National Park Service
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Natural Resource Stewardship and Science

Landsat-based Monitoring of Landscape Dynamics in the North Cascades National Park Service Complex

1985-2009

Natural Resource Data Series NPS/NCCN/NRDS—2013/532

ON THE COVER
Avalanche debris from 2009 event blocks a hiking trail near Dagger Lake, North Cascades National Park Service Complex
Photography by: Chris Lauver

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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 North Cascades National Park Service Complex (NOCA) in 2012 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 NOCA and surrounding areas from 1985 to 2009: Avalanches, Clearing, Development, Fire, Mass Movements, Progressive Defoliation, Riparian, Tree Topplings. 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 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 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.

Approximately 60,000 ha (5.65%) of the study area underwent detectable change at some point during the 25 year period of analysis, affecting about 2% of NOCA and about 7% of the areas outside the park boundary. The annual average area impacted by landscape change within the study area was just over 2000 ha. Within the park boundary, the annual average area undergoing change was about 250 ha.

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

The inter-annual variability in the total area experiencing landscape change was considerable. From 1985 to 2009, the greatest amount of change outside the park boundary occurred in 1986; 2006 and 2007 were also significant. Within the NOCA boundary, 2006 was the year with the greatest change detected followed by 1994 and 2003.

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. Progressive Defoliation events tend to affect large areas of the park and are represented by numerous small events.

Acknowledgments

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The work was funded via Task Agreements P12AC15058 and J8W07100011 through the Cooperative Ecosystem Study Unit Cooperative Agreement H8W07110001. The NCCN Science Learning Network (SLN) provided funding for Western Washington University students to conduct field work through CESU task agreement J8W07110003.

Acronyms

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

BC - British Columbia

CESU - Cooperative Ecosystem Study Unit

CMA - Census Metropolitan Area, Canada

ESRI - Environmental Systems Research Group

DFW - Department of Fish and Wildlife

DNR - Department of Natural Resources

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

MBSNF - Mt. Baker-Snoqualmie National Forest

MMU - minimum mapping unit

NAIP - National Agricultural Imagery Program

NCCN - North Coast and Cascades Network

NOCA - North Cascades National Park Service Complex

NPS - National Park Service

PNW - Pacific Northwest

PWRO - Pacific West Region Office

RF - Random Forests or randomForests

SLN - Science Learning Network

TM - Thematic Mapper

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. 2008). 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 severity 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 provides important and previously lacking knowledge about trends in the size, frequency or severity of these events. This knowledge can be used to improve the manner in which parks allocate funding and maintain existing or locate new park facilities. Results from this monitoring effort will feed into adaptive management strategies for park resources in the face of climate change. 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 (NPScape 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 resulting from an avalanche, clearing, development, fire, mass movement, progressive defoliation, riparian flooding, or tree toppling that are larger than 0.8 ha (2 ac).
- Determine trends in the size, magnitude, location, and spatial distribution of each landscape change category.

Table 1 lists landscape change types of interest to the NCCN that are 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 at North Cascades National Park Service Complex study area.

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 broadleaves.
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.
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, slow downward movements of 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 or 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, generally due to wind but sometimes due to root rot.

This report is the first product from the LDMP. It covers landscape changes which occurred from 1985 to 2009 and establishes baseline conditions for natural and anthropogenic changes both inside and outside North Cascades National Park Service Complex (NOCA, or Park). The next analysis for NOCA is scheduled for 2015, to analyze the 2010-2012 areas of change.

The report provides standard data summaries and maps of landscape changes which occurred inside the study area. Maps provide general overviews of landscape changes for the entire area of analysis, which are presented by year, magnitude or change type. The report presents the results by year, change type, and land ownership.

Study Area

The North Cascades 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. The boundary was slightly expanded in certain areas, including into British Columbia (BC) to include entire watersheds in the study area. 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 northwest and southeast corners in order to accommodate the geometry of the available Landsat imagery. The resulting area contains 1,043,453 ha of land and water, about 26% of which (275,694 ha) are inside the park boundary.

Figure 1. North Cascades National Park Service Complex 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 26% of the study area, NOCA was established in 1968 and is composed of three units: north and south sections of the North Cascades National Park, Ross Lake Recreational Area and Lake Chelan Recreational Area (Figure 1, Braaten 2005). Ninety three percent of the Park is Congressionally-designated wilderness (Figure 2, Braaten 2012). There are three significant hydroelectric dams (Ross, Diablo and Gorge) located within the Park.

Of the remaining study area, 24% is wilderness managed by the United States Forest Service (USFS) (Table 2, MBSNF 2004). Due to similar wilderness management requirements, the characteristics of change within the USFS wilderness should generally mirror those found within the NOCA boundary. The USFS also manages the third greatest area within the study area - these are non-wilderness areas within the Okanagan-Wenatchee and Mount Baker-Snoqualmie National Forests.

Table 2. Area and percent of total area contributed by various land management categories within the North Cascades National Park Service Complex study area.

Land Manager	Area (ha)	% of Area
BC Parks	96867	9.28
NPS-NOCA Complex	275694	26.42
US Forest Service	181226	17.37
US Forest Service - Wilderness	254585	24.40
Washington State DFW	529	0.05
Washington State DNR	15147	1.45
Washington State Parks	179	0.02
Seattle City Light	5225	0.50
All Other - BC	156369	14.99
All Other - US	57631	5.52

The Washington State lands managed by Parks and Recreation Commission, Department of Fish and Wildlife (DFW) and the Department of Natural Resources (DNR) comprise approximately 2% of the study area (WA DNR 2007a and 2007b). While all three categories of state lands are managed for recreational opportunities, DNR lands are primarily managed for timber harvest.

The "All-Other" category on both sides of the border includes privately held lands, which are subject to a large variety of uses, including timber management, mining, urban and rural development, and agriculture. In BC, the "All Other" category also includes Provincial and Federal Crown Lands managed by the BC Ministry of Forests, Lands and Natural Resource Operations for a variety of uses. The boundaries for the Crown Lands were not readily available for the purposes of this analysis.

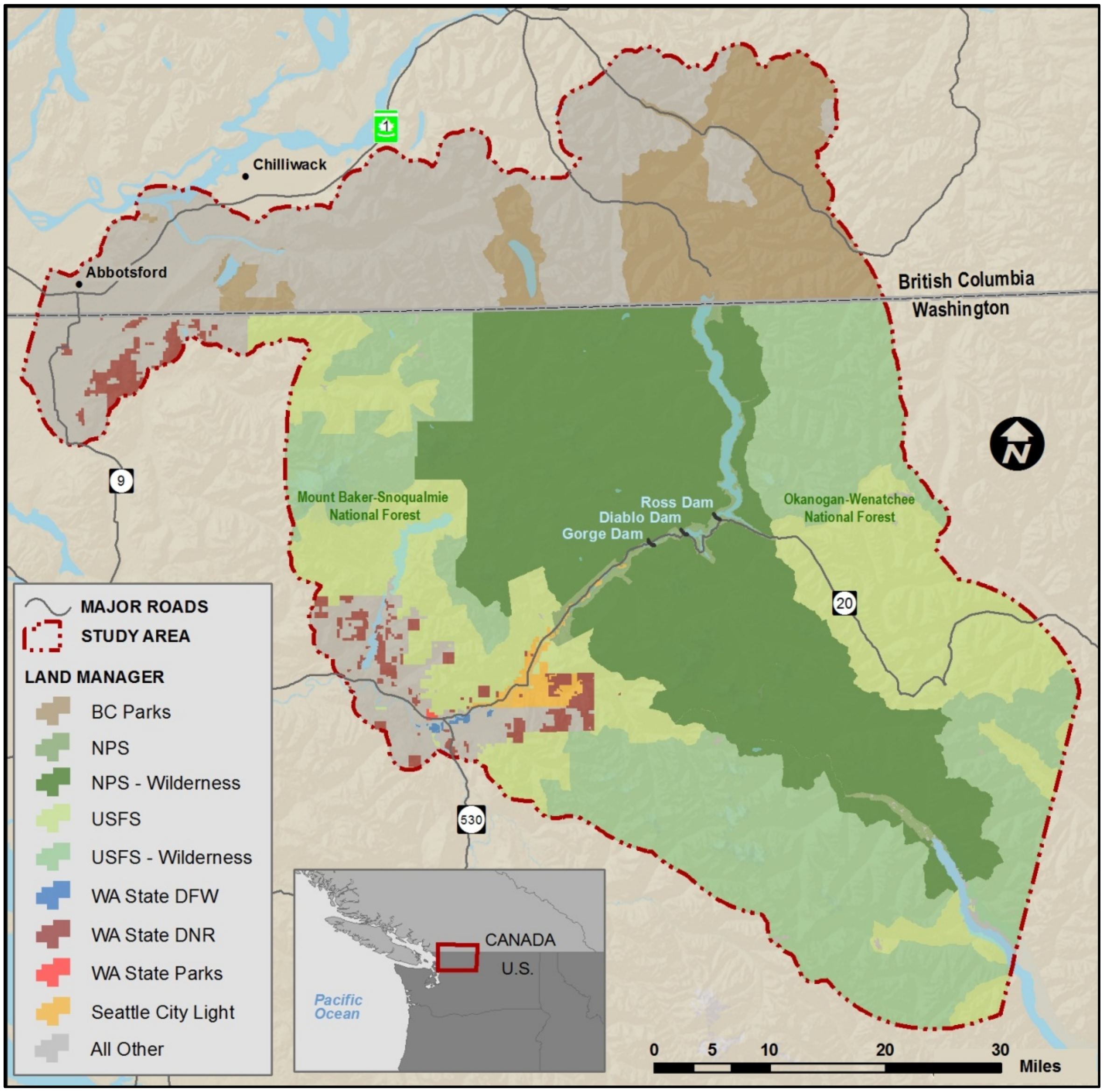

Figure 2. Land management categories within the North Cascades National Park Service Complex study area.

To the north of the NOCA boundary, BC Park lands occupy 9% of the study area and include 15 separate parks (BC 2003). Of the 15 parks, seven are Ecological Reserves, which are "areas most highly protected and least subject to human influence" (BC Parks 2011). All extractive activities are prohibited in these areas. Two of the parks, Cascade Falls and Sumas Mountain, are Regional parks and are managed primarily for recreational opportunities (Fraser Valley Regional District 2008). Five of the parks, including E.C. Manning, Skagit Valley, Chilliwack River, Cultus Lake, and Chilliwack Lake, are designated as "Class A" Provincial Parks. Class A designation prohibits any commercial logging, mining or hydroelectric development, but might allow for grazing, hay cutting and other uses that existed before the park was established. The remaining area is the Cascade-Sutslem Conservancy, which is Crown Land designated as a protected area that recognizes its importance to First Nations for social, ceremonial and cultural uses. Conservancy areas provide for a wider range of low impact commercial activity than a Class A park. However, commercial logging, mining and hydroelectric power generation, other than local run-of-the-river projects, are prohibited (BC Parks 2011).

Study Area: Urban Centers

The majority of the NOCA study area is sparsely populated, with the exception of the Chilliwack Valley north of park boundary and areas to the northwest, which have a number of urban communities in the greater Vancouver area, as well as agricultural communities and uses (Figure 3). Most of the communities within the study area only have populations between 2,500 and 100,000 people, but their cumulative impact on the land can be significant. The State Highway 20 corridor along Skagit River features a number of small communities. Seattle City Light, which operates hydroelectric facilities within the Ross Lake National Recreational Area, maintains the communities of Newhalem and Diablo for its employees. The community of Stehekin within the Lake Chelan Recreational Area has a mixture of private and NPS lands. Outside of the study area, development is concentrated along Trans-Canada Highway 1 in BC and Interstate 5 in the US, as well as state highway corridors.

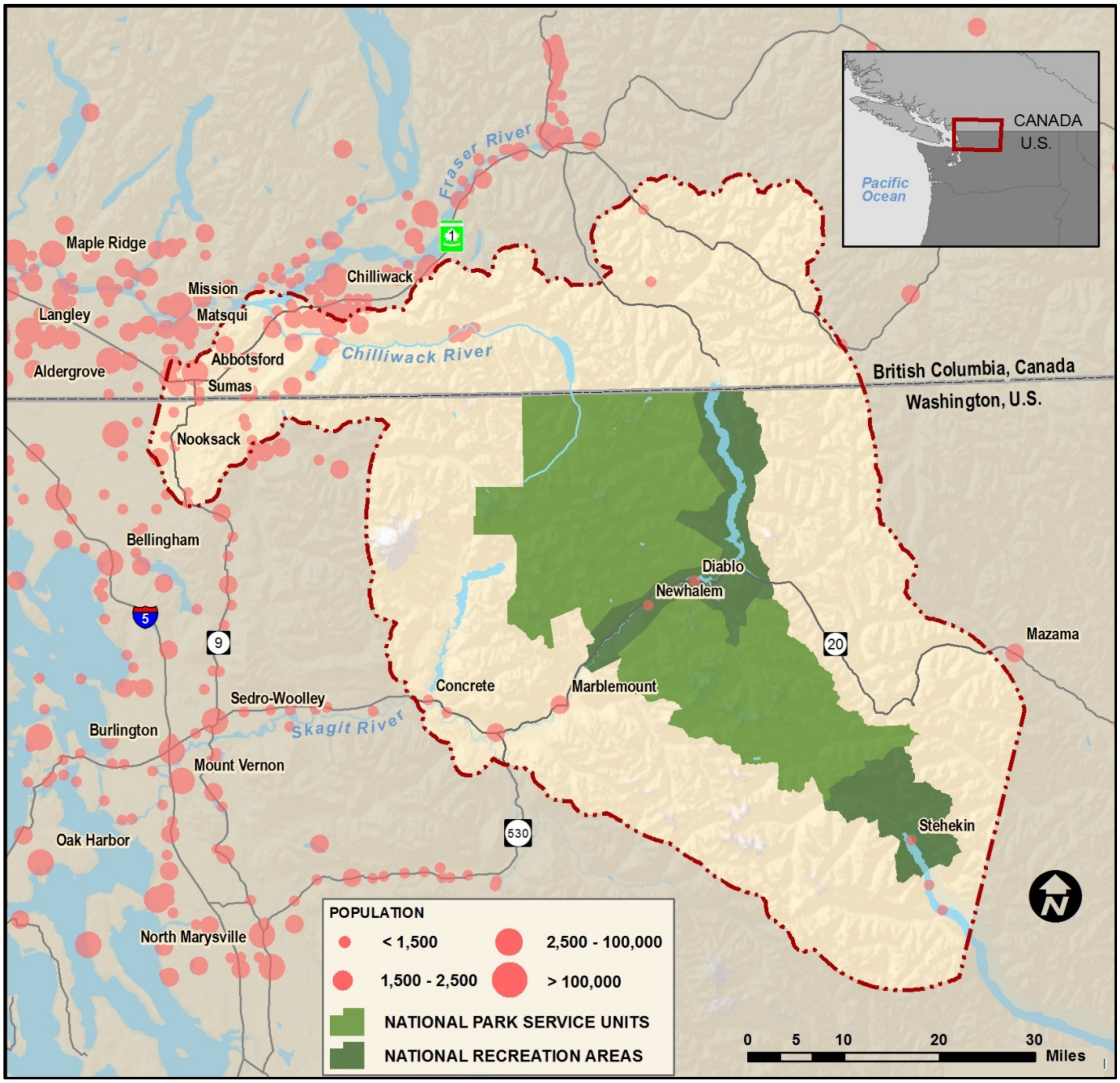

Figure 3. Population centers within and around the study area (Tele Atlas North America, 2009).

Methods

The methods used to detect the 1985-2009 NOCA 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 field and 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 4626 is shown in Figure 4.

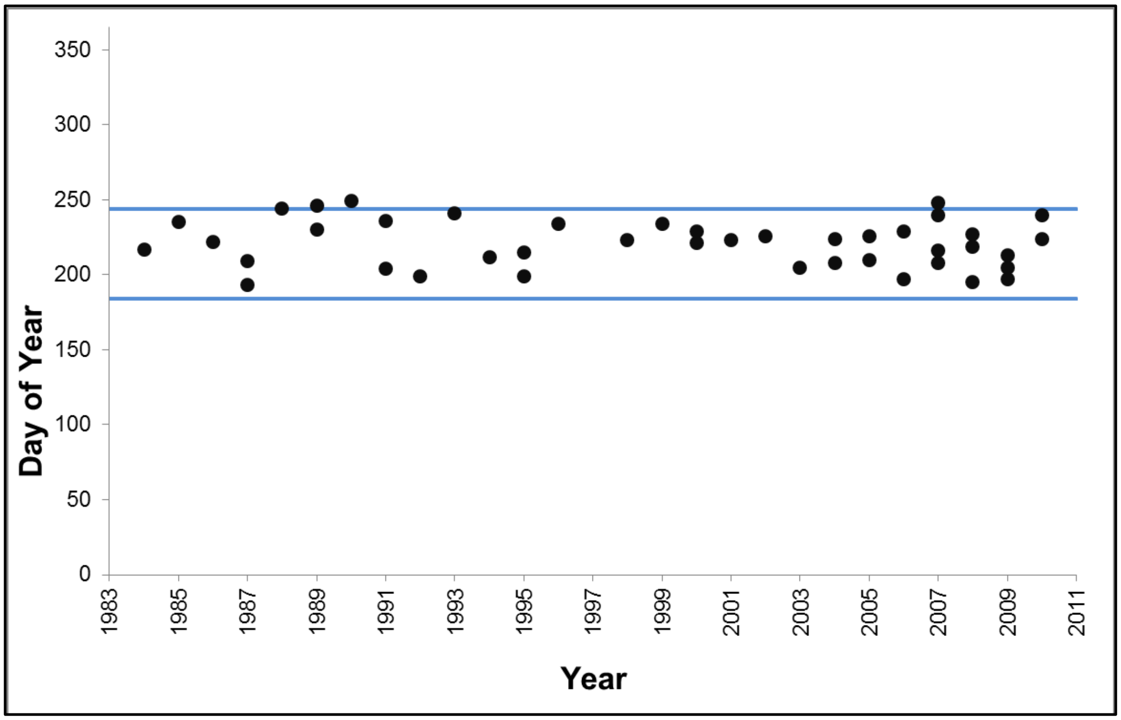

Figure 4. Day and year of Landsat images used for analysis for the scene 4626, with blue lines denoting the time period between July 1st and September 1st.

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 30x30 meter 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. most severe event.

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

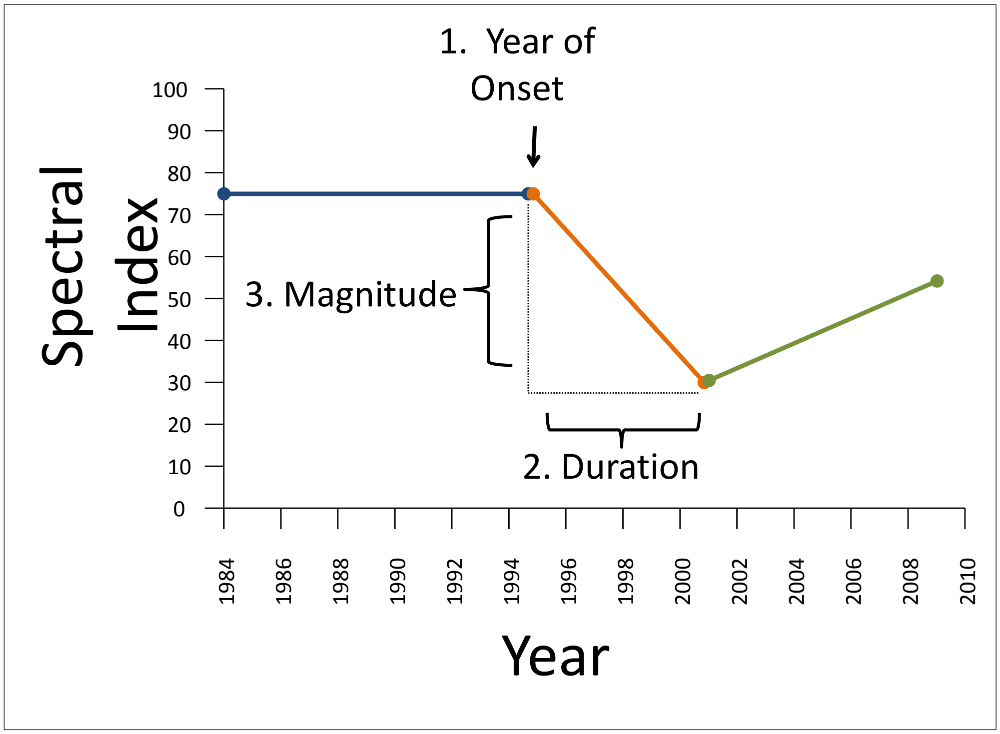

Figure 5. An idealized LandTrendr trajectory tracing a Landsat pixel through periods of stability, change and recovery. The period from 1984 to 1994 is a stable segment (blue line). A change event begins in 1994 (1) and lasts until 2001 (2), causing a drop of 45 spectral units (3). The change is followed 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 dataset only includes pixels that experienced rapid change occurring over a period of less than 4 years. The remaining 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 the patch shapes, 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 other landscape change within the NOCA 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 Mass Movements, to more subtle effects on forest canopy such as insect infestations, to smaller changes due to anthropogenic activities such as road construction.

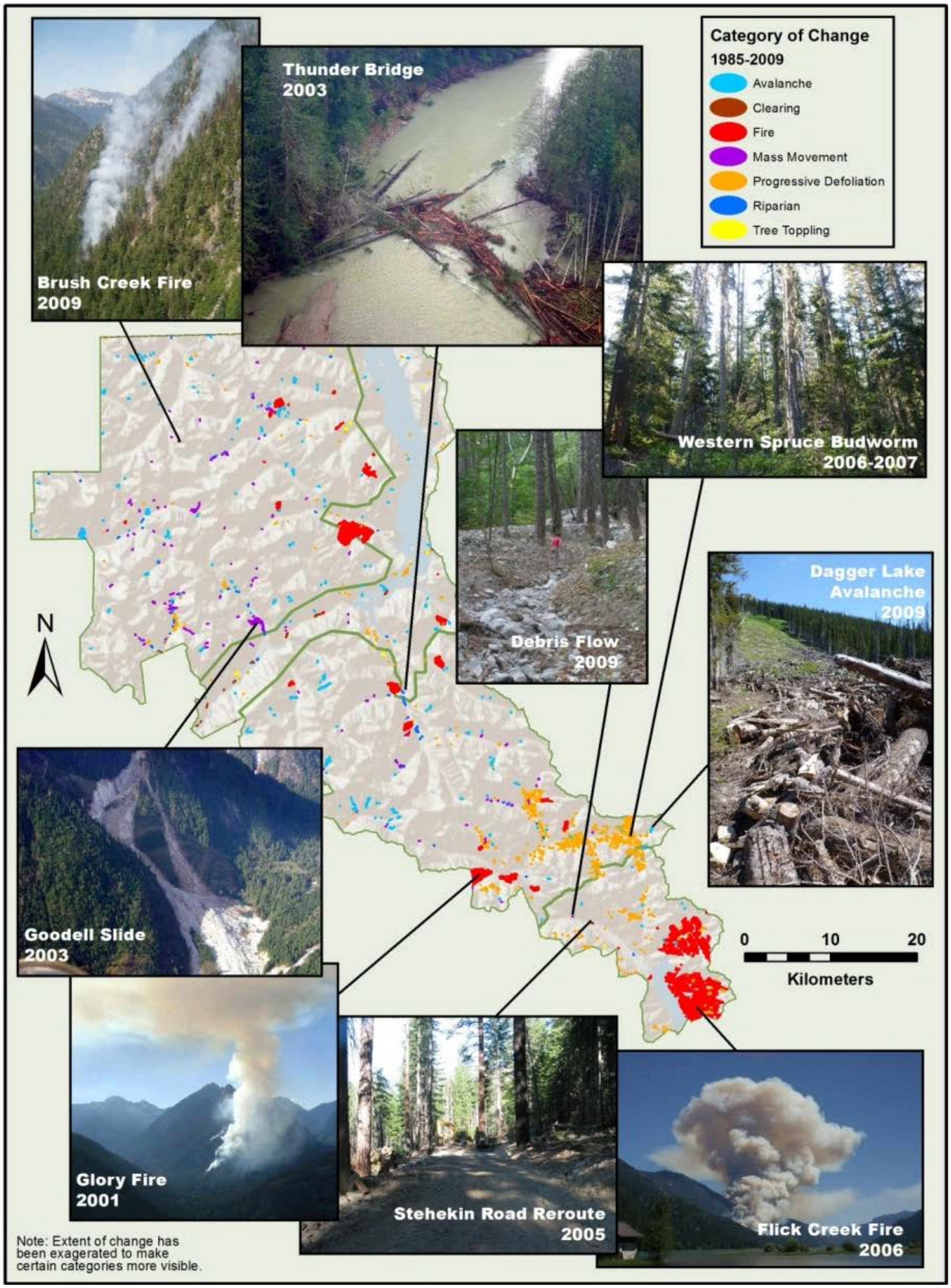

Figure 6. Examples of landscape changes documented within the North Cascades National Park Service Complex boundaries from 1985 to 2009.

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 interpreting the results provided below.

Annual Variability

The Annual Variability category is used to categorize landscape changes that are 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. To validate Fire patches within the park boundaries, we used data from the Pacific West Region Fire Program (M. Grupe, GIS Specialist, PWRO Fire Program, pers. comm., 2011).

Mass Movement

The Mass Movement category includes landslides as well as debris flows. 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 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. This threshold was based on the definition of a debris cone where debris flows usually originate (Ministry of Crown Lands Province of British Columbia 1997). The threshold was used in the development of the sample for the RandomForests classification model (see below). Patches classified by the model as Mass Movements will not necessarily have an average slope of 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 good Landsat images are not available due to cloud cover or the areas where the event occurred were 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, if an avalanche occurred in December 2010, LandTrendr would detect the disturbance in the July 2011 Landsat imagery and label the polygon with a year of onset of 2011. 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
RandomForests (RF) is an ensemble classification method that expands the relatively simple concept of classification and regression trees. The RF classification grows many such trees. To grow each tree, RF first takes a random subset of the training data. As RF grows each tree, it uses a random subset of two thirds of the predictor variables for each split or decision node. The outcome of growing a forest of trees is a single prediction- the tree which occurs with the most frequency represents the best classification model. The data held in reserve can 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 469 patches was used as training data to generate a RandomForests (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 RandomForest classification model. We performed this second type of validation using two methods. First, we performed validation in the office using multi-date aerial photography in Google Earth in conjunction with the TimeSync application. Table 3 indicates the imagery date and source available in Google Earth for validation.

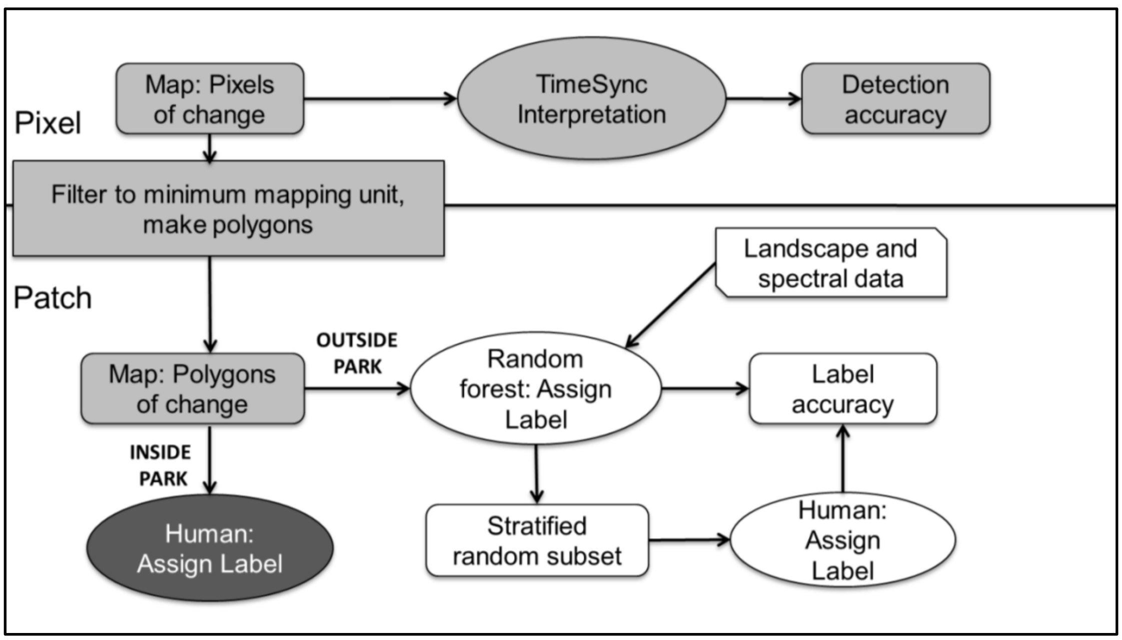

Figure 7. Steps in the validation process.

Table 3. Google Earth image sources for validation of change. All imagery is 1-meter resolution, with 1990 and 1998 in black and white and the remainder in color.

Date	Coverage	Image Source
Aug-1990	Washington State - partial	National Aeronautics Space Administration/ United States Geological Survey
Jul-1998	Washington State - partial	United States Geological Survey
Aug-2004	British Columbia-partial	Integrated Mapping Technologies
Aug-2005	British Columbia-partial	Province of British Columbia
Apr-2006	Washington State	United States Geological Survey
Aug-2006	Washington State	United States Geological Survey
Sep-2009	Washington State	United States Department of Agriculture – Farm Service Agency
Aug-2011	Washington State	United States Department of Agriculture – Farm Service Agency
Nov-2011	Washington State	United States Department of Agriculture – Farm Service Agency

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. During office validation, we assessed 2069 randomly selected change patches, representing approximately 10% of patches found inside and 20% of patches found outside the park boundary. 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, and soil moisture. 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 needed to label 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 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.

Second, we performed a field-based validation on a subset of 320 patches. Field visits were conducted in August of 2011 and included the following general areas of NOCA and surrounding areas: Bridge Creek drainage, areas along Devil’s Dome loop trail, areas along Highway 20, Cascade River Road and Ross Lake, and Stehekin Valley and adjacent trails. Field work was impeded by high snow levels, resulting in a non-random sample with limited geographic extent. We compared lab and field-generated labels to each other and field-and RF-generated labels and calculated the overall and class error rates and Kappa statistic. These results are presented in detail in Antonova et al. (2011) and are not presented in this report.

Comparing the field and office-based validation results, we found that the office approach was a more robust validation method for two reasons: 1) 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 could sometimes 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. Based on this assessment, we modified the patch-level validation methods to include procedures shown in Figure 7. We labeled and validated all patches found inside the park boundary using the office method and used the RF classification to label the remainder of patches outside the park boundary. In the future, validation methods will include field visits to a stratified random subset of patches, described in the LDMP, to supplement the office validation.

Results

A total of 13,687 patches were mapped within the North Cascades National Park study area from 1984 to 2009. Of these patches, 2,247 (16%) and 1515 (11%) were classified as Annual Variability and Agriculture respectively. These patches are excluded from the data summary below.

Total Area Affected by Landscape Change

Approximately 60,000 ha (5.65%) 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 2% of NOCA and about 7% (0.28%/year) of the areas outside the park boundary. The annual average area affected by landscape change within the study area was 2383 ±290 ha. Within the park boundary, the annual average area undergoing change was 290 ha ±424 ha. Rate of landscape change on an annual basis was 0.08% in the park and 0.28% outside the park boundary.

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 8). The greatest amount of change outside the park boundary was documented in 1986, when 4400 ha had some portion of vegetative cover removed; 2006 and 2007 were also significant years for landscape change outside the boundary. Within the NOCA boundary, 2006 was the year with the greatest change detected with 1688 ha. The second and third greatest years of change within the park were 1994 and 2003 with 778 and 759 ha, respectively.

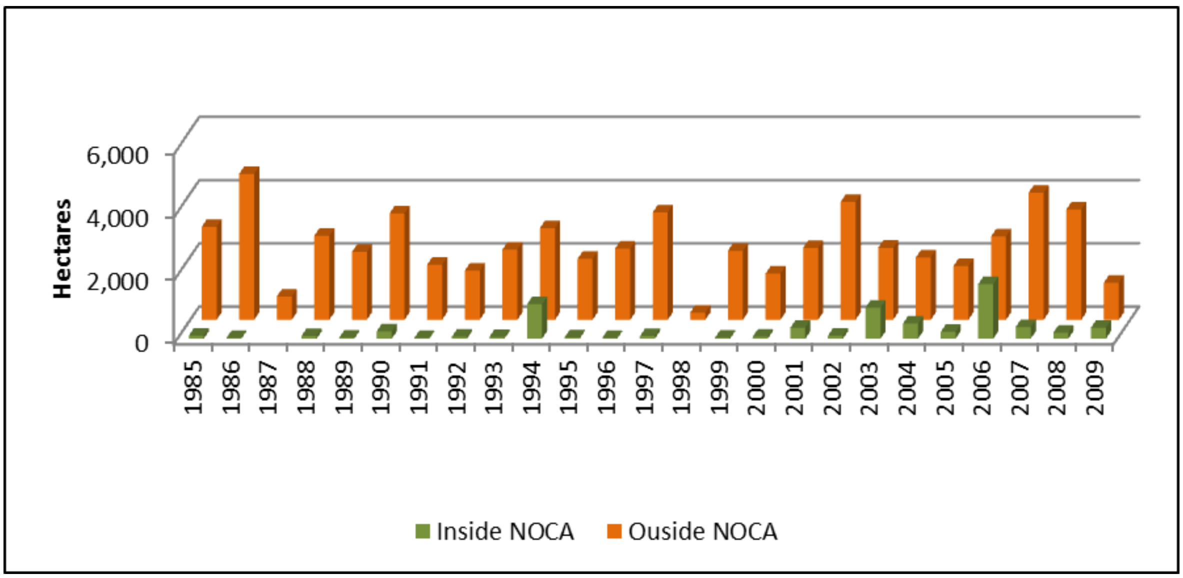

Figure 8. Total area disturbed within the North Cascades National Park Service Complex study area by year, separated by inside and outside the park boundary. Changes labeled as Annual Variability or Agriculture are not included.

A map of the year of onset shows the timing of disturbances across the study area (Figure 9). On the west side, an even distribution of changes is evident 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 northwest corner of the study area (Chilliwack Valley), and the large change patches in the southeastern part of the study area. The contrast between larger single-date events and the more consistently occurring smaller events suggests that change type must be driving this pattern.

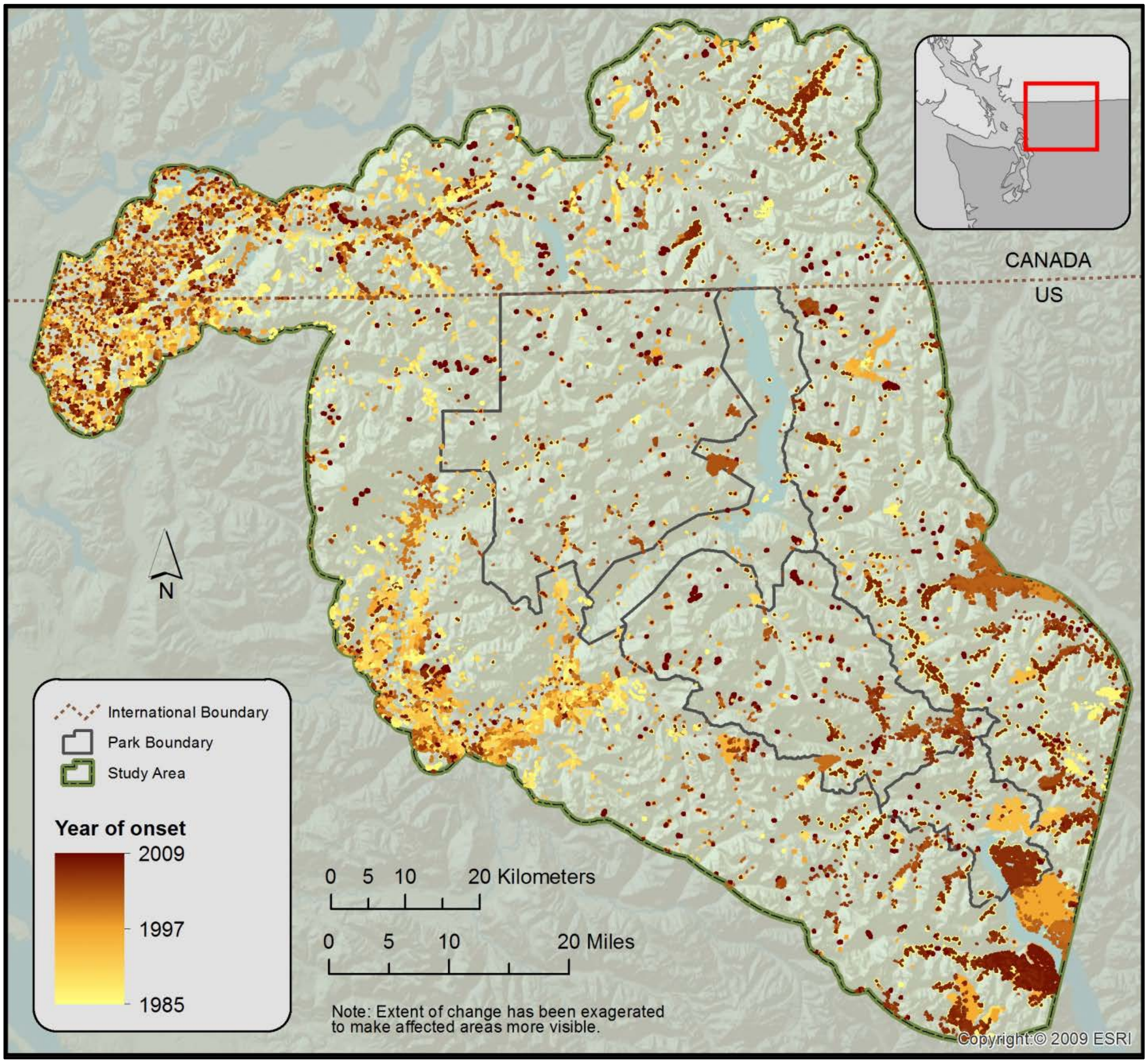

Figure 9. Map of North Cascades National Park Service Complex study area showing landscape changes from 1985 to 2009 by year of onset.

Type of Landscape Change

Within the entire study area, Clearing has caused the greatest total change over the last 25 years. Fire has also played a significant role in altering the landscape during this time. Inside NOCA, Fire was the predominant agent of landscape change. Progressive Defoliation and Avalanches were also important agents of change within the park (Table 4).

Table 4. Area (ha) affected by each disturbance type inside and outside the North Cascades National Park Service Complex boundary from 1985 to 2009. Agriculture and Annual Variability classes not included.

Type	Study Area	% Study Area	Inside NOCA	% NOCA	Outside NOCA	% Outside NOCA
Avalanche	1772.2	0.17	579.3	0.21	1192.9	0.16
Clearing	27830.4	2.67	26.2	0.01	27804.2	3.62
Development	2454.7	0.24	3.4	0.00	2451.3	0.32
Fire	20193.5	1.94	3656.8	1.33	16536.7	2.15
Mass Movement	372.2	0.04	270.8	0.10	101.3	0.01
Progressive Defoliation	5808.8	0.56	1053.6	0.38	4755.2	0.62
Riparian	507.9	0.05	79.3	0.03	428.6	0.06
Tree Toppling	230.2	0.02	26.4	0.01	203.8	0.03
Grand Total	**59169.8**	**5.69**	**5695.8**	**2.07**	**53474.0**	**6.97**

We mapped landscape change by type, which further illustrated the spatial segregation of change types within the study area (Figure 10). Changes due to Fire and Progressive Defoliation are aggregated to the south and east side of the study area. Clearing and Development activities dominate the change types found to the west and the northwest of the park, particularly along Skagit and Chilliwack Rivers, near the urban centers outside Vancouver, BC, and along the Highway 9 corridor near the towns of Sumas and Nooksack. Riparian changes are visible along large rivers, including Skagit, Baker and Nooksack Rivers on the US side and Chilliwack River in BC. Three patches were detected in British Columbia that could not be assigned a change type due to lack of imagery and for which the RF classification label did not make sense. These patches were assigned an “Unknown” category and will be revisited when more Canadian imagery becomes available in Google Earth.

The small extent of Clearings in the park (26.2 ha) were caused by clearing of the power line corridor along Highway 20, road construction projects in Stehekin Valley following the 2004 flood events, and border swath clearing along the Canadian border in the late 2000’s. The two Development patches detected within the park boundary equal 3.4 ha and are located in the Newhalem area and are associated with permanent clearings for lawns along Highway 20 around year 2000 and the construction of the Newhalem Visitor Center and associated facilities in the early 1990’s. Tree Toppling events were rare inside the park boundary, covering 26.4 ha and mostly located on the west side of the Cascade Crest. The total area of Riparian change detected inside the park boundary (79.3 ha) was lower than might be expected, as explained in the **Methods: Change Type Characteristics**. In contrast, Mass Movements were more readily detected, with 270.8 ha mapped within the park boundary.

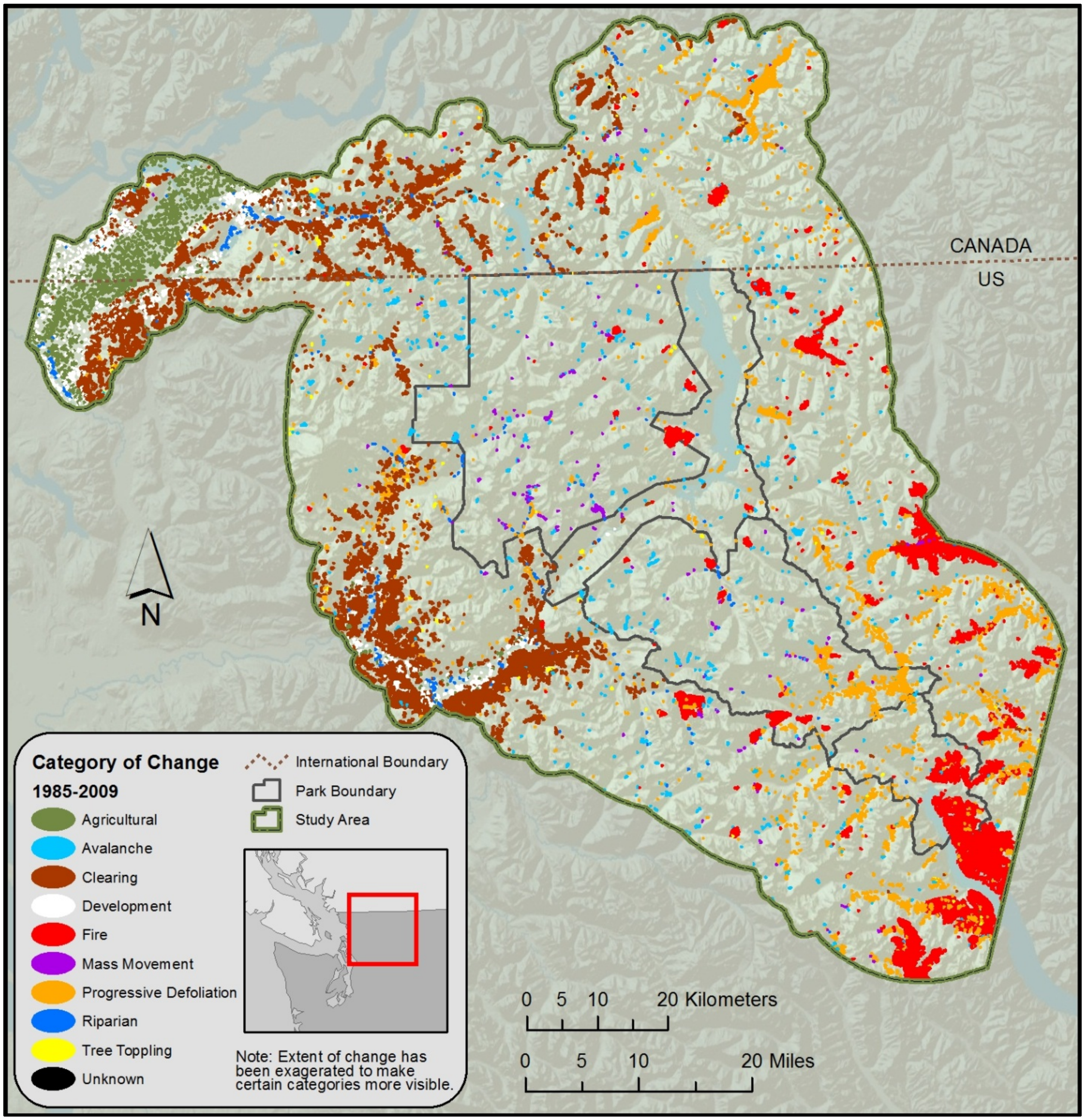

Figure 10. Map of North Cascades National Park Service Complex study area showing landscape changes from 1985 to 2009 by change type.

Trends in Landscape Change Types

Although Clearing has contributed the majority of change from 1985 to the present outside the park boundary, its role as an agent of change decreased considerably over the last decade (Figure 11). In contrast, the contribution of Progressive Defoliation to total change has increased in recent years, particularly during the period from 2003 to a peak value in 2007. Large fires were episodic, with 1997, 2002 and 2008 being the years with the largest change due to Fire. Avalanche exceeded any other change category in 2009.

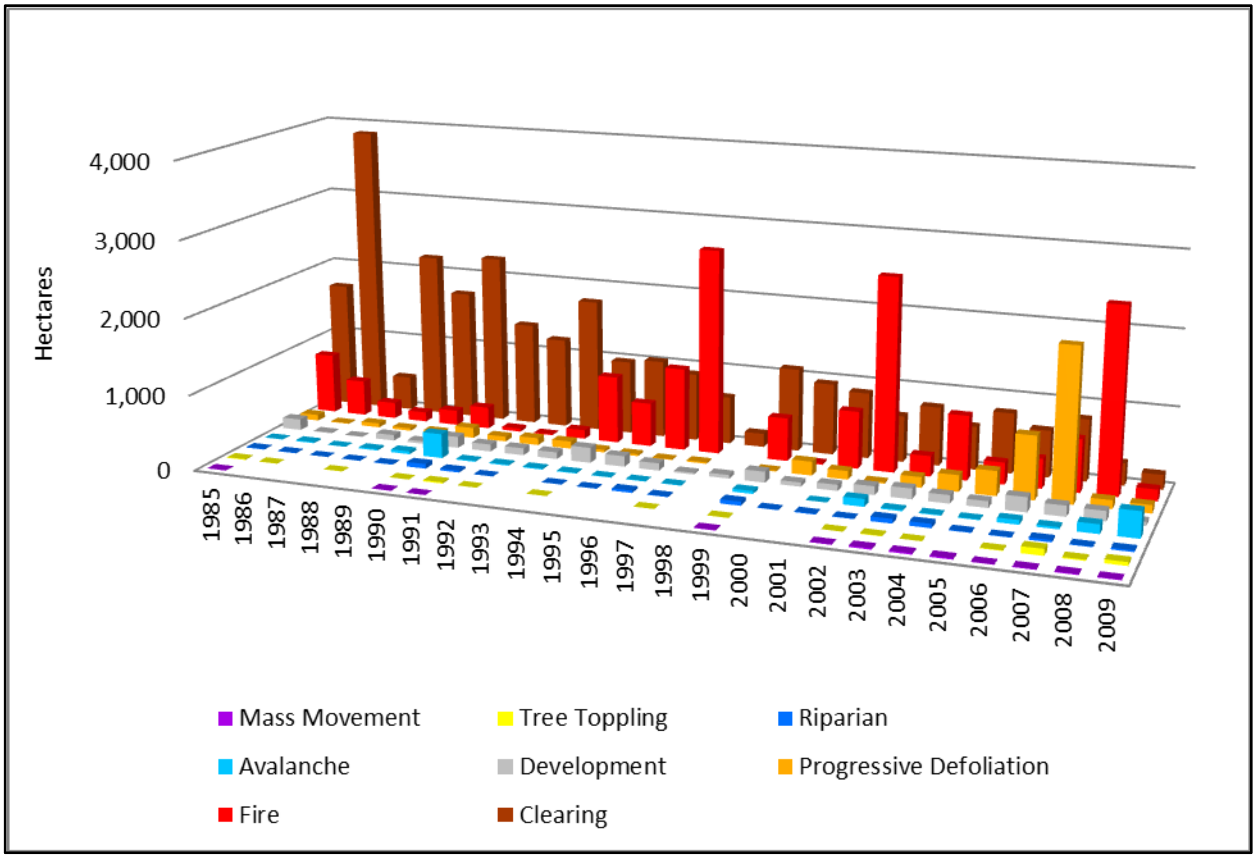

Figure 11. Time series of area disturbed outside the North Cascades National Park Service Complex boundary by change category.

Within the park, Fire contributes the majority of the disturbed area in most of the years with above-average hectares changed (Figure 12). In the later part of the time series, Avalanches, Progressive Defoliation, or Mass-Movements contributed more than average to the total landscape area changed. Years with considerable Avalanches were 1990, 2008 and 2009 (years represent the year of the summer following the winter in which the avalanches would have occurred). Mass Movements and Riparian changes contributed significantly to total changed area in 2004. Similarly to outside the park, the mid-2000's saw an uptick in areas affected by Progressive Defoliation. The years with more area changed due to Progressive Defoliation and Fires were the years in which the area affected by Avalanche was low.

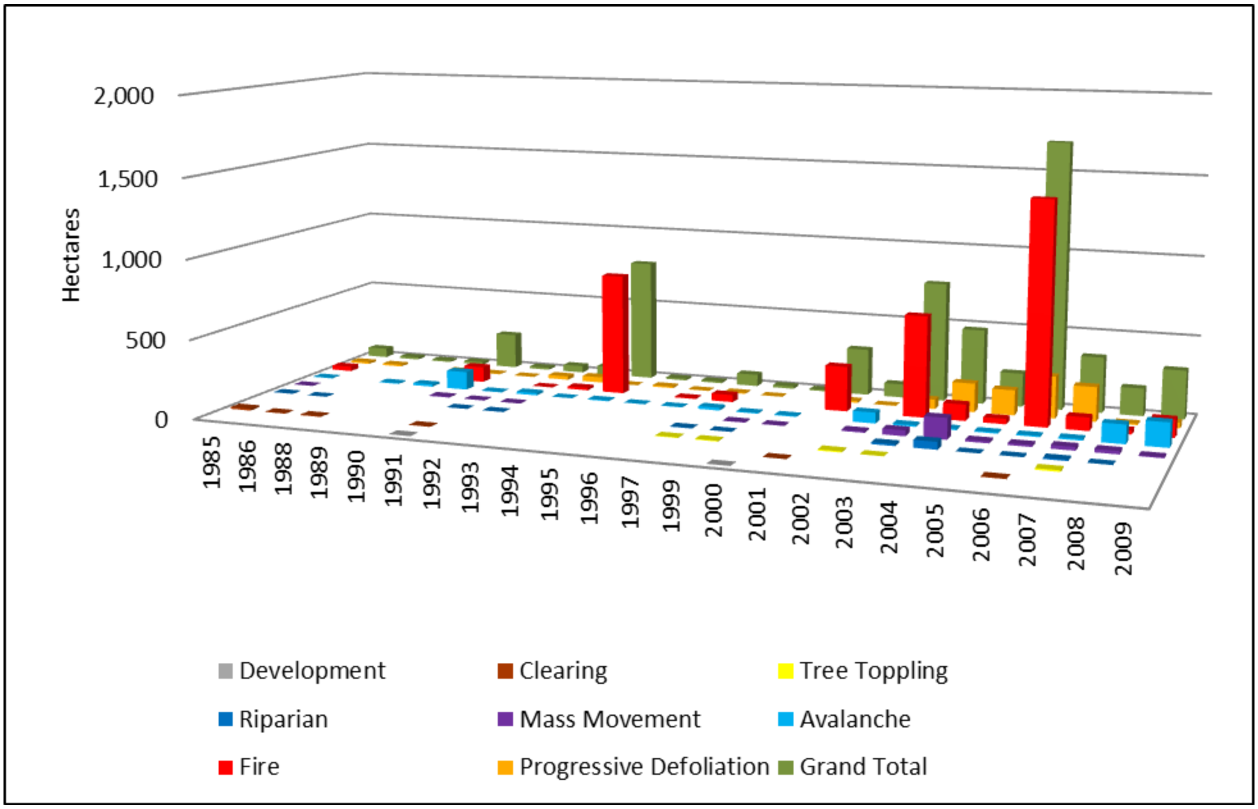

Figure 12. Time series of area disturbed within the North Cascades National Park Service Complex boundary by change category.

Characteristics of Landscape Changes

Number of Patches

An analysis of the number of change patches that occur each year was performed. The number of landscape change patches occurring in the study area during the time of analysis is presented in Table 5.

For outside the park boundary, the number of patches followed the same pattern as the total area. We detected 3,802 patches in the Clearing category within the study area, which had by far the largest number of patches (Table 5). Progressive Defoliation, with 2181 patches, was the second highest category within the study area, followed by Development with 754 patches and Fire with 819 patches. The Tree Toppling category had the lowest number of patches.

Within the park boundary, Progressive Defoliation was the most frequently occurring category with 544 patches detected between 1985 and 2009 (Table 5 and Figure 13). Avalanches were the next most frequent category with 250 patches detected, followed by Fire with 224 patches and Mass Movement with 133 patches.

Table 5. The number of patches[1] inside and outside North Cascades National Park Service Complex boundary from 1985 to 2009. Outside NOCA totals do not include three patches in the Unknown category.

Type	Study Area	Inside NOCA	Outside NOCA
Avalanche	754	250	504
Clearing	3802	13	3789
Development	931	2	929
Fire	1043	224	819
Mass Movement	197	133	64
Progressive Defoliation	2725	544	2181
Riparian	362	55	307
Tree Toppling	108	11	97
Grand Total	9922	1232	8690

[1] A single patch does not represent a single event. For example, 224 Fire patches inside the park boundary comprise about 29 individual fires.

The number of patches detected annually within the study area is shown in Figure 13. The year with the greatest number of patches was 2007, mostly consisting of Progressive Defoliation and Fire, followed by 2006, 2003, 1985 and 1990 when other categories were also prevalent. In general, some Avalanches and Fires occur every year, whereas patches within categories such as Mass Movement and Tree Toppling tend to occur intermittently. We found 2007 to be the biggest year for windthrow patches, 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).

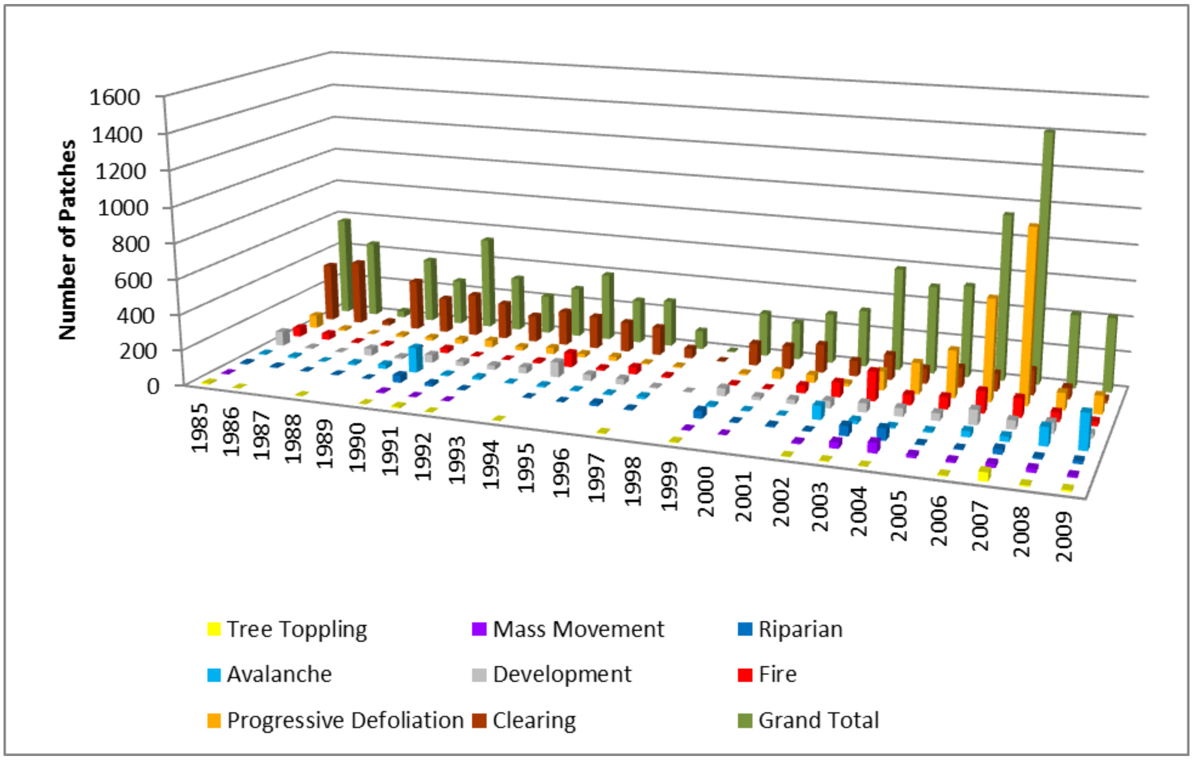

Figure 13. Number of landscape change patches inside the North Cascades National Park Service Complex study area by year and type.

Size and Severity of Landscape Changes

The median change patch size detected was 1.53 ha. Mass Movement, Progressive Defoliation and Riparian patches had the smallest median patch size, with Riparian changes also having the smallest variance (Figure 14), likely due to the linear nature of the events and the tendency by LandTrendr to separate single events into multiple patches. All landscape change categories had a large number of outliers with numerous patches being significantly larger than the median size. Clearing category had the largest median patch size of 2.43 ha, followed by Fire with median patch size of 2 ha. The largest patch was 2592 ha and was associated with 2001 Rex Creek fire on the east side of Lake Chelan.

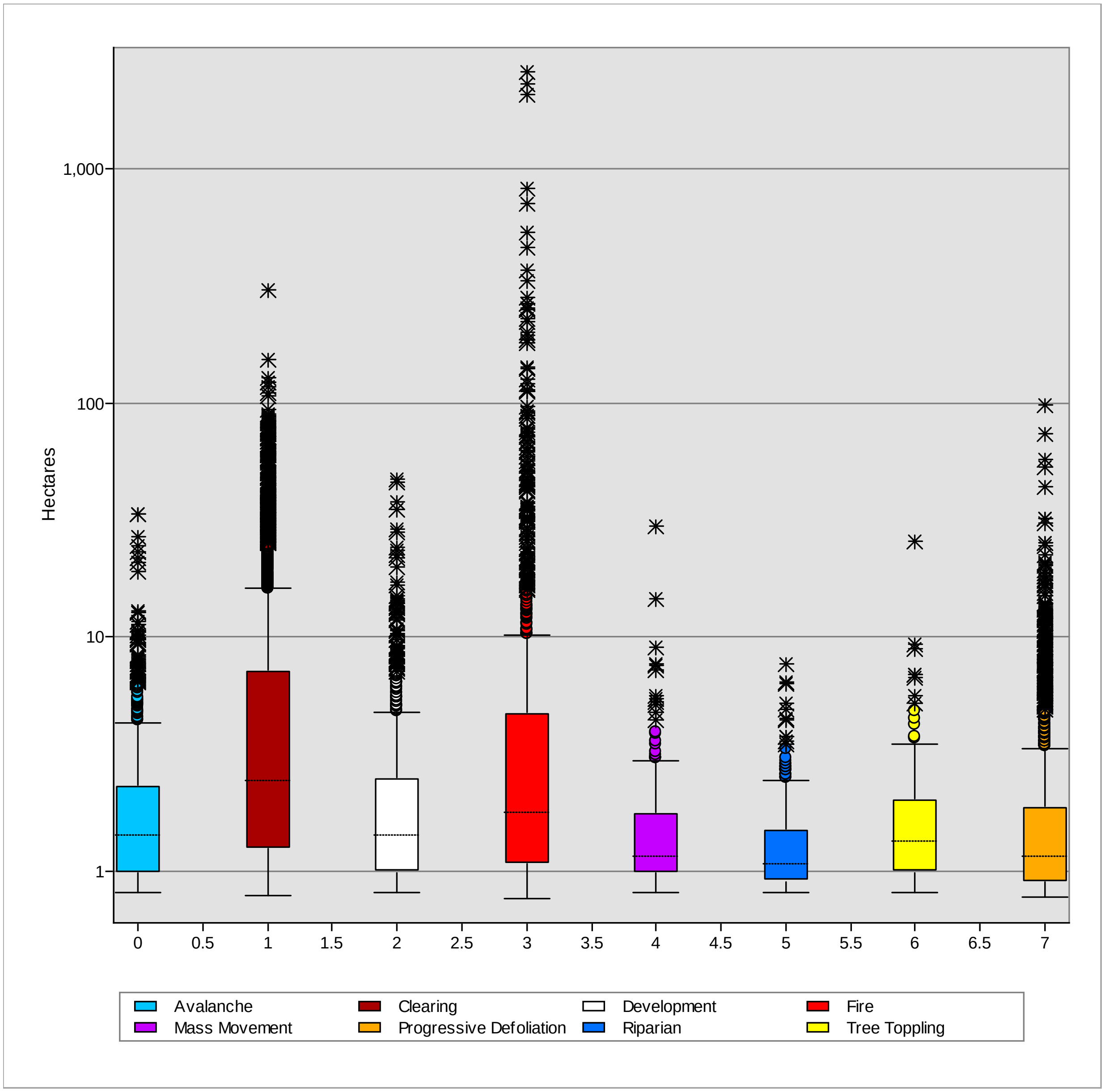

Figure 14. Patch size by change category within the North Cascades National Park Service Complex study area. Note that multiple patches can belong to same landscape change events. Dashed lines represent median, boxes represent quartiles, whiskers are 1.5 interquartile range.

A comparison of Figures 13 and 14 highlights the different characteristics of the landscape change categories. Avalanches, 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 areas of the park (Table 5) and is represented by numerous small patches.

The largest Progressive Defoliation patches within the study area were found in the Skaist River drainage in British Columbia, Canada. Inside the park boundary, the largest patches were found within the Bridge Creek drainage, the area that has been heavily damaged by the western spruce budworm (*Choristoneura occidentalis*) in 2006 and 2007. The largest five Avalanche patches by size inside the park boundary were all from 2008 and 2009 and were distributed throughout the park.

Figure 15 shows the patterns of severity expressed as percent vegetation cover removed, or magnitude. The large Fires are the events with the greatest percent vegetation cover removed.

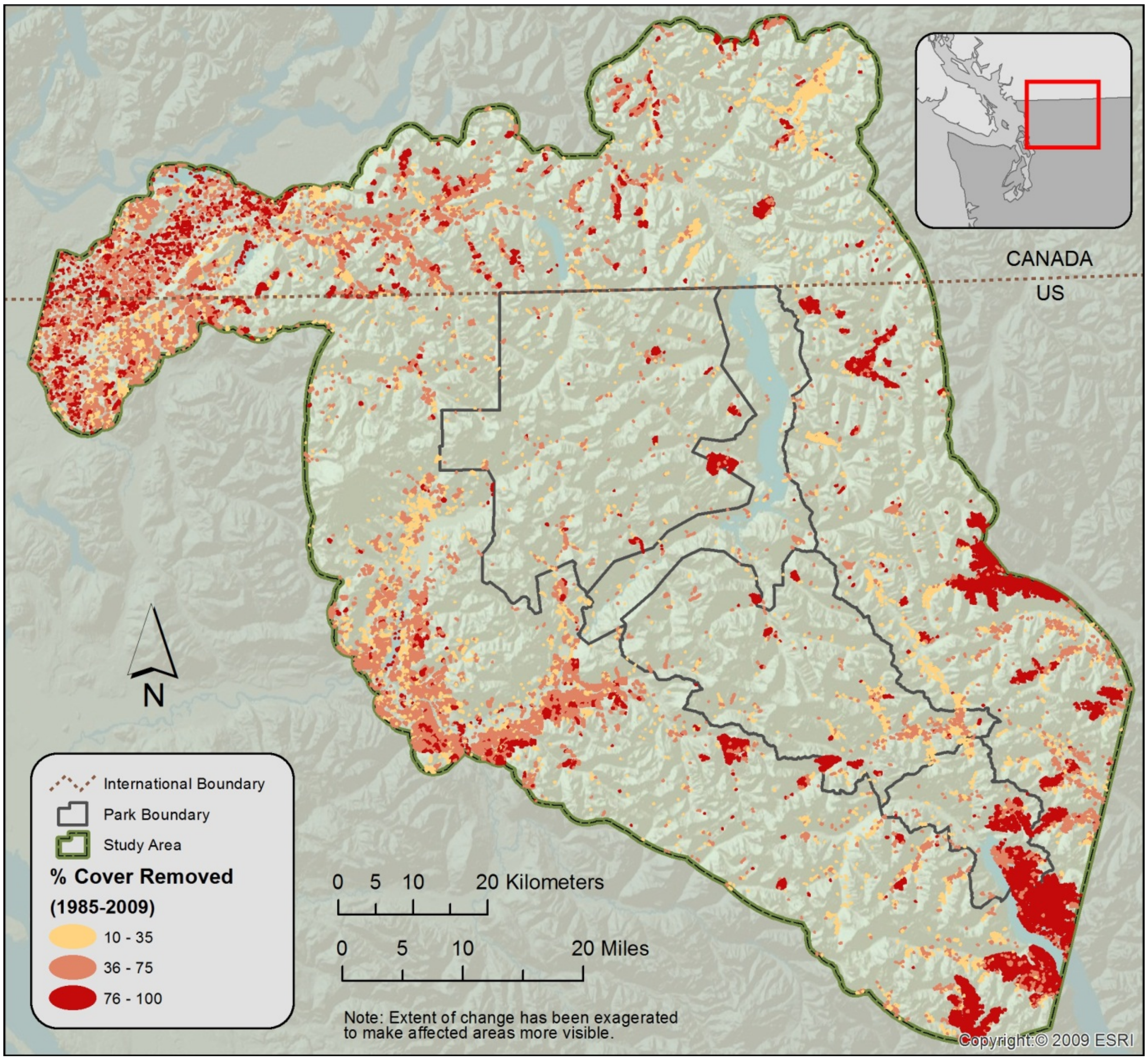

Figure 15. Map of North Cascades National Park Service Complex study area showing landscape changes from 1985 to 2009 by percent vegetation cover removed.

All change types show a wide range of severity (Figure 16). Fires are consistently the most severe change agent. The outliers with lesser percent vegetation cover removed in the Fire category can be attributed to patches that were on the edges of fire perimeter and were not damaged as heavily as other vegetation. LandTrendr usually did not detect this damage until a year or two following the fire.

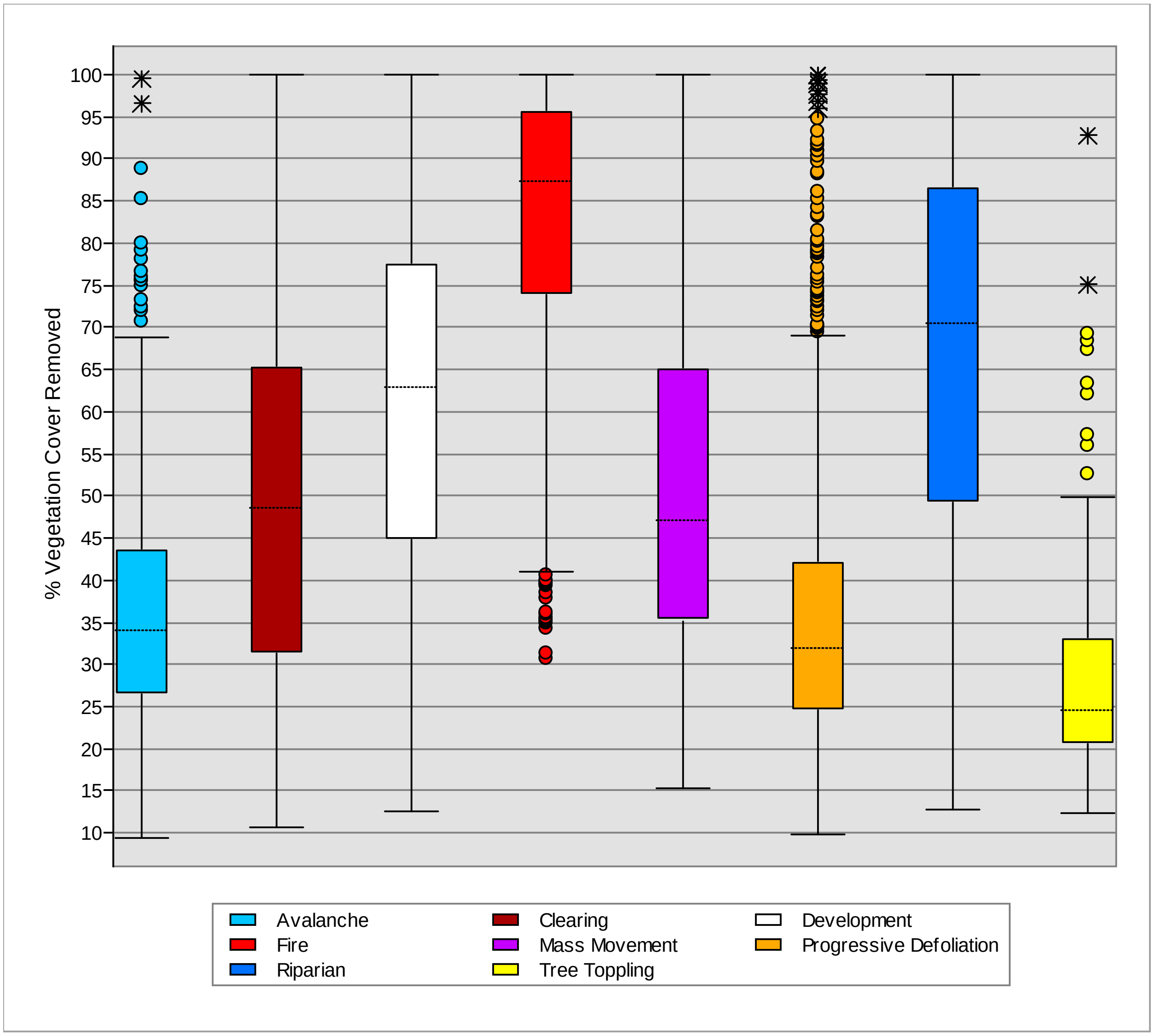

Figure 16. Percent vegetation cover removed by change category within the North Cascades National Park Service Complex study area. Dashed lines represent median, boxes represent quartiles, whiskers are 1.5 interquartile range.

Progressive Defoliation shows the majority of patches with below 70% vegetation cover removed and a large number of outliers with higher values. The Progressive Defoliation patches with the highest percent of cover removed were found within the boundaries of the 2006 Flick Creek Fire near the community of Stehekin. These Progressive Defoliation patches were mostly dated from a year or two before the fire, suggesting that the vegetation was severely damaged prior to the fire. A high rate of damage was also detected in the Bridge Creek drainage. In contrast, patches within the Avalanche and Tree Toppling categories weighted towards lower values of percent cover removed.

The relationship between patch size and percent vegetation cover removed for change categories within the study area is demonstrated in Figure 17. The Fire category had the largest and most severe events. The rest of the change categories had similar average patch size, but differed in severity. Development, Mass Movements and Riparian changes removed the most canopy, while Tree Toppling events had moderate effect on canopy removal. Avalanche and Progressive Defoliation patches were characterized by moderate (ca. 35%) amounts of canopy removal.

As with Progressive Defoliation, the largest Avalanches patches did not have the greatest severity. The five largest Avalanche patches within the park boundary had a range of percent vegetation cover removed between 38 and 50%. The five Avalanches with greatest severity (ranging between 78 and 99.5%) were all found on the east side of the cascade crest and of those, the top three were from 2008 and 2009.

Outside the park boundary, Clearing patches had a slightly larger patch size, but showed less severity than the patches in the Development category.

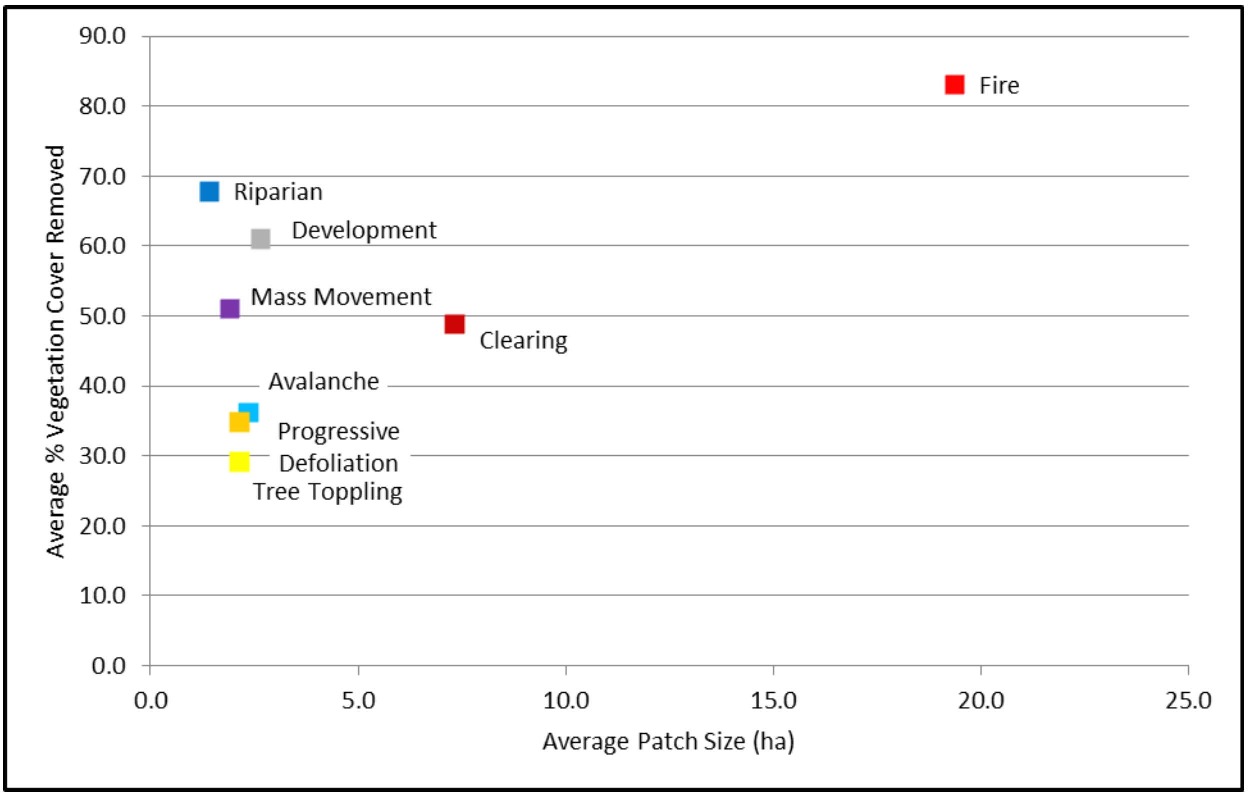

Figure 17. The relationship between average percent vegetation cover removed and average patch size by agent type within the study area (inside and outside park boundary).

Other Landscape Factors: Elevation and Slope

Overall, all landscape change types were found along large elevation ranges, with Fire having the largest range between 200 to 2,200 meters in elevation and the highest median value (Figure 18). Generally, Riparian changes were found at lower elevations. Avalanches and Progressive

Defoliation patches were distributed along a similar range: between about 350 and 1,800 meters with a median elevation of around 1,200 meters. Progressive Defoliation had a few lower elevation patches, the majority of which were found along East Fork of Bacon Creek and associated with western hemlock looper (*Lambdina fiscellaria lugubrosa*) infestation in 1992-93 as detected by the USFS Aerial Detection Surveys.

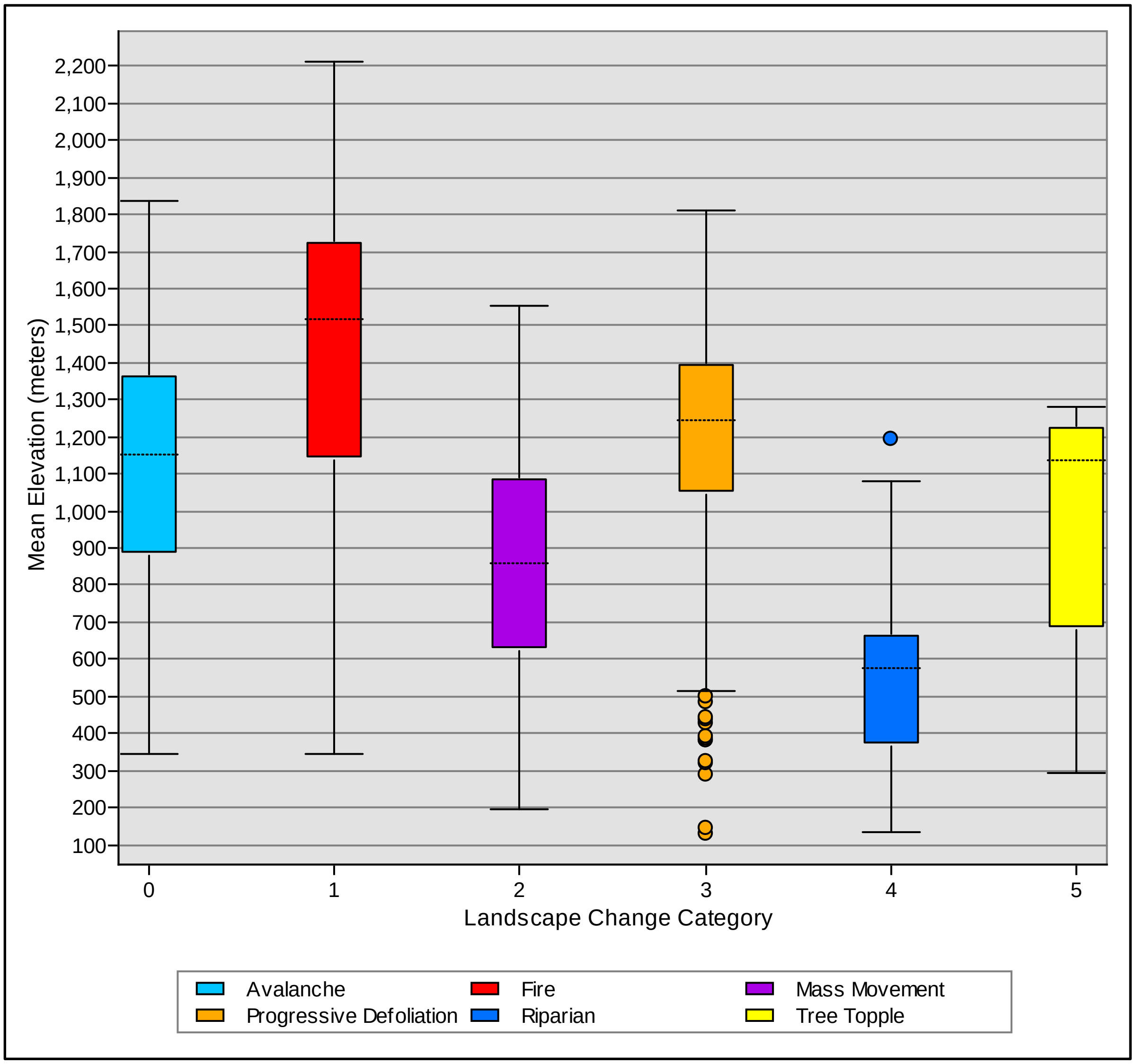

Figure 18. Distribution of mean elevation values for each landscape change category using patches detected between 1985 and 2009 inside the boundary of the North Cascades National Park Service Complex. Dashed lines represent median, boxes represent quartiles, whiskers are 1.5 interquartile range.

Mean slope values for patches in change categories inside the park boundary are shown in Figure 19. Fire had the largest median mean slope of above 30 degrees and a wide range of values; Progressive Defoliation patches had the widest range with values between 0 and 55 degrees. Of all natural landscape changes, Riparian category had the lowest median value. Mass Movement patches had a median mean slope value of about 20 degrees, but occurred on slopes of up to 55 degrees.

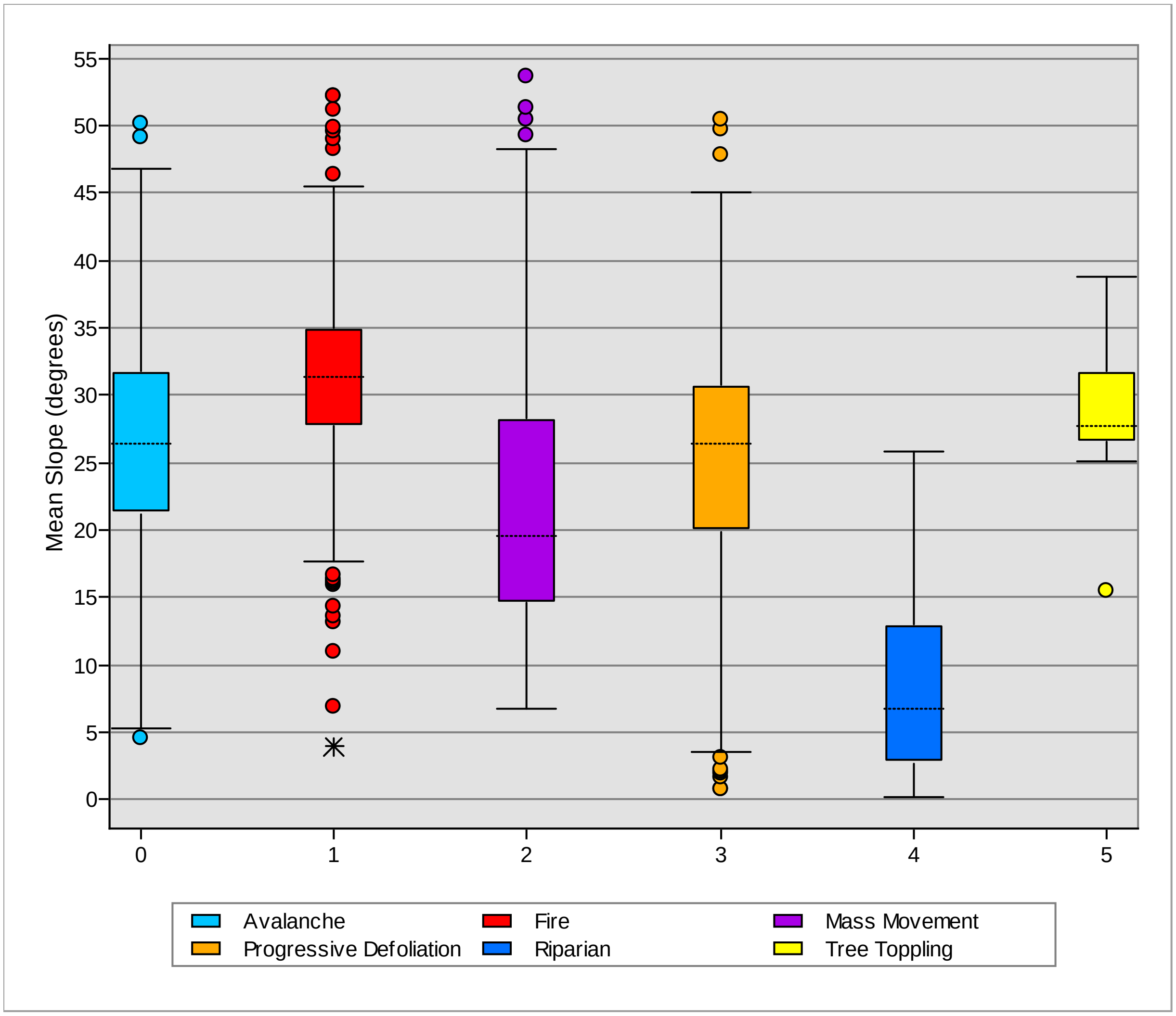

Figure 19. Range of mean slope values for patches in all change categories within the boundary of the North Cascades National Park Service Complex. Dashed lines represent the median, boxes represent quartiles, whiskers are 1.5 interquartile range.

Land Management and Landscape Change

Upon examining how land management category affected the area changed, the highest percentage of altered landscape within its lands during the period of analysis was managed by Seattle City Light (Figure 20). About 38% of its area was modified with an annual average of 1.5%. The All Other-US category (private, city and county lands) was the second largest with about 22% of the area modified between 1985 and 2009. Washington State DNR was the third highest, with 20% of its lands modified by landscape change. Both USFS land management categories showed about 5% of their land area modified, which was similar to the overall percentage calculated for inside the park boundary (Table 4).

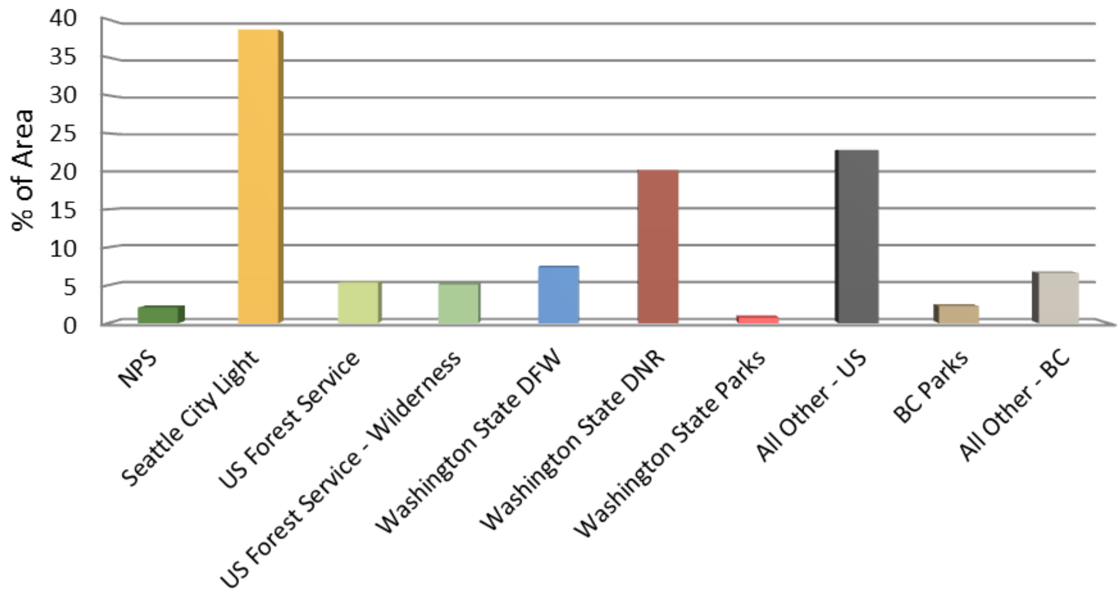

Figure 20. Percent of the total area within each management category outside the North Cascades National Park Service Complex boundary that underwent change between 1985 and 2009. Agriculture is not included.

Because the USFS and NPS wilderness management requirements are nearly identical, we expected that landscape change in USFS wilderness areas outside the NOCA boundary would be similar. Both types of wilderness had about 0.2% of total area affected by Avalanches, but USFS wilderness had higher percentages for Fire (4.19 vs. 1.33%) and Progressive Defoliation (0.65% vs. 0.38%) categories (Tables 4 and 6). USFS wilderness areas also had larger percent area affected by Mass Movements (0.02% vs. 0.01% for the park), but the park had higher percentage for Riparian changes (0.03% vs. 0.01%). USFS non-wilderness had lower percentage of area affected by Avalanches and Fire, but a larger percentage of land was affected by Progressive Defoliation (0.82%). As expected, we found no Clearing or Development patches on the USFS wilderness lands. Other USFS lands had about 1.45% and 0.04% of the total area modified by Clearing and Development change types, respectively.

Table 6. Percentage of total area affected by different landscape change categories on U.S. Forest Service lands within the study area between 1985 and 2009.

	USFS		USFS Wilderness	
Agent	**Hectares**	**% Total Area**	**Hectares**	**% Total Area**
Avalanche	137.36	0.08	560.35	0.22
Clearing	2634.13	1.45	0.00	-
Development	65.71	0.04	0.00	-
Fire	5240.18	2.89	10658.90	4.19
Mass Movement	11.84	0.01	54.68	0.02
Progressive Defoliation	1492.74	0.82	1646.77	0.65
Riparian	52.07	0.03	29.50	0.01
Tree Toppling	48.37	0.03	39.53	0.02
Grand Total	9682.40		12989.72	

The total number of hectares altered by Clearing and Development for each land management category within the analysis period is shown in Figure 21. Clearing was by far the larger of the two categories, with the All Other-US showing the largest number of hectares cleared between 1985 and 2009.

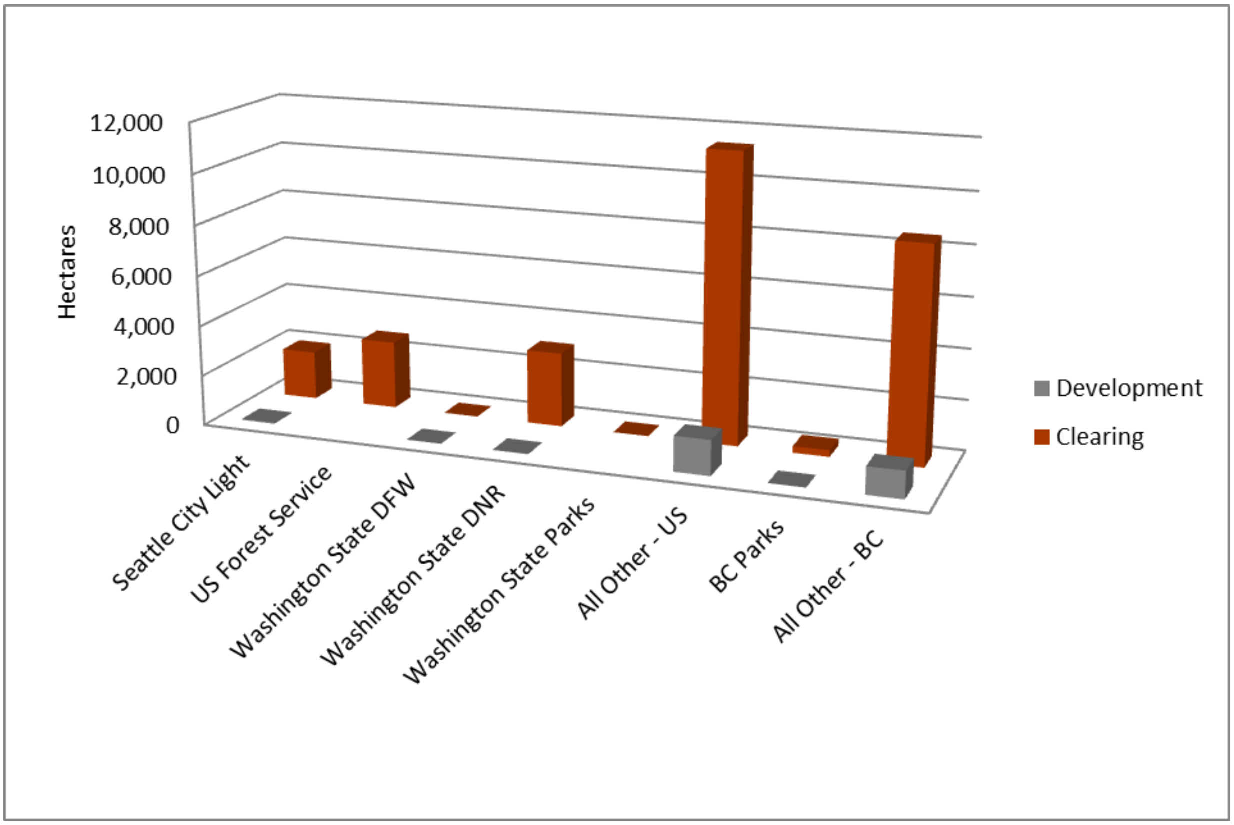

Figure 21. Total hectares disturbed by Clearing or Development outside the North Cascades National Park Service Complex boundary between1985 and 2009.

Total number of hectares affected by Clearing outside the park boundary has decreased during the time period studied (Figure 22).

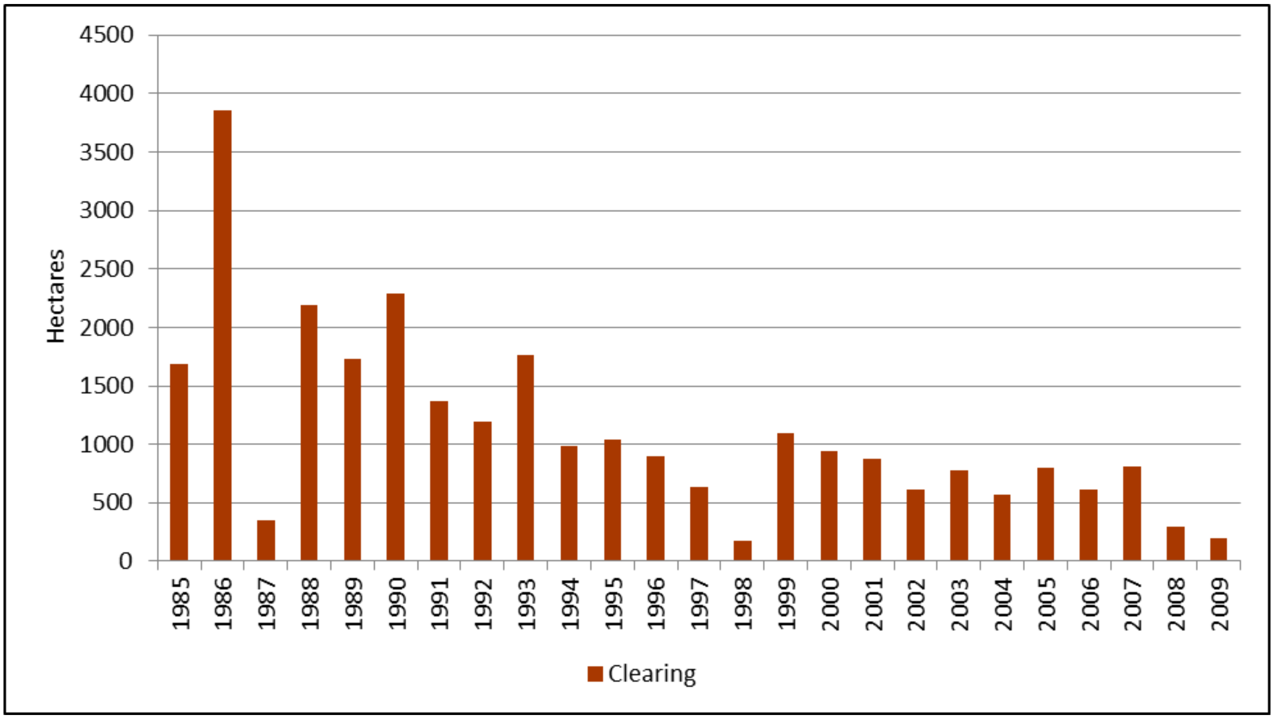

Figure 22. Decrease in area of Clearings outside North Cascades National Park Service Complex boundary from 1985 to 2009.

Trends in the Clearing change type for each of the land management categories are shown in Figure 23. An overall reduction in the number of hectares cleared is evident within all management categories. All Other-BC lands show a cyclical pattern with an increase of the number of hectares cleared in the mid-2000's. The number of hectares cleared on the lands belonging to the All Other-US category declined steadily from the mid-1990's to late 2000's. Seattle City Light lands showed an increase in Clearings between 1999-2001, which also coincided with a similar increase on the lands managed by USFS. Washington State DNR had a small increase between 2005 and 2007.

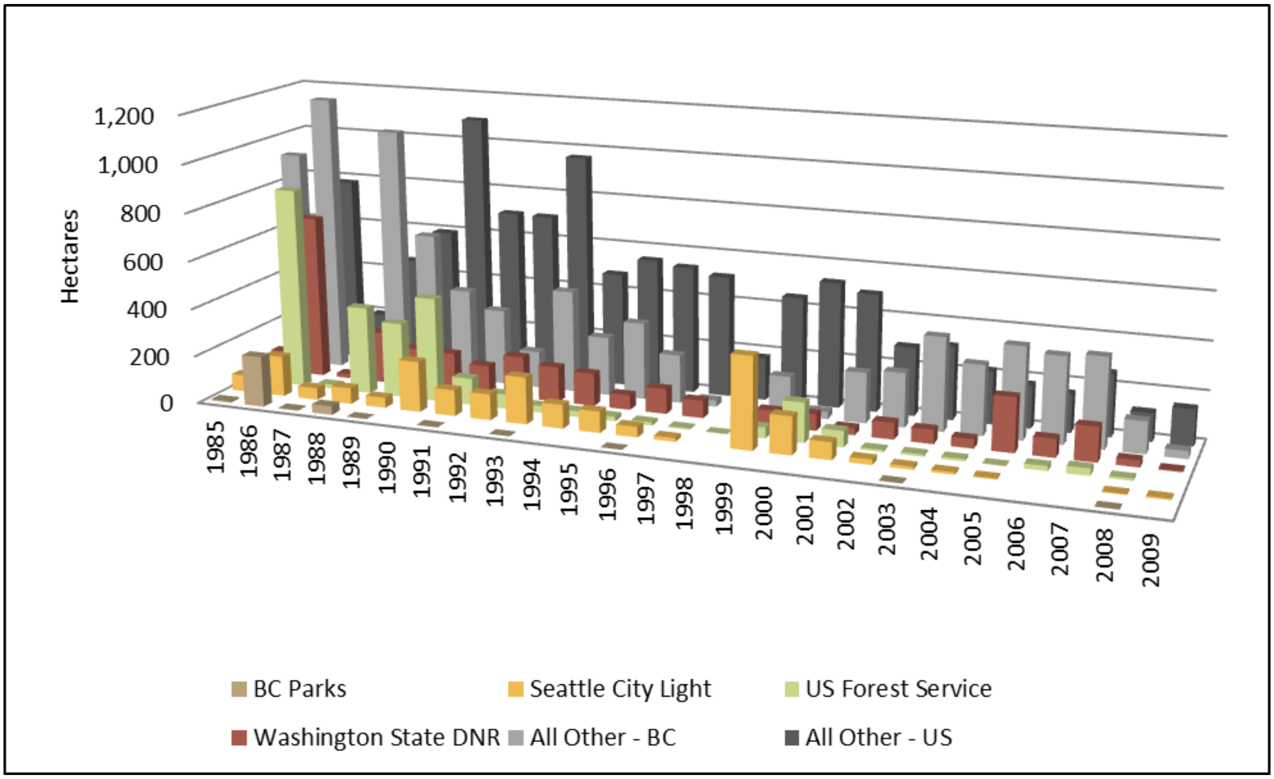

Figure 23. Total hectares disturbed by Clearing outside the North Cascades National Park Service Complex boundary between1985 and 2009 by year and land management category.

Change due to Development outside the park boundary shows a cyclical pattern (Figure 24). There was increase in Development observed in the early and mid-1990s and then again in mid-2000's. Figure 25 evaluates the contribution by the various land management types to the Development category, overlaid by the 2-year average trend line. The BC and US patterns are not synchronized, with US showing obvious peaks in the mid 1990's and 2000's. The BC lands show a more variable pattern with peaks and slumps every 4 or 5 years.

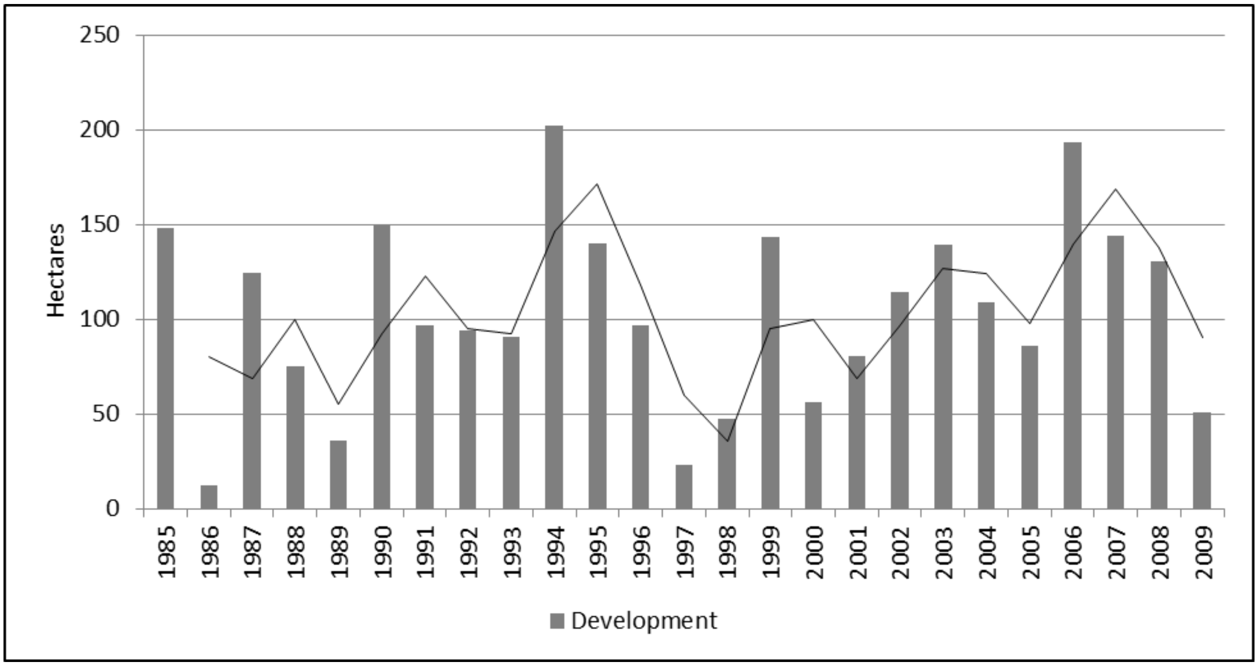

Figure 24. Changes in area of Development outside of the North Cascades National Park Service Complex boundary from 1985 to 2009, overlain with a two-year running average

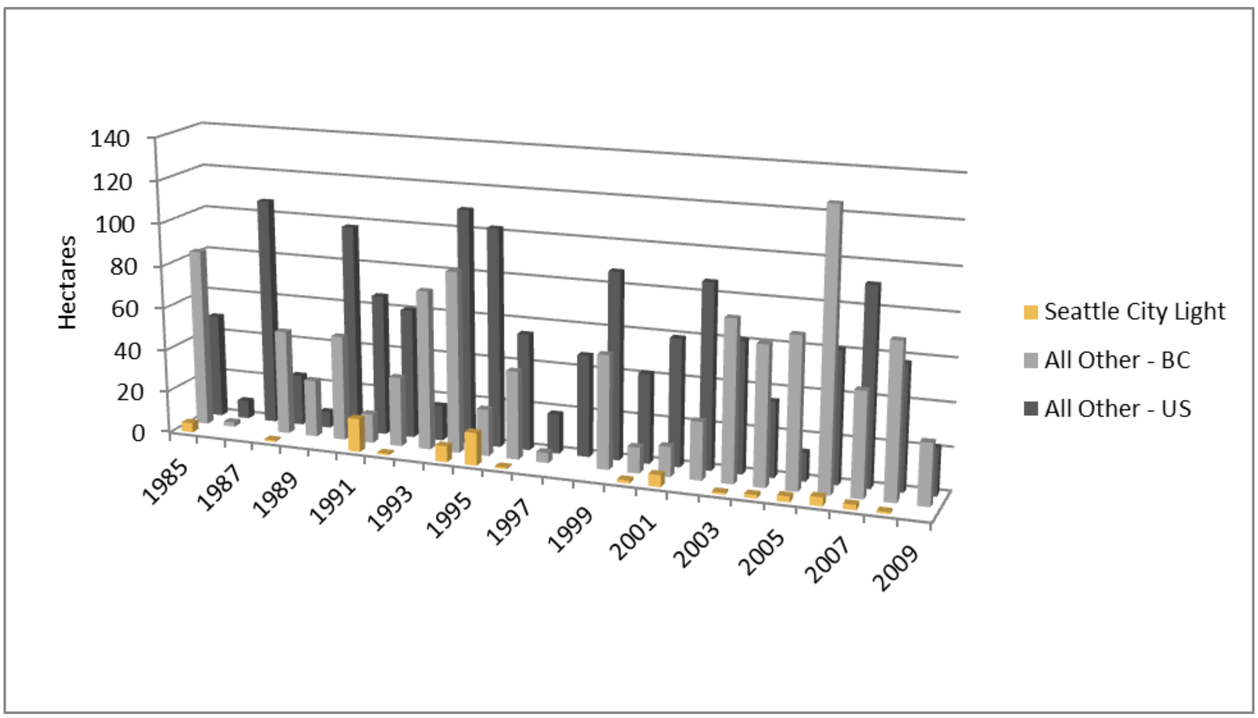

Figure 25. Total hectares disturbed by development outside the North Cascades National Park Service Complex boundary between1985 and 2009 by year and land management category.

Accuracy Assessment

Random Forests Classification

The overall classification accuracy was 85.29%. The accuracy assessment matrix for the RF classification applied to change patches outside the park boundary is shown in Table 7. The Clearing, Fire, and Progressive Defoliation categories had error rates below 10%. The Avalanche and Tree Toppling categories had the highest error rates, above 30%. Avalanches were often mistakenly labeled as Clearing or Mass Movement due to their similarities in spectral characteristics and location on landscape. Tree Toppling events had a very small sample size due to this type of event being rare in the study area and were often confused with Avalanches and Progressive Defoliation, probably because in all three categories the canopy is only partially removed. There was also some confusion between Clearings and Development.

Table 7. Accuracy assessment matrix for RF-derived labels for North Cascades National Park Service Complex training polygons used in model generation.

	Predicted										
Actual	Agriculture	Annual Variability	Avalanche	Clearing	Development	Fire	Tree Toppling	Progressive Defoliation	Mass Movement	Riparian	**Error**
Agricultural	**38**	0	0	0	5	0	0	0	0	1	0.14
Annual Variability	0	**42**	2	0	0	0	1	1	0	0	0.09
Avalanche	0	1	**31**	5	0	0	0	2	6	0	0.31
Clearing	0	1	1	**90**	3	1	0	0	0	1	0.07
Development	2	0	0	6	**38**	0	0	0	0	0	0.17
Fire	0	0	1	0	0	**43**	0	0	1	0	0.04
Tree Toppling	0	0	2	0	0	0	**7**	2	0	0	0.36
Progressive Defoliation	0	0	1	1	0	0	0	**43**	0	0	0.04
Mass Movement	0	1	6	1	0	0	0	1	**33**	3	0.27
Riparian	1	0	1	1	1	0	0	0	6	**35**	0.22

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 eighty seven 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 87% (Table 8). The Kappa statistic was 83.78, indicating that the RF classification of patches was 83.78% better than a random classification. The Progressive Defoliation category had the highest user's accuracy at 96% due to its unique spectral characteristics. Agricultural, Avalanche, Clearing, and Fire categories all had user's accuracies above 90%. The lowest accuracy from a user's standpoint was for the Tree Toppling category (20.6%), which is over-predicted by the model and most frequently, confused with the Clearing class. Because Tree Topplings are such rare events in the study area, we preferred that this category was over-predicted rather than under-predicted, so that patches with this label can be evaluated and corrected. From a producer's standpoint, the highest accuracy was assigned to the Annual Variability category at 94.7%, followed by Agriculture (90.7%), Clearing (88.5%) and Progressive Defoliation (87.8%) categories. The lowest accuracy was found in the Mass Movement category (40%), which had a low sample size and was confused with Clearing, and Tree Toppling (Table 8). The model originally labeled three patches in the Unknown category as Tree Toppling, which, upon examination, did not make sense and these were consequently relabeled as "Unknown" due to lack of information.

Table 8. Accuracy assessment of polygons outside the North Cascades National Park Service Complex boundary.

RF Model	Validation												
	Agriculture	Annual Variability	Avalanche	Clearing	Development	Fire	Mass Movement	Progressive Defoliation	Riparian	Tree Toppling	Unknown	Grand Total	User's Accuracy
Agricultural	**107**			3	3				1			114	93.9
Annual Variability		**89**		5		4	1	3				102	87.3
Avalanche			**52**	2		1		2				57	91.2
Clearing		1	6	**368**	8	4	1	15	1			404	91.1
Development	10			21	**48**				2			81	76.5
Fire			1	1		**62**		2				66	93.9
Mass Movement					1		**2**					3	66.7
Progressive Defoliation		2	1	2		3		**194**				202	96.0
Riparian	1			2	1			1	**19**			24	79.2
Tree Toppling		2	2	12		3	1	4		**7**	3	34	20.6
Unknown											**0**	0	N/A
Grand Total	118	94	62	416	61	77	5	221	23	7	3	**1087**	
Producer's Accuracy	90.7	94.7	83.9	88.5	78.7	80.5	40.0	87.8	82.6	100.0	0.0		
Overall Accuracy	87.21												
Kappa Statistic	83.78												

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 9. The RF classification model inside NOCA has slightly lower overall accuracy than for patches outside the park boundary. The Kappa statistic was also lower at 80.19. Similar to the validation results for patches outside the park boundary, RF labeled more patches in the Tree Toppling category incorrectly than correctly, leading to a user's accuracy of only 25%. Most of this category was confused with patches labeled as Progressive Defoliation. The Clearing category also had low accuracy (34.2%), with confusion with the Avalanche and Mass Movement reducing accuracy from the user's perspective. The highest user's accuracies were in Annual Variability, Progressive Defoliation, Fire, and Avalanche categories, all exceeding 80%. Producer's accuracy exceeded 70% in all categories except for Development, due to the very small sample size for that category in the park.

Table 9: Accuracy assessment of polygons inside the North Cascades National Park Service Complex boundary.

		Validation										
		Annual Variability	Avalanche	Clearing	Development	Fire	Mass Movement	Progressive Defoliation	Riparian	Tree Toppling	Grand Total	User's Accuracy
RF Model	Annual Variability	**646**	16			18	18	14	1		713	90.6
	Avalanche	7	**181**			2	5	25	1		221	81.9
	Clearing	2	10	**13**	1	1	7	3	1		38	34.2
	Development				**1**						1	100.0
	Fire	7	8			**183**		18			216	84.7
	Mass Movement	9	14	1		2	**98**	2	1		127	77.2
	Progressive Defoliation	16	14			20	2	**463**	2	2	519	89.2
	Riparian	3	1	3			2	4	**50**		63	79.4
	Tree Toppling	6	6				2	15		**9**	36	25.0
	Grand Total	696	250	17	2	226	132	544	56	11	**1934**	
	Producer's Accuracy	92.8	72.4	76.5	50.0	81.0	74.2	85.1	89.3	81.8		
	Overall Accuracy	85.01										
	Kappa Statistic	80.19										

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