Sierra Nevada, foxtail pine is the major (exclusive) subalpine and timberline tree (e.g., >3,000 m), likely providing important habitat and food resources for birds and mammals, and influencing snow melt and soil erosion. Foxtail pine seeds are wind dispersed. However, nutcrackers are known to harvest seeds from cones of the previous year and have been observed caching seeds within foxtail pine stands, although the seed species is as yet unknown (S. T. McKinney, personal observation). It is also currently unknown whether seed caching rodents play a role in foxtail pine seedling establishment.

The southern population of foxtail, subspecies *austrina*, provides important data for dendrochronological research on paleoclimate (Lloyd 1997) as a consequence of its great longevity (>1,000 years) and slow growth that is thought to be little affected by competition, groundwater, and factors not directly influenced by climate. In fact, all three species addressed in this protocol, and five-needle pines in general, have proven valuable in enhancing our understanding of past climates through dendrochronological investigations (e.g., Kipfmueller and Salzer 2010, Woodhouse et al. 2011).

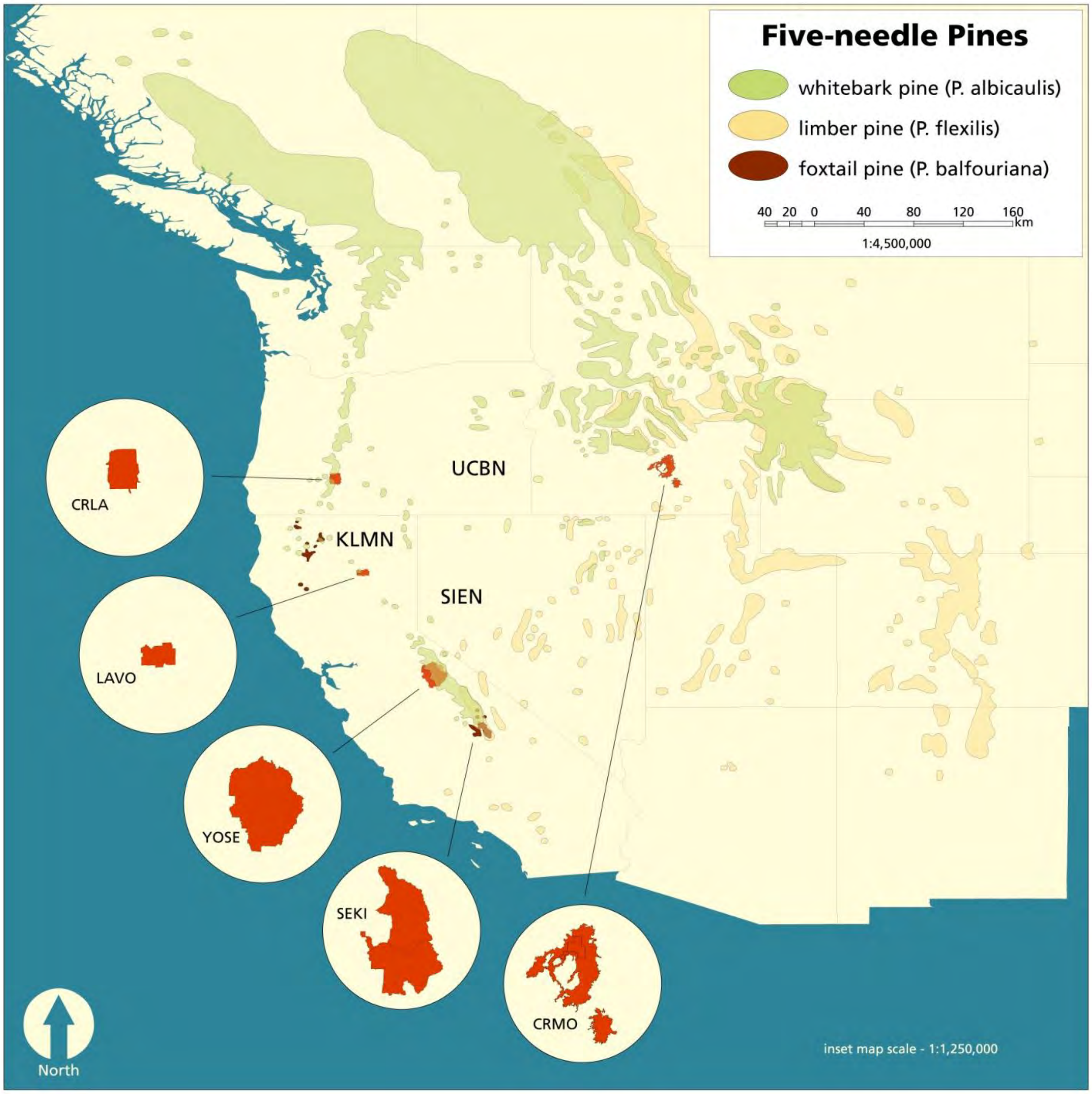

Figure 1. Distribution of whitebark pine, limber pine, and foxtail pine (from Little 1971) and locations of the three Pacific West Region networks and parks where this protocol is implemented.

History of Inventory and Monitoring Five-Needle Pines in the Pacific West Region

Klamath Network

As noted by Murray and Rasmussen (2003), every year, nearly 500,000 people view southern Oregon's Crater Lake from its pine-clad rim where the picturesque trees set against the lake's deep blue backdrop inspire postcards, artwork, and countless photographs. The loss of these trees is highly visible to visitors and conflicts with the National Park Service's obligation to maintain natural conditions for future generations. Impact to visitor experience motivated an inventory in

1999 to investigate and monitor the noticeable increase in whitebark pine mortality (Murray and Rasmussen 2003).

In 1999–2000, Murray and Rasmussen (2003) sampled whitebark pine on a series of 24 transects. Transects were located within each type of whitebark pine community common in the park, but avoided heavy use areas. Murray and Rasmussen assessed a total of 1,200 individuals of whitebark pine and found active blister rust cankers (i.e., with fruiting bodies called aeciospores) on 8% of mature trees (>25 cm diameter at 1.37 m height, dbh), with lower levels on saplings and seedlings. Mortality of trees >1.4 m tall was 13.5%. Blister rust was associated with *Ribes* species and was more common on the mesic west side of Crater Lake. Mountain pine beetle and dwarf mistletoe (*Arceuthobium cyanocarpum*) infections were localized. By considering mortality and reproductive rates, Murray and Rasmussen (2003) estimated that the whitebark pine population at CRLA would decline by 20 percent in a 50-year period, with blister rust being the primary mortality agent.

In 2003, Murray established seven monitoring plots containing 500 permanently marked trees in CRLA. Individual trees and cankers have been monitored annually (Michael Murray, CRLA, personal communication).

In 2009, KLMN conducted a pilot study at CRLA to test its proposed whitebark pine monitoring approach and to compare findings with those of Murray and Rasmussen (2003). The pilot study sampled most of the same general areas as Murray and Rasmussen. Results for active infection rates on trees were almost identical to those found by Murray and Rasmussen. However, Murray and Rasmussen (2003) found only 6.7 percent of trees >25 cm dbh had inactive or dead cankers. KLMN found a substantially larger number of trees (18%) with inactive cankers. It therefore seems conceivable that active infections increased after the sampling done by Murray and Rasmussen, and that many of these infections have since become inactive, leading to far more trees with inactive cankers. One reason such a pattern could occur would be that the most susceptible trees have died and the remaining trees are better able to deactivate or kill infections. However, the discrepancy between the findings by Murray and Rasmussen and KLMN‘s may also be related to different plot location and subjectivity regarding the identification of inactive cankers.

KLMN found no statistically significant difference between the percentages of trees infected in plots in the western (28.7%, $n = 9$) versus eastern (21.6%, $n = 11$) portions of CRLA. However, active cankers were more common on the west side (11%) than the east (4%) ($P = 0.04$), consistent with Murray and Rasmussen (2003). The number of inactive cankers was nearly identical east vs. west (17.7% vs. 17.5%). Active and inactive infections were also higher where alternative hosts (*Ribes* and *Castilleja*) were present in plots.

Mistletoe and mountain pine beetles were more widespread than observed by Murray and Rasmussen (2003). Twenty-three percent of whitebark pine trees >15 cm dbh were dead and mountain pine beetle infestation was determined to be the most important source of mortality. These results suggest that blister rust and mountain pine beetle are in an outbreak phase at CRLA and that whitebark pine populations may decrease more rapidly than projected by Murray and Rasmussen. Tree mortality will likely continue to rise as susceptible trees–which in general form the majority of any given whitebark population– succumb to rust mortality; leaving only the minority of rust-resistant trees and non-resistant trees that escape rust infection. However, offspring from susceptible parents will have a poor chance of survival in areas of high blister rust infection levels, further driving down subsequent population numbers. It will take future monitoring to accurately estimate the trend of the whitebark pine population in the park.

Whitebark pine has also been monitored in LAVO under a California state-wide program of the US Forest Service (P. Maloney, Research Associate UC-Davis, personal communication, August 2006). The USFS monitoring effort established 44 plots in the Sierra and Southern Cascades ranges. Four of these plots were in LAVO. A very low incidence of blister rust (~3% of trees) was reported from those four plots. However, more of the park needs to be sampled to adequately assess the incidence and severity of disease and beetle outbreaks in the population.

Sierra Nevada Network

The following history of surveys and monitoring of white pine blister rust and five-needle white pines in SIEN parks is excerpted and modified from Duriscoe and Duriscoe (2002). White pine blister rust was first discovered in California in 1929, and later found in SEKI in 1969. Since that time it has spread and intensified throughout the Sierra Nevada over the range of its lower elevation host, sugar pine (*Pinus lambertiana*), and has been documented on two of its higher elevation hosts–western white pine and whitebark pine. Until the late 1960s, it was believed that blister rust would be of minor importance in the southern Sierra Nevada because of climatic conditions. Surveys in the mid to late 1970s showed that rust could become established and intensify in the central and southern portion of the range. In the early 1980s, a dramatic increase in the incidence and severity of white pine blister rust was observed at Mountain Home Demonstration State Forest, just south of SEKI. The intensity of the disease and the damage it is causing to sugar pine has been greater than anticipated. Even upland sites where the disease was not expected to be a concern are experiencing some high levels of infection. Environmental and climatic conditions, once thought to limit infection, are not halting the southerly spread and intensification of the disease (DeNitto 1987).

Between 1977 and 1995 no formal monitoring of blister rust distribution or intensity in white pines within the parks existed. SEKI had a long history of work on white pine blister rust control and monitoring prior to 1977. In 1969, an epicenter of the disease was discovered in Garfield Grove during a contract detection survey. In 1970, USFS adopted a practice of direct control, shifting emphasis from *Ribes* eradication to elimination of infected pines. The Garfield Grove infection center was "sanitized" in this manner that year. Contract detection surveys were performed along streams in 1969–1971. From 1970 to 1972, NPS surveyed for blister rust along streams in the sugar pine zone of the Kaweah River basin. In 1973, NPS began a combination, detection, suppression, and protection program aimed at maintaining selected control units in a rust-free state. These eight control units comprised approximately 21,000 acres. The program consisted of a three-year search cycle with 100% stream check and approximately 33% upland check per control unit per year. In June 1977, there were 17 known infection centers in these parks. Eight of these were outside of the control units and were only monitored, the other nine, located within the units, were not successfully sanitized. By 1981, 54 infection centers were documented within the parks, all in sugar pine.

In spite of thorough searching and subsequent treatment, the control units were not rust-free and the rust continued to spread. It was concluded that it was not possible to keep the rust out of the parks or the protection units. The following options were proposed for future management:

1. Minimize the damage caused by the rust through stand management activities. Prescribed fire may reduce the level of rust infection and subsequent damage to the host.
2. Encourage natural selection by the host against the rust. NPS may wish to actively encourage the process by preserving rust-resistant candidate trees, or planting resistant seedlings in selected locations (high-use areas or areas burned by wildfires).
3. Continue to monitor blister rust within the parks or within the blister rust protection units of the parks.
4. Prune cankers to protect individual trees.

Monitoring of rust incidence, tree mortality, and residual population statistics exist primarily in raw data form in the SEKI park forester‘s files. Annual summaries of control activities are available, however no data synthesis or summary was found for monitoring data. Occasional reports of discoveries of blister rust infected trees continued to be filed through the early 1980s, when interest in tracking the extent of the disease waned. Information on the spread of the pathogen within the parks was entirely anecdotal between 1980 and 1995. Blister rust was observed on whitebark pine at 2,895 m in Bubbs Creek; at 3,078 m on the South Fork of the Kings River; at 2,743 m in the Lone Pine Creek drainage south of Elizabeth Pass; and at 3,110 m above Vidette Meadow near Bullfrog Lake. No reports of white pine blister rust on foxtail pine or limber pine within the park boundaries have been found.

An extensive ground survey of white pine species, including whitebark pine, foxtail pine, limber pine, sugar pine, and western white pine was performed during 1995–1999 in SEKI (Duriscoe and Duriscoe 2002). Permanent monitoring plots (n = 151) were installed and white pine distribution was mapped in selected areas in conjunction with plot establishment. Within each plot, an average of 48 white pines taller than 1 m were measured, mapped for long-term monitoring, and evaluated for white pine blister rust infection. The average incidence of rust infection was 6.6% for all plots; rust was found only in plots containing sugar pine (21.1% average incidence) and western white pine (2.7% average incidence). Incidence and severity of rust were related to associated *Ribes* species presence, elevation, and topographic position. Rust was rarely found above 2,680 m, and most often found in valley bottoms. Sugar pine and western white pine were significantly affected by bole infections in smaller trees in localized areas. The populations of foxtail, whitebark, and limber pine within Sequoia and Kings Canyon National Parks appeared virtually unaffected by blister rust at that time (Duriscoe and Duriscoe 2002).

In Yosemite, sugar pine is known to be infected by blister rust (van Mantgem et al. 2004), and rust was detected on whitebark pine in a USGS long-term monitoring plot in 2010 (A. Das, USGS, personal communication, July 2010). However, to our knowledge there are no documented inventory and monitoring reports of white pine blister rust incidence on white pine species in Yosemite National Park.

Upper Columbia Basin Network

Limber pine occurs in mixed stands of Rocky Mountain and Utah juniper (*Juniperus scopulorum* and *J. osteosperma*) and single-leaf pinyon pine (*Pinus monophylla*) in CIRO, and forms monotypic woodlands in much of the northern, highest-elevation portions of CRMO, and also occurs with Rocky Mountain juniper in the northeastern edge of that park. No prior inventory and monitoring efforts have been conducted in CIRO woodlands that contain limber pine. Limber pine is rare and sparsely distributed in CIRO and therefore does not lend itself to monitoring using this protocol and will therefore not be addressed further in this protocol. Limber pine contributes significantly to the biodiversity of CRMO, and is an integral part of the park's striking landscape. The presence of limber pine woodlands in CRMO dramatically contributes to visitor experience in addition to its important ecological significance.

There is no history of formal inventory and monitoring of the CRMO limber pine population. During the 1960‘s, park policy included removal and girdling of pines infected with dwarf mistletoe in the vicinity of the park visitor center and along the park loop road which penetrates the northern portion of the lava flows. Beginning in 2006, CRMO initiated informal surveys of limber pine stands for early detection of white pine blister rust infection. As in SIEN, there has been an expectation that the aridity of the park will slow or prevent blister rust infection, but in 2006, three infected trees with active cankers were found and removed. Subsequent surveys have not documented any additional infections. In 2009, UCBN initiated a small pilot survey of six limber pine stands following the *Interagency Whitebark Pine Monitoring Protocol for the Greater Yellowstone Ecosystem* (Greater Yellowstone Whitebark Pine Monitoring Working Group [hereafter referred to as GYWPMWG] 2007). No blister rust was found during that survey, although mountain pine beetle galleries were found in several trees, and dwarf mistletoe was ubiquitous. Blister rust was found infecting several trees in the same stand as the 2006 infection in spring of 2010 and 2011.

Rationale for a Three Network Approach to Monitoring White Pine Species

A single monitoring protocol for white pines for the three NPS Inventory and Monitoring Program (I&M) networks of the PWR considered here was developed for efficiency and to facilitate syntheses of ecological findings over time. These networks will all use the same core response design to measure the same parameters. We will also use the same data analysis approaches. These standardization efforts will decrease duplication and ensure that data are comparable across a larger region and facilitate comparisons. In addition, monitoring status and trends in the three white pine species in the PWR will provide greater opportunities to share information to better understand the dynamics of forest ecosystems under modern perturbations. The monitoring will add to a growing body of information on blister rust spread and epidemiology within white pine forest communities in a variety of biophysical settings. Monitoring of whitebark pine populations in the NPS North Coast and Cascades Network (NCCN, also in the PWR), and in the Greater Yellowstone Network (GRYN) is also ongoing (GYWPMWG 2007, Rochefort 2008), and presents another important opportunity for data sharing and regional synthesis of status and trends. At a broad level, long-term monitoring can show how mortality events and possibly even extirpation 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).

The three white pine species are broadly distributed among the three networks addressed by the protocol (Table 2 and Figure 1) and rust infection and tree mortality levels are relatively low compared to other parts of western North America (e.g., northern Rocky Mountains and North Cascades) where severe declines are occurring (Table 3). Therefore, monitoring in these parks will provide important additional data for describing the range of variation in rust incidence and damage across a less-infected range of conditions in different forest types. The presence of blister rust within the three networks, however, portends future declines, and demonstrates the need for broad-scale collaboration. Indeed, a range-wide restoration strategy is currently proposed for whitebark pine (Keane et al. *in press*). Moreover, the US Fish and Wildlife Service recently determined that whitebark pine warranted listing as a Threatened or Endangered species under the Endangered Species Act, but that this listing was precluded by higher priority actions (Federal Register 76, no.138 [July 19, 2011]: 42631-42654).

Table 2. Estimated extent (in hectares) of the distribution of white pine species by network and park. (*KLMN estimates are forthcoming with vegetation map planned for 2012.)

		White Pine Species			
Network	**Park Unit**	**Whitebark Pine**	**Limber Pine**	**Foxtail Pine**	**Total**
SIEN	SEKI	18,312	221	24,056	42,590
	YOSE	18,089	0	0	18,089
KLMN	CRLA	1,526	0	0	1526
	LAVO	257	0	0	257
UCBN	CRMO	0	9,244	0	9,244
	CIRO	0	35	0	35
Total		38,184	9,500	24,056	71,741

Table 3. Maximum blister rust infection values (percentage of trees infected within plots) of three white pine species by network and for each species' entire range.

	Location			
Species	**SIEN**[1]	**KLMN**[2]	**UCBN**[3]	**Rangewide**[4]
whitebark pine	0	30	NA	100
limber pine	0	NA	<1	70
foxtail pine	0	NA	NA	33

[1]Data from Duriscoe and Duriscoe (2002). No rust found in monitoring plots, but rust found on whitebark and foxtail pines in vicinity of plots.
[2]Data from most recent KLMN report for trees >25 cm DBH. Includes both active and inactive infections.
[3]Limber pine data from CRMO park staff personal communication and UCBN pilot monitoring in 2011. Note a small stand of limber pine in the northern portion of CRMO has active infections but no infected trees have been encountered in plots.
[4]Whitebark pine data from Tomback et al. (2001), limber pine data from Stucki and Rodhouse (2012), and foxtail pine data from Dunlap (2006).

The long-term monitoring effort outlined here will specifically complement other long-term monitoring within GRYN and NCCN, and efforts by USFS (both Rocky Mountains and Sierra/Cascades) and Parks Canada. It is important to note that most of these monitoring efforts share a high degree of similarity in sampling methods first published by the Whitebark Pine Ecosystem Foundation (Tomback et al. 2004, revised 2005). It is our goal to maintain similar methods for assessing parameters at sample locations and to have the most similar spatial sampling designs logistically possible across the three networks. Achieving these criteria will allow for more robust analyses of status and trend across species and forest types, and facilitate comparison among parks from different regions. Such a standardized collaborative approach will maximize our potential to assist and provide context for local management decisions within national parks, while contributing to larger scale syntheses that will inform management throughout the range of the high elevation pine species in KLMN, SIEN, and UCBN.

Project Goal and Problem Statements

The purpose of this monitoring project is to document and interpret changes in community dynamics in forests containing white pine species (*Pinus albicaulis, P. balfouriana,* 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 into the tree class (≥1.37 cm dbh) decreasing, and are there declines in the magnitude of seedling regeneration (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 white pine blister rust and mountain pine beetle in the participating network parks, but we are uncertain about the trajectory of dwarf mistletoe. We therefore predict an increase in the number of trees infected with blister rust 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 blister rust only affects white pines (Subgenus *Strobus*) and because mountain pine beetle only attacks *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 numbers 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 across KLMN, SIEN, and UCBN are based on collaboratively identified goals. The objectives were developed during a series of telephone meetings and refined by network ecologists and program managers. These objectives were also 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), and the anticipated impacts of blister rust, mountain pine beetle, mistletoe, and climate change to high-elevation white pines based on published scientific literature and expert opinion. By monitoring individual trees within plots, we will be able to estimate key demographic parameters and adequately address our objectives, which are as follows.

For white pine (*Pinus albicaulis, P. flexilis, and P. balfouriana*) forest communities in Klamath, Sierra Nevada, and Upper Columbia Basin Network parks, with constraints based on safety and accessibility, we will determine the status and trends in the following (see Table 5 for details on the relationship between the six objectives and measured variables):

1. Tree species composition and structure
2. Tree species birth, death, and growth rates
3. Incidence of white pine blister rust 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

Management Actions

The overall, range-wide recovery strategy for whitebark and limber pine is largely based on increasing the frequency of rust-resistant alleles within populations, 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 rust resistance. For artificial regeneration, phenotypically rust-resistant trees are identified; their cones are protected from vertebrate seed predators with wire cages in early summer, and then collected later in the summer when seeds mature. Seedlings are grown in a nursery and inoculated with rust to test for resistance. After three to four years, rust-resistant seedlings can be out-planted in suitable habitat. 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 nutcracker seed caching. Individual trees can be protected from pine beetles by placing verbenone (a synthetically-produced chemical to mimic beetle pheromones) patches on trees or by spraying trees. Wildland fire for resource benefit can also be used which entails allowing lightning-ignited fires to burn in remote areas.

All of these tools are now employed in various locations in the Rocky Mountains (Keane et al. *in press*) where severe declines are occurring. Decisions of where and when to initiate management action have also been studied in this region. For example, a threshold of cone production necessary to elicit nutcracker seed dispersal in whitebark pine has been identified by McKinney et al. (2009). Below the threshold of ~1,000 cones/ha, nutcracker seed dispersal probability sharply declines. In the northern Rocky Mountains, 1,000 cones/ha can be achieved in a forest with live whitebark pine basal area greater than 5.0 m^2/ha (McKinney et al. 2009). Below this level, artificial regeneration will likely be needed, and above this level, natural regeneration can be expected. Vertebrate pre-dispersal seed predators can also limit the amount of whitebark pine seeds available for avian dispersal, but their occurrence and magnitude of impact are dependent upon forest structure and composition (McKinney and Fiedler 2010). Therefore, site-specific evaluations must be made before determining whether seeds will be naturally dispersed into restoration areas, or whether more intensive management will be required (McKinney and

Tomback 2007). We will explore the potential use of these relationships and thresholds or assessment points (*sensu* Bennetts et al. 2007) with park management staff following the first three years of protocol implementation and establishment of baseline conditions in each park.

It is currently difficult to identify specific metric values that could be used in a ‗score card' rating system because of the general lack of detailed information about the forest communities in these network parks. 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 general relationships but with the caveat that these relationships must be revisited and further refined following several years of data collection and analyses. Blister rust infection of 1%, 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. A specific mortality value 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 to 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.

Sampling Design

Sampling Design Rationale

Monitoring large landscapes poses unique challenges that require compromises among: 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. Sampling design development is therefore an exercise in cost-benefit trade-offs, 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 have therefore 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 also 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 multiple parks and networks involved in this particular protocol. Finally, we have been highly motivated to closely follow the methodology outlined in the *Interagency Whitebark Pine Monitoring Protocol for the Greater Yellowstone Ecosystem* (GYWPMWG 2007) in order 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. Our protocol addresses a somewhat broader set of objectives but overlaps substantially with the Yellowstone protocol. KLMN‘s whitebark pine monitoring will be co-located with a subsample of its vegetation monitoring plots (Odion et al. 2011). The plot design for the vegetation monitoring, which will be nested within the whitebark pine plots described below, was adapted from methodologies of the Carolina Vegetation Survey (Peet et al. 1998). The Carolina Vegetation Survey techniques, suitable for sampling a wide variety of vegetation parameters, have been used successfully in Great Smoky Mountains National Park for vegetation monitoring since 1978.

Target Population, Sampling Frames, and Location of Plots

Target populations addressed in this protocol include white pine (*Pinus albicaulis*, *P. flexilis*, and *P. balfouriana*) forest and woodland communities in KLMN, SIEN, and UCBN parks, with sampling frame constraints based primarily on safety and accessibility. Sampling frames have been constructed individually for each park using available information such as park vegetation maps and road networks as described in the following subsections. Within respective park frames, we have 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 of sample sites as necessary (Stevens and Olsen 2004). Spatial point locations obtained from GRTS sample draws are used as plot locations. The sampling in each park 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.

Klamath Network Sampling Frames

The KLMN sampling frames comprise *P. albicaulis* stands at CRLA and LAVO that fall between 100 m and 1000 m from a road or trail at LAVO and between 50 m and 1000 m from a road or trail at CRLA and on slopes less than 35 degrees. The sampling frame was developed from several preliminary map sources and from ongoing mapping projects, along with review of aerial imagery for each park during development of this protocol (Figures 2-3). It may change as the vegetation mapping projects in both parks are finalized.

As with the KLMN vegetation protocol (Odion et al. 2011) and the UCBN sampling frame described below, the targeted whitebark sampling frame does not provide inference to all possible sites within the parks. However, it does sample a representative swath of high elevation *P. albicaulis* habitat that can be sampled safely and feasibly. Sampling in remote, steep, or unstable areas would likely lead to greater travel time and risk of worker injury and down time, and the consequence that a much smaller sample size of permanent plots could be sampled and statistical power would be insufficient to make predictions for any areas. Polygons smaller than 0.5 ha were excluded from the sampling frame because they were determined to be too small to reliably accommodate plots.

Sierra Nevada Network Sampling Frames

The protocol will be implemented in YOSE and the two jointly managed units of SEKI. Vegetation maps created for both YOSE and SEKI identify the distribution of whitebark and foxtail pine and were used to define sampling frames for the species. The mapped population distribution of whitebark pine forms one sampling frame and the corresponding foxtail pine population distribution forms a second sampling frame in SEKI (Figures 4 and 5). The sampling frame for YOSE includes all areas mapped for whitebark pine (Figure 6). For all three sampling frames, areas with a slope greater than 35 degrees are excluded due to safety considerations. Scope of inference extends broadly across mapped stands of YOSE and SEKI, limited only by the slope cutoff.

Upper Columbia Basin Network Sampling Frame

Three limber pine plant associations have been identified and mapped in CRMO by Bell et al. (2009): *P. flexilis/Purshia tridentata* Woodland, *P. flexilis/Artemisia spp.* Woodland, and *P. flexilis/Chamaebatiaria millefolium/Poa secunda* Sparse Vegetation. The *P. flexilis/Purshia tridentata* Woodland association is endemic to Idaho‘s Snake River Plain and has been identified by NatureServe as critically imperiled (G1 ranking; Bell et al. 2009). In the *P. flexilis/Chamaebatiaria millefolium/Poa secunda* Sparse Vegetation association, limber pine occurs as widely scattered individual trees on young lava flows with no substantial soil development or understory vegetation. Most of this association (73%) occurs beyond 2 km from roads. Because of the extremely sparse distribution and remoteness of this association, we have further restricted the target population in CRMO to include only the two *P. flexilis* woodland associations.

The sampling frame for CRMO includes all areas mapped as *P. flexilis* woodland within 2 km of roads and trails (Figure 7). The Wilderness Trail (Figure 7), which extends from the park loop road southward and south into the lava flows, was excluded beyond 2 km from the trailhead. The exclusion of woodlands beyond 2 km of roads and trails was seen as necessary to manage travel costs and safety concerns and to enable desired sample sizes to be achieved within each season. Backcountry travel in CRMO is across extensive and inhospitable lava which poses extreme logistical challenges and safety concerns. Of particular importance is the ability for a field crew to complete measurements at a plot and return to a vehicle within daylight hours. There is no ability to stage overnight backcountry forays in the interior of the lava flows. Twenty percent (1,260 ha) of the woodland target population occurs within this frame, representing a substantial and representative proportion of *P. flexilis* woodlands in the park (Figure 7). The CRMO lava landscape is mostly flat, but with a relatively steep elevation gradient from north to south. The sampling frame captures a substantial portion of this key biophysical gradient, and elevations in the frame range from 1,605–1,900 m. Figure 8 shows a histogram of elevations captured by the GRTS sample. Elevation is 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 rust infection dynamics to be addressed. The road and trail system in the northern portion of park penetrates deep into the lava flows. Road biases that may occur in other landscapes, for example, because roads follow valleys, are not present in CRMO. However, scope of inference is restricted to the 2 km road/trail corridor, and does not extend to the sparse vegetation plant association.

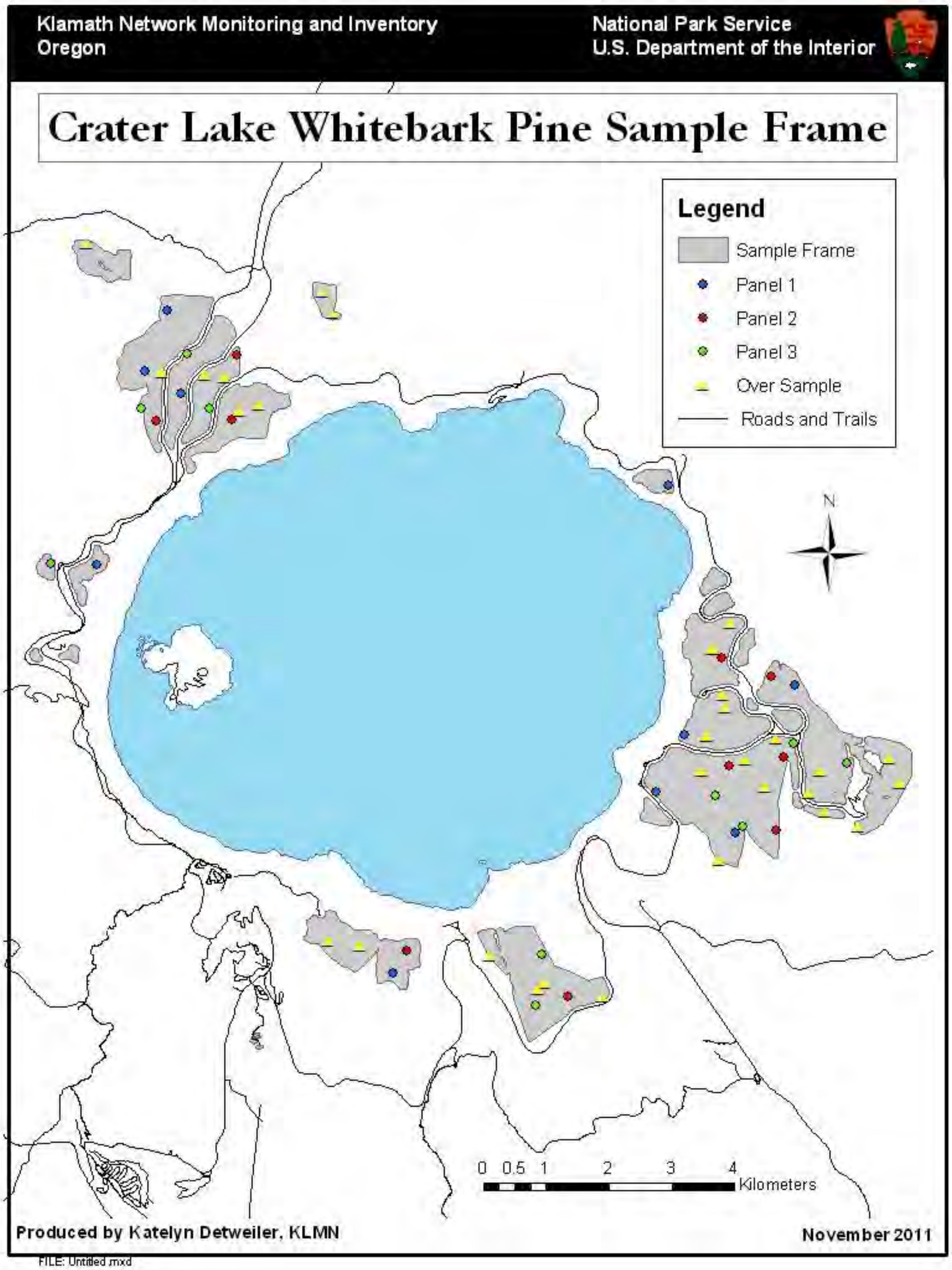

Figure 2. Whitebark pine sampling frame (gray, sampling frame equals known population) and GRTS sample of macroplot locations for Crater Lake National Park. Sample locations are separated into 3 equal panels of 10 macroplots each. Each macroplot will be sampled once every 3 years in a rotating panel sampling design. An oversample of points was also drawn using the GRTS algorithm to support any eventual site additions, deletions, or replacements.

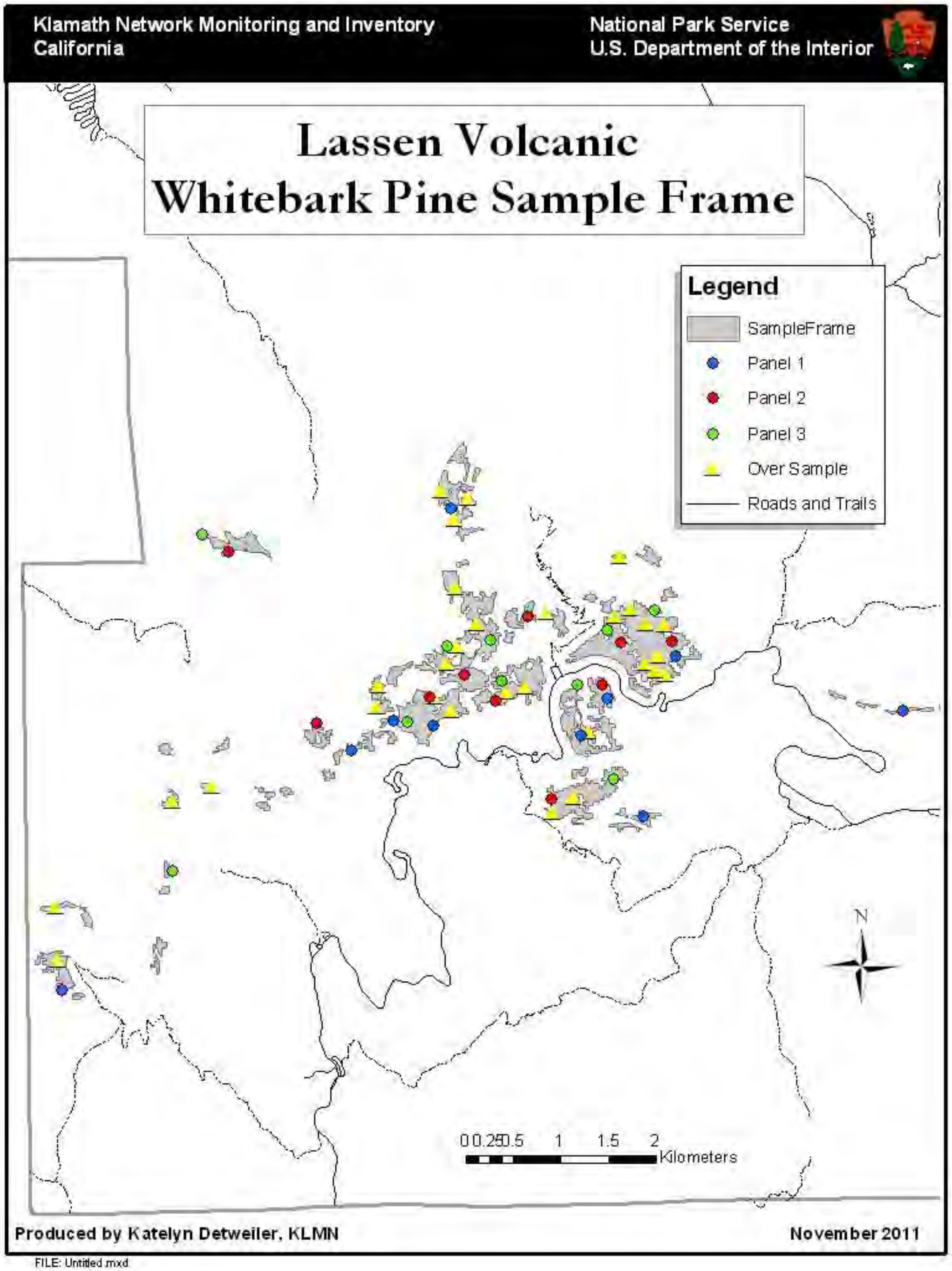

Figure 3. Whitebark pine sampling frame (gray, sampling frame equals known population) and GRTS sample of plot locations for Lassen Volcanic National Park. Sample locations are separated into 3 equal panels of 10 macroplots each. Each macroplot will be sampled once every 3 years in a rotating panel sampling design. An oversample of points was also drawn using the GRTS algorithm to support any eventual site additions, deletions, or replacements.

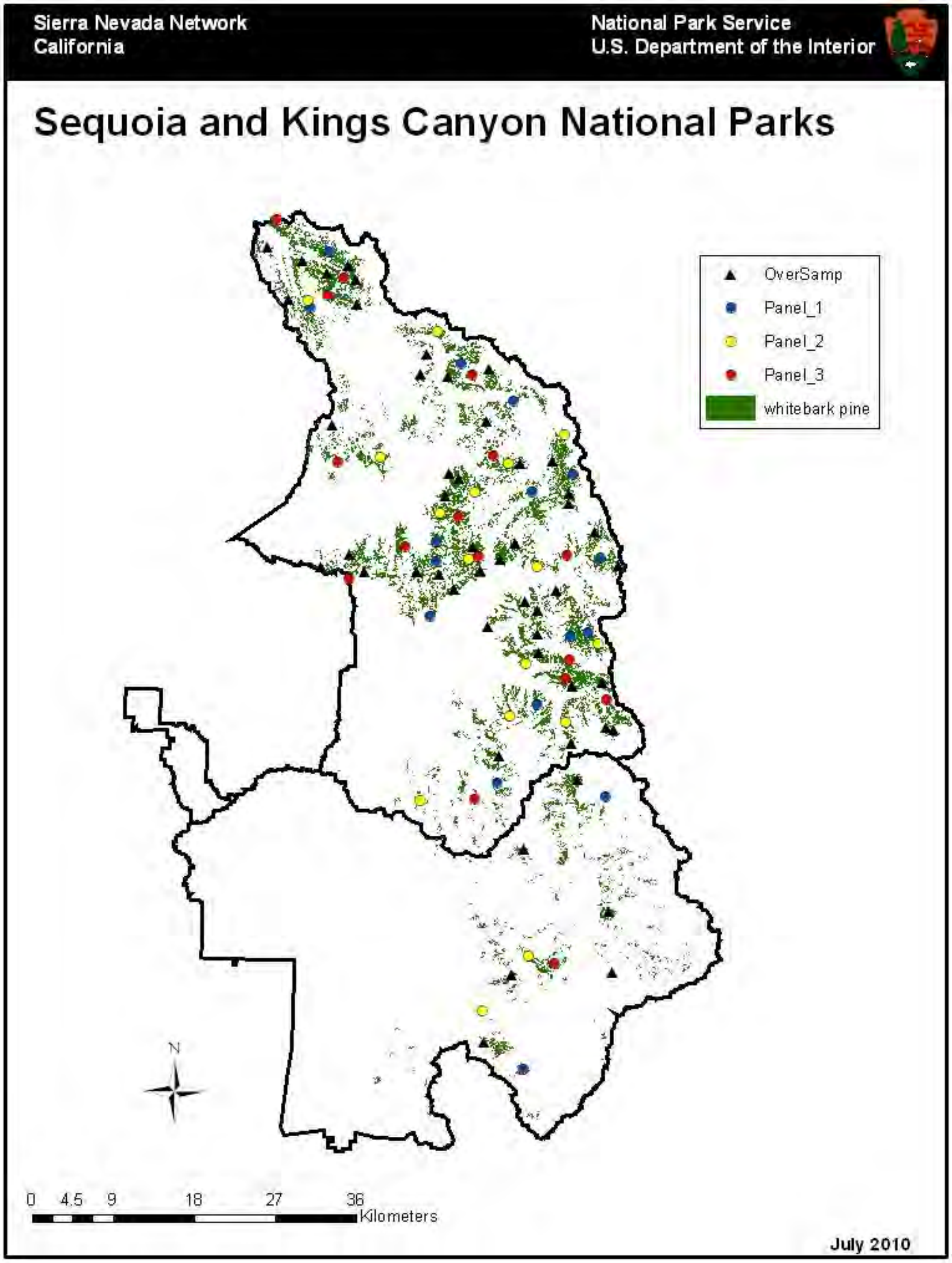

Figure 4. Whitebark pine sampling frame (green, sampling frame equals known population) and GRTS sample of macroplot locations for Sequoia (southern section of map) and Kings Canyon (northern section of map) National Parks. Sample locations are separated into 3 equal panels of 16 macroplots each. Each macroplot will be sampled once every 3 years in a rotating panel sampling design. An oversample of points was also drawn using the GRTS algorithm to support any eventual site additions, deletions, or replacements.

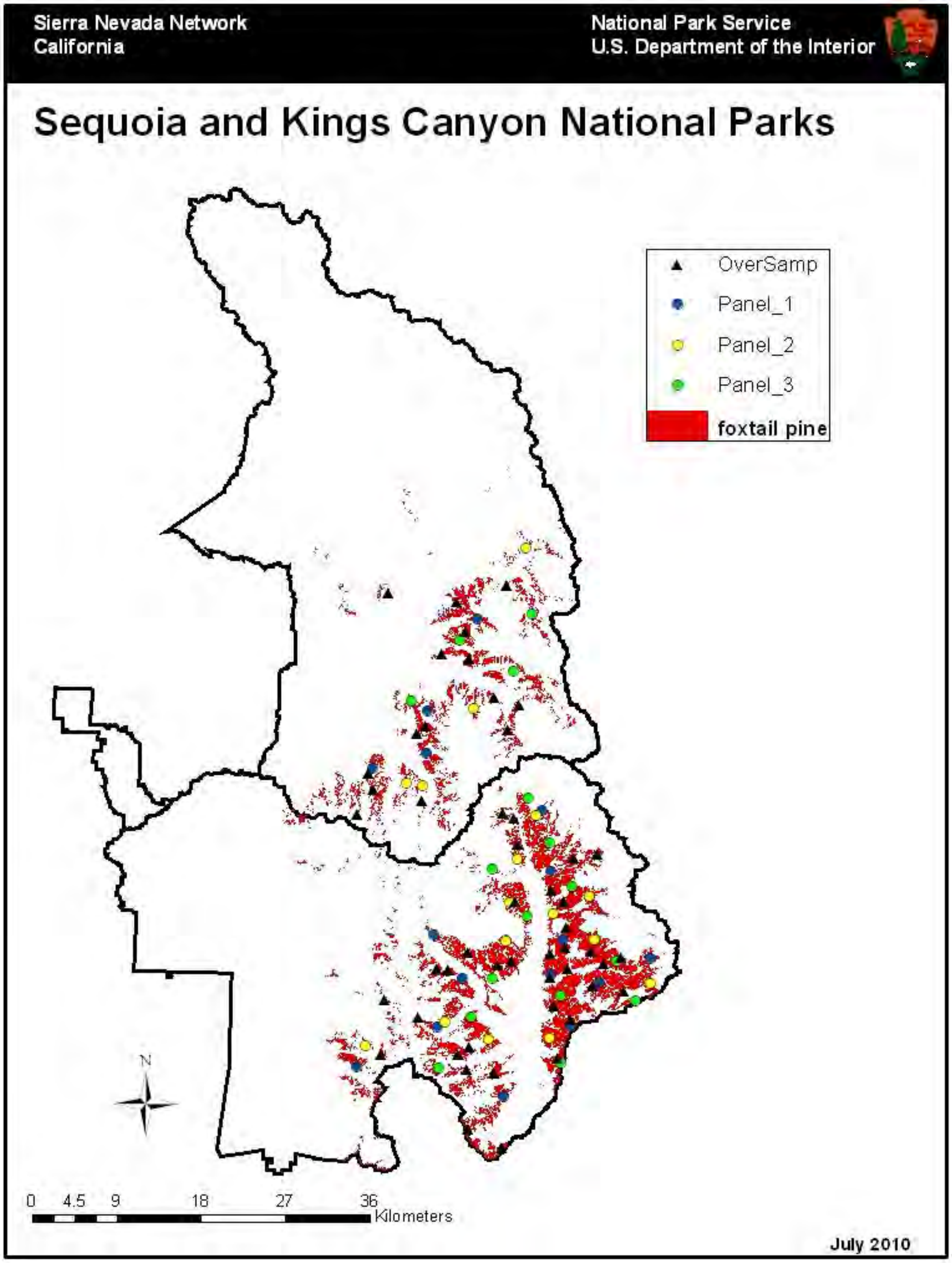

Figure 5. Foxtail pine sampling frame (red, sampling frame equals known population) and GRTS sample of plot locations for Sequoia and Kings Canyon National Parks. Sample locations are separated into 3 equal panels of 16 macroplots each. Each macroplot will be sampled once every 3 years in a rotating panel sampling design. An oversample of points was also drawn using the GRTS algorithm to support any eventual site additions, deletions, or replacements.

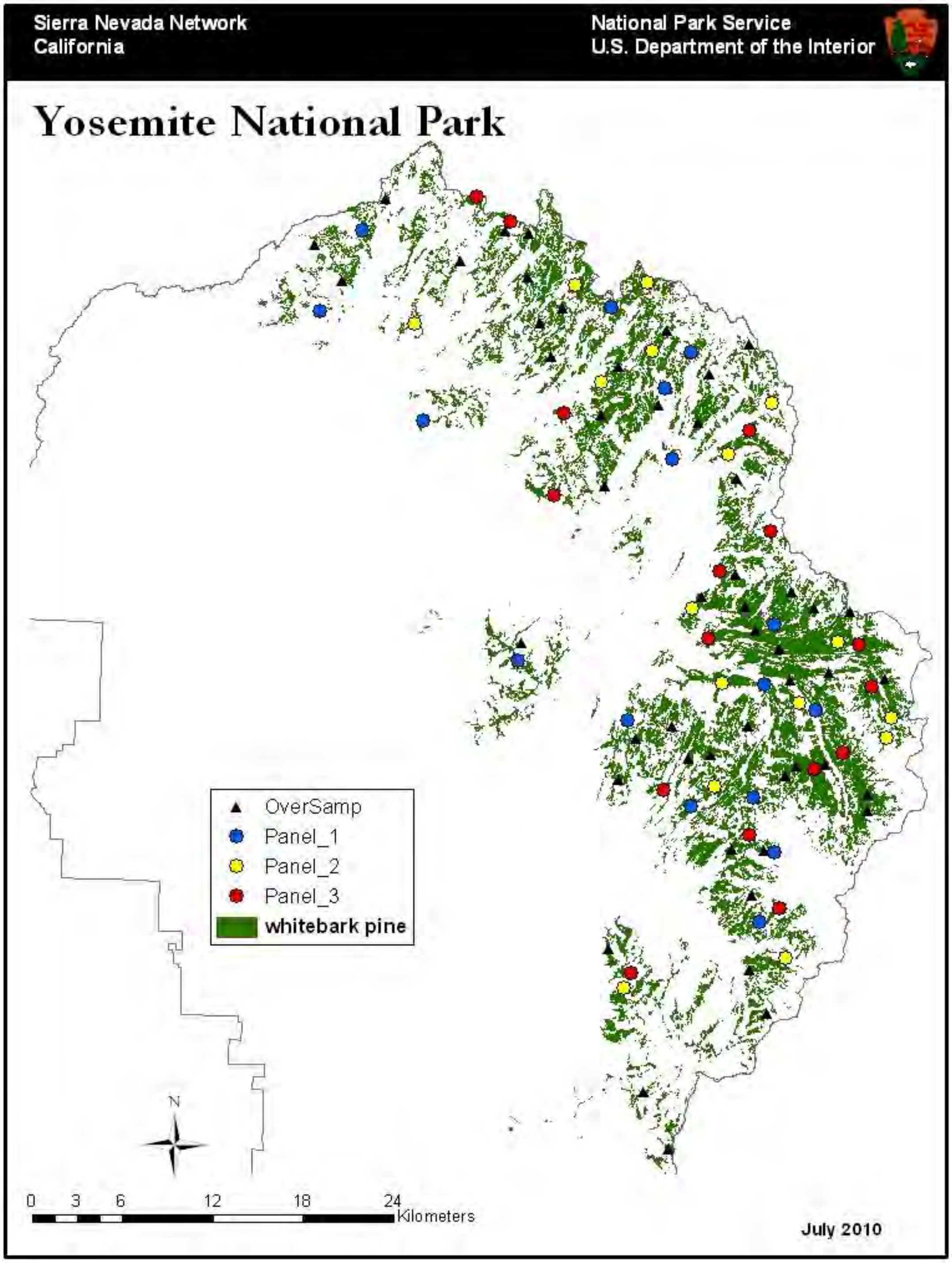

Figure 6. Whitebark pine sampling frame (green, sampling frame equals known population) and GRTS sample of macroplot locations for Yosemite National Park. Sample locations are separated into three equal panels of 16 macroplots each. Each macroplot will be sampled once every three years in a rotating panel sampling design. An oversample of points was also drawn using the GRTS algorithm to support any eventual site additions, deletions, or replacements.

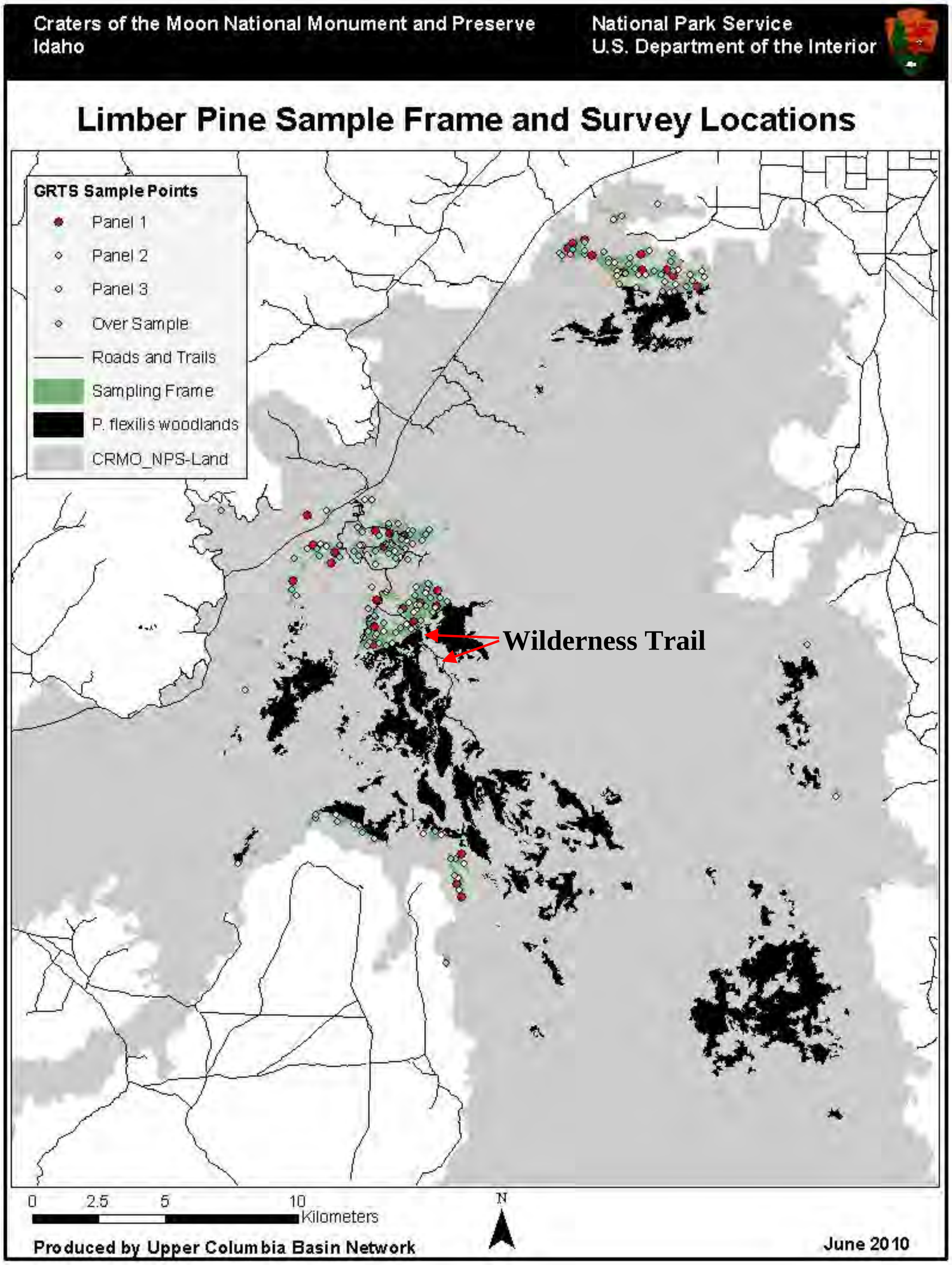

Figure 7. Limber pine monitoring sampling frame and GRTS sample of plot point locations within Craters of the Moon National Monument and Preserve. The sample frame (green) includes all areas of the park within 2 km of roads and trails that have been mapped by Bell et al. (2009) as *P. flexilis* woodland. Sample locations are separated into three equal panels of 30 points each of which will be visited once every three years in a rotating panel sampling design. The first year's panel of 30 points is illustrated in red. An oversample of points was also drawn using the GRTS algorithm to support any eventual site additions, deletions, or replacements.

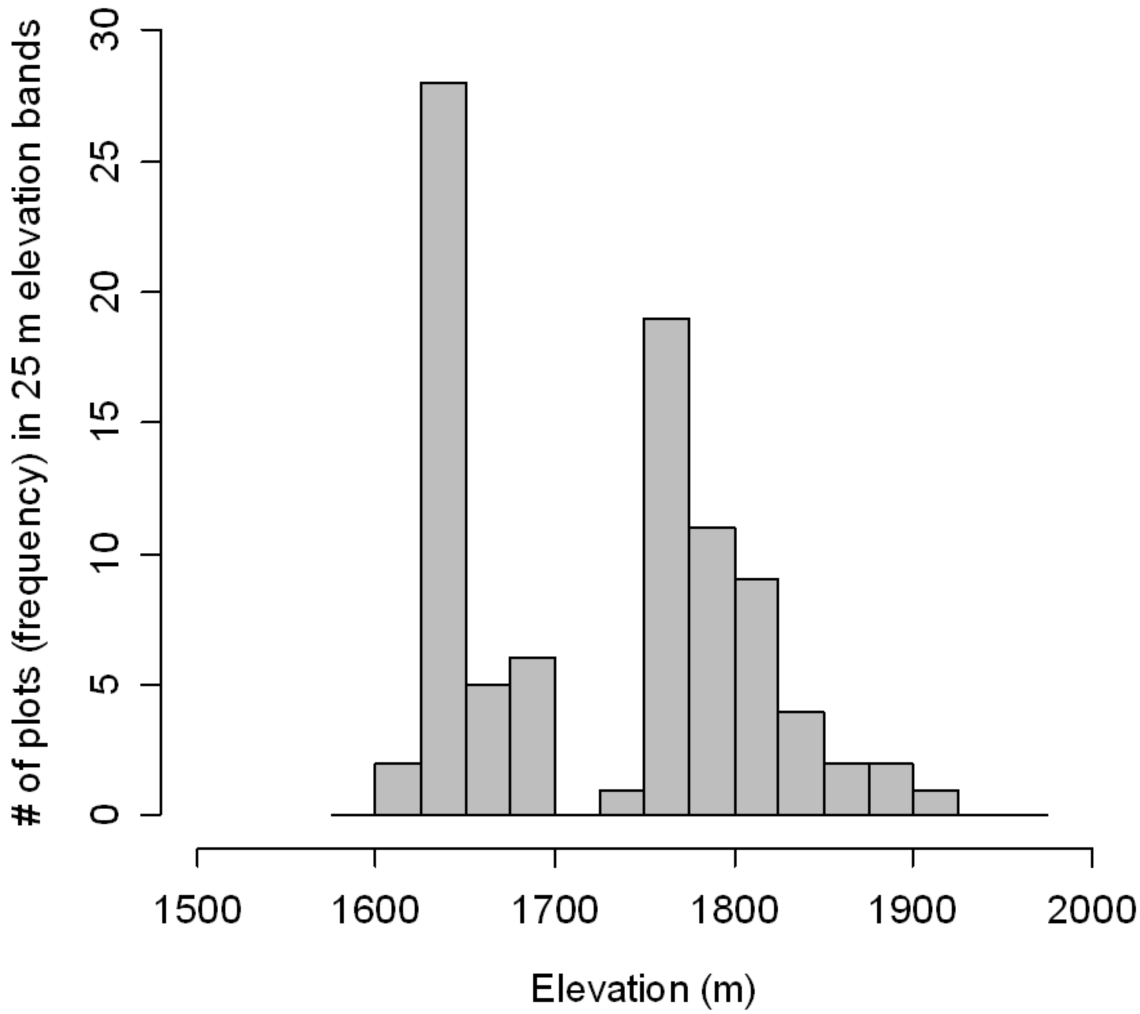

Figure 8. Histogram of elevations represented in the GRTS sample (*n* = 90) for Craters of the Moon National Monument and Preserve.

Sample Size and Timing of Sampling

We have adopted a 3-year rotating panel design for re-surveying permanent plots in all networks. The phenological window within each year for sampling is wide, since understory vegetation is not recorded by these networks in this protocol. Sampling will occur from June–October. Each plot will be surveyed once per 3-year rotation, but the panel structure differs slightly among networks as follows:

Klamath Network Sample Size and Revisit Design

A total of 60 macroplots will be monitored for whitebark pine population dynamics, evenly divided between CRLA and LAVO. KLMN has designated three 10-macroplot panels for each of the two parks (a [1-2^3] design, using notation from McDonald 2003) as outlined in Table 4a.

Sierra Nevada Network Sample Size and Revisit Design

A total of 48 macroplots will be monitored in each park (YOSE and SEKI) for each species, resulting in an overall total sampling effort of 96 macroplots in SEKI (48 whitebark and 48 foxtail) and 48 macroplots in YOSE (whitebark only). SIEN has subdivided its sample of macroplots for each park and species into three panels, each revisited once per 3-year rotation cycle (a [1-2^3] design, *sensu* MacDonald 2003) (Table 4b).

Upper Columbia Basin Network

UCBN has subdivided its total target sample size of 90 macroplots into three 30-macroplot panels, each revisited once per 3-year rotation cycle (a [1-2^3] design, *sensu* MacDonald 2003) (Table 4c).

Table 4. Revisit design for monitoring white pine species in a) the Klamath Network, b) the Sierra Nevada Network, and c) the Upper Columbia Basin Network.

a) KLMN. This panel design is followed for whitebark pine in both CRLA and LAVO *n* = 60 macroplots.

Panel	Year												
	2011	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
1 (n = 10)	deferred			x			x			x			x
2 (n = 10)		x			x			x			x		
3 (n = 10)			x			x			x			x	

b) SIEN. This panel design is followed for whitebark pine in YOSE and for whitebark and foxtail pine each in SEKI for a total SIEN *n* = 144 macroplots.

Panel	Year												
	2011	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
1 (n = 16)	x			x			x			x			x
2 (n = 16)		x			x			x			x		
3 (n = 16)			x			x			x			x	

c) UCBN. This panel design is followed in CRMO for a total UCBN *n* = 90 macroplots.

Panel	Year												
	2011	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
1 (n = 30)	x			x			x			x			x
2 (n = 30)		x			x			x			x		
3 (n = 30)			x			x			x			x	

Sample Size Calculations

Sample size requirements were estimated from 2009 pilot data available from KLMN and UCBN. Using these data, we 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 blister rust, and number of seedlings per ha. The formulas for simple random sampling (SRS) are conservative to use for estimating status of these variables with the proposed GRTS sampling design (Stevens and Olsen 2003, Theobald et al. 2007). The SRS formula for sample size 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 $n = (zS/e)^2$. We used different estimates of standard deviation (S) for KLMN and UCBN based on the available pilot data.

The sample size requirements for a given margin of error for basal area are displayed in Figure 9. The proposed sample sizes of 10 macroplots per year (panel) for KLMN and 30 macroplots per year for UCBN are sufficient to support adequately precise estimates of annual status for this metric. 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 (Figure 10), scaled to seedlings per 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 CRMO and SIEN indicate that the proposed methodology, which uses larger regeneration plots, will result in less variable values for seedling density than that employed in the pilot effort (Stucki and McKinney *In Prep*, Stucki and Rodhouse 2012).

In 2009 and 2011, UCBN and SIEN did not find blister rust on limber pine or whitebark pine trees (Stucki and McKinney *In Prep*, Stucki and Rodhouse 2012). KLMN found between 0 and 35% of whitebark pine trees infected with rust in macroplots during 2009. Using KLMN data only, we investigated an SRS estimator and a ratio estimator as used in GRYN (GYWPMWG 2007) to estimate the proportion of trees infected with blister rust. The sample size for the ratio estimator is $n = (zS_e/e\bar{x})^2$, where $\bar{x}$ is the estimated average number of trees, and S_e^2 is the estimated variance based on a ratio estimator. This variance is calculated as $S_e^2 = \frac{1}{n-1}\sum_i (y_i - \hat{B}x_i)^2$, where y_i is the number of infected trees in macroplot i, x_i is the number of trees in macroplot i, and $\hat{B} = \frac{\bar{y}}{\bar{x}}$ is the estimated ratio of infected trees.

Figure 11 displays the required sample size for different margins of error. There is a large gain in efficiency by using the ratio estimator, not surprisingly because within KLMN pilot data there was a strong relationship between number of total live trees and number of trees infected. The sample sizes for each network will provide a reasonable margin of error for the proportion of trees infected with blister rust. Ultimately, however, each network chose a target sample size to be distributed among the panel years by considering the above estimates of precision, estimated time required to access and sample plots, the extent of target pine forest in each park, and budget.

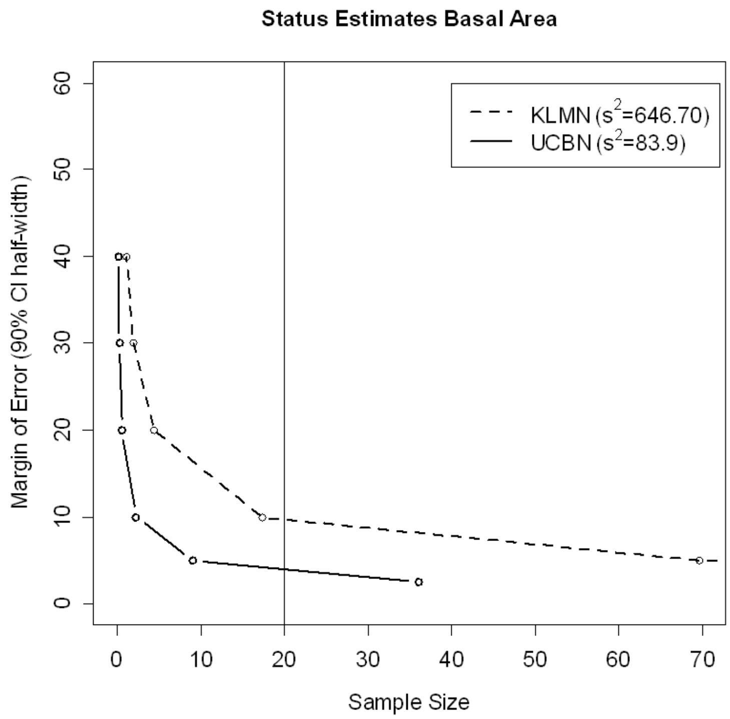

Figure 9. Sample size estimates for total basal area based on 90% confidence interval half-widths for KLMN and UCBN.

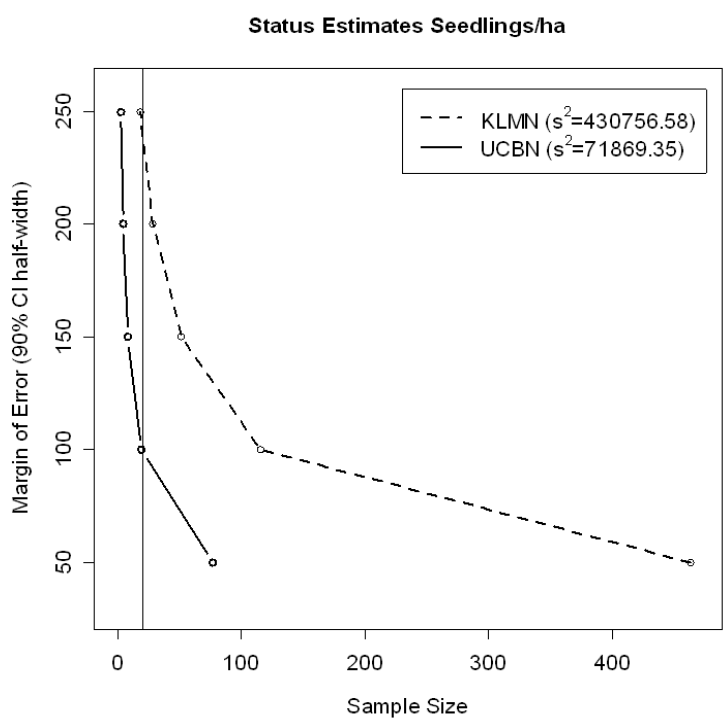

Figure 10. Sample size estimates for seedlings/ha (trees <1.37 m) based on 90% confidence interval half-width for KLMN and UCBN.

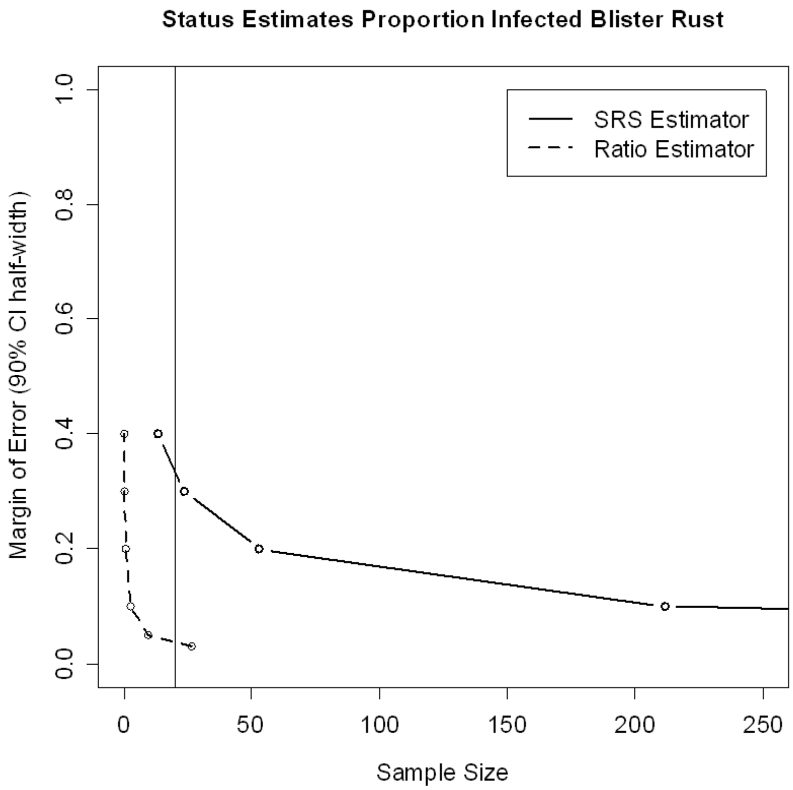

Figure 11. Sample size estimates based on using SRS and ratio estimators for the proportion of infected trees with blister rust for KLMN.

The KLMN originally explored sampling 25 macroplots every three years at CRLA and LAVO, which would have provided stronger status estimates for the sample years in each park. However, we decided to shift our resources to sample a smaller number of macroplots (n= 10) in each park each year, with a three year revisit plan. This change was intended to provide status estimates in each park in every year and to better align with yearly sampling at SIEN and UCBN. The yearly sampling will provide better estimates of yearly variation in disease dynamics and will allow a higher cumulative sample size for longer term trend analyses (n=30) in each park. Temporal estimates of variability were not available at the time this protocol was developed, but power for all parks is expected to be increased greatly when all plots are revisited (year 6), and when the number of revisits of each panel increase from 2-5 (years 6-15). Although the temporal variation for important forest impacts (e.g., blister rust, mountain pine beetle) will differ, most will be detectable over a 6-15 year time frame.

Response Design

Sample Unit

Macroplots, consisting of five subplots, and containing nine regeneration plots are used to measure and track forest demographic parameters, disease and insect occurrence, and magnitude of their impact. 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 5 times to accommodate the often sparse distribution of white pines in our parks, to adequately address forest demographic objectives. This design effectively represents five parallel 10 x 50 m subplots as used in the GRYN and as proposed by the Whitebark Pine Ecosystem Foundation (Tomback et al. 2005). In Figure 12, variation in mean basal area of limber pine in CRMO is shown to initially decrease and then increase slightly as plot size increases. Several metrics were analyzed as illustrated in Figure 12 from CRMO, SEKI, and YOSE, and results suggest that a large macroplot of approximately 50 x 50 m (Figure 13) would yield parametric estimates with the lowest error and would therefore be most efficient for these three networks.

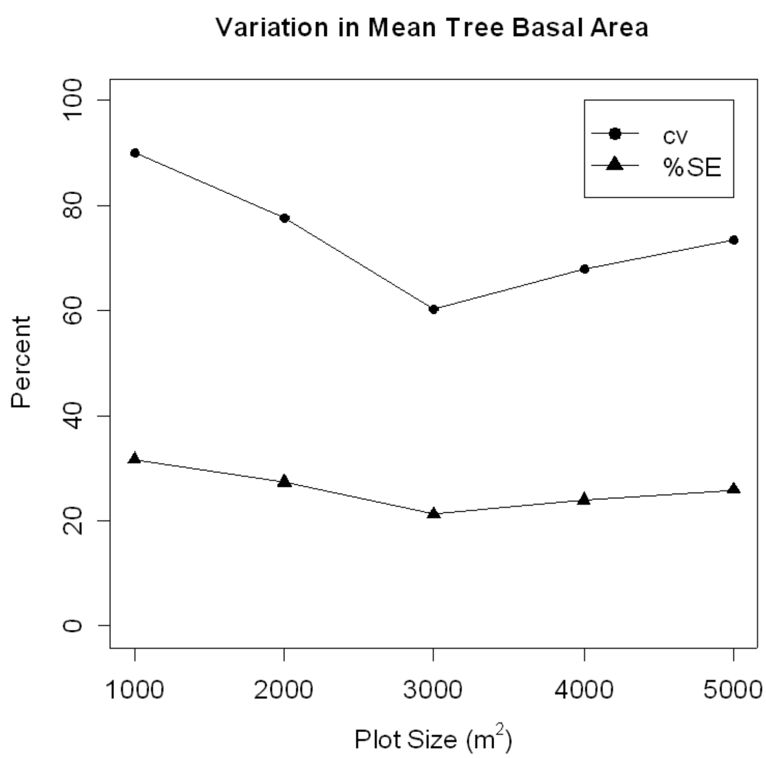

Figure 12. Variation in mean limber pine tree basal area (m^2/ha) for eight sets of five contiguous 20 x 50 m plots measured in CRMO in 2010. cv is the coefficient of variation, calculated as the sample standard deviation divided by the sample mean, and %SE is the percent standard error calculated as the sample standard error divided by the sample mean.

A total of nine square regeneration plots (3 x 3 m) are established within each 50 x 50 m macroplot to measure seedling regeneration (Figure 13). Regeneration plots are located at each corner (4), at each midpoint between corners (4), and in the middle (1) of the macroplot (Figure 13). We consulted multiple sources, including the U.S. Forest Service Forest Inventory and Analysis design (Bechtold and Patterson 2005) and forest ecologists from other agencies and universities to help inform the regeneration plot size and number decision. The current design was chosen because it provides a reasonable balance among sampling time constraints, observer accuracy and precision, and total area sampled.

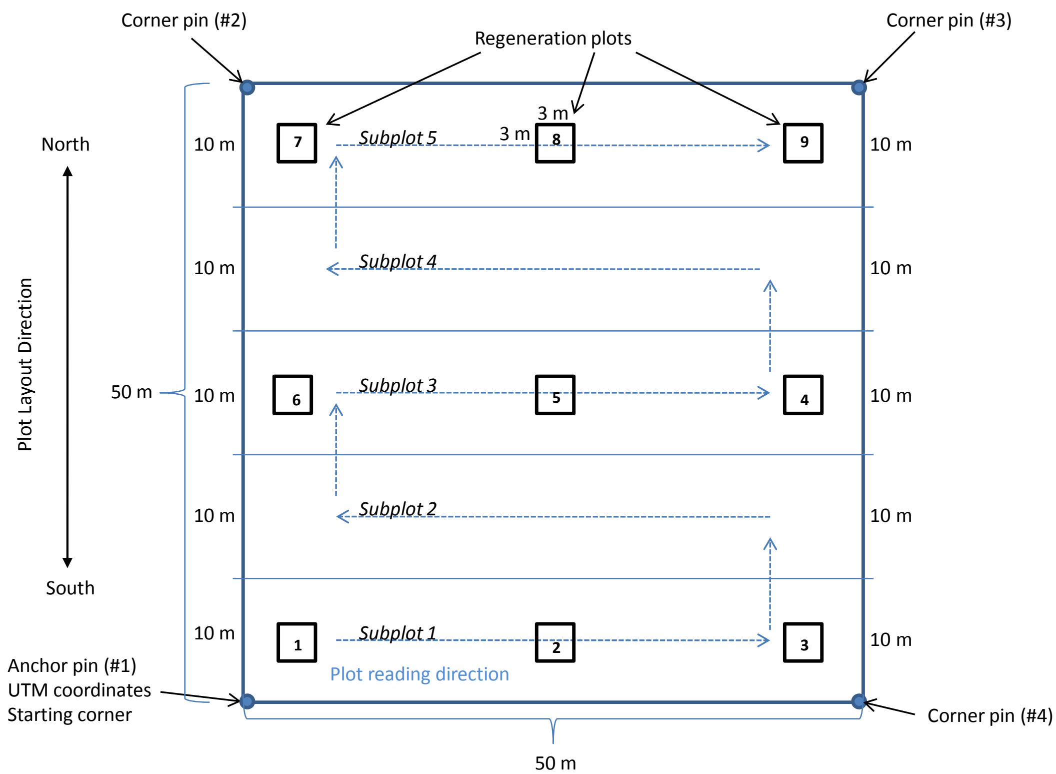

Figure 13. 50 x 50 m plot layout used in SIEN, UCBN, and KLMN white pine monitoring.

Plot Measurements

The response design for this protocol closely matches the *Interagency Whitebark Pine Monitoring Protocol for the Greater Yellowstone Ecosystem* (GYWPMWG 2007) but differs 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 5 outlines the relationship among the variables, raw data, summarized data, and monitoring objectives. Detailed instructions on response design measurements are provided in SOP 5 and only a general overview is presented here.

Each live tree ≥1.37 m has a uniquely numbered metal tag attached to it, its species identified, and diameter at 1.37 m (breast height, dbh) and height measured. Dead trees are not tagged but are distinguished between recently dead, and dead. Recently dead trees have red needles present (but no green needles) and dead trees have no needles present. White pine blister rust infection is assessed for all living white pine trees. The bole and branches of white pine trees are each vertically divided into thirds (upper, middle, and bottom) and each third is assigned one of three rust condition classes: 1) absent–no sign of rust infection, 2) active cankers (aeciospores present), or 3) no active cankers, but the presence of three of the following five indicators of infection: rodent chewing, flagging, swelling, roughened bark, and oozing sap. Mountain pine beetle occurrence is recorded for all pine trees using three indicators of beetle activity: pitch tubes, frass, and J-shaped galleries. The presence of galleries is only determined for recently dead and dead trees because bark has to be removed for this assessment. Dwarf mistletoe infection is recorded for all living white pine trees by noting presence or absence for each third of a tree. The level of canopy kill in live white pine trees is determined by dividing the tree‘s canopy (all the main branches that begin as bifurcations off the bole, encompassing all foliage and supporting twigs and side branches) into thirds and ocularly estimating the percentage of each third that is dead. Cone production is recorded as to whether female cones are present or absent on each white pine tree. Live seedlings are tallied by species and height class and summed across 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 5. Relationship among measured variables, data, and objectives for long-term monitoring of white pine communities in the Pacific West Region. (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. Mean diameter (cm) by spp. Diameter classes (5 cm); proportion and TPH by spp.	1. composition & structure 2. growth rate
Height	Tree (m)	Mean ht. (m); all spp. and by each spp. Height classes (3 m); proportion and TPH by spp.	1. composition & structure 2. growth rate
Status	Tree (live or dead)	Proportion live and dead; all spp and by each sp. TPH and proportion by 5 cm diameter classes in each condition; all spp and by each sp.	2. birth and death rates
Crown kill	Each of three parts of a tree (%)	Mean (%); individual trees, each sp, and all spp.	3. level of crown kill
Active canker	Each of three parts of a tree (p/a)	Proportion and TPH with active cankers by each white pine sp.	3. rust infection incidence
Inactive canker	Each of three parts of a tree (p/a)	Proportion and TPH with inactive cankers by each white pine sp.	3. rust infection incidence
Rust infection	Tree (p/a of active or inactive canker)	Proportion and TPH infected and healthy by each white pine sp. TPH by 5 cm diameter classes in each condition by each white pine sp.	3. rust infection incidence
Bark beetle	Tree (p/a)	Proportion and TPH with beetle sign; all spp and each sp.	4. incidence of bark beetle
Dwarf mistletoe	Tree (p/a)	Proportion and TPH with mistletoe sign; all spp 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 spp and each sp for each size class.	1. composition & structure 2. birth rates

Field Methods

Field Season Preparations

The protocol, including all standard operating procedures (SOPs), is reviewed by the Project Lead in each network to ensure that any changes to sampling procedures have been updated prior to the beginning of the coming field season. Specific park applications for research permits are available at the Research Permit and Reporting website (https://science.nature.nps.gov/research/ac/ResearchIndex). Wilderness compliance, minimum tool analyses, 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. If Personal Digital Assistant (PDA) or tablet Personal Computer (PC) devices are used by a network, they will be loaded with current versions of field data forms or database, respectively. All networks will photocopy enough hardcopy paper field forms to complete their sampling season, including back-up forms, even if digital data loggers are also being used. Forms are printed on *Rite in the Rain* waterproof paper. Equipment is checked against the equipment list (SOP 1) and repairs or purchases are made as needed to complete the list. Biological technicians are either hired as park service employees or through cooperating universities. In either case, the hiring process is initiated well in advance of the field season, i.e., by January. Field crews may be shared among networks, as feasible.

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 is provided by the project‘s lead investigator or other appropriate staff member, with assistance from the GIS Specialist and Data Manager and, after all crew members have reviewed the protocol narrative and SOPs, they will cover the use of sampling and navigation equipment, methodologies for data collection, tree species identification, and identifying symptoms of blister rust infection, beetle occurrence, and dwarf mistletoe infection. An assessment of crew competencies is 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., canopy 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 4. Travel times can be substantial and should be carefully planned. Once on site, access to sampling areas will require hiking across rugged terrain, backcountry camping, and field teams must be prepared for challenging weather conditions, including extreme heat, cold, rain, and snow. Each team member should maintain a supply of warm clothes and rain gear, sun hats, and plenty of water. Safety procedures outlined in SOP 9 should be adhered to, including maintaining 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 debriefing prior to initiation of field work, and throughout the duration of sampling, as necessary. First aid and other safety equipment must be kept in project vehicles and easily available at all times. Before the start of each field session, plot locations will be organized into convenient and efficient routes (―hitches”) through the study area according to the sample layout and topography. Each park has impassable barriers, such as cliffs and rugged lava flows that will interrupt travel between the sample locations. These routes will be illustrated on hard copy maps, developed and annotated during close-out of the previous season, drawing on accumulated field experience.

Plots will be located using GPS, following procedures outlined in SOP 3. 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 where field crews visit and sample a set of plots during a given hitch. Plot locations and trip routes are displayed 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), contingency plans, and notes and experiences from previous trips for plot revisits. 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 of the unit until the coordinates have been reached. At this point, the person 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 4). 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 (see SOP 4 for detailed description of locating established plots).

Azimuth directions of plot boundaries in relation to the plot monument are provided to the crew (SOP 4). Each plot corner is marked with metal rebar sticking 5 cm above the ground. SOP 4 details the procedure for laying out the plot. 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. See SOP 4 for how to establish regeneration plots. For plot revisits, regeneration plot locations are found after identifying plot boundaries.

All trees ≥1.37 m height in plots are marked with steel tags (2.5 cm diameter) displaying unique numeric identifiers. Tags are attached at 1.37 m height on the plot center side of the tree to aide in relocation. 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 4 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 4 for detailed instruction on taking and recording photos). Macroplots are sampled following a pre-established directional pathway by locating the starting point and following a specific azimuth across the slope until the other side of the macroplot is reached (Figure 13). Once the far side is reached, crew members turn 90°, move into the adjacent 10 x 50 m subplot, and return back in the opposite direction reading the plot across the slope contour. SOP 5 provides detailed instructions on how to work from the starting point to the ending point. Trees are numbered in consecutive order from the starting point to the end reflecting the directional pathway (SOPs 4 and 5 for instructions and diagrams). Data sheets 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 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 (see SOP 5 for detailed instructions on how to handle missing tags).

Data Entry and Management

This protocol includes an option for collecting data on field data sheets and electronically using digital data entry forms. The chosen method will vary by network. Field data sheets are located in SOP 1. Electronic data collection has not been implemented but is planned for 2012 following initial implementation. If electronic data collection devices are used, the data must be backed up daily on at least one other data storage media (e.g., jump drive, CD-ROM, backup hard drive, etc.).

There are two data sheets, one for tree-level data and one for plot-level and seedling data. The tree-level data sheet is constructed of columns with the response variables and rows for individual tree values. The plot-level data sheet has cells for plot information (e.g., UTMs, elevation, slope, etc.) and subplot seedling tallies. Plot dossiers are made for each plot and are given to crews prior to leaving for a hitch. Dossiers 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 dossiers is archived in the project database (i.e., notes and azimuths).

Data sheets and/or electronically entered 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 in between hitches, each network's Project Lead reviews the data and discusses them with the crew to ensure further QA/QC. Data from paper data sheets are entered into the white pine project database, a Microsoft Access application shared among networks. Validation rules programmed into the database help detect logical inconsistencies. Paper data sheets or PDA sheets are archived by each network on a short-term basis, allowing for sufficient time for all possible QA/QC problems to be resolved. Paper data sheets are scanned and kept electronically for the life of the project. The archived database, including backup copies and versions served off the NPS Reference Services, becomes the main repository for legacy data for this project.

Data are entered directly into a tablet PC with custom Microsoft Access data entry forms. A working copy of the project database will be used on the field tablets and provided to the Data Managers during regular updates throughout the field season or at the end. Paper data sheets are provided and only used in the event of tablet PC malfunction. Data collected using the tablet PC are reviewed for accuracy before performing a data backup prior to leaving the site on a flash drive or similar medium. At the end of sampling a park, data are downloaded to the permanent location, reviewed and certified by the Project Lead, and submitted to the Data Manager.

After the Field Season

Equipment is compared against the equipment check list 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. A final check of the equipment against the equipment list is made and the list annotated as necessary. Each network stores its own equipment. SIEN equipment is stored in the SIEN office in El Portal (YOSE). The KLMN equipment is stored at the network office in Ashland. UCBN equipment is stored at the network headquarters in Moscow, ID.

Data Handling, Analysis, and Reporting

While the following section outlines procedures for white pine monitoring data handling, analysis, and report development, additional details and context for this section may be found in the individual network data management plans (Dicus and Garrett 2007, Mohren 2007, Cook and Lineback 2008). The network monitoring plans also provide good overviews of each network‘s data management and reporting strategies.

Overview of Database Design

The white pine database is an application developed within Microsoft Access. It adheres to Natural Resource Database Template standards (NRDT v. 3.2). The database application consists of a front-end user interface linked to a back-end database file. The front-end provides forms for entering data, queries for facilitating QA/QC, and tools for exporting data. The back-end of the database holds the core data tables. The database application also contains an integrated data dictionary database file (holding various lookup tables), and an integrated species database file (holding species data from the NPSpecies database) that will be specific to each network.

The general data management strategy employs a —working copy” of the database application that is used to enter and store the current season‘s data, perform error-checking and validation. A —master copy” of the database application stores all validated data and is used to facilitate multi-year analyses and provide specific data report and export formats. Details of the database, including a description of core and peripheral tables, a logical model of table relationships, and a data dictionary, are presented in SOP 6.

Data Entry

Accurate data recording is viewed as an important step in the overall QA/QC process, and care should be taken to review all plot data while the observers are in the field so that any inconsistencies or questions can be resolved without relying on distant or hazy memories. Data entry is a group process, with a designated data entry crew member working the tablet PC. Other crew members carefully call entries, such as tree diameter or height, and wait for a correct return verification call from the crew member entering data. In this way a real-time double-checking process is established. In addition, the database has built-in quality assurance components such as pick lists and validation rules to standardize spelling and test for missing data or illogical combinations, respectively.

Quality Review

After the data have been entered and processed, they are reviewed by the Project Lead for quality, completeness, and logical consistency. The working database application will facilitate this process by showing the results of pre-built queries that check for data integrity, data outliers and missing values, and illogical values. The user may then fix these problems and document the fixes. Not all errors and inconsistencies can be fixed, in which case the resulting errors are then documented and included in the metadata and certification report.

Metadata Procedures

Data documentation is a critical step toward ensuring that data sets are useable for their intended purposes well into the future. This involves the development of metadata, which can be defined as structured information about the content, quality, and condition of data. Additionally, metadata provide the means to catalog data sets within intranet and internet systems, making data available to a broad range of potential users. Metadata for high-elevation five-needle pine monitoring data will conform to Federal Geographic Data Committee (FGDC) and NPS guidelines and will contain all components of supporting information such that the data may be confidently manipulated, analyzed, and synthesized. For long-term projects like this one, metadata creation is most time consuming the first time it is developed; after which most information remains static from year to year. Metadata records in subsequent years then only need to be updated to reflect current publications, references, taxonomic conventions, contact information, data disposition and quality, and to describe any changes in collection methods, analysis approaches or quality assurance for the project.

Specific procedures for metadata development and posting are outlined in the individual network Data Management Plans. In general, the Project Lead and the Data Manager (or Data Technician) work together to create and update an FGDC- and NPS-compliant metadata record in XML format. The Project Lead should update the metadata content as changes to the protocol are made, and each year as additional data are accumulated. Edits within the document should be tracked so that any changes are readily apparent to those who will use it to update the XML metadata file. At the conclusion of the field season, the Project Lead will be responsible for providing a completed, up-to-date metadata interview form to the Data Manager. The Data Manager will facilitate metadata development by creating and parsing metadata records, and by posting such records to national clearinghouses as described below.

Sensitive Information

Metadata development includes determining if the data contain sensitive information such as specific locations of rare, threatened, or endangered species. In some cases, it may be necessary to restrict access to data containing sensitive information, except where a written confidentiality agreement is in place. The Project Lead and Park Resource Manager should work together to identify any sensitive information in the data. Their findings should be documented and communicated to the Data Manager. We currently do not anticipate that sensitive information will be present in the white pine monitoring data.

Data Certification

Data certification is a benchmark in the project data management process that confirms 1) the data are complete for the period of record; 2) the data have undergone and passed quality assurance checks; and 3) the data are appropriately documented and suitable for archiving, posting, and distribution. Certification is not intended to imply that the data are completely free of errors or inconsistencies, which may not have been detected during quality assurance reviews.

To ensure that only data of the highest possible quality are included in reports and other project deliverables, the data certification step is an annual requirement for all tabular and spatial data. The Project Lead is primarily responsible for completing certification. The completed form, certified data, and updated metadata should be delivered to the Data Manager, see the Operational Requirements section. Additional details of the certification and delivery processes are included in SOP 6.

Data Delivery

Certification Form

The PWR white pine monitoring protocol will utilize a certification form submitted by the Project Lead to ensure:

- The data are complete for the period of time indicated on the form.
- The data have undergone the quality assurance checks indicated in the white pine monitoring protocol.
- Metadata for all data have been provided (when applicable).
- Project timelines are being followed and all products from the field season have been submitted.
- The correct level of sensitivity is associated with the deliverables.

A new certification form should be submitted each time a product is submitted. If multiple products are submitted at the same time, only one certification form is needed for those products. Certification forms can be obtained from the appropriate network web site or by contacting the network Data Manager.

Field Forms

Hardcopy field forms will be provided to crew members for use as backup in the event of tablet PC malfunction. If paper data sheets are used, they will be entered into the working database as soon as possible and stored and archived following procedures specified in each network‘s Data Management Plan.

A datasheet log will be maintained to record when a datasheet has been misplaced or when a datasheet is destroyed. Since the datasheets will be numbered, a missing datasheet must be accounted for at the end of the year. A datasheet log can be obtained by contacting the Data Manager.

Databases

At the end of the field season, following the timeline in Table 7, each network‘s Project Lead should transfer a copy of the project database to the Data Manager. The database should have gone through all validation and verification processes outlined in SOP 6 prior to the transfer. Once transferred, the Data Manager will subject the data to one more round of validation and verification checks. The Data Manager will work with the Project Lead to correct any errors. Once the data have been thoroughly checked, the data will be uploaded into the master copy of the project database.

Photos

Images and associated metadata will be transferred to the Data Manager in the format described in each network‘s data management plans following the timeline in Table 7.

GPS/GIS Files

The Project Lead is responsible for submitting a GIS layer of sites that are expected to be visited in a given field season to the Data Manager at least 3 weeks prior to the beginning of the field work. These layers will be stored in the spatial data folder of the project folder.

It is the responsibility of the field crew to collect GPS locations at the sampling site, or to verify existing GPS locations when relocating plots. At the end of the field season, the Project Lead will provide the Data Manager with a list of all sites that were surveyed along with the GPS files collected by the field crew. A polygon shapefile of the surveyed sites will be uploaded to the appropriate data folder for archiving on the network server.

Metadata
Following the timeline outlined in Table 7, the Project Lead should submit a Metadata Interview form for each GIS layer and the Project Database after the field season. If metadata have not been completed for this project, the form will need to be completed in full. If metadata have been completed, and no updates are needed, just complete question one on the form. In addition to the metadata form, an updated data dictionary should be submitted if the data collected in this protocol have been altered (e.g., new or deleted parameters measured, additions to picklists, etc). Prior to the start of the following field season, the Data Manager should update the full metadata (Parsed XML) and post it to the proper locations.

Equipment
Changes in the type or brand of equipment used to conduct field sampling can introduce errors or bias in data collection. To avoid this possibility, the field crew should maintain an equipment log to record any updates or changes to the equipment being used to measure the various parameters described in this protocol. It is the responsibility of the Project Lead to submit the equipment log to the Data Manager following the timeline in Table 7.

Data Archival Procedures
Each network implementing this monitoring protocol will follow archiving procedures described in network Data Management Plans and associated protocol SOPs. Digital data that have been certified will be permanently archived on a network server, posted to the network website, and posted to the national web-accessible secure Integrated Resource Management Application (IRMA) hosted by the NPS Washington Support Office (WASO) or National I&M Program. The IRMA application incorporates functionality previously handled by separate databases into a single web interface that comprises:

- The master database for natural resource bibliographic references.
- The master database for biodiversity information including species occurrences and physical or written evidence for the occurrence (i.e., references, vouchers, and observations).
- A centralized data repository with a graphical search interface.

A review of archive and expendable data products will be undertaken by the project leader and data manager during season close-out each year. An example of an expendable data product is an intermediate draft of an annual report that was saved during report preparation.

Data Analysis

Annual Status Analysis

Status results are summarized after each year of data collection. Standard summary statistics are presented with content similar to that shown in Table 5, and include measures of central tendency and spread. Data are summarized by species, park, and network. Estimation is design-based and will incorporate inclusion probabilities resulting from the membership design. The ratio estimator will be used to estimate blister rust incidence as described for sample size calculations previously, and as is used by the GRYN (GYWPMWG 2007). The ratio estimator allows additional information on the number of trees per plot to be incorporated and provides more precise estimates of incidence.

Exploratory data analyses are performed 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. GRTS samples are drawn using tools from the *spsurvey* package (Kincaid et al. 2011) in R (version 2.11.0, 2010; R Development Core Team, Vienna, Austria). This package also 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. The benefit of using this package for analysis is that the neighborhood variance estimator (Stevens and Olsen 2003) is used for confidence interval computation and hypothesis testing. This variance estimator incorporates the spatial balance of the GRTS sample and yields increased precision (i.e., smaller variances) compared to simple random sampling. Note that the current version of *spsurvey* does not support use of ratio estimators.

Trend Estimation and Hypothesis Testing

Analyses of trend 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, proportional 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 at the network level (H_0: $\beta_1 = 0$) 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 site-to-site variation, year-to-year variation, site-by-year variation, and variation in trends across sites so that 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 7 for a definition of terms):

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

For regional inference, a single overall fixed slope is estimated across all parks using the following model:

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

Given appropriate replication of parks over time, R code is provided in the CD accompanying this document or by request from a participating network to analyze the site-level means of 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 each park

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

Estimate trend across parks

```
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

Each network will produce an annual report after each year of data collection and a comprehensive report after each full panel rotation (i.e., every three years).The three networks will also collaborate to produce a regional synthesis report once three full panel rotations have been completed (after nine years), and every three years thereafter following the completion of each full panel rotation. The annual reports will:

- Provide a 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 the parks.
- Provide summary status statistics of the results relative to management goals.
- Provide a 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 and McKinney *In Prep*, Stucki and Rodhouse 2012). A 1–2 page resource brief will also be prepared from the annual report that will be provided to superintendents, park interpretive staff, and resource managers. A template for the resource brief is included in SOP 7. An NPS template for producing maps with ESRI ArcGIS or ArcView software is available at http://imgis.nps.gov/templates.html. Information from the annual report will also be provided to parks in time for park Government Performance Results Act (GPRA) goals reporting and for informing and evaluating park resource stewardship strategies.

Each network‘s comprehensive report 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 [nine years]). A regional synthesis report will be produced once all plots have been installed at the three networks and will summarize the full panel data at the regional scale. It 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 also 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 parks appear to be adequate for all parks, are there new management concerns that might dictate some reallocation of effort or additions to the indicator metrics that are routinely examined annually, is the sampling time still appropriate, etc. The regional synthesis reports may be completed through external contracts with universities or other agencies or by a collaborative effort of staff from the three networks. The SIEN Program Manager will initiate discussion of the first regional synthesis report, and Program Managers from each of the three networks will collaborate to secure funding, establish partnerships as needed with other agency staff, such as the USGS, to produce the report, and provide programmatic oversight.

Annual reports will use the NPS Natural Resource Publications Natural Resource Data Series template, a pre-formatted Microsoft Word template document based on current NPS formatting standards. Periodic comprehensive reports and regional synthesis reports will use the Natural Resources Technical Report template. Template guidelines and documentation of the NPS

publication standards are available at the following address:
http://www.nature.nps.gov/publications/NRPM/.

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 and technical reports will also be available from the national NRPM website (http://www.nature.nps.gov/publications/nrpm/nrr.cfm). All NPS protocols are available from (http://science.nature.nps.gov/im/monitor/protocoldb.cfm).

Protocol Testing and Revision

A draft version of this protocol was tested in 2010 and 2011 by each network. These field experiences and the analysis of data collected in 2010 were instrumental in forming recommendations for training, database design, measurement calibration, sample sizes, power analyses, and trend analyses. 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 white pine distributions and 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 8 describes procedures for protocol revision and provides a history of protocol development to date.

The KLMN program is intended to be a shared effort by the I&M Program, CRLA, and LAVO, but the sampling effort is limited by the available I&M funding at this time. If the parks are successful in obtaining additional funding for this project, the sample size will likely be increased in one or both parks. Any such changes will be included in updated versions of this protocol.

Personnel Requirements and Training

Personnel Requirements

UCBN and SIEN will share a crew of four biological technicians, and KLMN will use two teams of two technicians to collect field data. 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 white pine blister rust, pine beetle, and dwarf mistletoe as described in SOP 2. This protocol also requires a capable project leader who will train the technicians, oversee their work, and verify, summarize, analyze, and interpret data each year. The project leader may also double as one of the two technical team members. The network Ecologist and/or Program Manager may serve as the project leader in the absence of other qualified available personnel. Table 6 provides a general outline for the roles and responsibilities of personnel involved in this monitoring protocol. For each team, one technician will serve as a field leader responsible for protocol testing, staff training, and field oversight.

Depending on the park, each team can sample at a rate of 1 plot per day (UCBN and KLMN; about 20 plots in a four-week sampling period) to one plot per three days (SIEN; about nine plots in a four-week period). Thus, networks will require approximately six to eleven weeks of post-training sampling time to complete each season‘s field work. At these rates, networks should easily complete their goals of 16–30 plots per park per year. This number will yield an accurate statistical sample of the sample frame, and provide ample time to accommodate travel, foul weather, and unanticipated contingencies.

Roles and Responsibilities

Table 6. Roles and responsibilities for implementing the white pine monitoring program in the KLMN, SIEN, and UCBN

Role	Responsibilities	Name/Position
Project Leader	• Project oversight and administration. • Track project objectives, budget, requirements, and progress toward meeting objectives. • Facilitate communications between NPS and cooperator(s). • Coordinate and ratify changes to protocol. • Acquire and maintain field equipment. • Assist in training field teams. • Perform data summaries and analyses. • Maintain and archive project records. • Oversee project operations and implementation. • Certify each season's data for quality and completeness. • Complete reports, metadata, and other products according to schedule.	Network Ecologist (SIEN, UCBN) or Network Program Manager (KLMN)
Field Leader	• Direct training and safety of field teams. • Plan and execute field visits. • Oversee data collection and entry, verify accurate data transcription into database. • Complete a field season report.	Park, Cooperator, and/or Network staff persons
Technicians (2–4)	• Collect, record, enter and verify data.	Seasonal, Park, University employees, or interns (e.g., SCA)
Data Manager	• Consultant on data management activities. • Facilitate check-in, review and posting of data, metadata, reports, and other products to national databases and clearinghouses according to schedule. • Maintain and update database application. • Provide database training as needed. • Consultant on GPS use and data collection tools. • Work with Project Lead to analyze spatial data and develop metadata for spatial data products. • Primary steward of Access database and GIS data and products.	Network Data Manager
Program Manager	• Project leader oversight • Administration and budget • Consultant on all phases of protocol review and implementation • Review of annual and comprehensive reports	Network Program Manager

Table 6. Roles and responsibilities for implementing the white pine monitoring program in the KLMN, SIEN, and UCBN (continued).

Role	Responsibilities	Name/Position
Park Resource Managers	• Consultant on all phases of protocol implementation. • Facilitate logistics planning and coordination. • Communicate management and restoration plans and associated information to Project Lead. • Review reports, data and other project deliverables.	Park Resource Managers or representatives

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 technician must know or be able to learn quickly the principal tree species that will be encountered. They 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 project leader must have a basic understanding of sampling design and data management and analysis. Project leaders 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. Project leaders will supervise training of the technicians and must be available for consultation and oversight of their work during the sampling season.

The most important training elements are the use of sampling and navigation equipment, methodologies for data collection, tree species identification, and identifying symptoms of blister rust infection, beetle occurrence, and dwarf mistletoe infection. Many aids are available to assist in tree identification, including tree identification software (see SOP 2).

Operational Requirements

Annual Workload and Field Schedule

White pine surveys will begin no earlier than June and end no later than October each year. The phenological window for yearly sampling spans the entire snow-free season. Thus roughly four months define the sampling time-frame. The annual workload for field personnel ranges from 8–16 weeks, depending on network. This period includes 1–2 weeks of training and field preparation, 6–11 weeks of field sampling, and 2–3 weeks of data entry, validation, miscellaneous administrative duties, and close-out. Additional weeks of preparation and analysis and reporting will be required from the project and field leaders. Table 7 details the annual workload and schedule.

Table 7. 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, 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 and field work in lower elevation parks	
June		Continue field work	
July		Continue field work	
August		Continue field work	
September	Close-out of fiscal year.	Complete field work Field season report complete	Data entry and verification; Preliminary analysis of current year's results, Annual resource brief prepared for network meetings
October	Prepare & submit budget estimate for fiscal year. Draft network annual report and work plan.	Clean and store equipment	Metadata production, quality review; Data certification complete; Data archival and posting

Facilities and Equipment Needs

It is desirable to have use of park housing, especially when working at the more distant parks or for longer sampling trips, although some camping should be expected, particularly in SEKI and YOSE. A UCBN pop-up camper is available for longer field trips, for example in southern portions of CRMO. If digital equipment is to be used, access to power is essential for recharging batteries.

Housing must be arranged at or near each park well in advance of the field season. Housing options differ among the parks.

- CRMO: Housing must be arranged through NPS resource staff at CRMO, which has limited facilities at headquarters in the northern portion of the park, or else the sampling team must arrange permission to camp within or near CRMO. Housing at CRMO is limited, but is very useful to have for at least part of the time spent sampling CRMO, particularly during work in the northern half of the park. For work in the southern half, camping is a preferable option, as travel times back and forth to housing located at Park headquarters is prohibitively long, or there may be access to motels or other housing in Minidoka. Rental of a house in Arco is an option.
- CRLA: Housing must be arranged through NPS resource staff at CRLA, usually no later than February of the year of sampling. CRLA has limited housing facilities at park headquarters, although the sampling team may arrange to camp within the park to have better access to field sites.
- LAVO: Housing must be arranged through NPS resource staff at LAVO, usually no later than February of the year of sampling LAVO has limited housing at the northwest edge of the park. For locations in the far east or southwest edges of the park, camping may be a more suitable alternative.
- SEKI & YOSE: Housing options include NPS seasonal housing, park campgrounds, or university field stations. Crew housing will be arranged annually and will depend on sampling schedule and locations, availability of park housing, and other considerations.

One dedicated field vehicle per team, preferably 4-wheel drive, will be required each field season. Currently, the networks are dependent upon GSA motor pool availability for additional seasonal vehicles. The UCBN also has access to the University of Idaho motor pool via its cooperative task agreement through the Pacific Northwest Cooperative Ecosystem Studies Unit. Networks can also rent vehicles from private companies such as Hertz or Avis. Vehicle arrangements need to be made well in advance of field work. Seasonal technicians must be 25 years or older in order to rent and drive private rental vehicles.

Equipment Lists

Measuring Equipment

- Four 50-m reel tapes.
- 1 small tape measure 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.
- Yellow crayon for temporarily marking seedlings during counts.
- Plant ID references (e.g., regional floras and photographic tree guides).
- Binoculars (8x40 or with similar light gathering capacity, i.e., ~ 5).
- Small hatchet to peel bark off dead pine trees for beetle investigation.

Plot Marking and Tree Tagging Equipment:

- Short (e.g., 8–10 inches) ½" rebar.
- Yellow rebar caps ½" dia. with ―NPS‖ engraved. (Ordered from http://www.forestry-suppliers.com).
- 1¼" round aluminum or steel tree tags consecutively numbered in sets of 500.
- Wood siding sinker head style galvanized aluminum nails, 2¼" length.
- Medium gauge steel wire.

Navigation and Recording Equipment

- Weatherized data entry PDA or tablet PC with supporting data entry software (e.g., Microsoft Access, DataPlus, Pendragon).
- GPS, preloaded with sample location waypoints.
- Clipboard with mechanical pencils and extra lead.
- Backup paper data forms (weatherized Rite-in-the-Rain paper; see SOP Appendix 1).
- Field reference maps identifying clusters of proximal sample points, access locations, and other key travel information.

Miscellaneous Equipment

- Plastic file box for storage of data sheets (in vehicle) with folders and extra forms, mechanical pencils, and rite-in-the-rain note paper.
- Wire brush for cleaning tires, boots, and trousers of weed seeds and rust spores
- Small spray bottle for wetting tree bark.
- Daypack or longer trip backpack.
- Sunscreen.
- Water bottles.
- First Aid kit.
- Two-way handheld radio.
- Cell phone (optional).

- Digital camera.
- Spare batteries for GPS, PDA, and camera.
- Emergency contact information.
- Field-relevant SOPs (SOPs 1–5).
- Fire extinguisher, shovel, and other park-specific vehicle safety equipment required.

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 8 and vary among networks due to differences in the allocation of duties among staff, field crew sizes, lengths of sampling season, and field operations requirements. At Klamath Network, the Program Manager will serve as the Project Leader; hence the larger amount of time and funds allocated for this individual. Table 8 also identifies in-kind contributions of approximately 1 week of park staff time per network. Listed separately at the bottom of the table are the periodic costs for preparation of individual network trend reports.

The budget reflects a shared field crew for UCBN and SIEN. Four technicians will be shared between these two networks, and each network will pay for technician salaries and travel when work occurs within its respective parks. Crew training and data collection at CRMO (UCBN park) will occur early in the season, data collection at SEKI and YOSE (SIEN parks) will occur mid to late season, and data entry for all parks will occur at the end of the season. For UCBN and SIEN, this arrangement reduces collective costs for crew salaries, reduces the time the lead Ecologist spends training field crews, and increases consistency in data collection and data entry methods for the two networks.

The Servicewide I&M Program requires that one-third of project budgets be allocated towards data management. For this protocol, approximately 35–40% of each network‘s annual protocol budget is dedicated to data management, analysis, and reporting activities. Table 8 identifies the percentage of time committed by each staff member, the cost of individual staff member time, and the resulting budget allocated towards data management by each network.

Table 8. Annual and periodic costs for white pine monitoring in the KLMN, SIEN, and UCBN. The number of seasonal personnel, vehicles, and other items vary by network; thus network-specific costs are listed.

Expense	Time allotted for duties	Project Cost ($) SIEN	UCBN	KLMN	Data Management % of time	Cost ($)[2]
Permanent Staff						
Program Manager[1] (GS-13)	(SIEN, UCBN) 2 wk report review, & project support (KLMN) 2 wks prep work & logistics, 2 wks closeout & reporting	4,500	4,500	8,822	50	2,250 2,250 4,411
Data Manager (GS-11)	(SIEN, UCBN) 1 wk field season prep & 1 wk QA/QC, data archiving, & close-out. (KLMN) 1 month.	3,400	3,400	7,150	100	3,400 3,400 7,150
Ecologist (Project Leader[1]; GS-11)	(SIEN, UCBN) 2 wks prep work & logistics; 2 wks field training & sampling assistance; 3 wks data analysis, reporting, and close-out	11,900	11,900	0	60	7,140 7,140 0
Seasonal Staff						
(4) BioTechs (GS-5; combined field crew for UCBN & SIEN)	1 wk training, 3 wks sampling at UCBN, 11 wks sampling at SIEN, 2 wks QA/QC and close-out (64 person-weeks)	31,037	10,147		30	9,311 3,044
(4) BioTechs (GS-5; KLMN)	1 wk training, 4 wks sampling, 1 wk QA/QC and close-out (24 person-weeks)			17,016	30	5,105
Park Staff						
Resource Management Staff	1 wk field work prep and assistance, housing logistics, and report reviews	In-kind support				
Operations and Equipment						
Housing			2,000			
Field equipment		1,000	1,000	3,000		
Travel	Project Lead; field crews	6,235	4,200			
Vehicle lease &fuel		3,000	1,500	4,800		
Other[3]			1,000			
Total Annual Cost		61,067	39,647	54,214		22,101 15,834 19,944
Periodic cost for network trend analysis	Project Lead: 4 wks to perform periodic network trend analysis	6,800	6,800	6,800		

[1] In the KLMN, the Program Manager will serve as the project leader and perform field planning, logistics, and report preparation duties with the field crew lead.
[2] When listed together in the same cell, data management costs are presented in the following order: SIEN, UCBN, KLMN.
[3] Contingency funds are included only in the UCBN protocol budget. SIEN and KLMN set aside contingency funds at the network operations level rather than the protocol level.

Literature Cited

Arno, S. F., and R. J. Hoff. 1990. *Pinus albicaulis* Engelm. Whitebark pine. Pages 268-279 *in* R. P. Burns and B. H. Honkala, editors. Silvics of North America, Volume 1, Conifers. Agriculture Handbook 654. USDA Forest Service, Washington, D.C.

Arno, S. F., and T. Weaver. 1990. Whitebark pine community types and their patterns on the landscape. Pages 97-105 *in* W. C. Schmidt and K. J. McDonald, editors. Proceedings of the Symposium on whitebark pine ecosystems: ecology and management of a high-elevation resource. USDA Forest Service General Technical Report INT-GTR-270. USDA Forest Service, Rocky Mountain Research Station, Fort Collins, Colorado.

Baumeister, D., and R. M. Callaway. 2006. Facilitation by *Pinus flexilis* during succession: A hierarchy of mechanisms benefits other plant species. Ecology 87:1816–1830.

Bechtold, W. A., and P. L. Patterson, editors. 2005. The enhanced Forest Inventory and Analysis program – national sampling design and estimation procedures. General Technical Report SRS-80. U.S. Department of Agriculture Forest Service, Southern Research Station, Asheville, North Carolina.

Bell, J., D. Cogan, J. J. Erixson, and J. Von Loh. 2009. Vegetation inventory project report: Craters of the Moon National Monument and Preserve. Natural Resource Technical Report NPS/UCBN/NRTR—2009/277. National Park Service, Fort Collins, Colorado.

Bennetts, R. E., J. E. Gross, K. Cahill, C. McIntyre, B. B. Bingham, A. Hubbard, L. Cameron, and S. L. Carter. 2007. Linking monitoring to management and planning: assessment points as a generalized approach. The George Wright Forum 24:59–77.

Cook, R. R., and P. Lineback. 2008. Sierra Nevada Network data management plan. Natural Resource Report NPS/SIEN/NRR—2008/070. National Park Service, Fort Collins, Colorado.

DeNitto, G. A. 1987. Incidence and effects of white pine blister rust in plantations with sugar pine in the northern and central Sierra Nevada. Report No. 87-7. U.S. Department of Agriculture, Forest Service, Pacific Southwest Region, San Francisco, California.

Dicus, G. H., and L. K. Garrett. 2007. Upper Columbia Basin Network Data Management Plan. Natural Resource Report NPS/UCBN/NRR—2007/020. National Park Service, Fort Collins, Colorado.

Dunlap, J. 2006. Blister rust in California‘s high-elevation pines. Nutcracker Notes 10:8–9.

Duriscoe, D. M., and C. S. Duriscoe. 2002. Survey and monitoring of white pine blister rust in Sequoia and Kings Canyon National Parks: Final report on 1995-1999 survey and monitoring plot network. Science and Natural Resources Management Division Sequoia and Kings Canyon National Parks, Three Rivers, California. Unpublished.

Ebenman, B., and T. Jonsson. 2005. Using community viability analysis to identify fragile systems and keystone species. Trends in Ecology and Evolution 20:568–575.

Eckert, A. J., and J. O. Sawyer. 2002. Foxtail pine importance and conifer diversity in the Klamath Mountains and southern Sierra Nevada, California. Madroño 49:33-45.

Ellison, A. E., M. S. Bank, B. D. Clinton, E. A. Colburn, K. Elliott, C. R. Ford, D. R. Foster, B. D. Kloeppel, J. D. Knoepp, G. M. Lovett, and others. 2005. Loss of foundation species: consequences for the structure and dynamics of forested ecosystems. Frontiers in Ecology and the Environment 3:479–486.

Farnes, P. E. 1990. SNOTEL and snow course data describing the hydrology of whitebark pine ecosystems. Pages 302–304 *in* W. C. Schmidt and K. J. McDonald, editors. Proceedings of the Symposium on whitebark pine ecosystems: ecology and management of a high-elevation resource, 29–31 March 1989, Bozeman, Montana. USDA Forest Service General Technical Report INT-GTR-270. USDA Forest Service, Rocky Mountain Research Station, Fort Collins, Colorado.

Garrett, L. K., T. J. Rodhouse, G. H. Dicus, C. C. Caudill, and M. R. Shardlow. 2007. Upper Columbia Basin Network vital signs monitoring plan. Natural Resource Report NPS/UCBN/NRR—2007/002. National Park Service, Fort Collins, Colorado.

Geils, B. W., K. E. Hummer, and R. S. Hunt. 2010. White pines, *Ribes*, and blister rust: a review and synthesis. Forest Pathology 40:147-185.

Gernandt, D. S., G. G. Geada López, S. Ortiz Garcia, and A. Liston. 2005. Phylogeny and classification of *Pinus*. Taxon 54:29–42.

Gibson, K., K. Skov, S. Kegley, C. Jorgensen, S. Smith, and J. Witcosky. 2008. Mountain pine beetle impacts in high-elevation five-needle pines: Current trends and challenges. U.S. Department of Agriculture, Forest Service, Forest Health Protection Report R1-08-020.

Greater Yellowstone Whitebark Pine Monitoring Working Group. 2007. Interagency whitebark pine monitoring protocol for the Greater Yellowstone Ecosystem, v 1.0. Greater Yellowstone Coordinating Committee, Bozeman, Montana. Unpublished.

Heavilin, J., Powell, J., and J. A. Logan. 2007. Dynamics of mountain pine beetle outbreaks. Pages 527–553 *in* E. A. Johnson and K. Miyanishi, editors. Plant disturbance ecology. Academic Press, Amsterdam.

Hummer, K. E. 2000. History of the origin and dispersal of white pine blister rust. Horticulture Technology 10:515–517.

Keane, R. E., D. F. Tomback, C. Aubrey, A. Bower, E. Campbell, M. Jenkins, M. Manning, S. T. McKinney, M. Murray, D. Perkins, and others. *In press*. A range-wide restoration strategy for whitebark pine (*Pinus albicaulis*). General Technical Report RMRS-GTR. Fort Collins, CO. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Kincaid, T., T. Olsen, D. Stevens, C. Platt, D. White, and R. Remington. 2009. *spsurvey*: Spatial survey design and analysis. R package version 2.1. http://www.epa.gov/nheerl/arm/

Kipfmueller, K. F., and M. W. Salzer. 2010. Linear trend and climate response of five-needle pines in the western United States related to treeline proximity. Canadian Journal of Forest Research 40: 134-142.

Kliejunas, J., and J. Dunlap. 2007. Status of whitebark pine and other high elevation five-needle pines with emphasis on Pacific Coast ecosystems: perspective from California. Pages 29–35 *in* E. M. Goheen and R. A. Sniezko, technical coordinators. Proceedings of the Conference on Whitebark Pine: A Pacific Coast Perspective, 17–31 August 2006, Ashland, Oregon. Publication R6-NR-FHP-2007-01. USDA Forest Service, Pacific Northwest Region, Portland, Oregon.

Körner, C. 2007. The use of ‗altitude' in ecological research. Trends in Ecology and Evolution 22:569–574.

Lanner, R. M., and S. B. Vander Wall. 1980. Dispersal of limber pine seed by Clark's Nutcracker. Journal of Forestry 78:637-639.

Little, E. L., Jr. 1971. Conifers and important hardwoods. Volume 1 of Atlas of United States trees. U.S. Department of Agriculture Miscellaneous Publication 1146.

Little, E. L., Jr. 1980. The Audubon Society field guide to North American trees. Alfred A. Knopf, New York.

Lloyd, A.H. 1997. Response of tree-line populations of foxtail pine (*Pinus balfouriana*) to climate variation over the last 1000 years. Canadian Journal of Forest Research 27:936-942.

Logan, J. A., W. W. Macfarlane, and L. Willcox. 2010. Whitebark pine vulnerability to climate-driven mountain pine beetle disturbance in the Greater Yellowstone Ecosystem. Ecological Applications 20:895–902.

Mastrogiuseppe, R. J., and J. D. Mastrogiuseppe. 1980. A study of *Pinus balfouriana* Grev. & Balf. (Pinaceae). Systematic Botany 5:86–104.

McCaughey, W. W., and W. C. Schmidt. 2001. Taxonomy, distribution, and history. Pages 29–40 *in* D. F. Tomback, S. F. Arno, and R. E. Keane, editors. Whitebark pine communities: Ecology and restoration. Island Press, Washington, D.C.

McDonald, G. I., and R. J. Hoff. 2001. Blister rust: An introduced plague. Pages 193–220 *in* D. F. Tomback, S. F. Arno, and R. E. Keane, editors. Whitebark pine communities: Ecology and restoration. Island Press, Washington, D.C.

McDonald, G. I., B. A. Richardson, P. J. Zambino, N. B. Klopfenstein, and M. S. Kim. 2006. *Pedicularis* and *Castilleja* are natural hosts of *Cronartium ribicola* in North America: A first report. Forest Pathology 36:73–82.

McDonald, T. L. 2003. Review of environmental monitoring methods: Survey designs. Environmental Monitoring and Assessment 85:277–292.

McKinney, S. T., and C. E. Fiedler. 2010. Tree squirrel habitat selection and predispersal seed predation in a declining subalpine conifer. Oecologia 162: 697-707.

McKinney, S. T., and D. F. Tomback. 2007. The influence of white pine blister rust on seed dispersal in whitebark pine. Canadian Journal of Forest Research 37: 1044-1057.

McKinney, S. T., C. E. Fiedler, and D. F. Tomback. 2009. Invasive pathogen threatens bird-pine mutualism: Implications for sustaining a high-elevation ecosystem. Ecological Applications 19:597–607.

Millar, C. I., N. L. Stephenson, and S. L. Stephens. 2007. Climate change and forests of the future: Managing in the face of uncertainty. Ecological Applications 17:2145–2151.

Mohren, S. R. 2007. Data management plan, Klamath Inventory and Monitoring Network. Natural Resource Report NPS/KLMN/NRR—2007/012. National Park Service, Fort Collins, Colorado.

Murray, M. P. and M. C. Rasmussen. 2003. Non-native blister rust disease on whitebark pine at Crater Lake National Park. Northwest Science 77:87–91.

Mutch, L. S., M. G. Rose, A. M. Heard, R. R. Cook, and G. L. Entsminger. 2008. Sierra Nevada Network vital signs monitoring plan. Natural Resource Report NPS/ SIEN/NRR—2008/072. National Park Service, Fort Collins, Colorado.

National Park Service (NPS). 1999. National Park Service (NPS). 1999. Natural resource challenge: the National Park Service‘s action plan for preserving natural resources. US Department of the Interior National Park Service, Washington D.C. Online. (http://www.nature.nps.gov/challengedoc.html).

Oakley, K. L., L. P. Thomas, and S. G. Fancy. 2003. Guidelines for long-term monitoring protocols. Wildlife Society Bulletin 31:1000–1003.

Odion, D. C., D. A. Sarr, S. R. Mohren, and S. B. Smith. 2011. Monitoring vegetation composition, structure and function in the parks of the Klamath Network Parks. Natural Resource Report NPS/KLMN/NRR—2011/401. National Park Service, Fort Collins, Colorado.

Oline, D. K., J. B. Mitton, and M. C. Grant. 2000. Population and subspecific genetic differentiation in the foxtail pine (*Pinus balfouriana*). Evolution 54:1813–1819.

Peet, R. K., T. R. Wentworth, and P. S. White. 1998. A flexible multipurpose method for recording vegetation composition and structure. Castanea 63:262–274.

Piepho, H. P., and J. O. Ogutu. 2002. A simple mixed model for trend analysis in wildlife populations. Journal of Agricultural, Biological, and Environmental Statistics 7:350–360.

R Development Core Team. 2010. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0. Available from http://www.R-project.org (accessed 12 August 2010).

Rocca, M. E. and W. H. Romme. 2009. Beetle-infested forests are not ―destroyed.” Frontiers in Ecology and Environment 7:71–72.

Rochefort, R. M. 2008. The influence of white pine blister rust (*Cronartium ribicola*) on whitebark pine (*Pinus albicaulis*) in Mount Rainier National Park and North Cascades National Park Service Complex, Washington. Natural Areas Journal 28:290–298.

Sarr, D. A., D. C. Odion, S. R. Mohren, E. E. Perry, R. L. Hoffman, L. K. Bridy, and A. A. Merton. 2007. Vital signs monitoring plan for the Klamath Network: Phase III report. Natural Resource Technical Report NPS/KLMN/NRR—2007/016, National Park Service, Fort Collins, Colorado.

Schuster, W. S., F., J. B. Mitton, D. K. Yamaguchi, and C. A. Woodhouse. 1995. A comparison of limber pine (*Pinus flexilis*): Ages at lower and upper treeline sites east of the Continental Divide in Colorado. American Midland Naturalist 133:101–111.

Stevens, D. L., and A. R. Olsen. 2003. Variance estimation for spatially balanced samples of environmental resources. Environmetrics 14:593–610.

Stevens, D. L., and A. R. Olsen. 2004. Spatially balanced sampling of natural resources. Journal of the American Statistical Association 99:262–278.

Storer, T. I., R. L. Usinger, and D. Lukas. 2004. Sierra Nevada natural history. University of California Press. Berkeley, California.

Stucki, D. S., and S. T. McKinney. *In Prep*. Sierra Nevada Network white pine community dynamics 2011 annual monitoring report: Sequoia and Kings Canyon National Parks (SEKI) and Yosemite National Park (YOSE). Natural Resource Data Series NPS/SIEN/NRDS—2012/XXX. National Park Service, Fort Collins, Colorado.

Stucki, D. S., and T. J. Rodhouse. 2012. Upper Columbia Basin Network limber pine community dynamics 2011 annual monitoring report: Craters of the Moon National Monument and

Preserve. Natural Resource Data Series NPS/UCBN/NRDS—2012/266. National Park Service, Fort Collins, Colorado.

Theobald, D. M., D. L. Stevens, Jr., D. White, N. S. Urquhart, A. R. Olsen, and J. B. Norman. 2007. Using GIS to generate spatially balanced random survey designs for natural resource applications. Environmental Management 40:134–146.

Tomback, D. F. 1982. Dispersal of whitebark pine seeds by Clark‘s nutcracker: A mutualism hypothesis. Journal of Animal Ecology 51:451–467.

Tomback, D. F., and P. Achuff. 2010. Blister rust and western forest biodiversity: ecology, values, and outlook for white pines. Forest Pathology 40:186-225.

Tomback, D. F., and K. C. Kendall. 2001. Biodiversity losses: the downward spiral. Pages 243–262 *in* D. F. Tomback, S. F. Arno, and R. E. Keane, editors. Whitebark pine communities: Ecology and restoration. Island Press, Washington, D.C.

Tomback, D. F., and K. A. Kramer. 1980. Limber pine seed harvest by Clark‘s Nutcracker in the Sierra Nevada: timing and foraging behavior. Condor 82:467–468.

Tomback, D. F., S. F. Arno, and R. E. Keane. 2001. The compelling case for management intervention. Pages 3–25 *in* D. F. Tomback, S. F. Arno, and R. E. Keane, editors. Whitebark pine communities: Ecology and restoration. Island Press, Washington, D.C.

Tomback, D. F., R. E. Keane, W. W. McCaughey, and C. Smith. 2004 (revised 2005). Methods for surveying and monitoring whitebark pine for blister rust infection and damage. Whitebark Pine Ecosystem Foundation, Missoula, Montana. Unpublished.

Tomback, D. F., A. S. Schoettle, K. E. Chevalier, and C. A. Jones. 2005. Life on the edge for limber pine: seed dispersal within a peripheral population. Écoscience 12:519-529.

van Mantgem, P. J., N. L. Stephenson, M. Keifer, and J. Keeley. 2004. Effects of an introduced pathogen and fire exclusion on the demography of sugar pine. Ecological Applications 14:1590-1602.

van Mantgem, P. J., N. L. Stephenson, J. C. Byrne, L. D. Daniels, J. F. Franklin, P. Z. Fulé, M. E. Harmon, A. J. Larson, J. M. Smith, A. H. Taylor, T. T. Veblen. 2009. Widespread increase of tree mortality rates in the western United States. Science 323:521–523.

Vander Wall, S. B. 1988. Foraging of Clark‘s Nutcrackers on rapidly changing pine seed resources. The Condor 90:621– 631.

VanLeeuwen, D. M., L. W. Murray, and N. S. Urquhart. 1996. A mixed model with both fixed and random trend components across time. Journal of Agricultural, Biological, and Environmental Statistics 1:435-453.

VanLeeuwen, D. M., D.S. Birkes, and J. F. Seely. 1999. Balance and orthogonality in designs for mixed classification models. The Annals of Statistics 27:1927–1947.

Woodhouse, C. A., G. T. Pederson, and S. T. Gray. 2011. An 1800-yr record of decadal hydroclimatic variability in the upper Arkansas River basin from bristlecone pine. Quaternary Research doi:10.1016/j.yqres.2010.12.007.

Glossary of Important Terms

Canopy cover: The percentage of the ground covered by a vertical projection of the outermost perimeter of the natural spread of foliage of plants. Openings within an individual plant‘s foliar canopy are included in cover estimation. Canopy cover is typically restricted to live plants and live portions of plants with dead limbs, unless otherwise specified.

Forb: Herbaceous plants other than grasses, sedges, and rushes (graminoids).

Generalized Linear Model: A generalization of the ordinary least squares method of regression. A generalized linear model relates the random response component of the model, which may be non-linear, to the non-random predictor variables (e.g., year) through a link function.

Phenology: The time frame for any seasonal phenomena. Examples include the date of emergence of leaves and flowers, the first flight of butterflies and the first appearance of migratory birds.

Power analysis: The **power** of a statistical test is the probability that the test will reject a false null hypothesis, or in other words that it will not make a Type II error. As power increases, the chances of a Type II error decrease, and vice versa. The probability of a Type II error is referred to as β. Therefore power is equal to $1 - \beta$. Power is a function of effect size or minimum detectable change, variance of the parameter (e.g., standard error of the mean), and sample size. A power analysis determines the probability of correctly rejecting a false null hypothesis given fixed values of effect size, variance, and sample size.

Sampling frame: The portion of the target population that is mapped and sampleable, after accounting for safety and logistical constraints, as well as mapping errors that inaccurately portray the target population. The sampling frame is an imperfect representation of the portion of the target population that is accessible and that can be identified, typically with maps.

Spatially-balanced sample: A probability sample that optimizes the location so sample locations in space so as to efficiently account for spatial auto-correlation. Such a sample typically has advantages over alternatives such as **simple random** and **stratified** samples in terms of statistical efficiency and logistical flexibility. The generalized random tessellation stratified (GRTS) approach is one important and widely used method of obtaining a spatially-balanced sample.

Status: Status is a measure of a current attribute, condition, or state, and is typically measured with population means.

Target population: The statistical population for which statistical inference is desired. Note this is not the same as the realized sampled population, represented by the sampling frame which accounts for mapping errors and practical constraints which limit access to the entire target population.

Temporal variation: Variation in a population parameter, such as a mean, over time. For our purposes this typically refers to variation seasonally or annually.

Trend: Trend is a measure of directional change over time and can occur in some population parameter, such as a mean (**net trend**), or in an individual member or unit of a population (**gross trend**).

Type I error: Is ―false change” error or an error of commission in statistical hypothesis tests, in which a researcher declares a statistically significant difference when in fact no difference exists.

Type II error: Is a ―missed change” error or an error of omission in statistical hypothesis tests, in which a researcher fails to detect a statistically significant difference when in fact a real difference exists.

Vital signs: A subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values. 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).

Appendix A. Index of Standard Operating Procedures

(Bound as a separate volume)

This appendix is available from the Upper Columbia Basin Network website (http://www.nature.nps.gov/im/units/ucbn) and the Natural Resource Publications Management website (http://www.nature.nps.gov/publications/nrpm).

NPS 963/114718, June 2012

National Park Service
U.S. Department of the Interior

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

www.nature.nps.gov