



Monitoring Forest Vegetation in the North Coast and Cascades Network

2011 Annual Report

Natural Resource Technical Report NPS/NCCN/NRTR—2012/615



ON THE COVER

Little Jackass Mountain in Ross Lake National Recreation Area, site of a permanent forest plot with mortality caused by the beetle *Dendroctonus pseudotsugae*.

Photograph courtesy of North Cascades National Park Service Complex

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Steven A. Acker and John R. Boetsch
National Park Service
Olympic National Park
600 E. Park Ave
Port Angeles, WA 98362

Mignonne Bivin
National Park Service
North Cascades National Park Service Complex
7280 Ranger Station Road
Marblemount, WA 98267

Lou Whiteaker
National Park Service
Mount Rainier National Park
55210 238th Ave. East
Ashford, WA 98304

Carla Cole
National Park Service
Lewis and Clark National Historical Park
92343 Fort Clatsop Road
Astoria, OR 97103

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Abstract

Late-successional, coniferous forest is critical for ecosystem function and biological conservation in the Pacific Northwest. Such forests are well-represented in the North Coast and Cascades Network (NCCN) of the National Park Service. As part of monitoring of natural resources within the NCCN, we track trends in tree recruitment, growth, and mortality in forests which represent the range of environments in network parks. At the initiation of the project in 2008, we established 35, 1-hectare plots in three parks (Mount Rainier (MORA), North Cascades (NOCA), Olympic (OLYM)), at elevations from near sea-level to almost 1800 m. To select monitoring locations, we began by generating a spatially-balanced, random set of potential plot locations using the Generalized Randomized-Tessellation Stratified algorithm. Initial screening was conducted in the office, using GIS to evaluate suitability factors including safety of access routes and proximity to trails and roads. Potential plot locations that passed the office screening were evaluated in the field for safety of access, forest species composition and age, and other factors. Field activities in 2011 included several field evaluations at MORA and NOCA, establishment of plots at Lewis and Clark National Historical Park (LEWI), MORA, and NOCA, and annual checks for tree mortality at MORA, NOCA, and OLYM.

In 2011 we performed field evaluations of six potential plot locations at MORA and NOCA, to address residual ambiguities from the early years of the project. None of the points were found to be appropriate for permanent plots.

We established six plots in 2011 in the 0-300 m elevation stratum (stratum 1) at LEWI at locations identified in 2010. The climate in stratum 1 at LEWI is characterized by mild winters and high precipitation, similar to stratum 1 at OLYM. The plots in stratum 1 at LEWI were similar to stratum 1 at OLYM with respect to species composition and stand structure (i.e., predominantly *Tsuga heterophylla* and *Picea sitchensis*). However, hardwoods (particularly *Rhamnus purshiana*) were more numerous at LEWI than at OLYM. The plots at LEWI included two tree species not present in other plots in the network, including the first exotic species to be measured in the network's permanent forest plots (*Ilex aquifolium*). In 2011 we also established one new plot at MORA and two new plots at NOCA.

As in previous years, most of the newly-dead trees observed in 2011 died standing. Unlike previous years, a particular cause of death was identified for the majority of standing dead trees. Insects (usually *Dendroctonus pseudotsugae*) were by far the most commonly identified cause of death for the standing trees.

With three consecutive years of annual observations of tree mortality, we performed the first evaluation of trends. Over two-thirds of plots showed no consistent trend in tree mortality. The remaining plots were split evenly, with half showing decreasing and half showing increasing trends.

Introduction

This report presents results from monitoring of forest vegetation in the North Coast and Cascades Network (NCCN) as part of the Inventory and Monitoring Program of the National Park Service (NPS). The program focuses on “vital signs,” which are defined as “a relatively small set of information-rich attributes that are used to track the overall condition or "health" of park natural resources and to provide early warning of situations that require intervention” (Fancy et al. 2009). Monitoring is being implemented throughout the National Park System; for this purpose, 270 park units have been organized by ecoregion into 32 networks (Fancy et al. 2009). As one of these networks, the NCCN is composed of eight NPS units including five with significant forest area: Lewis and Clark National Historical Park (LEWI), Mount Rainier National Park (MORA), North Cascades National Park Service Complex (NOCA), Olympic National Park (OLYM), and San Juan Island National Historical Park (SAJH). Since 1997, numerous monitoring workshops and meetings have been conducted in the NCCN to identify key park ecosystem components and core indicators within each ecosystem component, in addition to allocating limited funding to the development and implementation of monitoring protocols (Weber et al. 2009). As part of this process, forest vegetation was identified as one of the park ecosystem components for protocol development. The U.S. Geological Survey (USGS), through the Forest and Rangeland Ecosystem Science Center, was integrally involved in the development of monitoring protocols in the NCCN (Weber et al. 2009), and was the lead agency for development of the original version of the forest monitoring protocol (Woodward et al. 2009). The protocol was subsequently revised to limit its scope and reduce costs, and was published by NPS in the Natural Resource Report Series (Acker et al. 2010).

In this third annual report on forest monitoring in the NCCN we begin with a description of the rationale and design of the program. In the remainder of the report we present results pertaining to the following topics:

- 1) Screening of potential plot locations through the process of site selection at MORA and NOCA;
- 2) Baseline information on site characteristics, species composition, and stand structure of the permanent plots established at LEWI in 2011;
- 3) Baseline information on species composition and stand structure of the three additional permanent plots established at MORA and NOCA in 2011;
- 4) Observations of tree mortality for the interval 2010 to 2011; and
- 5) Trends in tree mortality between 2008 and 2011.

Background and Objectives

A. Background and History

Plant communities are the foundation for terrestrial trophic webs and animal habitat, and their structure and species composition are an integrated result of biological and physical drivers (Gates 1993). Additionally, they have a major role in geologic, geomorphologic and soil development processes (Jenny 1941, Birkeland 1984). Throughout most of the Pacific Northwest, environmental conditions support coniferous forests as the dominant vegetation type. In the face of anthropogenic climate change, forests have a global role as potential sinks for atmospheric carbon (Goodale et al. 2002); forests of the Pacific Northwest have some of the greatest potential for carbon sequestration in the U.S. and in the world (Keith et al. 2009, Ryan et al. 2010). Consequently, knowledge of the status of forests in the NCCN is fundamental to understanding the condition of Pacific Northwest ecosystems.

Diverse precipitation, temperature and soil properties across the Pacific Northwest result in a variety of forest types (Franklin and Dyrness 1988, Franklin et al. 1988, Henderson et al. 1989, 1992). Mountainous terrain creates steep elevation and precipitation gradients within and among the parks of the NCCN. These parks span an elevation gradient from sea level to over 4200 m; annual precipitation ranges from 50 cm to over 500 cm. The resulting forests range from coastal rainforests with massive trees draped with epiphytes and surrounded by dense understories; to areas with the drought-adapted *Pinus ponderosa*; to high-elevation *Abies lasiocarpa* forests interspersed with meadows just below treeline. These forests, in turn, are the foundation for other biotic communities constituting Pacific Northwest ecosystems.

Wood products have long been central to the region's economy, resulting in at least a five-fold decrease in the late successional and old-growth forests in the range of the northern spotted owl (northern California to southern British Columbia) from early historic times (FEMAT 1993). Much of what is left is located at mid- and high-elevations and in national parks and other protected areas such as USDA Forest Service wilderness areas (Lehmkuhl and Ruggiero 1991). The effects of diminishing late successional and old-growth forest on endangered species, recreational opportunities, and aesthetic values led to numerous legal challenges to federal land management policies (Thomas 1997). Monitoring changes in unmanipulated forests in national parks will help federal managers of harvested lands to sustainably manage those lands in the face of increasing environmental threats. Specifically, a better understanding of how natural systems respond to climate change will help these managers to set realistic management targets.

Several global and regional stressors (i.e., anthropogenic climate change, atmospheric and precipitation chemistry, introduced pests, pathogens, invasive species and forest harvest) alter forest structure, species composition and abundance, thereby threatening the quality and quantity of habitat for terrestrial birds and wildlife. We expect that climate change and air quality will be among the greatest threats to national parks in the Pacific Northwest (Weber et al. 2009). Changes in forest structure and composition will also alter the chemistry of water moving from terrestrial to aquatic systems (Edmonds et al. 1998, McClain et al. 1998). Consequently, forest monitoring is a fundamental part of the overall monitoring plan for the parks of NCCN.

Potential changes in vegetation due to anthropogenic threats include migration of species ranges within and outside parks, loss of suitable habitat, and competitive exclusion by invasive exotic

species. Developing management responses to these changes may require the National Park Service to take a more active role (e.g., planting seeds outside of their present range) in managing resources than prescribed by current policy (Tweed 2010). The purpose of monitoring vegetation change is to provide early warning of the types and severity of future changes so that management options can be developed and evaluated in time to be effective.

The original goal of forest monitoring in the NCCN was to detect changes in the composition of forest understory vegetation in the face of climate change and other stressors with tree demography as an important, subsidiary goal (Woodward et al. 2009). However, in the time between development and full implementation of the monitoring protocol, it became clear that it was too expensive to be sustainably funded. In the current, reduced monitoring protocol the focus is limited to tree demography (recruitment, growth, and mortality; Acker et al. 2010). We have been able to take advantage of the substantial effort expended since 2005 to generate a stratified random sample of potential locations for monitoring plots, screen locations in the office and in the field, and establish monitoring plots. The statistical validity (and power) of our sample design remains, although the emphasis has changed.

B. Rationale for Selecting Forest Communities to Monitor

Forest structure and composition are physical manifestations of cumulative biological and physical processes that are difficult to measure directly. Changes in forest composition will occur when driving factors such as climate change reduce suitability for particular plant species and enhance suitability for others (Davis 1981, Barnosky 1984). Changes in forest structure and composition consequently affect a wide range of resource properties and processes such as habitat quality, biodiversity, the hydrologic cycle, and carbon storage (Pastor and Post 1986, 1988). Therefore we have established permanent forest plots for monitoring forest demography, structure, and composition to detect biologically significant changes that are too subtle to monitor remotely and are not adequately covered at the scale of individual national parks by the existing, regional program of forest monitoring (USFS Forest Inventory & Analysis, or FIA; <http://www.fia.fs.fed.us/>).

Our general approach is to focus on coniferous forest zones that represent the range of climatic regimes and elevation in the NCCN. We sample relatively warm and wet conditions in the *Picea sitchensis* zone (LEWI and OLYM), cold and dry conditions in the *Abies lasiocarpa* zone (MORA and NOCA), plus the intermediate *Tsuga heterophylla* zone, which is represented in all three large parks (MORA, NOCA, and OLYM) (Franklin and Dyrness 1988). Limited resources and the need for sample replication require that we further focus on particular vegetation associations within forest zones (see Acker et al. 2010).

C. Measurable Objectives

Our objectives are to monitor trends in tree species recruitment, growth, and mortality; and in forest structure and composition. Because we are interested in direct responses to ecological change, we minimize the effects of succession by focusing on mature forests, which have not experienced recent stand-replacing disturbance. We also measure several environmental parameters in the permanent plots to help with interpretation. Specifically we are monitoring the following parameters:

Structure and Composition

- Trees – We monitor dimensions (diameter at breast height (dbh), height), indicators of health (i.e., the type, severity, and location of damage when present), and indicators of wildlife habitat (e.g., mistletoe brooms, bole cavities) by species to detect changes in the structural framework of forests upon which the other inhabitants depend. Wildlife habitat indicators will link this protocol with wildlife monitoring protocols (Siegel et al. 2007, Griffin et al. 2011, 2012).
- Snags – We monitor changes in density and size as indicators of forest structure and carbon cycling.

Processes

- Tree recruitment – We monitor saplings (i.e., stems reaching 2.5 cm dbh) to track changes in establishment and species composition as indicators of changing forest structure.
- Tree growth – We monitor growth of tagged trees as an indicator of changing conditions for forests.
- Tree mortality – We monitor numbers of deaths annually by species to detect changes in rate and cause (if possible) as indicators of changing forest structure and composition.

Environment (some of these are relatively static and only need to be measured once)

- Landscape position of plot including slope, aspect, terrain position.
- Soil properties (descriptive attributes such as texture and soil series).
- Physical characteristics (e.g., gap formation, water distribution on plot).

These parameters are monitored in an array of permanent plots designed to intensively sample forest types selected to represent regional environmental extremes and a common forest type across the three large parks.

Sampling Design

A. Rationale

Basic Principles

We applied several basic principles or assumptions in developing our sample frame:

- Communities will change, and therefore should not be the basis for sample stratification. Rather, we should stratify on static landscape characteristics such as elevation.
- An inferential statistical design is necessary.
- We must consider crew safety and accessibility of plots because we are sampling large wilderness parks with steep terrain and dangerous rivers.

We also sought replicates of communities defined by understory vegetation due to the need to detect change in community composition under the original primary objective of the protocol.

Sample Frame

In designing the sample frame for monitoring forest vegetation in NCCN, our goal was to develop a comprehensive spatial sample frame for the parks, recognizing that we could only monitor part of this frame initially. We wanted the sample to be interpretable based on vegetation types, yet flexible enough to be useful in the face of expected future changes in community composition and/or elevation range (Gates 1993) as organisms respond independently to changing environment (Peters and Lovejoy 1992). Therefore, we conducted double-sampling by initially stratifying our sample using elevation, and secondly by current vegetation. We chose the Generalized Randomized-Tessellation Stratified algorithm (GRTS, Stevens 1997) to obtain a random sample of our target populations. GRTS samples have the advantage of being spatially dispersed but without a repeating interval. Unlike systematic samples, they have an excellent variance estimator and they allow for excluding sites when some selected sites cannot be sampled or are not within the population of interest. Permanent plots are added to the sample in the numerical order generated by GRTS.

Our fixed strata in each park are 300-m elevation bands, of which we can only afford to sample two in each of the large parks at present. We will sample one 300-m elevation band in the smaller parks. Our general approach is to encompass the range of climatic regimes and elevation where forests occur in the network; thus we include one elevation stratum at low and high elevations, as well as one at intermediate elevations. We number strata consecutively, starting with “1.” We are monitoring in strata 1 (0-300 m), 3 (600-900 m), and 6 (1500-1800 m). We sample the chosen strata at random using GRTS to create a spatially balanced sample. We are using sets of vegetation communities as proxies for climate within elevation strata, so as to increase the signal of vegetation change due to external drivers and decrease the potential for noise due to environmental differences within strata. The rationale for selecting target vegetation communities varied by strata. For the 0-300 m and 600-900 m strata, we chose vegetation communities which characterize the middle of the moisture gradient within the stratum and are relatively widespread in the Pacific Northwest (Agee and Kertis 1986, Franklin et al. 1988, Henderson et al. 1989, Crawford et al. 2009). In the 1500-1800 m stratum, we chose vegetation

communities which characterize the dry end of the moisture gradient within high-elevation, cold forests (Franklin et al. 1988).

Within the random sample for each stratum, we intensively sample mature or old-growth examples of a specific set of vegetation communities to get a biologically interpretable sample. We are working in forests that have centuries-old trees, which have survived substantial environmental changes during their lives. We expect changes in tree species distributions to be facilitated by catastrophic events (which the network will monitor in the satellite-based remote sensing protocol). However, mortality of trees occurs throughout the life of any forest stand (Franklin et al. 1987, 2002). In earlier successional stages, tree mortality tends to result from competition with other trees rather than external factors (Franklin et al. 1987, 2002, Oliver and Larson 1990). Consequently we are working in mature or older forests where the primary drivers of tree mortality are environmental factors external to the stand (Franklin et al. 1987, 2002).

In addition to stand age and vegetation community, we also included criteria for safe accessibility and labor costs. We used two-stage sampling for stratification (Thompson 2002). The stage 1 GRTS sample for a stratum was evaluated in the office using GIS and became the population for the stage 2 sample that further stratified the population into mature or old-growth examples of a specific set of vegetation communities and other vegetation types. The second stage was evaluated by field reconnaissance. Therefore our target populations and range of inference for intensive sampling are a specific set of vegetation communities within one or two specific elevation bands within each park. For example, our range of inference in elevation stratum 3 is plant associations having *Tsuga heterophylla* and/or *Thuja plicata* in the overstory, *Mahonia nervosa* or *Gaultheria shallon* in the understory, between 600 m and 900 m elevation, in stands at least 80 years old, within 1.5 km of roads or trails, on less than 35° slope and not requiring dangerous river crossings to access. To identify the target number of plots for each combination of stratum and park, we used a set of power analyses based on tree mortality data from existing permanent plots in the Pacific Northwest (Acker et al. 2010). We asked what number of plots per stratum would be necessary to detect trends similar to those reported by van Mantgem and Stephenson (2007; 3% annual increase in mortality rate over 20 years), with $\alpha \leq 0.1$ and power $\geq 80\%$. We concluded that six plots per combination of stratum and park was an appropriate compromise between statistical power and cost (Acker et al. 2010).

B. Site Selection

To avoid subjectivity in plot selection, we used the quantitative key to vegetation associations developed by the Washington Natural Heritage Program to determine the vegetation type at each point (Crawford et al. 2009). To avoid being arbitrary we used the published definition of 80 years to be the stand age when Pacific Northwest forests can be considered mature (Franklin et al. 2002). Using this definition, we only sample plots where the main cohort is at least 80 years old (determined by obtaining an increment core from a codominant or dominant tree representing the main cohort of the stand).

In addition to selecting plot sites based on vegetation association and stand age, we also have criteria for crew safety and sampling feasibility. First, we limited our sample to accessible regions of the parks by excluding areas more than 1.5 km away from roads and trails. We excluded plots in areas having greater than 35° slope for safety reasons and because significant damage to soils and understory vegetation occurs when crews work on steep slopes. We also

took dangerous river crossings and other hazards into account when we determined accessible areas. We excluded points closer than 100 m to roads and trails at the larger parks, and closer than 30 m at LEWI and SAJH, to minimize vandalism and the visual impacts to park visitors. The closer allowable proximity to roads and trails at the smaller parks is due to the smaller total area of the parks and lower off-trail travel by visitors.

Points were evaluated in the ascending numerical order generated by the GRTS algorithm. The initial review was performed in the office, using GIS to assess accessibility, steepness at the site, distance to the nearest road or trail, whether or not the location overlapped with a park boundary, a river, or an area of private land or development, whether or not there was greater than 25% tree cover, and whether or not inclusions such as meadows or avalanches chutes encompassed more than 10% of the area. Points satisfying these criteria were then visited in the field to assess access, steepness at the site, whether or not there was greater than 25% tree cover, whether or not inclusions encompassed more than 10% of the area, stand age, and vegetation association.

We began the process of site selection in 2005. By the fall of 2010 selection was complete for four of the five parks (i.e., all but SAJH). However, there were a small number of points at MORA and NOCA which required reconnaissance in 2011, either to resolve ambiguities from earlier evaluations, or to provide suitable monitoring locations to hold in reserve in case of catastrophic disturbance at existing monitoring plots in the future (Acker et al. 2010).

C. Sampling Frequency and Replication

Choosing a temporal sample frame for monitoring involves a trade-off between describing status and detecting trend (Urquhart et al. 1998, McDonald 2003). Status is best described by visiting as many sites as possible in a given time, while trend is best detected by visiting the same plots repeatedly. Our emphasis is on detecting trends; however we also want to have a sample large enough to capture a significant portion of the variability of vegetation dynamics within each set of vegetation associations.

We record tree mortality annually for several reasons. Annual observations will better enable us to identify proximate causes of mortality (van Mantgem and Stephenson 2007), inasmuch as signs of relevant insects and pathogens may fade quickly and trees that die standing may soon fall or break. Annual observations also allow for correlation with specific weather events and short-term climate change (van Mantgem and Stephenson 2007). Finally, tree mortality is often an episodic process (Franklin et al. 1987). Longer measurement intervals lead to underestimates of the true rate of tree mortality (Sheil 1995, Sheil and May 1996) and of the temporal variability of tree mortality. Every five years we will measure trees and add trees that have grown large enough to include in the measured population (see Section D for diameter-classes of trees subsampled in different portions of the permanent plots). This interval should be long enough to detect tree growth, and short enough to ensure that growth information is captured from most trees, that few new recruits die before being added to the monitored population, and that gross errors are detected and corrected promptly (Avery and Burkhart 1994, Sheil 1995).

The measurements at all plots will occur on the same schedule (Table 1). We inspect every plot each year to tally newly-dead trees and record information pertaining to causes of mortality. We calculate the mortality rate for each plot as the number of newly-dead trees per hectare divided by the number of live trees per hectare the previous year. With four years of observations, we

now have our third set of data points for tree mortality and hence the first opportunity to assess trends in the annual rate of tree mortality. After the second full measurement of all plots (tentatively scheduled for 2014), we will have our first set of data points for tree recruitment and growth. After the third full measurement we will be able to describe change in tree recruitment and growth, and after the fourth measurement we will be able to describe trends.

Table 1. Monitoring variables and frequency of measurement.

Variable	Frequency	Population
Tree mortality	Annual	All tagged trees that were alive at last visit
Tree recruitment	Approximately every five years	Stems attaining measurable diameter since last measurement (see Figure 1 for diameter-classes of trees subsampled in different portions of the permanent plots)
Tree growth	Approximately every five years	All tagged trees that were alive at last mortality check

D. Plot Design

Our permanent plots are slope-corrected one-hectare squares with edges oriented along cardinal directions (Figure 1). This total area is consistent with FIA and other permanent monitoring plots in the Pacific Northwest (Acker et al. 1998). We permanently mark the corners and center of the plot with rebar. We centrally locate a 0.25 ha intensive plot (a 50 x 50 m square) divided into 25, 100 m² subplots (each a 10 x 10 m square) within the 1-ha macroplot (Figure 1; lengths represent one side of a square plot or subplot). The delineations within the 1-ha macroplot are used to subsample different segments of the tree population by size: large trees (>76.2 cm dbh) in the entire plot; small trees (12.7 to 76.2 cm dbh) in the 0.25 ha intensive plot; and saplings (2.5 to 12.6 cm dbh) in nine of the 100 m² subplots (see Figure 1). The outer corners of the 0.25 ha intensive plot are marked with rebar and the corners of the 100 m² subplots are marked with wooden stakes. The wooden stakes help minimize the visual impact of permanent markings in wilderness areas and can be replaced as they decay. At LEWI and SAJH, the 50 x 50 m square comprises the entire plot.

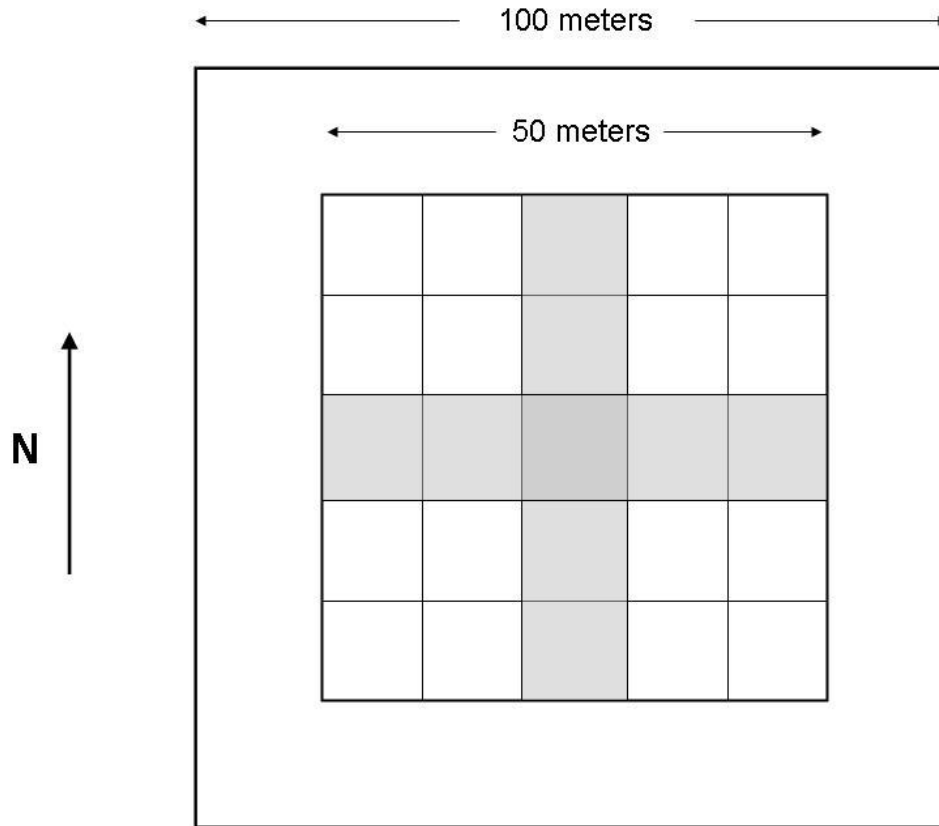


Figure 1. One-ha macroplot showing location of 0.25 ha intensive plot divided into 100 m² subplots. All plots are oriented along cardinal directions. The subplots within which saplings (2.5 to 12.6 cm dbh) are monitored are shaded. Small trees and snags (12.7 to 76.2 cm dbh) are measured within the entire 0.25 ha intensive plot. Large trees and snags are measured within the entire macroplot. At Lewis and Clark National Historical Park and San Juan Island National Historical Park, the 50 x 50 m square comprises the entire plot. The diagram is not to scale.

Results

A. Field Evaluations of Potential Plot Locations at MORA and NOCA

In 2011 we carried out field evaluations of six potential plot locations at MORA and NOCA, to address points that had been inadvertently skipped in the numerical order generated by the GRTS algorithm, or for which questions remained from field evaluations performed during the initial, developmental years of the project. All six of the locations were found inappropriate. Reasons for rejection included non-target vegetation (two cases), excessively steep access, insufficient distance from a trail, excessive steepness at the site, and excessive area at the location occupied by a non-target inclusion.

B. Monitoring Plots at LEWI

In 2011, six permanent plots were established at LEWI. In this section we provide baseline information on site characteristics, species composition, and stand structure of the permanent plots.

Physical Attributes

To compare climatic conditions in the newly-established plots at stratum 1 at LEWI to other combinations of stratum and park, we obtained data from a nearby station of the Cooperative Observer Program of the National Weather Service as recommended by Davey et al. (2006) (Table 2). The climate at stratum 1 at LEWI is characterized by mild winters and high precipitation.

Table 2. Climate data representative of conditions at permanent plots at Lewis and Clark National Historical Park.

Station	Elev. (m)	Period of record	Mean annual precipitation (cm)	Mean min. Jan. temp. (°C)	Mean max. Jul. temp. (°C)
Long Beach Experiment Station, Washington	9	1971-2000	206	2.1	18.7

The plots at LEWI were similar to one another in occupying the lower 1/3 of the elevation range of stratum 1, being situated on the upper portions of valley wall landforms, with moderately steep slopes and relatively fine-textured soils (Table 3). However, the plots represented a wide variety of aspects.

Table 3. Site characteristics of monitoring plots at Lewis and Clark National Historical Park.

Plot	Elevation (m)	Slope (°)	Aspect (°)	Land- form ^a	Topographic position	Surface soil texture
1-004	70	16	31	VW	Side hill, upper 1/3	Clay loam
1-027	43	19	192	VW	Side hill, upper 1/3	Silt
1-036	20	22	54	VW	Side hill, upper 1/3	Clay loam
1-047	85	11	268	VW	Side hill, upper 1/3	Silt loam
1-055	76	16	190	VW	Side hill, upper 1/3	Silt loam
1-063	12	12	161	VW	Side hill, upper 1/3	Clay loam

^a VW = valley wall.

Species Composition and Stand Structure

Six tree species occurred on the permanent forest plots at LEWI (Table 4), including four hardwoods and two conifers. Tree species richness was either three or four on all plots; the average tree species richness was 3.7. *Tsuga heterophylla*, *Picea sitchensis*, and *Rhamnus purshiana* accounted for nearly all of the stems (Table 5). *Tsuga heterophylla* and *Picea sitchensis* accounted for nearly all of the basal area (Table 6). The permanent forest plots at LEWI had relatively few snags (Table 7). Most of the snags had moderate to advanced decay (i.e., decay classes 3 through 5).

Table 4. Tree species included in permanent forest plots at Lewis and Clark National Historical Park.

Scientific name	Common name
<i>Alnus rubra</i>	red alder
<i>Ilex aquifolium</i>	English holly
<i>Malus fusca</i>	western crabapple
<i>Picea sitchensis</i>	Sitka spruce
<i>Rhamnus purshiana</i>	cascara
<i>Tsuga heterophylla</i>	western hemlock

Table 5. Live trees per hectare in permanent forest plots at Lewis and Clark National Historical Park, averaged by species (standard errors in parentheses).

<i>Alnus rubra</i>	<i>Ilex aquifolium</i>	<i>Malus fusca</i>	<i>Picea sitchensis</i>	<i>Rhamnus purshiana</i>	<i>Tsuga heterophylla</i>	Total
1.3 (0.8)	3.7 (2.3)	1.3 (1.3)	60.2 (21.4)	40.8 (19.7)	146.7 (44.3)	254.1 (56.2)

Table 6. Average basal area of live trees in permanent forest plots at Lewis and Clark National Historical Park (m² per hectare), summarized by species (standard errors in parentheses).

<i>Alnus rubra</i>	<i>Ilex aquifolium</i>	<i>Malus fusca</i>	<i>Picea sitchensis</i>	<i>Rhamnus purshiana</i>	<i>Tsuga heterophylla</i>	Total
0.2 (0.1)	0.0 (0.0)	0.0 (0.0)	36.7 (11.5)	0.4 (0.2)	29.5 (9.0)	66.8 (15.5)

Table 7. Mean number of snags per hectare in permanent forest plots at Lewis and Clark National Historical Park summarized by decay class (standard errors in parentheses).

Decay class ^a						Total
1	2	3	4	5	Missing	
3.3 (1.9)	6.0 (2.3)	11.3 (5.0)	8.7 (3.0)	8.7 (3.3)	0.7 (0.7)	38.7 (6.0)

^a Decay class 1 is the least decayed; decay class 5 is the most decayed. See Forest Inventory and Analysis Program 2006.

C. Species Composition and Stand Structure of New Permanent Plots at MORA and NOCA

In 2011 we established one additional permanent plot each in stratum 3 at MORA, stratum 3 at NOCA, and stratum 6 at NOCA. The two plots in stratum 3 had been rejected in the field early in the evaluation process (2005 and 2006) for reasons which upon review in 2010 we determined to be invalid. These points were lower in the numerical order generated by the GRTS algorithm than established permanent plots in their respective combinations of stratum and park. We established permanent plots at these points to maintain consistency with our sampling design. As a consequence, we are monitoring more than the target number of six plots in those combinations of stratum and park. We added the plot in stratum 6 at NOCA to complete the set of six plots for that combination of stratum and park; a suitable location for the sixth plot had been identified in the field in 2010 (Acker et al. 2011b).

New Permanent Plot in Stratum 3 at MORA

The forest at the newly-established plot in stratum 3 at MORA (identified as 'MORA.3-005') consisted entirely of *Pseudotsuga menziesii*, *Tsuga heterophylla*, and *Thuja plicata*, in descending order of abundance of stems (Table 8). *Pseudotsuga menziesii* comprised over four-fifths of the basal area. Snags included all but those with the most advanced decay, with moderately intact snags (decay class 2) most abundant (Table 9). There were slightly more than 200 snags per hectare.

Table 8. Live tree count and basal area per hectare by species for plot MORA.3-005.

Species	Stem count	Basal area (m ²)
<i>Pseudotsuga menziesii</i>	406.0	99.4
<i>Thuja plicata</i>	135.1	8.1
<i>Tsuga heterophylla</i>	228.8	11.7
Total	769.9	119.2

Table 9. Count of snags per hectare by decay class for plot MORA.3-005.

Decay class ^a	Number per hectare
1	12
2	113
3	80
4	10
5	0
Missing	4
Total	219

^a Decay class 1 is the least decayed; decay class 5 is the most decayed. See Forest Inventory and Analysis Program 2006.

New Permanent Plot in Stratum 3 at NOCA

The forest at the newly-established plot in stratum 3 at NOCA (identified as 'NOCA.3-076') consisted primarily of *Tsuga heterophylla*, *Abies amabilis*, and *Thuja plicata*, in descending order of abundance of stems (Table 10). *Tsuga heterophylla* comprised nearly four-fifths of the basal area. Snags included all but those with the most advanced decay, with snags in the middle of the decay range (decay class 3) most abundant (Table 11). There were 45 snags per hectare.

Table 10. Live tree count and basal area per hectare by species for plot NOCA.3-076.

Species	Stem count	Basal area (m ²)
<i>Abies amabilis</i>	193.8	0.9
<i>Pseudotsuga menziesii</i>	7.0	2.5
<i>Taxus brevifolia</i>	55.6	0.1
<i>Thuja plicata</i>	140.4	8.9
<i>Tsuga heterophylla</i>	527.0	47.6
Total	923.8	59.9

Table 11. Count of snags per hectare by decay class for plot NOCA.3-076.

Decay class ^a	Number per hectare
1	8
2	8
3	21
4	4
5	0
Missing	4
Total	45

^a Decay class 1 is the least decayed; decay class 5 is the most decayed. See Forest Inventory and Analysis Program 2006.

New Permanent Plot in Stratum 6 at NOCA

The forest at the newly-established plot in stratum 6 at NOCA (identified as 'NOCA.6-304') consisted primarily of *Abies amabilis* and *Abies lasiocarpa* in descending order of abundance of stems (Table 12). *Abies amabilis* comprised more than three quarters of the basal area. Snags included only those in the two least-decayed categories, with the most intact snags (decay class 1) most abundant (Table 13). There were fewer than 40 snags per hectare.

Table 12. Live tree count and basal area per hectare by species for plot NOCA.6-304.

Species	Stem count	Basal area (m ²)
<i>Abies amabilis</i>	1531.1	37.2
<i>Abies lasiocarpa</i>	450.2	5.7
<i>Chamaecyparis nootkatensis</i>	141.3	0.6
<i>Picea engelmannii</i>	35.3	1.5
<i>Tsuga mertensiana</i>	51.1	4.1
Total	2209.1	49.1

Table 13. Count of snags per hectare by decay class for plot NOCA.6-304.

Decay class ^a	Number per hectare
1	29
2	8
3	0
4	0
5	0
Total	37

^a Decay class 1 is the least decayed; decay class 5 is the most decayed. See Forest Inventory and Analysis Program 2006.

D. Tree Mortality in Most Recent Interval

In the 2010 to 2011 interval, tree mortality at individual plots ranged from zero to over 9% (Figure 2). Almost 1/2 of the plots had no tree mortality, while three plots had mortality greater than 2%. The two plots with the highest mortality rates in the 2010 to 2011 interval represented contrasting proximate causes of tree mortality and tree sizes. Three-quarters of the newly dead trees in the high-mortality plot in stratum 3 at MORA were attributed to weather (and found uprooted). The newly dead trees ranged in dbh from 8 to 82 cm. All of the newly dead trees in the high-mortality plot in stratum 3 at NOCA were attributed to insects (and found standing). These trees ranged in dbh from 46 to 97 cm. Between the various combinations of stratum and park, the average rate of tree mortality varied by more than a factor of six (0.3% to 1.9%, Table 14). The overall average rate of tree mortality was 0.91% (standard error 0.31%).

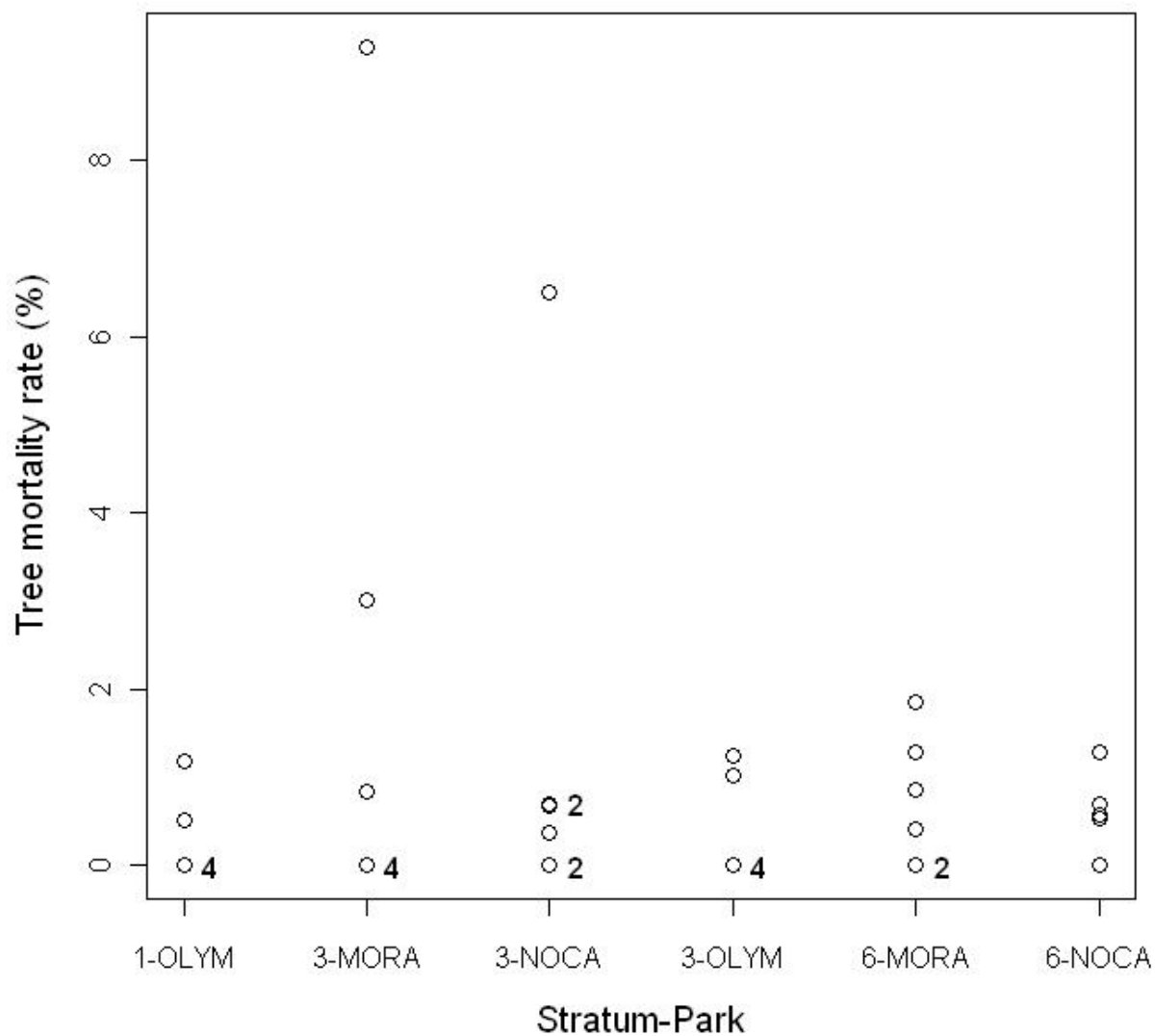


Figure 2. Rates of tree mortality observed from 2010 to 2011, by stratum and park. The numbers next to several of the points indicate the number of plots within a combination of stratum and park which had the same rate of tree mortality (usually 0.0).

Table 14. Rate of tree mortality from 2010 to 2011, in percent, by stratum and park.

Stratum	Park	Tree mortality rate (%)		
		Minimum	Mean	Maximum
1	OLYM	0.0	0.3	1.2
3	MORA	0.0	1.9	9.3
3	NOCA	0.0	1.4	6.5
3	OLYM	0.0	0.4	1.2
6	MORA	0.0	0.7	1.8
6	NOCA	0.0	0.6	1.3

The two most common conditions of trees reported dead in 2011 were standing with no obvious cause of death and standing with death attributed to insects (27% and 24%, respectively, Table 15). Uprooted and broken trees killed by weather together accounted for over 20% of cases. Including all reported causes, standing dead trees accounted for 60% of cases. A smaller number of newly dead trees were found uprooted (22%), or with broken boles (18%). *Pseudotsuga menziesii*, *Tsuga heterophylla*, and *Abies lasiocarpa* accounted for most of the trees reported dead in 2010 (31%, 29%, and 20%, respectively).

Table 15. Characteristics of trees reported dead in 2011.

Tree position	Reported cause of death	Number of cases	Percentage of total
Standing	Unknown	12	26.7
Standing	Insects	11	24.4
Uprooted	Weather	6	13.3
Broken	Weather	5	11.1
Uprooted	Unknown	3	6.7
Broken	Disease	2	4.4
Standing	Vegetation	2	4.4
Broken	Unknown	1	2.2
Standing	Animal activity	1	2.2
Standing	Disease	1	2.2
Uprooted	Disease	1	2.2

E. Trends in Tree Mortality Between 2008 and 2011

For the plots which were established in 2008 there are now three consecutive years of observation of tree mortality, providing the first opportunity to evaluate trends. Most of these 35 plots (25) showed no consistent trend in tree mortality (Table 16). In this group were plots with an initial increase in mortality rate followed by a decrease (13 plots), plots with no change in mortality rate across the three intervals (five plots), and plots with an initial decrease in mortality rate followed by an increase (seven plots). The plots with no change in mortality rate had no tree mortality between 2008 and 2011. Five plots showed decreasing trends and five plots showed increasing trends.

Table 16. Change in mortality rate between 2008-2009 interval and 2009-2010 interval, versus change in mortality rate between 2009-2010 interval and 2010-2011 interval, to indicate trend in mortality rates. The cells with dark shading represent plots with decreasing trends, the unshaded cells represent plots with no trend, and the cells with light shading represent plots with increasing trends.

		Change in mortality rate, 2009-2010 interval to 2010-2011 interval		
		Decrease	No Change	Increase
Change in mortality rate, 2008-2009 interval to 2009-2010 interval	Decrease	2	3	7
	No Change	0	5	3
	Increase	13	1	1

Discussion

The set of plots established at stratum 1 at LEWI had much in common with the other plots in stratum 1, at OLYM. At both locations the climate is wet and relatively warm, though at LEWI both precipitation and summer high temperatures are lower (by about 100 cm and 2°C, respectively). The average, total number stems at LEWI was similar to the average for the plots in stratum 1 at OLYM (i.e., 254 and 241 per ha, respectively) and was much less than the average, total number of stems for other combinations of stratum and park (Acker et al. 2011a). At both locations, *Tsuga heterophylla* and *Picea sitchensis* accounted for most of the stems. Hardwoods were more numerous at LEWI than in stratum 1 at OLYM (18% and 4% of stems, respectively); most of the hardwoods at LEWI were *Rhamnus purshiana*. Average total basal area at LEWI was similar to the average for the plots in stratum 1 at OLYM (i.e., 67 and 74 m² per ha, respectively) (Acker et al. 2011a). As in stratum 1 at OLYM, *Tsuga heterophylla* and *Picea sitchensis* accounted for most of the basal area at LEWI. The plots at LEWI were also similar to the plots in stratum 1 at OLYM with respect to the average density of snags (i.e., 39 and 50 per ha, respectively); no other combination of stratum and park had fewer than 100 snags per hectare on average (Acker et al. 2011a). The permanent forest plots at LEWI had proportionally fewer snags in the least decayed states (Decay classes 1 and 2) and more in the most decayed states (Decay classes 4 and 5) compared to the other combinations of stratum and park. Two tree species on plots at LEWI had not been recorded on permanent forest plots elsewhere in the NCCN (Acker et al. 2011a, 2011b): *Ilex aquifolium* and *Malus fusca*. *Ilex* is the first exotic tree species to be measured in the network's permanent forest plots.

The newly-established plots at MORA and NOCA were notably dissimilar to the previously-established plots for the same combination of stratum and park with respect to both species composition and stand structure. The newly-established plot in stratum 3 at MORA was more strongly characterized by *Pseudotsuga* than the first six plots established there (i.e., 53% of stems and 83% of basal area, versus 21% of stems and 60% of basal area on average for the first six plots; Acker et al. 2011a). Compared to averages for the first six plots, the new plot had 58% higher basal area and twice the density of snags. The newly-established plot in stratum 3 at NOCA had much less *Pseudotsuga* than average for the first six plots established there (i.e., 1% of stems and 4% of basal area, versus 38% of stems and 60% of basal area on average for the first six plots; Acker et al. 2011a); the plot also included abundant *Abies amabilis* (21% of stems); the species was not recorded on any of the first six plots. Total stem density and basal area on the new plot were similar to averages for the first six plots, though the density of snags on the new plot was less than half the average for the first six plots. On the newly-established plot in stratum 6 at NOCA, the relative proportions of *Abies amabilis* and *A. lasiocarpa* were nearly reversed with respect to the averages for the first five plots established there (e.g., 69% and 20% of stems on the new plot and 33% and 56% of stems on average for the first five plots; Acker et al. 2011a). The stem density on the new plot was almost twice the average for the first five plots, while the density of snags was less than one-fourth the average for the first five plots.

As in previous years, most of the newly-dead trees observed in 2011 died standing. Unlike past years, a cause of death was reported for the standing dead trees more often than was the cause of death unknown. Insects were by far the most common identified cause of death for the standing trees. Uprooted and broken trees accounted for a much larger proportion of newly-dead trees in 2011 than in previous years (i.e., 40% versus 9% in 2009 and 22% in 2010).

Tree mortality in the most recent interval averaged over all plots was within the range for the first two intervals (i.e., 0.9% versus 0.6% in 2009 and 1.1% in 2010). Compared to the 2009-2010 interval, the most recent interval had fewer plots with annual mortality greater than 2% and more plots with no mortality. The rate in the most recent interval is slightly higher than the range expected for old, unmanipulated forests in the Pacific Northwest (Franklin et al. 1987, Larson and Franklin 2010). The relatively high mortality rate in the most recent interval is mostly due to the two plots with mortality in excess of 6%, one in which most of the mortality was attributed to weather (i.e., wind), and one in which all of the mortality was attributed to insects (i.e., the bark beetle *Dendroctonus pseudotsugae*). The latter plot also had a high mortality rate in 2010 due mostly to *D. pseudotsugae*. It is likely that tree mortality at this plot due to the beetle will wane quickly, based on its usual behavior in the region (Goheen and Willhite 2006).

No consistent trend in rates of tree mortality emerged from evaluation of the first applicable set of data from these plots. It is clear that on individual plots, the rate of tree mortality tends to change from one year to the next. Year-to-year variability may obscure longer-term trends. However, van Mantgem et al. (2009) have recently reported that mortality rates in old, unmanaged forests in the Pacific Northwest have increased rapidly in recent decades (i.e., estimated doubling time of 17 years). If this trend continues, it is likely to become apparent soon in mature and old-growth forests in the NCCN.

In 2012, we plan to carry out the office and field evaluation of potential monitoring locations at SAJH, in addition to performing annual observations of tree mortality at LEWI, MORA, NOCA, and OLYM. We will also continue collecting measurements of height and dbh for live trees of the most abundant species to enable us to estimate changes in biomass of tree boles over time (Acker et al. 2002).

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