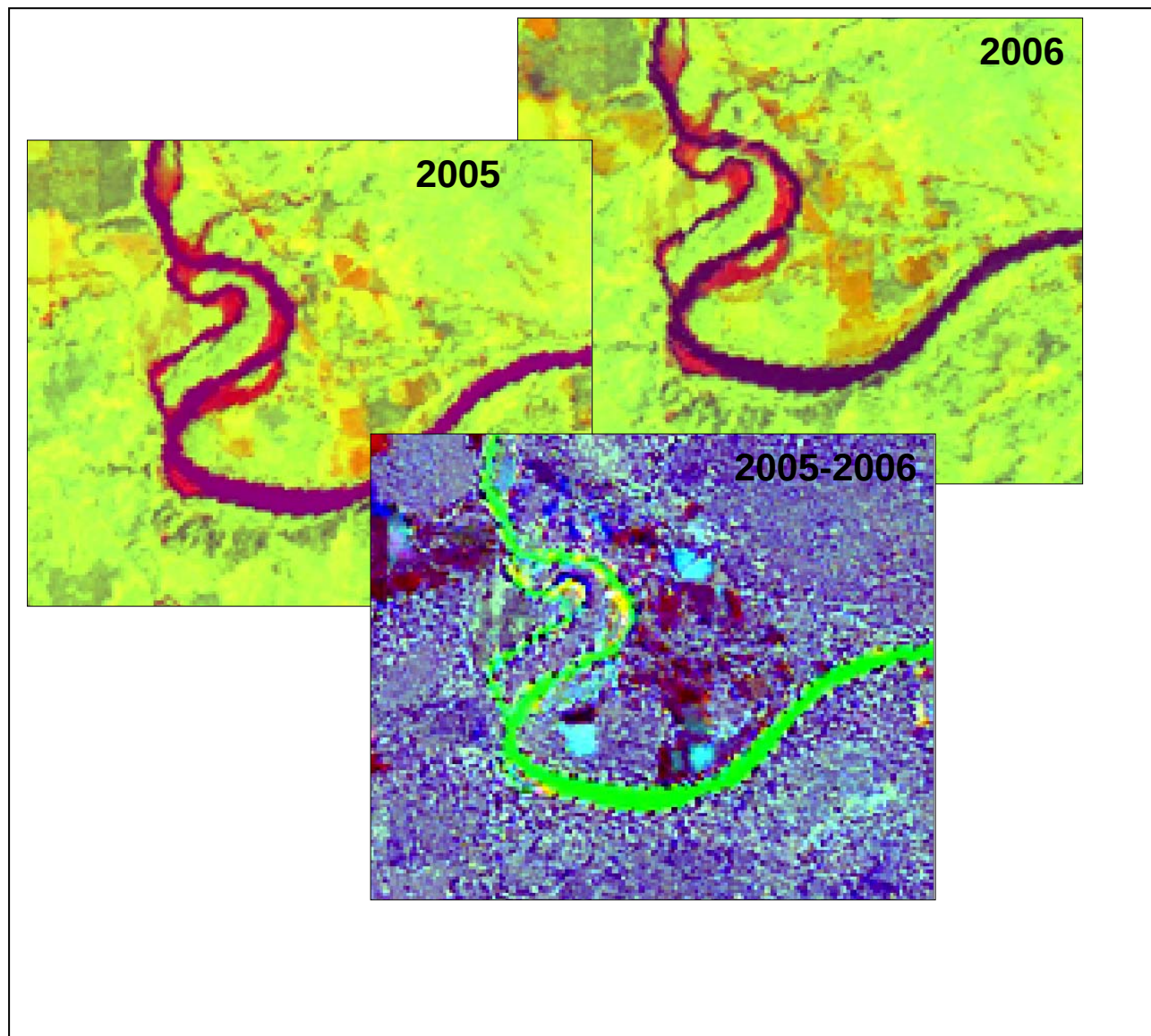




Implementation of Landscape Dynamics Monitoring at the North Coast and Cascades Network: *Initial Assessment of Change Detection Methods*

Natural Resource Technical Report NPS/NCCN/NRTR—2010/328



ON THE COVER

2005 and 2006 Tasseled Cap images and 2005 minus 2006 change image for areas in the vicinity of the North Cascades National Park Complex showing changes in vegetation clearcut and regrowth patterns.

Implementation of Landscape Dynamics Monitoring at the North Coast and Cascades Network:

Initial Assessment of Change Detection Methods

Natural Resource Technical Report NPS/NCCN/NRTR—2010/328

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Executive Summary

This report describes the first implementation of the “Protocol for Landsat-Based Monitoring of Landscape Dynamics at North Coast and Cascades Network Park” (Kennedy et al. 2007a). The Protocol contains a detailed description of the methodology for the NCCN landscape dynamics monitoring and provides the context for this report. In this report, we summarize the changes made to the original protocol methodology during its implementation. We also provide the results of the 2004/2005-2006 change detection analysis and validation for MORA, NOCA and OLYM. Lastly, we evaluate the ability of this protocol to address the NCCN’s landscape dynamics monitoring goals.

The North Coast and Cascades Network (NCCN) selected landscape dynamics as a Vital Sign for monitoring. A list of targeted disturbance types for yearly monitoring included: avalanche chutes, landslides, fire, insect defoliation in forests, windthrow, riparian disturbance, clearcuts, and rural development. A remote-sensing based two date change detection protocol was developed by cooperators at Oregon State University (OSU, Kennedy et al. 2007a). Several key modifications were made to the protocol’s initial “startup” phase. First, baseline images from 2004 and 2005, rather than circa 1994 were used in order to link to recent NPS field data. Second, the OLYM baseline image development method had to be substantially altered to accommodate the fact that OLYM is covered by multiple satellite scenes.

In the change detection phase, the 2005 baseline image (2004 for OLYM) was then compared to a 2006 image. The results from the two-date change detection demonstrated that the current protocol could detect the types of change of interest to the NCCN. However, the results were dominated by a large amount of real but “uninteresting” changes due to differences in phenology, cloud cover, shadows and snow, and image to image registration. Techniques for reducing the uninteresting change were explored, including developing cloud, shadow, and snow masks and increasing the minimum mapping unit. False change due to differences in phenology remained particularly intractable.

Difficulties were encountered during change validation and accuracy assessment step. Individual interpreters varied in their approach to the validation process, both in delineating polygons and handling fuzzy boundaries. The accuracy assessment became more of a measure of how well the interpreter mimicked the computer algorithm process, rather than an assessment of how well the algorithm mapped real change. The reported accuracy results are therefore not a reliable representation of the accuracy of the change detection.

The NCCN protocol incorporated the best remote sensing methods for two date change detection available at the time. In the interim, the OSU group has developed a new change detection method that takes advantage of the entire Landsat archive and minimizes the number of “uninteresting” changes present in the final product (Kennedy et al. 2007b). The existence of improved methods makes it difficult to envision continuing with this current protocol.

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We are grateful to Robert Kennedy of the Forestry Sciences Laboratory of the U.S.D.A.'s Pacific Northwest Research Station for continuous support during protocol implementation and report writing. Dr. Andrea Woodward, USGS, shepherded the protocol through its early phases. We thank Roger Hoffman for guiding protocol implementation, assisting with methods assessment, and reviewing the report. Substantial contributions towards the development of physiognomic class descriptions and review of the report were provided by the members of the NCCN vegetation monitoring workgroup, including Mignonne Bivin, Steve Acker and Regina Rochefort. We appreciate additional review provided by Mark Huff. Ronald Holmes greatly assisted with report formatting and production.

Glossary of terms and acronyms

COST -	A series of algorithms applied to images to reduce noise associated with differences in atmospheric conditions. First described in (Chavez, 1996).
ENVI -	Image processing and analysis software developed by ITT Visual Information Solutions.
Georectification -	Geometrical correction. Adjustments made to an image to change its geometrical character, so that it conforms to a standard map projection such as Universal Transverse Mercator.
I&M -	Inventory and Monitoring Program of the National Park Service.
Landsat -	The Land Remote Sensing Satellite Program managed by the US Geological Survey designed to gather data about the Earth's surface resources. A series of remote sensing satellites in sun-synchronous, polar orbit, with first launch in 1972. The Landsat satellites are the platforms for TM sensors.
LEDAPS -	Landsat Ecosystem Disturbance Adaptive Processing System. Designed to create decadal surface reflectance (SR) images from the North American Landsat GeoCover archive for the period 1975-2000 and analyze these images for forest disturbance, recovery, and conversion. In this project, LEDAPS provides geometrically corrected Landsat images, against which new images could be georectified.
MADCAL -	Multiple Alteration Detection Calibration. A method for radiometric correction of imagery to reduce misalignment of spectral space, including engineering, sun angle and atmospheric effects. Applied to images following COST processing.
MORA -	Mount Rainier National Park
NAIP -	National Agricultural Imagery Program. Acquires aerial imagery during the agricultural growing seasons in the continental U.S.
NCCN -	North Coast and Cascades Network of the National Park Service.
NOCA -	North Cascades National Park Complex, consisting of North Cascades National Park, Ross Lake National Recreation Area and Lake Chelan National Recreation Area.
OLYM -	Olympic National Park

Pixel -	Abbreviation for “picture element.” In remote sensing and GIS, pixel is synonymous with “cell.” A datum in a digital image, having both a spatial aspect (its position in the image and its rectangular dimension on the ground) and spectral aspect (the brightness in a particular waveband of the terrain with the pixel’s rectangular dimension on the ground).
Physiognomic class -	A partition of the tasseled-cap spectral space that can be mapped onto the landscape and linked with existing datasets to represent a broad park-specific vegetation community type. Used to develop multivariate-normal probability distribution (POM) for the baseline image.
POM -	Probability of Membership. Represents the probability of a pixel belonging to each of the nine broadly defined physiognomic classes. It is based on a multivariate-normal distribution and is calculated using a standard maximum likelihood classification process.
S2S-	Satellite to Satellite. Fifteen change classes based on the calculated differences in Probability of Membership for a given pixel. Used for summary and interpretation of changes among the different physiognomic classes.
Tasseled-cap -	Kauth-Thomas Tasseled- cap transformation. A set of linear transformations that converts 6 non-thermal Landsat TM bands into three axes that represent the greenness, yellowness (brightness), and wetness within the terrain.
TM -	Thematic Mapper. A sensor carried by Landsats 4 and 5 satellites, which records scenes in seven wavebands. Used synonymously with Landsat.

Introduction

Landscape dynamics refer to a broad suite of ecological and geomorphological processes occurring across broad spatial scales. Landscape dynamics can be considered both system drivers (e.g., changes in land use) and response variables (e.g., changes in canopy closure of forested stands due to disease). As part of the National Park Service's larger goal of developing long-term monitoring programs in response to the Natural Resource Challenge of 2000, the North Coast and Cascades Network (NCCN) parks¹ determined that monitoring landscape dynamics was necessary to track the health of park ecosystems (Weber et al. 2005). Global climate change could significantly affect ecosystems through changes in the frequency, magnitude and distribution of landscape disturbances (Dale et al. 2001). The products of a long-term landscape dynamics monitoring program were determined to be valuable to park managers in evaluating if and how park resources are being impacted by changes in the landscape disturbance regime and assist in planning and budgeting for disturbance event mitigation in response to climate change.

Landscape-level change monitoring addresses phenomena at broad spatial and temporal scales, making remote sensing the most appropriate monitoring tool. Following a remote sensing workshop, it was determined that Landsat systems have the appropriate spatial and temporal resolution to detect the majority of the disturbance events and ecological processes of interest to the NCCN (Woodward et al. 2002). In 2004 cooperative work between the Forestry Sciences Laboratory of the U.S.D.A.'s Pacific Northwest Research Station and the US. Geological Survey began to develop a landscape dynamics monitoring protocol, based on Landsat systems, which would achieve the landscape dynamics monitoring goals of the network (Kennedy et al. 2007a).

Researchers from the Forestry Sciences Laboratory guided the NCCN Landscape Dynamics work group through a careful and extensive evaluation process. During this process monitoring questions were reduced to those achievable using Landsat. Monitoring goals were grouped into two categories (Table 1). The Type I category included changes resulting from disturbance events that required monitoring on an annual basis. The high frequency of monitoring is needed for the Type I events because post-event recovery can obscure the original spectral signal if the time interval between monitoring occurrences is too long. The Type II category included changes resulting from ecological processes that could be monitored less frequently. These processes, primarily slow vegetation change, are usually subtle and require longer time periods before changes can be detected.

¹ NCCN consists of the following seven park units: Mount Rainier National Park (MORA), Olympic National Park (OLYM), North Cascades National Park Complex (NOCA), Fort Vancouver National Historical Site (FOVA), San Juan Island National Historical Park (SAJH), Ebey's Landing National Historical Reserve (EBLA), and Lewis and Clark National Historical Park (LEWI).

Table 1. North Coast and Cascade Network monitoring schedule (from Kennedy et al. 2007a).

Type I: Monitor yearly	Disturbance Event
	Avalanche chute clearing
	Landslides
	Fire
	Insect/disease defoliation in forest
	Windthrow
	Riparian disturbance
	Clearcuts
	Rural development
Type II: Monitor decadal	Ecological Process
	Alpine tree establishment
	Changes in hardwood/conifer forest composition
	Changes in forest structure

The Landsat-based protocol would address parks' needs by generating annual and decadal maps that indicate areas where change had been detected. These maps would trigger further investigation either on the ground or using more detailed imagery. Second, the long-term nature of this program would provide a chronological sequence of images for the study area, analysis of which would have allowed the calculation of changes in frequency and size of disturbances over time. Third, the monitoring results would provide a context for interpreting plot level changes documented through other Vital Signs monitoring programs such as mountain lakes, landbirds and vegetation.

In this report, we describe the first implementation of the Protocol for Landsat-Based Monitoring of Landscape Dynamics at North Coast and Cascades Network Parks ("The Protocol," Kennedy et al. 2007a) and summarize the changes to methodology for the "startup" and the first Type I change detection phases of the protocol. The objective of the "startup" phase was to establish foundation images for three NCCN parks which could serve as a baseline against which all further change detection could be compared. The base images could also be linked with the field data collected by NCCN in the early and mid 2000s. We also provide the results of the 2004/2005-2006 Type I change detection analysis and validation for MORA, NOCA. Lastly, we evaluate the effectiveness of the current protocol's methodology in answering NCCN's monitoring questions.

Study Area

Between 2005 and 2008, NCCN implemented the Landsat-based monitoring protocol in the three largest NCCN Parks (Figure 1).

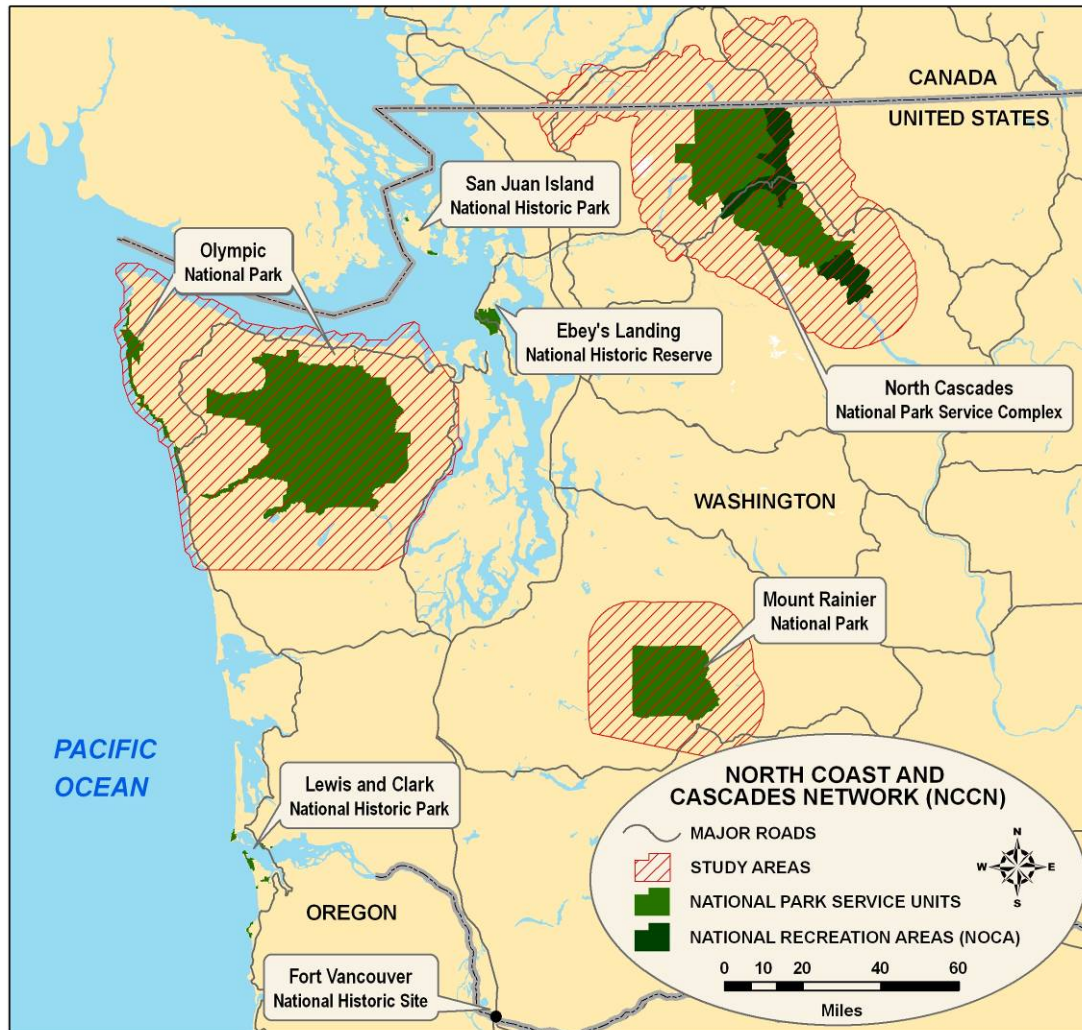


Figure 1. National Parks System units within the North Coast and Cascades Network (NCCN) and Landscape Dynamics Monitoring study areas.

Mount Rainier National Park (MORA)

MORA was established in 1899 and covers 95,395 ha. The summit of Mount Rainier, an active volcano, stands at 3900 meters. Approximately 58 percent of the park is forested, 23 percent is subalpine parkland, and the remainder is above tree line, of which approximately half is vegetated and the other half consists of permanent snowfields and rock. The park has 26 named glaciers in nine major watersheds, 382 lakes, and numerous rivers, streams and wetlands. MORA is home to four federally listed threatened or endangered vertebrate species, including 3 species of birds and one species of fish (<http://www.nps.gov/mora/naturescience/index.htm>).

North Cascades National Park Service Complex (NOCA)

NOCA consists of North Cascades National Park, Lake Chelan National Recreation Area, and Ross Lake National Recreation Area. The Complex was established in 1968 to preserve the scenery and natural features of the area while allowing for recreational use and for the development and operation of four hydroelectric reservoirs and two run-of-the-river hydroelectric projects, the use of renewable resources, and mineral development. The Complex covers 277,019 ha at the northern end of the Washington Cascade Range, adjacent to the Canadian border. Variation in elevation, soil types, rainfall and exposure combine to form eight distinctive life zones from the lowland forests and wetlands to the alpine peaks and more than 300 glaciers. The park has over 300 lakes, 1600 species of plants, 75 species of mammals, and more than 200 species of birds, three of which are federally listed as “threatened.” The park also includes part of the Skagit River Watershed, which is the only watershed in the continental US to contain runs of all five Pacific salmon species (<http://www.nps.gov/noca/naturescience/index.htm>).

Olympic National Park (OLYM)

OLYM was established in 1938. The park covers 373,543 ha on the Olympic Peninsula of Washington, and is said to be three parks in one: rugged, glacier capped mountains, over 60 miles of wilderness coastline, and stands of old-growth temperate rain forest. Habitats and communities of the park include intertidal areas, coastal bogs, temperate rainforests, riparian zones, montane and subalpine forests, alpine fellfields, and glaciers. In addition to the biological diversity found in these communities, the park provides habitat for 16 endemic plant and animal species and 37 species of fish, including all 5 species of Pacific salmon (<http://www.nps.gov/olym/naturescience/index.htm>).

For each park, a landscape dynamics study area was developed by generating a 16-km (10-mi) buffer around the existing park boundary. An additional two kilometers were added to the perimeter of the study area to avoid loss of outer pixels if coarser resolution datasets were ever processed with the existing imagery. At NOCA, the study area boundary was adjusted to include the entire 6th field watersheds, the headwaters of Skagit watershed and parts of Chilliwack watershed to address questions about changes in fish habitat. The entire Olympic Peninsula was included in the OLYM’s study area to contain entire 6th field watersheds. MORA’s study area did not extend the full 16 km south of the park boundary, instead it was limited by the edge of the Landsat scene in order to avoid extra image processing steps.

Methods

A detailed description of the methodology is found in the NCCN landscape dynamics monitoring protocol (Kennedy et al. 2007a). Here, we provide a brief summary of methods relevant to the work described in this report as well as a discussion of any changes made to the original protocol methodology during its implementation.

Development of Baseline Physiognomic Images

The initial stage of the analysis, also called the “startup” phase, focused on establishment of physiognomic class foundation images for each of the three large NCCN parks (MORA, NOCA and OLYM). The original protocol called for using foundation images from circa 1994 which would correspond to vegetation field data and land cover maps generated at the time by Pacific Meridian Resources (PMR 1996). However, we instead decided to obtain foundation images from 2004 (OLYM) and 2005 (NOCA and MORA) to take advantage of more recent field data collected by NPS under the Vegetation Inventory project. The Vegetation Inventory project was designed to 1) assess the accuracy of land cover maps produced by PMR, 2) develop vegetation classifications for three large NCCN parks, and 3) create vegetation maps based on the new classifications.

Figure 2 shows the steps in the “startup” phase used to obtain MORA and NOCA physiognomic class foundation images. We purchased August 14, 2005 and July 29, 2005 Thematic Mapper (TM) 5 images to serve as base radiometric images for MORA and NOCA, respectively. Other than altering the date of acquisition, the processing steps for the MORA and NOCA image followed the Protocol “startup” phase. We georectified these images to 1990 and 2001 Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS) images, which were downloaded from the following website: http://ledaps.nascom.nasa.gov/ledaps/products2005_new.html. The LEDAPS was setup to develop, validate and distribute a high-resolution, 30-year record of surface reflectance and vegetation disturbance and recovery by processing the North American Geocover Landsat record from 1975 to 2000. The images obtained from LEDAPS are geometrically corrected and therefore could be used as source images for georectifying newly acquired images for use in the landscape dynamics protocol.

Next, we applied atmospheric corrections to the MORA and NOCA 2005 images. We then generated baseline physiognomic class images for SE and NW aspects for both parks. We derived these physiognomic classes by applying unsupervised classification techniques to the tasseled-cap images of each park and combining the unsupervised classes based on general understanding of the distribution of reflectance in spectral space (Figures 3 and 4). Robert Kennedy, from the Oregon Forestry Science Laboratory, checked NOCA’s physiognomic classes for spectral separation using ENVI image processing software (<http://www.itvvis.com/ProductServices/ENVI.aspx>). These spectral separation checks ensured that the nine physiognomic classes developed for each aspect were statistically distinguishable in the spectral space of the tasseled-cap transformation. Figure 5 gives two examples of separation checks. Next, we generated probability of membership algorithms from the signatures of the physiognomic classes and applied them to the original tasseled-cap aspect images. This created nine probability-of-membership (POM) layers for each aspect class.

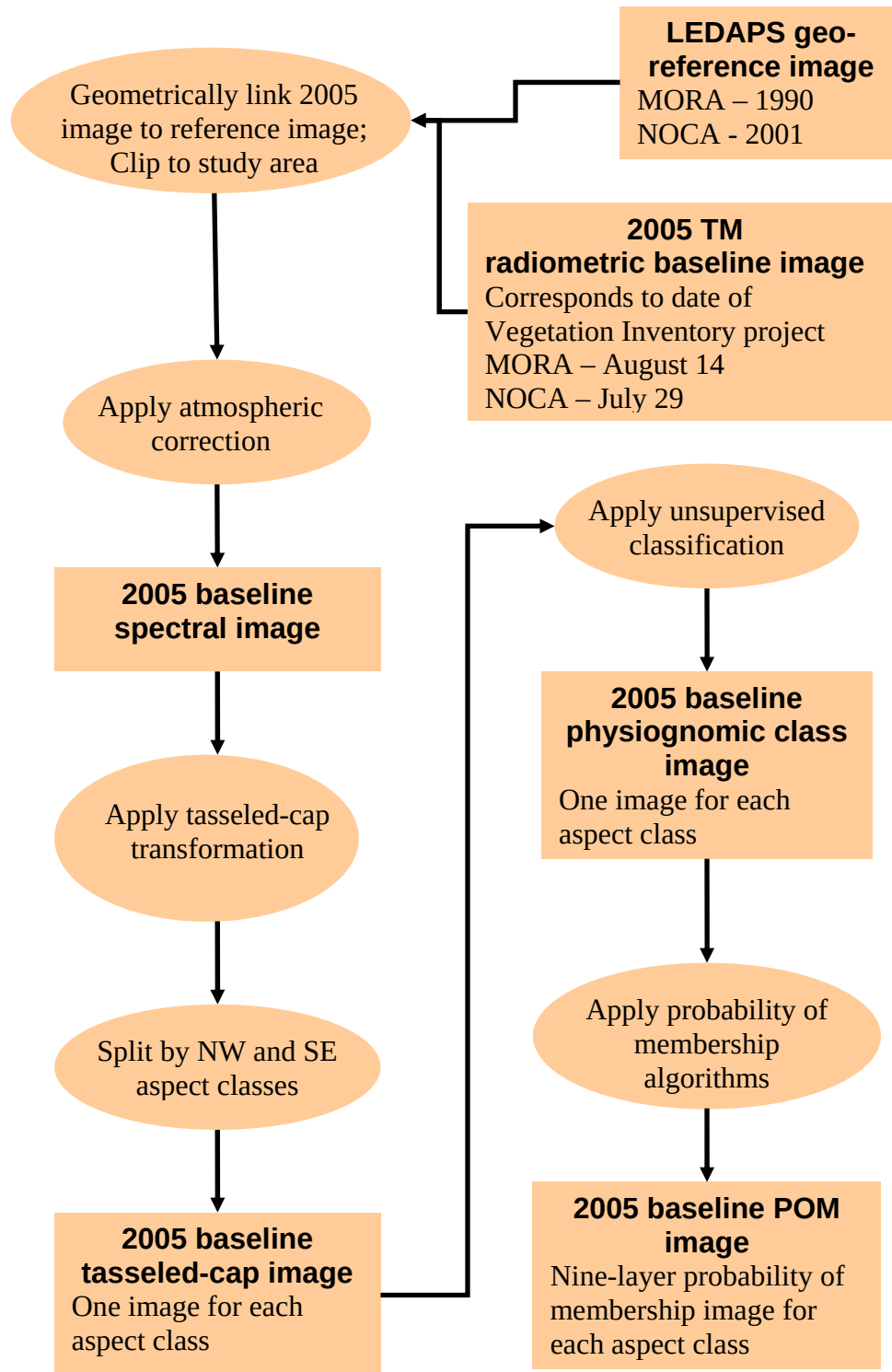


Figure 2. Steps in the “startup” phase for NOCA and MORA. An image from the era corresponding to the date of recent field validation is normalized to a reference image, classified, and translated into probability-of-membership (POM) images for two aspect classes. Modified from Kennedy et al. 2007a.

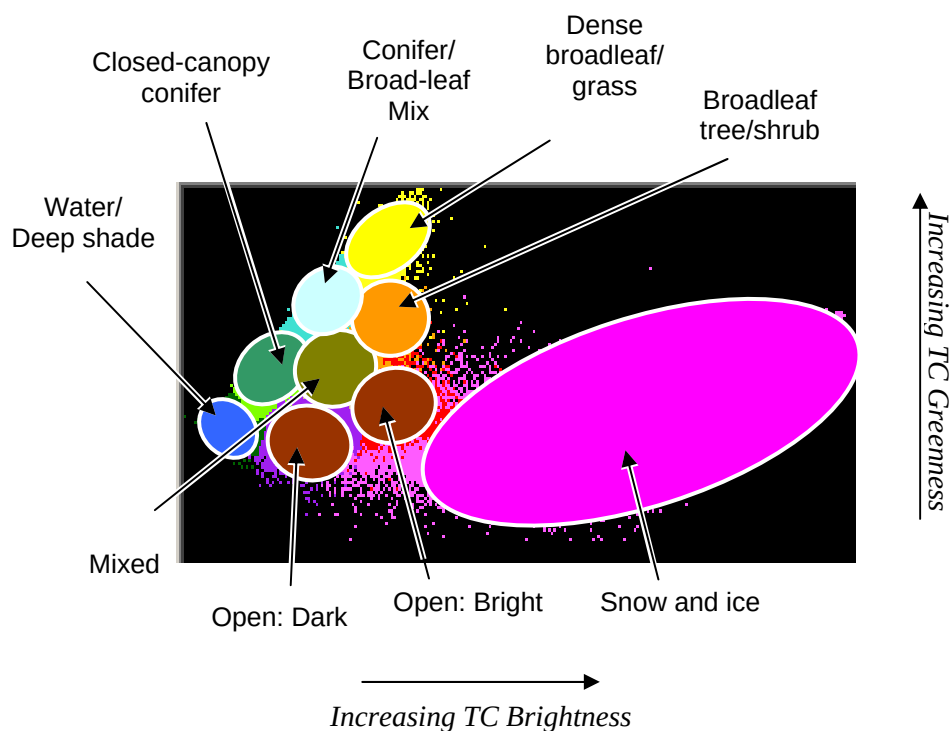


Figure 3. Approximate location of the nine physiognomic classes within the Brightness and Greenness spectral space of the tasseled-cap transformation.

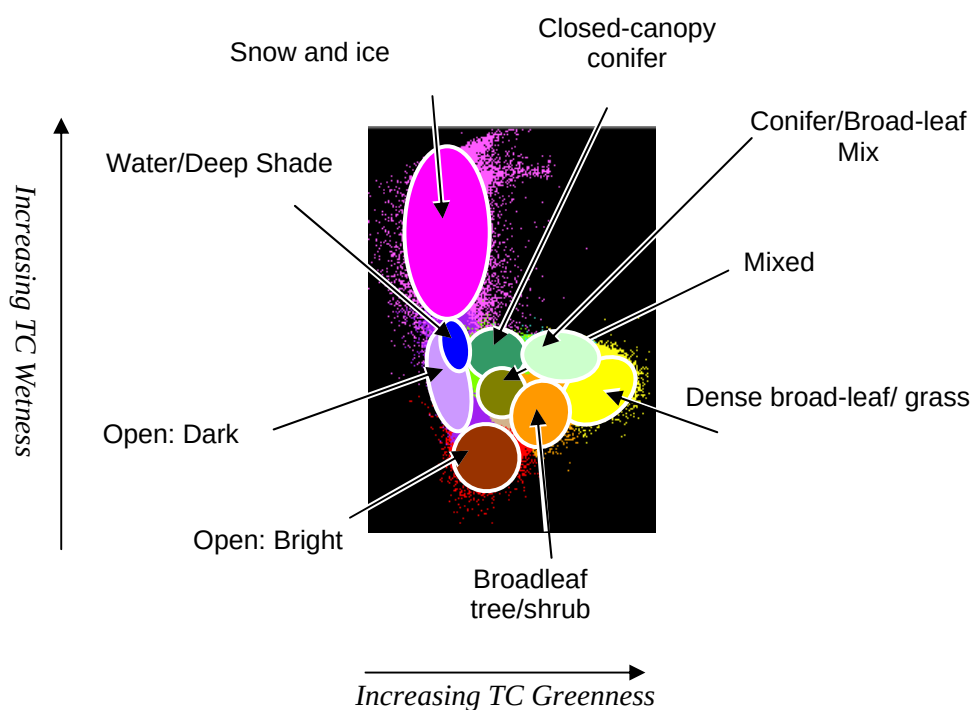


Figure 4. Approximate location of the nine physiognomic classes within the Wetness and Greenness spectral space of the tasseled-cap transformation.

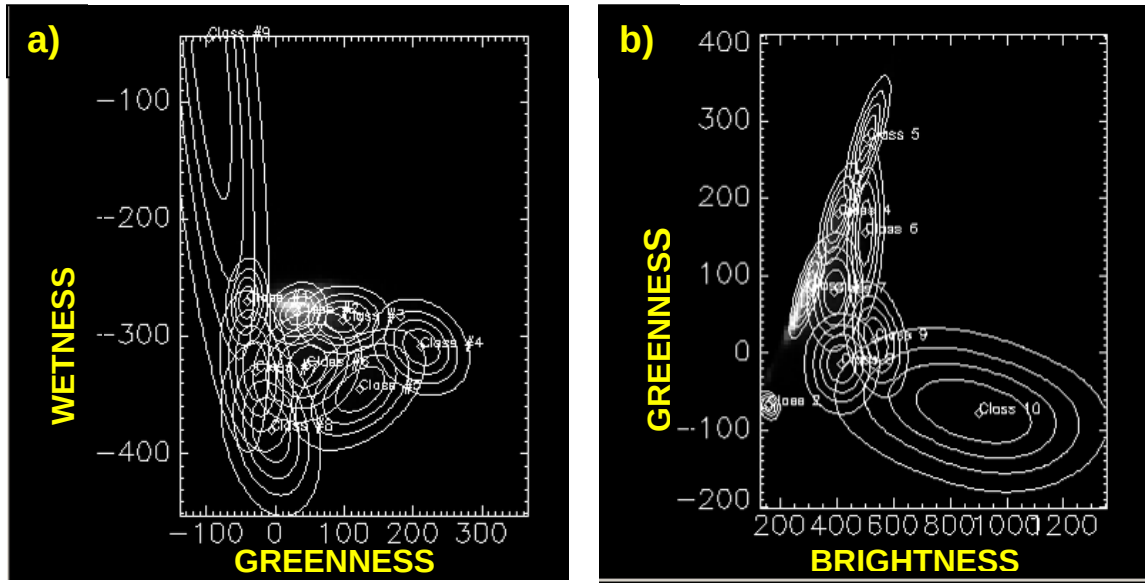


Figure 5. Examples of ENVI image processing software graphs depicting separation of NOCA's nine physiognomic classes in spectral space along the Wetness/Greenness axis of the tasseled-cap transformation for (a) the NW aspect and (b) along the Brightness/Greenness axis for the SE aspect.

In contrast to MORA and NOCA, the “startup” phase of the protocol was significantly altered for OLYM. Because the OLYM study area is covered by three TM scenes (47/27 (east), 48/26 (northwest) and 48/27 (southwest)) the methods needed to be adjusted. First, when we ordered the TM scenes, we shifted the location of 48/26 scene to the south to include the entire Olympic Peninsula, thereby reducing the number of scenes for processing from three to two (Figure 6). Next, we merged LEDAPS 48/26 and 48/27 images to create a single West image used for georectification of the shifted 48/26 TM image. We then separately georectified and atmospherically corrected the West and East TM images. The East OLYM image became the radiometric base image for all further processing and we radiometrically corrected the West image to the East image using Multiple Alteration Detection Calibration (MADCAL) algorithm (Canty, et al., 2004). Finally, we merged the two images into one for the rest of the processing.

The timing of the OLYM imagery differed from that of MORA and NOCA. There were no cloud-free or low-cloud cover images from 2005 for OLYM's study area, so we purchased 2004 images instead. Since the West and East scenes are located in different Landsat paths, the West image was acquired a week later than the East image.

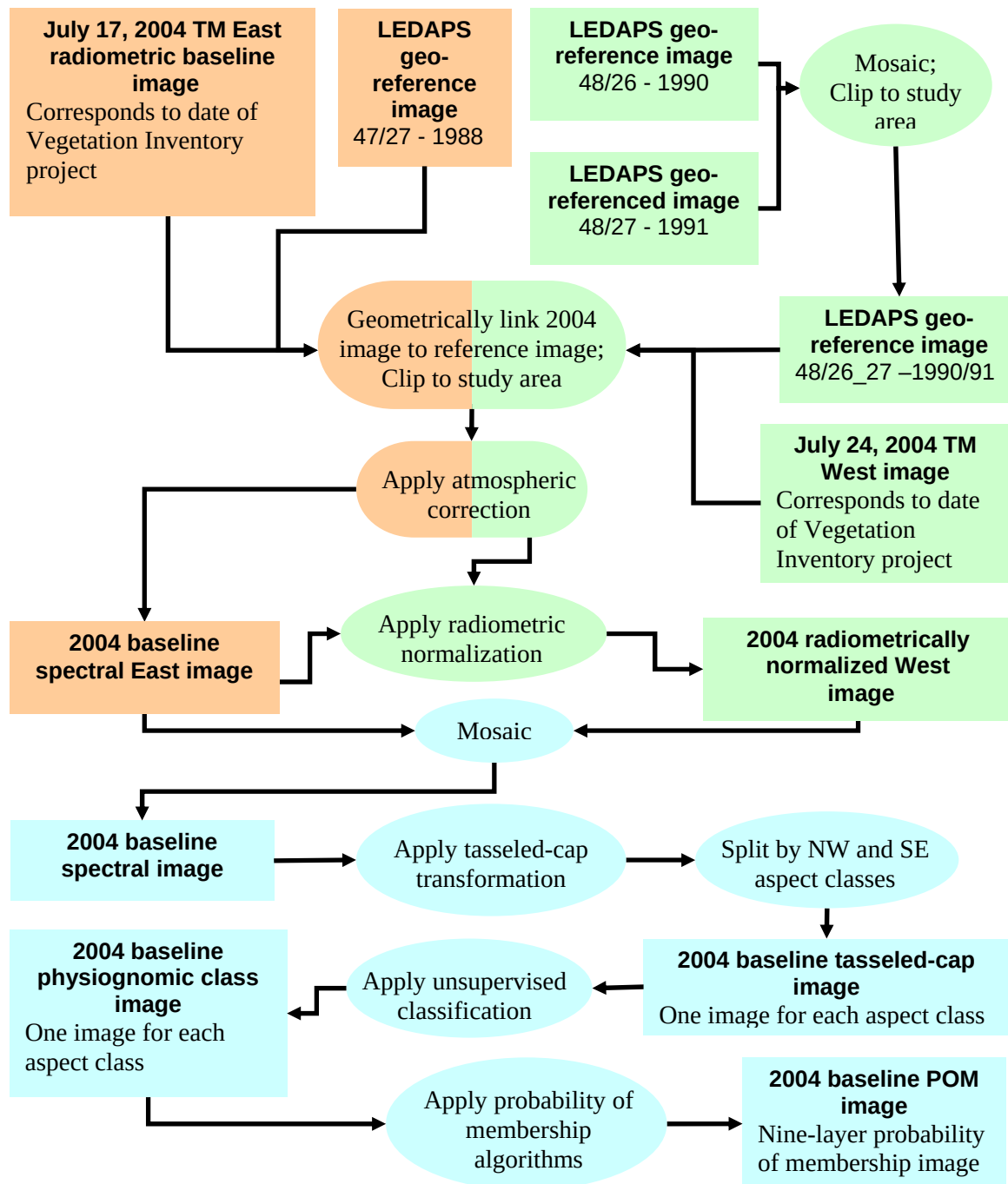


Figure 6. Steps in the startup phase for OLYM. We adjusted the original methodology to incorporate multiple base and reference images that cover the study area. East and West images from 2005 were normalized separately to their respective reference image and atmospherically corrected. The West image was then radiometrically normalized to the East image and the two were merged for classification and translation into POM images for the two aspect classes. Modified from Kennedy et al. 2007a.

Development of Baseline Physiognomic Class Descriptions

Once the physiognomic class foundation images were generated for all three parks, the last part of the start up phase was to summarize the physiognomic classes using field data in order to describe them in terms of park-specific vegetation community types. Regions of spectral space describe broad vegetation classes based on physiognomic properties and have wide geographic applicability. Although class changes can be documented spatially and temporally at a high resolution (30 m), the low resolution of physiognomic classes limits the applicability of the changes to park management without a link to the park-specific vegetation community types that they represent. In order to improve the definition of the broad physiognomic classes and link them to park-specific plant communities, we classified field plots from two vegetation mapping projects described below by their tasseled-cap physiognomic classes. We then summarized plot level vegetation attributes for each physiognomic class and used the information to expand the descriptions of the physiognomic classes.

PMR data

In 1992, the Pacific Northwest Region of the NPS contracted with the private consulting company Pacific Meridian Resources (PMR) to develop and produce a comprehensive Landsat-based vegetation land cover database for four national parks in the region, including MORA, NOCA and OLYM (Pacific Meridian Resources 1996). PMR collected field data within the three parks for the purposes of providing an estimate of vegetative characteristics throughout each park and ground-truthing the vegetation cover map. The field sampling was conducted on nested fixed area plots (1/40, 1/10 and 1/5 acre) systematically located along transects of approximately 1.5 miles long. Transects were positioned to cover variations in vegetation conditions based on spectral reflectance and variations in slope, elevation and aspect. PMR characterized the variation in forested and non-forested vegetative types in the park using the following attributes: tree species, stem density, stand age, tree diameter size class, crown cover by species, stranding dead trees, woody debris accumulation, dominant understory species in forested areas, and species cover in non-forested areas. PMR collected these attributes for 596 plots in OLYM, 395 plots in NOCA and 379 plots in MORA.

ArcGIS software was used to extract the tasseled-cap physiognomic class for each of the PMR plots. For each tasseled-cap physiognomic class, except Water/deep shade and Snow/Ice, we calculated the average and standard deviation of the following variables from the PMR plot data:

- Conifer basal area per acre
- Conifer standing trees per acre
- Hardwood basal area per acre
- Hardwood standing trees per acre
- Snag basal area per acre
- Percent cover for trees < 4.5 feet tall
- Percent cover for trees $\geq$ 4.5 feet tall and < 4.0 inches diameter breast height (DBH)
- Percent cover for bare ground, rock, lesser vegetation, and moss.

For this analysis, we grouped all the PMR plots for each physiognomic class regardless of aspect or elevation.

Each plot was also summarized by understory species and their percent cover within the plot to get an idea of vegetation associations common to each physiognomic class. In this case, each plot was reviewed individually since no average of cover was calculated.

Vegetation Inventory Project

During 2005-2007, NCCN conducted an accuracy assessment of the PMR Vegetation Maps and also developed a vegetation classification for OLYM, MORA and NOCA (Crawford et al. 2009). The project used a targeted approach to sample in areas or vegetation types known to be gaps in previous vegetation classification work in the region. A fixed radius plot was used and plot size was scaled depending on vegetation structure. The field crews recorded the following vegetation characteristics within each plot: physiognomic class, leaf type and phenology, the cover of dominant species by vertical layers (strata), and crown cover (in classes) by species for all species seen in the plot. The project also used several legacy datasets for MORA and OLYM, which were incorporated into the project database.

We used ArcGIS software to extract class designations from the classified physiognomic maps for 546 Vegetation Inventory plots in MORA, 600 plots in NOCA and 581 plots in OLYM. We then used the Vegetation Inventory project database to summarize plots by categorical classes of Leaf-type, Physiognomy, and Phenology. This allowed us to determine which categories were most common to each of the physiognomic classes. The Vegetation Inventory project database also contained structure and diameter information for the PMR plots. This information was also summarized for each physiognomic class by park.

NCCN ecologists used the summary statistics from PMR and Vegetation Inventory project plots, in combination with the 2006 1-meter National Agricultural Inventory Program (NAIP) aerial photography, to develop more detailed descriptions of the tasseled-cap based physiognomic classes, attempting to explicitly link the spectral classes to vegetation of NCCN. Because field plots from other mapping efforts were used, rather than collecting data specifically for this effort, some physiognomic classes were underrepresented.

Type I Change Detection

We undertook Type I change detection for the disturbance events in Table 1 by comparing 2005 (MORA, NOCA) or 2004 (OLYM) images with a 2006 image. We chose the imagery dates to be not only cloud-free and as close as possible to the peak of vegetation growth, but also as close as possible to change interval's beginning date. This was done to minimize artificial spectral changes due to differences in sun angles between the two dates. We used August 17, 2006 scenes for both MORA and NOCA. OLYM West and East images had to be separated by almost a month (June 28 and July 23, 2006, respectively) due to cloud cover. Figure 7 shows processing steps for the MORA and NOCA Type I change detection. The steps did not differ from the steps described in the original protocol. We applied a threshold level of 80 to the differenced POM image for each park to map high-certainty changes where probability of physiognomic class membership changed dramatically. While there is no one correct threshold level for change detection, the level of 80 was suggested in the original protocol SOPs as a good starting point. We then used the labeling algorithm to arrive at the final change products for all parks.

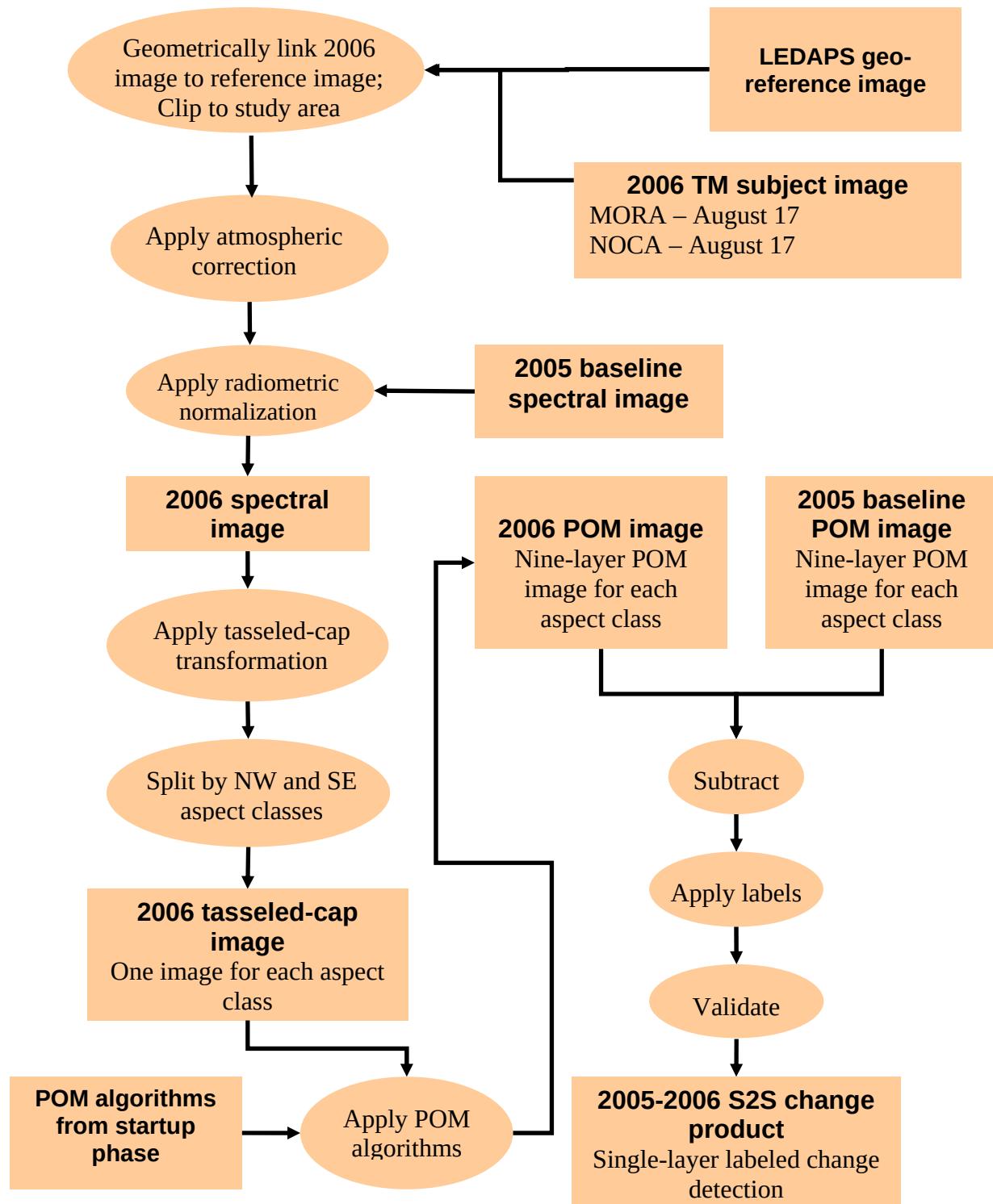


Figure 7. Steps in 2005-2006 Type I change detection for MORA and NOCA. An image from 2006 was normalized and converted to a POM image based on POM algorithms developed for the 2005 baseline images. POM images from 2006 and 2005 were subtracted, creating POM difference images. These are translated to satellite-to-satellite (S2S) labels allowing for direct S2S validation.

As with the “startup” phase, we slightly modified processing steps for the OLYM’s Type I change detection to accommodate the two scenes (Figure 8). We separately geometrically and atmospherically corrected West and East scenes. Then, we radiometrically linked two of the 2006 images to the 2004 East image, creating a baseline radiometric image. After radiometric correction, we merged the two images together and followed the original processing steps described in the protocol.

We developed snow, cloud and shadow masks to be applied to the NOCA’s change layer before the labeling stage. We hoped that the masks would minimize the false positives associated with changing cloud cover, snow levels and shadows and reduce the number of polygons for interpretation in the final product. We generated the masks using an unsupervised classification and adjusted them by taking out all known water bodies plus a 100-meter buffer around their perimeters. Application of masks did not significantly reduce the number of NOCA’s final polygons that needed to be interpreted (129476 from 165311) and the mask development efforts were abandoned. Instead, we took a different approach and, during the sieving stage of the analysis, we increased the minimum mapping size from 6 pixels (0.375 ha) to 16 pixels (1 ha). This eliminated from the final change layer any clusters of polygons of similar change with area less than one hectare. Increasing the minimum mapping size reduced the number of final polygons to 76,679, but also potentially eliminated a significant number of change polygons of interest to the park. We then increased the minimum mapping size for the other two parks to 16 pixels for consistency.

During the labeling portion of the image processing, each pixel was assigned to one of the 15 “Satellite to Satellite” (S2S) interpretation change classes shown in Table 2 based on the calculated differences in POM for that pixel.

Table 2. Satellite to Satellite (S2S) interpretation change classes (from Kennedy et al. 2007a).

S2S Code	Class description
1	No change
2	water/shade to rock/soil
3	Water/shade to partial vegetation cover
4	Water/shade to complete vegetation cover
5	Rock/soil to water/shade
6	Partial vegetation to water/shade
7	Complete vegetation to water/shade
8	Increase in broadleaf
9	Increase in conifer
10	Increase in vegetation
11	Decrease in broadleaf
12	Decrease in conifer
13	Decrease in vegetation
14	Increase in snow
15	Decrease in snow

An individual pixel was assigned to an S2S change class based on whether its POM decreased or increased within each physiognomic class. For example, if a pixel had an increase in POM within the “Conifer-broadleaf mix” physiognomic class, while simultaneously having either no

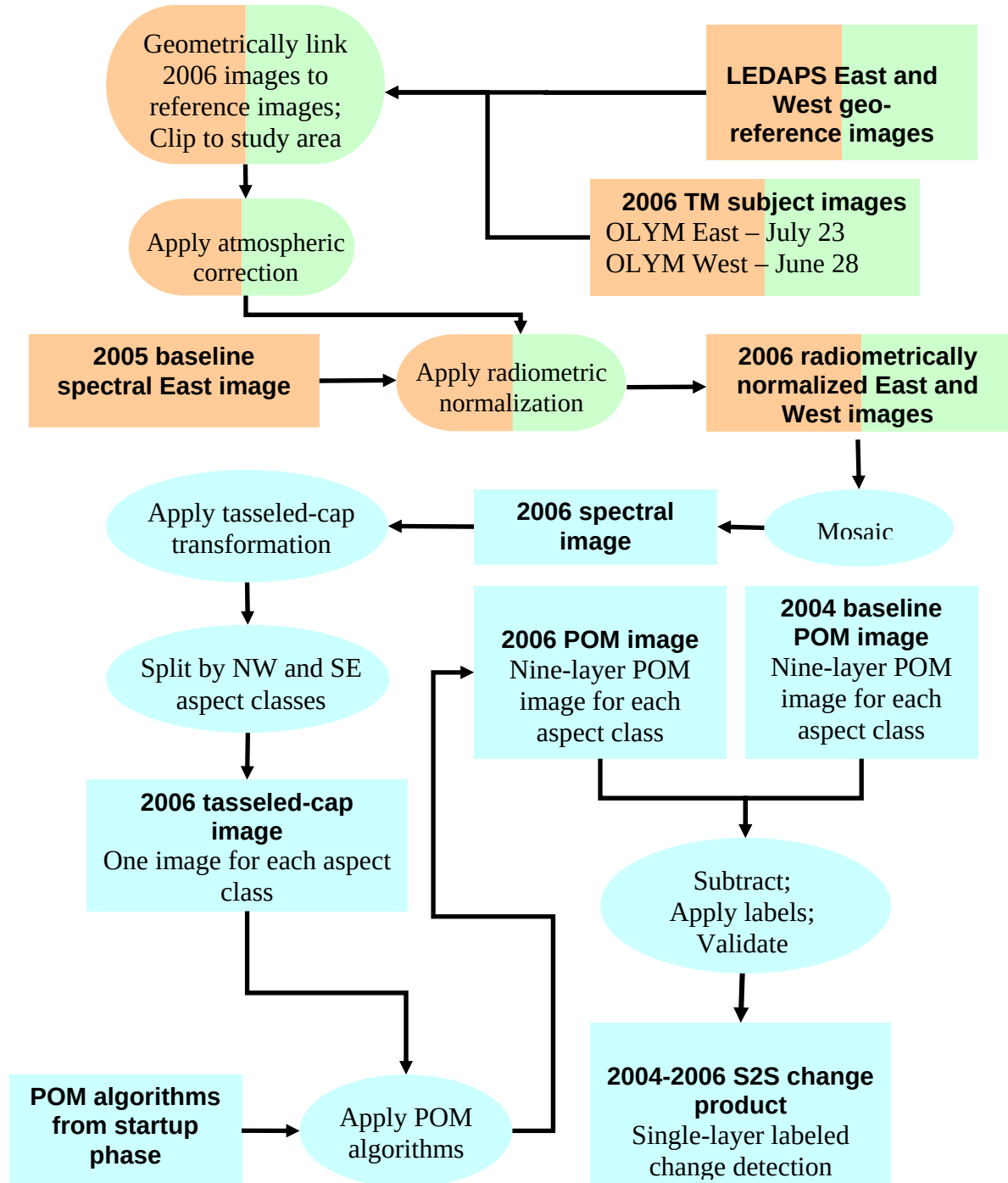


Figure 8. Steps in 2004-2006 Type I change detection for OLYM. East and West images from 2006 were georectified to their corresponding LEDAPS images, atmospherically corrected, and radiometrically normalized to the 2004 baseline East spectral image. After merging, the POM algorithms developed for the 2004 baseline image were applied to the 2006 image. POM 2006 and 2004 images was subtracted and translated to satellite-to-satellite (S2S) labels.

decreases in other classes or decreases in either “Mixed” or one of the “Open” categories, and if these changes passed the selected threshold level, the pixel was assigned to an “Increase in vegetation” S2S change class. Similarly, if a pixel with a high probability of being in “Closed-canopy conifer” class had a decrease in that category or an increase in the “Mixed” or the two “Open” classes, and the magnitude of changes was big enough to pass the selected threshold level, the pixel was assigned the “Decrease in conifer” S2S change class. The changes could take place both within and among the different physiognomic classes, thereby allowing detection of slow disturbance or regeneration. The rules used to assign pixels to an S2S change class are shown in Table 3.

Table 3. Linking observed increases and decreases in probability of membership (POM) with S2S change classes. Values are most probable S2S change class code (1-15), given decreasing POM in the row heading and increasing POM in the column heading. From Kennedy et al. 2007a.

		Increasing									
Decreasing		No increases	Water/deep shade	Closed-canopy conifer	Conifer-broadleaf mix	Dense broadleaf/grass	Broadleaf tree/shrub	Mixed	Open: dark	Open: bright	Snow and ice
	No decreases	1	1	9	10	8	8	10	1	1	14
	Water/deep shade	1	n.a.	4	4	4	4	3	2	2	14
	Closed-canopy conifer	12	7	n.a.	8	8	8	12	12	12	14
	Conifer-broadleaf mix	13	7	9	n.a.	8	8	13	13	13	14
	Dense broadleaf/grass	11	7	9	9	n.a.	11	11	11	11	14
	Broadleaf tree/shrub	11	7	9	9	8	n.a.	11	11	11	14
	Mixed	13	6	9	10	8	8	n.a.	13	13	14
	Open: dark	1	5	9	10	8	8	10	n.a.	1	14
	Open: bright	1	5	9	10	8	8	10	1	n.a.	14
	Snow and ice	15	15	15	15	15	15	15	15	15	n.a.

Once we assigned the pixels to an S2S change class, we calculated the number of hectares within each change class of the final product for the three parks. We also calculated the proportion of each buffer area, as well as the proportion of each park, affected by each type of change.

Visual Validation of Change Detection Products

We generated 1.5 km by 1.5 km random grid validation boxes representing 5% of the three study areas. We looked at tasseled-cap imagery from the two change-interval years, a differenced tasseled-cap image and the 2006 National Agricultural Inventory Program (NAIP) aerial photography to outline and label areas of change within these validation boxes. After outlining areas that appeared to have changed, we visually compared the tasseled-cap images from the initial and final years of change detection to determine the physiognomic classes of starting and ending points of pixels within the outlined areas. Table 3 was then used as a guide to determine

the final label for the outlined polygon. For example, if the starting location of an area appeared to be within the “Mixed” physiognomic class and the final location was visually determined to be within “Conifer/broadleaf mix” class, the label of “Increase in vegetation” was assigned to the area of change. We then used the outlined change and no change areas within the validation boxes to randomly generate accuracy assessment points, drawn equally from the change and no-change areas, for two types of accuracy assessment. The first type of accuracy assessment determined how well the computer algorithm detected change. The second type assessed the accuracy of assigning labels based on the 15 S2S change classes shown in Table 3. The reference labels for the accuracy assessment points were determined by the algorithm using the Majority Threshold rule. At least 4 out of 9 pixels around the accuracy assessment point needed to be included within the change polygon outlined by the interpreter for it to be labeled as “Change.”

Accuracy assessment of change detection

For each park, we collapsed all change categories derived from S2S visual validation into two classes: “Change” and “No change.” We did the same with all of the satellite classification-generated categories. Then we compared the visual validation and classification categories to determine how well the satellite classification detected change. We calculated the overall classification accuracy for all three parks, as well as Producer’s and User’s Accuracies of both “Change” and “No change” categories. The overall accuracy is the number of correct observations divided by the number of observations. This is a very crude measure of accuracy. Producer’s Accuracy is a measure of how accurately the computer classified the pixels by category. The Producer’s Accuracy details the errors of omission. An error of omission results when a point is incorrectly classified into another category. The pixel is omitted from its correct class. User’s Accuracy details errors of commission. An error of commission results when a point is committed to an incorrect class.

We also calculated a Kappa statistic that expresses the proportionate reduction in error generated by a classification process compared with the error of a completely random classification. For example, a value of 0.82 implies that the classification process is avoiding 82 percent of the errors that a completely random classification generates (Congalton, 1991). It is an accuracy measure that is more robust than overall accuracy measures.

Accuracy assessment of change labeling

Following the accuracy assessment of the change itself, we conducted an accuracy assessment of the computer-generated labels for the three parks. The methodology for this type of accuracy assessment was identical to the one used for the accuracy assessment of change detection, except that the full 15-class S2S change products were used. We compared interpreter- and algorithm-assigned labels for the random points generated for the accuracy assessment and produced contingency tables and classification accuracy statistics for each park.

Results

Development of Baseline Physiognomic Class Images

Figure 9 shows the distribution of nine physiognomic classes within the NOCA boundary and the study area. Table 4 summarizes the proportion of the park and the study area occupied by these broad physiognomic classes.

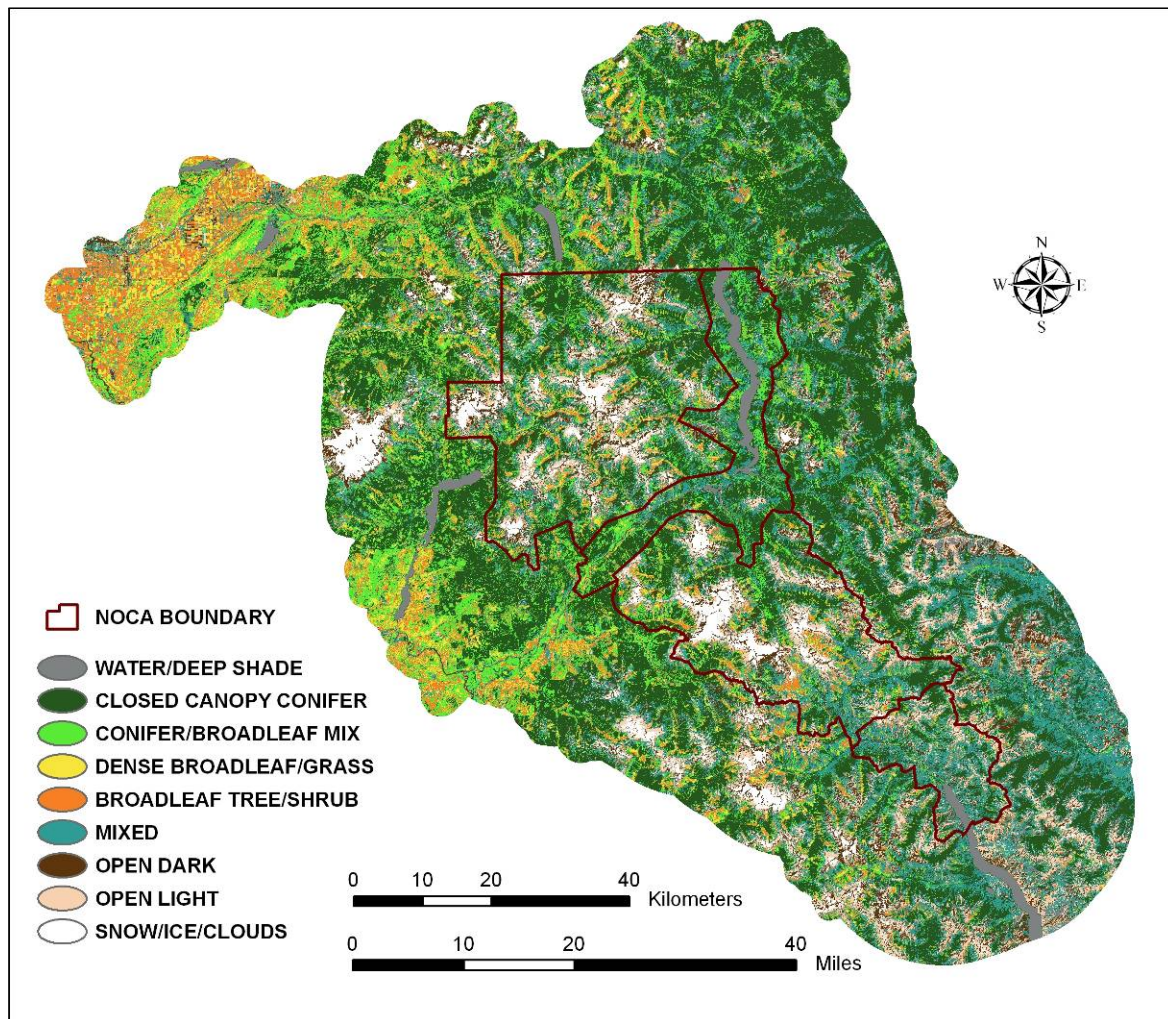


Figure 9. NOCA physiognomic class map based on 2005 TM imagery. General descriptions of classes were derived from their predictable spectral characteristics within tasseled-cap spectral space. They were later expanded based on 1994 and 2005-2007 field data.

“Closed-canopy conifer” category is the largest physiognomic class represented within NOCA and entire study area. Next largest in the extent is the “Mixed” class, whose pixels includes a combination of vegetation and soil, followed by the “Conifer/broadleaf mix” class (Table 4). As expected, the percentage of pixels in the “Mixed” and “Snow/ice/clouds” classes are higher within the park boundary, reflecting higher frequency of high elevation areas with partial

vegetation and snow cover as compared to the lower elevation areas which dominate areas outside the park boundary.

Table 4. Number of hectares and proportion of the area occupied by each physiognomic class within NOCA and its buffered study area.

Physiognomic class	Hectares			% Area		
	Park	Buffer	Total	Park	Buffer	Total
Water/deep shade	11891	17735	29626	4.31	2.18	2.72
Closed-canopy conifer	80465	285478	365942	29.19	35.04	33.56
Conifer/broadleaf mix	33098	142931	176029	12.01	17.54	16.14
Dense broadleaf/grass	9576	50775	60351	3.47	6.23	5.54
Broadleaf tree/shrub	14183	50699	64882	5.15	6.22	5.95
Mixed	66991	157409	224400	24.30	19.32	20.58
Open: dark	26070	65307	91377	9.46	8.02	8.38
Open: bright	13310	25746	39056	4.83	3.16	3.58
Snow/ice/clouds	20073	18579	38651	7.28	2.28	3.54
Total	275657	814657	1090314			

Table 5 summarizes the proportion of MORA and its study area occupied by each of the nine physiognomic classes. Figure 10 shows the distribution of the nine classes within the MORA study area.

Table 5. Number of hectares and proportion of the area occupied by each physiognomic class within MORA and its study area.

Physiognomic class	Hectares			% Area		
	Park	Buffer	Total	Park	Buffer	Total
Water/deep shade	2164	2213	4377	2.27	0.74	1.11
Closed-canopy conifer	40465	105946	146411	42.53	35.29	37.03
Conifer/broadleaf mix	9836	78509	88345	10.34	26.15	22.34
Dense broadleaf/grass	1951	24658	26609	2.05	8.21	6.73
Broadleaf tree/shrub	3984	14371	18355	4.19	4.79	4.64
Mixed	14477	52090	66567	15.21	17.35	16.84
Open: dark	11390	11209	22600	11.97	3.73	5.72
Open: bright	4887	11238	16126	5.14	3.74	4.08
Snow/ice/cloud	5996	1	5997	6.30	0.00	1.52
Total	95150	300235	395386			

Similar to NOCA, “Closed-canopy conifer” class is the most frequently observed category at MORA and surrounding areas covering 42.5 and 35% of the areas, respectively, followed by the “Mixed” and “Conifer/broadleaf mix” classes. “Open: dark,” “Open: bright” and “Snow/ice/cloud” classes are also well represented within the park boundary at 12%, 5% and 6% each, reflecting extensive areas of wet and dry rock and soil below Mt. Rainier’s glaciers. Physiognomic classes with broadleaf component show up in higher percentages in the areas outside of park boundaries (over 39% overall), especially to the west of the park, reflecting agricultural and forest management activities prevalent in this area.

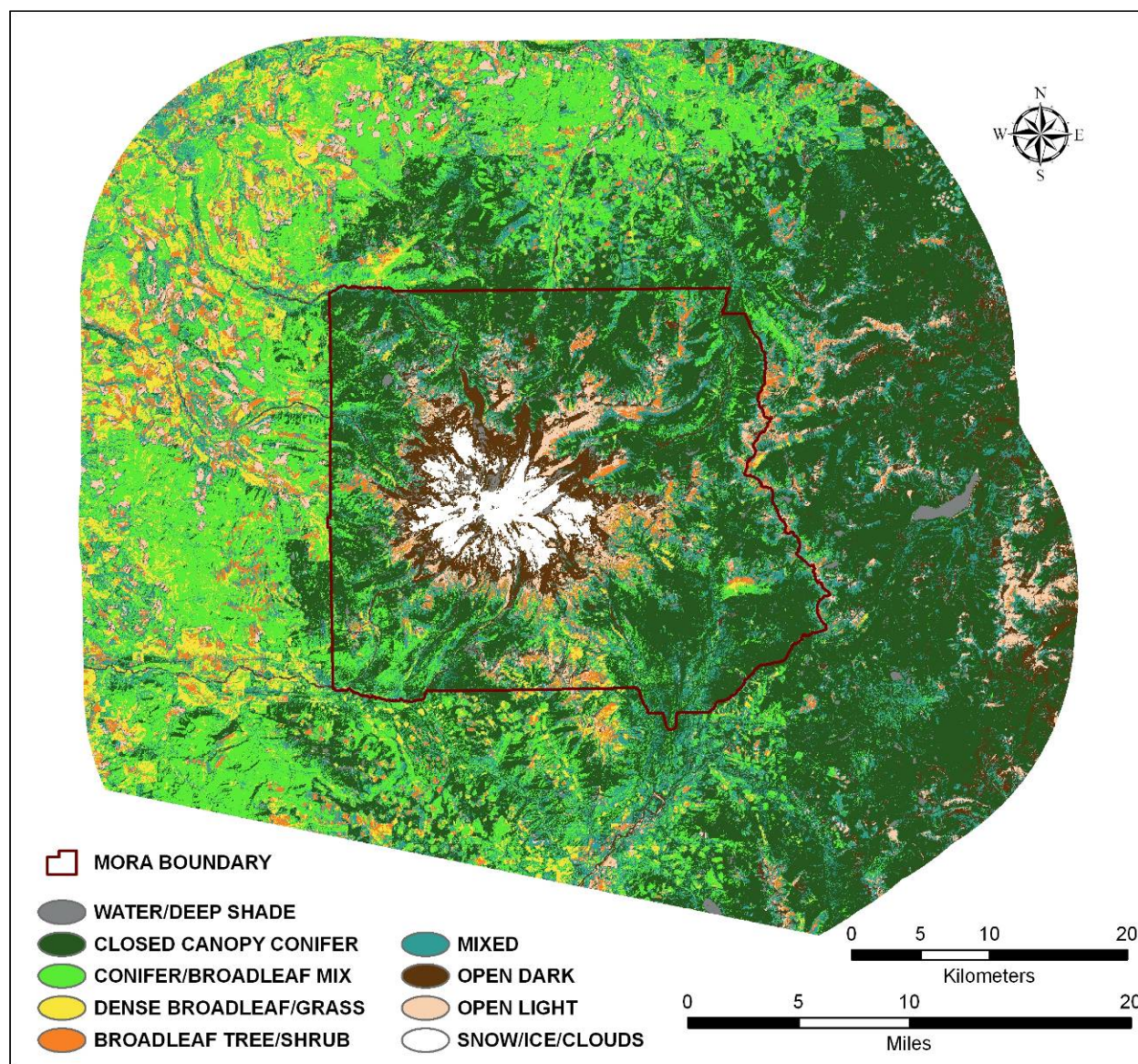


Figure 10. MORA physiognomic class map based on 2005 TM imagery. General descriptions of classes were derived from their predictable spectral characteristics within tasseled-cap spectral space. They were later expanded based on 1994 and 2005-2007 field data.

Figure 11 shows the distribution of nine physiognomic classes within the OLYM boundary and its study area. “Closed-canopy conifer” is the prevailing category of land cover found within the park boundary covering 60% of the area. “Conifer/broadleaf mix” and “Mixed” classes are the next most common categories, with 15% and 11%, respectively, representing riparian vegetation and high elevation areas. The areas outside the park are dominated by the “Conifer/broadleaf mix” and “Dense broadleaf/grass” categories at 37% and 10%, respectively. Table 6 summarizes the proportion of the park and the study area occupied each of the nine physiognomic classes at OLYM.

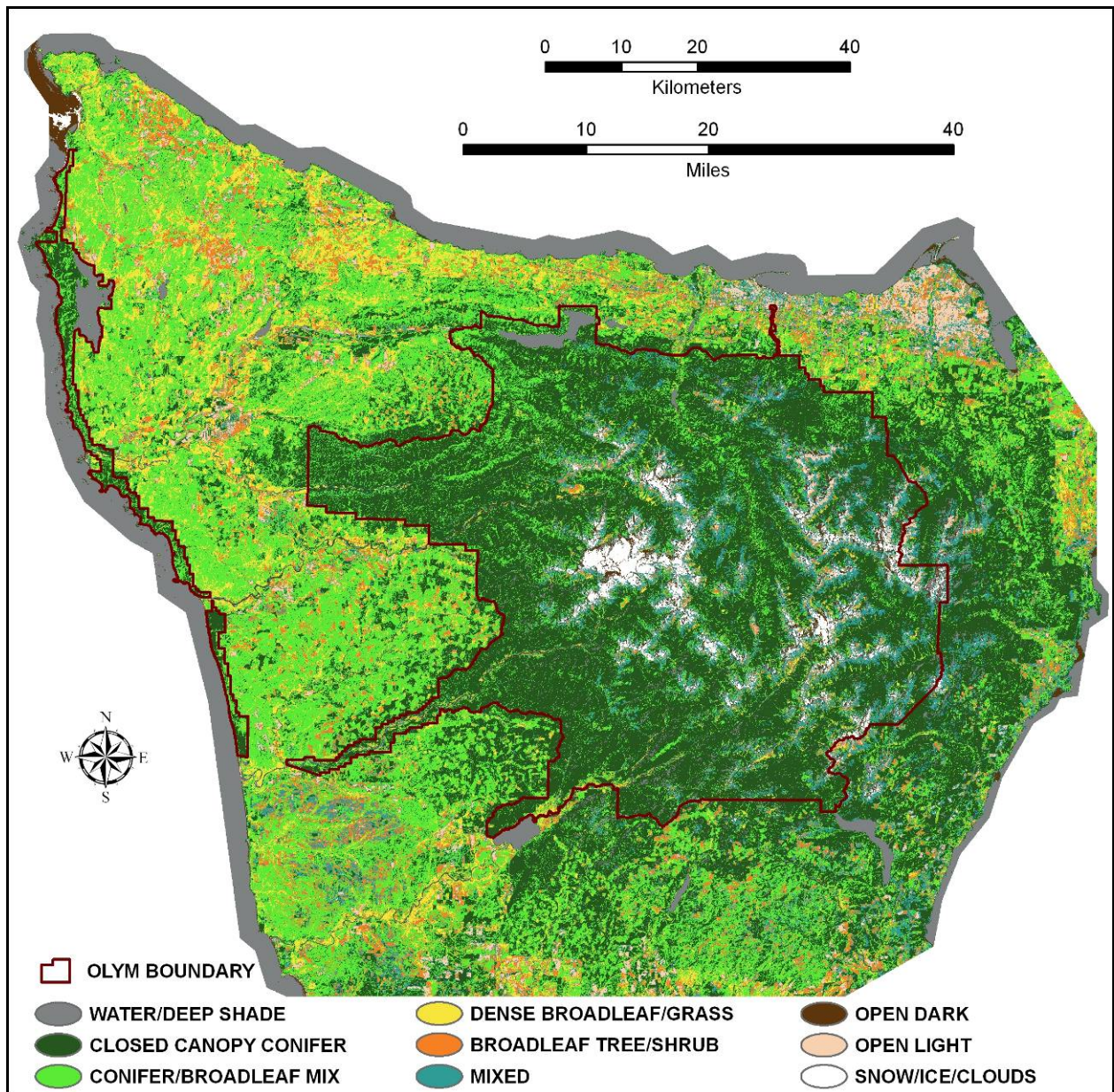


Figure 11. OLYM physiognomic class map based on 2004 TM imagery. General descriptions of classes were derived from their predictable spectral characteristics within tasseled-cap spectral space. They were later expanded based on 1994 and 2005-2007 field data.

Table 6. Number of hectares and proportion of the area occupied by each physiognomic class within OLYM and its study area.

Physiognomic class	Hectares			% Area		
	Park	Buffer	Total	Park	Buffer	Total
Water/deep shade	13385	88023	101408	3.62	10.18	8.22
Closed-canopy conifer	221808	204354	426162	60.00	23.64	34.53
Conifer/broadleaf mix	55340	323780	379120	14.97	37.45	30.72
Dense broadleaf/grass	3428	88450	91878	0.93	10.23	7.44
Broadleaf tree/shrub	8097	73312	81409	2.19	8.48	6.60
Mixed	40672	55117	95789	11.00	6.38	7.76
Open: dark	8614	8104	16718	2.33	0.94	1.35
Open: bright	4212	22097	26308	1.14	2.56	2.13
Snow and ice	14100	1304	15403	3.81	0.15	1.25
Total	369656	864539	1234196			

Development of Baseline Physiognomic Class Descriptions

PMR data and Vegetation Inventory project

Appendices A and B contain summaries of the PMR and Vegetation Inventory project data that were used to develop more detailed descriptions of the nine physiognomic classes that would assist class change interpretation. Table 7 shows the new descriptions of classes generated by NCCN plant ecologists.

Table 7. Detailed physiognomic class descriptions derived from NCCN vegetation plots.

Physiognomic Class	Detailed Physiognomic Class Description
Closed-canopy conifer	Coniferous forest ranging from sea level to forestline (about 5700' elevation) with understory ranging from low growing herbaceous plants to tall shrubs such as white rhododendron and thinleaf huckleberry. Found on all aspects and slope positions. Some sites may have a slightly open canopy, but the taller understory shrubs contribute to a closed canopy reflectance signature.
Conifer/broadleaf mix	Forest with an open canopy, ranging from open wet lowland areas with devil's club, big leaf maple, or ferns to open montane areas with subalpine herbaceous understory such as lupine or evergreen shrubs. In OLYM and MORA, the hardwood basal area does not seem to change much between closed-canopy forest and this category, but there is a significantly greater amount (density and basal area) of hardwoods in this category in NOCA (than closed-canopy).
Dense broadleaf/grass	Broad-leaved, deciduous shrubland.
Broadleaf tree/shrub	Low-statured vegetation, usually mixed with bare ground. Includes subalpine/alpine meadows, dwarf shrubland and herbaceous categories.
Mixed	Open forest to sparse woodland. Shrubs predominate and some bare ground is present.
Open: dark	Rock or bare ground of at least 20% cover or in partial sun; species lists include moist-tolerant species such as willows and devil's club.

Physiognomic Class	Detailed Physiognomic Class Description
Open: bright	Areas with at least 30% cover of rock or bare ground. Subalpine meadows or forest openings with incomplete vegetation cover where, if trees are present, they are relatively short (<4').

Type I Change Detection

NOCA

Figure 12 shows the results of the 2005-2006 NOCA change detection at the threshold level of 80. We made several general observations concerning differences between 2005 and 2006 images. First, the amount of shadow increased in 2006 image due to the two-week difference between the timing of 2005 and 2006 images (July 29th and August 17th, respectively) and the lower sun angle at the later date. The increase in shadow resulted in 2006 image appearing darker, with a high number of “Vegetation to water/shade” or “Soil/rock to water/shade” labels. Second, there were higher snow levels in 2006 imagery, even though the image was taken later in the year. At comparable higher elevations on both east and west sides (1800 m east side vs. 1500 m west side) less vegetation was observed in 2006 because it has not fully emerged yet following snowmelt – leading to a high number of “Decrease in vegetation” polygons. Popcorn clouds and cloud shadows were present throughout the study area in both years, resulting in a large number of “Vegetation to water/shade” and “Increase in snow” labels. Some of the “Increase in broadleaf” labels resulted when locations covered by clouds and shadows in 2005 became unobscured in 2006, revealing vegetation.

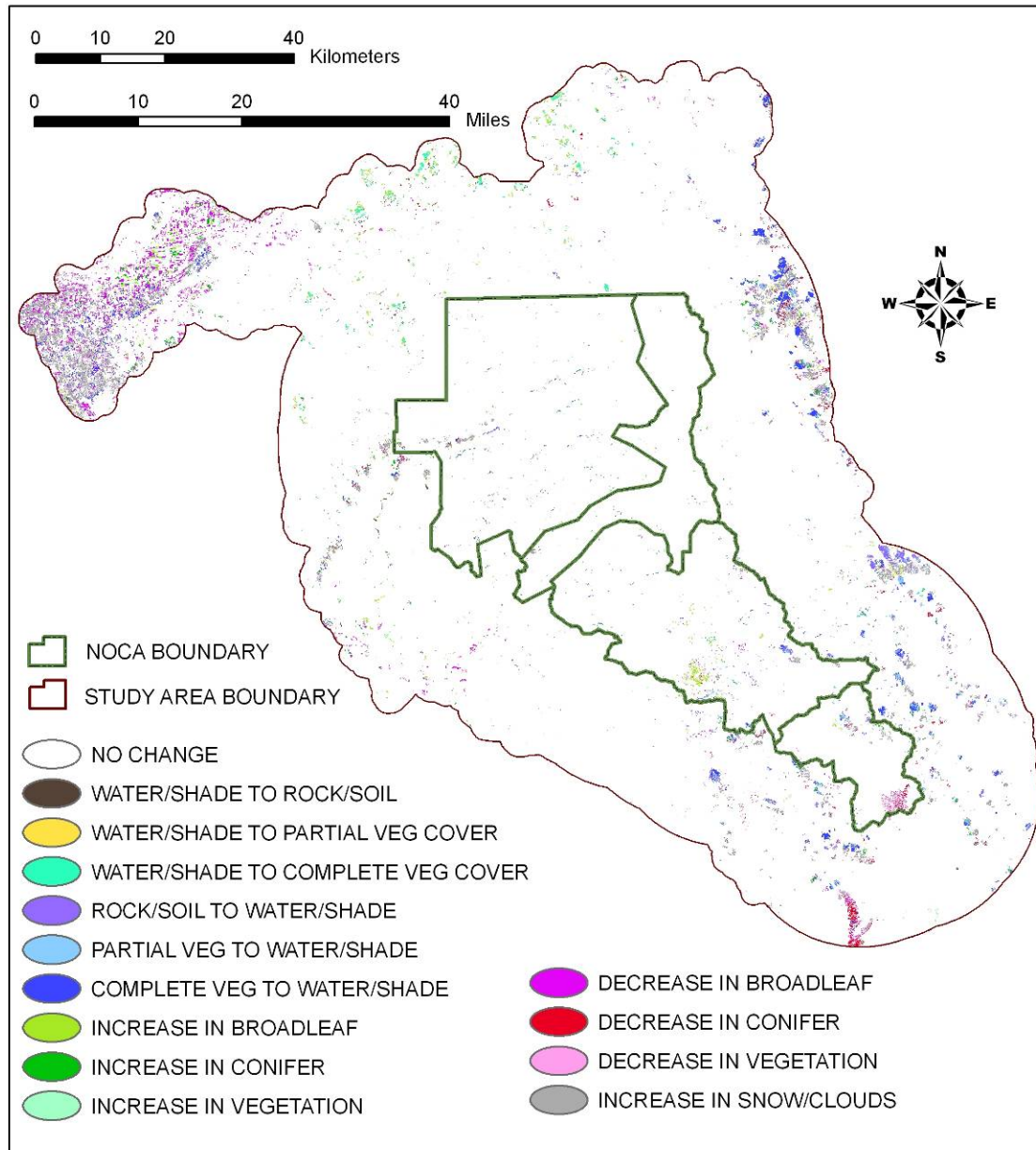


Figure 12. NOCA 2005-2006 satellite-to-satellite labeled change image. Minimum mapping area of one hectare and threshold level of 80 were applied to raw change detection results.

The northwestern-most part of the study area, covering the Chilliwack valley of British Columbia, is heavily agricultural. A large number of polygons labeled “Increase in vegetation or “Decrease in vegetation” came from this area as fields were newly replanted or left fallow (Figure 13). The picture was further complicated by a large number of popcorn clouds

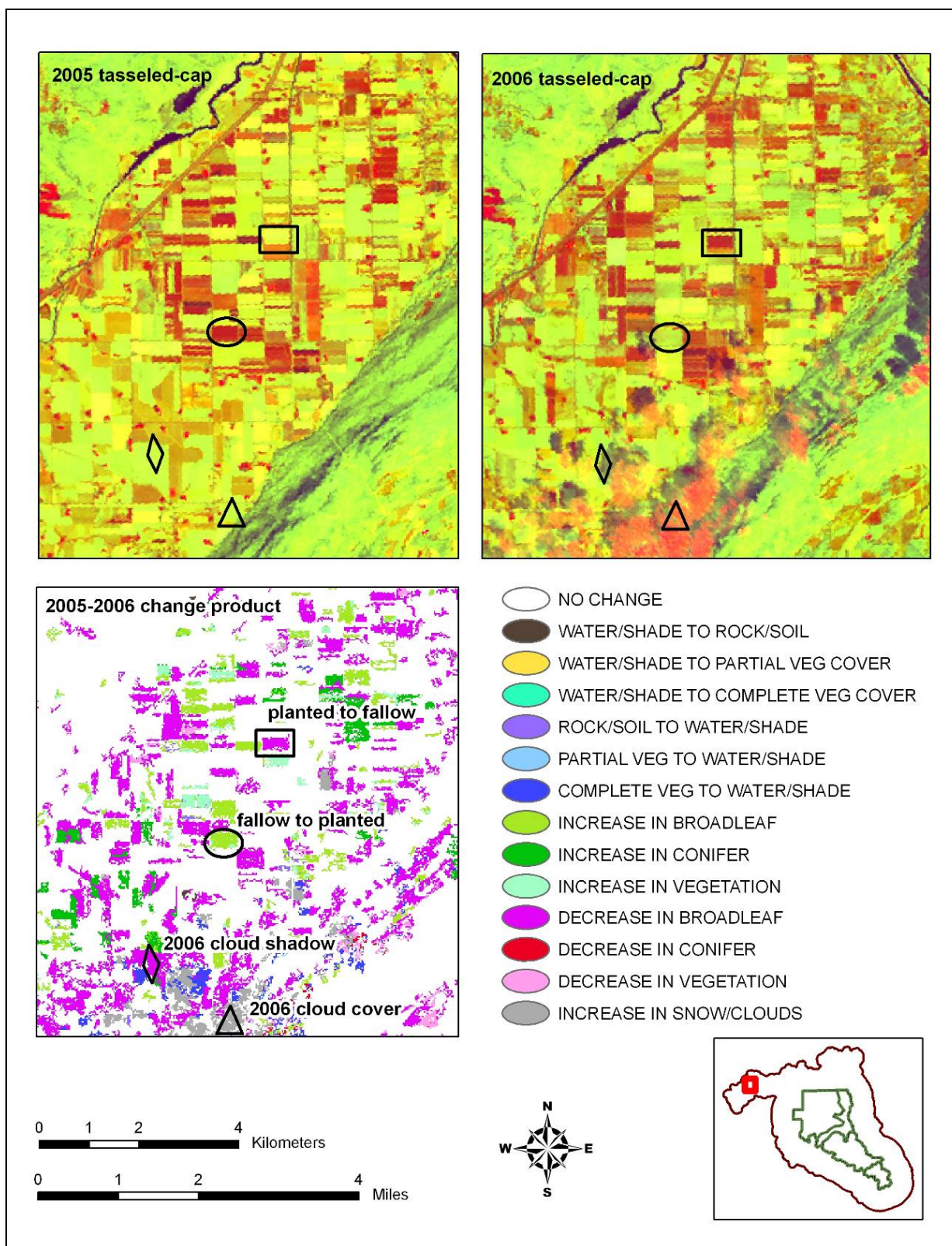


Figure 13. Detected agricultural activity and cloud changes between 2005 and 2006 in Chilliwack Valley, BC.

present in 2006 in this area. We calculated the total number of acres that changed in NOCA and the study area within the fifteen S2S classes in Table 8, along with percent of park and study area that these change polygons represent.

Table 8. Number of hectares and proportion of NOCA and its study area occupied by 2005-2006 change polygons.

S2S Change Class	Buffer		Park	
	Area changed (ha)	Proportion of buffer (%)	Area changed (ha)	Proportion of park (%)
No change	774373	95.13	271725	98.57
Water/shade to rock/soil	258	0.03	43	0.02
Water/shade to partial vegetation cover	244	0.03	31	0.01
Water/shade to complete vegetation cover	998	0.12	59	0.02
Rock/soil to water/shade	2061	0.25	339	0.12
Partial vegetation to water/shade	1981	0.24	295	0.11
Complete vegetation to water/shade	5599	0.69	338	0.12
Increase in broadleaf	2626	0.32	556	0.20
Increase in conifer	2399	0.29	375	0.14
Increase in vegetation	786	0.10	138	0.05
Decrease in broadleaf	6967	0.86	194	0.07
Decrease in conifer	1821	0.22	253	0.09
Decrease in vegetation	2322	0.29	550	0.20
Increase in snow/cloud	11585	1.42	763	0.28
Decrease in snow/cloud	0	0.00	0	0.00

Ninety-five percent of the area surrounding NOCA's boundary remained unchanged from 2005 to 2006. As expected, the changes were less extensive within the park boundary with 98.7% of area remaining unchanged. Overall, NOCA experienced 0.42% increase in vegetation and 0.59% decrease in vegetation. The majority of decrease came from the "Decrease in vegetation category." Summing all classes that represent an increase or decrease in vegetation, areas surrounding the park showed 0.86% increase in vegetation and 1.9% decrease in vegetation classes. A visual examination of the imagery from the two dates and the difference image showed that the majority of the "Water/shade to partial vegetation cover" and "Water/shade to complete vegetation cover" categories were a result of 2005 cloud shadows, which obscured the underlying land cover. Similarly, "Partial vegetation to water/shade" and "Complete vegetation to water/shade" labels were usually assigned to areas that were cloud shadows in 2006. These

categories should probably be ignored when calculating the overall increases and decreases in vegetation since there is no way to determine whether or not they are a result of changes in clouds and cloud shadows or legitimate changes between water and vegetation cover types.

Within the park boundary, the largest changes were within the “Decrease in vegetation” change class (0.2 %) that resulted when a pixel went from a “Conifer-broadleaf mix” or “Mixed” class to one of the “Open” classes (Table 3). Close examination of the imagery revealed that the majority of these changes resulted from either phenological differences in vegetation at higher elevations or large fires that took place in the summer of 2006. Similarly large changes were seen within the “Increase in the broadleaf” category resulting from a pixel moving from one of the “Open” or a “Mixed” category to one of the “Broadleaf” categories.

Caution should be exercised when interpreting changes in the “Increase in conifer” class both within and outside the park boundary. The areas that were often assigned to this change class had a high probability of being in the “Closed-canopy conifer” physiognomic class in 2005 and were covered by cloud shadows in 2006, thereby appearing spectrally darker, similar to a more mature conifer forest. The large areas within the “Decrease in broadleaf” category outside of park boundary appeared to be a result from the agricultural activities in Chilliwack Valley, B.C. Changes within the “Increase in snow” category was mostly attributed to increased cloud cover in 2006 image.

MORA

Figure 14 shows the results of the 2005-2006 MORA change detection at the threshold level of 80. We made several general observations concerning differences between 2005 and 2006 images. Minimum differences in shade existed because the images were taken only three days apart and there was no significant change in sun angle. Similar to the NOCA images, the 2006 MORA image appeared significantly darker than the 2005 image. Both soil and vegetation appeared much darker and wetter in 2006. The northwest corner of the study area was completely covered by clouds in 2006, appearing as “Complete vegetation to water/shade” change class in the final change image. We detected a large number of clearcuts in areas where the cloud cover did not obscure the satellite view. These areas are shown with the “Decrease in vegetation” label on the final image.

The eastern part of the study area, outside of park boundary, was significantly affected by a reduction of greenness signal. These areas show up having a “Decrease in conifer” label in the final image. Similar areas were detected within the park boundary, but their extent and severity were much smaller. Further annual and decadal change detection might help in identifying the cause and the extent of these spectral differences. Additional losses in greenness are visible around the perimeter of Mt. Rainier’s snow line, reflecting higher snow levels of 2006.

Eighty-five percent of the area surrounding MORA’s boundary remained unchanged from 2005 to 2006 (Table 9). As with NOCA, the changes were less extensive within the park boundary with 97.3% of MORA remaining unchanged. Overall, areas around MORA’s boundary had pronounced decreases within the “Closed-canopy conifer” physiognomic class (5.3%), which results in a change of physiognomic class. It is possible that some of the disturbance in these areas was “artificial,” resulting from 2006 cloud cover. However, from the experience we gained while validating the change detection, the areas under the cloud cover in the later year of the

change interval were usually assigned a “Vegetation to water/shade” label rather than a “Decrease in vegetation” label. Clouds therefore likely caused a large portion of the areas outside of park boundary (6.5%) to be classified in either “Partial” or “Complete vegetation to water/shade” categories. MORA also had decreases in broadleaf, mixed and partial vegetation categories, most of which were due to increased snow level in 2006 image and could be traced to higher elevation areas just below the permanent snow and ice belt of Mount Rainier. Some of these losses were also likely related to disturbances caused by storms of the fall and winter 2005-2006.

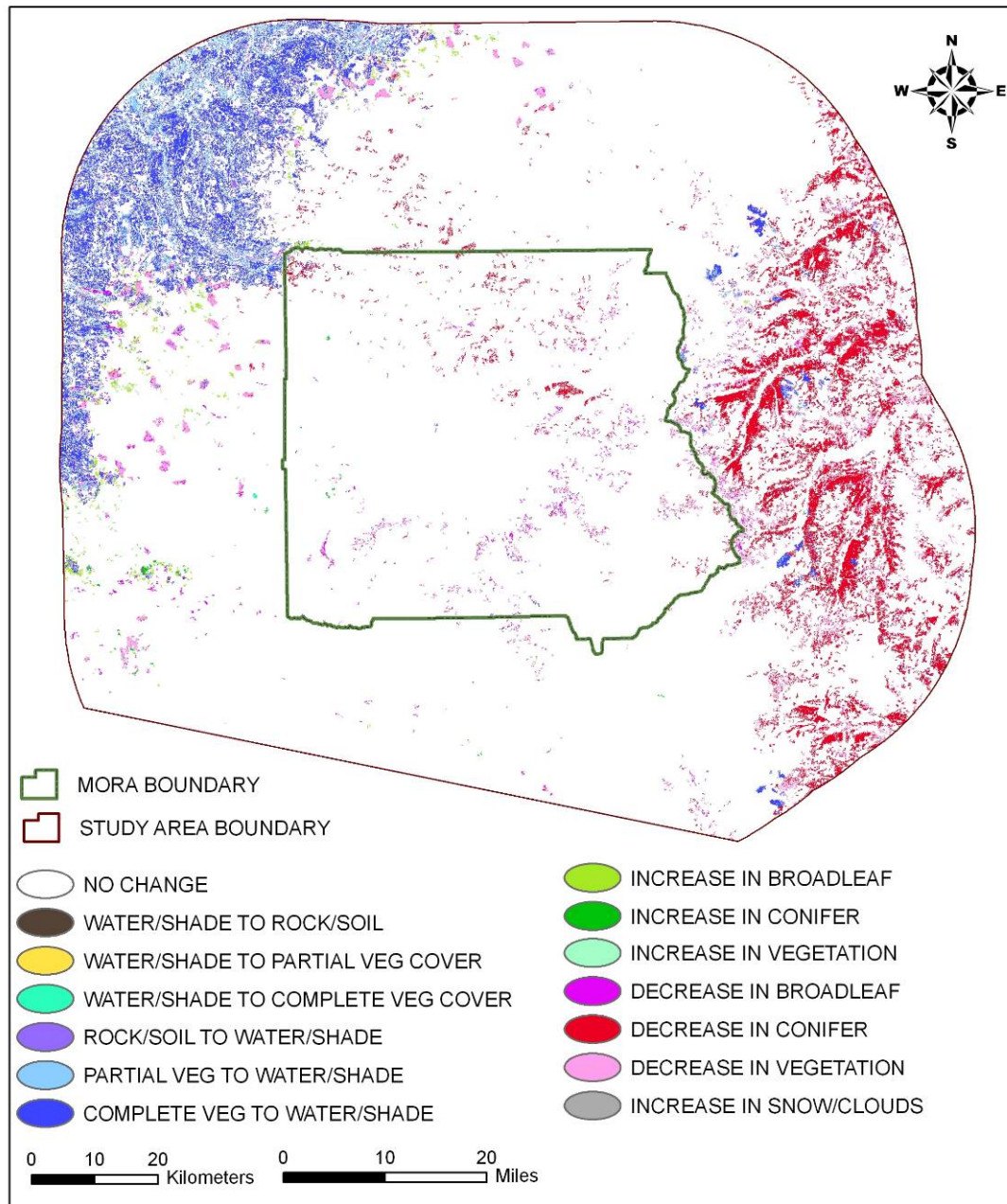


Figure 14. MORA 2005-2006 satellite-to-satellite labeled change image. Minimum mapping area of one hectare and threshold level of 80 were applied to raw change detection results.

Table 9. Number of hectares and proportion of MORA and its study area occupied by 2005-2006 change polygons.

S2S Change Class	Buffer		Park	
	Area changed (ha)	Proportion of buffer (%)	Area changed (ha)	Proportion of park (%)
No change	256499	85.50	92607	97.33
Water/shade to rock/soil	43	0.01	19	0.02
Water/shade to partial vegetation cover	6	0.00	1	0.00
Water/shade to complete vegetation cover	15	0.01	5	0.00
Rock/soil to water/shade	716	0.24	24	0.03
Partial vegetation to water/shade	3857	1.29	19	0.02
Complete vegetation to water/shade	15624	5.21	96	0.10
Increase in broadleaf	955	0.32	7	0.01
Increase in conifer	148	0.05	16	0.02
Increase in vegetation	142	0.05	7	0.01
Decrease in broadleaf	979	0.33	446	0.47
Decrease in conifer	15903	5.30	1048	1.10
Decrease in vegetation	5065	1.69	848	0.89
Increase in snow/cloud	30	0.01	7	0.01
Decrease in snow/cloud	0	0.00	0	0.00

OLYM

Figure 15 shows the results of the 2004-2006 OLYM change detection at the threshold level of 80. We made several general observations concerning differences between 2004 and 2006 images. First, shadows were longer in the 2006 eastern image, which was taken a week later than the 2004 image. This could have increased the likelihood of polygons labeled “Vegetation to water/shade.” However, most of these areas were eliminated from the final change product when the minimum mapping size was increased to one hectare. Second, the 2004 image had small patches of fog in coastal areas, which were also eliminated from the final change product due to their small size. A large number of “Increase in snow” patches that were detected between 2004 and 2006 as a result of higher snow levels in the later year were also eliminated when the minimum mapping size was increased. We also detected a several-pixel registration error in the north/south direction between the 2006 and the 2004 images. This often caused false change in bands of single or two pixels widths.

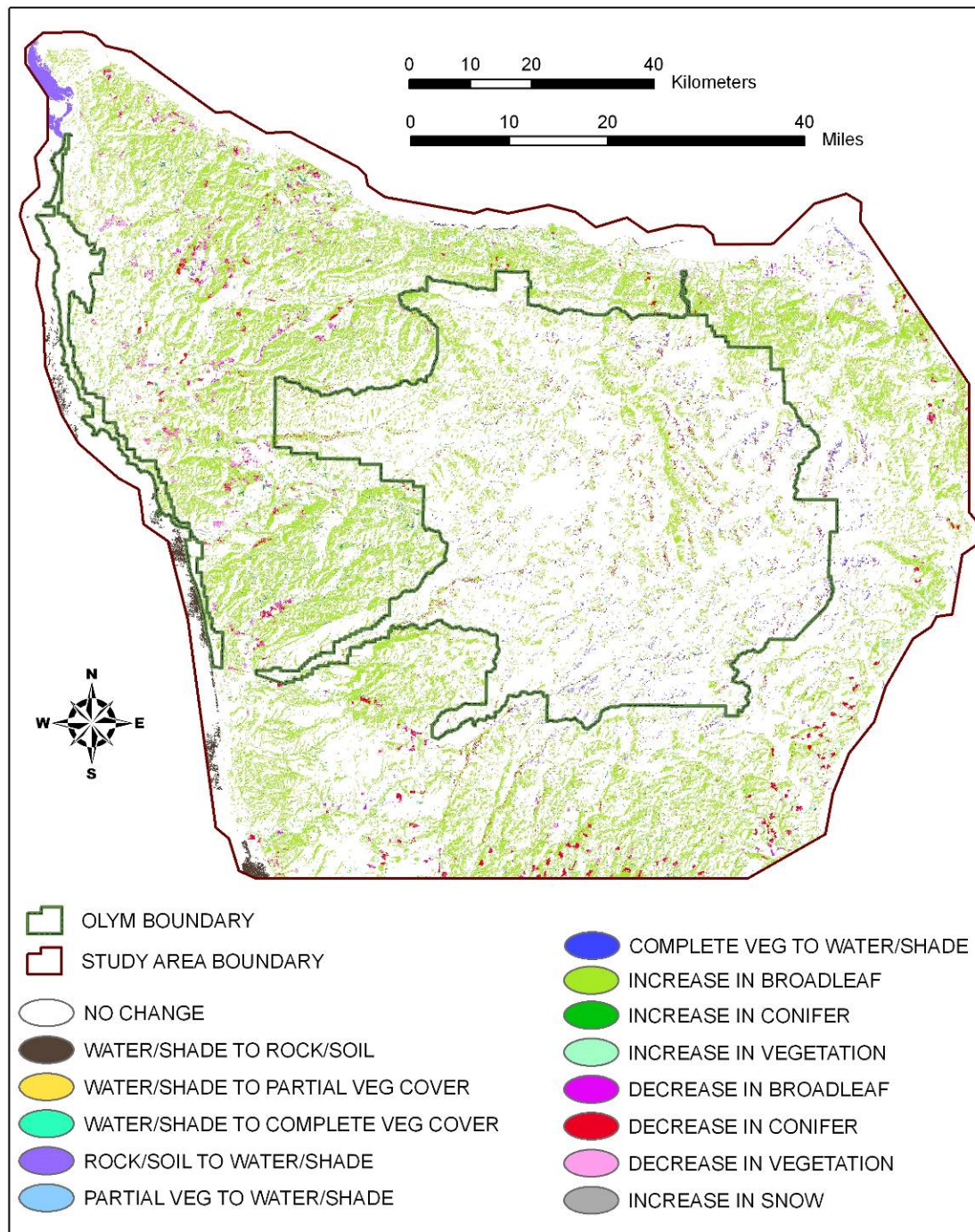


Figure15. OLYM 2004-2006 satellite-to-satellite labeled change image. Minimum mapping area of one hectare and threshold level of 80 were applied to raw change detection results.

The OLYM final change product shows a dramatic increase in the broadleaf vegetation component from 2004 to 2006 across the entire Peninsula. This increase was most likely due to differences in broadleaf phenology between the two years and made it difficult to distinguish

increases in broadleaf vegetation types caused by actual disturbances. A large number of clearcuts were detected throughout the study area, which appear under “Decrease in conifer” or “Decrease in vegetation” labels in the final change image. Table 10 summarizes the amount of change in each S2S class category for OLYM.

Table 10. Number of hectares and proportion of OLYM and its study area occupied by 2004-2006 change polygons.

S2S Change Class	Buffer		Park	
	Area changed (ha)	Proportion of buffer (%)	Area changed (ha)	Proportion of park (%)
No change	652707	75.53	328270	88.8
Water/shade to rock/soil	4257	0.49	7	0.00
Water/shade to partial vegetation cover	14	0.00	6	0.00
Water/shade to complete vegetation cover	204	0.02	49	0.01
Rock/soil to water/shade	4164	0.48	1802	0.49
Partial vegetation to water/shade	55	0.01	57	0.02
Complete vegetation to water/shade	767	0.09	1319	0.36
Increase in broadleaf	173249	20.05	32813	8.88
Increase in conifer	7286	0.84	873	0.24
Increase in vegetation	4158	0.48	1009	0.27
Decrease in broadleaf	2504	0.29	29	0.01
Decrease in conifer	7294	0.84	3103	0.84
Decrease in vegetation	7157	0.83	214	0.06
Increase in snow/cloud	366	0.04	106	0.03
Decrease in snow/cloud	0	0.00	0	0.00

Only 75% of the area surrounding OLYM’s boundary remained unchanged from 2004 to 2006. The changes were less extensive with the park boundary, with 88.8% of the area remaining unchanged. The greater extent of change detected at OLYM compared to the other two parks can primarily be explained by the “Increase in broadleaf” category, which affected 20% and almost 9% of the areas outside and inside the park boundary, respectively. We concluded that the large changes in the “Increase in broadleaf” category are artificial and are probably due to changes in broadleaf phenology between 2004 and 2006. There were both increases and decreases in other vegetation categories, most likely resulting from the dynamic nature of agricultural and forest use activities outside of park boundary. The “Increase in conifer” category was common in areas that were clearcut before and are now regenerating. Not all pixels within these regenerating

clearcuts passed the current threshold level of 80 and were labeled as changed, however. Analysis of one year of change at NOCA and MORA did not detect any regeneration within clearcut areas, even though they were visible to the human eye, suggesting that changes representing vegetation recovery following disturbance will be better detected at change intervals larger than two years. “Increase in vegetation” pixels were common along the coast, possibly reflecting either differences in phenology between the 2004 and 2006 or errors in the georectification process.

Within OLYM, the analysis detected a number of areas of “Decrease in conifer” (0.84%), “Complete vegetation to water/shade” (0.36%) and “Rock/soil to water/shade” (0.49%) change that could not be readily explained. These areas were especially prevalent on the northwest slopes of the southern and eastern parts of the study area, although “Rock/soil to water/shade” labels were found throughout the park. Upon careful examination of the physiognomic class image and the tasseled-cap images, it appeared that most of the “Decrease in conifer” areas were a result of misregistration errors. Narrow bands of pixels near ridgelines on the northwestern slopes, which were classified as “Closed/canopy forest” in 2004, were displaced in 2006 by a few pixels to areas on the southeastern slopes with a larger soil component.

The “Complete vegetation to water/shade” label was assigned to areas of mature conifer forest that showed an increase in wetness component in 2006, making a spectral transition to the “Deep water/shade” physiognomic class (Figures 3 and 4). The “Rock/soil to water/shade” label was assigned to areas that were already classified as “Deep water/shade” in 2004 and moved spectrally further away from “Closed-canopy conifer” physiognomic class in 2006. It was unclear, however, why transition from the existing shade to deeper shade resulted in the “Rock/soil to water/shade” label. As evident from Figures 3 and 4, shade is spectrally similar to water. NCCN was only interested in changes related to presence or absence of water, but our inability to distinguish shade from water due to their spectral similarity had to be accounted for by including shade in all change class labels with water component (Table 2). It is likely that when rules for Table 3 were being developed, spectral similarity between shade and water was not taken into account. The protocol development group probably made an assumption that the changes from water to deeper water would only occur in riparian areas when the water depth increased due to channel migration or seasonal changes in water level. The “Rock/soil to water/shade” label would describe such changes without having to create an extra category of “Increase in water.” When, however, the same label is applied to areas of spectral changes that translate into varying degrees of shade, the label does not make sense.

Validation and Accuracy Assessment

The initial objective of the validation was to examine 5% of each park plus buffered study area. This resulted in the random selection of 82 1.5 km x 1.5 km boxes for MORA and 230 boxes for NOCA for visual validation using Satellite-to-Satellite (S2S) interpretation methodology. Due to time constraints, final OLYM validation covered 5% of area inside the park boundary and 2.5% of area outside of park boundary, resulting in a total of 190 boxes. NOCA staff conducted the NOCA and MORA validations, and OLYM staff conducted OLYM validation. We generated 728, 1500, and 5032 random points for NOCA, MORA and OLYM, respectively, for two types of accuracy assessment using the “Change” and “No change” areas outlined during the validation process. The goal was to generate a balanced sample of change and no-change classes. This

means that the number of random points was limited by the number of change events captured during the validation process. More random points were generated for OLYM because a larger proportion of the OLYM study area was classified as changed by the interpreter, as compared to NOCA and MORA.

Accuracy assessment of change detection

Table 11 shows results of “Change/No change” accuracy assessment for the three parks. The term “Reference” refers to data generated by the image interpreter within the validation boxes. The term “Classified” refers to data generated by the automated computer algorithm and represents the dataset that is being validated. NOCA had the best overall accuracy of 82.03%, followed by MORA (74.35%) and OLYM (63.82%). All three parks had a fairly high Producer’s Accuracies in “No Change” category, meaning that when the interpreters identified a particular point as “No Change,” there was a high likelihood that the computer algorithm did the same. The Producer’s Accuracies for the “Change” class, however, were much lower, indicating that the interpreters classified a high number of points as “Change,” when the computer classification put them in the “No Change” category. This is likely due to pixels with a magnitude of change that did not pass the threshold and were therefore excluded from the computer’s final classification product but were clearly visible to the interpreter as showing change.

Table11. Change/No Change accuracy totals for the three parks.

Park	Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy %	Users Accuracy %	Overall Accuracy %	Kappa Statistic
NOCA	No change	500	619	494	98.80	79.81		0.36
	Change	228	109	103	45.18	94.50		0.92
	Totals	728	728	597			82.03	0.52
MORA	No change	750	1067	716	95.47	67.10		0.34
	Change	750	433	399	53.20	92.15		0.84
	Totals	1500	1500	1115			74.35	0.49
OLYM	No change	3000	3821	2500	83.33	65.43		0.14
	Change	2032	1211	711	34.99	58.71		0.31
	Totals	5032	5032	3211			63.82	0.20

Figure 16 shows an example of an error of omission for a validation box in NOCA. During the S2S validation process, the tasseled-cap image from 2005 (a) is compared to a similar image from 2006 (b). The simple 2006-2005 differenced image (c), used to highlight possible changes, shows slight increase in conifer for the two regrowing clearcuts that are visible on the 2006 1-m NAIP aerial photo (d). The increases in conifer show up as areas of darker blue, and are then outlined by the person doing the validation with an orange hollow polygon. There is also an area of change outlined in the upper right corner. Image e) shows areas outlined by the computer

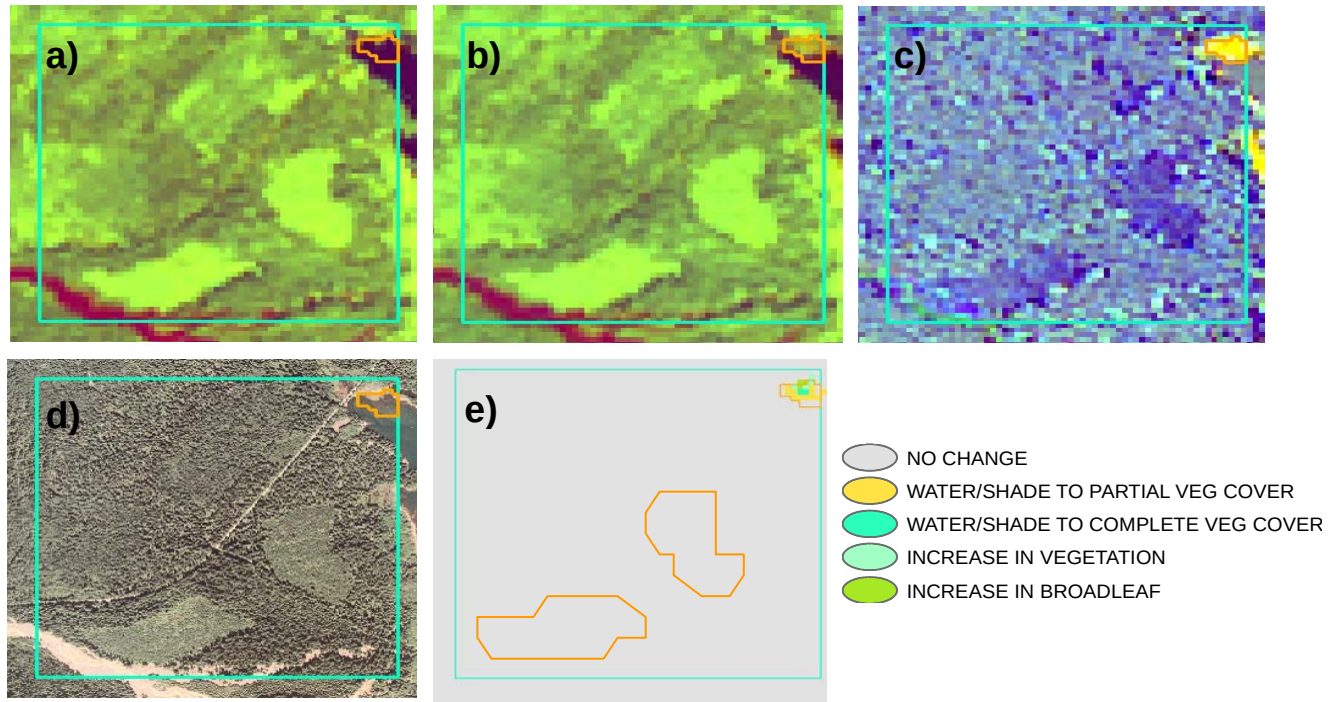


Figure 16. An example of an error of omission. a) NOCA 2005 tasseled-cap image. b) NOCA 2006 tasseled-cap image. c) 2005-2006 differenced image. d) 2006 NAIP aerial photo. e) Areas outlined by the interpreter as “Change” (orange hollow polygons) compared to “Change” polygons generated by the algorithm. The legend to the right of image e) corresponds to values of computer-generated change polygons.

algorithm as “Change” in the final product, as indicated by a yellow polygon. Under the current threshold level of 80, the regrowing clearcuts are not included in the final product, even though the increase in conifer is visible to the human eye and the areas can be seen by the interpreter as indicated by the orange polygons.

The User’s Accuracies for the “No change” class for all three parks are much lower than the Producer’s Accuracies for the same category (79.81% for NOCA, 67.10% for MORA and 65.43% for OLYM). This indicates that a large number of points that were classified as “No change” by the computer algorithm were recorded as “Change” by the interpreter. For the “Change” category, the User’s Accuracies for NOCA and MORA were high (94.5% and 92.15%, respectively), showing that the points classified in that category by the computer were also seen as changed by the interpreter. The User’s Accuracy for OLYM’s “Change” class was much lower (58.71%) indicating that a large number of pixels, which the classification identified as “Change,” were recorded as “No change” by the interpreter. This happened when, for a given pixel the interpreter could not discern a difference in colors on the screen between the two years, but the computer determined that the change has occurred based on the calculated POM.

Figure 17 gives an example of both errors of omission and commission for one of the validation boxes in MORA. During the S2S validation process, the tasseled-cap image from 2005 (a) is compared to a similar image from 2006 (b). The simple 2006-2005 differenced image (c) shows areas with increased greenness outlined by the interpreter with a hollow orange box. Similar to

the example from OLYM above, the majority of the areas outlined by the interpreter as “Change” in this image were not classified by the computer as such, resulting in errors of omission. Image d) shows the final change product with pixels in red labeled by the computer algorithm as “Change.” On the other hand, the broad swath of area outlined by the computer as “Change” was not detected by the interpreter, resulting in the errors of commission. The subtle increase in reddish hue, which indicates a subtle decrease in vegetation, is difficult to detect visually by the image interpreter unless it is compared to a differenced image from a validation box from another section of the study area shown in image (e). The grayish hues of image (e) are typical of areas that have not changed dramatically. Only by comparing images (c) and (e) side by side, the interpreter is able to discern a slight decrease in vegetation in image (c).

We calculated the Kappa statistic for all “Change” and “No change” categories for the three parks. The Kappa statistic was highest for the “Change” classes for NOCA and MORA (0.92 and 0.84, respectively). The statistic was the lowest for the “No Change” category for OLYM. This is consistent with the type of S2S changes found in the three parks (Figures 12, 14 and 15). Changes at NOCA and MORA were, for the most part, limited in extent, well defined and easy to detect. One exception to this was the decreases in vegetation on the east side of the study area for MORA.

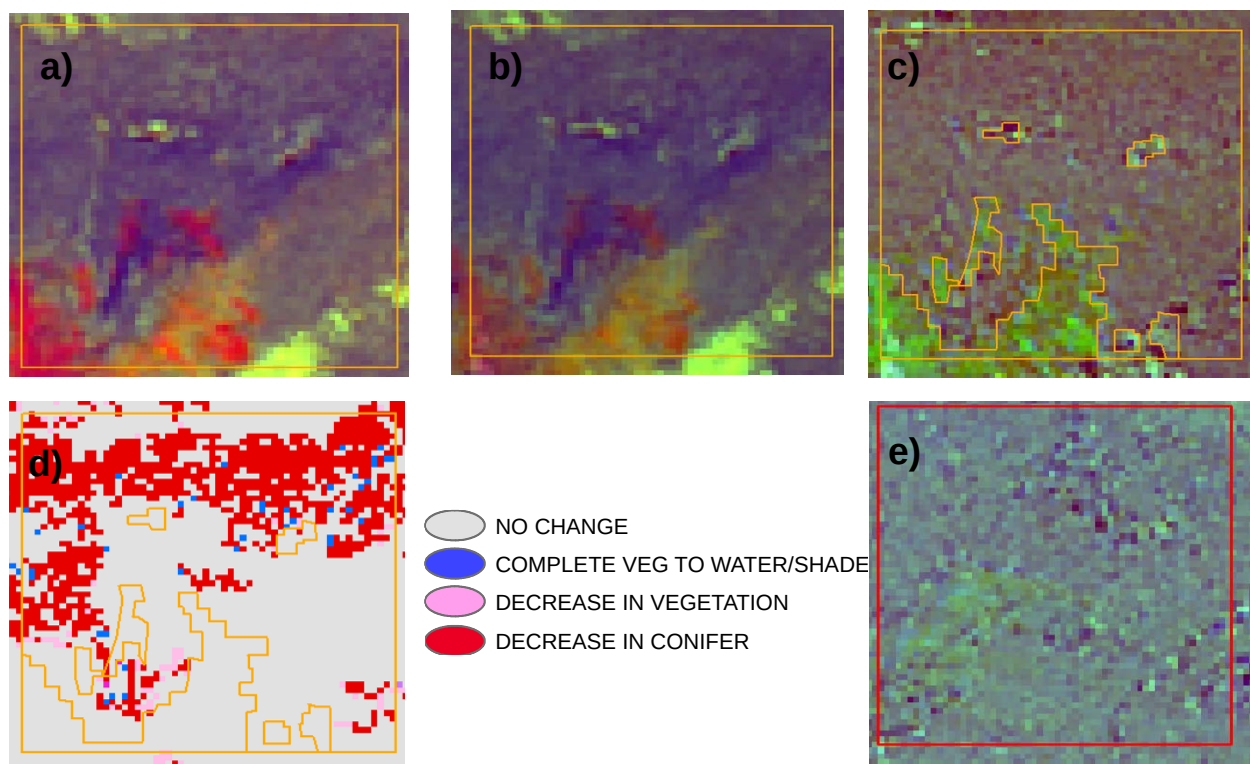


Figure 17. An example of an error of commission for a validation box on the east side of MORA's study area. a) MORA 2005 tasseled-cap image. b) MORA 2006 tasseled-cap image. c) 2005-2006 differenced image. d) Areas outlined by the interpreter as “Change” (orange hollow polygons) compared to “Change” polygons generated by the algorithm. The legend to the right of image d) corresponds to values of computer-generated change polygons. e) 2005-2006 differenced image from the east side of MORA's study area for comparison to image c).

Changes at OLYM, however, were widespread, poorly visible between the two tasseled-cap images and hard to interpret. Figure 18 shows an example of a validation box from OLYM, typical of the changes seen in the entire study area. The tasseled-cap image from 2004 (a) is compared with a similar image from 2006 (b). The two images are differenced (c) to highlight possible changes. Image d) compares the computer-generated final product with change polygons outlined by the interpreter (blue). Image e) shows the area overlaid on the 2006 1-m NAIP aerial photo. Errors of omission (a new logging road in the upper-mid portion of the box) and commission (light green areas of “increase in broadleaf”) are present throughout the box. This example highlights the difficulty of outlining subtle changes in cover during the validation process.

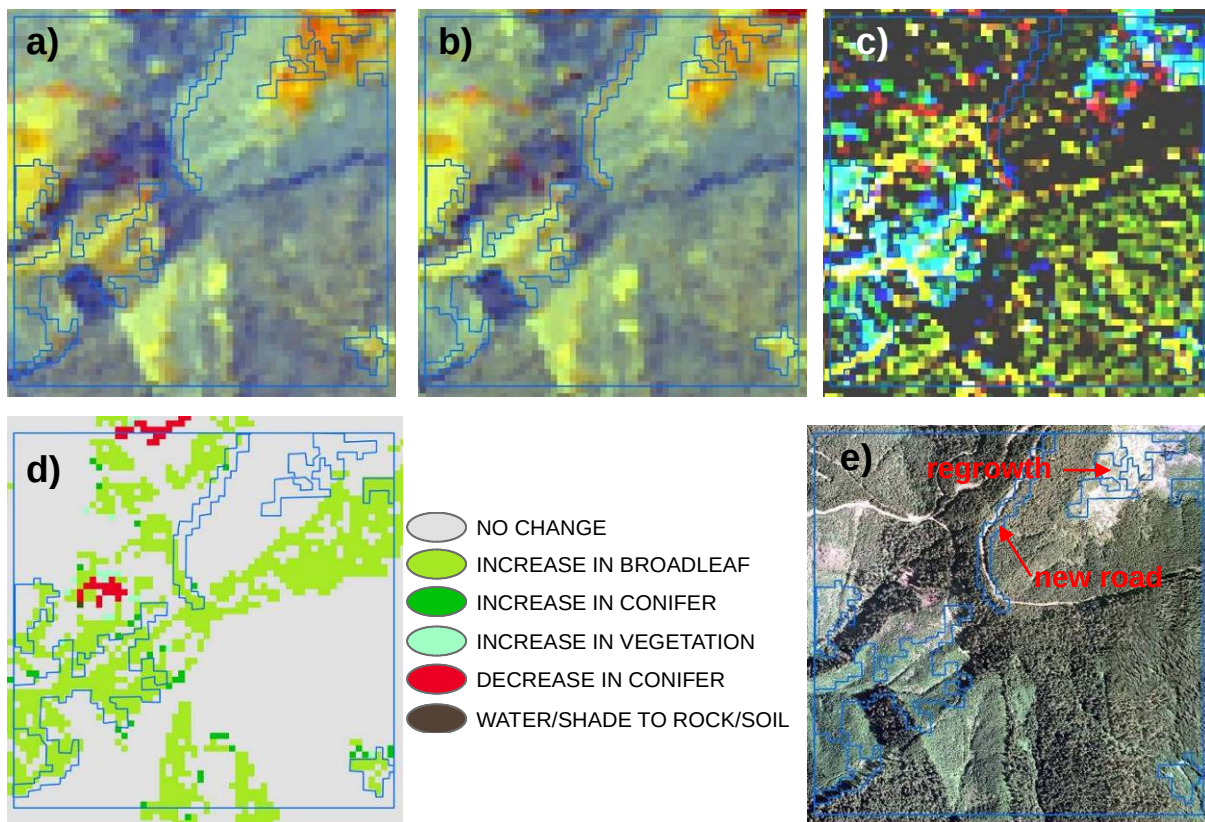


Figure 18. An example of a validation box at OLYM. a) OLYM 2004 tasseled-cap image. b) OLYM 2006 tasseled-cap image. c) 2004-2006 differenced image. d) Areas outlined by the interpreter as “Change” (blue hollow polygons) compared to “Change” polygons generated by the algorithm (solid polygons). The legend to the right of image d) corresponds to values of computer-generated change polygons. e) 2006 NAIP aerial photo.

Accuracy assessment of change labeling

Table 12 shows the contingency table for NOCA. A number of classes were represented with only a few points making them difficult to interpret because a single point labeled correctly or incorrectly had a large influence on the result. Because so few instances of changes within S2S change classes 2 through 6, 14 and 15 were detected (Table 2) and because the detected changes in those classes were primarily due to changes in cloud cover, the discussion will concentrate on the remaining categories, which involve decrease or increases in various vegetation types.

A large number of validation points were assigned by the interpreter to one of the vegetation-change classes, while the computer-generated final product assigned these points to the “No change” class. This is a result of the interpreter outlining areas that have visibly changed but not knowing whether or not they passed the threshold or the minimum mapping size set for the automated analysis. Entries in other cells can be mainly traced to two issues. First, the

Table 12. Comparison of computer-generated ("Classification") and interpreter ("S2S reference") classification of pixels from NOCA.

		S2S Reference															Totals
	Change type	1-No change	2-Water/shade to rock/soil	3-Water/shade to partial vegetation	4-Water/shade to complete vegetation	5-Rock/soil to water/shade	6-Partial vegetation to water/shade	7-Complete vegetation to water/shade	8-Increase in broadleaf	9-Increase in conifer	10-Increase in vegetation	11-Decrease in broadleaf	12-Decrease in conifer	13-Decrease in vegetation	14-Increase in snow/cloud	15-Increase in snow/cloud	
Classification	1-No change	497	1						13	44	5	38	10	16	3	4	631
	2-Water/shade to rock/soil		0														0
	3-Water/shade to partial vegetation			0													0
	4-Water/shade to complete vegetation				0				1	2							3
	5-Rock/soil to water/shade					0				5			2				7
	6-Partial vegetation to water/shade						0			7				2			9
	7-Complete vegetation to water/shade	1						0		7			5	2			15
	8-Increase in broadleaf								1		6	1					8
	9-Increase in conifer	2								3			2				7
	10-Increase in vegetation										0						0
	11-Decrease in broadleaf	1								6		7		4			18
	12-Decrease in conifer	2								1			2	1			6
	13-Decrease in vegetation													1			1
	14-Increase in snow/cloud											3	7	13	0		23
	15-Decrease in snow/cloud															0	0
Totals		503	1	0	0	0	0	0	15	75	11	49	28	39	3	4	728

interpreter was not doing a very good job of identifying beginning and end locations of changing pixels within the nine physiognomic classes, resulting in incorrect application of the rules in Table 3 for assigning labels to change polygons. Figure 19 shows an example of classification errors when the interpreter incorrectly identified the physiognomic class of the pixel's starting point. Image (a) shows physiognomic classes generated from 2005 TM image for a portion of two adjacent validation boxes. Note that "Conifer/broadleaf mix" and "Mixed" classes are occupying the majority of the left and right change areas delineated by the interpreter, respectively. Images (c) and (b) show the 2005 and 2006 tasseled-cap images for the same area. Image (d) shows combined results of the change detection produced by the computer algorithm and interpreter's classification of the delineated change polygons.

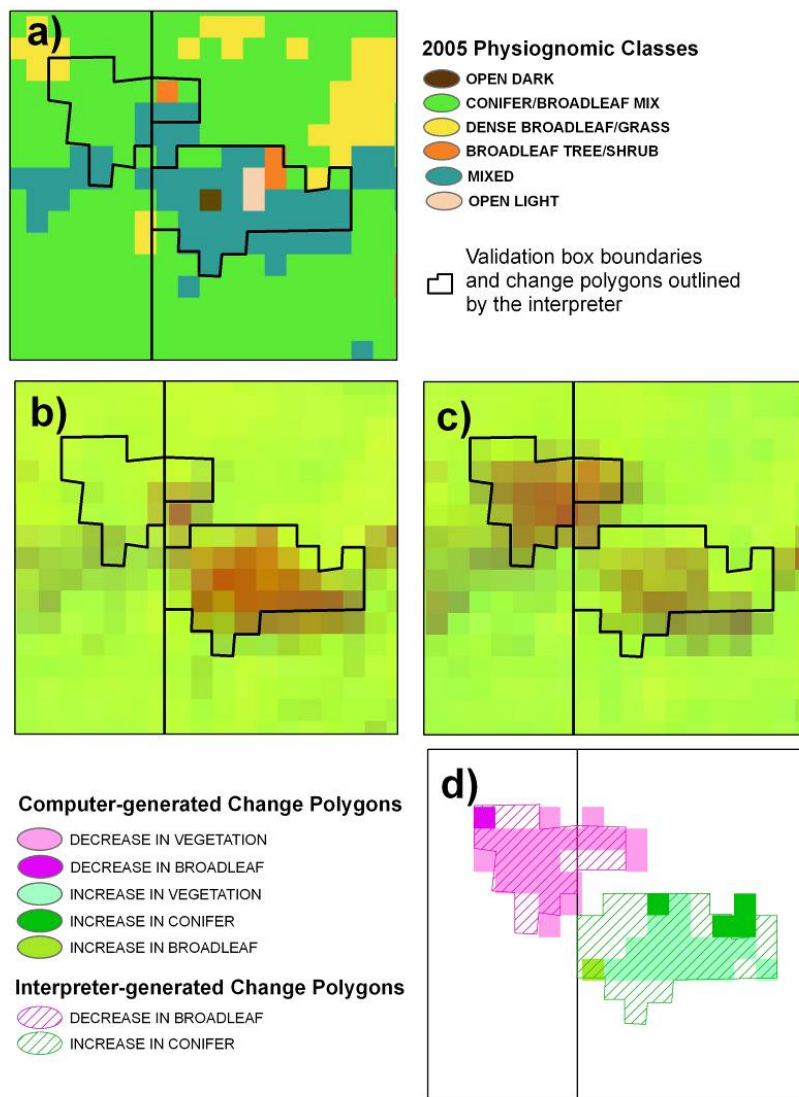


Figure 19. An example of differences in change class label assignments between the computer algorithm and the interpreter associated with changes in cloud cover. a) NOCA 2006 TM image with a validation box. b) Close-up of the validation box with the 2005 tasseled-cap image. c) same as a) but using 2006 tasseled-cap image. d) Areas outlined by the interpreter as "Change" (hatched polygons) compared to "Change" polygons generated by the algorithm (solid polygons). The colors shown in the legend can be applied to both the computer-generated change polygons and interpreter-delineated polygons.

The interpreter labeled the left polygon with the “Decrease in broadleaf” category, which would be correct if the starting point of the pixels within this polygon was within one of the broadleaf physiognomic classes. Because the initial location of the pixel was instead within the “Conifer/broadleaf mix” category, the resulting change class should have been labeled as “Decrease in vegetation,” as shown in Table 3. The polygon on the right was mislabeled by the interpreter as “Increase in conifer” because the end location of the pixels within the polygon was identified as “Closed canopy conifer” rather than “Conifer/broadleaf mix.” The same areas were labeled by the computer algorithm as “Increase in vegetation,” which is consistent with the labeling rules in Table 3 for pixels starting in ‘Mixed’ physiognomic classes and ending in “Conifer/broadleaf mix” physiognomic class. This example highlights the difficulty of the interpreter to determine the start and end points of pixels based solely on visual analysis of tasseled-cap images for the two dates and a simple differenced image.

The second reason for low classification accuracy was the difference in cloud shadow depth and how it affected the end points of the changed pixels. For example, in Table 12, a number of pixels within the interpreter’s “Increase in conifer” category were assigned to “Partial vegetation to water/shade,” “Complete vegetation to water/shade” or “Decrease in broadleaf” categories by the automated analysis. “Partial vegetation to water/shade” or “Complete vegetation to water/shade” categories resulted when cloud shadows were found in 2006 over areas that were within the “Closed-canopy conifer,” “Conifer/broadleaf mix” or “Mixed” categories in 2005 (Figure 20). The interpreter assigned the labels based on the spectral location of the pixel in 2006, failing to incorporate the initial position of the pixel in 2005.

It was also difficult to determine if cloud shadows were spectrally more similar to “Water/deep shade” physiognomic class or the “Closed-canopy conifer,” resulting in incorrect labeling of the pixel’s end point. Similarly, the interpreter assigned the “Increase in conifer” label to some of the broadleaf pixels that were under cloud shadows in 2006, but the computer, using actual calculations of the direction and length of the change vector within spectral space, determined that the shadow was not deep enough to move those pixels from one of the broadleaf spectral categories to the one occupied by conifer vegetation. The same explanation can be given to the number of points that were assigned by the interpreter to the “Increase in snow/cloud” category and which were placed in the “Decrease in broadleaf,” “Decrease in conifer” or “Decrease in vegetation” categories by the algorithm. The degree of cloud density determined whether or not the pixel’s end point stayed within the original physiognomic class or moved to a different class.

The automated algorithm evaluates change vectors in a nine-dimensional probability space. In situations where more than one dimension experienced equal amount of change that was larger than the threshold level, the algorithm selects only one of them and assigns the label based on that change. For example, if the same pixel experienced a 95 unit positive change in the “Closed-canopy conifer” probability layer and a 95 unit positive change in the “Broadleaf tree/shrub” probability layer, the computer can either assign an “Increase in conifer” label to the pixel or an “Increase in broadleaf” label. This can result in seemingly totally unrelated labels assigned by the algorithm and the interpreter to the same pixel.

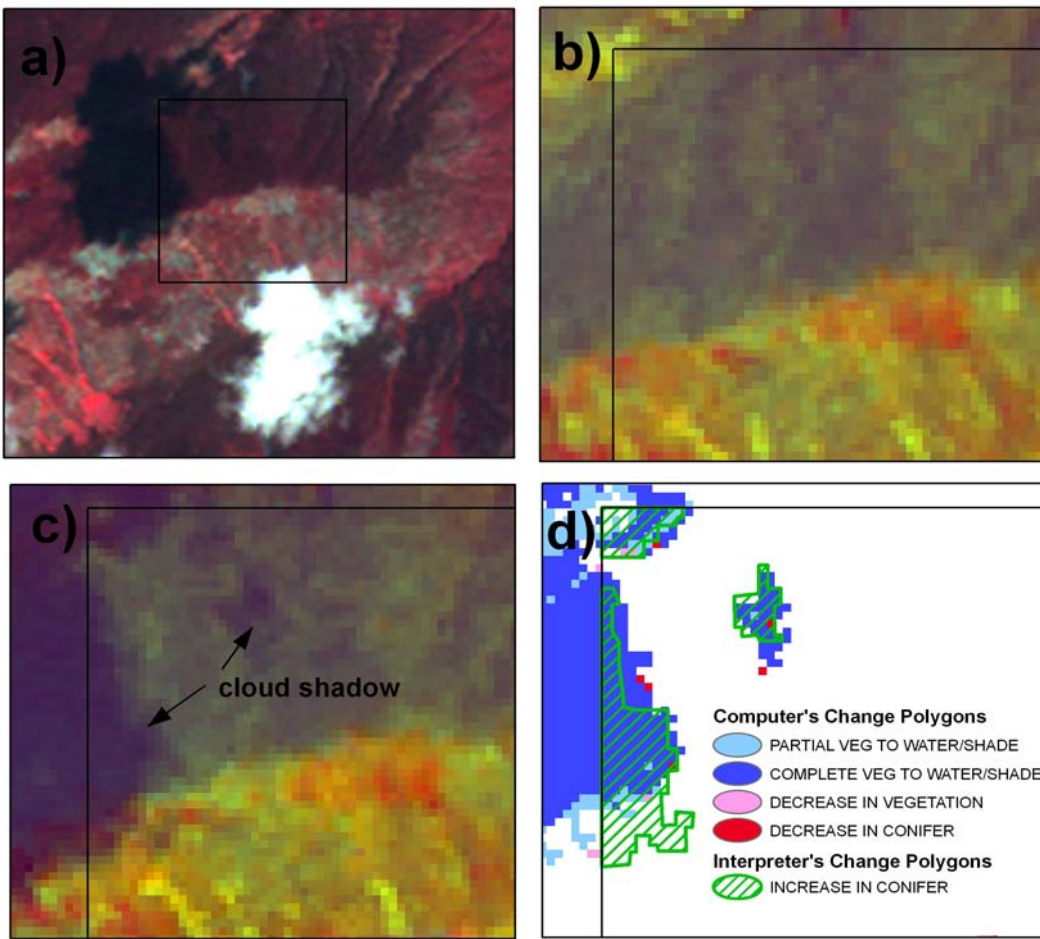


Figure 20. An example of differences in change class label assignments between the computer algorithm and the interpreter associated with changes in cloud cover. a) NOCA 2006 TM image with a validation box. b) Close-up of the validation box with the 2005 tasseled-cap image. c) same as a) but using 2006 tasseled-cap image. d) Areas outlined by the interpreter as “Change” (hatched polygons) compared to “Change” polygons generated by the algorithm (solid polygons). The colors shown in the legend can be applied to both the computer-generated change polygons and interpreter-delineated polygons.

The validation exercise was done first for NOCA and then for MORA. Examining the contingency table for MORA (Table 13), one can see that the interpreter did a better job of assigning correct labels to the change polygons during the validation process, mostly due to adjustment of labeling process after examining NOCA’s results. Similarly to NOCA, one can see a number of validation points that were assigned to one of the change classes by the interpreter, but were found not to have changed by the computer algorithm. Again, this was probably due to the interpreter not being able to assess whether or not a change polygon would pass the assigned threshold level or minimum mapping size. Interestingly, compared to NOCA, there were a larger number of points labeled “no change” by the interpreter, but found to have changed by the algorithm. Most of these were within the “Complete vegetation to water/shade” category, representing changes from vegetation in 2005 to cloud cover in 2006 and within the “Decrease in conifer” category, representing reductions in conifer spectral signal on the east side of the study area.

Table 13. Comparison of computer-generated ("Classification") and interpreter ("S2S reference") classification of pixels from MORA.

	Change type	S2S Reference															Totals
		1-No change	2-Water/shade to rock/soil	3-Water/shade to partial vegetation	4-Water/shade to complete vegetation	5-Rock/soil to water/shade	6-Partial vegetation to water/shade	7-Complete vegetation to water/shade	8-Increase in broadleaf	9-Increase in conifer	10-Increase in vegetation	11-Decrease in broadleaf	12-Decrease in conifer	13-Decrease in vegetation	14-Increase in snow/cloud	15-Increase in snow/cloud	
Classification	1-No change	726				16		247	3	1	9	2	100	13			1117
	2-Water/shade to rock/soil		0														0
	3-Water/shade to partial vegetation			0													0
	4-Water/shade to complete vegetation				0												0
	5-Rock/soil to water/shade					3		1									4
	6-Partial vegetation to water/shade	1				2	0	26									29
	7-Complete vegetation to water/shade	11				2		192						2			207
	8-Increase in broadleaf	1						2	0				2				5
	9-Increase in conifer							2		0							2
	10-Increase in vegetation	2			1						0						3
	11-Decrease in broadleaf	1						3				1	1				6
	12-Decrease in conifer	9											92				101
	13-Decrease in Vegetation	2											12	12			26
	14-Increase in snow/cloud														0		0
	15-Decrease in snow/cloud															0	0
Totals		753	0	0	0	24	0	473	3	1	9	3	207	27	0	0	1500

A number of points were mislabeled due to the spectral overlap among different physiognomic classes as with “Conifer/broadleaf mix” class and “Mixed” class, which has a soil component (Figures 3 and 4). A number of pixels that were assigned to the “Partial vegetation to water/shade” category by the algorithm were labeled as “Complete vegetation to water” by the interpreter, representing differences in assessment of how much vegetation was originally in the pixel. Similarly, because of the spectral overlap between the “Closed-canopy conifer” and “Conifer/broadleaf mix” physiognomic classes, pixels assigned to the “Decrease in vegetation” category by the algorithm were sometimes identified as “Decrease in conifer” by the interpreter, representing differences in assessment of how much conifer component was contained in the pixel in the starting year.

Accuracy assessment results for OLYM, shown in Table 14, present similar issues. The interpreter categorized a large number of validation points as “Increase in vegetation”, while the algorithm assigned them to the “Increase in broadleaf” category. On the other hand, a large number of points labeled as “Increase in broadleaf” by the algorithm were missed by the interpreter and placed in the “No change” category. The wide-spread extent of changes in OLYM, resulting from increase in greenness signal in 2006 (Figure 15), made it very difficult to determine which pixels had change exceeding the threshold and whether or not they were part of a cluster of pixels large enough to exceed the minimum mapping size (Figure 18).

These difficulties were compounded by the fact that the computer algorithm calculates the size of pixel clusters based on aggregation of similar change classes rather than a single class. For example, all pixels within change classes containing decreases in vegetation are aggregated together to determine whether or not the cluster of pixels pass the minimum mapping unit. To reproduce the algorithm’s decision making process, for every pixel within the validation box, the interpreter has to first assess whether the apparent change would pass the threshold level, then assign the change class, and finally determine whether or not the pixel belongs to a cluster of pixels exhibiting similar type of change that is big enough to pass the minimum mapping size. It is virtually impossible for the interpreter to conduct this analysis given the number of pixels involved in the validation process. In that respect, keeping the minimum mapping size to the original number of pixels proposed in the protocol (six) would make the change delineation process easier, but it would increase dramatically the number of polygons to be delineated.

Table 14. Comparison of computer-generated ("Classification") and interpreter ("S2S reference") classification of pixels from OLYM.

	Change type	S2S Reference															Totals
		1-No change	2-Water/shade to rock/soil	3-Water/shade to partial vegetation	4-Water/shade to complete vegetation	5-Rock/soil to water/shade	6-Partial vegetation to water/shade	7-Complete vegetation to water/shade	8-Increase in broadleaf	9-Increase in conifer	10-Increase in vegetation	11-Decrease in broadleaf	12-Decrease in conifer	13-Decrease in vegetation	14-Increase in snow/cloud	15-Increase in snow/cloud	
Classification	1-No change	2543		6			3		41	203	599			143	367	2	3907
	2-Water/shade to rock/soil	3	0														3
	3-Water/shade to partial vegetation			0													0
	4-Water/shade to complete vegetation				0												0
	5-Rock/soil to water/shade	8				0											8
	6-Partial vegetation to water/shade						0										0
	7-Complete vegetation to water/shade	6						0			2						8
	8-Increase in broadleaf	425							16	17	327			39	1		825
	9-Increase in conifer	8								1							9
	10-Increase in vegetation										14						14
	11-Decrease in broadleaf	2									1	0		5			8
	12-Decrease in conifer	16									1		0	79	1		97
	13-Decrease in vegetation	3							1		1			127			132
	14-Increase in snow/cloud													21	0		21
	15-Decrease in snow/cloud															0	0
Totals		3014	0	6	0	0	3	0	58	221	945	0	0	414	369	2	5032

Tables 15 through 17 allow for comparison between the results for the three parks. Overall accuracy and Kappa statistics were similar for NOCA and MORA, whereas accuracy for OLYM was somewhat lower. For the change classes that had enough validation points, Producer's accuracies increased between NOCA and MORA, likely the result of the interpreter gaining experience and improving on label placement. Overall, statistics were better for classes that were widespread and easy to detect.

Table 15. S2S interpretation change classes accuracy totals for NOCA.

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy %	Users Accuracy %	Overall Accuracy %	Kappa Statistic
No change	503	631	497	98.81	78.76		0.31
Water/shade to rock/soil	1	0	0	-	-		0.00
Water/shade to partial vegetation	0	0	0	-	-		0.00
Water/shade to complete vegetation	0	3	0	-	-		0.00
Rock/soil to water/shade	0	7	0	-	-		0.00
Partial vegetation to water/shade	0	9	0	-	-		0.00
Complete vegetation to water/shade	0	15	0	-	-		0.00
Increase in broadleaf	15	8	1	6.67	12.50		0.11
Increase in conifer	75	7	3	4.00	42.86		0.36
Increase in vegetation	11	0	0	-	-		0.00
Decrease in broadleaf	49	18	7	14.29	38.89		0.34
Decrease in conifer	28	6	2	7.14	33.33		0.31
Decrease in vegetation	39	1	1	2.56	100.00		1.00
Increase in snow/cloud	3	23	0	0	0		0.00
Decrease in snow/cloud	4	0	0	-	-		0.00
Totals	728	728	511			70.19	0.25

Table 16. S2S interpretation change classes accuracy totals for MORA.

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy %	Users Accuracy %	Overall Accuracy %	Kappa Statistic
No change	753	1117	726	96.41	65.00		0.30
Water/shade to rock/soil	0	0	0	-	-		0.00
Water/shade to partial vegetation	0	0	0	-	-		0.00
Water/shade to complete vegetation	0	0	0	-	-		0.00
Rock/soil to water/shade	24	4	3	12.50	75.00		0.75
Partial vegetation to water/shade	0	29	0	-	-		0.00
Complete vegetation to water/shade	473	207	192	40.59	92.75		0.89
Increase in broadleaf	3	5	0	0	0		0.00
Increase in conifer	1	2	0	0	0		0.00
Increase in vegetation	9	3	0	0	0		-0.01
Decrease in broadleaf	3	6	1	33.33	16.67		0.17
Decrease in conifer	207	101	92	44.44	91.09		0.90
Decrease in vegetation	27	26	12	44.44	46.15		0.45
Increase in snow/cloud	0	0	0	-	-		0.00
Decrease in snow/cloud	0	0	0	-	-		0.00
Totals	1500	1500	1026			68.40	0.25

Table 17. S2S interpretation change classes accuracy totals for OLYM.

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy %	Users Accuracy %	Overall Accuracy %	Kappa Statistic
No change	3014	3907	2543	84.37	65.09		0.13
Water/shade to rock/soil	0	3	0	-	-		0.00
Water/shade to partial vegetation	6	0	0	-	-		0.00
Water/shade to complete vegetation	0	0	0	-	-		0.00
Rock/soil to water/shade	0	8	0	-	-		0.00
Partial vegetation to water/shade	3	0	0	-	-		0.00
Complete vegetation to water	0	8	0	-	-		0.00
Increase in broadleaf	58	825	16	27.59	1.94		0.01
Increase in conifer	221	9	1	0.45	11.11		0.07
Increase in vegetation	945	14	14	1.48	100.00		1.00
Decrease in broadleaf	0	8	0	-	-		0.00
Decrease in conifer	0	97	0	-	-		0.00
Decrease in vegetation	414	132	127	30.68	96.21		0.96
Increase in snow/cloud	369	21	0	0	0		-0.08
Decrease in snow/cloud	2	0	0	-	-		0.00
Totals	5032	5032	2702			53.69	0.13

Case Studies of Detected Disturbance

We selected one example from each of three parks that demonstrates the results from the Type I change detection with respect to landscape disturbances of interest to the NCCN (Table 1).

NOCA

Monitoring fire on an annual basis is one of the network's goals for the landscape dynamics protocol. Documenting changes in fire frequency and extent can provide park managers with valuable information on how climate change affects disturbance regimes. Figure 21 shows an example of a fire that was successfully detected using the 2005 and 2006 imagery. The Flick Creek Fire started in late July 2006 on the east slopes above Lake Chelan within NOCA. The fire extent, which was being mapped periodically by the NOCA fire program, was approximately 1730 ha on August 17th when the 2006 imagery was taken.

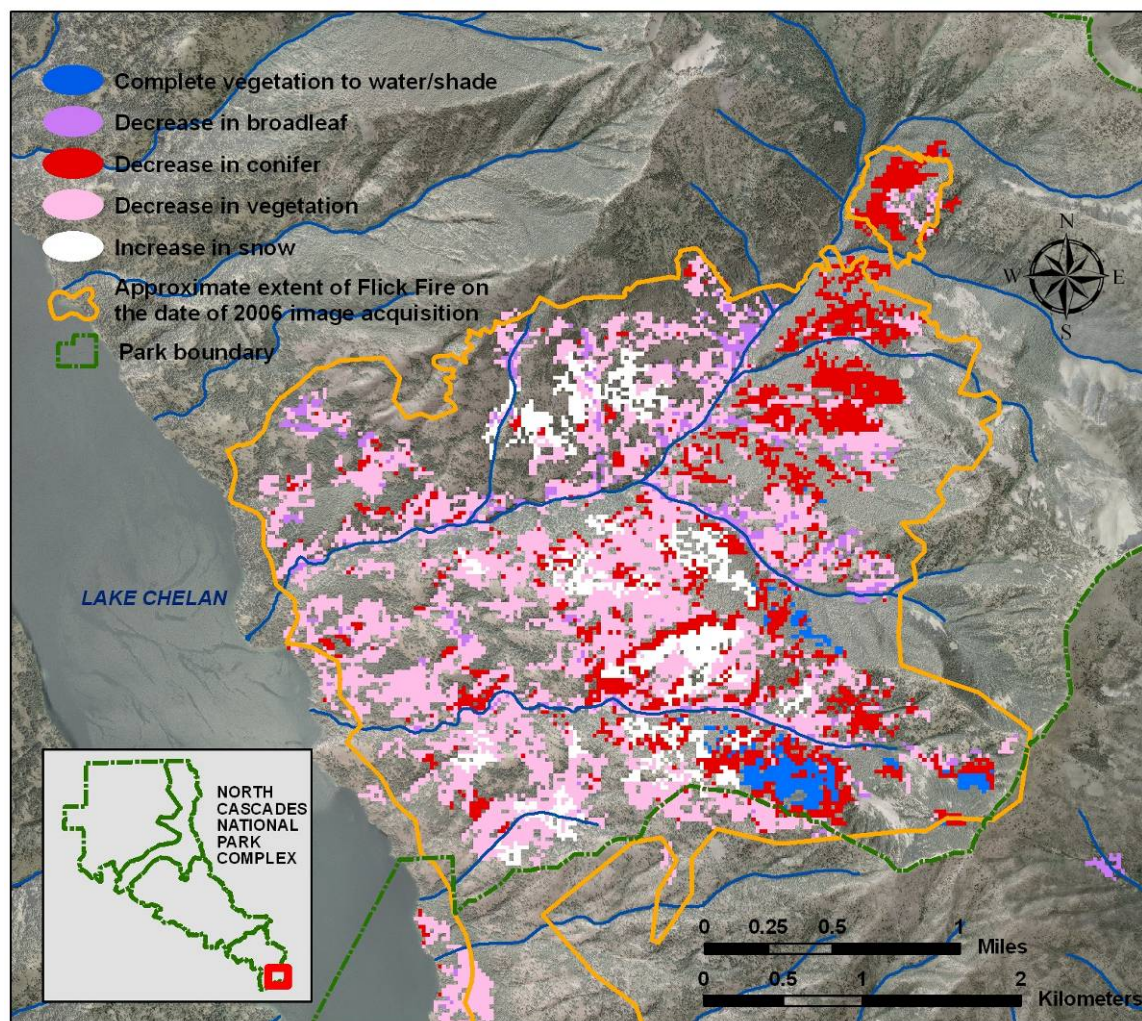


Figure 21. Detected 2005-2006 S2S interpretation change classes at North Cascades NP following 2006 Flick Creek fire.

The analysis of the burned area identified several change classes depending on the spectral location of the pixel in the 2005 imagery (Table 4). The “Decrease in conifer” label was given to pixels that had a high probability of membership in the “Closed-canopy conifer” physiognomic

class in 2005, whereas the “Decrease in broadleaf” label was given to pixels that had a higher probability of membership in one of the classes with a high broadleaf component. The “Decrease in vegetation” label was assigned to pixels that originally were classified as “Conifer/broadleaf mix” or “Mixed” because closed-canopy mixed vegetation or open forests and woodlands with some cover of soil and rock. These class changes match expectations of vegetation decreases due to fire.

The computer algorithm also generated the unexpected change classes of “Increase in snow/cloud” and “Complete vegetation to water/shade.” After consulting with the park’s fire and resource management staff who were familiar with the area, it was determined that areas labeled as “Increase in snow/cloud” most likely corresponded to locations that burned with the highest intensity leaving behind a large amount of ash, which is spectrally similar to snow. “Complete vegetation to water/shade” areas seemed to correspond to locations that burned twice, once in 2001 and again in 2006, and were likely heavily charred and therefore spectrally similar to shade. These labels emphasize the importance of examination and interpretation of each change polygon to determine the presence and type of disturbance.

MORA

The frequency and extent of riparian disturbance can also fluctuate with climate change. Tahoma Creek, flowing out of the South Tahoma Glacier at Mount Rainier National Park, has been called by USFS geomorphologist, Gordon Grant, the most dramatic example of potential catastrophic climate change impacts in the United States (Paul Kennard, NPS). In 1967 South Tahoma Glacier experienced a large glacial outburst flood. Such outburst floods usually occur during the periods of unusually hot or rainy weather when the base of the glacier is overwhelmed by large amounts of meltwater or rainwater (Walder and Driedger, 1993). Since 1967, Tahoma Creek experienced at least 27 debris flows following smaller glacial outburst floods (Paul Kennard, NPS) resulting in the closure of the Westside road and the accumulation of boulder deposits at a rapid rate (Walder and Driedger, 1993). The debris flow, which resulted in disturbance shown in Figures 22 and 23, occurred on Sept. 29, 2005, after about 13 cm of rain during a warm storm. As with the Flick Creek fire at NOCA, the disturbance was picked up by the change detection analysis as a decrease in different types of vegetation, primarily decreases in broadleaf types which reflects the instability of this landscape relative to the more stable conifer forests which surround it.

OLYM

The importance of understanding the effects of disturbance on fish and wildlife habitat has been the primary reason the NCCN chose to include a 16-km buffer around park boundaries in which to monitor landscape dynamics. For OLYM, this means monitoring the landscape dynamics of the entire Olympic peninsula, including the watersheds east of the park’s coastal strip and around Lake Ozette. Sixty-seven percent of the lake’s watershed is privately owned, and most of the area is managed for timber production (Jacobs *et al.* 1996). Intensive logging has been identified as one of the conditions contributing to the decline of sockeye salmon (*Oncorhynchus nerka*) in Lake Ozette due to its possible negative impact upon spawning grounds and disruption of natural hydrology (Bortleson and Dion 1979, Dlugokenski *et al.* 1981, Blum 1988, Adkison and Burgner 1996, Geiger 1996, Jacobs *et al.* 1996, Lestelle 1996). Sockeye salmon in the Ozette Lake Basin comprise a unique stock that is genetically distinct from all other sockeye populations on the Washington coast and in Puget Sound (NMFS 2001). The lake’s sockeye salmon population has

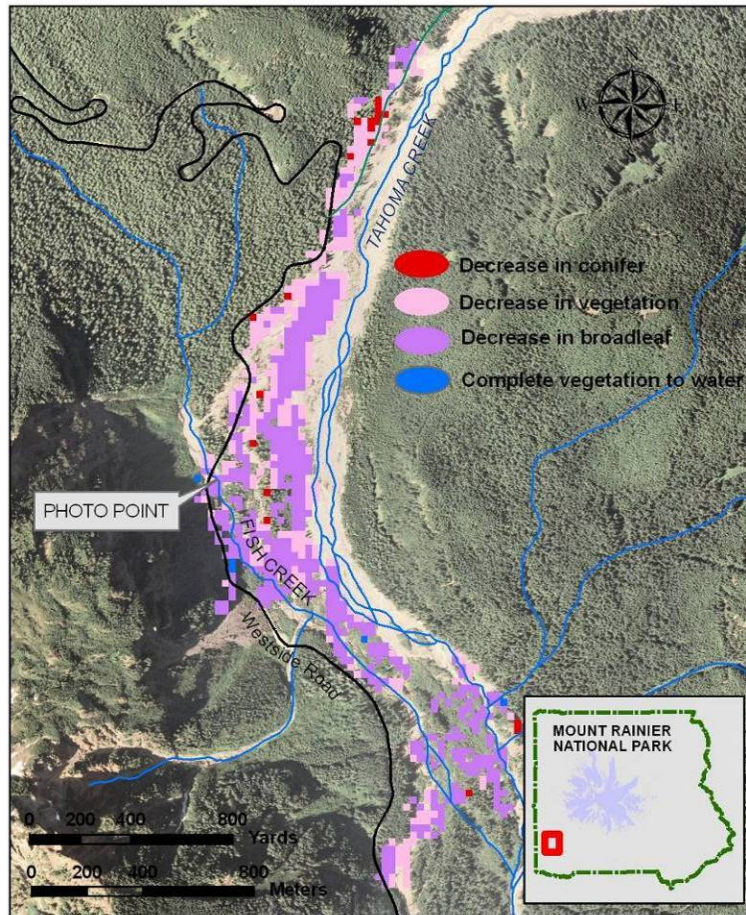


Figure 22. Disturbance following September 29, 2005 debris flow on Tahoma Creek.



Figure 23. Fish Creek, following the September 29, 2005 debris flow flood, below debris flow deposit, just downstream where the creek crosses the West-side Road. See photo point in Figure 22.

experienced drastic declines in the last 60 years (Adkison and Burgner 1996) and has been listed as “threatened” through the Endangered Species Act (ESA 1973: Section 3) by the National Marine Fisheries Service (NMFS).

The 2004-2006 change detection analysis for OLYM identified several new clearcut areas in the Upper Big River watershed above Lake Ozette (Figure 24). Continuous monitoring of the changes in land use around the lake could help OLYM to quantify logging effects on aquatic habitat and to identify management priorities, as well as provide valuable information for working with neighboring land owners on salmon habitat conservation.

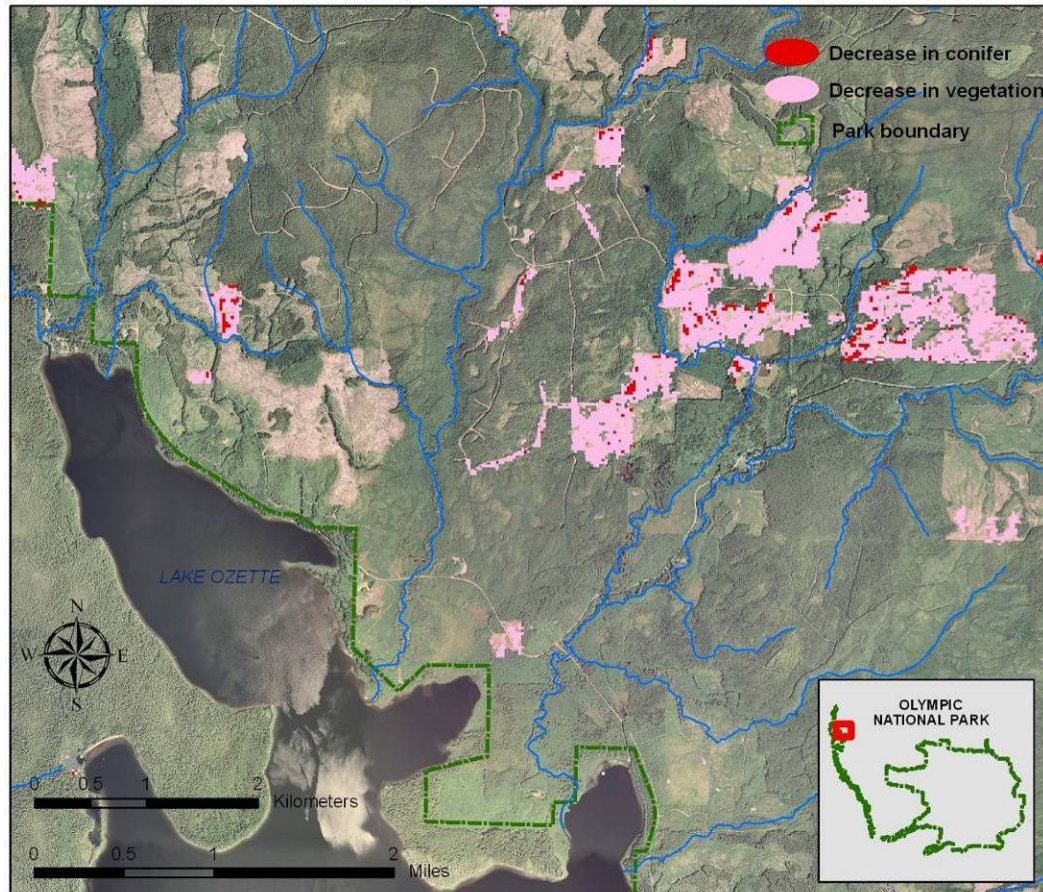


Figure 24. Detection of new clearcuts between 2005 and 2006 in the Upper Big River watershed above Lake Ozette.

Discussion

Image Acquisition

It is of primary importance to obtain images that are 1) free of clouds and 2) as close in date as possible to minimize the different amounts and types of shadows. With the original minimum mapping size of six pixels, the NOCA change detection results yielded hundreds of thousands of polygons, the majority of which were a result of differences in shadowing and cloud cover between the images. Similarly, it is important to get imagery that was taken towards the end of the summer to minimize the annual variability in plant phenology. The imagery for MORA presented the best example of “good timing,” although in 2006, a large portion of the study area was covered by clouds. Large amounts of “false” change, or change that is not of interest to the network, result in an unreasonable amount of digitizing during the validation stage. In addition, all the “false change” polygons have to be interpreted by NCCN ecologists.

That said, given the annual climate variations that influence the phenology, moisture availability, snow levels, etc., and difficulty in obtaining cloud-free imagery of the same or similar date, it would be nearly impossible for the NCCN to come up with an annual “perfect” pair of images that would produce results with minimum “false” change. Looking at biannual or triennial change detection, as we did with OLYM during the 2004-2006 change interval, might be required.

New tools recently have become available that could remedy many of the problems encountered during our initial implementation of the protocol. A “trajectory-based” approach has been developed by the researchers at the PNW Research Station in Corvallis, Oregon (Kennedy et al 2007b). The advantage of this approach is that it eliminates the year-to-year variability that has caused problems in our analysis by looking at “stacks” of annual images for any given time interval and evaluating disturbance polygons based on their trajectories in time, rather than single-year events. This approach also incorporates the use of cloud and cloud shadow masks, significantly reducing the number of change polygons that are not of interest to the network. The result of this analysis is a series of maps depicting:

1. Disturbance by type, year and intensity across all ownership categories;
2. Slow disturbance, such as insect infestation;
3. Regrowth, including post disturbance recovery rates and changes within areas of no disturbance.

In addition to eliminating problems with annual variations in phenology, cloud cover and shadow, this new approach allows further automation of image processing and validation (Robert Kennedy, personal communications).

Image Processing

The image-processing methods in the protocol worked well for NOCA and MORA because a single Landsat TM scene was used. The use of a single scene helped reduce misregistration errors and, consequently, minimized the number of false positives in the final change products. Having to use two scenes for the OLYM study area introduced a number of difficulties, including having to develop new methodology for processing images from the initial year in relation to each other as well as in relation to images from the second year of the change-detection interval. Larger misregistration errors resulting from multiple georectifications

increased the number of false positives in the final change product. The false positives were mostly along physiognomic-type boundaries along narrow, long features such as riparian areas and avalanche chutes. They were also common in open forest and subalpine areas where different vegetation types are mixed with soil and rock. Applying the larger minimum mapping size to the final change product helped eliminate some of the false positives resulting from the misregistration errors.

Development of Physiognomic Class Descriptions

In a change detection analysis that does not involve land cover maps, the assignment of an individual pixel to a physiognomic class is less important than the direction and the amount of change in POM for each pixel vis-à-vis each physiognomic class. With that in mind, we feel that the process of separating the nine physiognomic classes in spectral space worked well. More work, however, needs to be done to better describe the physiognomic classes in relation to the typical vegetation communities found in NCCN's three large parks. The generic physiognomic class titles developed in the original protocol do not reflect well the actual vegetation types found on the ground. For example, the difference between "Dense broadleaf/grass" and "Broadleaf tree/shrub" categories is unclear. It appears that neither of them includes a broadleaf tree component. Wide variations in "Closed-canopy conifer" category could be better described by looking at changes in tree and understory species and DBH measurements along the elevation gradient. A better profile of "Conifer/broadleaf mix" category could be developed if one further used Vegetation Inventory project data to compare patterns of forest canopy closure (conifer), with broadleaf cover and understory components across the three parks and along elevation, aspect or climate gradients. In addition, current descriptions were developed based on plot data from inside the park boundaries. Descriptions need to be expanded to include the land cover types found outside parks, such as ones resulting from forest management and agricultural activities.

Questions remain with regard to whether or not the use of 2004 imagery to develop physiognomic class descriptions for OLYM will have lasting effects on the future change detections. As noted elsewhere in the report, the greenness component of the 2004 image was significantly different from the 2006 image, resulting in widespread detection in the final change product of areas labeled as "Increase in broadleaf." Theoretically, only general spectral characteristics of the individual physiognomic classes are important for our analysis. We are assessing the direction and amount of movement in spectral space that occurs at a pixel within the change interval, rather than the precise location of the pixel within that space. On the other hand, if one physiognomic class was disproportionately affected by the annual phenological variability, as appears to have happened with broadleaf vegetation in OLYM, the spectral description of that particular class might be permanently skewed with relation to the other physiognomic classes, subsequently affecting every subsequent change detection. If that is the case, selecting a different base image for physiognomic class delineation for OLYM might be warranted. Subsequent annual change detections, as well as conversations with professionals in the remote sensing field, would help us determine whether using a different base image would improve our results.

Type I Change Detection

This initial implementation demonstrated that the current methods of change detection could detect the types of change of interest to the NCCN. However, this first round of the change

detection protocol for all parks contained an enormous number of change polygons, numbering in the hundreds of thousands. A large proportion of the polygons were very small, just over the minimum mapping size of six pixels. The results also contained a large amount of real but “uninteresting” changes such as differences in phenology, cloud cover, shadows, etc. This overwhelming area of false or uninteresting change presented a number of problems. First, the validation process took a very long time, as the interpreters had to delineate every six-pixel area that appeared to have changed within the 3600-pixel validation box, of which each park had a few hundred. Second, the current protocol did not provide the methods or a time estimate for determination of disturbance agents for each change polygon. This step is necessary in order to answer the NCCN landscape dynamics monitoring questions posed in Table 1. Upon seeing the amount of work to assign a disturbance agent to all change polygons, questions were raised about whether or not this work could be accomplished and its cost.

Reducing Uninteresting Change- Image Processing

To attempt to reduce the impact of the problem of false or uninteresting change, we created a snow/cloud/shadow mask to reduce the number of change polygons available for validation and interpretation. The mask worked well for snow and clouds, but was too inaccurate and too time consuming to develop for shadows. Shadows presented two difficulties. They exhibit varying degrees of deepness and are spectrally similar to closed-canopy conifer forests within the spectral space of the tasseled-cap (Figures 3 and 4). We had difficulty creating a mask that included all the shadows while also excluding areas occupied by mature closed-canopy conifer forests. Additionally, shadows are also spectrally indistinguishable from water. On the other hand, changes in the extent and location of water are of interest to the network. In order for the shadow mask to work, we had to exclude from the mask all areas within the study area that were occupied by water. This resulted in a complex process of combining different masks together, which was very time-consuming and inaccurate. The process also had to be repeated for each new image we acquired. In the final product, the application of this mask would have also resulted in the loss of any changes in water features that were outside of known extents, since they would have been masked out as shadows. Finally, application of snow/cloud/shadow mask did not significantly reduce the number of change polygons left for interpretation. We abandoned this avenue of action and instead increased the minimum mapping size.

The increase in minimum mapping size worked very well to reduce the number of change polygons for validation and interpretation. It also helped to reduce the amount of “uninteresting” change. For example, changes in snow levels were, for the most part, eliminated from the final products. However, we did not evaluate what percent of “interesting” change was eliminated as a result of the increase in the minimum mapping size. Different minimum mapping sizes could be applied in order to answer different monitoring questions. Application of larger minimum mapping sizes might be appropriate for the areas outside of park boundaries, where NCCN is focused in changes in land use, whereas smaller minimum mapping size could be used to detect some of the smaller natural disturbances inside park boundaries.

Threshold level is another variable in the change detection analysis that can be manually set by the user. From the limited amount of time we spent looking the imagery from the 2004/05-2006 change interval, it appeared that lower thresholds allowed for detection of slower and lower intensity landscape processes such as vegetation regrowth and insect infestations. Higher thresholds worked well for dramatic changes such as clearcuts, river disturbances, landslides,

and avalanches. Use of lower thresholds also generated a large number of polygons with "uninteresting" change, making it too time-consuming to interpret the results. A solution might be to develop a combination of different minimum mapping sizes and thresholds tailored for different types of disturbances. Small, dramatic disturbances might be better assessed using a combination of small minimum mapping size and high threshold, whereas large, subtle or slow disturbances might be better evaluated with larger minimum mapping size and lower threshold.

Reducing Uninteresting Change- Phenology

Differences in vegetation phenology were another factor contributing to the large amount of "uninteresting" change detected by the analysis. The most dramatic example of uninteresting change due to phenology was found in the OLYM 2004-2006 change detection. We first assessed the possibility that the large changes in the greenness component of the tasseled-cap transformation were somehow related to the modified radiometric correction methods (MADCAL) used for that park (Figures 6 and 8). Upon careful examination of the images, however, it seemed unlikely that this was the case. First, we knew that MADCAL process worked well when only one image was involved, as NOCA and MORA analyses have shown. Further, all additional West OLYM images were radiometrically corrected to the 2004 East image. If there were any problems with radiometric correction methods, we would have expected them to only show up under the area of the western image, which was not the case. The increase in greenness was seen throughout the study area.

The second possibility was that actual phenological differences existed in the broadleaf vegetation between 2004 and 2006. This explanation was supported by the pattern of distribution of the "Increase in broadleaf" change category in the change detection product (Figure 15). The distribution pattern closely mimicked the distribution pattern of physiognomic classes with a broadleaf component in the physiognomic class image (Figure 11). For example, the Elwha and Sol Duc River valleys that were most affected by the increase in greenness within the park boundary in the final change image were also the areas with highest broadleaf component within the park according to the physiognomic class map.

"Decrease in conifer" and "Complete vegetation to water/shade" labels, common in the final change product for OLYM, could also be a result of phenological differences in coniferous vegetation between 2004 and 2006. The labels would have been a result of pixels moving away from the spectral centroid of the "Closed-canopy conifer" class toward the one of the "Water/deep shade" class. For some pixels, the POM could have changed enough to actually put them in "Water/deep shade" physiognomic class. For other pixels, the difference in POM could have been large enough to pass the threshold of change, but not large enough to move these pixels into a different physiognomic class category, resulting in the "Decrease in conifer" designation.

Phenological differences will continue to present a problem if NCCN continues with the two-date change detection method. With clouds commonly present in the areas covered by the three parks, acquiring images close enough in date to minimize both shadow and phenological differences will pose a significant challenge. Thresholds can be increased to reduce the amount of "uninteresting" change detected by the analysis. However, as we have seen in the 2004/2005-2006 change detection, the "uninteresting" change can have a more pronounced spectral signal than many of the subtle "interesting" changes the network would like to monitor. That is why

the “trajectory-based” approach developed by the Corvallis group is an attractive alternative to the current methodology. Because each pixel’s location in tasseled-cap spectral space is traced through time, annual variations can be smoothed and eliminated.

Validation

The traditional validation of satellite imagery classification relies on field data. The S2S validation used by the Landscape Dynamics protocol differs from traditional methods in that it relies on human interpretation of the satellite imagery that has undergone statistical modification in the form of the tasseled-cap transformation. The validation process was further hindered by the small number of validation points for certain classes and the difficulties the interpreter encountered while trying to delineate perceived change. Additionally, we found that individual interpreters varied in their approach to the validation process, potentially complicating comparisons between products interpreted by different network staff. Overall, we found that the accuracy assessment results for specific change classes were unreliable. For example, even though the interpreters performing the NOCA/MORA and the OLYM validation trained jointly and communicated frequently, there were stark differences in how each interpreter delineated the polygons.

The OLYM interpreter digitized change polygon boundaries that were slightly smaller than the areas of perceived change, whereas NOCA’s and MORA’s interpreter digitized change polygon boundaries using the outer pixels of the perceived change area. The difference in digitizing techniques caused accuracy assessment points that fell close to the boundary of the area outlined by the interpreter to be labeled as “Changed.” Figure 25 shows a hypothetical example of how different digitizing techniques could potentially result in an accuracy assessment point being classified as “No Change” rather than “Change.” Image (a) shows, in light grey, an area of 4x5 pixels that represents change delineated by the computer algorithm. The red outline represents the changed area delineated by the interpreter using the tasseled-cap images from the two dates. The area is digitized to be a bit smaller than the pixel boundaries of the underlying change. After the delineation process is complete, the red outline is converted from vector to raster format with pixels inside the outline receiving “Change” label. The boundary pixels of the “Change” area are determined based on where within the original pixel the outline was located. If the outline included more than 50% of the original pixel, the entire pixel in the output raster was labeled as “Change.” On the other hand, if the outline included less than 50% of the original pixel, the entire pixel was labeled as “No Change.” Red pixels in image (b) are the raster representation of the polygon delineated by the interpreter in image (a).

According to the current methodology, accuracy assessment was to be performed by selecting a large number of points inside the visual validation boxes, representing both change and no change labels applied by the interpreter. These points represented the reference dataset and their labels were compared to the ones generated by the computer algorithm. According to the protocol, the label for the pixel was determined by the algorithm using the Majority Threshold rule. The rule defines the minimum number of pixels within the 3 by 3 window needed to achieve the “majority” class status. According to the protocol, 4 out of 9 pixels around the validation point needed to be the same for a potential accuracy assessment plot to be labeled and used. Imagine that the black dot in image (b) represents a hypothetical accuracy assessment point that happens to fall close to the boundary of the “Change” area outlined by the interpreter. Applying the majority rule described above, the accuracy assessment point would be labeled as

“No Change” because only three out of nine surrounding pixels were delineated as change by the interpreter. The same pixel, however, would be labeled as “Change” within the computer algorithm’s raster. If the change polygon was delineated by the interpreter to follow closely the outer boundaries of the pixels deemed to show change, the point would have shown “Change” label for both classifications. This difference in digitizing techniques could have contributed to OLYM’s lower accuracy compared to the other two parks.

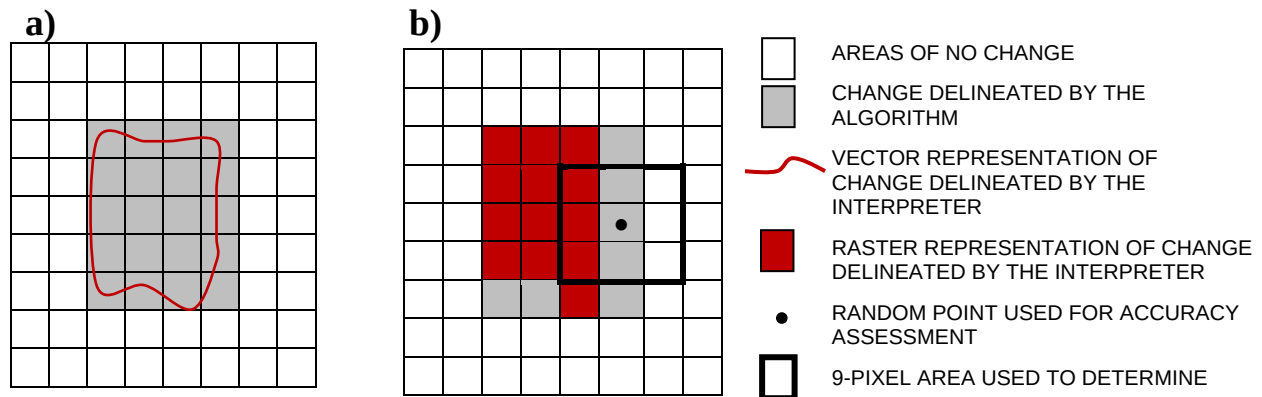


Figure 25. Hypothetical example of how differences in change polygon digitizing techniques can influence assignment of “Change” and “No Change” labels to accuracy assessment points for the change detection.

Digitizing the boundaries of change polygons was challenging for a second reason. The example in Figure 25 worked well for areas that changed along clear boundaries that also happened to fall on the boundary between two pixels. If the boundary between changed and unchanged area happened to be blurry, which could be the case in a mild insect infestation or a low intensity fire, the interpreter had a difficult time determining whether the change in each pixel was significant enough to be classified as “Change.” Figure 20 (c) shows a good example of blurry boundaries created by a cloud shadow. The interpreter had difficulty determining which pixels on the edge of the shadow passed the threshold, resulting in the “Change” areas delineated by the interpreter and the computer algorithm in Figure 20 (d) being quite different. The same difficulty was encountered when an abrupt boundary fell in the middle of the pixel. The spectral reflectance values of changed and unchanged areas were then blended, resulting in the same blurry effect. Because of the difficulties associated with fuzzy boundaries, the accuracy assessment became more of a measure of how well the interpreter mimicked the computer algorithm process, rather than an assessment of how well the algorithm mapped real change. Validation methods using field visits or aerial photo interpretation would be a better assessment of how well the current methodology delineates landscape changes of interest to the NCCN.

Because the change detection results were dominated by “uninteresting” changes, such as changes in cloud cover, shadows and phenology, the majority of the effort associated with validation process went to outlining these changes rather than documenting the landscape changes that the NCCN would like to monitor. And because these “uninteresting” changes dominated all detected changes, the accuracy assessment was skewed towards a few S2S change classes without providing an accurate picture of the accuracy of method for detecting and monitoring real disturbances affecting the parks.

Finally, the misregistration errors greatly reduced the ability to accurately detect change along narrow, long features of interest, such as avalanche chutes and river corridors. This problem was especially pronounced in the case of OLYM. Spectral values show high variability along the boundaries of these features, due to the mixture of cover types. The existing spectral variability was compounded by “false” variability resulting from pixel shift during georectification. This made it difficult to discern “interesting” change from the artificial change introduced by the nature of landcover or georectification errors. Similarly, upper elevation areas with lots of bare ground mixed with different types of vegetation and patches of snow appeared as pure speckle when images from two years were differenced. It is possible that detection of disturbance in these areas would only be possible on a scale larger than six pixels, or over a time period longer than one year.

Conclusions

Significant challenges were encountered during initial implementation of the 2004/05-2006 change detection in the NCCN. These initial results do show that the current Landscape Dynamics protocol methods can detect landscape changes outlined in Table 1. However, in this first implementation, the changes of interest were swamped by the large amount of “uninteresting” change detected. If the NCCN were to move forward using this protocol several significant improvements would need to be tested and incorporated. First, steps in the image processing would need to be fine-tuned to account for need to combine several images to cover OLYM’s study area. Second, manipulation of the minimum mapping size and varying thresholds to detect different intensities and sizes of disturbance could reduce the issues resulting from large amount of “uninteresting” change being delineated. Third, accuracy assessment procedures would need to be monitored to reduce variation between technicians.

The NCCN protocol incorporated the best remote sensing methods for two date change detection available at the time. However, after producing the protocol, researchers in the Forest Science Laboratory moved the science forward by developing a new method that takes advantage of the entire Landsat archive (Kennedy et al. 2007b). The existence of improved methods makes it difficult to envision continuing with this current protocol.

Lastly, we are developoing methods and time/cost estimates for the work to assign disturbance agents to the detected change. Without this step, the processing results from any remote sensing-based change detection method will not be fully useful to park managers, nor meet the landscape dynamics monitoring goals of the NCCN

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Appendix 1. Vegetation mapping data summary, MORA.

Diameter (from PMR)	Physiognomic class						
	Closed-canopy conifer	Conifer/broadleaf mix	Dense broadleaf / grass	Broadleaf tree/shrub	Mixed	Open: dark	Open: bright
no measurable DBH	4	1	12	22	6	1	5
0-9 inch DBH	3	4		2	5		2
9-21 inch DBH	39	21	3		6		1
21-32 inch DBH	31	14			2		
32-48 inch DBH	16				1		
48+ inch DBH	3						
Structure (from PMR)							
multi-size	55	7		1	5		
single-size	37	32	3	1	9		3
not applicable	4	1	12	22	6	1	5
Leaf type							
Broad-leaved	16	8	26	16	31	1	2
Forb	2	1	1	2	8		2
Graminoid		1		9	4		1
Herbaceous							
Microphyllous			1	5	5		7
Needle-leaved	249	74	2	7	59	2	4
Pteridophyte							
Physiognomy							
Dwarf Shrubland	3		1	15	13	1	5
Forest	222	68	5	4	39	1	
Herbaceous	2	3	1	11	13		3
Shrubland	11	7	21	5	15	1	1
Sparsely Vegetated	1				1		3
Woodland	28	6	2	4	26		4
Phenology							
Annual					1		1
Cold deciduous		1	13	7	5	1	1
Deciduous	16	6	13	7	21		1
Evergreen	247	73	2	9	62	2	5
Mixed evergreen							
cold-deciduous	1	1	1	4	3		4
Perennial	3	3	1	12	15		4

Appendix 2. Vegetation mapping data summary, NOCA.

Diameter (from PMR)	Physiognomic class						
	Closed-canopy conifer	Conifer/broadleaf mix	Dense broadleaf/grass	Broadleaf tree/shrub	Mixed	Open: dark	Open: bright
no measurable DBH		2	6	10	6	1	5
0-9 inch DBH	6	13	3	3	30		5
9-21 inch DBH	36	20	1		23	1	
21-32 inch DBH	37	7			8	1	
32-48 inch DBH	3				2		
48+ inch DBH	1						
Structure (from PMR)							
multi-size	39	10	1		16	1	
single-size	44	30	3	3	47	1	5
not applicable		2	6	10	6	1	5
Leaf type							
Broad-leaved	1	31	29	18	26	1	1
Forb		2		5	4	1	1
Graminoid	1	2	1	7	9	1	3
Herbaceous				1	1		
Microphyllous				6	9	1	4
Needle-leaved	227	63	1	6	121	7	6
Pteridophyte		1			1		1
Physiognomy							
Dwarf Shrubland				11	13	1	5
Forest	217	76	9	4	66	4	2
Herbaceous	1	5	1	13	14	1	5
Shrubland		10	21	11	15	1	
Sparsely Vegetated					1	1	
Woodland	11	8		4	62	3	4
Phenology							
Annual				2	2		
Cold deciduous		13	11	6	3		
Deciduous	1	15	18	12	15		
Evergreen	223	63	1	12	136	9	11
Mixed evergreen cold-deciduous	3	3			2		
Perennial	2	5	1	11	13	2	5

Appendix 3. Vegetation mapping data summary, OLYM.

Diameter (from PMR)	Closed-canopy conifer	Conifer/broadleaf mix	Physiognomic class					Open: dark	Open: bright
			Dense broadleaf/grass	Broadleaf tree/shrub	Mixed				
no measurable DBH	10	10	3	22	29		1		6
0-9 inch DBH	5	4			2				2
9-21 inch DBH	25	13	2		8		1		
21-32 inch DBH	30	9	1	1					
32-48 inch DBH	18	2	1	2	1				
48+ inch DBH	5	1							
Structure (from PMR)									
multi-size	46	10	2	2	4				
single-size	37	19	2	1	7		1		2
not applicable	10	10	3	22	29		1		6
Leaf type									
Broad-leaved	13	36	26	28	10				1
Forb		2		3	4				3
Graminoid	1	2	2	2	5				2
Herbaceous				1	2				
Microphyllous	1	6		13	12				5
Needle-leaved	262	98	1	2	35		2		1
Pteridophyte									
Physiognomy									
Dwarf Shrubland	1	8		16	19				5
Forest	244	110	14	11	20		1		
Herbaceous	1	5	2	6	10				5
Shrubland	4	8	11	14	6		1		1
Sparsely Vegetated			1		2				
Woodland	27	13	1	2	11				1
Phenology									
Annual		1			1				
Cold deciduous	2	9	5	13	3				
Deciduous	8	20	20	15	2				1
Evergreen	258	101	2	15	53		2		7
Mixed evergreen cold-deciduous	3	8	1	1	2				
Perennial	6	5	1	5	7				4

Appendix 4. PMR data summary, NOCA park-wide.

Physiognomic Class		Closed-canopy conifer	Conifer/broadleaf mix	Dense broadleaf/grass	Broadleaf tree/shrub	Mixed	Open: dark
Percent Crown Cover	Conifer basal area/acre	Mean	262.64	179.99	137.95	52.96	144.37
		St. Dev	135.14	165.67	198.05	131.43	136.52
		# of Plots	203	66	8	8	103
	Conifer trees/acre	Mean	228.52	176.82	68.75	83.13	176.41
		St. Dev	154.63	145.68	102.63	215.36	176.01
		# of Plots	203	66	8	8	103
	Hardwood basal area/acre	Mean	18.95	124.79	0.00	0.00	62.15
		St. Dev	13.42	73.85	0.00	0.00	45.07
		# of Plots	9	12			6
	Hardwood trees/acre	Mean	80.00	170.83	0.00	0.00	75.00
		St. Dev	77.46	103.85	0.00	0.00	46.26
		# of Plots	9	12			6
	Snag basal area/acre	Mean	43.68	28.44	15.26	18.34	26.11
		St. Dev	49.62	53.33	28.44	37.26	48.39
		# of Plots	203	66	8	8	103
	Trees < 4.5 feet tall	Mean	5.09	3.79	1.25	0.00	3.46
		St. Dev	7.64	7.34	3.54	0.00	9.68
		# of Plots	203	66	8	8	103
	trees >= 4.5 feet tall and < 4.0 inches DBH	Mean	9.94	11.79	8.13	1.88	8.01
		St. Dev	14.30	15.62	15.57	3.72	13.87
		# of Plots	203	66	8	8	103
	Bare Ground	Mean	0.99	0.38	0.00	2.50	1.75
		St. Dev	4.98	1.60	0.00	3.78	7.13
		# of Plots	203	66	8	8	103
	Rock	Mean	2.54	0.61	1.88	1.25	6.75
		St. Dev	9.59	2.24	3.72	2.31	13.24
		# of Plots	203	66	8	8	103
	Lesser Vegetation	Mean	42.56	64.47	91.25	86.25	61.02
		St. Dev	36.28	42.14	35.73	43.07	39.25
		# of Plots	203	66	8	8	103
	Moss	Mean	24.29	17.58	11.88	6.25	12.96
		St. Dev	27.12	20.89	24.49	6.94	21.68
		# of Plots	203	66	8	8	103

Appendix 5. PMR data summary, NOCA west of Cascade Crest.

Physiognomic Class			Closed-canopy conifer	Conifer/broadleaf mix	Dense broadleaf/grass	Broadleaf tree/shrub	Mixed	Open: dark
Percent Crown Cover	Conifer basal area/acre	Mean	272.01	204.75	354.44	141.23	162.26	217.99
		St. Dev	138.51	160.80	140.50	204.36	137.91	153.16
		# of Plots	165	50	2	3	56	2
	Conifer trees/acre	Mean	232.33	207.60	222.50	221.67	225.54	217.50
		St. Dev	159.12	142.16	38.89	340.97	186.10	166.17
		# of Plots	165	50	2	3	56	2
	Hardwood basal area/acre	Mean	22.22	120.14			77.03	174.04
		St. Dev	13.41	75.60			60.57	
		# of Plots	7	11			3	1
	Hardwood trees/acre	Mean	85.71	164.55			56.67	100.00
		St. Dev	87.72	106.50			24.66	
		# of Plots	7	11			3	1
	Snag basal area/acre	Mean	52.23	42.74	54.83	73.34	39.15	8.05
		St. Dev	50.69	62.20		40.62	46.49	1.74
		# of Plots	143	41	1	2	41	3
	Trees < 4.5 feet tall	Mean	10.48	10.4545	10		12.84	5.00
		St. Dev	7.76	9.50			16.39	0.00
		# of Plots	82	22	1		25	2
	Trees >= 4.5 feet tall and < 4.0 inches DBH	Mean	18.39	19.16	27.5	7.50	19.05	5.00
		St. Dev	16.25	16.47	24.75	3.54	17.43	
		# of Plots	95	38	2	2	37	1
	Bare Ground	Mean	14.29	6.25		6.67	10.00	20.00
		St. Dev	13.42	2.5		2.89	6.61	
		# of Plots	14	4		3	9	1
	Rock	Mean	14.83	7.5	5.00	5.00	18.39	5.00
		St. Dev	20.99	5		0.00	18.50	0.00
		# of Plots	30	4	1	2	31	2
	Lesser Vegetation	Mean	45.20	68.5714	93.00	86.25	67.258	51.25
		St. Dev	36.01	41.2023	42.37	43.07	36.30	26.58
		# of Plots	149	56	5	8	62	4
	Moss	Mean	36.99	27.02	45.00	10.00	29.05	17.50
		St. Dev	26.41	20.81	35.36	6.12	26.32	10.61
		# of Plots	128	42	2	5	42	2

Appendix 6. PMR data summary, NOCA east of Cascade Crest.

Physiognomic Class			Closed-canopy conifer	Conifer/broadleaf mix	Dense broadleaf/grass	Broadleaf tree/shrub	Mixed	Open: dark
Percent Crown Cover	Conifer basal area/acre	Mean	234.29	273.61	394.72		192.79	132.40
		St. Dev	101.63	148.27			119.26	41.33
		# of Plots	36	6	1		30	2
	Conifer trees/acre	Mean	223.75	215.00	105.00		184.67	150.00
		St. Dev	127.62	63.87			142.48	84.85
		# of Plots	36	6	1		30	2
	Hardwood basal area/acre	Mean	7.49	175.88			47.28	
		St. Dev	4.88				27.32	
		# of Plots	2	1			3	
	Hardwood trees/acre	Mean	60.00	240.00			93.33	
		St. Dev	28.28				61.10	
		# of Plots	2	1			3	
	Snag basal area/acre	Mean	39.95	31.07	67.22		45.17	14.86
		St. Dev	46.61	39.55			69.42	
		# of Plots	35	4	1		24	1
	Trees < 4.5 feet tall	Mean	10.94	6.67			5.83	
		St. Dev	9.17	2.89			2.04	
		# of Plots	16	3			6	
	trees >= 4.5 feet tall and < 4.0 inches DBH	Mean	11.25	12.50	10.00		10.00	
		St. Dev	7.70	11.90			7.69	
		# of Plots	24	4	1		12	
	Bare Ground	Mean					45.00	
		St. Dev					14.14	
		# of Plots					2	
	Rock	Mean	6.36	5.00	10.00		9.62	
		St. Dev	2.34	0.00			7.21	
		# of Plots	11	2	1		13	
	Lesser Vegetation	Mean	52.92	69.17	88.33		68.23	77.50
		St. Dev	32.26	29.57	29.30		34.39	31.82
		# of Plots	36	6	3		31	2
	Moss	Mean	13.93	12.50	5.00		9.58	5
		St. Dev	11.96	3.54			4.98	
		# of Plots	14	2	1		12	1

Appendix 7. PMR data summary, MORA park-wide.

			Closed-canopy conifer	Conifer/ broadleaf mix	Dense broadleaf/ grass	Broadleaf tree/shrub	Mixed	Open: dark	Open: bright
Percent Crown Cover	Conifer basal area/acre	Mean	288.72	240.07	161.42	178.09	178.30	265.74	51.17
		St. Dev	148.27	166.54		160.45	132.65	141.36	62.49
		# of Plots	207	57	1	4	47	3	2
	Conifer trees/acre	Mean	240.56	211.32	280.00	180.00	205.85	335.00	65.00
		St. Dev	197.92	167.10		188.86	153.88	269.30	21.21
		# of Plots	207	57	1	4	47	3	2
	Hardwood basal area/acre	Mean	68.91	60.80	131.40		37.22		
		St. Dev	54.26	49.13			42.25		
		# of Plots	7	8	1		6		
	Hardwood trees/acre	Mean	115.71	115.625	360.00		113.33		
		St. Dev	119.42	121.345			92.66		
		# of Plots	7	8	1		6		
	Snag basal area/acre	Mean	57.61	56.10		86.04	54.58	80.99	110.38
		St. Dev	56.39	71.37		42.54	56.37	101.86	115.19
		# of Plots	194.00	49		2	38	2	2
	Trees < 4.5 feet tall	Mean	15.10	17.19	5.00	6.67	10.89	25.00	15.00
		St. Dev	11.61	11.91	0.00	2.89	10.72		9.35
		# of Plots	135	32	2	3	28	1	5
	trees >= 4.5 feet tall and < 4.0 inches DBH	Mean	16.28	20.58		10.00	17.91	47.50	40.00
		St. Dev	16.40	21.32			18.05	45.96	
		# of Plots	98	26		1	22	2	1
	Bare Ground	Mean	20.47	22.50	28.33	28.13	20.83	60.00	29.67
		St. Dev	18.90	18.64	20.21	23.59	17.07	28.28	18.27
		# of Plots	32	6	3	8	30	2	15
	Rock	Mean	13.10	21.83	15.00	16.00	22.00	12.50	25.00
		St. Dev	12.19	18.17		6.52	20.86	10.61	16.83
		# of Plots	21	6	1	5	20	2	7
	Lesser Vegetation	Mean	36.87	47.02	67.50	60.00	51.53	68.75	47.12
		St. Dev	27.63	27.28	26.79	22.36	26.74	23.23	20.20
		# of Plots	185	52	6	12	58	4	17
	Moss	Mean	26.83	22.05	10.00	5.00	22.89	38.33	20.00
		St. Dev	21.17	19.15	8.66		20.77	28.43	
		# of Plots	101	39	3	1	19	3	1

Appendix 8. PMR data summary, OLYM park-wide.

			Physiognomic Class	Closed-canopy conifer	Conifer/broadleaf mix	Dense broadleaf/grass	Broadleaf tree/shrub	Mixed	Open: bright
Percent Crown Cover	Conifer basal area/acre	Mean	329.16	338.15	135.71	47.52	212.61	11.37	
		St. Dev	167.02	167.56	68.69		165.87		
		# of Plots	353	97	3	1	16	1	
	Conifer trees/acre	Mean	179.18	201.44	223.33	80.00	189.38	80.00	
		St. Dev	160.43	190.66	77.67		130.37		
		# of Plots	353	97	3	1	16	1	
	Hardwood basal area/acre	Mean	57.45	58.73	45.41		28.75		
		St. Dev	52.12	59.87			28.02		
		# of Plots	16	14	1		2		
	Hardwood trees/acre	Mean	85.00	87.14	80.00		60.00		
		St. Dev	97.78	69.88			28.28		
		# of Plots	16	14	1		2		
	Snag basal area/acre	Mean	82.42	65.02	24.90	2.45	48.20	11.00	
		St. Dev	80.69	73.23	10.34	0.47	40.73	9.91	
		# of Plots	358	103	3	2	16	2	
	Trees < 4.5 feet tall	Mean	11.80	9.07			6.43		
		St. Dev	11.56	7.09			2.44		
		# of Plots	130	43			7		
	trees >= 4.5 feet tall and < 4.0 inches DBH	Mean	19.95	14.46		10.00	10.71		
		St. Dev	21.45	11.59			9.32		
		# of Plots	130	37		1	7		
	Bare Ground	Mean	12.22	12.22		20.00	37.50	40	
		St. Dev	10.74	10.74		14.14	39.26	28.28427	
		# of Plots	18.00	18.00		2.00	4.00	2	
	Rock	Mean	15.11	21.67		20.00	31.00	60	
		St. Dev	16.45	12.58		14.14	33.24		
		# of Plots	46.00	3.00		2.00	5.00	1	
Lesser Vegetation	Mean	50.27	56.55	90.00	60.00	48.53	32.5		
	St. Dev	29.05	31.24	21.79	28.28	28.96	10.6066		
	# of Plots	318.00	91.00	3.00	2.00	15.00	2		
Moss	Mean	30.48	30.78	35.00		34.29			
	St. Dev	25.34	24.81			30.88			
	# of Plots	241	58	1		7			

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

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