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Monitoring Forest Vegetation in the North Coast and Cascades Network

2009 Annual Report

Natural Resource Technical Report NPS/NCCN/NRTR—2011/446

ON THE COVER
North Cascades National Park employee Alyssum Cohen at a long-term monitoring plot in the Ohanapecosh watershed, Mount Rainier National Park.
Photograph courtesy of North Cascades National Park.

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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

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This report is available from the North Coast and Cascades Network website http://science.nature.nps.gov/im/units/nccn/reportpubs.cfm and the Natural Resource Publications Management website http://www.nature.nps.gov/publications/nrpm/.

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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 have begun to track trends in tree recruitment, growth, and mortality in forests representing the range of environments in network parks. We have established 35, 1-hectare plots in three parks (Mount Rainier, North Cascades, Olympic), 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 Random Tesselation Stratified algorithm. Initial screening was in the office, using GIS to evaluate suitability factors including safety of access routes and proximity to trails and roads. Points that passed the office screening were evaluated in the field on safety of access, forest species composition and age, and other factors. We evaluated over 1700 points in the office, 640 of which passed. Three reasons accounted for most of the rejection of points in the office: excessively steep access, excessive steepness at the proposed location, and proximity to trails (either too close or too far). We evaluated 579 points in the field, 107 of which passed. Most of the rejections of points in the field were due to forest species composition which was not one of the target types.

We selected three different elevation strata at the network-level (two within each park) for forest monitoring, with plans to establish six plots within each strata-park combination. As of 2008, we established six plots in five of the six elevation strata-park combinations, and five plots in the highest-elevation stratum at North Cascades National Park. For the most part, plots are located on hillsides occupying a variety of aspects within each combination of stratum and park. A total of 21 tree species occurred within the 35 plots, 15 of which were conifers. The plots include all of the tree species which are widespread and dominant in the parks. Average density of trees varies by a factor of five (from 241 to 1213 per ha) between the various combinations of stratum and park, with the lowest elevation stratum distinguished from the other two by its low average density of trees. Basal area of live trees was less variable than stem density; high-elevation plots on average had roughly two-thirds of the basal area of plots at low and mid-elevations (overall range of average by stratum and park 44 to 75 m^2/ha). *Tsuga heterophylla* had the highest average density in more combinations of stratum and park than any other species; *Pseudotsuga menziesii* had the highest average basal area in more combinations of stratum and park than any other species. Other abundant and/or dominant species were *Abies lasiocarpa*, *A. amabilis*, *Picea sitchensis*, *Thuja plicata*, and *Picea engelmannii*.

Our first interval for measuring tree mortality was 2008 to 2009. Roughly half of the plots had no tree mortality; the overall average rate of tree mortality was 0.6%. The most common condition of trees reported dead in 2009 was standing with no obvious cause of death (over 60% of cases). The overall average rate of tree mortality was within the range to be expected for older forests in the Pacific Northwest in the absence of severe wind damage. That field crews were unable to assign a cause in most cases is not surprising, inasmuch as tree death usually results from multiple, interacting factors.

Introduction

This report presents initial 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 development of monitoring in 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 first 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 on the following four topics:

1) Screening of potential plot locations through the process of site selection;
2) Physical characteristics of the locations selected for permanent plots;
3) Baseline information on species composition and stand structure of the permanent plots established to date; and
4) Initial observations of tree mortality for the interval 2008 to 2009.

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 (Birkeland 1984, Jenny 1941). 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 North Coast and Cascades Network 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. 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 are 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 will require the National Park Service to take a more active role (e.g., planting seeds outside of their present range) in managing resources than current policy describes. 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 this approach, 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 (Barnosky 1984, Davis 1981). 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).

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, cold and dry conditions in the *Abies lasiocarpa* zone, plus the intermediate *Tsuga heterophylla* zone, which is represented in all three large parks (Mount Rainier, North Cascades, and Olympic). Limited resources and the need for sample replication require that we further focus on particular vegetation associations within forest zones.

C. Measurable Objectives

Our objectives are to monitor trends in tree species recruitment, growth, and mortality; and forest structure and composition. Because we are interested in direct responses to ecological change, we want to 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 will monitor dimensions (diameter at breast height (dbh), height), indicators of health, and indicators of wildlife habitat (especially for birds) 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.
- Snags – We will monitor changes in density and size as indicators of forest structure and carbon cycling.

Processes
- Tree recruitment – We will monitor saplings to track changes in establishment (i.e., stems reaching 2.5 cm dbh) and species composition as indicators of changing forest structure.
- Tree growth – We will monitor growth of tagged trees as an indicator of changing conditions for forests.
- Tree mortality – We will 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 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 can 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. Finally, 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). We chose Generalized Random Tesselation Stratified (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 are including 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 get a spatially balanced sample. 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 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 the sets of vegetation communities is different for the different strata. For the 0-300 m and 600-900 m strata, we have chosen sets of 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 have chosen a set of vegetation communities which characterize the dry end of the moisture gradient within high-elevation, cold forests (Franklin et al. 1988).

In addition to stand age and vegetation community, we also include criteria for safe accessibility and financial feasibility. We use two-stage sampling for stratification (Thompson 2002). The stage 1 GRTS sample for a stratum is evaluated in the office using GIS and becomes the population for the stage 2 sample that further stratifies the population into mature or old-growth examples of a specific set of vegetation communities and other vegetation types. The second stage is evaluated by field reconnaissance. Therefore our target populations and range of inference for intensive sampling will be one example of 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 will be 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 greater than 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 found by van Mantgem and Stephenson (2007; 3% annual increase in mortality rate over 20 years), with alpha <= 0.1 and power >= 80%. We concluded that a target of 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 for determining 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 for interpretability, 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^o slope for safety reasons and because significant damage to soils and understory vegetation occurs when crews work on steep slopes. We also take dangerous river crossings and other hazards into account when we determine 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 area and less off-trail travel by visitors.

Points were evaluated in the ascending numerical order generated by the GRTS algorithm. The initial review was 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 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 2009 it was nearly complete for the three larger parks, with only one more plot in the 1500-1800 m elevation band at NOCA to be identified. Site selection had not been carried out for LEWI and SAJH at that time.

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 represent each set of vegetation associations.

We have chosen to 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 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 two years of observations, we now have our first set of data points for tree mortality; we will have information on change and trends after three and four years, respectively. After five years we will have our first set of data points for tree recruitment and growth. After ten years we will be able to describe change in tree recruitment and growth, and after 15 years 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	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	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 50-m intensive plot divided into 25 10-m subplots 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 50-m intensive plot; and saplings (2.5 to 12.6 cm dbh) in nine of the 10-m subplots (see Figure 1). The outer corners of the 50-m intensive plot are marked with rebar and the corners of the 10-m 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 area comprises the entire plot.

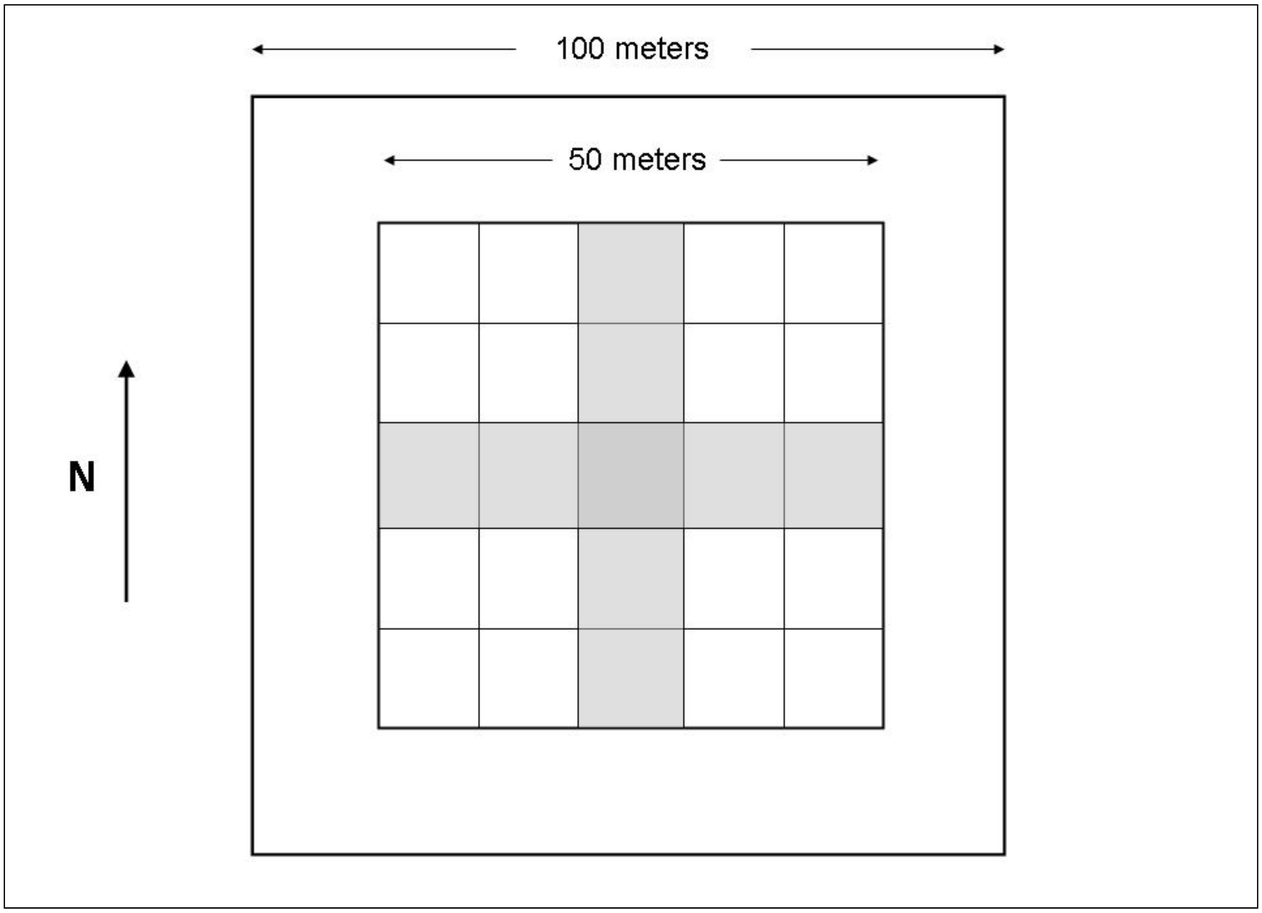

Figure 1. One-ha macroplot showing location of 50-m intensive plot divided into 10-m subplots. All plots are oriented along cardinal directions. The subplots within which saplings (2.5 to 12.6 cm dbh) are monitored are shaded. Small trees and snags (12.7 to 76.2 cm dbh) are measured within the entire 50-m intensive plot. Large trees and snags are measured within the entire macroplot. At LEWI and SAJH, the 50 x 50 m area comprises the entire plot.

Results

A. Site Selection

Office Evaluation

The process of site selection has been incremental. That is, we began to perform field evaluations shortly after the initial batches of office screenings, rather than completing all the office screenings first. The differences between the stratum and park combinations in the total number of office evaluations (Table 2) is due to our accumulating experience of the relative difficulty of finding suitable monitoring locations. The extreme example is stratum 6 at NOCA, where the first selection of 300 GRTS points was exhausted without finding six locations that passed the field evaluation (see Table 6). In general, the proportion of points which passed the office evaluation decreased with elevation, and was higher at a given elevation for MORA than for the other parks (Table 2).

Table 2. Results of office evaluations.

Stratum	Park	Number evaluated	Number passed	Percent passed
1	OLYM	250	164	66
3	MORA	152	80	53
3	NOCA	300	122	41
3	OLYM	250	72	29
6	MORA	251	111	44
6	NOCA	500	91	18

In order to standardize site selection, we incorporated into the project's database a set of reasons for rejecting potential plots reflecting the criteria enumerated in the protocol document (Table 3; Acker et al. 2010). Of the nearly 1100 points which were rejected in the office evaluation, three reasons accounted for over two-thirds of the cases: excessively steep access, excessive steepness at the proposed location, and proximity to trails (either too close or too far)(Table 4). Since physical barriers to safe access commonly are cliffs, in many cases either the presence of a physical barrier or excessively steep access are equally valid reasons for rejecting a point. The two reasons are combined in the rest of the summaries.

Stratum 1 at OLYM stands in contrast to the other combinations of stratum and park in that no points were rejected in the office evaluation due to a physical barrier or excessively steep access (Table 5**.** In all the other combinations of stratum and park, physical barrier or excessively steep access was the leading or second-leading reason for rejection. The leading cause of rejection for stratum 1 at OLYM was proximity to a road, a cause which occurred rarely elsewhere. In stratum 3 at OLYM, excessive steepness at the proposed location was the reason for over half of the rejections, a much higher incidence than elsewhere.

Table 3. List of codes describing reasons for failure of office and field evaluations.

Code	Full label	Explanation
AS	Access too steep	Access crosses slopes greater than 35 degrees in steepness
BP	Boundary proximity	Site is rejected due to being too close to the park boundary
DI	Disturbance	Site has significant disturbance (disease, fire, avalanche etc.)
IN	Inclusion	Site has a non-target inclusion
NT	Non-target	Site is not a member of the target population
PB	Physical barrier	A physical barrier prevented access to the site
PR	Privately owned	Site is privately owned or subject to development
RI	River or stream	A river or stream crosses the site
RP	Road proximity	Site is rejected due to being too close to a road
SS	Site too steep	The site is too steep to be sampled safely
TP	Trail proximity	Site is rejected due to being too close to or distant from a trail

Table 4. Breakdown of reasons for failure of office evaluation, combined across strata and parks.

Reason for rejection	Number of cases	Percentage of cases
Access too steep	309	29
Boundary proximity	10	1
Disturbance	17	2
Inclusion	23	2
Non-target	68	6
Physical barrier	96	9
Privately owned	6	1
River or stream	57	5
Road proximity	40	4
Site too steep	267	25
Trail proximity	170	16

Table 5. Percentage of reasons for failure of office evaluation by stratum and park.

Stratum	Park	AS/PB	BP	NT	RI	RP	SS	TP
1	OLYM	0	12	0	29	36	7	12
3	MORA	21	0	1	18	11	12	29
3	NOCA	36	0	6	4	0	27	15
3	OLYM	34	0	0	6	1	54	4
6	MORA	36	0	11	0	0	29	18
6	NOCA	52	0	10	0	0	16	20

Field Evaluation

For most of the combinations of stratum and park, nearly all of the points which passed the office evaluation had been evaluated in the field by the end of the 2009 field season (Table 6). However, just under two-thirds of the points which passed the office evaluation for stratum 6 at NOCA had been evaluated in the field by that time. This was due to the additional points we screened in the office to prepare to continue searching for the sixth monitoring plot in stratum 6 at NOCA during the 2010 field season.

The rate of acceptance of points in the field was low throughout, ranging from about one in 12 to one in three (Table 6). The rate of acceptance was lower at the extremes of elevation than in stratum 3. However, due to the large number of points evaluated in the field, by 2009 in all but one of the combinations of stratum and park we had identified enough suitable locations for the target of six monitoring plots, plus additional points as a hedge against catastrophic disturbance (Acker et al. 2010). The exception was stratum 6 at NOCA.

Table 6. Results of field evaluations.

Stratum	Park	Number evaluated	Percent evaluated[a]	Number passed	Percent passed	Number of plots established
1	OLYM	155	95	19	12	6
3	MORA	76	95	23	30	6
3	NOCA	116	95	23	20	6
3	OLYM	68	94	23	34	6
6	MORA	105	95	14	13	6
6	NOCA	59	65	5[b]	8	5

[a] Percentage of points which passed office evaluation that had been evaluated in the field as of 2009.
[b] There were two points which passed the field evaluation in 2006 but for which access was judged unsafe by the field crew in 2010. These are not included in the number passed.

In more than three-quarters of the cases, the reason for rejection of points in the field was non-target vegetation (Table 7). The preponderance of non-target vegetation as the reason for rejection in the field was consistent across strata and parks (Table 8). Unsafe access was also a common reason for rejection in the field for potential plots at high elevation. In the mid-elevation stratum at NOCA and OLYM, excessive steepness of the proposed location was a common reason for rejection.

Table 7. Breakdown of reasons for failure of field evaluation, combined across strata and parks.

Reason for rejection	Number of cases	Percentage of cases
Access too steep	29	6
Boundary proximity	1	0
Disturbance	1	0
Inclusion	17	4
Non-target	357	76
Physical barrier	11	2
River or stream	1	0
Site too steep	36	8
Trail proximity	15	3

Table 8. Percentage of reasons for failure of field evaluation by stratum and park.

Stratum	Park	Reason for rejection		
		AS/PB	NT	SS
1	OLYM	1	88	2
3	MORA	6	83	4
3	NOCA	11	70	13
3	OLYM	4	69	20
6	MORA	16	71	7
6	NOCA	20	67	8

Rejection in the field due to non-target vegetation may be due to either inappropriate species composition (non-target vegetation association), or insufficiently old forest (stand age less than 80 years). For all combinations of strata and park, nearly all of the rejections in the field for non-target vegetation were due to inappropriate species composition (Table 9).

It is important to note that the field evaluation is a sequential process, with evaluation of the vegetation association occurring prior to the evaluation of stand age. That is, a point with vegetation that is not one of the target associations for the stratum cannot be rejected on grounds of insufficiently old forest. Stand age was evaluated in the field for slightly fewer than half of the points which were rejected due to non-target species composition.

Table 9. Non-target vegetation association as a percentage of cases of failure of field evaluation with code "NT," by stratum and park.

Stratum	Park	Percent of NT due to vegetation association
1	OLYM	96
3	MORA	95
3	NOCA	85
3	OLYM	90
6	MORA	92
6	NOCA	94

B. Physical Attributes of Monitoring Plots

Spatial variation of climate is high within and between parks of the NCCN due largely to mountainous topography and differences in proximity to the Pacific Ocean (Davey et al. 2006). Representative stations of the Cooperative Observer Program of the National Weather Service (Davey et al. 2006) for the various combinations of stratum and park illustrate the intended contrasts in climate, from mild winters and high precipitation in stratum 1 to cold winters and less precipitation in stratum 6 (Table 10).

Table 10. Climate data from representative stations for each stratum and park.

Stratum	Park	Station	Elev. (m)	Period of record	Mean annual precipitation (cm)	Mean min. Jan. temp. (°C)	Mean max. Jul. temp. (°C)
1	OLYM	Forks 1 E	107	1971-2000	309	0.9	21.3
3	MORA	Longmire	842	1971-2000	205	-3.6	22.7
3	NOCA	Ross Dam	377	1971-2000	146	-2.1	24.6
3	OLYM	Elwha Ranger Station	110	1971-2000	141	-0.8	22.3
6	MORA	Bumping Lake	1049	1910- 1967	119	-10.0	23.5
6	NOCA	Holden	1049	1930-1957	89	-9.2	23.8

In order to estimate the particular climatic conditions at each of the plot locations, we will eventually obtain data from GIS layers generated by a spatial-interpolation model such as PRISM (Parameter Regression on Independent Slopes Model; Davey et al. 2006). Such models can also be used to estimate year-to-year weather variability at plot locations. We intend to exploit such information as potential explanatory variables for our observations of tree recruitment, growth, and mortality.

As of 2008 we had established the target number of six plots each in all but one of the combinations of stratum and park at MORA, NOCA, and OLYM. In stratum 6 at NOCA we had established five plots. For the most part, plots are located on hillsides occupying a variety of aspects within each combination of stratum and park (Table 11). One exception is stratum 1, in which most of the plots are relatively flat and only two occur on hillslopes. The other exception is stratum 3 at OLYM, where plots are on hillsides, but only on south and west aspects.

Table 11. Site characteristics of monitoring plots.

Stratum	Park	Plot	Elevation (m)	Slope (°)	Aspect (°)	Land-form[a]	Topographic position	Surface soil texture
1	OLYM	1-006	40	0	0	T	Bench, terrace, flat	Silt loam
1	OLYM	1-020	236	32	140	VW	Side hill, lower 1/3	Silt loam
1	OLYM	1-031	183	0	360	T	Bench, terrace, flat	Sandy loam
1	OLYM	1-038	170	6	170	VW	Side hill, lower 1/3	Loamy sand
1	OLYM	1-063	130	2	204	T	Bench, terrace, flat	Clay loam
1	OLYM	1-066	68	0	215	SH	Ridge or peak	Silt loam
3	MORA	3-012	704	20	242	VW	Side hill, mid 1/3	Loamy sand
3	MORA	3-015	799	18	227	VW	Side hill, lower 1/3	Loamy sand
3	MORA	3-023	767	34	28	VW	Side hill, lower 1/3	Loamy sand
3	MORA	3-033	864	22	196	VW	Side hill, lower 1/3	Loamy sand
3	MORA	3-034	884	15	10	VW	Side hill, upper 1/3	Loamy sand
3	MORA	3-037	806	23	139	VW	Side hill, lower 1/3	Loamy sand
3	NOCA	3-035	776	10	146	VW	Side hill, mid 1/3	Sandy loam
3	NOCA	3-044	825	26	90	VW	Side hill, lower 1/3	Loamy sand
3	NOCA	3-056	834	13	334	VW	Side hill, lower 1/3	Sandy loam
3	NOCA	3-064	859	20	245	VW	Side hill, lower 1/3	missing
3	NOCA	3-080	607	24	270	VW	Side hill, lower 1/3	missing
3	NOCA	3-083	723	25	351	VW	Side hill, lower 1/3	Silt loam
3	OLYM	3-010	696	30	287	VW	Side hill, mid 1/3	Sandy loam
3	OLYM	3-023	712	22	205	VW	Side hill, mid 1/3	Sandy loam
3	OLYM	3-057	605	25	165	VW	Side hill, upper 1/3	Silt
3	OLYM	3-074	616	28	235	VW	Side hill, lower 1/3	Loamy sand
3	OLYM	3-080	740	7	240	VW	Side hill, upper 1/3	Loamy sand
3	OLYM	3-086	764	30	276	VW	Side hill, lower 1/3	Loamy sand
6	MORA	6-002	1671	24	188	VW	Side hill, upper 1/3	Sandy loam
6	MORA	6-028	1796	28	258	VW	Side hill, lower 1/3	Sandy loam
6	MORA	6-063	1573	8	104	VB	Side hill, lower 1/3	Sandy loam
6	MORA	6-139	1546	8	80	PK	Side hill, lower 1/3	Sandy loam
6	MORA	6-160	1545	26	128	VW	Side hill, upper 1/3	Loamy sand
6	MORA	6-164	1565	12	139	VW	Side hill, lower 1/3	Loamy sand
6	NOCA	6-011	1574	11	236	VW	Side hill, upper 1/3	Sandy loam
6	NOCA	6-061	1710	29	260	VW	Side hill, lower 1/3	Sandy loam
6	NOCA	6-065	1554	26	167	VW	Side hill, lower 1/3	Sandy loam
6	NOCA	6-161	1603	30	214	VW	Side hill, lower 1/3	Sandy loam
6	NOCA	6-237	1786	18	225	VW	Side hill, upper 1/3	Sandy loam

[a] PK = parkland (gentle terrain surrounded by steeper); SH = shoreline; T = terrace; VB = valley bottom; VW = valley wall.

C. Species Composition and Stand Structure of Permanent Plots

Twenty-one tree species occurred among the 35 plots includes (Table 12). Fifteen species were conifers; and the remaining species were deciduous hardwoods. There were more species per combination of stratum and park at low and mid-elevations than at high elevations (Table 13). The highest mean number of species per plot occurred at mid-elevations at both MORA and NOCA. There was only one of the 35 plots (stratum 6, MORA) in which all of the tagged trees were of a single species.

Table 12. Tree species included in permanent forest plots for North Coast and Cascades Network.

Scientific name	Common name
Abies amabilis	Pacific silver fir
Abies grandis	grand fir
Abies lasiocarpa	subalpine fir
Abies procera	noble fir
Acer macrophyllum	bigleaf maple
Alnus rubra	red alder
Alnus sinuata	Sitka alder
Chamaecyparis nootkatensis	Alaska yellow cedar
Cornus nuttallii	Pacific dogwood
Picea engelmannii	Engelmann spruce
Picea sitchensis	Sitka spruce
Pinus albicaulis	whitebark pine
Pinus contorta	lodgepole pine
Pinus monticola	western white pine
Populus balsamifera ssp. trichocarpa	black cottonwood
Pseudotsuga menziesii	Douglas-fir
Rhamnus purshiana	cascara
Taxus brevifolia	Pacific yew
Thuja plicata	western red cedar
Tsuga heterophylla	western hemlock
Tsuga mertensiana	mountain hemlock

Table 13. Tree species richness by stratum and park.

		Tree species richness per plot			Total tree species richness
Stratum	Park	Minimum	Mean	Maximum	
1	OLYM	2	3.7	5	8
3	MORA	3	4.8	8	9
3	NOCA	3	5.2	7	8
3	OLYM	2	3.7	6	9
6	MORA	1	3.3	6	6
6	NOCA	3	4.2	5	6
All					21

Average density of trees varied by a factor of five between the various combinations of stratum and park, with stratum 1 distinguished from the other strata by its low average density of trees (Table 14). Of the 21 tree species, six accounted for 10% or more of the stems in any of the combinations of stratum and park. *Pseudotsuga menziesii* occurred in all combinations of stratum and park, though its average density is less than one tree per hectare in stratum 6 at MORA. *Tsuga heterophylla* was the most abundant species in three of the six combinations of stratum and park, more than any other species. The average densities of *Abies lasiocarpa* in stratum 6 at both MORA and NOCA were greater than the average density of any other species in any of the combinations of stratum and park.

Table 14. Live trees per hectare averaged by species and stratum-park combination (standard errors in parentheses).

Stratum	Park	*Abies amabilis*	*A. lasiocarpa*	*Picea sitchensis*	*Pseudo-tsuga men-ziesii*	*Thuja plicata*	*Tsuga hetero-phylla*	Hard-woods	Other conifers	Total
1	OLYM	0	0	58.7 (18.8)	3.8 (2.5)	10.5 (6.1)	158.5 (70.2)	9.7 (4.0)	0	241.3 (58.1)
3	MORA	117.2 (94.6)	0	0	155.0 (53.4)	77.7 (31.2)	331.7 (61.6)	3.3 (3.3)	60.8 (38.7)	745.8 (142.7)
3	NOCA	0	0	0	327.3 (137.9)	133.2 (38.6)	316.7 (89.2)	0	49.8 (12.6)	826.8 (95.1)
3	OLYM	24.5 (24.5)	0	0	466.7 (136.5)	73.0 (71.4)	611.8 (160.0)	5.0 (3.3)	32.3 (20.0)	1213.5 (313.2)
6	MORA	236.3 (119.1)	751.0 (137.0)	0	0.2 (0.2)	0	0	0	31.5 (16.9)	1019.0 (56.2)
6	NOCA	389.2 (128.0)	666.0 (163.7)	0	2.4 (1.6)	0	0	0	127.6 (45.7)	1185.2 (264.4)

Basal area of live trees was less variable than stem density; high-elevation plots on average had roughly two-thirds of the basal area of plots at low and mid-elevations (Table 15). Of the 21 tree species, seven accounted for 10% or more of the basal area in any of the combinations of stratum and park. The one addition to the six most abundant tree species was *Picea engelmannii* which accounted for slightly more than 10% of the basal area in stratum 6 at NOCA. *Pseudotsuga menziesii* accounted for the majority of the basal area in stratum 3 at all three parks. *Tsuga heterophylla* had the second greatest basal area in all combinations of stratum and park within the low and mid-elevation strata. *Abies lasiocarpa* was the only species which accounted for both the most stems and the largest portion of basal within any combination of stratum and park. This was the case for stratum 6 in both MORA and NOCA.

Table 15. Average basal area of live trees (m^2 per hectare), summarized by species and stratum-park combination (standard errors in parentheses).

Stratum	Park	*Abies amabilis*	*A. lasiocarpa*	*Picea engelmannii*	*P. sitchensis*	*Pseudotsuga menziesii*	*Thuja plicata*	*Tsuga heterophylla*	Hardwoods	Other conifers	Total
1	OLYM	0	0	0	35.2 (5.8)	6.9 (4.4)	7.6 (4.0)	21.7 (8.5)	2.0 (1.1)	0	73.5 (5.4)
3	MORA	4.9 (3.3)	0	0	0	45.3 (10.7)	6.0 (2.7)	18.1 (6.1)	0.2 (0.2)	0.4 (0.2)	75.1 (5.1)
3	NOCA	0	0	0	0	38.0 (6.2)	10.8 (6.5)	14.1 (4.5)	0	0.5 (0.3)	63.3 (7.9)
3	OLYM	3.9 (3.9)	0	0	0	44.4 (11.3)	1.8 (1.0)	17.1 (3.4)	0.1 (0.05)	0.2 (0.1)	67.5 (9.6)
6	MORA	9.2 (4.9)	32.8 (5.3)	0.4 (0.3)	0	0.1 (0.1)	0	0	0	1.8 (1.3)	44.4 (6.3)
6	NOCA	14.0 (4.5)	26.3 (2.6)	5.4 (3.9)	0	0.4 (0.2)	0	0	0	3.8 (2.3)	50.0 (3.5)

The pattern in average, total number of snags was similar to that for average, total number of live trees: stratum 1 had many fewer than the other strata (Table 16). The distribution of snags by decay class also varied between the combinations of stratum and park. The proportion of snags in the least decayed states (Decay classes 1 and 2) was lowest in stratum 1 (34% of the total). In the other combinations of stratum and park, the least-decayed snags ranged from 40% (stratum 3, MORA) to 67% (stratum 6, NOCA) of the total. The proportion of snags in the most decayed states (Decay classes 4 and 5) was highest in stratum 3, MORA, and stratum 1 (32% and 28%, respectively). In the other combinations of stratum and park, the most-decayed snags ranged from 9% (stratum 6, NOCA) to 16% (stratum 3, OLYM) of the total. In two of the 35 plots, there were no snags which met the size criteria for tagging (both in stratum 6, MORA).

Table 16. Mean number of snags per hectare summarized by decay class and by stratum-park combination (standard errors in parentheses).

Stratum	Park	Decay class[a]						Total
		1	2	3	4	5	Missing	
1	OLYM	2.0 (0.9)	15.2 (8.5)	18.0 (6.3)	10.0 (2.6)	3.7 (1.5)	0.8 (0.7)	49.7 (16.8)
3	MORA	13.8 (2.6)	28.5 (7.5)	27.3 (7.5)	21.7 (8.4)	12.3 (5.7)	3.3 (2.6)	107.0 (26.9)
3	NOCA	30.2 (6.9)	42.0 (10.3)	32.3 (5.5)	14.2 (4.2)	1.5 (0.8)	2.7 (1.3)	122.8 (19.6)
3	OLYM	37.7 (18.8)	32.0 (13.1)	34.8 (17.2)	12.8 (5.7)	7.0 (2.6)	1.5 (1.5)	125.8 (32.9)
6	MORA	45.7 (18.6)	41.0 (18.9)	60.2 (32.8)	22.0 (11.3)	2.0 (2.0)	0.7 (0.7)	171.5 (76.1)
6	NOCA	60.2 (28.7)	47.2 (15.4)	35.2 (9.4)	13.6 (5.6)	0	2.4 (2.4)	158.6 (51.2)
Average		31.6 (8.7)	34.3 (4.7)	34.6 (5.7)	15.7 (2.0)	4.4 (1.9)	1.9 (0.4)	122.6 (17.6)

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

D. Initial Observations of Tree Mortality

Our first interval for measuring tree mortality was 2008 to 2009. Roughly half of the plots had no tree mortality while three plots had mortality greater than 1.5% (Figure 2). Between the various combinations of stratum and park, the average rate of tree mortality varied by more than an order of magnitude (0.1% to 1.1%; Table 17). The overall average rate of tree mortality was 0.6%.

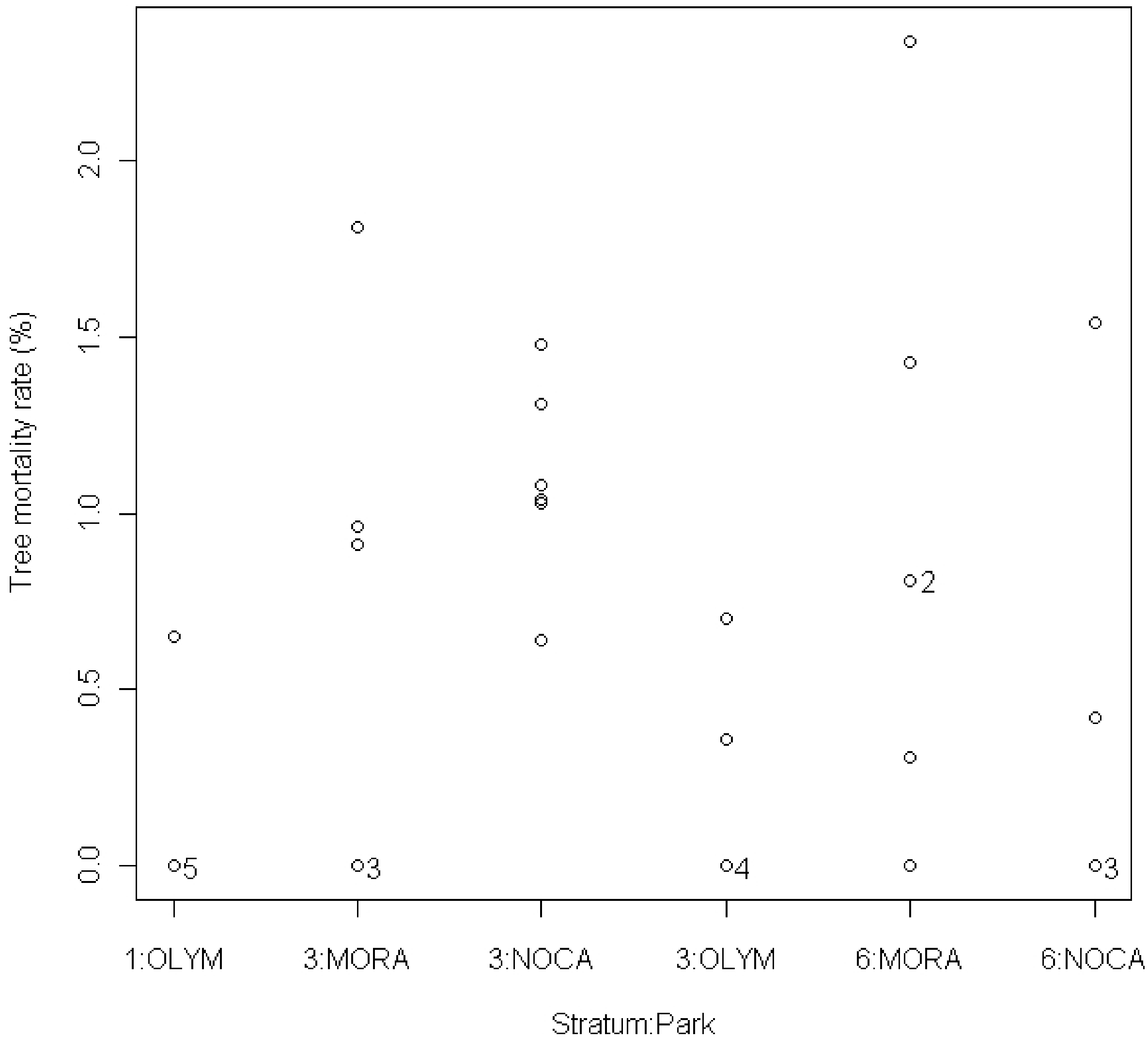

Figure 2. Rates of tree mortality observed from 2008 to 2009, by stratum and park. The numbers next to several of the points indicate the number of plots within a combination of stratum and park which had the same rate of tree mortality (usually 0.0).

Table 17. Rate of tree mortality from 2008 to 2009, in percent, by stratum and park.

		Tree mortality rate (%)		
Stratum	Park	Minimum	Mean	Maximum
1	OLYM	0.0	0.1	0.6
3	MORA	0.0	0.6	1.8
3	NOCA	0.6	1.1	1.5
3	OLYM	0.0	0.2	0.7
6	MORA	0.0	1.0	2.3
6	NOCA	0.0	0.4	1.5

The most common condition of trees reported dead (63%) in 2009 was standing with no obvious cause of death (Table 18). Including all reported causes, standing dead trees accounted for 91% of cases. A small number of newly dead trees were found with broken boles or uprooted. *Abies lasiocarpa*, *Pseudotsuga menziesii*, and *Tsuga heterophylla* accounted for most of the trees reported dead in 2009 (34%, 31%, and 22%, respectively).

Table 18. Characteristics of trees reported dead in 2009, by stratum and park.

Tree position	Reported cause of death	Number of cases
Standing	Unknown	20
Standing	Vegetation	4
Standing	Weather	3
Standing	Disease or Insects	2
Broken	Weather	2
Uprooted	Unknown	1

Discussion

We have implemented long-term monitoring of mature and old-growth forests in the North Coast and Cascades Network in keeping with the vision of the revised protocol. The process of site selection was time-consuming and arduous, but after five years of screening randomly-selected points we have established all but one of the intended set of plots for the three large parks. From a logistical perspective, the two-stage selection of sites was successful, in that we were able to find appropriate locations for monitoring, and in that the predominant criteria for screening out points was different in the office versus the field screening. Thus, the effort expended in evaluating potential monitoring locations in the field was in general devoted to aspects of the locations which could not have been discerned in the office.

The plots capture most, but not all of the tree species diversity present in the three large parks. The plots include all of the tree species which are widespread and dominant in the parks (Agee and Kertis 1986, Franklin et al. 1988, Buckingham et al. 1995). The plots do not contain some species which are dominant but of limited distribution within the parks (e.g., *Larix lyallii*, *Pinus ponderosa*).

Taking into account the patterns of density and basal area of live trees, it is evident that stand structure varies across the strata from few, large trees in the lowest elevation plots, to many, smaller trees at the highest elevations. Plots in the mid-elevation stratum are intermediate in both numbers and size of trees. Patterns in abundance and stage of decay of snags suggest differences in stand history between the strata. The relatively high proportion of snags in the most-decayed states in the low elevation plots is consistent with less-frequent stand-replacing disturbance. The greater abundance of less-decayed snags in the highest elevation plots, and the observation of plots lacking in snags, could be due to relatively recent establishment of forest in former meadows (Franklin and Dyrness 1988).

The overall average rate of tree mortality was within the range to be expected for older forests in the Pacific Northwest in the absence of severe wind damage (Franklin et al. 1987). That field crews were unable to assign a proximate cause of death in most cases is not surprising, inasmuch as tree death usually results from “complex interactions among multiple factors” (Franklin et al. 1987). However, given that most trees died standing, it is likely that biotic factors such as competition with other plants, diseases, and/or insects were major contributing factors (van Mantgem and Stephenson 2007). Continuing measurement of the plots will allow us to assess whether or not the reported increase in tree mortality in old, unmanaged forests in many parts of the western United States (van Mantgem et al. 2009) is also occurring in the National Parks of the North Coast and Cascades Network.

Literature Cited

Acker, S. A., A. Woodward, J. R. Boetsch, K. Hutten, M. Bivin, R. Rochefort, C. C. Thompson, and L. Whiteaker. 2010. Forest vegetation monitoring protocol for the North Coast and Cascades Network. Natural Resource Report NPS/NCCN/NRR_2010/242. National Park Service, Fort Collins, Colorado.

Acker, S. A., W. A. McKee, M. F. Harmon, and J. F. Franklin. 1998. Long-term research on forest dynamics in the Pacific Northwest: a network of permanent plots. Pages 93-106 *in* F. Dallmeier and J. A. Comiskey, editors. Forest biodiversity in the North, Central and South America, and the Caribbean: Research and monitoring. UNESCO, Paris.

Agee, J. K. and J. Kertis. 1986. Vegetation cover types of the North Cascades. National Park Service, Cooperative Park Studies Unit, Report CPSU/UW 86-2. University of Washington, Seattle.

Avery, T. E. and H. E. Burkhart. 1994. Forest measurements, 4th edition. McGraw-Hill, Boston.

Barnosky, C. W. 1984. Late Pleistocene and early Holocene environmental history of south-western Washington, U.S.A. Canadian Journal of Earth Sciences **21**:619-629.

Birkeland, P. W. 1984. Soils and geomorphology. Oxford University Press, New York.

Buckingham, N. M., E. G. Schreiner, T. N. Kaye, J. E. Burger, and E. L. Tisch. 1995. Flora of the Olympic Peninsula. Northwest Interpretative Association, Seattle, Washington.

Crawford, R. C., C. B. Chappell, C. C. Thompson, and F. J. Rocchio. 2009. Vegetation classification of Mount Rainier, North Cascades, and Olympic National Parks. Natural Resource Technical Report NPS/NCCN/NRTR—2009/D-586. National Park Service, Fort Collins, Colorado.

Davey, C. A., K. T. Redmond, and D. B. Simeral. 2006. Weather and climate inventory, National Park Service, North Coast and Cascades Network. Natural Resource Technical Report NPS/NCCN/NRTR—2006/010. National Park Service, Fort Collins, Colorado.

Davis, M. B. 1981. Quarternary history and stability of forest communities, Pages 132-177 *in* D. C. West, H. H. Shugart, and D. B. Botkin, editors. Forest succession: concepts and application. Springer-Verlag, New York.

Edmonds, R. L., R. D. Blew, J. L. Marra, J. Blew, A. K. Barg, G. Murray, and T. B. Thomas. 1998. Vegetation patterns, hydrology, and water chemistry in small watersheds in the Hoh River Valley, Olympic National Park. Scientific monograph NPSD/NRUSGS/NRSM-98/02. National Park Service, Washington DC.

Fancy, S. G., Gross, J. E., and S. L. Carter. 2009. Monitoring the condition of natural resources in US national parks. Environmental Monitoring and Assessment **151**:161-174.

FEMAT. 1993. Forest ecosystem management: and ecological, economic, and social assessment. Report of the Forest Ecosystem Management Team (FEMAT). 1993-793-071. GPO, Washington, D.C.

Forest Inventory and Analysis Program. 2006. Field instructions for the annual inventory of Washington, Oregon, and California. Pacific Northwest Research Station, USDA Forest Service.

Franklin, J. F. and C. T. Dyrness. 1988. Natural vegetation of Oregon and Washington. Oregon State University Press, Corvallis.

Franklin, J. F., H. H. Shugart, and M. E. Harmon. 1987. Tree death as an ecological process. BioScience **37**: 550-556.

Franklin, J. F., W. H. Moir, M. A. Hemstrom, S. E. Greene, and B. G. Smith. 1988. The forest communities of Mount Rainier National Park. Scientific Monograph Series 19. National Park Service, Washington, D.C.

Franklin, J. F., T. A. Spies, R. Van Pelt, A. B. Carey, D. A. Thornburgh, D. R. Berg, D. B. Lindenmayer, M. E. Harmon, W. S. Keeton, D. C. Shaw, K. Bible, and J. Chen. 2002. Disturbance and structural development of natural forest ecosystems with silvicultural implications, using Douglas-fir forests as an example. Forest Ecology and Management **155**:399-423.

Gates, D. M. 1993. Climate change and its biological consequences. Sinauer Associates, Inc., Sunderland, MA.

Goodale, C. L., M. J. Apps, R. A. Birdsey, C. B. Field, L. S. Heath, R. A. Houghton, J. C. Jenkins, G. H. Kohlmaier, W. Kurz, S. Liu, and others. 2002. Forest carbon sinks in the northern hemisphere. Ecological Applications **12**:891-899.

Henderson, J. A., D. H. Peter, R. D. Lesher, and D. C. Shaw. 1989. Forested plant associations of the Olympic National Forest. R6 Ecol. Technical Paper 001-88. U.S. Department of Agriculture, Forest Service, Pacific Northwest Region.

Henderson, J. A., D. H. Peter, R. D. Lesher and D. C. Shaw. 1992. Field guide to the forested plant associations of the Mt. Baker-Snoqualmie National Forest. R6 Ecol. Technical Paper 028-91. U.S. Department of Agriculture, Forest Service, Pacific Northwest Region.

Jenny, H. 1941. Factors of soil formation. McGraw-Hill, New York.

Keith, H., B. G. Mackey, and D. B. Lindenmayer. 2009. Re-evaluation of forest biomass carbon stocks and lessons from the world's most carbon-dense forests. Proceedings of the National Academy of Sciences **106**:11635-11640.

Lehmkuhl, J. F. and L. F. Ruggiero. 1991. Forest fragmentation in the Pacific Northwest and its potential effects on wildlife. Pages 35-46 *in* L. F. Ruggiero, K. B. Aubry, A. B. Carey, and M. H. Huff, editors. Wildlife and vegetation of unmanaged Douglas-fir forests. General Technical Report PNW-GTR-285. U.S. Department of Agriculture, Forest Service, Portland, OR.

McClain, M. E., R. E. Bilby, and F. J. Triska. 1998. Nutrient cycles and responses to disturbance. Pages 347-372 *in* R. J. Naiman and R. E. Bilby editors. River ecology and management: Lessons from the Pacific Coastal Ecoregion. Springer, New York.

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

Oliver, C. D., and B. C. Larson. 1990. Forest stand dynamics. McGraw-Hill, Inc., San Francisco.

Pastor, J. and W. M. Post. 1986. Influence of climate, soil moisture and succession on forest carbon and nitrogen cycles. Biogeochemistry **2**:3-27.

Pastor, J. and W. M. Post. 1988. Response of northern forests to CO2-induced climate change. Nature **334**:55-58.

Peters, R. L. and T. E. Lovejoy, editors. 1992. Global warming and biological diversity. Yale University Press, New Haven CT.

Ryan, M. G. Ryan, M. E. Harmon, R. A. Birdsey, C. P. Giardina, L. S. Heath, R. A. Houghton, R. B. Jackson, D. C. McKinley, J. F. Morrison, B. C. Murray, D. E. Pataki, and K. E. Skog. 2010. A synthesis of the science on forests and carbon for U.S. forests. Issues in Ecology No. 13. Ecological Society of America, Washington, DC.

Sheil, D. 1995. A critique of permanent plot methods and analysis with examples from Budongo Forest, Uganda. Forest Ecology and Management **77**:11-34.

Sheil, D. and R. M. May. 1996. Mortality and recruitment rate evaluations in heterogeneous tropical forests. Journal of Ecology **84**:91-100.

Stevens, D. L., Jr. 1997. Variable density grid-based sampling design for continuous spatial populations. Environmetrics **8**:167-195.

Thomas, J. W. 1997. Foreward. Pages ix-xii *in* K. A. Kohm and J. F. Franklin, editors. Creating a forestry for the 21st Century. Island Press, Washington, D.C.

Thompson, S. K. 2002. Sampling. Wiley, New York.

Urquhart, N. S., S. G. Paulsen, and D. P. Larsen. 1998. Monitoring for policy-relevant regional trends over time. Ecological Applications **8**:246-257.

van Mantgem, P. J. and N. L. Stephenson. 2007. Apparent climatically induced increase of tree mortality rates in a temperate forest. Ecology Letters **10**:909-916.

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, and T. T. Veblen. 2009. Widespread increase of tree mortality rates in the western United States. Science 323:521-524.

Weber, S., A. Woodward, and J. Freilich. 2009. North Coast and Cascades Network vital signs monitoring report (2005). Natural Resource Report NPS/NCCN/NRR—2009/098. National Park Service, Fort Collins, Colorado.

Woodward, A., K. M. Hutten, J. R. Boetsch, S. A. Acker, R. M. Rochefort, M. M. Bivin, and L. L. Kurth. 2009. Forest vegetation monitoring protocol for national parks in the North Coast and Cascades Network: U.S. Geological Survey Techniques and Methods 2-A8.

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Natural Resource Program Center
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

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