National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Landsat-based Monitoring of Landscape Dynamics in Mount Rainier National Park

1985-2009

Natural Resource Data Series NPS/NCCN/NRDS—2014/637

ON THE COVER
1930 Sunset Park Fire, Mount Rainier National Park
Photograph courtesy of NPS, 2005

Landsat-based Monitoring of Landscape Dynamics in Mount Rainier National Park

1985-2009

Natural Resource Data Series NPS/NCCN/NRDS—2014/637

Natalya Antonova[1], Catharine Copass[2], Shelby Clary[2]

[1]North Coast and Cascades Network
National Park Service
North Cascades National Park Complex
810 State Route 20
Sedro Woolley, WA 98284

[2]North Coast and Cascades Network
National Park Service
Olympic National Park
600 E Park St
Port Angeles, WA 98362

April 2014

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

This report received informal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data. Data in this report were collected and analyzed using methods based on established, peer-reviewed protocols and were analyzed and interpreted within the guidelines of the protocols.

This report is available in digital format from the North Coast and Cascades Network Inventory and Monitoring website (http://science.nature.nps.gov/im/units/nccn/publications.cfm) and the Natural Resource Publications Management website (http://www.nature.nps.gov/publications/nrpm/). To receive this report in a format optimized for screen readers, please email irma@nps.gov.

Please cite this publication as:

Antonova, N., C. Copass, and S. Clary. 2014. Landsat-based monitoring of landscape dynamics in Mount Rainier National Park: 1985-2009. Natural Resource Data Series NPS/NCCN/NRDS—2014/637. National Park Service, Fort Collins, Colorado.

NPS 105/124292, April 2014

Contents

Page

Contents (continued)

Figures

Page

Figures (continued)

Page

Tables

Page

Abstract

As part of Vital Signs Monitoring, the North Coast and Cascades Network (NCCN) of the National Park Service (NPS) developed a protocol for monitoring landscape dynamics using Landsat satellite imagery. The protocol was implemented at Mount Rainier National Park (MORA) in 2013 using LandTrendr (Landsat-based Detection of Trends in Disturbance and Recovery) algorithms developed by the Laboratory for Applications of Remote Sensing in Ecology (LARSE) at Oregon State University.

We mapped eight categories of landscape change that occurred at MORA and surrounding areas from 1985 to 2009: Avalanches, Clearing, Development, Fire, Mass Movements, Progressive Defoliation, Riparian, and Tree Toppling. The Avalanche category captures long, linear change which partially or completely removes vegetation from the valley wall following a release of a large mass of snow down a mountain side. Clearings are areas under forest management where practices vary from thinning to clearcuts. The Development category captures changes associated with complete and persistent removal of vegetation and transformation to a built landscape. Changes due to Fire vary in intensity from full canopy removal to partial burns that leave behind a mixture of dead and singed trees. The Mass Movement category includes both landslides found on valley walls and debris flows associated with steep gradient streams. Progressive Defoliation is a change type in which the forest cover remains but has declined due to insect infestation, disease or drought. Riparian changes are restricted to the valley floors alongside major streams and rivers and capture areas where either conifer or broadleaf vegetation previously existed and has been converted to river channel. Change due to Tree Toppling is evidenced by fallen, broken or topped trees, generally due to wind but sometimes to root rot. Only changes larger than 0.8 ha (2 ac) and for which the duration of the period of landscape change was less than 4 years were mapped.

The MORA study area is 385,000 hectares, of which 25% (96,000 ha) are inside the park. Approximately 56,500 ha (14.5%) of the study area underwent detectable change at some point during the 25 year period of analysis, affecting about 0.54% MORA and about 19.34% of the areas outside the park boundary. The annual average area impacted by landscape change within the study area was about 2,235 ha. Within the park boundary, the annual average area undergoing change was about 21 ha.

Clearing was the major change type within the study area over the last 25 years, followed by Progressive Defoliation. Clearing occurred predominately outside the park boundary. Inside the park, Riparian was the most significant agent of landscape change, followed by Fire and Tree Toppling.

The inter-annual variability in the total area experiencing landscape change was considerable. The greatest amount of change outside the park boundary was documented in 1985 and was associated with the Clearing category. The years 2006 and 2004 also had higher than average change. Within the MORA boundary, 2007 was the year in which the greatest change was detected, due to a significant flood event which occurred November of 2006, followed by 2004, the year of the Redstone Fires.

An analysis of the size of change patches showed that, on average, Avalanches, Mass Movements and Riparian changes are smaller but more numerous, whereas Fires tend to be larger but fewer.

Acknowledgments

The authors would like to thank S. Beason, R. A. Lofgren, and R. Rochefort for providing peer reviews. M. Huff, NCCN Inventory and Monitoring Program Manager, conducted the administrative review and L. Grace shepherded the report through the NPS publication process. LandTrendr data were provided by Oregon State University's Laboratory for Applications of Remote Sensing in Ecology (LARSE) under direction of W. Cohen and participation of R. Kennedy, Z. Yang, and J. Braaten.

The work was funded in part via Task Agreement P12AC15058 through the Cooperative Ecosystem Study Unit Cooperative Agreement H8W07110001.

Acronyms

ArcGIS™ - A group of geographic information system (GIS) software products produced by ESRI

CESU - Cooperative Ecosystem Study Unit

DFW - Department of Fish and Wildlife

DNR - Department of Natural Resources

ESRI - Environmental Systems Research Group

GIS - Geographic Information System

I&M - Inventory and Monitoring

Landsat - A global land-imaging project consisting of a series of satellites that routinely gather land imagery from space

LandTrendr - Landsat-based Detection of Trends in Disturbance and Recovery

LARSE - Laboratory for Applications of Remote Sensing in Ecology

LDMP - Landscape Dynamics Monitoring Protocol

MMU - minimum mapping unit

MORA – Mount Rainier National Park

NAIP - National Agricultural Imagery Program

NBR – Normalized Burn Ratio

NCCN - North Coast and Cascades Network

NPS - National Park Service

PNW - Pacific Northwest

PWRO - Pacific West Region Office

RF - Random Forests or randomForest

TM - Thematic Mapper

Glossary

Duration – An output variable from LandTrendr, defined as the length of time it took for a given landscape change to occur and is expressed in years.

Kappa Statistic – Used as a measure of agreement between a prediction and reality. In this project the prediction is derived from a classification model compared to reality as determined by photo-interpretation process. It can also be used to determine if the values contained in an error matrix represent a result significantly better than random.

Producer's Accuracy – The probability that a reference sample will be correctly mapped. In other words, if you were to stand in a patch that had experienced a landslide, would that event be labeled as a landslide on the map? Producer's accuracy measures the errors of omission. The reference sample in this project is a photo-interpreted landscape change type.

Magnitude – The estimated change in percent vegetative cover following a landscape change event. Magnitude is calculated by differencing a pixel's Normalized Burn Ratio (NBR) index values prior to and following the landscape change event. The percent reduction is relative to the original cover value.

Random Forests – An ensemble learning method for classification (and regression) that operates by constructing a multitude of decision trees at training time and outputting the class that is the mode of the classes output by individual trees.

randomForest – Statistical package in R that conducts Random Forests analysis.

User's Accuracy – The Probability that a mapped landscape change type matches the reference sample. In other words, if you look at the map and see a landslide, then visit that spot in the field, would you find a landslide? User's accuracy measures the error of commission. The reference sample is photo-interpreted landscape change type in this project.

Introduction

The overall purpose of natural resource monitoring in national parks is to develop scientifically sound information on the current status and long term trends in the composition, structure, and function of park ecosystems and to assess how well ecosystems are being sustained (Fancy et al. 2009). One way the North Coast and Cascades Network (NCCN) achieves this is by monitoring landscape changes within and adjacent to NCCN parks. The NCCN developed its Landscape Dynamics Monitoring Protocol (LDMP) to provide park managers with information on the type, location, frequency, and magnitude of landscape changes found within the parks (Antonova et al. 2012).

Individual landscape change events such as windthrow, landslides, floods, and fires can have significant impact on visitor experiences and park facilities. The information provided by the LDMP offers important insights regarding trends in the size, frequency or magnitude of these events. This knowledge can be used to better target and prioritize funding allocations and contribute to park facilities planning and maintenance. By providing maps of landscape change in conjunction with other information, results from this monitoring effort will contribute to ongoing work to assess park vulnerability to climate change via the development and validation of park resource vulnerability models. The LDMP also provides complimentary information to the NPScape program, which provides landscape-scale indicators that broadly address the environmental drivers, natural attributes and conservation context of NPS units (see NPScape website: http://science.nature.nps.gov/im/monitor/npscape/; accessed 30 May 2013).

The Landscape Dynamics Monitoring Protocol was developed in cooperation with the Laboratory for Applications of Remote Sensing in Ecology (LARSE) at Oregon State University, which utilizes the Landsat platform as their primary remote sensing tool. LARSE developed Landsat- based Detection of Trends in Disturbance and Recovery (LandTrendr) - a suite of change-detection algorithms which track the spectral trajectory of Landsat pixels through time.

The primary objectives of Landscape Dynamics Monitoring Protocol are to:

- Detect and map landscape changes that are larger than 0.8 ha (2 ac) resulting from an avalanche, clearing, development, fire, mass movement, progressive defoliation, riparian flooding or tree toppling.

- Determine trends in the size, magnitude, location, and spatial distribution of each landscape change category. The term “magnitude” is used to quantify percent change in vegetation cover removed.

Table 1 lists the landscape change types of interest to the NCCN covered by this report. The types were originally selected based on NCCN’s priorities and with input from NCCN employees following a series of workshops during the development of the original version of the protocol (Kennedy et al. 2007). The types were subsequently modified during the development of the second version of the LDMP (Antonova et al. 2012).

Table 1. Landscape change types monitored within Mount Rainier National Park study area. Annual Variability and Agriculture are two additional categories that are mapped but not reported on with this protocol.

Landscape Change Type	Definition
Avalanche	Long, linear change areas which originate in snow receiving zones or valley walls. Typically remove some but not all of the vegetation.
Clearing	Reflect a range of forest management practices, from clearcuts, select cuts and thinning, and chemical removal of broadleaf vegetation.
Development	Areas which show a complete, persistent removal of vegetation and transformation to a built landscape with evidence of urbanization such as houses or other structures. Also includes first-time removal of vegetation for agricultural activities. Consequent changes due to crop planting and harvest are included in the Agricultural category.
Fire	Often corroborated from outside sources, wildland fires vary in intensity from full canopy removal to partial burns which leave behind a mixture of dead and singed trees.
Mass Movement	Category includes a variety of vegetation-removing changes that expose rock and bare ground: landslides, which are found on valley walls and away from streams; creeps, which are slow downward movements of slope-forming soil or rock; and debris flows that are associated with steep gullies and involve water. Mass Movement is distinguished from the Riparian category because it occurs on slopes greater than 15 degrees.
Progressive Defoliation	Assigned to polygons where the forest cover remains but has undergone slow change in spectral values representing a loss of greenness and wetness. Several patterns of decline in tree health can be seen.
Riparian	Change areas of this type are restricted to the valley floor in areas where either conifer for broadleaf vegetation previously existed and has been converted to active river channel, with water or river banks.
Tree Toppling	Forest areas where trees have been broken off or topped by some action other than Avalanche or Clearing, generally due to wind but sometimes due to root rot.

In this report, we present the first assessment of landscape change at Mount Rainier National Park (MORA, or Park) using the LDMP. The assessment spans 25 years, from1985 to 2009, and establishes baseline conditions for natural and anthropogenic changes both inside and outside MORA. The report provides standard data summaries by year, change type and land ownership, accompanied by maps of landscape changes which occurred inside the study area by year, magnitude and change.

Study Area

The Mount Rainier landscape change monitoring study area integrates ecological features with constraints of the Landsat imagery (Figure 1). First, a 16 km (10 mi) buffer was established around the Park boundary. The buffer was designed to capture the spatial domain of connections between the parks and surrounding lands. Changes in these areas are of interest to the network's scientists due to their importance for wildlife and fish populations. The resulting study area was then truncated in the south in order to accommodate the geometry of the available Landsat imagery. The resulting area encompasses 384,708 ha of land and water, about 25% of which (95,616 ha) are inside the park boundary. The Park is dominated by Mount Rainier, a 4,392 m (14,410 ft) tall volcanic peak capped by numerous glaciers which cover about 12,173 ha (30,080 ac). The volcanic peak creates a strong rainshadow effect, driving vegetation patterns that shift from west to east in combination with lower to higher elevations. The western and central parts of the study area, including the park, are dominated by mesic Douglas-Fir and Western Hemlock and Silver Fir forests at lower and middle elevations transitioning into woodlands and meadows as elevation increases. In the eastern side of the study area drier forests and woodlands predominate.

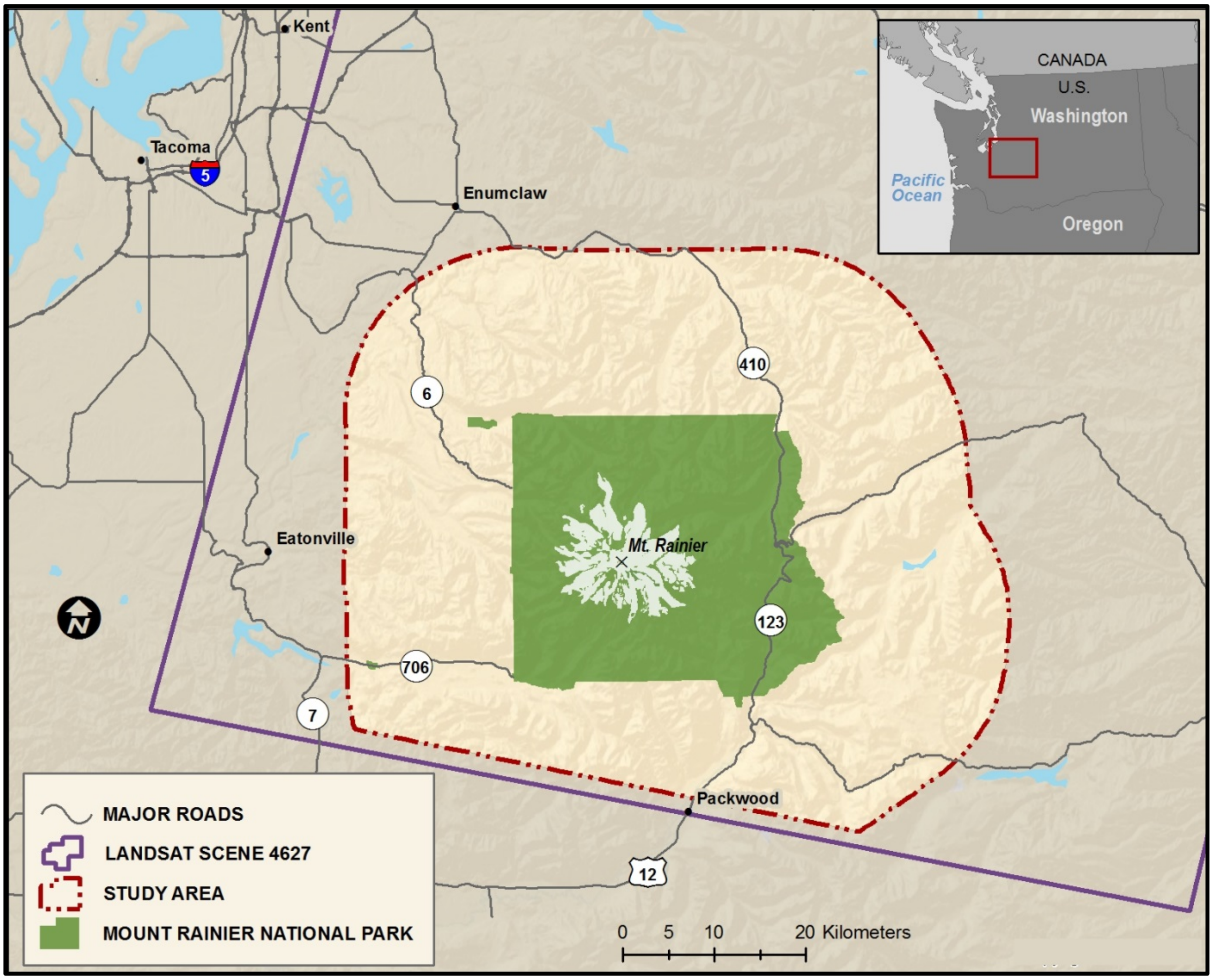

Figure 1. Mount Rainier National Park study area used for monitoring landscape dynamics.

Study Area: Land Management Characteristics

The landscapes within the study area represent a broad mix of ownership types. Covering about 25% of the study area, Mount Rainier National Park was established in 1899 (Figure 2, NPS – Land Resources Division 2008, Antonova and Clary 2013). Ninety seven percent of the Park is Congressionally-designated wilderness (United States Congress 1988; Swinney 2005). The three percent of the Park that is non-wilderness is concentrated in road corridors, parking lots and the heavily visited areas at Sunrise and Paradise.

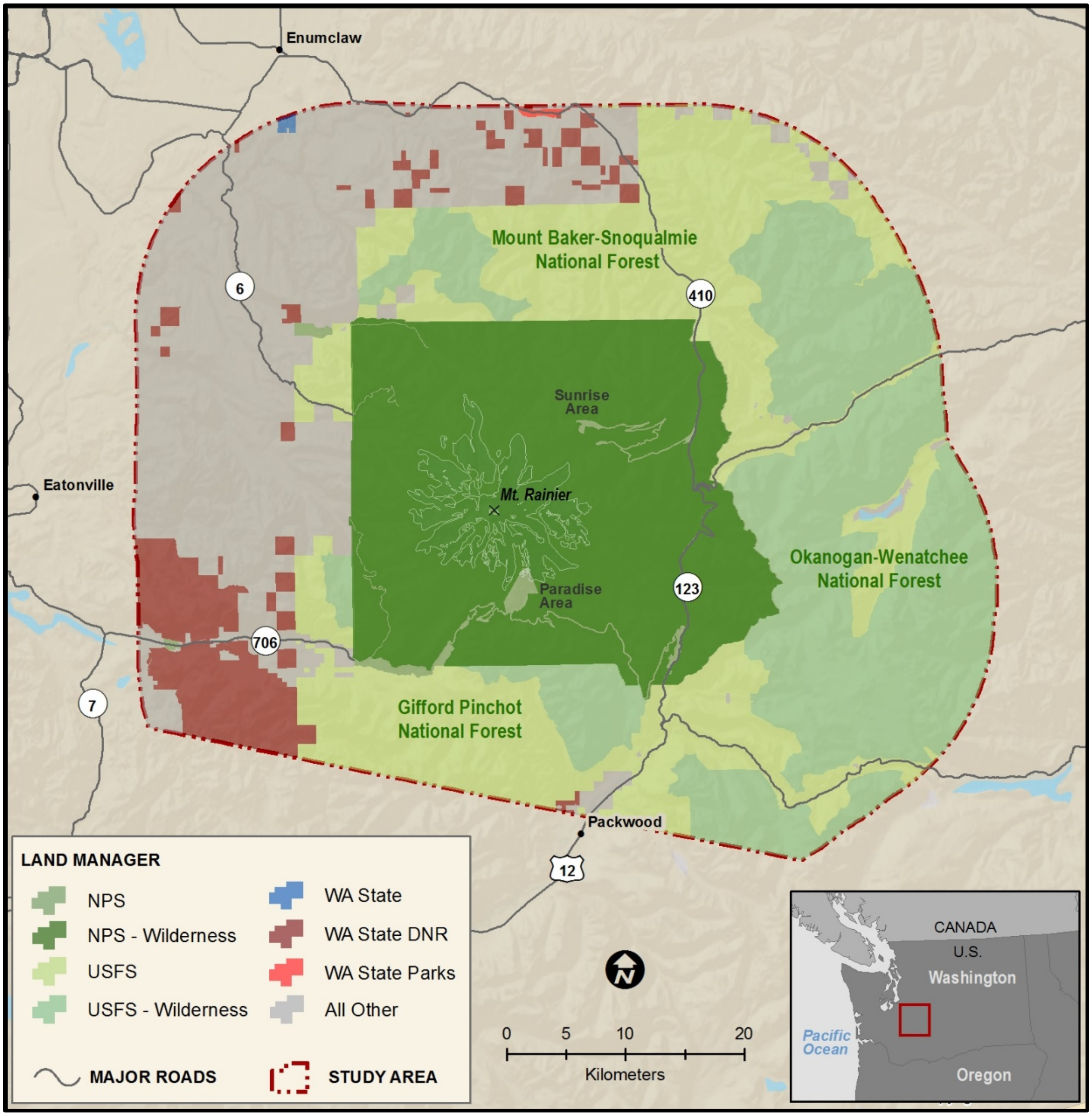

Figure 2. Land management categories within the Mount Rainier National Park study area.

Of the remaining study area, 24% is wilderness managed by the United States Forest Service (USFS) (Table 2, WA DNR 2007a). MORA is bordered by the Clearwater Wilderness to the north, the William O. Douglas Wilderness to the east, the Tatoosh Wilderness to the south, and the Glacier View Wilderness to the west. The Goat Rocks Wilderness and Norse Peak Wilderness are located in the south eastern and north western corners of the study area respectively. Elevation in the USFS wilderness areas ranges from 333 m (1,092 ft) to 3,283 m (10,771 ft). The USFS also manages the second greatest area within the study area - these are non-wilderness areas within the Gifford Pinchot, Wenatchee and Mount Baker-Snoqualmie National Forests (MBSNF 2004). Elevation in the non-wilderness areas ranges from 60 m (197 ft) to 3,024 m (9,921 ft), with an average of 1,263 m (4,144 ft). The USFS lands of both categories are found primarily on the eastern side of the study area.

The "All-Other" category includes city, county and privately held lands. Lands within this category are subject to a large variety of uses, including timber management, mining, urban and rural development, and agriculture. These areas are concentrated on the western side of the study area.

The Washington State lands primarily managed by the Parks and Recreation Commission and the Department of Natural Resources (DNR) comprise approximately 5% of the study area (WA DNR 2007a and 2007b). While State Parks are managed for recreational opportunities, DNR lands are primarily managed for timber harvest.

Table 2. Area and percent of total area contributed by various land management categories within the Mount Rainier National Park study area.

Land Manager	Area (ha)	% of Area
Mount Rainier National Park	3831	1
Mount Rainier- Wilderness	91785	24
US Forest Service	92434	24
US Forest Service- Wilderness	91831	24
WA DNR	19762	5
Washington State Parks	226	0.06
WA State Other	207	0.05
All Other	84632	22

Study Area: Population and Housing

The majority of the MORA study area is sparsely populated, with the exception of the areas to the northwest, which have a number of urban communities (Figure 3). Most of the communities outside of the Interstate 5 corridor have less than 10,000 people; however, these communities have been growing steadily over the last two decades (Table 3, WAOFM 2011). Unincorporated areas within Pierce, Lewis, Thurston and especially Kittitas counties have also seen an increase in population. Yakima and King Counties have seen decreases.

To add further information to the county-wide population summary above, the NPScape program (see NPScape website: http://science.nature.nps.gov/im/monitor/npscape/; accessed 30 May 2013) has provided processed housing and population density data for a study area surrounding MORA.

From 1980 to 2010, the percent of area occupied by the lowest density housing categories decreased from 11.8% to 8.2% while the percent of area occupied by the higher density housing increased from 0.5% to 2%. Concurrent with the shifts in housing density was a 64% increase in population density in the study area (Grace, L. P., and M. H. Huff. NPScape landscape analysis for Mount Rainier National Park: Housing, population, and roads metrics. Draft report on file at North Cascades National Park).

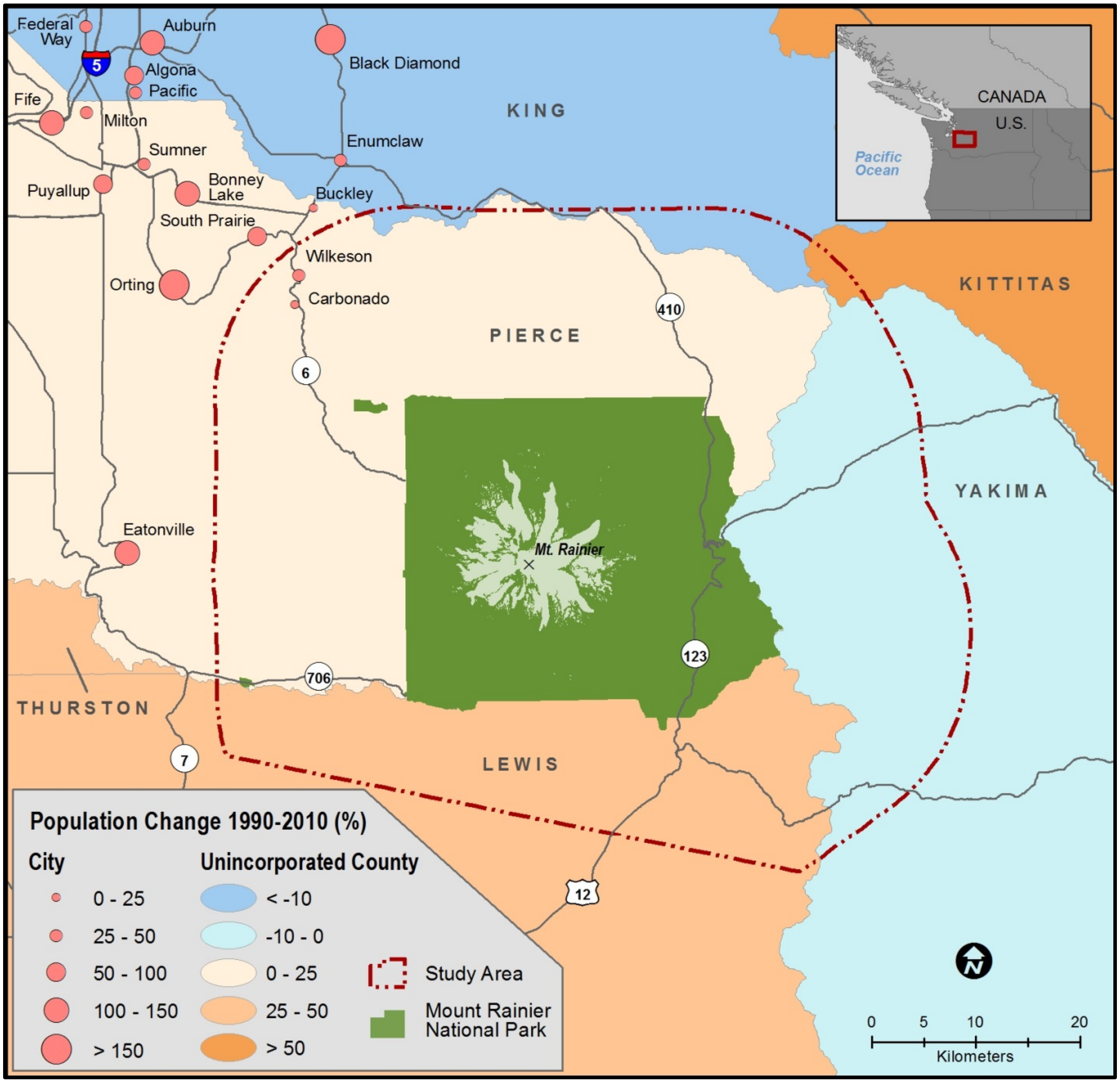

Figure 3. Percent population change for cities and unincorporated county areas in and around Mount Rainier National Park study area.

Table 3. Population numbers and percent change in population for cities and unincorporated Counties in and around Mount Rainier National Park study area.

	Population			% Change		
	1990	**2000**	**2010**	**1990-2000**	**2000-2010**	**1990-2010**
County						
King	513257	349234	325000	-31.96	-6.94	-36.68
Kittitas	10418	13614	18063	30.68	32.68	73.38
Lewis	35829	40821	44892	13.93	9.97	25.30
Pierce	339679	315359	366738	-7.16	16.29	7.97
Thurston	94098	114061	135123	21.22	18.47	43.60
Yakima	88214	93192	83755	5.64	-10.13	-5.05
City						
Algona	1694	2460	3014	45.22	22.52	77.92
Auburn	33650	43047	70180	27.93	63.03	108.56
Black Diamond	1422	3970	4153	179.18	4.61	192.05
Bonney Lake	7494	9687	17374	29.26	79.35	131.84
Buckley	3516	4145	4354	17.89	5.04	23.83
Carbonado	495	621	610	25.45	-1.77	23.23
Eatonville	1374	2012	2758	46.43	37.07	100.73
Enumclaw	7227	11116	10669	53.81	-4.02	47.63
Federal Way	67449	83259	89306	23.44	7.26	32.41
Fife	3864	4784	9173	23.81	91.74	137.40
Milton	4995	5795	6968	16.02	20.24	39.50
Orting	2106	3931	6746	86.66	71.61	220.32
Puyallup	23878	33014	37022	38.26	12.14	55.05
South Prairie	245	382	434	55.92	13.613	77.14
Sumner	6459	8504	9451	31.66	11.14	46.32
Wilkeson	366	395	477	7.92	20.76	30.33

Methods

The methods used to detect the 1985-2009 MORA landscape changes are described in detail in the second version of the NCCN LDMP (Antonova et al. 2012). The methods include: running LandTrendr change detection algorithms, processing and classifying results, and determining accuracy via office validation.

Change Detection

LandTrendr change detection starts with downloading and processing Landsat imagery. Images are preferentially chosen to be near the mid-July date. A consistent date minimizes noise related to annual changes in sun angle, which causes topographic shadows, and vegetation phenology. The day and year of Landsat images used in the analysis for scene 4627 is shown in Figure 4.

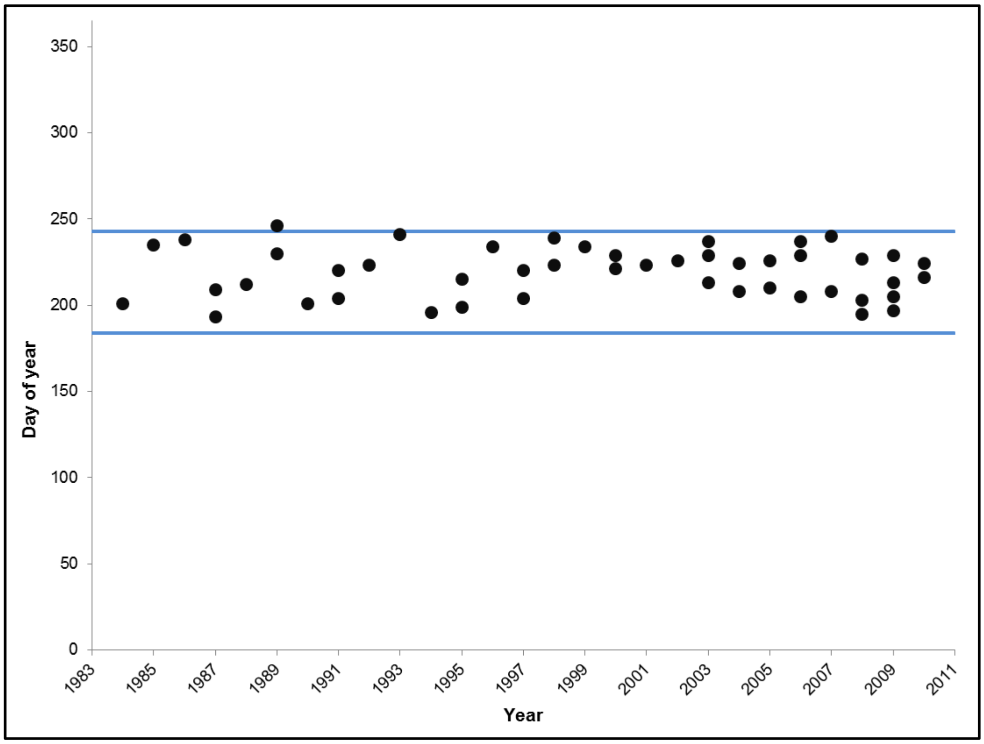

Figure 4. Day and year of Landsat images used for analysis for the scene 4627, with blue lines denoting the time period between July 1st and September 1st.

Next, statistical line-fitting techniques are used to create a smooth line tracking the spectral index signature of each pixel. The fitted line is separated into coherent segments describing periods of stability or change. The primary outputs from LandTrendr are 30-meter resolution raster datasets with layers containing pixel-level data on the year of change onset, the duration of change expressed as the number of years, and the magnitude of the change expressed as percentage of vegetative cover that was removed by the event (Figure 5). For each pixel, only the year of the greatest disturbance within the time series is reported. For example, if a pixel is affected by repeated avalanches, the only reported change would correspond to the avalanche that removed the most vegetation, i.e. event with highest magnitude.

LandTrendr results only include pixels where more than 10% of the canopy cover has been removed (Kennedy et al., 2010). This parameter has been optimized during LandTrendr development and was not modified for application to the LDMP.

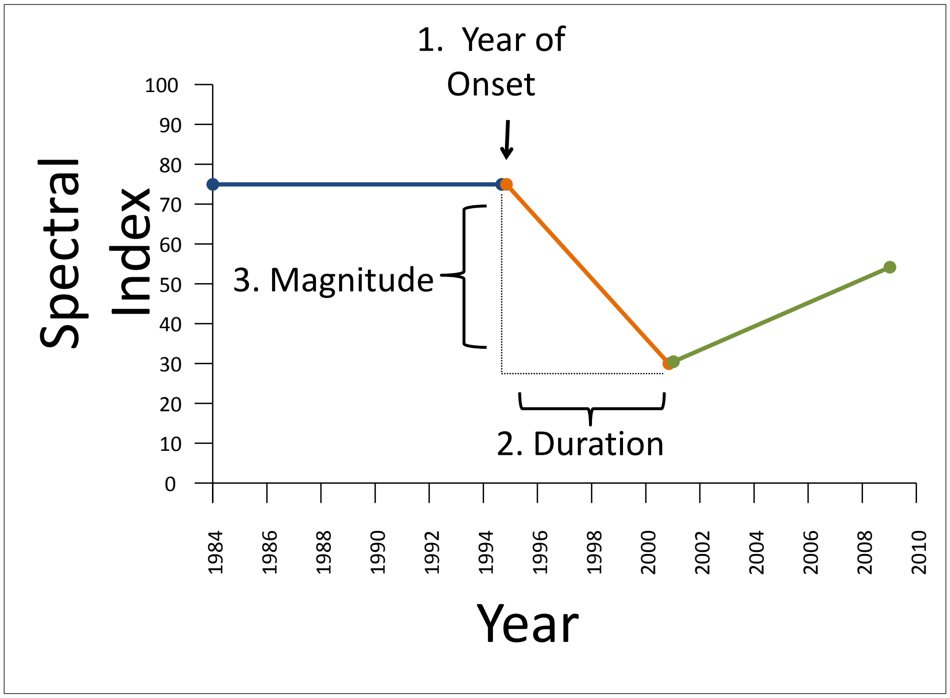

Figure 5. An idealized LandTrendr trajectory tracing a Landsat pixel through periods of stability, change and recovery. The period from 1984 to 1994 is a stable segment (blue line). A change event begins in 1994 (1) and lasts until 2001 (2), causing a drop of 45 spectral units (3). The change is followed by a recovery period from 2001 to 2010 (green line).

LandTrendr pixel outputs are grouped into patches based on the year the change began and the duration of change. For this protocol, the patches are first screened by duration, so that the first dataset only includes pixels that experienced rapid change occurring over a period of less than 4 years. These pixels are then grouped into patches based on the year of change onset. Only pixels with the same year of onset can belong to the same patch. Patches must be nine-pixels (0.8 ha or 2 ac) or larger to be included in the monitoring dataset. Although using a nine-pixel patch size means that the results underestimate the total change within the study area, it was determined during protocol development that this minimum mapping unit (mmu) size was the smallest area that could still be accurately validated using the validation techniques described below. After the formation of patches, the data set is converted to vector format (polygons) and a variety of attributes are extracted that describe each patch's shape, spectral characteristics and location on the landscape. A classification model is applied in order to attribute the patches with their change type (Table 1). Lastly, validation and accuracy assessment is performed.

Examples of landscape change within the MORA boundary that the NCCN LDMP is designed to detect are shown in Figure 6. They range from high intensity, large natural disturbances such as Fire and Riparian changes, like those that affected large areas of the park following the November 2006 floods, to more subtle effects on forest canopy such as insect infestations.

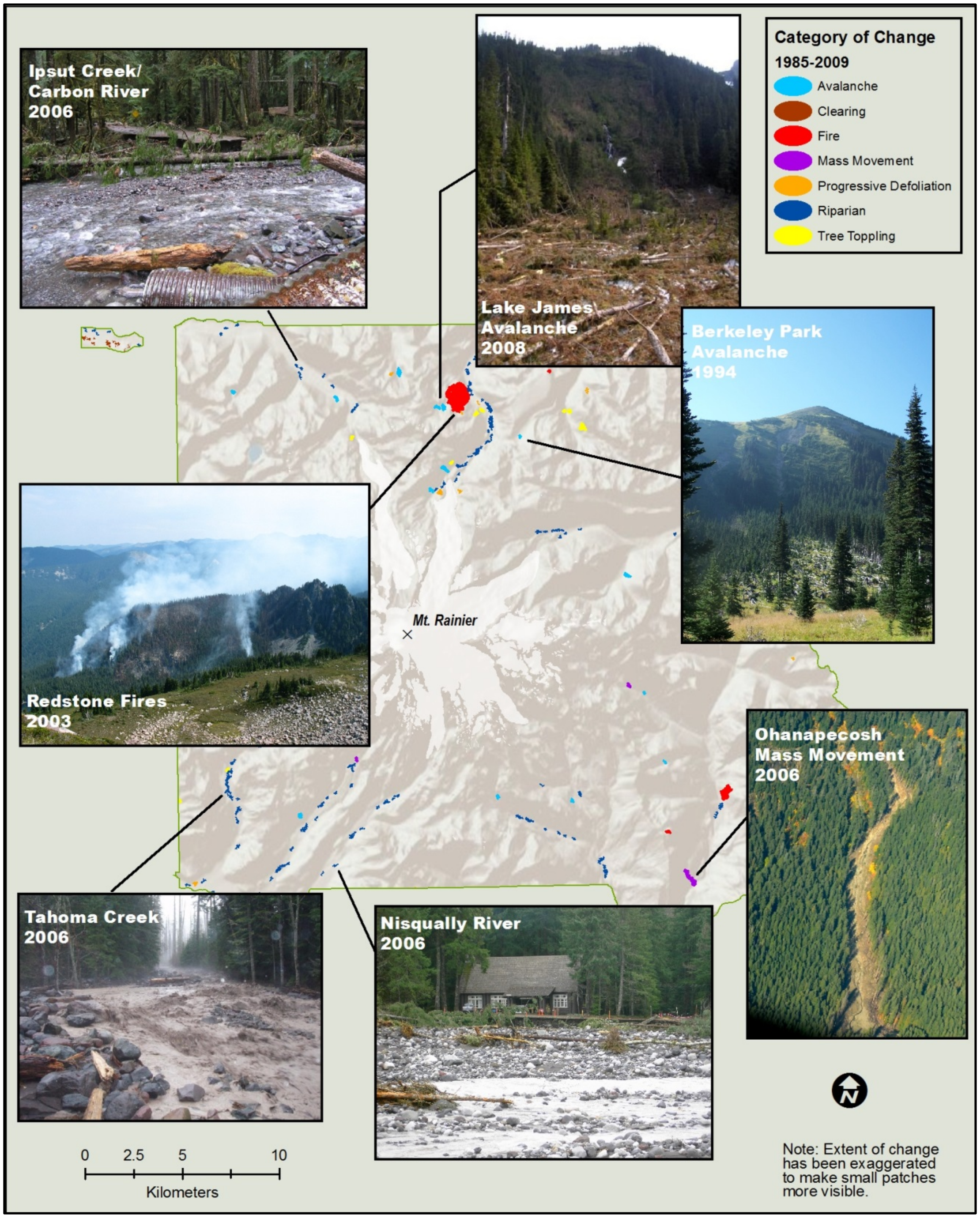

Figure 6. Examples of landscape changes documented within the Mount Rainier National Park boundaries from 1985 to 2009.

Change Type Characteristics

A thorough description of the change types is provided in the LDMP (Antonova et al. 2012). In this section, additional details are provided in order to facilitate interpretation of the results provided below.

Annual Variability

The Annual Variability category is used to categorize landscape changes caused by annual differences in cloud cover, sun angle, phenology, and soil moisture. Annual Variability patches are explicitly modeled so that they can be eliminated from the analysis and results, because they do not capture change of interest to the NCCN.

Agriculture

The Agriculture category captures changes associated with annual agricultural activities, such as planting and harvesting of crops. Landscape change that has created new agricultural areas from previously forested or otherwise undisturbed areas are categorized as Development. The Agriculture category is shown on maps, but, similar to the Annual Variability category, Agriculture is not included in the summary statistics.

Fire

The Fire category includes both human-caused and natural events. Smaller and/or low intensity fires are not included in the analysis due to size and spectral thresholds. As for all other landscape change categories, results for Fire are reported using patches rather than events. First, individual fire events sometimes span days or weeks, and if the Landsat image used for analysis is taken while the event is in progress, the individual event can be captured as two adjacent patches with different years. Second, because fires can vary in intensity over short distances, some burned pixels do not spectrally show the effects of fire until one or two years after the event, when the cumulative effect of the fire on the pixel exceeds the detection threshold. These two factors contribute to a single fire event often being represented by a large number of patches with different onset dates.

Mass Movement

The Mass Movement category includes landslides as well as debris flows and debris torrents. Debris flows or torrents are defined as fast moving, liquefied landslides of mixed and unconsolidated water and debris. For the purposes of the LDMP, if the mapped patch representing a debris flow or torrent had a calculated average slope of more than 15 degrees, it was included in the Mass Movement category. If the mapped patch had an average slope of less than 15 degrees and was located along the valley bottom, it was classed as Riparian. The 15 degree threshold is a modification of the 10 degree value used to define a Debris Torrent for the landform mapping project at MORA (Riedel, J. and S. Dorsch. Geomorphology of Mount Rainer: Landform mapping at Mount Rainer National Park, WA. Draft report on file at North Cascades National Park). After evaluation, it was increased in order to accommodate the often steeper valley walls included in the landscape change polygons due to the resolution of the imagery. The threshold was used in the development of the sample for the Random Forests classification model (see below). Patches classified by the model as Mass Movements will not necessarily have an average slope of more than 15 degrees, as slope was not the only variable used in the classification.

Progressive Defoliation

The Progressive Defoliation category includes insect infestations, diseases, and losses in vegetation vigor due to drought or inundation. In general, these changes are long-term and progressive, i.e. the declines happen over several years and spread incrementally to larger areas. This pattern of change presents challenges to detecting and mapping this type. To belong to the same patch, adjacent pixels must have the same year of onset. For this reason, the changes that are mapped in the Progressive Defoliation category using current methods only include pixels that changed rapidly (duration of less than 4 years) and were located adjacent to enough other pixels that changed in the same year to form a patch.

Riparian

Riparian disturbances are defined as patches along a river or stream on a valley bottom with an average patch slope of less than 15 degrees. These events are often linear and narrow and do not occupy the entire width of a Landsat pixel. Because changes in spectral characteristics are averaged over an entire pixel, if the average spectral change for a pixel does not meet the threshold of change, the pixel is not labeled as “changed.” In addition, many pixels in riparian zones that are designated as “changed” are removed from results during filtering because the size of patches composed of aggregated pixels do not meet the minimum mapping unit requirement.

Year of Onset

The “year of onset” assigned by the LandTrendr algorithms to individual patches can sometimes be offset by a year or two from when the event actually happened. There are two reasons for this offset. First, there might be years when Landsat images are not suitable due to cloud cover or the areas where the event occurred are masked out due to localized cloud cover or topographic shadows. Second, the Landsat images for the analysis are prioritized by date closest to the middle of July in order to minimize snow cover and phenological noise and capture the greatest vegetation vigor. A number of landscape changes being monitored by NCCN occur in the winter months and are readily detected by the analysis when Landsat images from the following summer are examined. The detected change is then assigned the year of onset that corresponds to the year of the following summer. If, on the other hand, the landscape change event took place during the summer months, as is usually the case with fires, it could potentially be detected during the year of analysis that follows the year of the actual event. For example, the changes at MORA due to the significant flooding that occurred in November 2006 are all labeled with the year 2007. Alternatively, a fire that occurs in the summer of 2009 could be labeled with 2009 or 2010, depending on the timing and usability of the August and September imagery from 2009.

Random Forests Classification

Random Forests (RF) is an ensemble classification method that expands the relatively simple concept of classification and regression trees. The RF classification produces many regression trees. To produce each tree, RF first takes a random subset of the training data. As RF creates each tree, it uses a random subset of two thirds of the predictor variables for each split or decision node. The outcome is a single prediction - the tree which occurs with the most frequency represents the best classification model. Data are held in reserve to be used to test the accuracy of the classification. This provides a statistical assessment of how well RF can predict the training data used in the modeling process, and is one view of the accuracy of the classification approach.

A sample size of 293 patches was used as training data to generate an RF classification model to labels patches within the study area with one of the landscape change types listed in Table 1 and Agriculture and Annual Variability categories.

Validation

Validation is the process of determining how well the change detection method captures and labels landscape changes of interest to the NCCN. Underpinning the NCCN LDMP are two layers of validation (Figure 7). The first layer is pixel-based overall validation of the LandTrendr method and its ability to detect and map change. This method of validation has been performed and documented by LARSE (Cohen et al. 2010). The second layer is patch-based validation of the change category labels from Table 1, assigned to change patches by the Random Forests classification model. We assessed all 659 patches within the park boundary and a randomly selected subset of 1249 change patches, representing approximately 18% of patches found outside the park boundary. We performed validation in the office using multi-date aerial photography in Google Earth in conjunction with the TimeSync application. Table 4 indicates the date and source of the most widespread imagery available in Google Earth for validation. In addition to these, numerous other images with small extent are available, mostly covering the western-most part of the study area.

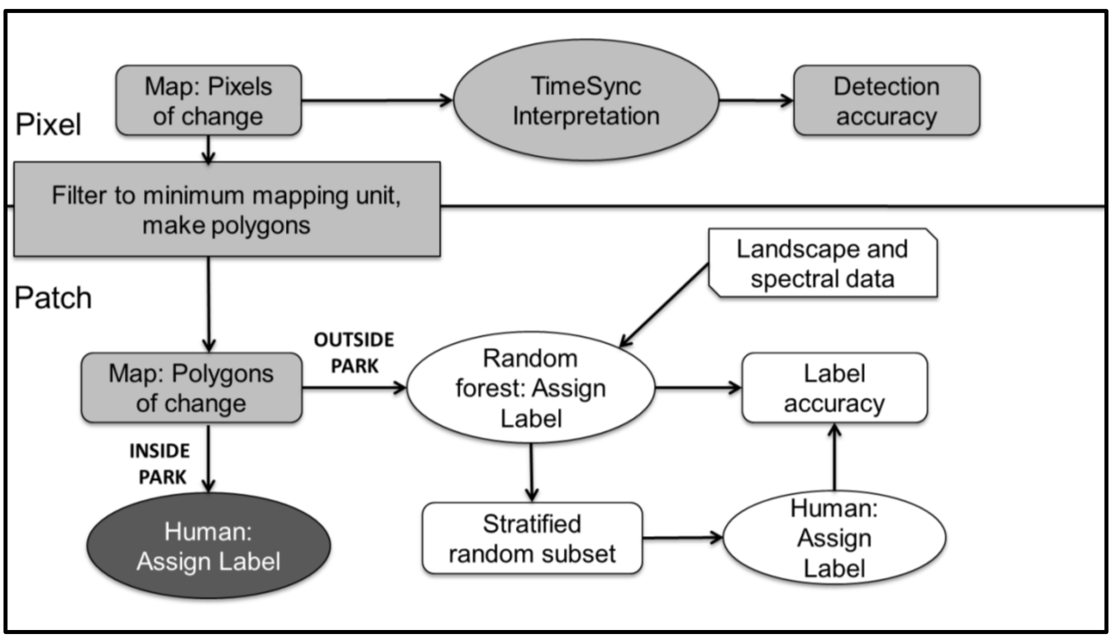

Figure 7. Steps in the validation process.

Table 4. Google Earth image sources for validation of change. All imagery is 1-meter resolution, except 2012 imagery, which is higher resolution. 1993 through 1998 images are in black and white and the others dates are in color.

Date	Coverage	Image Source
1993-1998	Partial	National Aeronautics Space Administration/ United States Geological Survey
Aug-2006	Full	United States Geological Survey
May 2009	Partial	United States Department of Agriculture – Farm Service Agency
Sep-2009	Full	United States Department of Agriculture – Farm Service Agency
Aug-2011	Partial	United States Department of Agriculture – Farm Service Agency
Nov-2011	Full	United States Department of Agriculture – Farm Service Agency
August 2012	Partial	Unknown

The TimeSync computer program, developed by LARSE, displays trajectories of groups of pixels through time using one of the spectral indices most sensitive to changes in vegetative cover. In addition to using the change types listed in Table 1, during office validation we applied an “Annual Variability” label to polygons detected as changed because of annual variations in cloud cover, cloud and topographic shadows, phenology, soil moisture, and snow characteristics. Even though the LandTrendr algorithm includes procedures that minimize the inclusion of annual variations in the final dataset, we still found residual effects of these variations and labeled them explicitly. We compared the labels generated during the office validation to the labels generated by the RF model and calculated the overall classification accuracy, class error rates from both a user’s and producer’s perspective, and the Kappa statistic. User’s accuracy is the probability that a patch classified into a given category actually represents that category on the ground and represents errors of commission. Producers’ accuracy indicates how well training set patches of a given landscape change agent are classified and represents errors of omission. Users’ accuracies are important to users going to a particular mapped location for a particular reason. Producers’ accuracies estimate the true areas of types that may have been missed in mapping and could be important to people interested in the true area a type occupies.

Following the validation of randomly selected patches, we validated an additional 623 patches outside the park boundary in categories that were either rare (Tree Toppling or Development) or patches with Random Forests labels that did not make sense relative to the patch location, for example, Clearcuts in wilderness areas. In a few cases, patches were relabeled. A unique case at Mount Rainier was found in the zones immediately downslope of glaciers where the valley is relatively wide and rocky but the gradient is relatively steep. Eighteen Mass Movement patches found in this zone were relabeled as Riparian, even though the average slope of these patches was greater than 15 degrees. This relabeling was done to create consistency with the downriver Riparian patches (Figure 8), and to maintain consistency with protocol application across the network. These changes are not reflected in the classification accuracy matrices. Auxiliary data were used to office validate Fire patches inside and outside the park boundary (LANDFIRE 2010, NPS 2013).

Field-based validation was not performed for 1985-2009 MORA analysis because we found office-based validation to be a more accurate method for validating legacy data (Antonova et al. 2011). First, office validation using TimeSync allowed the spectral characteristics associated with change to be assessed quickly alongside the aerial photo view, and 2) for changes older than about 4 years, recovery processes often mask the agent of disturbance. In contrast, the time series of aerial photos accessible through Google Earth's "time" toolbar allowed one to view the patch as it looked closer to the time of original change. This was particularly helpful for landscape changes which occurred prior to about the year 2000. Validation methods in the next implementation time step will include field visits to a stratified random subset of patches, and will supplement the office validation.

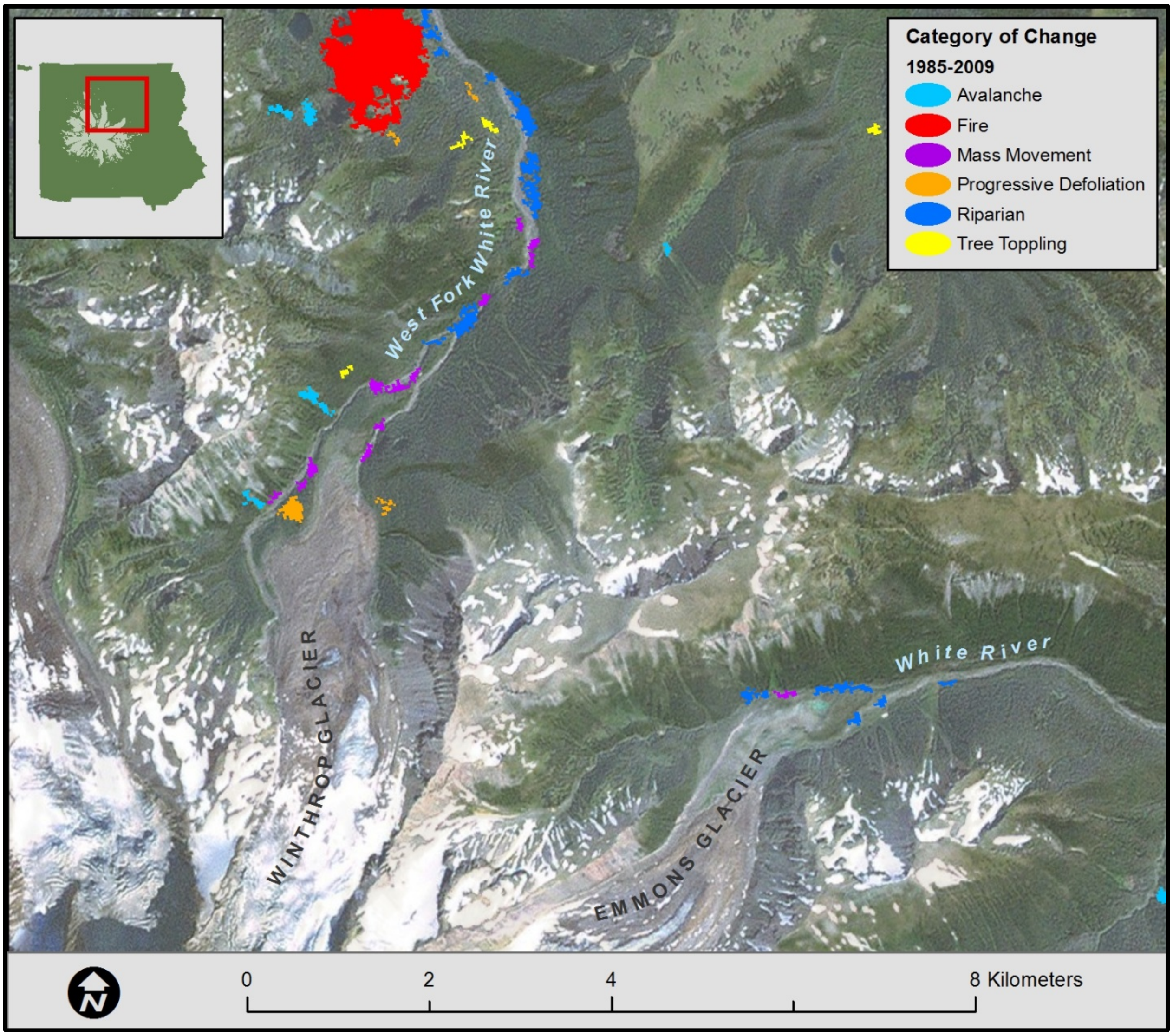

Figure 8. Examples of Mass Movement patches that were manually relabeled as Riparian.

Results

A total of 7,480 patches were mapped within the MORA study area from 1985 to 2009. Of these patches, 593 (7.9%) and 13 (0.17%) were classified as Annual Variability and Agriculture respectively. These patches are excluded from the summaries below.

Total Area Affected by Landscape Change

Approximately 56,500 ha (14.5%) of the study area underwent detectable change at some point during the 25 year period of analysis, not including changes associated with agricultural activities. Landscape change affected about 0.54% of MORA and about 19.34% of the areas outside the Park boundary. The annual average area affected by landscape change outside the Park boundary was 2,235 ha ± 680 ha. Within the Park boundary, the annual average area undergoing change was about 21 ha ± 41 ha. The rate of landscape change on an annual basis was 0.02% ± 0.04% in the Park and 0.77%± 0.23% outside the Park boundary respectively.

Timing of Landscape Change

The inter-annual variability in the total area experiencing landscape change was considerable and differed between inside and outside the park boundary (Figure 9). The greatest amount of change outside the Park boundary was documented in 1985, when 4,396 ha had some portion of vegetative cover removed. The remaining years in the series show a cyclical pattern, with increases in annual rates of change lasting on average longer than decreases. Within the MORA boundary, 2007 was the year with the greatest change detected with 180 ha. The second greatest year of change within the Park was 2004 with 120 ha.

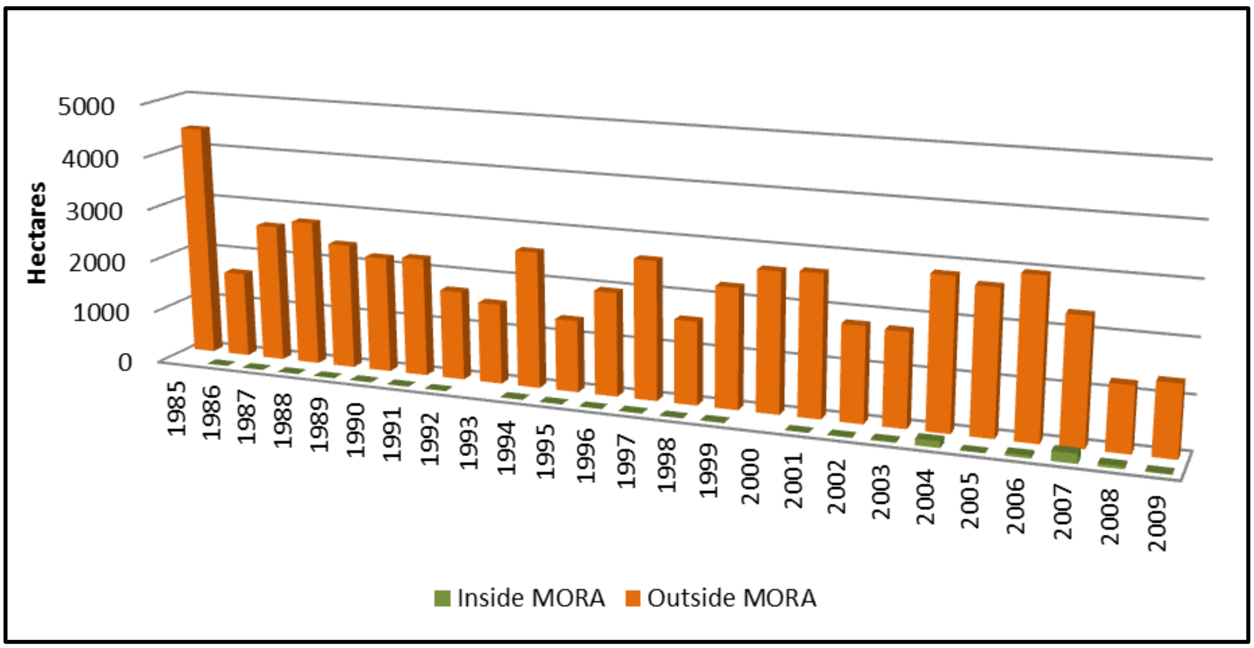

Figure 9. Total area disturbed within the Mount Rainier National Park study area by year, separated by inside and outside the Park boundary. Changes labeled as Annual Variability or as Agriculture are not included.

A map of the year of onset shows the timing of disturbances across the study area (Figure 10). Areas to the west of the Park are characterized by an even distribution of changes from 1985 to 2009. Other parts of the study area are dominated by disturbances of either one particular year, or a particular part of the time series. This contrast is particularly evident between the west side of the study area dominated by private and WA DNR lands, and the large change patches in east part of the study area under management of USFS. The changes on the east side tend to be more recent. The contrast between larger single-date events and the more consistently occurring smaller events suggests that change type outside the Park boundary must be driving this pattern. Inside the Park boundary, landscape change also appears to be more recent and a large proportion of change is associated with riparian corridors.

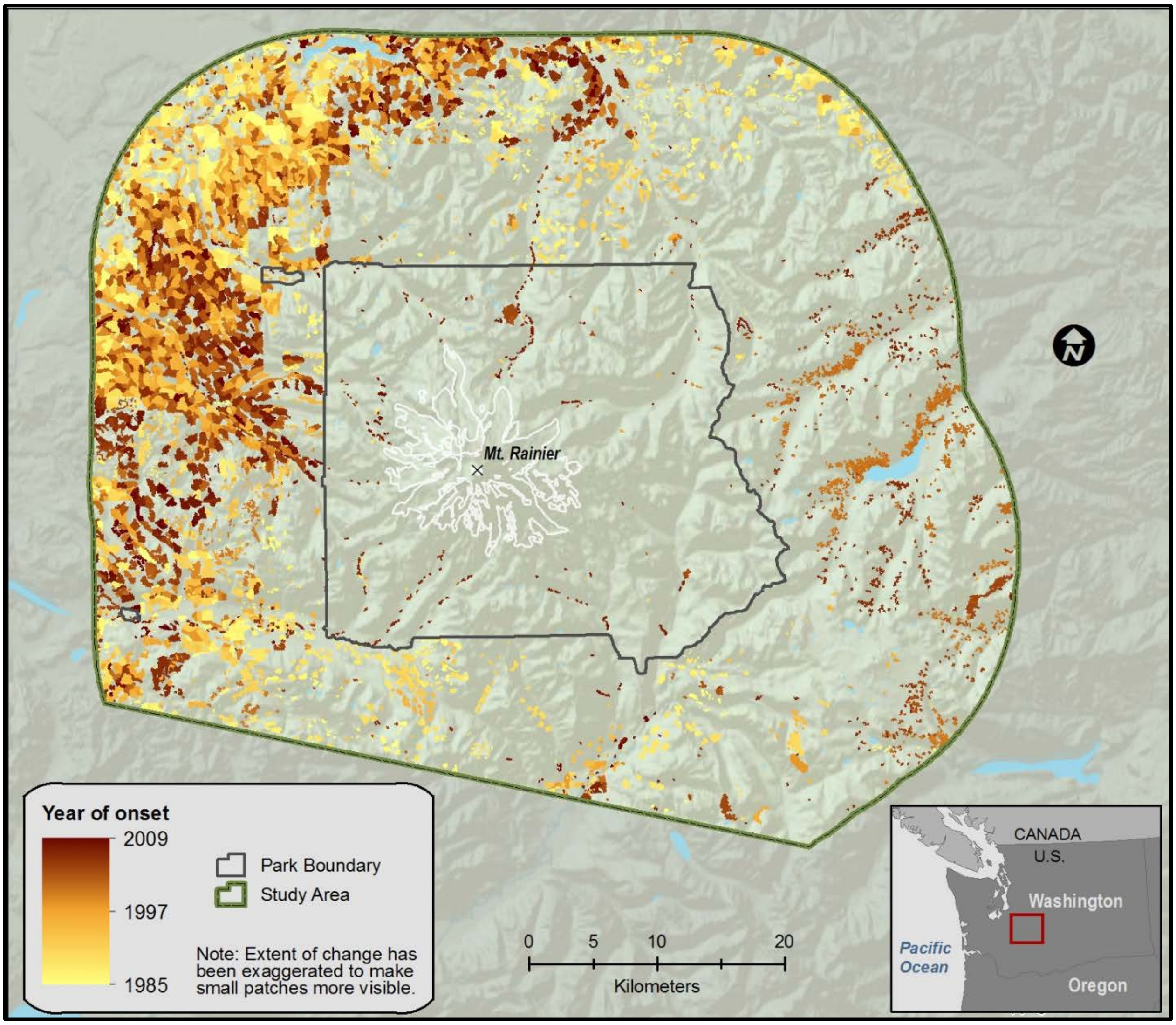

Figure 10. Map of Mount Rainier National Park study area showing landscape changes from 1985 to 2009 by year of onset.

Type of Landscape Change

Within the entire study area, Clearing has caused the greatest total change over the last 25 years. Progressive Defoliation has also played a significant role in altering the landscape during this time. Inside MORA, Riparian was the predominant category of landscape change (Table 5). Even though Fire was the second largest category of landscape change in terms of area inside MORA, over 100 ha came from a single event- the 2003 Redstone Fire Complex (detected by LandTrendr in 2004).

Table 5. Area (in ha) affected by each disturbance type inside and outside the Mount Rainier National Park boundary from 1985 to 2009. Agriculture class is not included.

Type	Study Area	% Study Area	Inside MORA	% MORA	Outside MORA	% Outside MORA
Avalanche	86.40	0.02	49.05	0.05	37.35	0.01
Clearing	52449.12	13.63	20.79	0.02	52428.33	18.14
Development	327.15	0.09	0.90	0.00	326.25	0.11
Fire	875.07	0.23	126.18	0.13	748.89	0.26
Mass Movement	66.78	0.02	14.22	0.01	52.56	0.02
Progressive Defoliation	1968.39	0.51	26.01	0.03	1942.38	0.67
Riparian	546.21	0.14	230.49	0.24	315.72	0.11
Tree Toppling	90.09	0.02	51.12	0.05	38.97	0.01
Grand Total	**56409.21**	**14.66**	**518.76**	**0.54**	**55890.45**	**19.34**

We mapped landscape change by type, which further illustrated the spatial segregation of change categories within the study area (Figure 11). Changes due to Fire and Progressive Defoliation are aggregated to the east side of the study area. Clearing activities dominate the change types found to the west, northwest and south of the Park, with some Development visible on the outskirts of towns of Buckley in the northwest, Packwood in the south and along state highway 706 in the southwest of the study area. Riparian changes are visible along large rivers predominantly on the west side of the study area, including along Carbon, North Puyallup, Muddy Fork Cowlitz, and West Fork White Rivers and Tahoma and Kautz Creeks. The total area of Riparian change is probably an underestimate, as explained in the **Methods: Change Type Characteristics**.

The Clearings in the Park (20.79 ha) were all found within the newly acquired parcel of land along the Carbon River to the northwest of the Park boundary. A 0.9 ha Development patch was detected within NPS owned lands that include park headquarters and other administrative functions about 10 km west of the main MORA entrance. Circa 2002, we detected clearing of a historical firing range for a maintenance storage area. Avalanches, Mass Movements and Tree Toppling were equally important agents of change inside and outside the Park boundary, distributed throughout the study area.

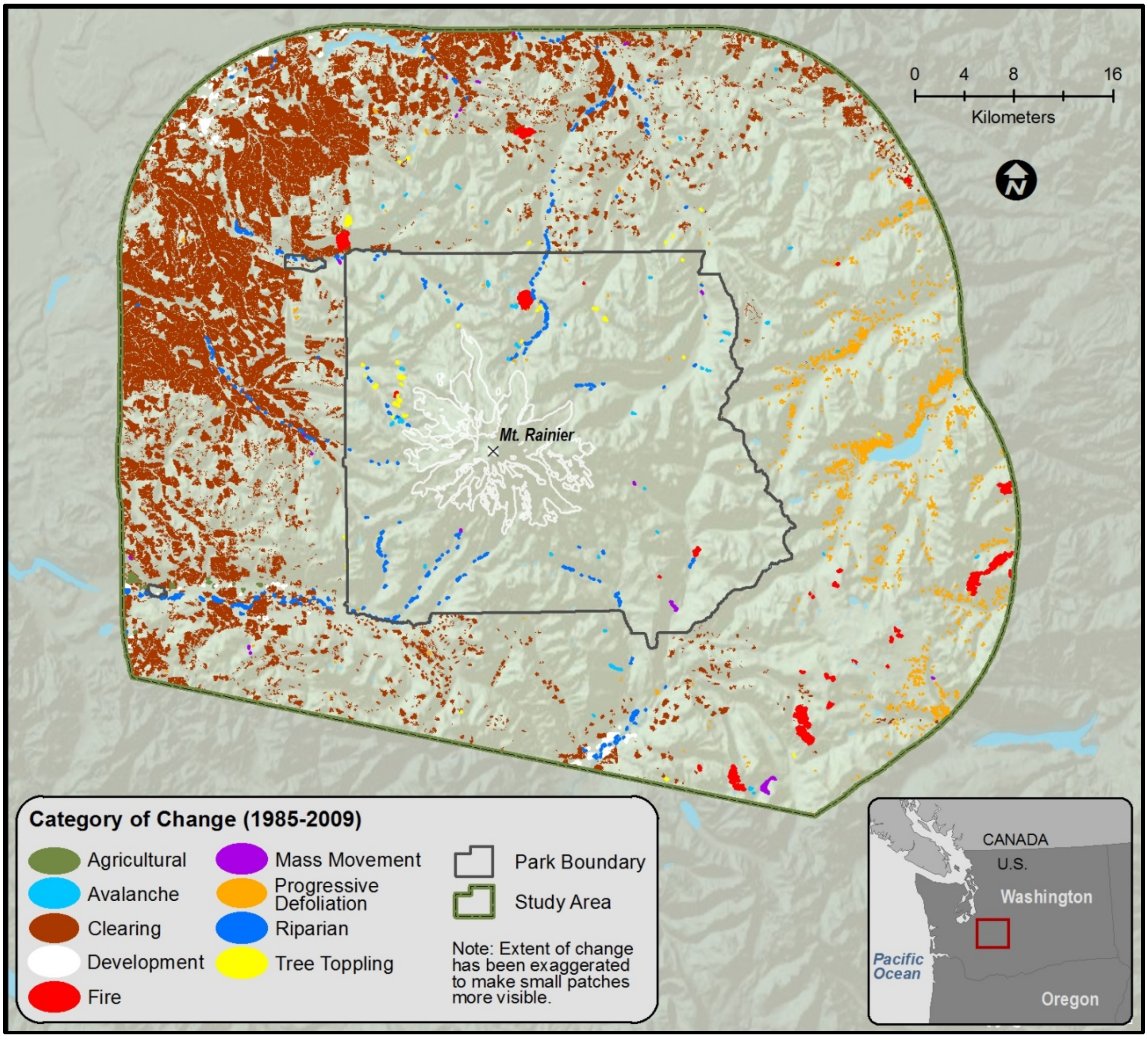

Figure 11. Map of Mount Rainier National Park study area showing landscape changes from 1985 to 2009 by change type.

Trends in Landscape Change Types

Clearing has contributed the majority of change outside the Park boundary from 1985 to 2009, showing a cyclical pattern (Figure 12). The contribution of Progressive Defoliation to total change has increased in recent years, particularly during the early 2000's and in 2006. Large fires were episodic, with 1990, 1998, 2004, and 2007 being the years with the largest change due to Fire. Riparian Changes showed increase in 1996 and 2007.

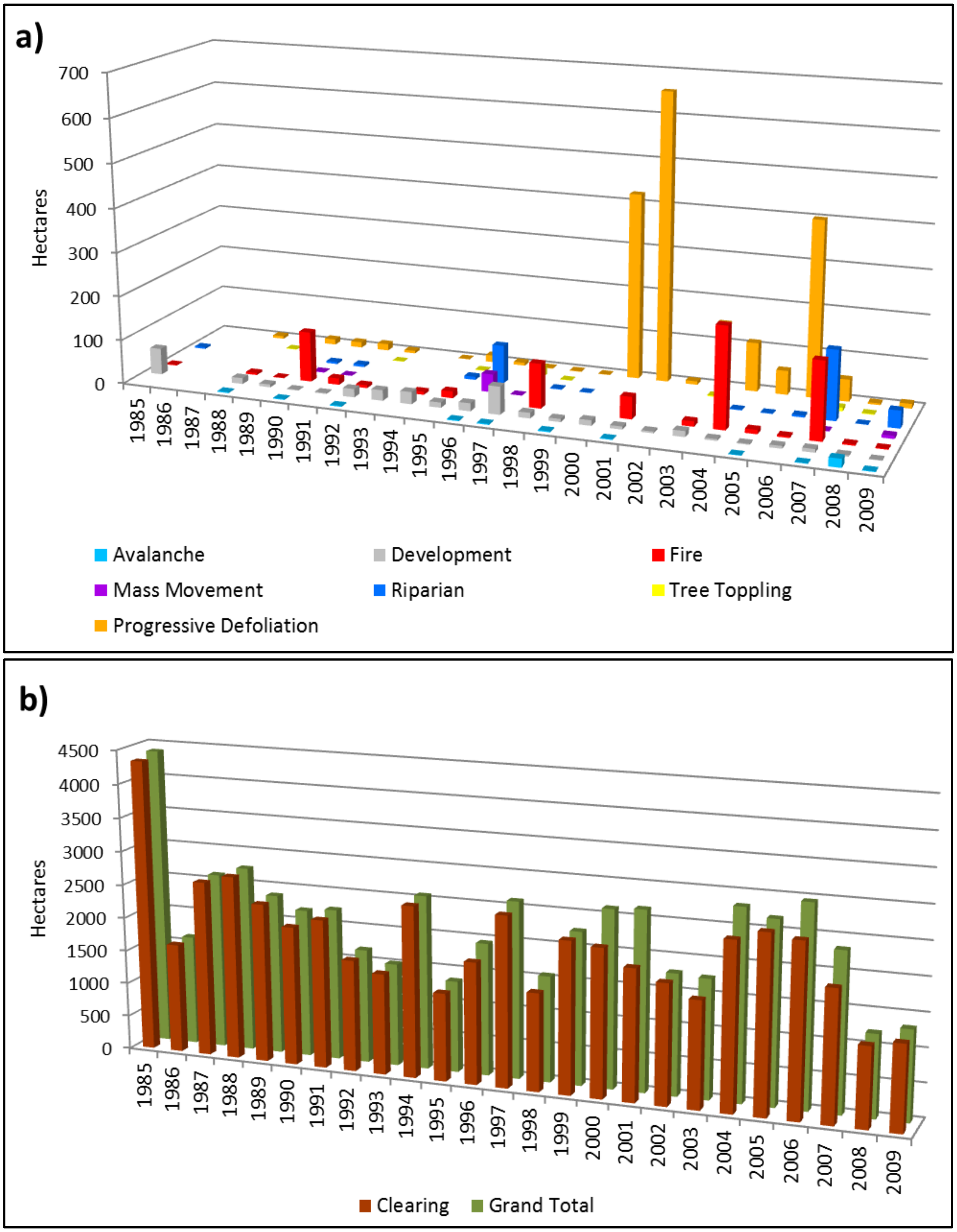

Figure 12. Time series of area disturbed outside the Mount Rainier National Park boundary by a) all change categories except Clearing and b) Clearing as compared to the total area disturbed.

Within the Park, Fire and Riparian categories contribute the majority of the disturbed area in most of the years with above-average hectares changed (Figure 13). Fire was the main agent of change in 2004 and Riparian changes played a major role in landscape change in 2006 and 2007. In the later part of the time series, Tree Topplings and Mass-Movements contributed more than average to the total landscape area changed. Years with considerable Avalanches were 1991, 1999 and 2002, with the largest area affected in 2008 (years represent the year of the summer following the winter in which the avalanches would have occurred). An uptick in the amount of area in affected by Progressive Defoliation is seen in 2009. The greatest year of change in the series was 2007 with Tree Toppling, Mass Movement and Riparian categories contributing the largest areas.

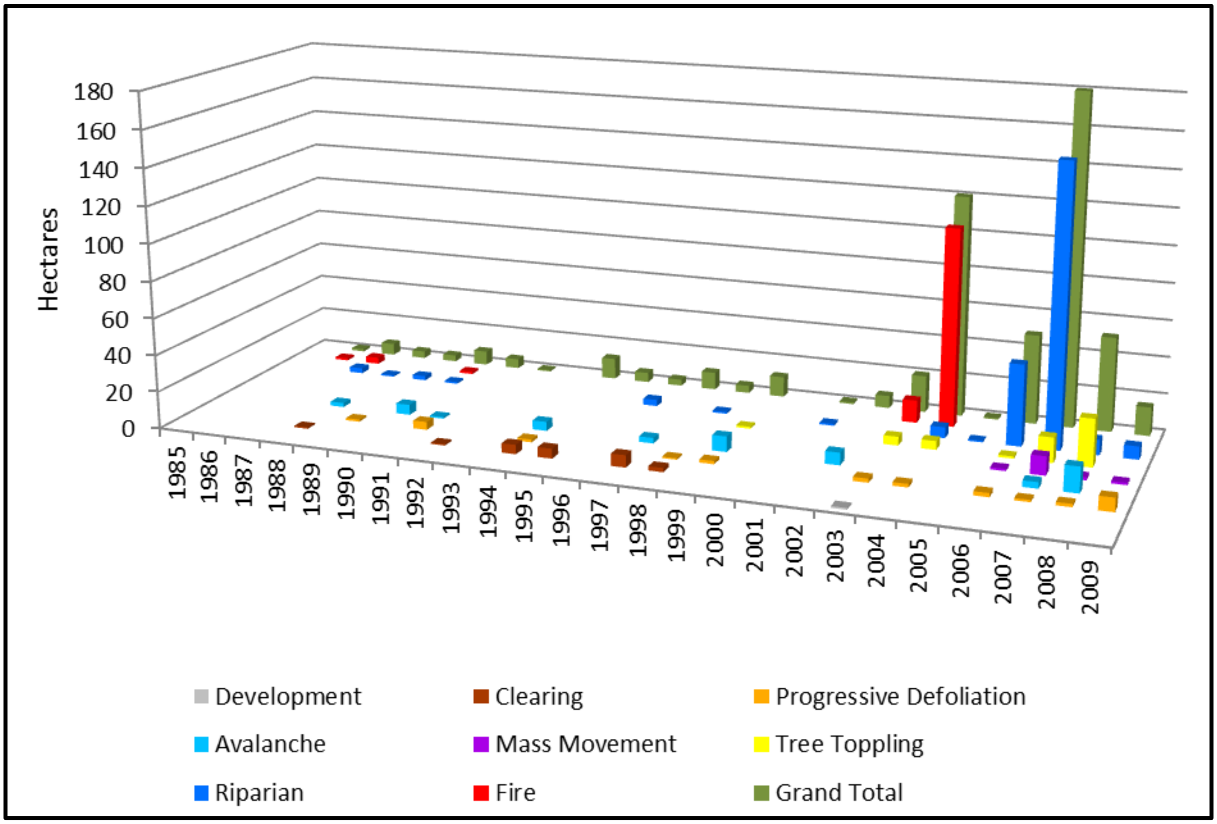

Figure 13. Time series of area disturbed within the Mount Rainier National Park boundary by change category.

Characteristics of Landscape Changes

Number of Patches

The number of landscape change patches occurring in the study area during the time of analysis is presented in Table 6. We detected 5,200 patches in the Clearing category within the study area, which had by far the largest number of patches (Table 6). Progressive Defoliation, with 1,058 patches, was the second highest category within the study area, followed by Riparian with 329 patches and Development with 113 patches. The Mass Movement category had the lowest number of patches, in part due to relabeling of some of these patches along stream headwaters inside the Park boundary to Riparian.

Within the Park boundary, Riparian was the most frequently occurring category with 140 patches detected between 1985 and 2009. Tree Toppling and Avalanche were the second and third most frequent categories and had an almost equal number of patches, 27 and 26 respectively. More patches were detected inside the Park boundary than outside in these two categories. Among the natural landscape changes, the Mass Movement category had the lowest number of patches.

Table 6. The number of patches[1] and percent of total contributed by each landscape change type inside and outside Mount Rainier National Park boundary from 1985 to 2009.

Type	Outside MORA	% Outside MORA	Inside MORA	% Inside MORA	Study Area	% Study Area
Avalanche	21	0.32	26	10.92	47	0.68
Clearing	5190	78.21	10	4.20	5200	75.65
Development	112	1.69	1	0.42	113	1.64
Fire	57	0.86	12	5.04	69	1.00
Mass Movement	14	0.21	4	1.68	18	0.26
Progressive Defoliation	1040	15.67	18	7.56	1058	15.39
Riparian	189	2.85	140	58.82	329	4.79
Tree Toppling	13	0.20	27	11.34	40	0.58
Grand Total	**6636**		**238**		**6874**	

[1] A single patch does not necessarily represent a single event. For example, 12 Fire patches inside the park boundary comprise about 5 individual fires.

The number of patches detected annually within the study area is shown in Figure 14. The year with the greatest number of patches was 1985, mostly consisting of Clearings. The next largest year was 2006 with Progressive Defoliation category contributing the largest number of patches; Progressive Defoliation also dominated by number in 2000 and 2001. Riparian patches were most prevalent in 2007, with smaller contribution to the total numbers in 1996, 2006 and 2009. In general, patches within Avalanche, Fire, Riparian, and Progressive Defoliation categories occurred regularly, whereas patches within categories such as Mass Movement and Tree Toppling tended to occur intermittently. We found 2007 to be the biggest year for windthrow events, which are part of the Tree Toppling category, which is consistent with other areas in the Pacific Northwest with large patches of forest toppled following 2006-2007 winter storms (data on file at Olympic National Park).

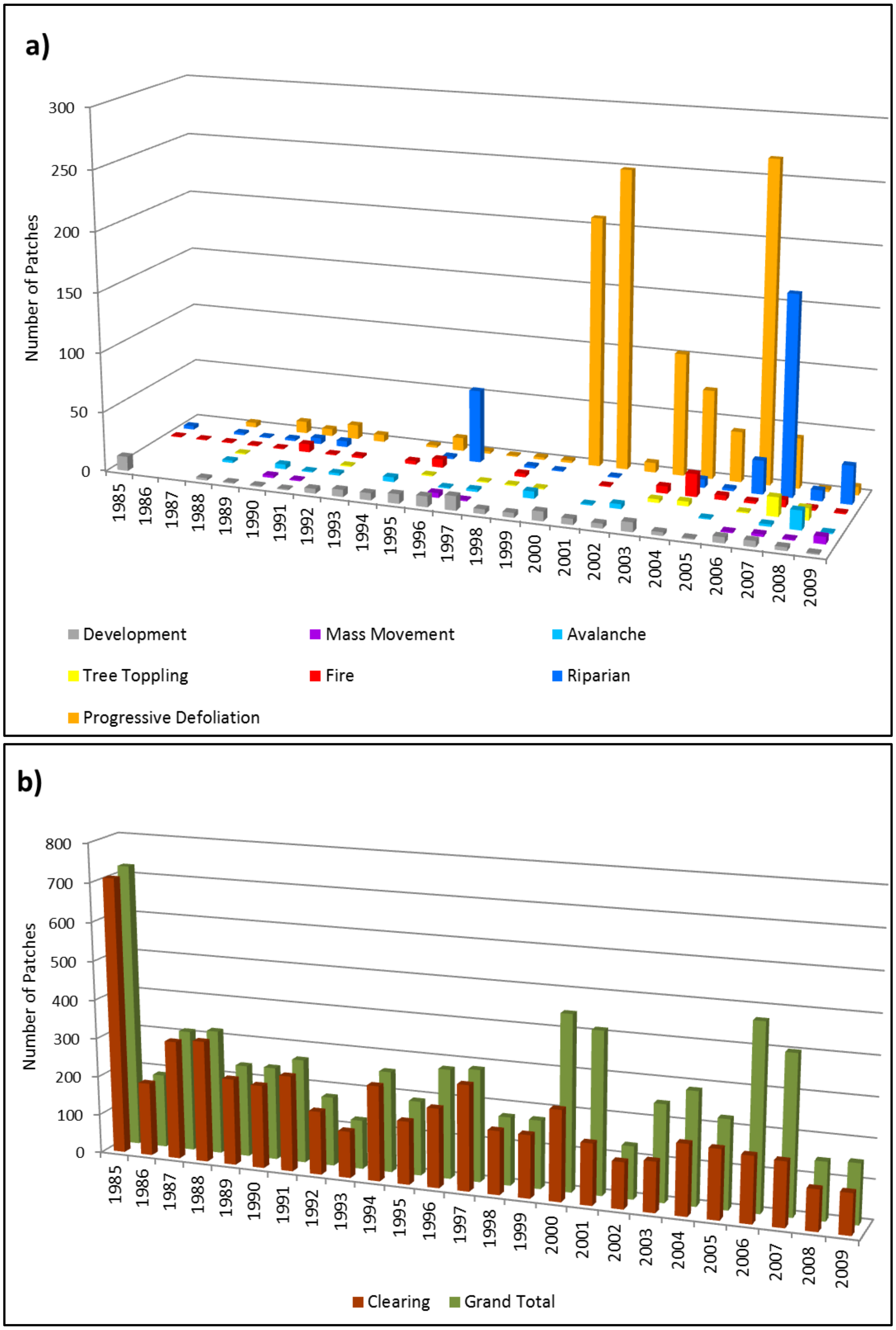

Figure 14. Number of landscape change patches detected inside and outside Mount Rainier National Park by year and type. Panel a) shows the number of patches in all change categories except Clearing and panel b) shows the number of Clearing patches as compared to the total number of patches.

Size and Magnitude of Landscape Changes

The median patch size detected was relatively small, 2.12 ha. All categories except Clearing and Fire had a median size of less than 1.5 ha (Table 7, Figure 15). The Clearing category had the largest median patch size of 3.15 ha, followed by Fire with median patch size of 2.7 ha. The Fire category had the largest variance and Avalanche and Riparian category the smallest. All landscape change categories except Avalanche had a large number of outliers with numerous patches being significantly larger than the median size. The largest patch was 330 ha and was associated with a 1985 Clearing patch in the northwest portion of the study area.

The largest patches outside the Park boundary for the Mass Movement, Progressive Defoliation, Riparian, and Tree Toppling categories were each examined. The largest Mass Movement patch was 36 ha in size and was found southeast of Park boundary along Coyote Creek in Goat Rocks Wilderness. The largest Riparian change of just over 14 ha occurred in 2007 just north of Packwood along the Cowlitz River. A 22.5 ha Tree Toppling event from 1997 was found on the north side of Carbon Ridge just north of the Park boundary. The majority of large Progressive Defoliation patches, ranging from 20 to 50 ha, were from 2000-2001 and corresponded to Spruce Budworm infestations around Bumping Lake and along State Route 410 to the east of the Park boundary (USFS 1980-present).

Table 7. Patch size characteristics of different landscape change types within Mount Rainier National Park study are from 1985 to 2009.

	Patch size (ha)		
Type	**Mean**	**Median**	**Variance**
Avalanche	1.84	1.44	1.39
Clearing	10.09	3.15	235.73
Development	2.90	1.26	31.01
Fire	12.68	2.70	573.29
Mass Movement	3.71	1.17	66.79
Progressive Defoliation	1.86	1.17	8.26
Riparian	1.66	1.26	1.67
Tree Toppling	2.25	1.26	13.05

Inside the Park boundary, the largest Mass Movement patch, occurring in 2007 and just over 10 ha in size, was found below the Steven’s Canyon Road and above the Ohanapecosh campground in the southeast part of the Park. The largest Riparian patch was associated with a 2006 event along the Tahoma Creek near the confluence with Fish Creek. This patch was just over 9 ha in size and was surrounded by smaller patches most likely associated with the same event. The second and third largest Riparian patches, each 6.2 ha in size, were found on the north side of the Park along the West Fork White River at the confluence with Lodi Creek. Both patches were from 2007 and adjacent to each other. The largest Tree Toppling patch was from 2008, 10.5 ha in size and located above the North Mowich River to the west of Division Rock. The largest Fire patch in the study area was found inside the Park boundary, was over 100 ha, and was associated with 2003 (reported as 2004) Redstone Fires above Lake James.

A comparison of Figures 14 and 15 highlights the different characteristics of the landscape change categories. Mass Movements and Riparian patches are smaller but more numerous, whereas Fire patches tend to be larger but fewer. Progressive Defoliation tends to affect large portions of the study area (Table 5) and is represented by numerous small patches (Table 6).

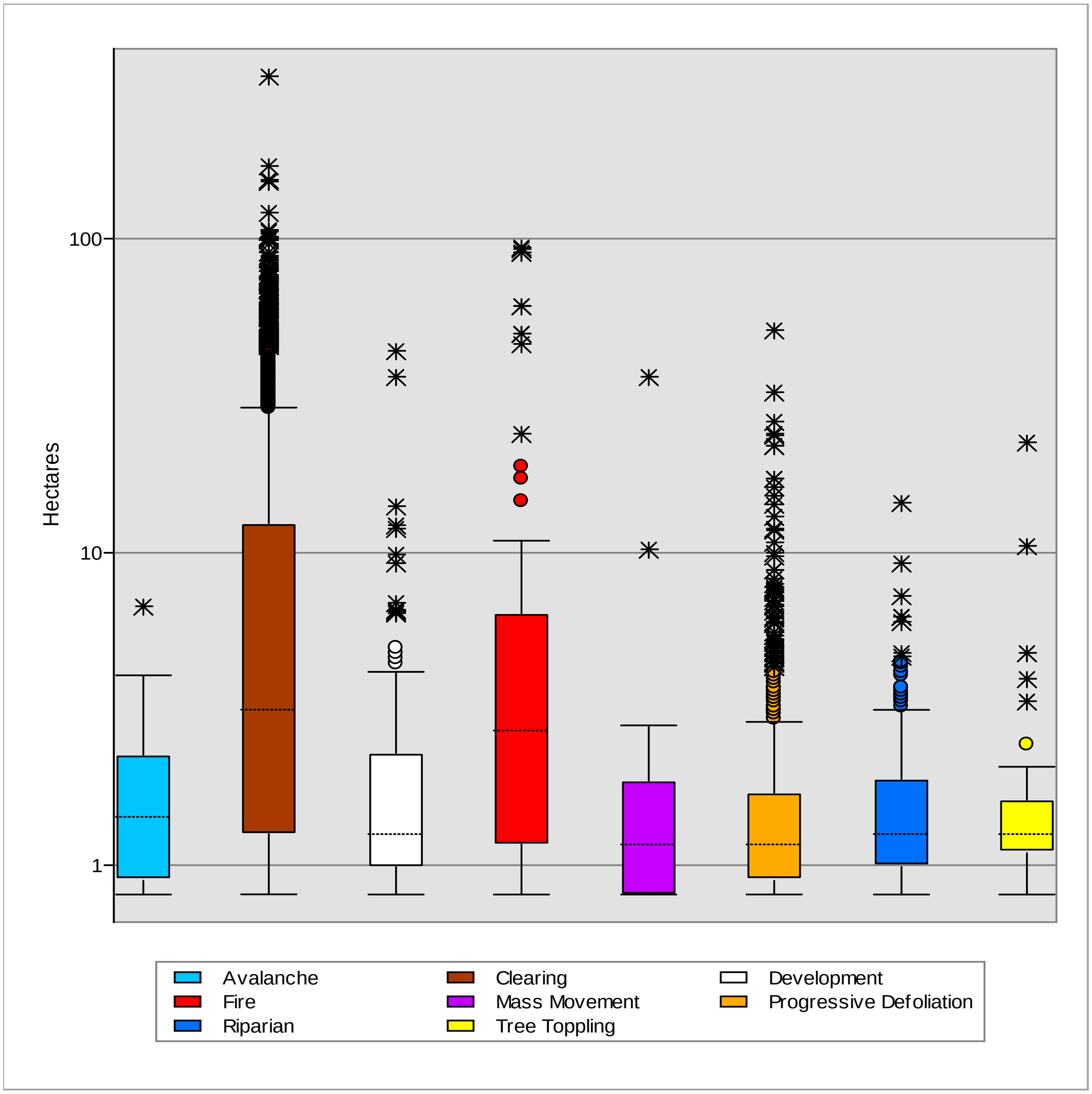

Figure 15. Patch size by change category within the Mount Rainier National Park study area. Dashed lines represent median, boxes represent quartiles (middle 50% of data points), whiskers are 1.5 interquartile range (1.5 times the box length). Circles represent “mild” outliers that occur between 1.5 and 3 times the box length. Stars represent “extreme” outliers that occur beyond 3 times the box length.

Figure 16 shows the patterns of magnitude expressed as percent vegetation cover removed, or magnitude. The large Fires and some Clearings are the events with the greatest percent vegetation cover removed.

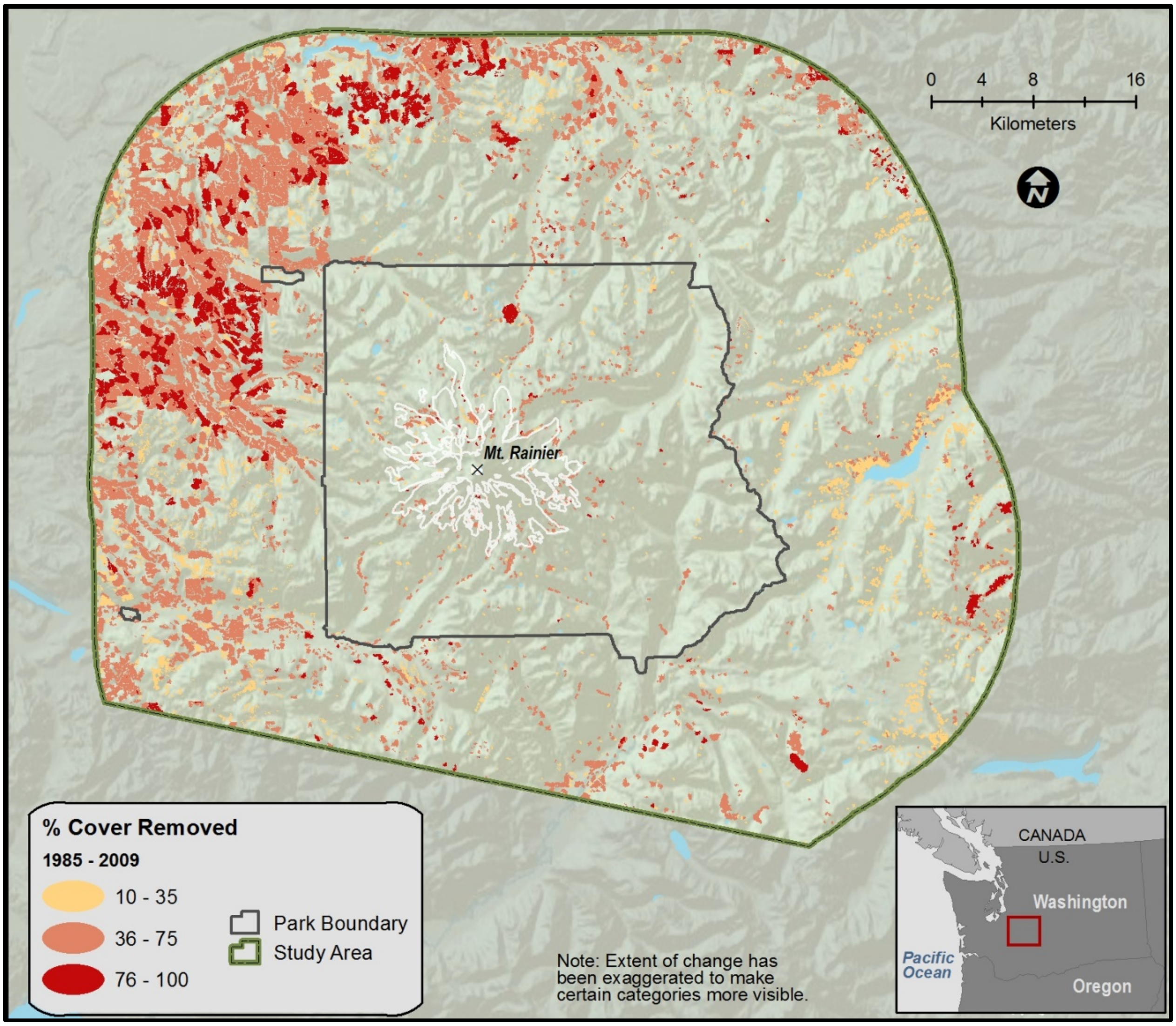

Figure 16. Map of Mount Rainier National Park study area showing landscape changes from 1985 to 2009 by magnitude (% vegetation cover removed).

All change types show a wide range of magnitude (Figure 17). Fire is consistently the change agent with highest magnitude. Progressive Defoliation shows the majority of patches with magnitude below 35% of cover removed and a large number of outliers with high magnitude values (i.e., ≥76%). The Progressive Defoliation patches with the highest magnitude were found on the east side of the study area along Bumping Lake and Highway 410 corridor and along edges of fires.

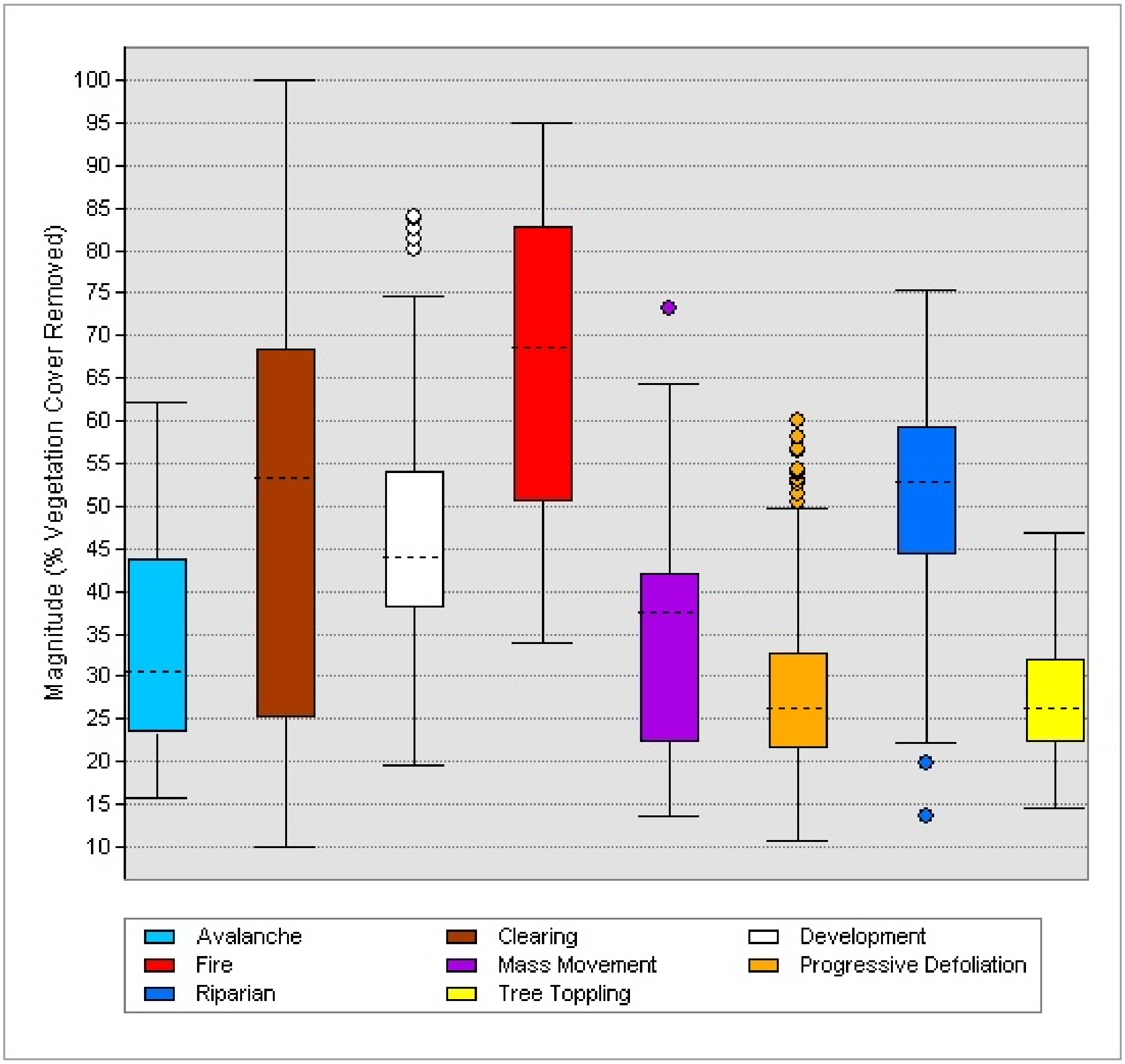

Figure 17. Magnitude (% vegetation cover removed) by change category within the Mount Rainier National Park study area. Dashed lines represent median, boxes represent quartiles (middle 50% of data points), whiskers are 1.5 interquartile range (1.5 times the box length). Circles represent "mild" outliers that occur between 1.5 and 3 times the box length. Stars represent "extreme" outliers that occur beyond 3 times the box length.

The relationship between patch size and magnitude for change categories within the study area is demonstrated in Figure 18. The Fire category had the largest events with highest magnitude, followed by Clearing. The rest of the change categories had similar average patch size, but differed in magnitude as expressed in percent vegetation cover removed. Development and Riparian changes removed the most canopy, while Tree Toppling and Progressive Defoliation events had a moderate effect on canopy removal. Avalanche and Mass Movement patches were characterized by moderate (ca. 35%) amounts of canopy removal, but Mass Movements were slightly larger in size.

As with Progressive Defoliation, the largest Avalanches patches did not have the highest percent vegetation removed. The five Avalanches with greatest magnitude of vegetation removed ranged between 51 and 62% of the vegetation removed. The Avalanche patch of largest magnitude occurred during the winter of 2006-2007 and was found within the Park boundary at the headwaters of the South Mowich River. The largest Avalanche event occurred in the winter of 2001-2002; at 4 ha in size, this event was detected at the headwaters of Chenius Creek on the north side of the Park.

Outside the Park boundary, Clearing patches had a much larger patch size and slightly larger magnitude than the patches in the Development category.

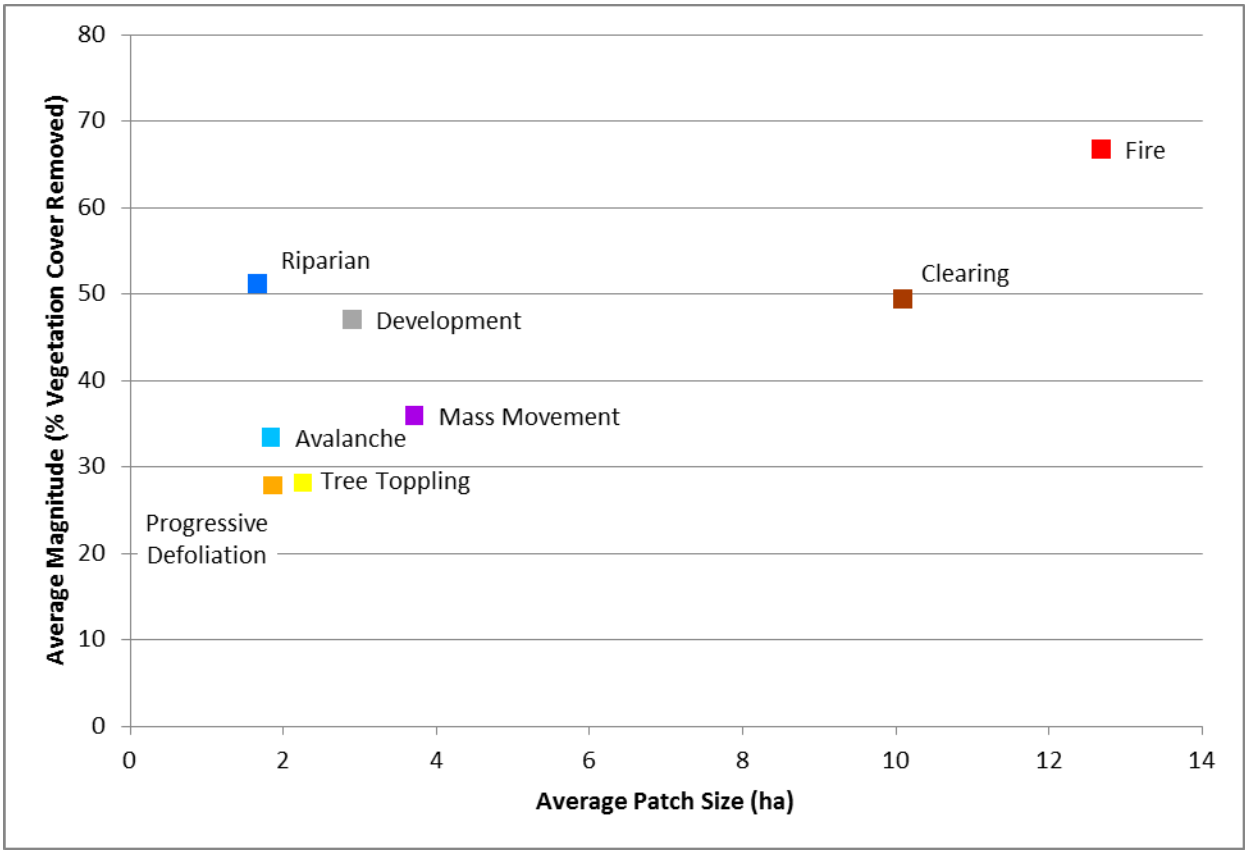

Figure 18. The relationship between average magnitude (% vegetation cover removed) and average patch size by agent type within the study area (inside and outside park boundary).

Other Landscape Factors: Elevation and Slope

Overall, all landscape change types were found along large elevation ranges, with Riparian category having the largest range between 400 to 1,500 meters (1,312 to 4,921 feet) in elevation (Figure 19). The larger values in this range came from the eighteen patches at higher elevation that were relabeled from Mass Movement to Riparian for consistency. This also contributed to the Mass Movement category having a lower median mean elevation value than the original classification showed. Riparian changes had the second lowest median value, with the highest elevation values attributed to the areas along Inter Fork on the east flanks of Mt. Rainier.

The Fire category had the highest median elevation value at just below 1,500 meters. The lowest elevation fire was the 2003 Panther fire in the southeastern corner of the park above Highway 123. The Avalanche category had the smallest range, from about 850 to 1,650 meters.

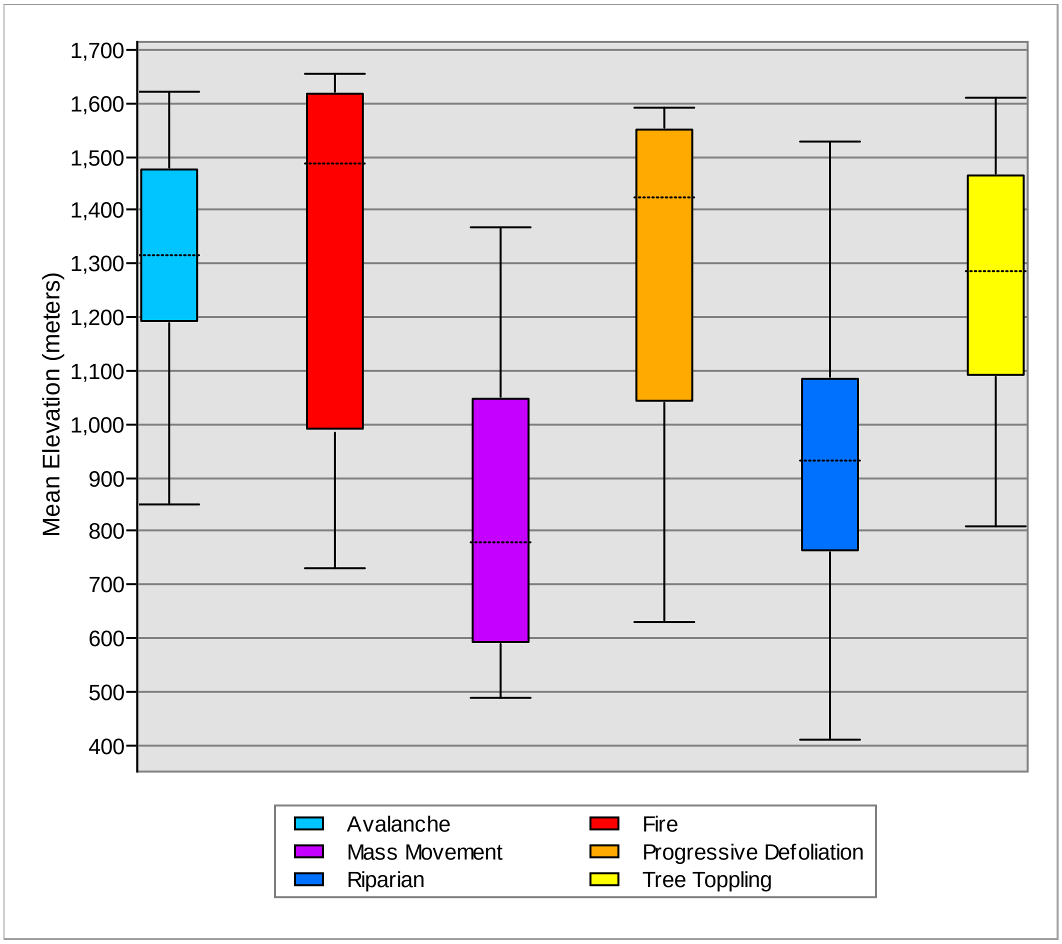

Figure 19. Distribution of mean elevation values for each landscape change category using patches detected between 1985 and 2009 inside the boundary of the Mount Rainier National Park. Dashed lines represent median, boxes represent quartiles (middle 50% of data points), whiskers are 1.5 interquartile range (1.5 times the box length).

Mean slope values for patches in change categories inside the park boundary are shown in Figure 20. Fire had the largest median mean slope of about 29 degrees and a wide range of values; Tree Toppling patches had the widest range with values between 5 and 44 degrees. Of all natural landscape changes, the Riparian category had the lowest median value, with outliers in the upper range coming from patches at the headwaters of rivers that were relabeled from the Mass Movement category. The remaining Mass Movement patches had a median mean slope value of about 19 degrees, but occurred on slopes of up to 26 degrees.

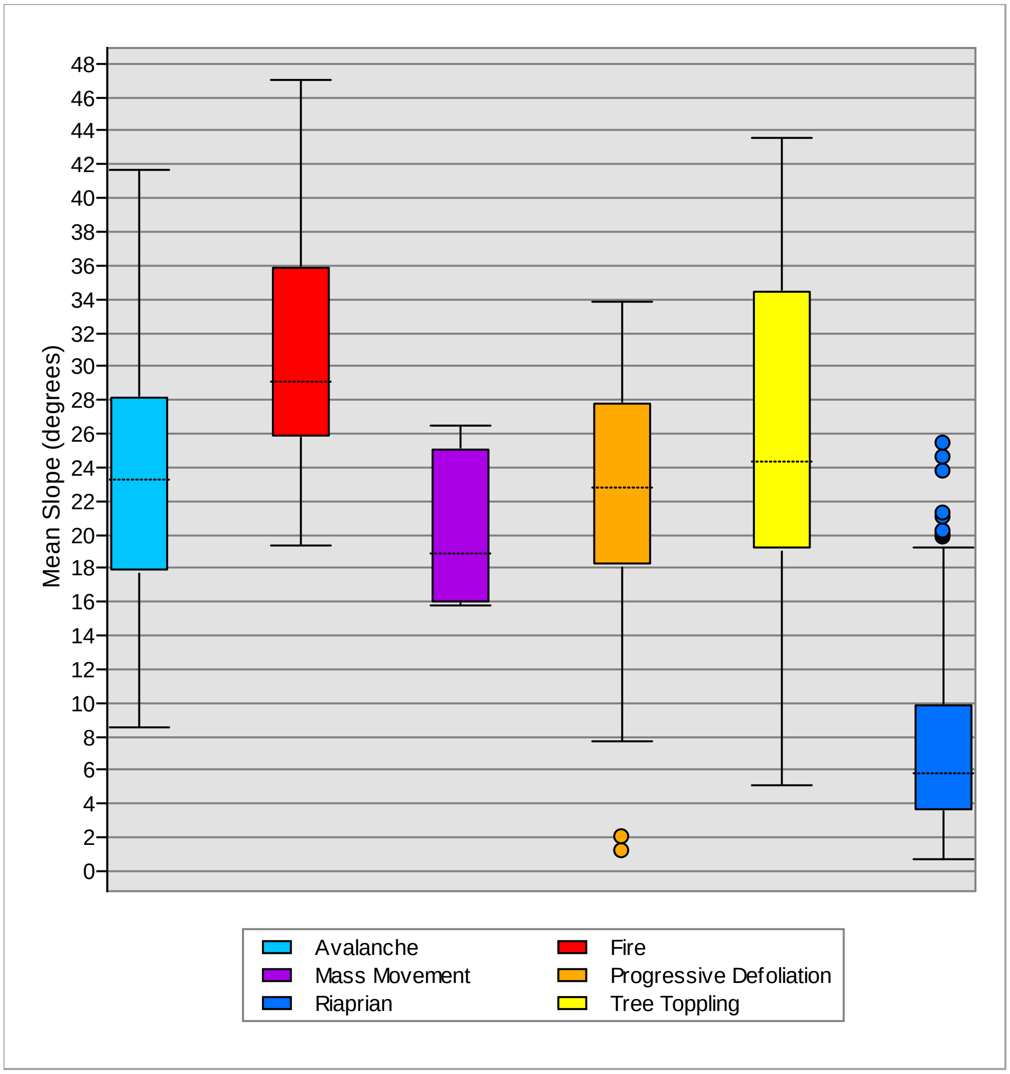

Figure 20. Range of mean slope values for patches in all change categories within the boundary of the Mount Rainier National Park. Dashed lines represent median, boxes represent quartiles (middle 50% of data points), whiskers are 1.5 interquartile range (1.5 times the box length). Circles represent "mild" outliers that occur between 1.5 and 3 times the box length. Stars represent "extreme" outliers that occur beyond 3 times the box length.

Land management and Landscape Change

The highest percentage of landscape change during the period of analysis was within the All Other land management category. This category is mostly comprised of private lands but also includes City and County holdings (Figure 21). About 48% area within the All Other category was modified, with an annual average of 1.9% land changed. The WA State DNR category had the second largest amount of change, with about 34% of the area modified between 1985 and 2009. US Forest Service non-wilderness was the third highest, with 6.6% of its lands modified by landscape change. NPS wilderness had the lowest value of 0.5%.

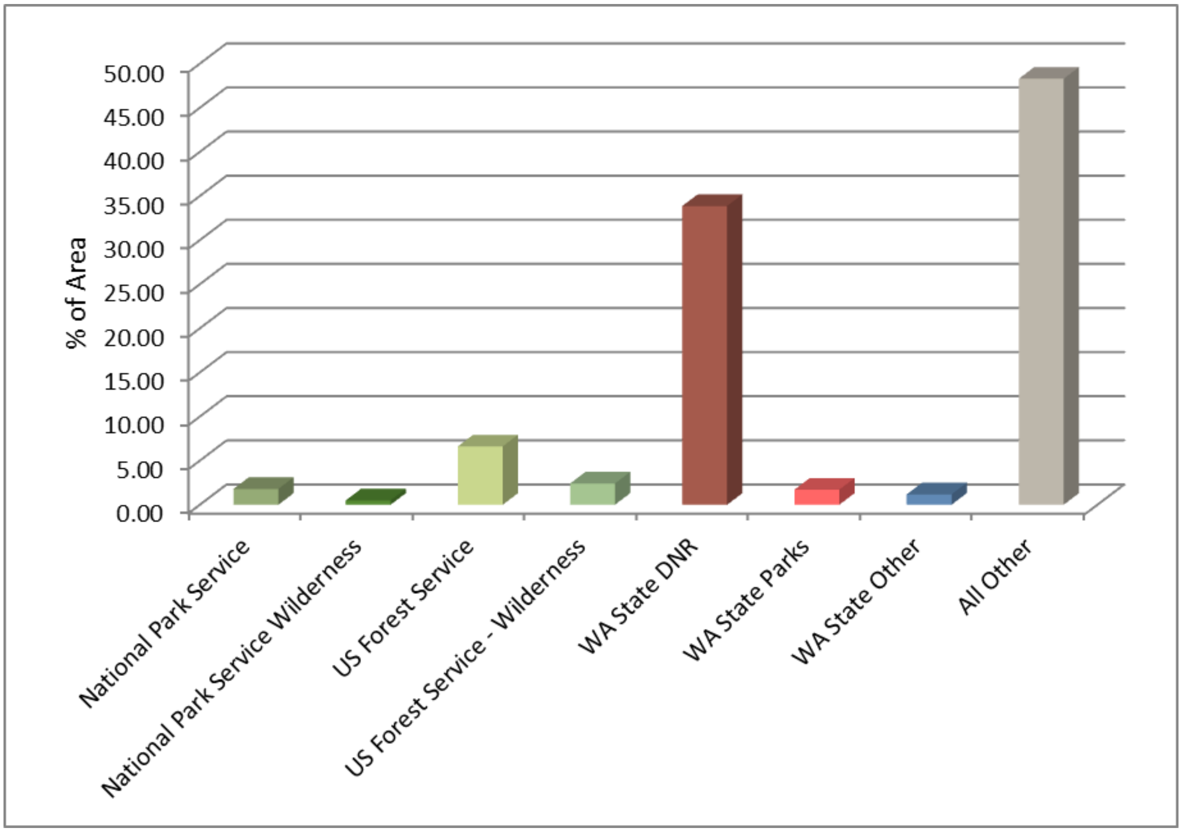

Figure 21. The percent of the total area within each land management category in the study area that underwent change between 1985 and 2009. Agriculture is not included.

NPS wilderness and USFS wilderness show similar patterns of landscape change, though USFS wilderness had a slightly higher percent of its land affected by landscape change (Table 8). Progressive Defoliation was the most common agent of change in USFS wilderness areas, affecting 1.71% of the area, which was below the 0.02% of area affected within the Park. Riparian was the agent affecting the highest number of ha within the NPS wilderness (0.21%). NPS wilderness areas had higher percentages of area affected by Riparian, Avalanche and Tree Toppling categories. Forest Service wilderness had higher percentages in Fire and Mass Movement and Progressive Defoliation categories.

As expected, we found no Clearing or Development patches within either NPS or USFS wilderness lands. Clearing was the most common landscape change within the USFS non-wilderness areas, affecting 6.13% of the area. No patches within the Development category were detected in USFS non-wilderness areas. Progressive Defoliation, at 0.37%, was the second highest category affecting the USFS non-wilderness areas.

Table 8. Percentage of total area affected by different landscape change categories within the Mount Rainier National Park study area on National Park Service and U.S. Forest Service lands between 1985 and 2009.

	USFS		USFS Wilderness		NPS		NPS Wilderness	
Type	**Ha**	**% USFS**	**Ha**	**% USFS Wilderness**	**Ha**	**% NPS**	**Ha**	**% NPS Wilderness**
Avalanche	4.68	0.005	28.80	0.031	2.07	0.058	46.98	0.051
Clearing	5662.89	6.126	0.00	-	18.54	0.522	-	-
Development	0.00	-	0.00	-	0.9	0.025	-	-
Fire	26.01	0.028	567.18	0.618	-	-	126.18	0.137
Mass Movement	2.79	0.003	37.08	0.040	-	-	14.22	0.015
Progressive Defoliation	343.71	0.372	1568.43	1.708	3.69	0.104	22.32	0.024
Riparian	63.99	0.069	3.60	0.004	38.7	1.090	191.79	0.208
Tree Toppling	12.42	0.013	5.76	0.006	-	-	48.24	0.052
Grand Total	**6116.49**	**6.616**	**2210.85**	**2.407**	**63.9**	**1.799**	**449.73**	**0.487**

The total number of hectares altered by Clearing for each land management category within the analysis period is shown in Figure 22. The All Other category shows the largest number of hectares cleared between 1985 and 2009.

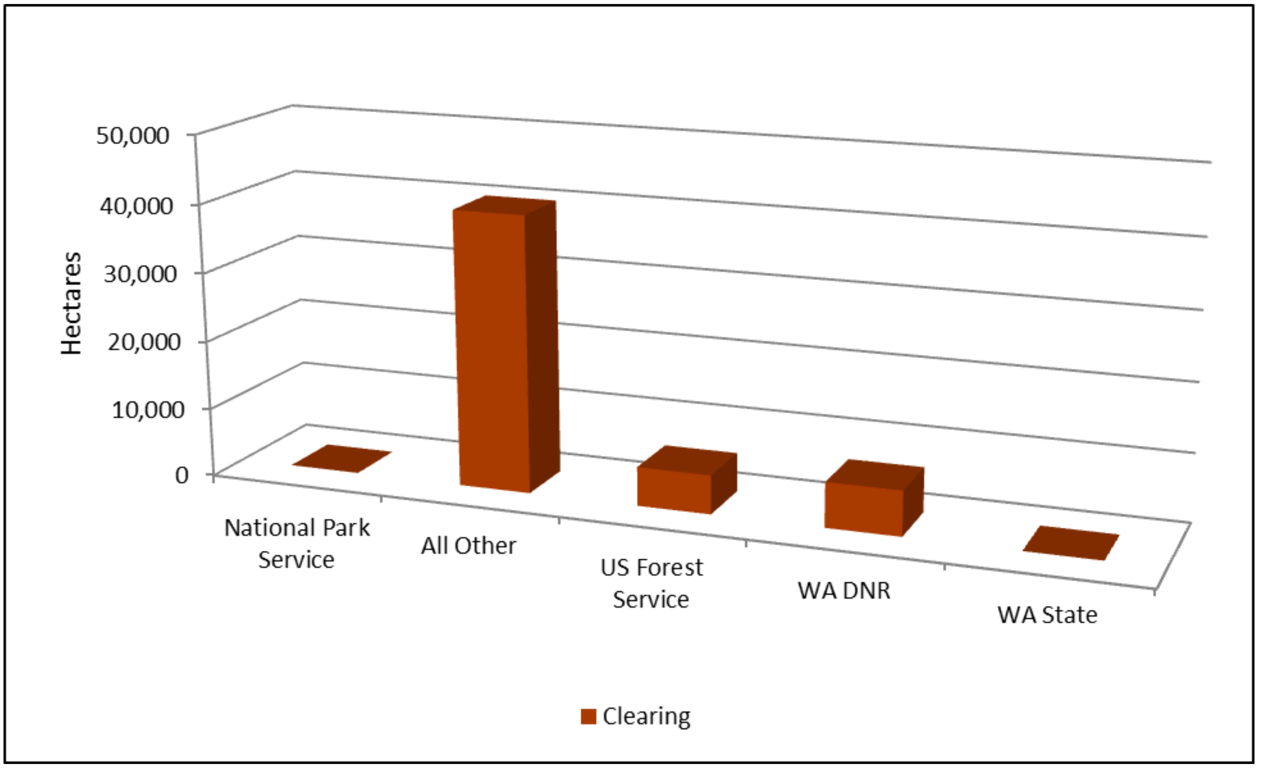

Figure 22. Total hectares disturbed by Clearing outside the Mount Rainier National Park boundary between1985 and 2009.

After a peak year in 1985, the number of hectares affected by clearing was variable over the next 24 years, reflecting an up and down, cyclic pattern (Figure 23).

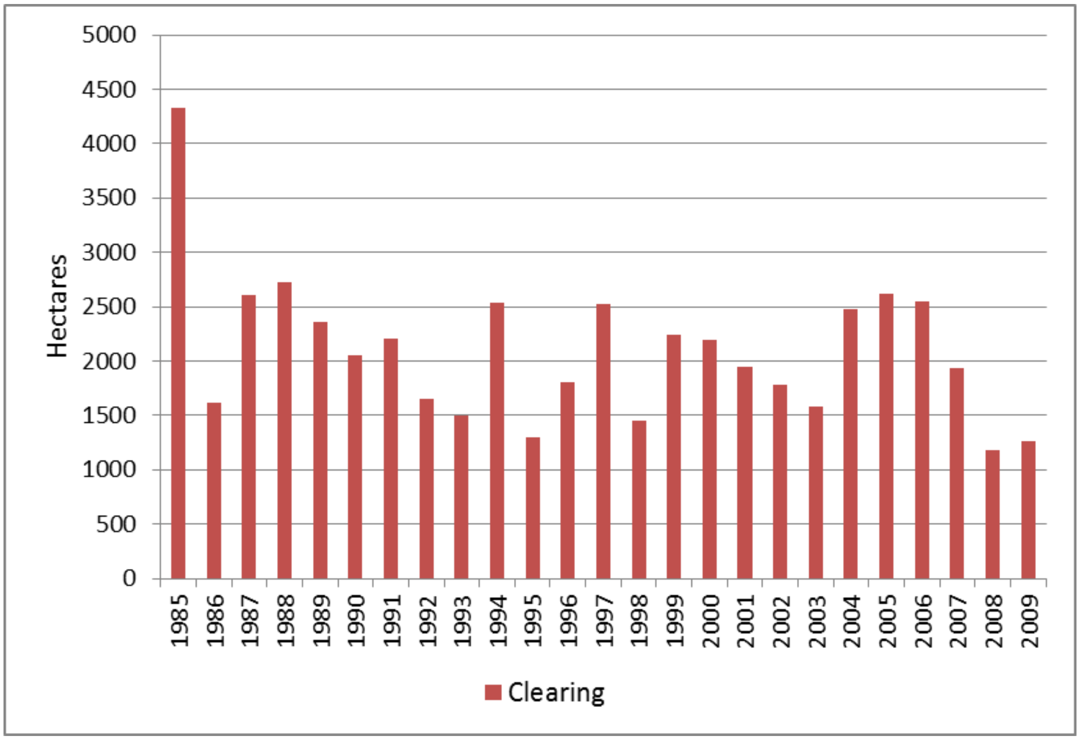

Figure 23. Area of Clearing outside the Mount Rainier National boundary from 1985 to 2009.

Annual patterns in the Clearing change type are shown by land management categories in Figure 24. The US Forest Service land management category showed a steady decline after 1988. The All Other category, mostly consisting of privately owned lands, showed a cyclical pattern, with an increase of the number of hectares cleared in the early- and mid-2000's and averaging about 1,600 ha per year. The Washington State DNR Clearing category shows a similar trajectory, but with much smaller numbers, averaging about 260 ha per year.

Change attributed to Development outside the park boundary showed a cyclical pattern, with an increase in the number of hectares developed in the mid-1980's and then again in the early- and mid-1990's (Figure 25). The greatest change in the Development category occurred in 1997 when 63 ha were converted. After 1997, however, the trajectory showed a slight decline, ending with 2009, when only 1 ha was converted, the lowest value in the entire time period. Almost all of the area developed, 317 ha, fell under the All Other land management category, with an additional 9 ha converted on WA State DNR lands.

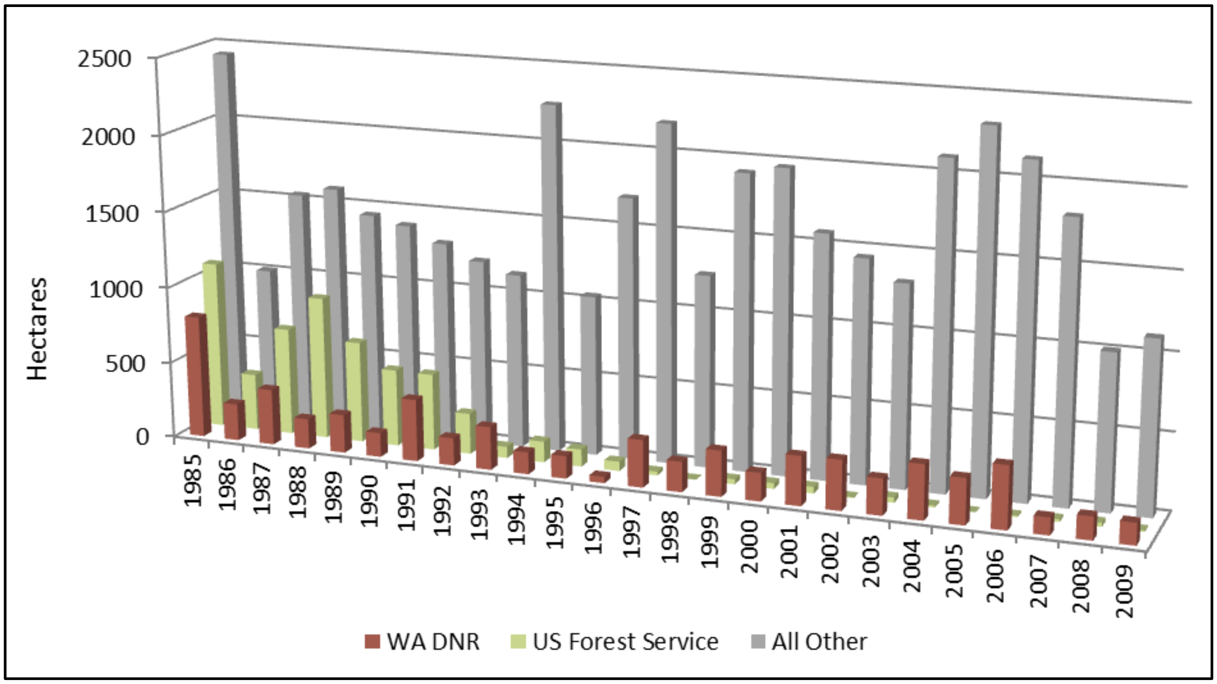

Figure 24. Total hectares disturbed by Clearing outside the Mount Rainier National Park boundary between 1985 and 2009 by year and land management category.

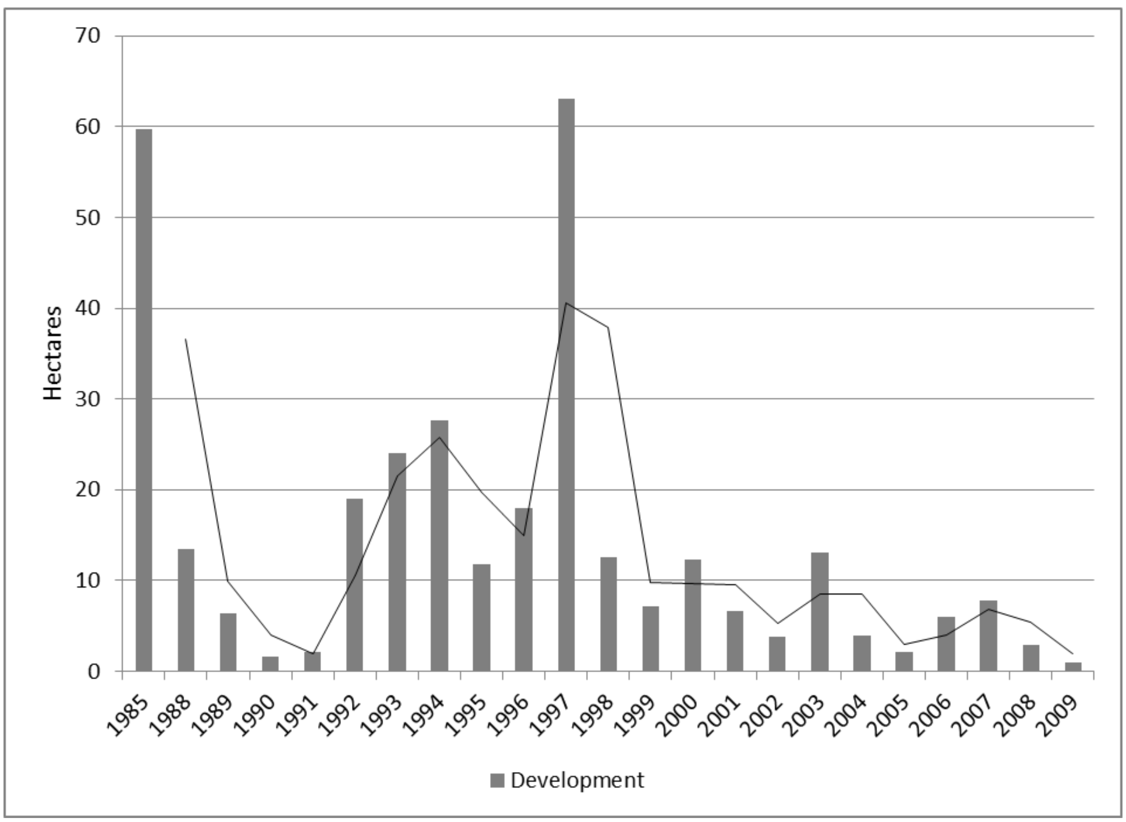

Figure 25. Changes in area of Development outside of the Mount Rainier National Park boundary from 1985 to 2009, overlain with a two-year running average.

Accuracy Assessment

Random Forests Classification

The overall classification accuracy was 77.47%. The accuracy assessment matrix for the RF classification applied to change patches inside and outside the park boundary is shown in Table 9. The Clearing category had the lowest error rate of 7%. The Annual Variability and Riparian categories had error rates at or below 15%. Rare categories, such as Agriculture Development had error rates at or above 40% and were confused with each other and the Clearing category. Avalanches were often mistakenly labeled as Clearing or Mass Movement due to their similarities in spectral characteristics and location on landscape. Tree Toppling were often confused with Avalanches, probably because in both of these categories the canopy is only partially removed.

Table 9. Accuracy assessment matrix for RF-derived labels for Mount Rainier National Park training polygons used to create model.

	Predicted										
Actual	Agriculture	Annual Variability	Avalanche	Clearing	Development	Fire	Mass Movement	Progressive Defoliation	Riparian	Tree Toppling	**Error (%)**
Agricultural	**3**	0	0	3	5	0	0	0	0	0	73
Annual Variability	0	**26**	1	2	0	1	0	0	0	0	13
Avalanche	0	0	**17**	5	0	0	4	0	0	2	39
Clearing	0	0	0	**89**	5	1	0	0	0	1	7
Development	1	0	0	7	**13**	0	0	0	1	0	41
Fire	0	1	1	0	0	**9**	1	0	0	1	31
Mass Movement	0	0	1	4	0	1	**18**	0	1	1	31
Progressive Defoliation	0	0	1	2	0	0	1	**15**	0	0	21
Riparian	0	0	0	0	1	0	2	0	**17**	0	15
Tree Toppling	0	0	4	2	1	0	0	1	0	**20**	29

Office Validation

The office validation, which compares the RF-generated labels with those determined by office evaluation, provides a second view of the accuracy of the change labels.

<u>Outside the Park Boundary</u>

One thousand two hundred and forty seven randomly selected polygons outside of the park boundary were assigned a change label based on spectral characteristics of change viewed through TimeSync and visual assessment using aerial images from various time periods available in Google Earth. The RF model labeled the polygons outside the park boundary with an overall accuracy of 91% (Table 10). The Kappa statistic was 91.02, indicating that the RF classification of patches was 91% better than a random classification. The Annual Variability, Clearing, Mass Movement, Progressive Defoliation, and Riparian categories all had user's accuracies greater than 90%. The lowest accuracy from a user's standpoint was for the Development category (26.6%), which is over-predicted by the model and is most frequently confused with the Clearing class. The Tree Toppling and Avalanche categories also had low user's accuracy of 36.4 and 42.9% respectively. Because these two categories were relatively rare outside the Park boundary, we preferred that those categories were over-predicted rather than under-predicted, so that patches with these labels could be evaluated and corrected. Avalanches were most commonly confused with the Progressive Defoliation category, probably due to incomplete removal of vegetation by both of these landscape change types and because they both occur on valley walls.

From a producer's standpoint, the highest accuracy was assigned to the Annual Variability, Avalanche and Tree Toppling categories at 100% each, followed by the Development (95.5%), Clearing (92.8%) and Progressive Defoliation (90.5%) categories. The lowest accuracy was found in the Annual Variability category (54.2%), which was underpredicted by the model and most commonly confused with Clearing (Table 10).

Table 10. Accuracy assessment of polygons outside Mount Rainier National Park boundary.

	Validation											
RF Model	Agricultural	Annual Variability	Avalanche	Clearing	Development	Fire	Mass Movement	Progressive Defoliation	Riparian	Tree Toppling	Grand Total	User's Accuracy
Agricultural	**6**			5							11	54.5
Annual Variability		**13**						1			13	100.0
Avalanche		1	**3**	1			1	13			7	42.9
Clearing		8		**909**	1	2			5		938	96.9
Development		1		56	**21**				1		79	26.6
Fire				2		**4**					6	66.7
Mass Movement							**4**				4	100.0
Progressive Defoliation				1				**143**			144	99.3
Riparian				2					**32**		34	94.1
Tree Toppling		1		4			1	1		**4**	11	36.4
Grand Total	6	24	3	980	22	6	6	158	38	4	1247	
Producer's Accuracy	100.0	54.2	100.0	92.8	95.5	66.7	66.7	90.5	84.2	100.0		
Overall Accuracy	91.34											
Kappa Statistic	91.02											

Inside the Park Boundary

Every patch within the park boundary was assessed visually using TimeSync and aerial photography. The office validation results for inside the park boundary are shown in Table 11. The RF classification model inside MORA has slightly lower overall accuracy than for patches outside the park boundary. The Kappa statistic was also lower at 86.2. Avalanche and Mass Movement categories had the lowest user's accuracy, often being confused with Annual Variability by the model. The Mass Movement category was also confused with Riparian, most likely due to the unique geography of MORA, as explained previously. The highest user's accuracies were in the Annual Variability, Clearing, Development (sample size of only 1), Fire, and Riparian categories, all exceeding 75%. Producer's accuracy exceeded 80% in all categories except Progressive Defoliation, which was often labeled by the model as Tree Toppling.

Table 11. Accuracy assessment of polygons inside the Mount Rainier National Park boundary.

		Validation										
		Annual Variability	Avalanche	Clearing	Development	Fire	Mass Movement	Progressive Defoliation	Riparian	Tree Toppling	Grand Total	User's Accuracy
RF Model	Annual Variability	**392**									392	100.0
	Avalanche	15	**26**								41	36.6
	Clearing			**10**							10	100.0
	Development				**1**						1	100.0
	Fire	3				**11**					14	78.6
	Mass Movement	8				1	**21**		22	1	53	39.6
	Progressive Defoliation	4						**3**			7	42.9
	Riparian							1	**96**		97	99.0
	Tree Toppling	6					1	14	4	**26**	51	51.0
	Grand Total	428	26	10	1	12	22	18	118	27	666	
	Producer's Accuracy	91.6	100.0	100.0	100.0	91.7	95.5	16.7	81.4	96.3		
	Overall Accuracy	87.99										
	Kappa Statistic	86.2										

Literature Cited

Antonova, N., and S. Clary. 2013. Updates to the Mount Rainier National Park boundary. Unpublished geospatial dataset, MORA_boundary_update_9May2013.shp. Mount Rainier National Park, Tahoma Woods, Washington.

Antonova, N., C. Copass, R. K. Kennedy, Z. Yang, J. Braaten, and W. Cohen. 2012. Protocol for Landsat-based monitoring of landscape dynamics in North Coast and Cascades Network Parks: Version 2. Natural Resource Report NPS/NCCN/NRR—2012/601. National Park Service, Fort Collins, Colorado.

Antonova, N., C. Thompson, D. Wallin, R. Bryson, S. Clary, A. Hayes, I. Oehler, B. Pickard, M. Ponce-McDermott, and N. Schaller. 2011. Identifying the causes of landscape change in the North Coast and Cascades Network parks. Published Report-2184853, Task Agreement J8W07110003; PNW CESU Agreement H8W07110001. North Coast and Cascades Network, National Park Service, Sedro-Woolley, Washington.

Cohen, W. B., Z. Yang, and R. Kennedy. 2010. Detecting trends in forest disturbance and recovery using yearly Landsat time series: 2. TimeSync - Tools for calibration and validation. Remote Sensing of Environment 114:2911-2924.

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

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 No. 19. U.S. Department of the Interior, National Park Service, Washington, D.C.

Kennedy, R. E., W. B. Cohen, A. A. Kirschbaum, and E. Haunreiter. 2007. Protocol for Landsat-based monitoring of landscape dynamics and North Coast and Cascades Network Parks. 2-G1. U.S. Geological Survey Techniques and Methods, Reston, Virginia. Available from: http://pubs.usgs.gov/tm/2007/tm2g1/pdf/tm2g1.pdf (accessed 19 June 2012).

Kennedy, R. E., Z. Yang, and W. B. Cohen. 2010. Detecting trends in forest disturbance and recover using yearly Landsat time series: 1. LandTrendr - Temporal segmentation algorithms. Remote Sensing of Environment 114:2897-2910.

LANDFIRE. 2010. LANDFIRE public events geodatabase. Geospatial dataset. Available from: http://www.landfire.gov/public_data.php (accessed 26 July 2013).

Mt. Baker-Snoqualmie National Forest (MBSNF). 2004. The administrative boundary of the Mt. Baker-Snoqualmie National Forest. Geospatial dataset. Available from: http://www.fs.fed.us/r6/data-library/gis/mtbaker-snoqualmie/ (accessed 30 May 2013).

National Park Service (NPS). 2013. NPS Fire SDE Geodatabase. Unpublished Geospatial Dataset. National Park Service – National Interagency Fire Center, Boise, Idaho.

NPS – Land Resources Division. 2008. Mount Rainier National Park tract and boundary data. NPS – Land Resources Division. Geospatial Dataset-2171131. Available from: https://irma.nps.gov/App/Reference/Profile/2171131 (accessed 7 September 2013).

Swinney, D. 2005. Mount Rainier Wilderness boundary, Mount Rainier National Park, Washington, BND_Wilderness. Unpublished geospatial dataset. Mount Rainier National Park, Tahoma Woods, Washington.

United States Congress. 1988. House. Senate. 100th Congress. 2nd Session. *S.2165*. Washington Park Wilderness Act of 1988. Government Printing Office, Washington, D.C.

United States Forest Service (USFS). 1980-present. Insect and disease aerial survey data. Geospatial dataset. Available from: http://www.fs.usda.gov/detail/r6/forest-grasslandhealth/insects-diseases/?cid=fsbdev2_027393 (accessed 26 July 2013).

Washington Department of Natural Resources (WA DNR). 2007a. NDMPL – Washington State Non-Department of Natural Resources major public lands. Geospatial dataset. Available from: http://fortress.wa.gov/dnr/app1/dataweb/dmmatrix.html (accessed 30 May 2013).

WA DNR. 2007b. CADASTRE.PARCEL - Washington State Department of Natural Resources managed parcels. Geospatial dataset. Available from: http://fortress.wa.gov/dnr/app1/dataweb/dmmatrix.html (accessed 30 May 2013).

Washington Office of Financial Management (WAOFM). 2011. April 1 Population estimates for the State, counties, and cities, 1990 to present. Available from: https://data.wa.gov/Demographics/PopChange/2iv2-857p (accessed 4 September 2013).