MONITORING VEGETATION CHANGES IN THE SHAWNIGAN WATERSHED WITH REMOTE SENSING: A STUDY IN SUPPORT OF ADAPTIVE MANAGEMENT AND ECOLOGICAL GOVERNANCE

By

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We accept this paper as conforming
to the required standard

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"We are trying to piece back together our culture, our language, our economy
and most important of all our community, so that
we can leave footprints on this Earth that our children will be proud to walk in"

(Chief Delores Alex, Nazko First Nation, January 25, 2007)

Abstract

Increasing threats to ecological integrity of the Shawnigan Watershed on southern Vancouver Island catalyzed in 2012 the creation of the Shawnigan Basin Society, a non-profit citizen's group, committed to establishing a model of participatory ecological governance, and restore the natural integrity and hydrologic functions necessary for a sustainable water supply. Key to the model is to understand the current conditions of the watershed through an interdisciplinary body of knowledge. In that context, remote sensing is a unique tool that provides a synoptic view of the entire watershed and its evolution over time. This study mapped the vegetation changes between 1984 and 2014 in the Shawnigan Lake Watershed using the Normalized Differential Vegetation Index (NDVI) derived from Landsat data. As climate in the region continues to change and anthropogenic pressures build-up, mapping the changing landscape becomes critical for the adaptive management of the basin.

Keywords: Remote sensing; Landsat; vegetation changes; Shawnigan watershed; ecological governance; community

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Last but not least, I want to remember my two grandmothers, Carmen and Julia, and my great aunt Isabel, three strong, brave and perseverant women, always present in my heart.

Glossary

AOI	Area Of Interest
BCLSS	British Columbia Lake Stewardship Society
CVRD	Cowichan Valley Regional District
in situ	"on the ground" - in the document refers to field work
ETM +	Enhanced Thematic Mapper Plus (Landsat 7)
GIS	Geographic Information Systems
GLOVIS	USGS Global Visualization viewer
MOE	Ministry of Environment (British Columbia government)
NDVI	Normalized Difference Vegetation Index
NIR	Near Infra-red
OLI	Operational Land Imager (Landsat 8)
ROI	Region Of Interest
SBA	Shawnigan Basin Authority
SBS	Shawnigan Basin Society
SWR	Shawnigan Watershed Roundtable
TEV	Total Economic Valuation
TM	Thematic Mapper (Landsat 5)
TOA	Top-Of -Atmosphere (reflectance)
USGS	United States Geological Service
UTM	Universal Transverse Mercator (map projection)
WGS	World Geodetic System
WMP	Watershed Management Plan

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Introduction

The Shawnigan Watershed, located on southern Vancouver Island, British Columbia, feeds the Shawnigan Lake, the second largest lake within the Cowichan Valley Regional District (CVRD) and the sole domestic water source for a community of presently over 7,000 people (CVRD, 2010; Fraser, 2014a; Rieberger, Epps, & Wilson, 2004). The basin's land base is highly fragmented among private ownerships, with crown land parcels mostly allocated by the province as woodlots, and significant park areas owned by the Regional District (Fraser, 2014b; Kemshaw, 2006). Consequently, the governance of land and water resources in the basin is also fragmented among federal, provincial and local government agencies resulting in unresolved environmental problems derived from decades of intense industrial practices and increasing subdivision development (Fraser, 2014b; Nordin, Zu, & Mazumder, 2007). The cumulative impact is high and is leading to significant threats to the public water supply that will be amplified by the progressing consequences of climate change (CVRD, 2014a,b).

The mounting risks to the ecological integrity of the basin raised the concerns of a community that increasingly knows and cares about its watershed and water security (Bainas, 2014; Cullington & Associates, 2012a,b; Desmond, 2012). In February 2012 the Shawnigan community established the Shawnigan Watershed Roundtable (SWR) to promote active ecological stewardship of the watershed. In 2013 this initiative led to the creation of the Shawnigan Basin Society (SBS), a non-profit citizen's group committed to establishing a model of participatory ecological governance of the Shawnigan Community Watershed, and to gain and account for public funds for watershed management (Fraser, 2012a). A third initiative, presently in progress and being addressed collaboratively with the CVRD, is the Shawnigan Basin Authority (SBA). The SBA aims to attain some decision making power from the government agencies and achieve locally collaborative ecological governance of the watershed, though this is expected to take several years to be accomplished (Fraser, 2014b; Rusland, 2013). The overall objective is to develop and execute the Watershed Management Plan (WMP), shown in Appendix A, which addresses the ecological risks to the basin, engages the many relevant senior and local government jurisdictional agencies and involves the public and the Málexet[1] First Nations of the region (Fraser, 2013).

Basic to the ecosystem based conservation planning model is the acquisition of a strong scientific base of geographic, ecological and hydrological information, aimed to establish a baseline of the basin ecosystems; assembly of some of this knowledge is under way (Cullington & Associates, 2012b; Rieberg et al., 2004). However, there have not been systematic ground observations in the area over time, except for private managed forest land parcels. There are presently still no accurate maps of our source streams, filtering wetlands and forest ecosystems, which are critical to understanding the present state of ecological integrity and help focusing efforts to restore the natural hydrologic functions of the watershed required for sustainable water supplies into the future (B. Fraser, pers. comm., February 7, 2015).

Background on the Study Area

South Cowichan, home to the Cowichan, Shawnigan and Saanich Inlet watersheds (Figure 1), was inhabited over 8,000 years ago by Coastal Salish First Nation peoples who were displaced as a result of the E&N Railway land grant in the late 1800's. Since then, the area has been heavily impacted by industrial logging, mining, recreation and urban sprawl (CVRD, 2010). Although the Shawnigan watershed boundaries expand to the northeast towards Cobble Hill and east into Mill Bay, the SBS has focused their preliminary efforts on the Shawnigan Lake

[1] Malahat

watershed due to its ecological unity and its relevance as sole water supply for 7,000 residents (SBS, 2014).

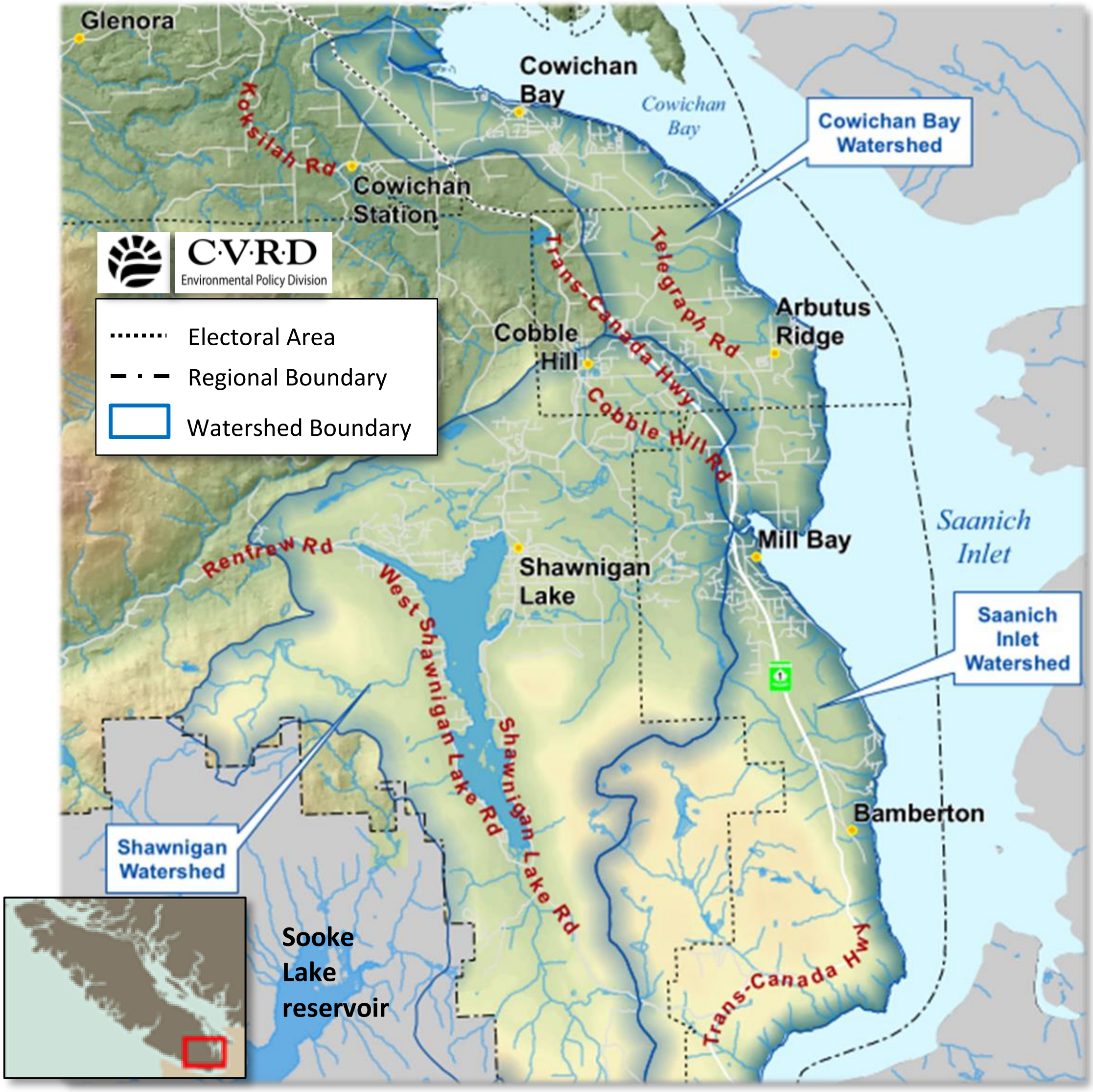

Figure 1. Map of the South Cowichan watersheds (CVRD, n.d.). An extension of the Sooke Lake Reservoir watershed is shown in Appendix B.

Allegedly, the official designation of “community watershed” in Bill 18-1995, *Forest Practices Code of B.C. Amendment Act,* protects watersheds such as Shawnigan that supply drinking water from harmful industrial practices (BC MOE[2], 2004). However, the reality is quite different (Cullington & Associates, 2012a,b; Desmond, 2012; The Council of Canadians, 2014). There are concerns for surface water quality due to impacts of human activities in the upper watershed, around the lake and on the lake itself (Fraser, 2012b). In addition, the watershed upland forests, harvested in the early 1900s, continue to be presently impacted by logging, further threatening the ecological integrity of the basin and the conditions in the lake (CVRD, 2010).

Shawnigan Lake is considered oligotrophic[3], but algal patterns changes and hypoxia events recorded in the past have been associated with intensive logging and settlement (Gregory, 2014; Nordin & McKean, 1984). Water quality was reported to remain within Provincial guidelines a decade ago (Rieberger et al., 2004), but recent studies point to a trend of increasing concentrations of chemicals and human feces (Mazumder, 2012; McGillivar, 2009). In addition, for the last two years, the Shawnigan community has been fighting a permit granted by the MOE that allows South Island Aggregates (SIA)[4] to dump five million tons of toxic soil directly above Shawnigan Lake's main feeder creek (Fraser, 2012b; McCulloch, 2014).

Research Objectives and Question

The main objective of this paper is to contribute to the body of knowledge required for the science-based adaptive management of the basin by investigating the use of satellite imagery to map vegetation changes in the Shawnigan watershed for the 31-year period 1984 to 2014, and to characterize its current condition.

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[2] BC Ministry of Environment (MOE): In 2004 with the objective-driven and results-based *Forest and Range Practices Act* and its regulations came into effect. http://www.env.gov.bc.ca/wld/frpa/cwwqo.html
[3] Low production; never leading to a coloring or even a clouding of the water (Carlson & Simpson, 1996)
[4] aka Cobble Hill Holdings

The main question was: *How can Landsat data be used to identify critical ecological areas and assist in the prioritization of restoration and conservation efforts in the Shawnigan watershed?*

The data set used for this study centres on four decades of satellite imagery from the Landsat series, which provide an invaluable resource for scientific studies (NASA, 2015). The analytical capability of the Landsat data includes: providing data for remote, inaccessible locations and for areas where historical data are missing; deriving vegetation changes over the time sequence to identify areas that had been impacted; quantifying habitat losses or gains, and determining if the changes can be associated with any specific time interval, thus potentially indicating where recovery efforts might be most effective.

Another point of interest was to investigate the dynamics taking place in the adjacent Sooke Lake Watershed (Appendix B) which is 98% owned and operated exclusively as a protected watershed by the Victoria Capital Regional District (CRD, 2014), in contrast to the uncontrolled and largely privately owned nature of the Shawnigan Basin.

Methodology

Acquisition and Processing of Landsat Data

The Landsat satellites, first launched in 1972, have been acquiring optical and thermal data over the globe, with orbit swaths of 185 km that are wide enough for global coverage every season of the year (United States Geological Service [USGS], 2014a, 2015a). The digital multi-spectral nature of the Landsat data, the acquisition frequency and the moderate spatial resolution (30x30m), make the data suitable for meaningful analysis of land cover changes over time. The data are freely available and can be downloaded from the USGS Global Visualization Viewer (GLOVIS) historical archive (USGS, 2015b).

The area of interest (AOI) for this study, the Shawnigan Watershed, is entirely captured by Landsat path 47 and row 26 (48.9 deg Latitude, -122.8 deg Longitude), as shown in Figure 2.

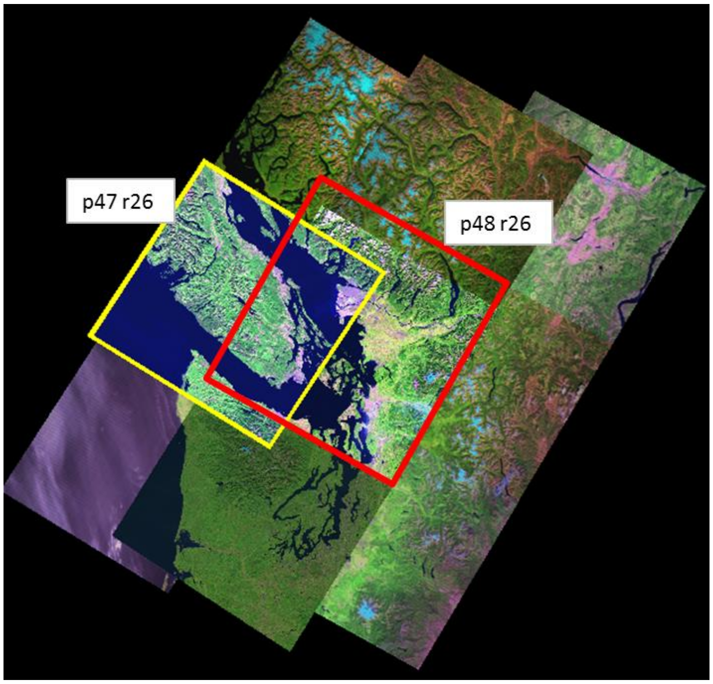

Figure 2. USGS GLOVIS browser showing an overview of Landsat scenes covering southern Vancouver Island: The area of interest is encompassed by both paths between the yellow and the red areas.

The selection of images in GLOVIS focused on cloud-free scenes for the month of September from 1984 to 2014; no data were available for Shawnigan before 1984. For years with no suitable scene for September, the search expanded to include the end of August and beginning of October. Cloud-free scenes out of that period were also downloaded and archived for potential future analyses.

A total of 218 Level 1[5] images were downloaded and reviewed using ENVI™ image processing software property of ASL Environmental Sciences Inc. (processing flow summarized in Appendix C). A total of 51 images were found suitable for the study period, and included 39 Landsat 5 Thematic Mapper ™, nine Landsat 7 Enhanced Thematic Mapper Plus (ETM+) and three Landsat 8 Operational Land Imager (OLI) (Appendix C). Band specifications are shown in Table 1 which shows the differences between OLI and the previous sensors.

Table 1. Band specifications for the Landsat sensors used in this paper (USGS, 2014b); bands used to calculate the vegetation index, are shown in red.

		Landsat 5 TM	**Landsat 7 ETM +**	**Landsat 8 OLI**	
		Wavelength (µm)		*Wavelength (µm)*	
Blue	Band 1	*0.45-0.52*	*0.45-0.52*	Band 2	*0.452- 0.512*
Green	Band 2	*0.52-0.60*	*0.525-0.605*	Band 3	*0.533 - 0.590*
Red	Band 3	*0.63-0.69*	*0.63-0.69*	Band 4	*0.636 - 0.673*
Near Infrared (NIR)	Band 4	*0.76-0.90*	*0.77-0.90*	Band 5	*0.851- 0.879*

In order to better describe the imaged surfaces and reduce some of the scene-to-scene variability, it is best to convert the raw image counts of the downloaded products to physical quantities of reflectance (Pacifici, Longbotham, & Emery, 2014). All selected images were converted to Top-of-Atmosphere (TOA) reflectance which takes into account variation in solar radiation due to the Earth[6], but does not include correction for absorption and scattering within the atmosphere (Olsson, 1995; Chander & Markham 2003). Several studies comparing OLI and ETM+ report agreement between the two sensors within + 4% in TOA spectral reflectance

[5] Level 1 Product Generation System (LPGS): 30 metre pixel resolution, UTM map projection, WGS 84 datum, mapped north up (USGS Landsat Processing Details, 2014)
[6] sun distance and seasonal and diurnal changes in solar elevation

(Czapla-Myers et al., 2015; Irons, Dywer, & Barsi, 2012). Further discussion on the spectral differences between the Landsat series is addressed in the next section. While it would be preferable to use atmospherically corrected data[7], adequate surface reflectance corrections of the Landsat 8 data could not be generated with the available processing software, thus only TOA calibration was done at this time.

The reflectance images (example in Figure 3-A) were cropped to include the entire southern section of Vancouver Island (Figure 3-B), and the Shawnigan watershed headwaters (Figure 3-C). The resulting analysis maps are compatible with Geographic Information Systems (GIS).

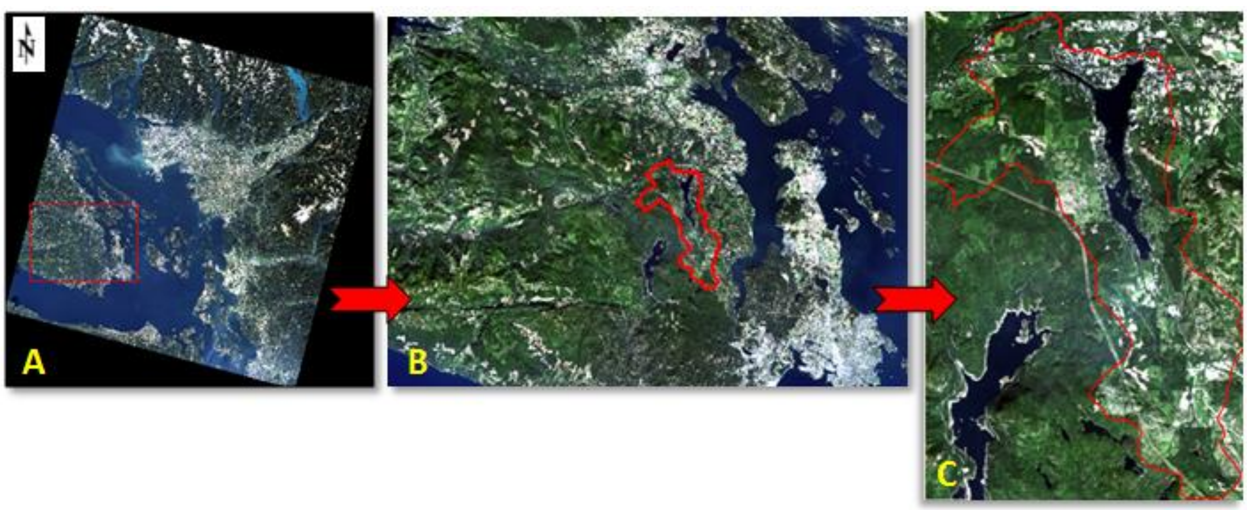

Figure 3. Near true colour composite (NTC)[8] of 15 September 2014 L5TM (A). Insets show subscenes for southern Vancouver Island (B), and Shawnigan Watershed (C) – the watershed boundaries are shown in red in B and C.

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[7] TOA reflectance signatures are larger than the surface reflectance values at shorter wavelengths due to Rayleigh scattering (caused particles much smaller than the wavelength) and smaller at 0.949 μm due to water vapor absorption features (Pacifici et al., 2014)

[8] NTC is created combining R: red band (0.660 μm), G: green band (0.569 μm) and B: blue band (0.485 μm)

The Normalized Difference Vegetation Index (NDVI)

There are many remote sensing vegetation indices intended to characterize the type amount and condition of vegetation for each pixel in a satellite image (Baret & Guyot, 1991; Jackson & Huete, 1991; Li, Jiang, & Feng, 2014; Silleos, Alexandridis, Gitas, & Perakis, 2006). The chosen index was the Normalized Difference Vegetation Index (NDVI), a surrogate for photosynthetic capacity based on the principle that chlorophyll in healthy plants strongly absorbs incoming sunlight in the visible blue and red regions of the electromagnetic spectrum to fuel photosynthesis and create chlorophyll, whereas the cell structure of the leaves scatters the near-infrared (NIR) wavelengths back into the sky (Rouse, Haas, Schell, & Deering, 1974; Tucker, 1979; Lyon, Yuan, Lunetta, & Elvidge 1998).

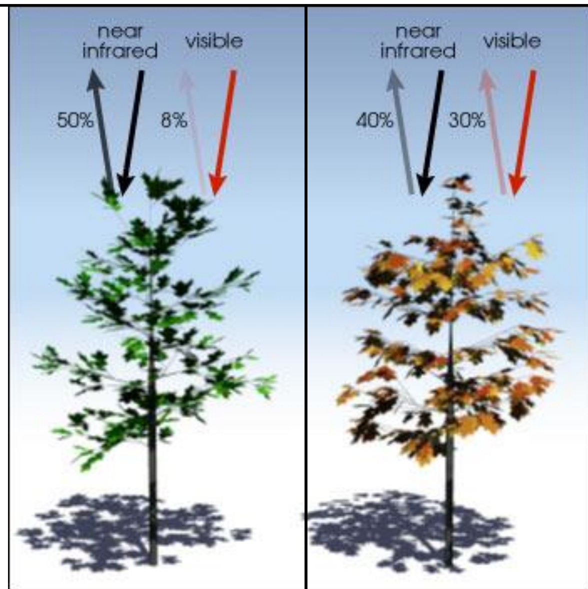
NDVI for each pixel of each TOA reflectance image was calculated using the formula:

$$NDVI = (Near\ Infrared - Red) / (Near\ Infrared + Red)$$

where the red band is generally centered near 0.65 µm, and the NIR band varies over a broader range between about 0.76 and 0.88 µm.

As shown in Figure 4, vigorously growing healthy vegetation with low red reflectance and high infrared reflectance will exhibit high NDVI values greater than 0.5, sparse vegetation such as shrubs and grasslands or senescing crops result in moderate NDVI values (approximately 0.2 to 0.5), and non-vegetated features, such as barren rock, soil, and water will have NDVI values 0.1 or less (USGS, 2015c).

Healthy green vegetation absorbs most of the visible light that hits it, and reflects a large portion of the NIR light



Unhealthy, senescent or sparse vegetation reflects more visible light and less NIR light

NDVI $\frac{(0.50 - 0.08)}{(0.50 + 0.08)} = 0.72$ $\frac{(0.4 - 0.30)}{(0.4 + 0.30)} = 0.14$

Figure 4. Difference in NDVI of healthy green vegetation (left) and unhealthy, senescent or sparse vegetation (right) (Weier & Herring, 2000).

Caveat. The Operational Land Imager (OLI) in Landsat 8 was designed to be continuous with ETM+ while attempting to improve the instrument to avoid atmospheric attenuation features by narrowing the red (R) and near infrared (NIR) bands (Flood, 2013; Irons et al., 2012).

This means that the NDVI values of Landsat 8 and 7are consistent when dealing with high vegetation covered areas (e.g. forest area and tall grass) because the difference between NDVI is close to zero when the value of NDVI is high. In contrast, as shown in Figure 5, the NDVI difference between Landsat 8 and 7 is higher in lower vegetation covered areas, with some grassland studies indicating overestimations of about 5% (Flood, 2014; Li et al., 2014; Xu & Guo, 2014). It is important to be aware of this potential source of variability since no between-sensor reflectance or NDVI corrections were done at this time.

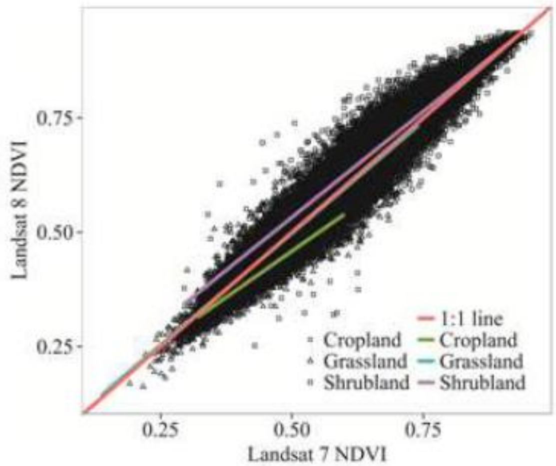


Figure 5. Comparison of Landsat 8 NDVI and Landsat 7 NDVI for different vegetation covers (Xu & Guo, 2014).

Seasonality. Ideally, the more years that can be included in a temporal analysis, the more robust the outcome. However, acquiring satellite data for all years in a time series is normally a challenge due to clouds, thus the compromise to have a temporal window wide enough to be able to include as many years as possible. As shown in Figure 4, NDVI values are determined by the state and density of the vegetation which among several factors are affected by seasonality. Therefore, in order to ensure that vegetation changes in the time series were interpreted correctly, NDVI values were obtained for three locations identified as forested areas that have remained undisturbed between 1984 and 2014, and examined for seasonal variations.

Temporal Changes of the Vegetation Cover

There are many techniques based on multi-temporal satellite-sensor-acquired data that have demonstrated potential as a means to detect, identify, map and monitor ecosystem changes, regardless of their causal agents (Coppi, Jonckheere, Nackaerts, Muys, & Lambin, 2010). This paper explored several methods illustrated in Appendix C and described hereafter to assess the changes in the Shawnigan watershed vegetation cover between 1984 and 2014.

Reflectance RGB Composite. The TOA reflectance green bands (0.56 μm) of three years in the time series were used to create a three-layer Red-Green-Blue (RGB) composite in ENVI™ , where Red: 15 September 2014, Green: 26 September 1998, and Blue: 28 September 1984. This method makes it easier to see the history of vegetation cover in the area.

NDVI trends. The analysis of vegetation changes using the NDVI images (Appendix E) were based on two methods (Borstad, Martínez de Saavedra Álvarez, Hines, & Dufour, 2008, 2010; Martínez de Saavedra Álvarez, Brown, Ersahin, & Henley, 2013):

(1) the difference between 1984 NDVI and 2014 NDVI (beginning and end of the time series); this was done only for the southern Vancouver Island scene, and

(2) analysis of the NDVI time series ("cube") to determine the areal extent of change over the 31-year study period (1984-2014); this was done only for the Shawnigan Basin. The cube was then used to carry out a linear regression of NDVI *versus* year on a pixel-by-pixel basis. This analysis generates images of slope that allow valuable mapping of the rate and direction of change (gains or losses) and its significance ($p \leq 0.05$).

Unsupervised classification of NDVI change. Trends analysis does not provide information of when changes happen, or if the vegetation cover shows signs of recovery after a disturbance (characterized by a decreasing slope).

To obtain that information, and generate maps of habitat change over the entire watershed a pixel-by-pixel temporal land cover classification was done using the unsupervised algorithm ISODATA in ENVI 5.0™, which generated seventy groups of pixels with similar NDVI histories. The classification included the watershed uplands only, and excluded the lake.

CVRD Vectors

Two sets of vectors were provided for this study by Ms. Emily Doyle-Yamaguchi, CVRD: a vector delimiting the boundary of the Shawnigan Lake watershed (shown in red in Figure 6), and eleven vectors (outlined in white) that provide a representative sample of protected parklands, crown forest land in various tenures, private forest land in various management regimes, and ecologically sensitive areas including wetlands (B. Fraser, pers. comm., February 17, 2015).

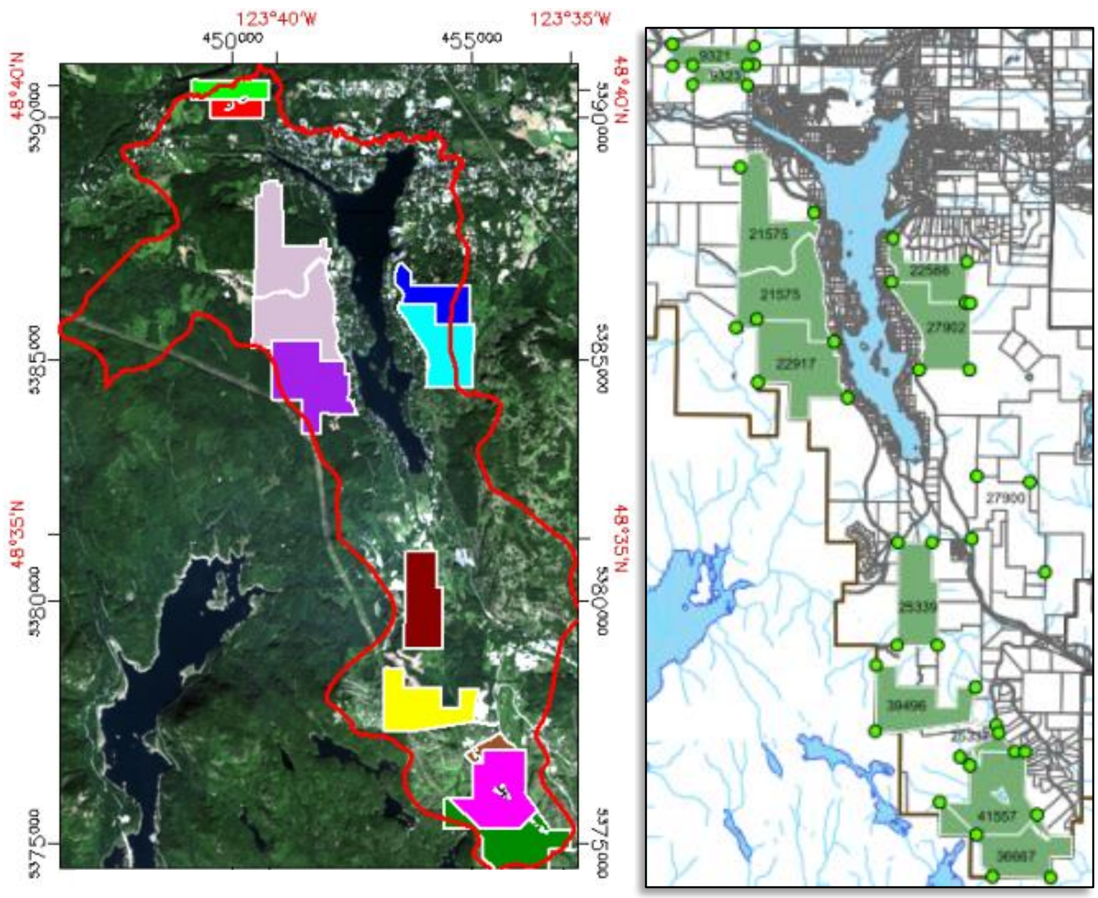


Figure 6. Overview of the Shawnigan watershed boundary (in red) and the eleven study parcels (white outline and coloured) laid over 15 September 2014 Landsat image. Inset on the right shows the original CVRD map and the parcels in green.

The vectors for the eleven CVRD parcels were converted in ENVI™ to digital regions of interest (ROIs) in preparation for the multi-temporal analyses. Since sections of some of the parcels fall outside of the watershed boundary (as shown in Figure 6), the parts were excluded from the generated ROIs before the analyses. Changes in the vegetation cover were estimated for all the CVRD parcels using the methods described in the previous section.

Field Survey

A GoogleEarth compatible KML file[9] was created in ENVI™ with the multi-temporal NDVI classification map described earlier, and the boundaries for the eleven CVRD parcels in the watershed. The objective was to direct a field survey and acquire some photos to assist with interpretation of the vegetation change classes. A total of 42 locations were chosen inside the CVRD parcels, carefully positioned in the center of large homogenous classes to avoid inaccurate information caused by positional error (Stehamn, & Czaplewski, 1998; Zăvoianu, Caramizoiub, & Badeaa, 2004). The KML file was sent to Mr. David Hutchinson (IT specialist and Board Member of the SBS), and Mr. Barry Gates (ecological forester manager and Board Member of the Ecological Design Panel for Shawnigan Lake) to assist in their field planning. The photo survey was carried on between 15th February and 4th March 2015; 14 more locations were added during the survey, though eight of the initially planned sites were not accessed at the time. All the photographs were taken by Mr. Hutchinson, and made available with no restrictions on their use via google sharing.

[9] KML is a file format used to display geographic data in an Earth browser such as Google Earth (Google Developers, 2013)

Results and Discussion

Seasonality Analysis

Seasonal changes have marked impacts on the spectral characteristics of vegetation, especially in grasslands and deciduous forest (Vogelmann, Xian, Homer, & Tolk, 2012). NDVI values for three locations in the Shawnigan basin identified as ‘forested and undisturbed between 1984 and 2014’ were extracted in ENVI^{TM}. When the NDVI values were plotted by Julian Day (JD) in Excel, it became evident that there was a seasonal effect (Figure 7), in particular affecting Pt2 (shown in red), with NDVI values greater in 21 August (JD233) than in 11 October (JD 284).

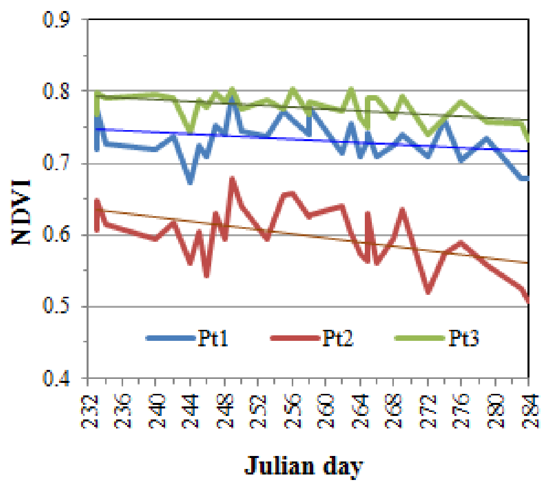


Figure 7. NDVI values at three locations derived from 33 NDVI images between 21 August (JD 233) and 11 October (JD 284) 1984 to 2014. Seasonality is noted by the decreasing trends.

In order to ensure that the changes observed in the temporal analyses were not caused by different seasonality patterns of “green-up” and senescence, only NDVI images from 15 to 30 September (Appendix E) were chosen at this time.

Vegetation Changes in Southern Cowichan Watersheds

Reflectance RGB three-year composite map. This map (Figure 8) tells a very compelling story: The bright red areas indicate where vegetation losses have occurred since 1984 or 1998; while blues and greens illustrate areas that were deforested in 1984 or 1998 and have since fully restored the vegetation cover. Forested regions that remained unchanged during the three years are shown in dark green.

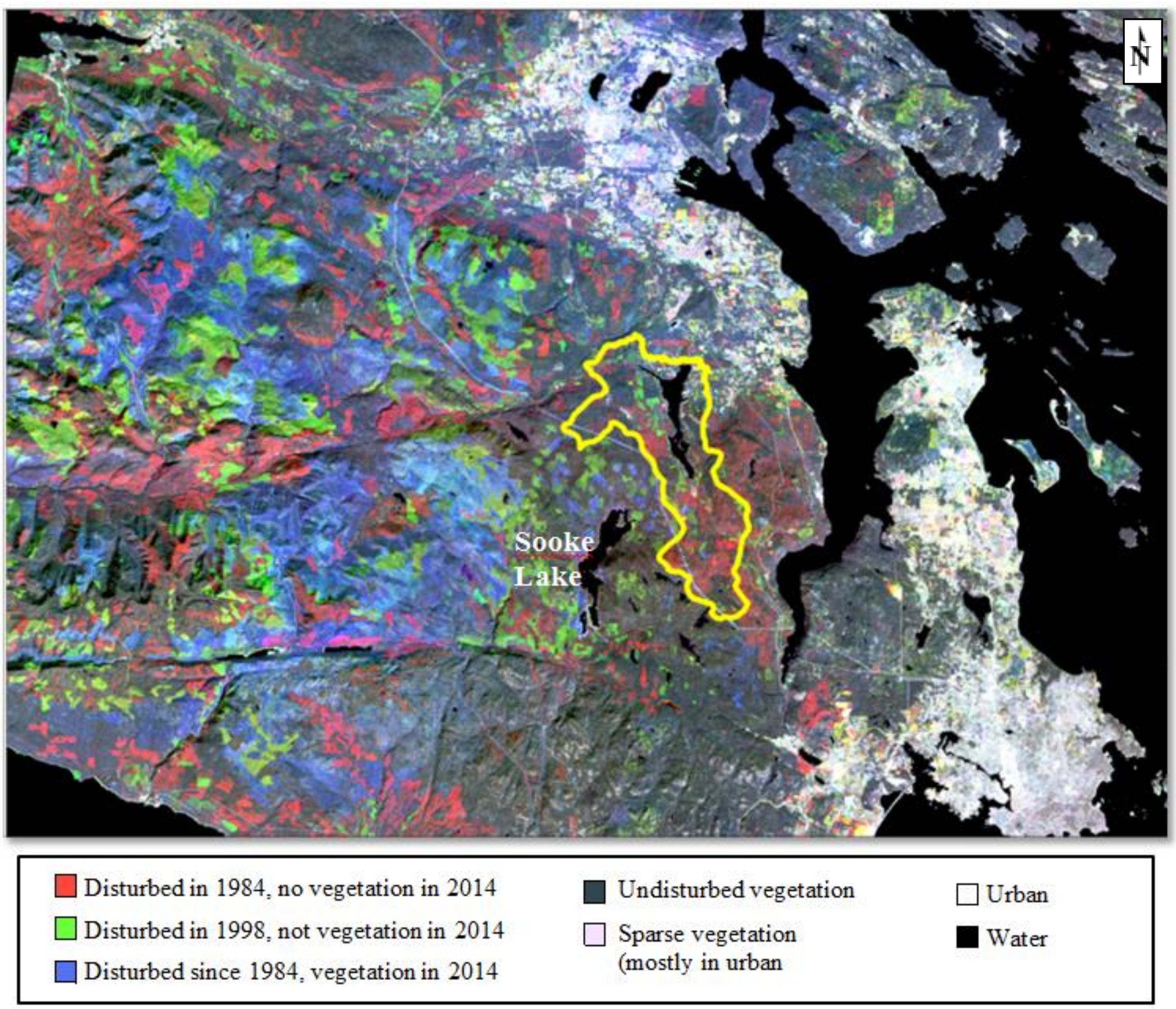


Figure 8. Overview of RGB composite for southern Vancouver Island (Red: 15Sep 2014; Green: 26 Sep 1998, Blue: 28 Sep. 1984). The watershed boundary is shown in yellow.

This visual narrative illustrates the contrast between the recent forest conservation management strategy (old growth restoration) in the Sooke Lake watershed. This has led to forest recovery (green and blue areas southwest from Shawnigan) compared to the Shawnigan Watershed, where industrial forestry, mining, soil dumping and urban pressures have led to extensive forest losses, as indicated by the bright red coloured areas.

The contrast in this map paints a clear picture of the scale of the challenge that lies ahead for the Shawnigan Lake community. Also worth mentioning is the striking vegetation losses in the adjacent Saanich Inlet Watershed and the dense development in the Cowichan Bay Watershed.

NDVI difference map. The map derived from the difference in 2014 and 1984 NDVIs (Figure 9) uses a three-colour scheme: loss of vegetation cover occurred when NDVI2014 < NDVI1984 (shown in brown); increase in vegetation when NDVI2014 > NDVI1984 (in green). Areas were considered "unchanged" (shown in white) when the NDVI differences between 2014 and 1984 were less + 0.1.

This analysis corroborated the same message of losses and gains in the area shown in the composite map (Figure 8).

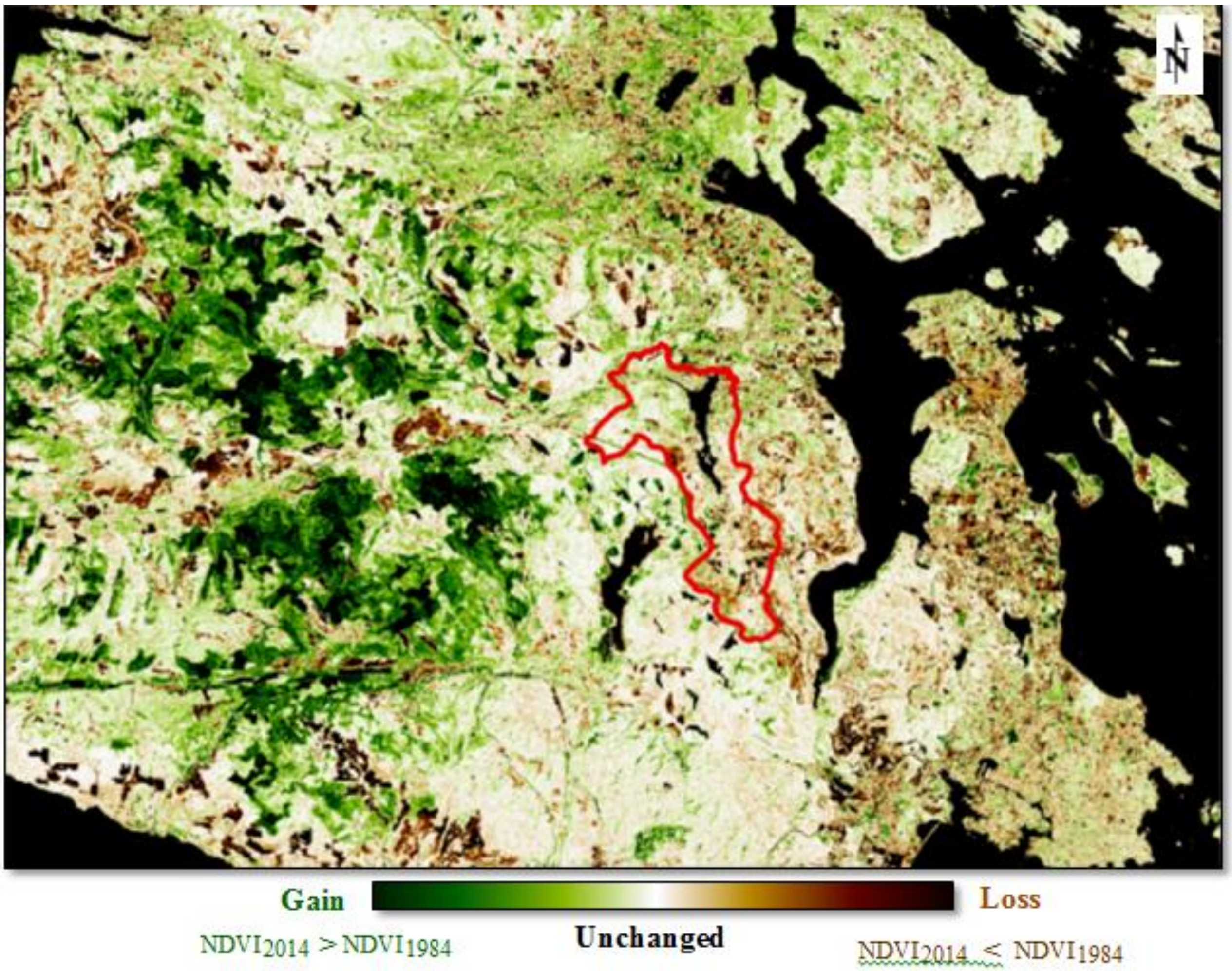


Figure 9. Map of vegetation changes derived from the difference $NDVI_{2014}$ - $NDVI_{1984}$. The watershed boundary is shown in red.

Long-Term Vegetation Changes in the Shawnigan Watershed

Trends in Average NDVI. The NDVI-year linear regression analysis generated slope trends for each pixel of the data series which indicates the direction of change (gains or losses) and its significance[10] ($p \leq 0.05$). Five classes were created using slope thresholds of $\pm$ 0.002 and p values. Examples of NDVI trends for each class are shown in Figure 10.

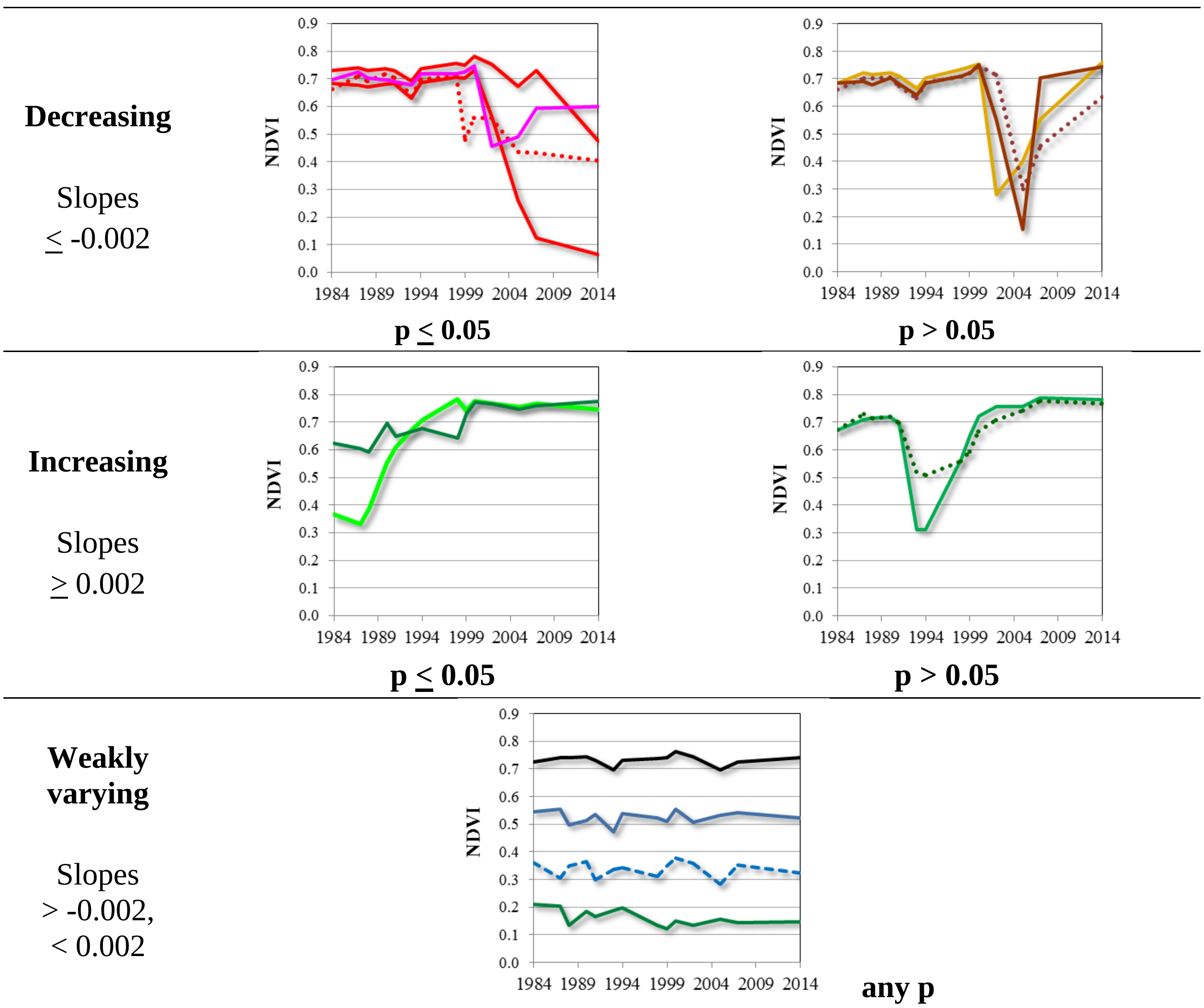


Figure 10. Examples of NDVI trends for the change classes shown in Figure 11.

[10] the $p \leq 0.05$ are statistically significant at the 95% level or better.

Trends were considered ‘unchanged or weakly varying’ when slopes ranged between -0.002 and 0.002, regardless of p; ‘decreasing’ (vegetation loss), when slope values <-0.002; and ‘increasing’ (vegetation gains) when slope values > 0.002.

It is important to mention that while changes in the slope might not be statistically significant they are still ecologically meaningful: Steady changes in slope will have $p < 0.05$, while abrupt slope changes will exhibit $p> 0.05$. Abrupt changes are the result of landscape-transforming events, such as those related to logging, agricultural expansion, urbanization, and fire, which alter the spectral properties of the imaged surface (Vogelmann, Xian, Homer, & Tolk, 2012). One important limitation of the trend analysis is that while decreasing slopes technically represent vegetation losses, as shown in Figure 10 some examples show (regardless of p) a recovery of the vegetation cover with NDVI values close to or above 0.5 in 2014. Another drawback is the ‘weakly varying’ class since it pools NDVI histories with very different thresholds, thus a densely forested area and water are included in the class. Nonetheless, trends are useful because they provide a synoptic view of long-term changes of the vegetation cover.

The NDVI trends map for the Shawnigan basin (Figure 11) shows vegetation losses in 25% of the watershed, most noticeable in the west and south sections. Vegetation gains, observed in 24% of the area, are most evident in the north and some well-defined patches in the southwest. Overall, 51% (3400 ha) of the Shawnigan watershed has experienced little changed since 1984. The trend classes varied among the CVRD: Nine of the eleven parcels had 46% to 84% of their areas unchanged since 1984, with parcels 41577 and 9321 emerging as the most stable (Figure 12, plot B). Parcels 22197 and 39496 were characterized by vegetation losses, while parcels 25339, 27902 and 9323 showed significant vegetation gains. Further details on the areal distribution of trends in each parcel are included in Appendix F.

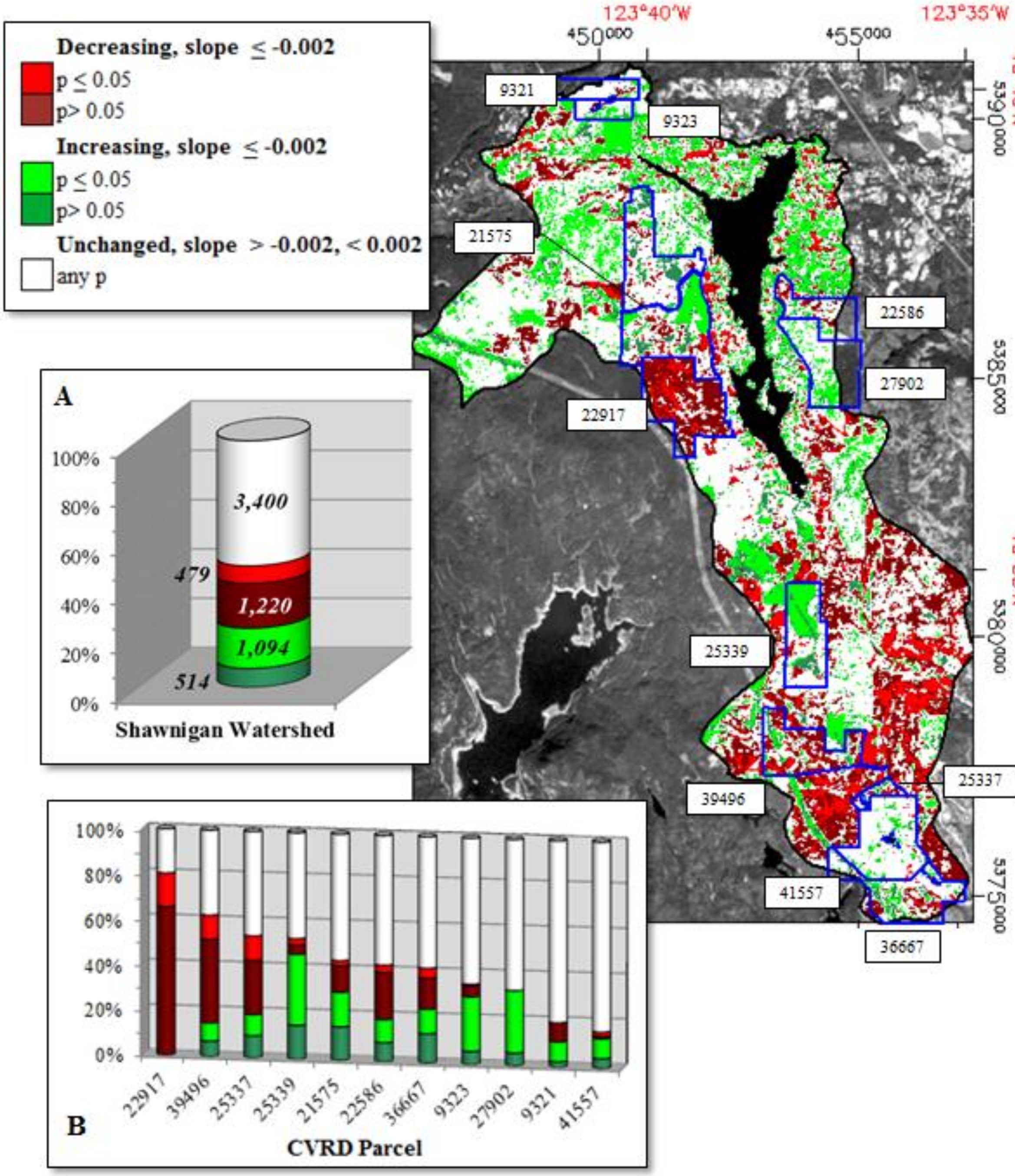


Figure 11. Map of 1984-2014 vegetation trends in the Shawnigan Watershed superimposed over the 15 Sep 2014 red band (0.65 µm). Plots show the distributions and areas (ha) of each trends class for the entire watershed (**A**) and for each of the CVRD parcels (**B**), which are presented from the most to the least changed. Details for each parcel are included in Appendix F.

Unsupervised classification of vegetation changes. Figure 10 illustrated how pixels could be characterized beyond the overall tendencies by using NDVI thresholds, date of disturbance and other criteria described in Table 2, thus providing more detailed information on the conditions of the basin's vegetation and its history. The resulting multi-temporal classification map is shown in Figure 12.

Table 2. Criteria used to group ten vegetation change classes derived from the unsupervised classification of the NDVI time series.

Criteria	Class Colour	Description
Variable trend NDVI < 0.5		
Low NDVI < 0.3	1	Only found on the edges of the lake, thus it was considered aquatic emergent vegetation.
NDVI ≥ 0.3	2	Reflectance data indicate these are areas of sparse vegetation, which would be strongly affected by desiccation; needs field data.
Weakly varying		
NDVI < 0.3	3	Limited cover: poorly vegetated areas; some pixels also found around the shoreline.
NDVI 0.3-0.5	4	Moderate cover: includes areas mixed within urban settings
NDVI ≥ 0.5	5	Dense cover: Forested areas.
Disturbed		
Between 1984-2014 & not recovered (Loss)	6	Areas that were disturbed during the time series and have not recovered
Before 2000, ^{2014}NDVI ≥0.5	7	Areas that were disturbed before 2000 and by 2014 had NDVI values > 0.5
After 1999, ^{2014}NDVI ≥0.5	8	Areas that were disturbed after 2000 and by 2014 had NDVI values > 0.5
Areas showing growth, 2014 NDVI ≥ 0.5		
^{1984}NDVI ≤ 0.5	9	Areas that started with NDVI ≤ 0.5 and show a fast increase
^{1984}NDVI > 0.5	10	Areas that started with NDVI > 0.5 and are still increasing

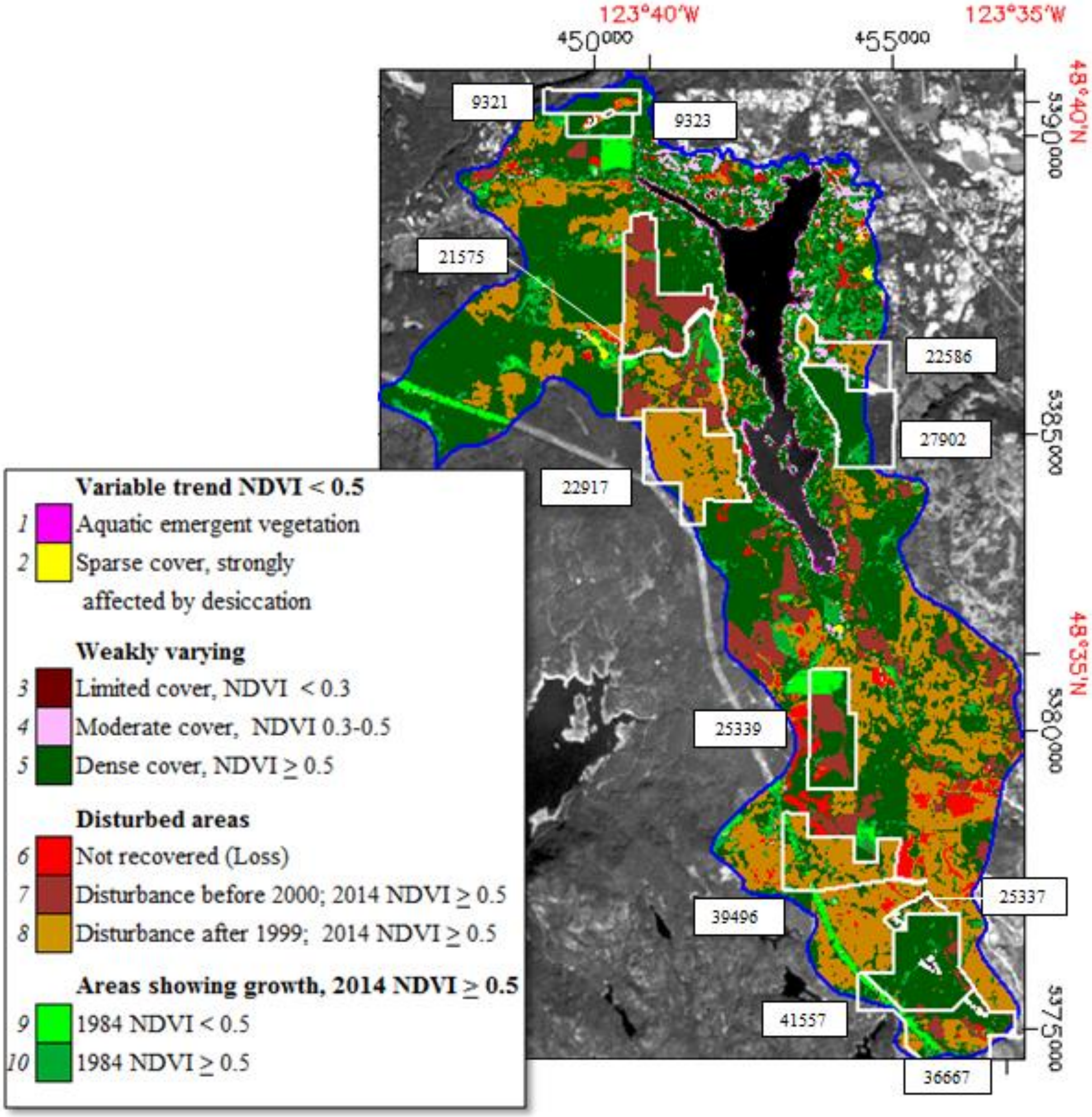


Figure 12.Temporal classification of the Shawnigan Basin superimposed over the 15 Sep 2014 red band (0.65 μm).

As shown in Figure 13-plot A, the Shawnigan watershed is mostly represented by Class 5 weakly varying dense vegetation cover (47% of the total area), and Class 8, which are areas that were disturbed sometime after 1999 and exhibited regrowth above 0.5 NDVI values by 2014

(25% of the basin). Areas disturbed before 2000 and recovered by 2014 (Class 7) represented 9% of the uplands and were mostly found in the west sector of the basin.

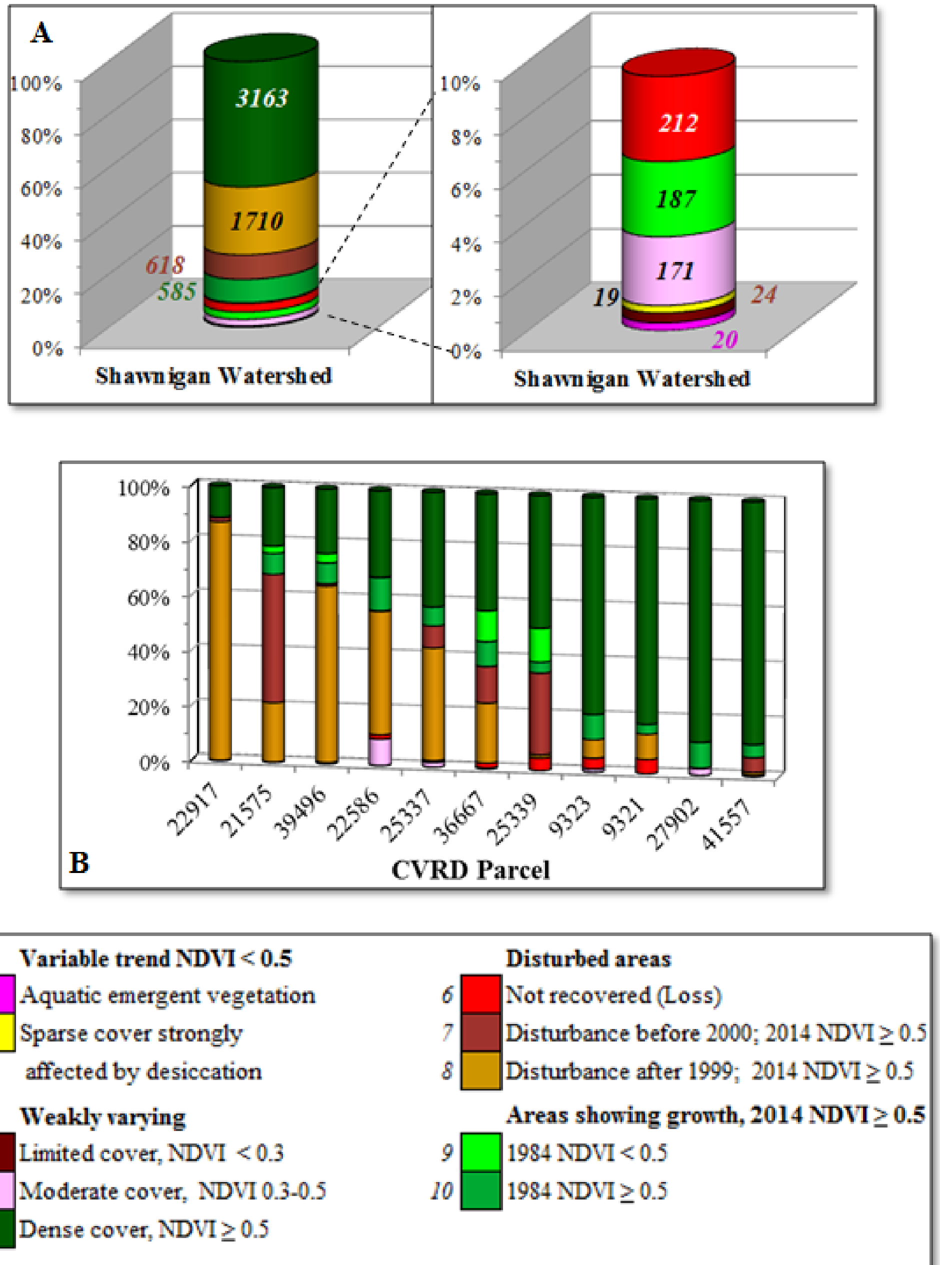


Figure 13. Representative contributions of each temporal class in the entire watershed with areas (ha) in italics (A) and for each of the CVRD parcels (B), sorted from the most disturbed to the least; further details for each parcel are included in Appendix G.

Vegetation loss (Class 6, 3% of the area) was found mostly in the southern section of the basin. Vegetation growth trends were observed in areas that already had a vegetation cover with NDVI > 0.5 in 1984 (Class 10, 9%), and patches that showed NDVI < 0.5 in 1984, probably due to disturbance, and had NDVI values >0.5 in 2014 (Class 9, 3%). The moderate cover Class 4 represented approximately 3% of the basin and was found mostly in the northeast, within the urban settings. The variable and low NDVI Class 5 (0.3% of the entire area) was found in a few isolated patches that are probably disturbed areas covered with sparse vegetation. Aquatic vegetation (Class 1) was found along the shoreline of the lake with NDVI trends consistently below 0.1 values; similarly, the limited cover (Class 3) was mostly found sparsely distributed along the lake. Both classes account for 0.3% and 0.4% of the studied area.

The distribution of the temporal classes varied greatly among the CVRD parcels (Figure 13-plot B). Parcels 9323, 9321, 27902 and 41557 were the most unchanged, showing a dense vegetation cover (Class 5) since 1984 between 79% and 88% of their areas. Other parcels were mostly composed represented by early disturbances and regrowth by 2014 with NDVI>0.5: Class 7 (disturbed before 2000) was most predominant in parcel 21575 (47% of the parcel), and Class 8 (disturbed after 1999) in parcel 22917 (87% of the parcel).

Field Data

The purpose of the February and March surveys was to acquire photos to assist with the interpretation and assessment of the classification map shown in Figure 12. All photos were taken by Dave Hutchinson[11], and have been used with his permission. The surveys' sites are indicated in Figures 14 and 15.

[11] Board Member of the Shawnigan Basin Society

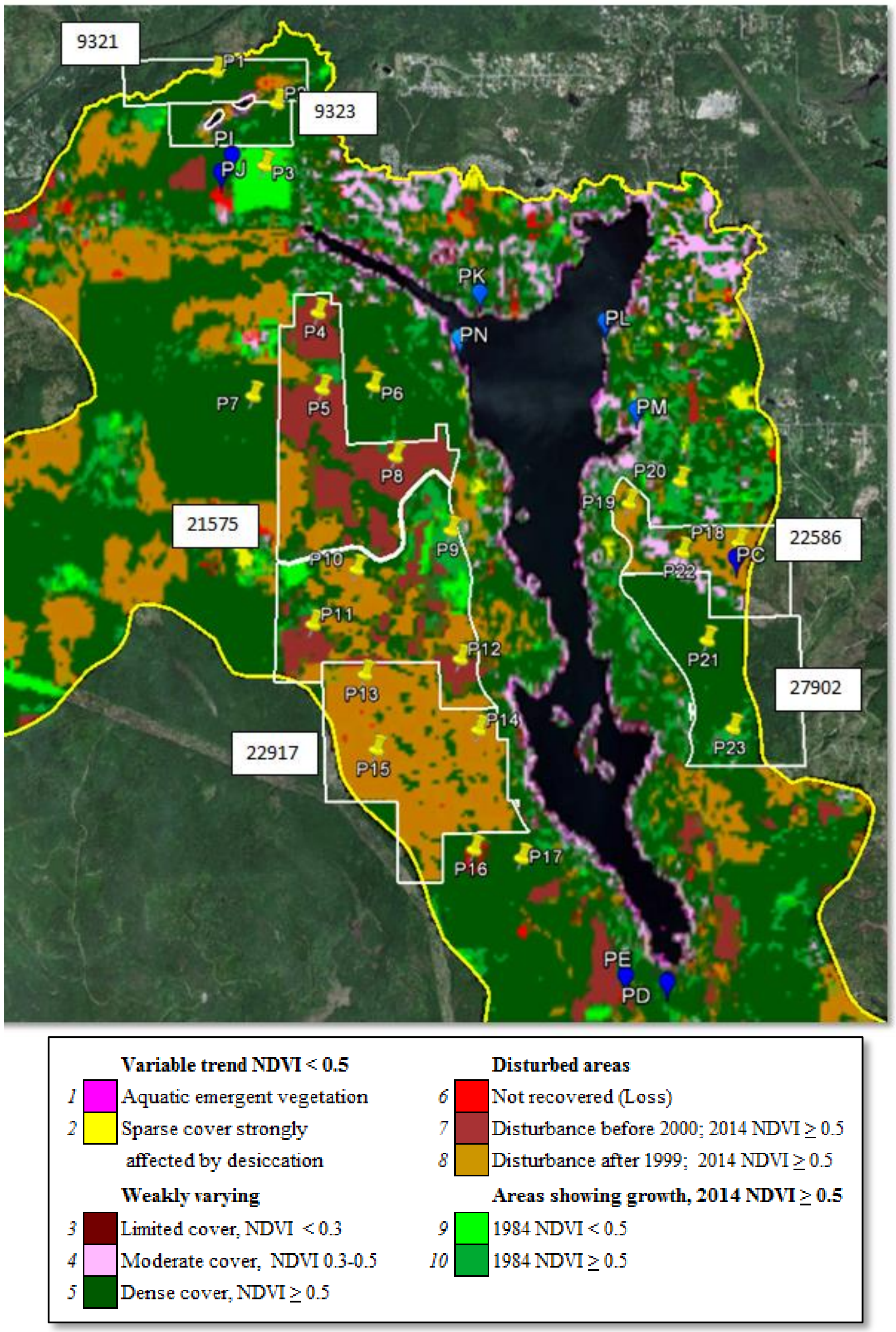


Figure 14. Overview of the GoogleEarth file showing the classification map for Shawnigan basin north, the watershed boundary in yellow, CVRD parcels in white, February photo-locations (P1-P23) with yellow pins, and March locations (PI-PM) in blue.

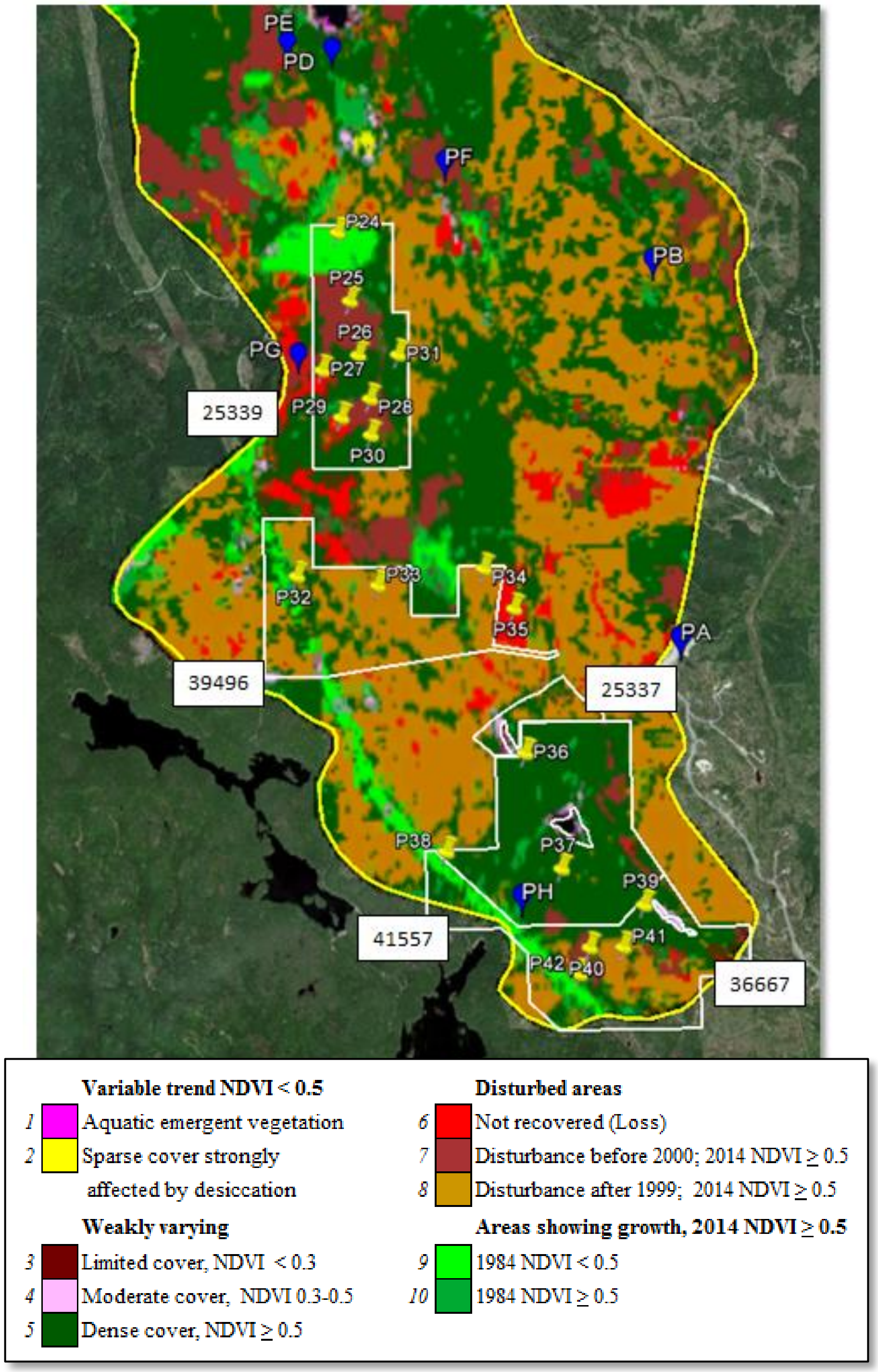


Figure 15. Overview of the GoogleEarth file showing the classification map for Shawnigan basin south, the watershed boundary in yellow, CVRD parcels in white, February photo-locations (P1-P23) with yellow pins, and March locations (PI-PM) in blue.

A synthesis of the assessment analysis is provided in Table 3: There were no field photos at this time to interpret classes 2 and 3.

Table 3. Assessment of the Shawnigan Watershed temporal vegetation classes using field photos.

				Descriptions from SBS photos										
			Temporal classes & desc	**Aquatic**	**??**	**??**	**Rock outcrop, arbutus moss, conifers**	**Mature Forest: dense conifers, salal, moss, woody debris**	**Loss**	**Conifers, grass, moss, salal, road**	**Conifers, grass, railway, trails, Scottish B**	**Grass, low bush, Scottish B**	**Thin & tall sparse conifers, ferns, oregon grape, leaf litter**	*total rows*
Classification Results	**Variable trend NDVI <0.5**	1	Aquatic vegetation	4										*4*
		2	Sparse cover, variable											*0*
	Weakly varying	3	Limited, NDVI<0.3											*0*
		4	Moderate, NDVI 0.3-0.5				1							*1*
		5	Dense cover, NDVI > 0.5					11						*11*
	Disturbed sites	6	Loss (disturbed, not recovered)						4					*4*
		7	Disturbed bef. 2000, 2014 NDVI >0.5							8				*8*
		8	Disturbed after 1999, 2014 NDVI >0.5								10			*10*
	Growth, 2014 NDVI >0.5	9	1984 NDVI <0.5									4		*4*
		10	1984 NDVI ≥ 0.5										3	*3*
			total columns	*4*	*0*	*0*	*1*	*11*	*4*	*8*	*10*	*4*	*3*	**45**

Each temporal class is briefly discussed and illustrated with examples of photos (Figure 16 to 19). The March photos for Class 1 shown in Figure 16. illustrate senescent land and aquatic vegetation, which would have looked very different at the time of the imaging in September. Some species were identified by David Polster (pers. comm., March 17, 2015): The reddish branches in PL-E and PL-x are *Spiraea douglasii* (hardhack), a common native lake-shore species that is being removed by many property owners (D. Hutchinson, pers. comm., March 18, 2015); the white tress are *Populus trichocarpa* (black cottonwood); and the emergent sticks shown in PM-N and PN-N belong to *Scirpus lacustris* (bulrush), an important shoreline plant that provides food, cover, and nesting habitat for waterfowl and it is currently being used in restoration for bank stabilization and to treat contaminated water (Washington State Department of Ecology, n.d.).

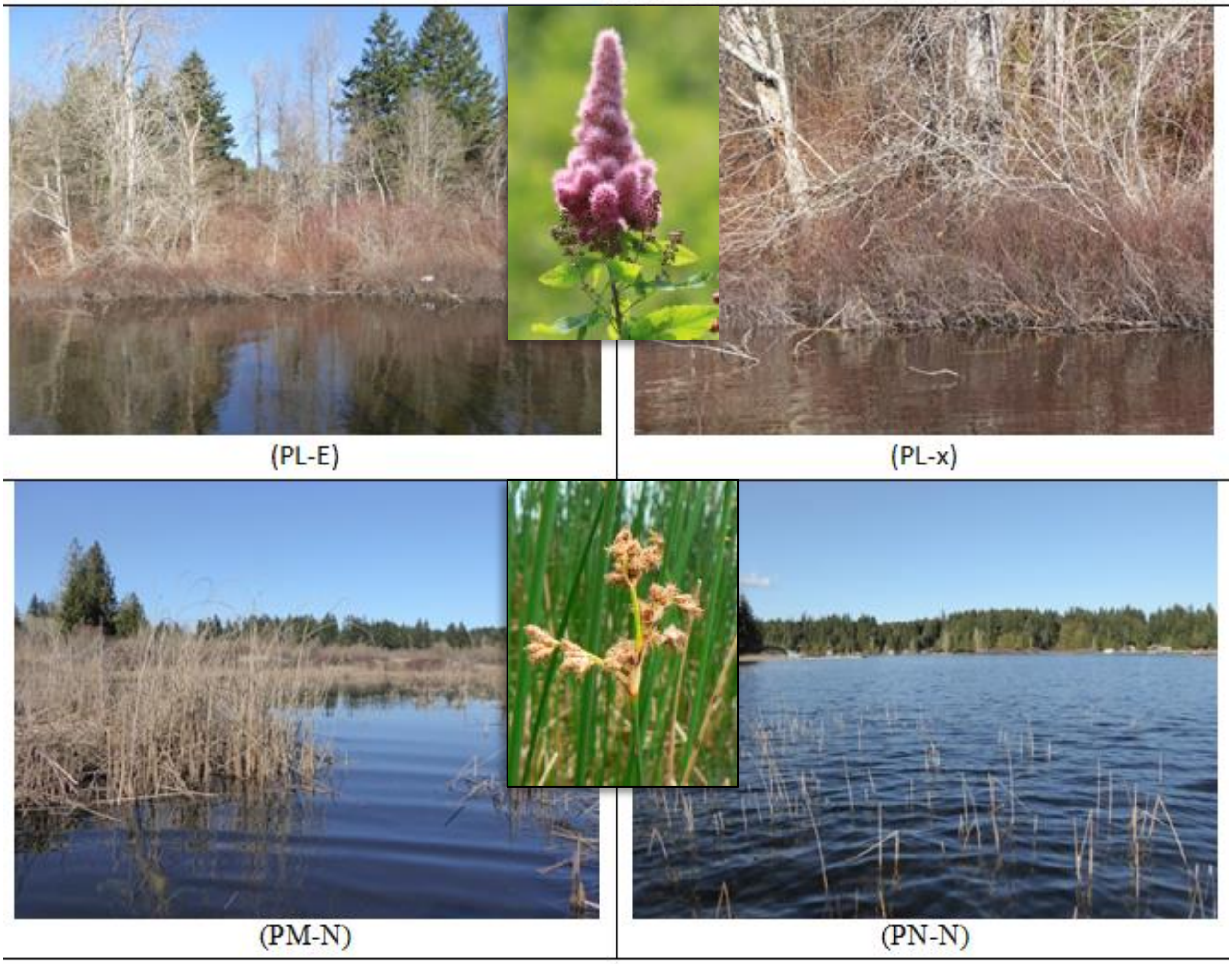


Figure 16. March 2015 photos of Shawnigan lake shoreline. Insets show hardhack in bloom (top) and bulrush in full growth (bottom) (*E-Flora BC, 2014*).

Photos at parcel 22586 (Figure 17, top) for Class 4 (weakly varying moderate cover, NDVI 0.3-0.5) show a rocky outcrop with moss growth, sparse conifers and arbutus; P22-S also shows patches of the invasive plant *Cytisus scoparius* (Scotch broom). Class 5, dense cover class with weakly varying NDVI values > 0.5 during the entire study period, is illustrated by photos P02 and P36 (Figure 17, bottom), which show densely forested areas with Douglas fir, salal, moss, ferns, and Oregon grape.

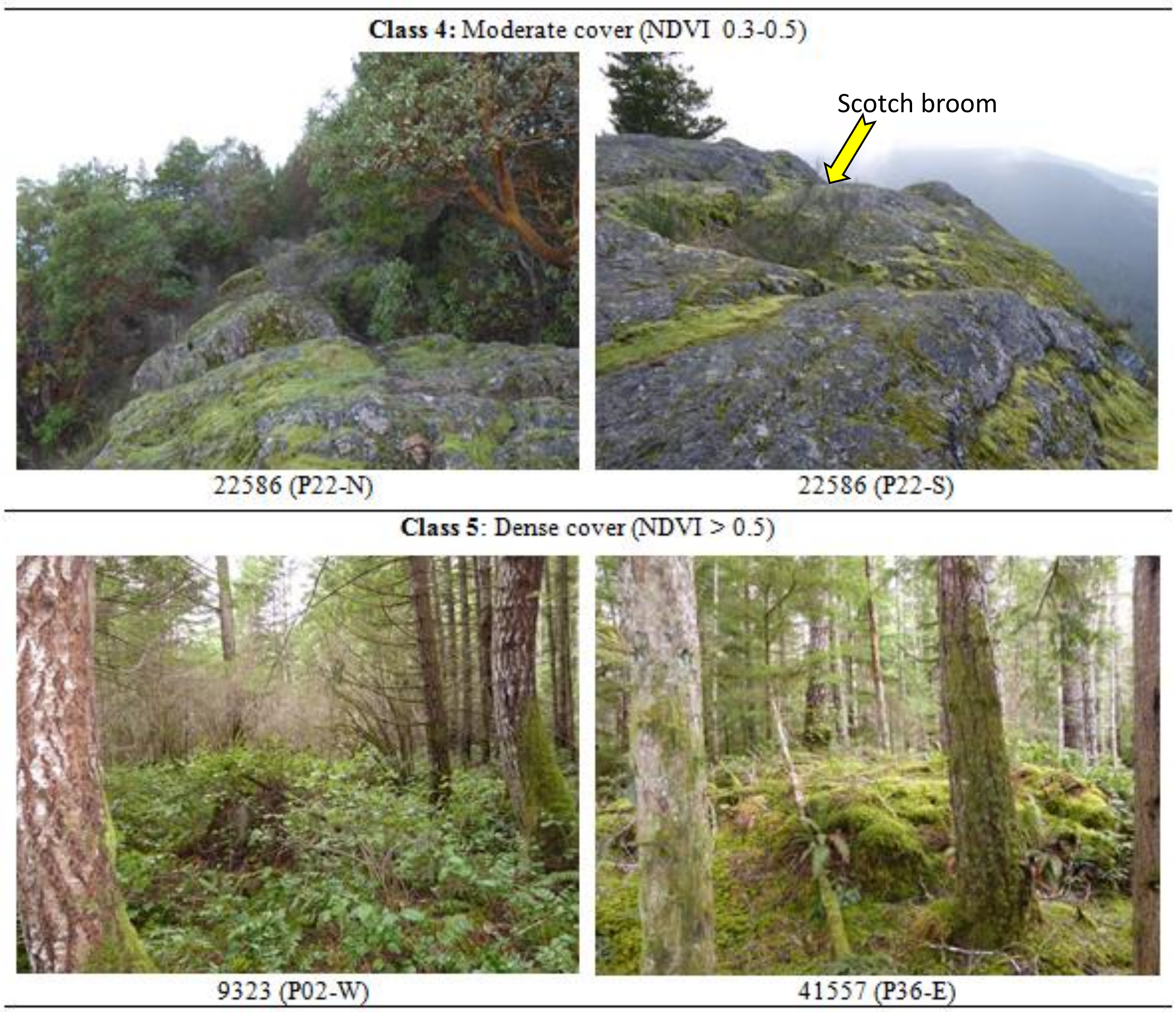


Figure 17. February 2015 photos illustrating weakly varying classes 4 and 5. Parcel and photo number are indicated at the bottom of each picture.

Salal (*Gaultheria shallon*) is an important indigenous evergreen, beneficial as a soil stabilizer after site disturbances. However, the dominant proliferation of salal after logging or burning has been reported to render a replanting operation unsuccessful, as the plant recolonizes sites rapidly and completely both above-ground and below-ground from rhizomes present before the disturbance, and can resist invasion by other species (including authoctonous species) by pre-emptying resources (Dorwoth, Sieber, & Woods, 2001).

Sites classified as disturbed and not recovered by 2014 (Class 6) are illustrated in Figure 18: P27-W shows a logged area, and P35-E the South Island Aggregates site with rocky debris and bare soils.

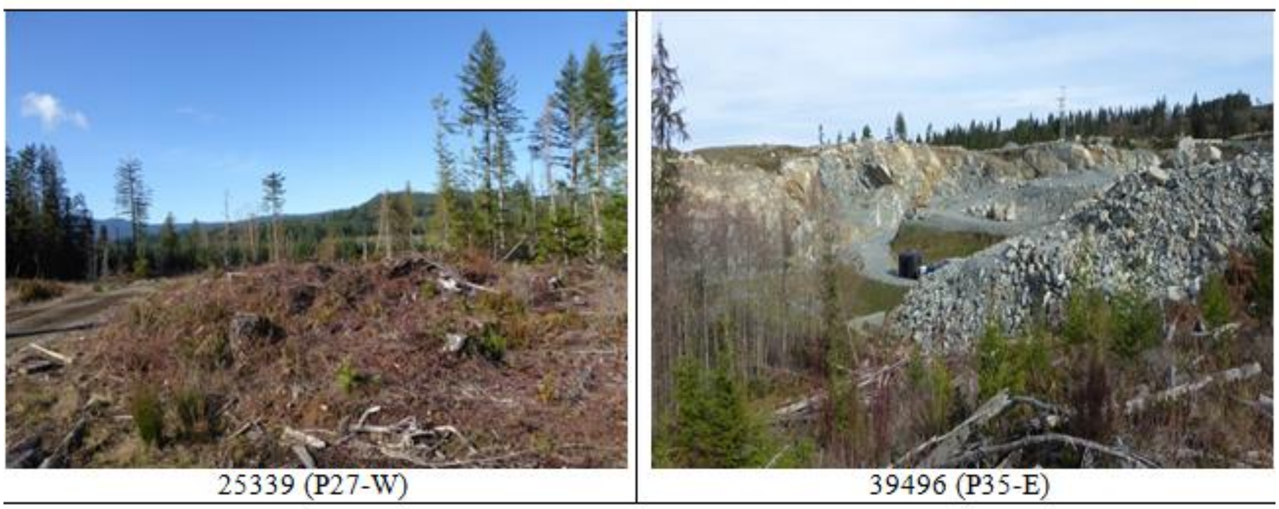


Figure 18. February 2015 photos of sites disturbed and not recovered by 2014 (Class 6). Parcel number and photo number are indicated at the bottom of each picture.

Sites disturbed and revegetated by 2014 are shown in Figure 19: Photos for Class 7 (disturbed before 2000) show young conifers and some open spaces covered with moss, grass, salal and ferns; and photos Class 8 (disturbed after 1999) show sparser growth of smaller conifers, which would leave the undergrowth more exposed to desiccation, and potentially to invasive species.

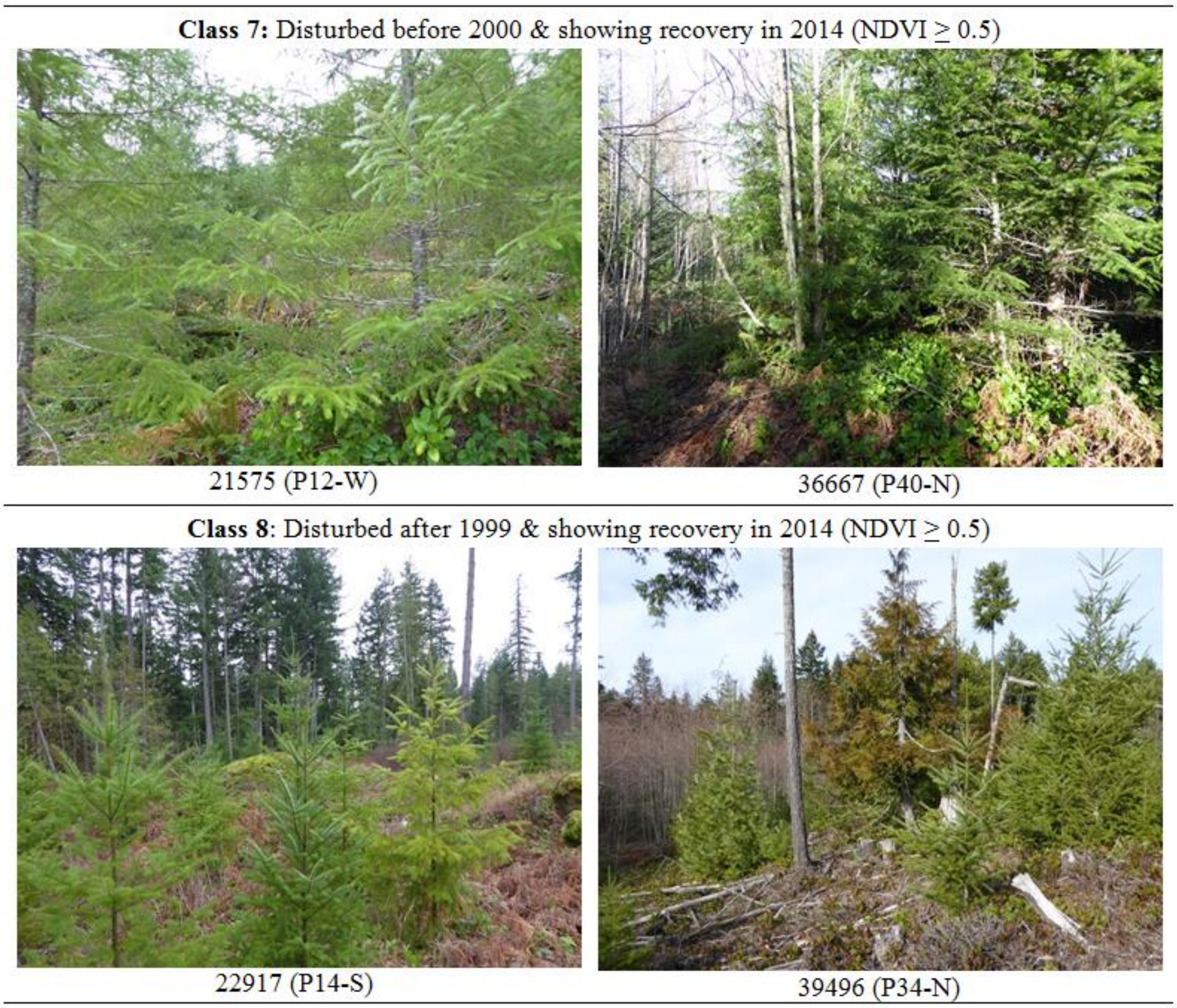


Figure 19. February 2015 photos of disturbed sites and recovered by 2014 (Class 7 and 8). Parcel number and photo number are indicated at the bottom of each picture.

Examples of the fast growing classes that in 2014 had NDVI $\geq$0.5 are included in Figure 20: P38-W for Class 9 (started in 1984 with NDVI <0.5) shows a dense dead vegetation cover that would have been green at the time of the imaging; the area is a wetland lying on the power line right of way (D. Hutchinson, pers. comm., March 17, 2015). Photo P42-N was also taken on the power line clearing, but further south in the basin; some green small bushes are observed in the area, but also, a large number of patches of Scotch broom. These photos indicate that Class 9 at these parcels is composed of a grass dominated vegetation cover strongly affected by seasonality, and vulnerable to invasive species.

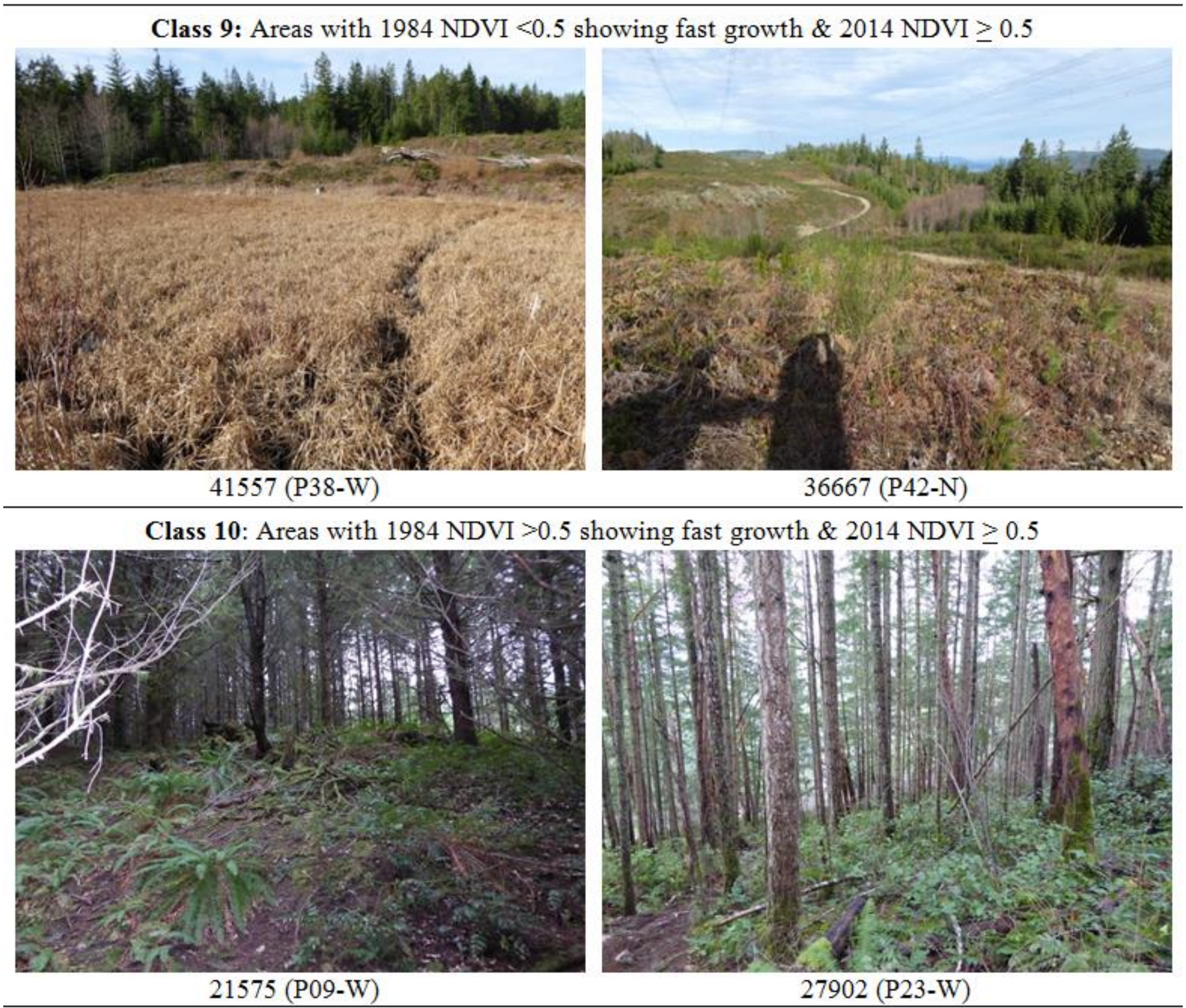


Figure 20. February 2015 photos for Classes 9 and 10 classified as fast growth with 2014 NDVIs ≥ 0.5.

Photos for Class 10 (started in 1984 with NDVI $\geq$0.5) show areas with tall and thin sparse conifers, large open spaces with ferns, and Oregon grape; if left undisturbed, these areas will regenerate naturally.

In summary, the photos taken during this preliminary survey, even though out of temporal sync with the imagery (survey was done in February and March 2015, and the images were acquired in September), have validated the temporal vegetation classes that were created solely on the basis of the NDVI histories.

Conclusions

Remote Sensing Data and Results.

This study has proven successful to meet the SBS needs to map the vegetation changes in the Shawnigan watershed since 1984, and has made a significant contribution to characterize its current condition.

Although remote sensing methodology is not a silver bullet, it has delivered much more than pretty pictures: It has provided a synoptic view of the watershed dynamics in context with the adjacent watershed, the long-term vegetation trends and characterization of the Shawnigan Basin. Remote sensing methodology has provided a tool to be used in conjunction with land based information, and a cost-effective means to focus restoration and conservation efforts on specific locations most needing it. This is particularly critical for community-based initiatives, such as the Watershed Management Plan at Shawnigan, that face the daunting challenge to address highly degraded ecosystems with limited financial resources.

The main limitation with Landsat imagery, as with any other satellite data, is the cloud coverage, which often limits the number of scenes available. As well, Landsat's moderate spatial resolution and the low number of spectral bands limit the use of more refined algorithms that can be calculated using other satellites (such as WorldView-3). In addition, the accuracy of land characterization due to signal mixing in the 30x30m pixel size is another limitation. However, the freely-available 40-year data archive is still unmatched by any other satellite archives, and its scientific value is incalculable as it provides the longest record of remote sensing data (Campbell & Miller, 2013; NASA, 2015).

It is also important to understand the limitations of the methods: the NDVI works very well to identify trends, but it identifies pixels in the imagery that are green regardless of the species. This is important because increased vegetation growth does not imply it is the right ecological type of vegetation for the area (Polster, 2010, 2014): Restoration of the watershed requires rebuilding the ecosystem's resilience by helping natural processes re-establish the areas with autochthonous vegetation and successional sequences lying within the natural range of variation, and avoiding the proliferation of invasive species or reliance on planted monocultures. Species discrimination and on-the ground restoration is the strength of *in situ* work. In combination, remote sensing and *in situ* based-data provide the interdisciplinary tools to generate a comprehensive understanding required to undertake the complex adaptive management of watersheds.

The remote sensing maps generated with this work have already been used to direct a preliminary field survey in early 2015, and for a public meeting in late 2014:

> "We have already used the remote sensing images to illustrate the immensity of the challenge to the Shawnigan public. The maps were presented at a public meeting on 10th December 2014 and now reside in the Watershed Planning

Office of the Authority in Shawnigan Village" (B. Fraser, pers. comm., December, 10 2014).

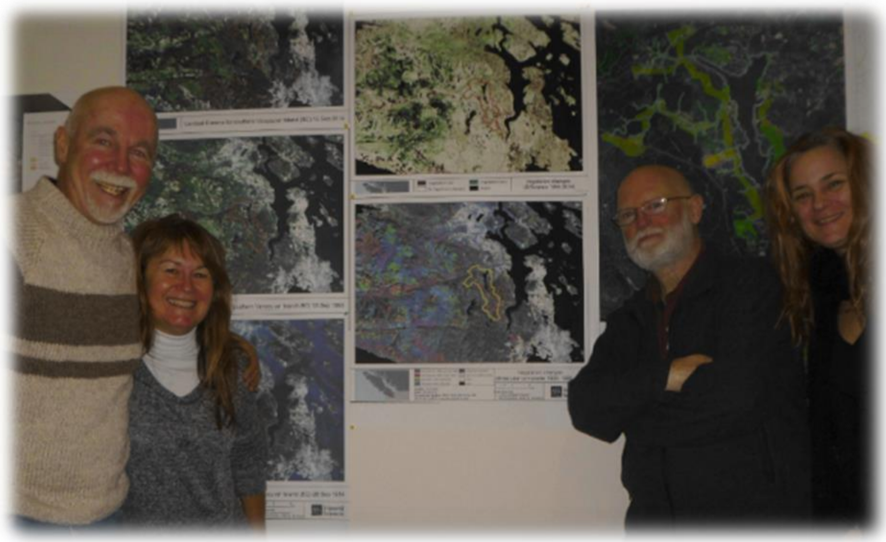


Figure 21. At the Shawnigan Basin Society watershed planning office, 1 February 2015. Left to right: Barry Gates (ecoforester responsible for the forest management design of the Living Forest Community in the Elkington Forest), myself, Dr. Bruce Fraser (president of the Shawnigan Basin Society), and Kelly Musselwhite (RRU colleague and executive director of the SBS).

Beyond Remote Sensing: Is Sustainability Possible in the Shawnigan Lake Watershed?

Sustainability in the Shawnigan basin is presently not a reality: the high degree of ecological degradation after decades of anthropogenic exploitation has eroded the watershed's natural resilience[12]. The threat of increasing anthropogenic forces has triggered the transformation of a community that has realized that previous socio-economic mechanisms are untenable (Allen, Angeler, Garmestani, Gunderson, & Holling, 2014; Folke, Carpenter, Walker,

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[12] the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks (Walker, Holling, Carpenter, & Kinzig, 2004).

Scheffer, Chapin III, & Rockström, 2010). In this transition period, a new narrative is being written: The community Watershed Management Plan is a collaborative effort with the goal of restoring ecological resilience and attain water security. The SBS vision (appendix A) is to purposely reduce the ecological uncertainty derived from the lack of knowledge about the watershed ecosystem by bridging across disciplines, and aims to do so within a broader social, political and institutional framework of adaptive governance (Folke, Hahn, Olsson, & Norberg, 2005; Rist, Felton, Samuelsson, Sandström, & Rosvall, 2013).

While the SBS is striving to create an ecological governance model for the Shawnigan Lake watershed, the fragmentation of knowledge and planning is obvious when considering the larger socio-economic system. It appears that politicians from adjacent municipalities are not as proactive or are perhaps resistant to accepting that an ecological governance model is critical to preserving the watershed. The lake water that drains into Shawnigan Creek flows to Mill Bay and then to the Saanich Inlet. Both the lake and sea become heavily contaminated by urban and agricultural runoffs with deleterious effects on the marine ecosystems. At this time, there are no known studies of actual downstream effects (Fraser, pers. comm., March 10, 2015). Shawnigan Lake's water flow is controlled by a weir installed in 2008 which accounts for the recorded differences of 2.9 m between the dry season and the wet winter months (Hutchinson, 2011). Additionally, the water levels during the summer in Shawnigan Creek are so low that they are considered detrimental to aquatic ecosystems (CVRD, 2010; Riebergeg et al 2004). It is clear that the South Cowichan communities need to work together and follow the SBS's leadership in order to restore the ecological resilience of the complex system that includes the lake, creeks and sea. Ecological balance will not be achieved without a concerted and collaborative effort among neighbouring municipalities. Furthermore, as long as the detrimental mindset that accepts the discharge of refuse into the ground and effluent to run into an ephemeral stream that flows into Shawnigan Lake (Figure 22) remains[13], the problems will persist. Ephemeral and intermittent streams provide the same ecological functions and landscape hydrologic connections as perennial streams (Bond & Cottingham, 2008; Dowell, 2009; Levick et al., 2008).

Figure 22. Map with yellow pin showing the location of South Island Aggregates toxic soil remediation site; the red pin indicates location for 4 March photo showing contaminated material flowing into Shawnigan Creek (photos by D. Hutchinson)

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[13] As per permit given to South Island Aggregates by the MoE, and presently in dispute (Environmental Appeal Board, 2015).

If the last 20 years are any indication of our planet's rate of changes, the next 20 years will bring more change than the last 100 years. The urgency to change course is clear. While restoring and monitoring ecosystems, science-based decision models, public engagement and roundtable discussions may be costly, they are necessary. It is imperative to build local ecological and social resilience to withstand the rapid changes and maintain livable communities (Meadows, 2012; Olsson, Folke, & Berkes, 2004).

From an Ecological Economics perspective, it is possible to understand the limitations of complex biophysical systems, and the urgency to conserve their integrity for the social wellbeing of present and future generations. In that context, total economic valuation can be a powerful tool in conjunction with the SBS adaptive management plan which will put into perspective the true cost of not valuing the environment that we depend on (Max-Neef, 2005; Olewiler, 2010). Theoretically, by estimating the 'monetized value' of the Shawnigan Watershed, legislation can be adapted to address urgent issues by creating adequate timely policies (Mickwitz, 2003). As well, tax incentives, such as the Natural Area Protection Tax Exemption Program (NAPTEP) promoted by Islands Trust (2014), can be explored at the Shawnigan Lake Watershed to stimulate private land-owners collaboration.

A vision of a future with resilient communities requires creating a new narrative, radically changing our mindset, and challenging the dominant worldview –which invariably implies uncomfortable confrontation, collective political engagement, and an involved community (Fielding, MacDonald, & Louis, 2005; Lacasse, 2013). Trying to change the world at large is a daunting task, but by focusing our efforts at a local scale, such as the SBS Watershed Management Plan, communities can foster participatory and integrative frameworks to guide adaptive strategies and policies that address the restoration of local resilience. Furthermore, this focus can ensure the preservation of its integrity, and the rational use of the ecological goods and services the ecosystems make available to the communities, present and future (Dale, 2001; Stelk and Christie, 2014; Westley, 2002). This, in turn, might help the communities develop a collective ‘sense of place’ and stewardship pride that will hopefully lead to a paradigm shift in which the natural world is not simply viewed as ‘natural capital,’ and the Shawnigan Lake Watershed simply as a ‘tradable asset’ (Monbiot, 2014).

Future Directions. It is recommended to continue, if possible, the existing Landsat time series in order to maintain ongoing monitoring of the evolution of the watershed, and perhaps explore what other analyses can be carried out as the Watershed Management Plan evolves. For example, vegetation indices other than NDVI could be tested, and regression analyses using variables such as precipitation, and temperature could be explored for a thorough understanding of ecological resilience variability in the basin. The extent of the Scotch broom invasion can be mapped if the imagery is acquired when the plants are in bloom (flowers are yellow and easily detected with satellite data). Trends in water level fluctuations as well as water quality studies (for sporadic events of turbidity and algal blooms) can also be done successfully with Landsat data. It is important to acquire ground truth for all the classes created and for the same period as the images, in order to generate an accuracy assessment and validate the work done to date. In addition, a detailed land-cover inventory can be created using the most recent Landsat data, though it would be preferably to acquire higher spatial and spectral resolution data, such as World-View 3 (1.5m pixel resolution). This could be the baseline for a future high resolution time series.

Visualization techniques can be improved using Digital Elevation Model drapes, to assist interpretation, especially for public demonstrations. Bridging the scientific information to the general public is critical to help bring understanding and promote collaboration. Public talks on the results of this study (as requested by Dr. Fraser) are planned for 2015. I would like to explore the possibility of training community volunteers and field specialists on the use of remote sensing maps as tools for watershed management. It would be valuable to transfer the remote sensing maps into iPad tablets for integration in a multi-layer GIS style database that would also include field data, First Nations knowledge, and any other available information relevant to the area.

It is important to share the results of the studies prepared for the SBS's Watershed Management Plan in platforms such as the British Columbia Lake Stewardship Society (BSLSS) forum, and the 2016 conference of the Society for Ecological Restoration (SER).

"We abuse land because we regard it as a commodity belonging to us.

When we see land as a community to which we belong,

we may begin to use it with love and respect" (Leopold, 1949).

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D9jS8CuuDKbnusWGZOaXx9tU&hl=en&sa=X&ei=mcUTVcOVIMywogS_7IG4Bw&ved=0CFIQ6AEwCQ#v=onepage&q=ecological%20importance%20of%20ephemeral%20streams&f=false

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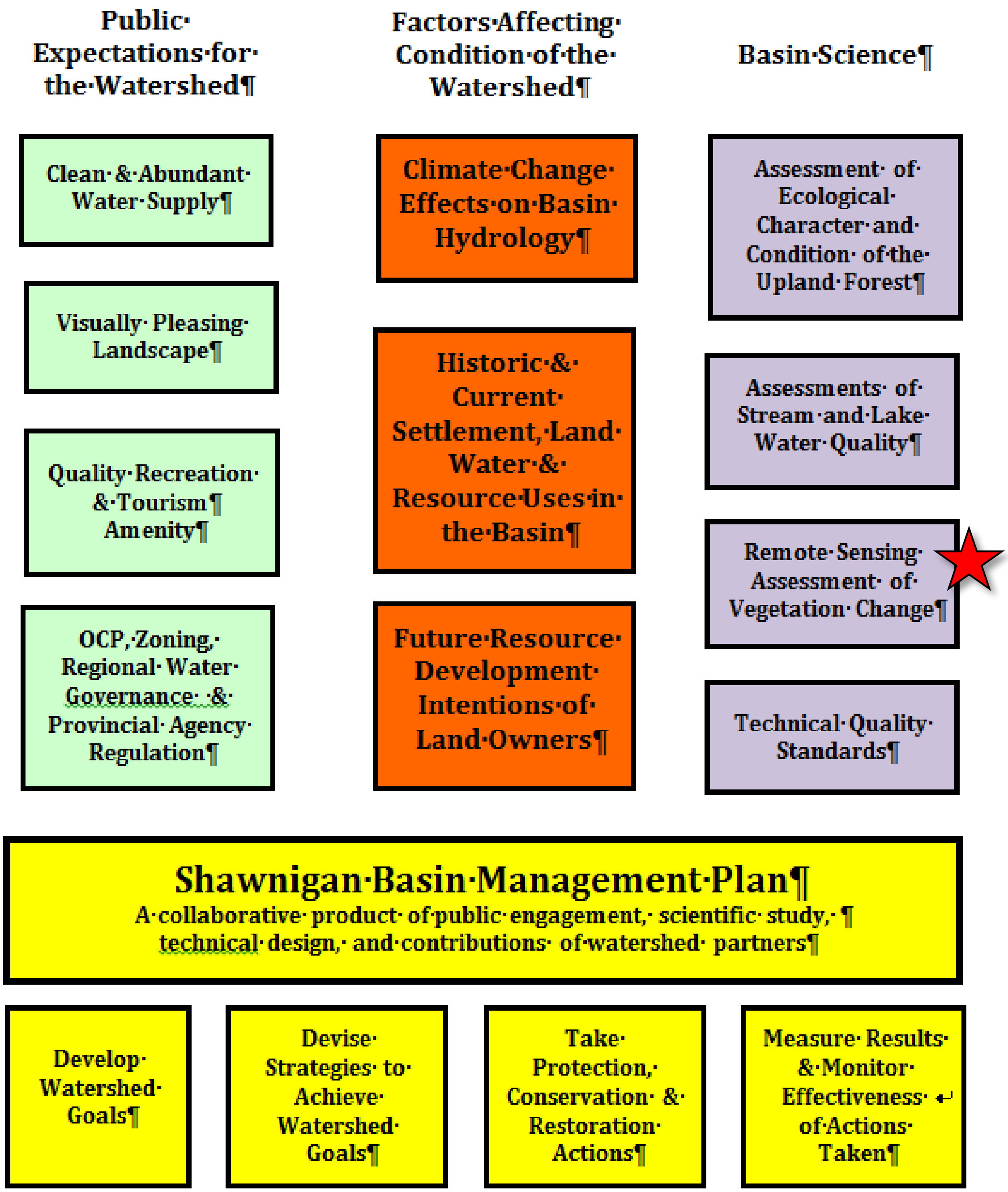
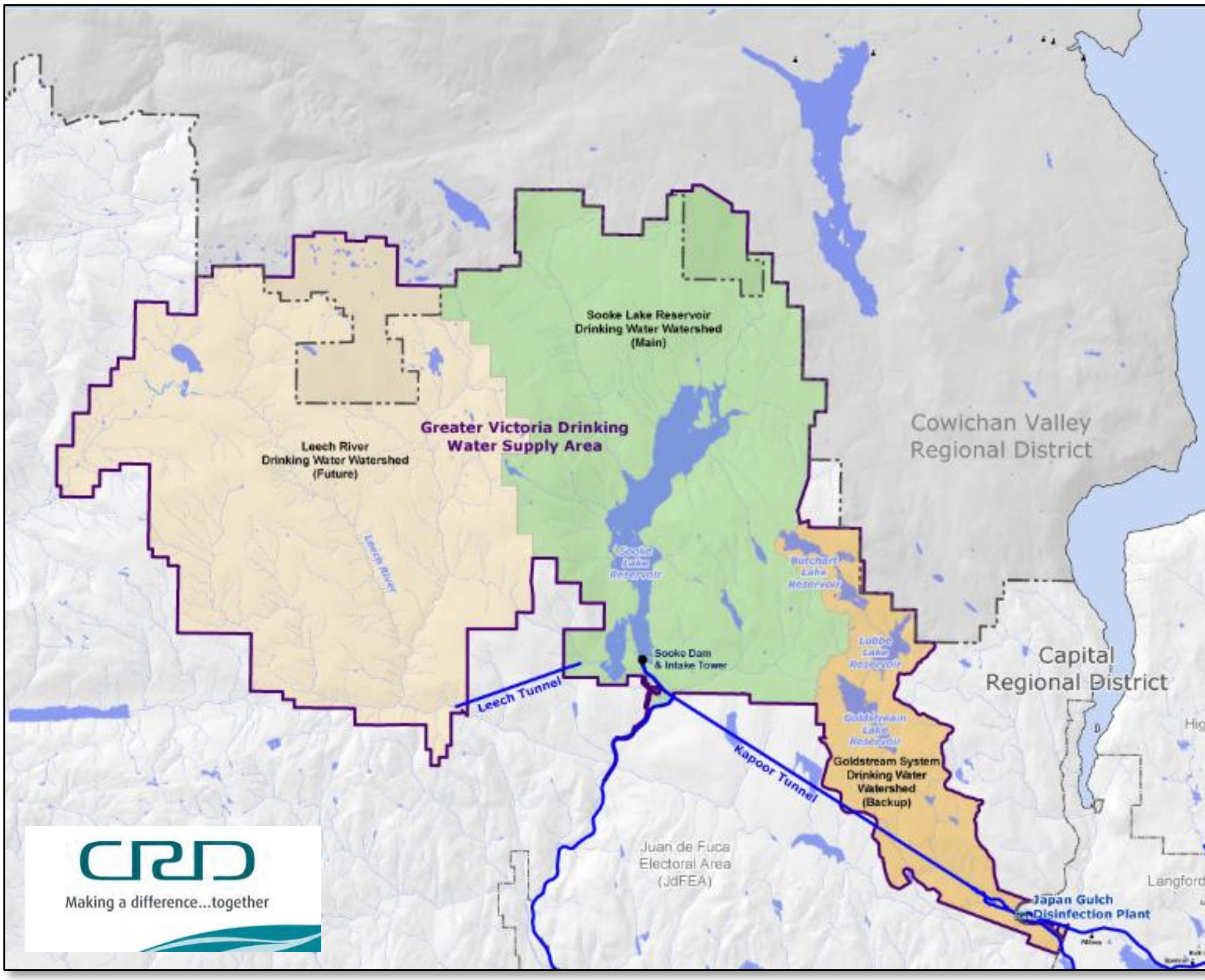
Appendix A: Shawnigan Watershed Management Plan

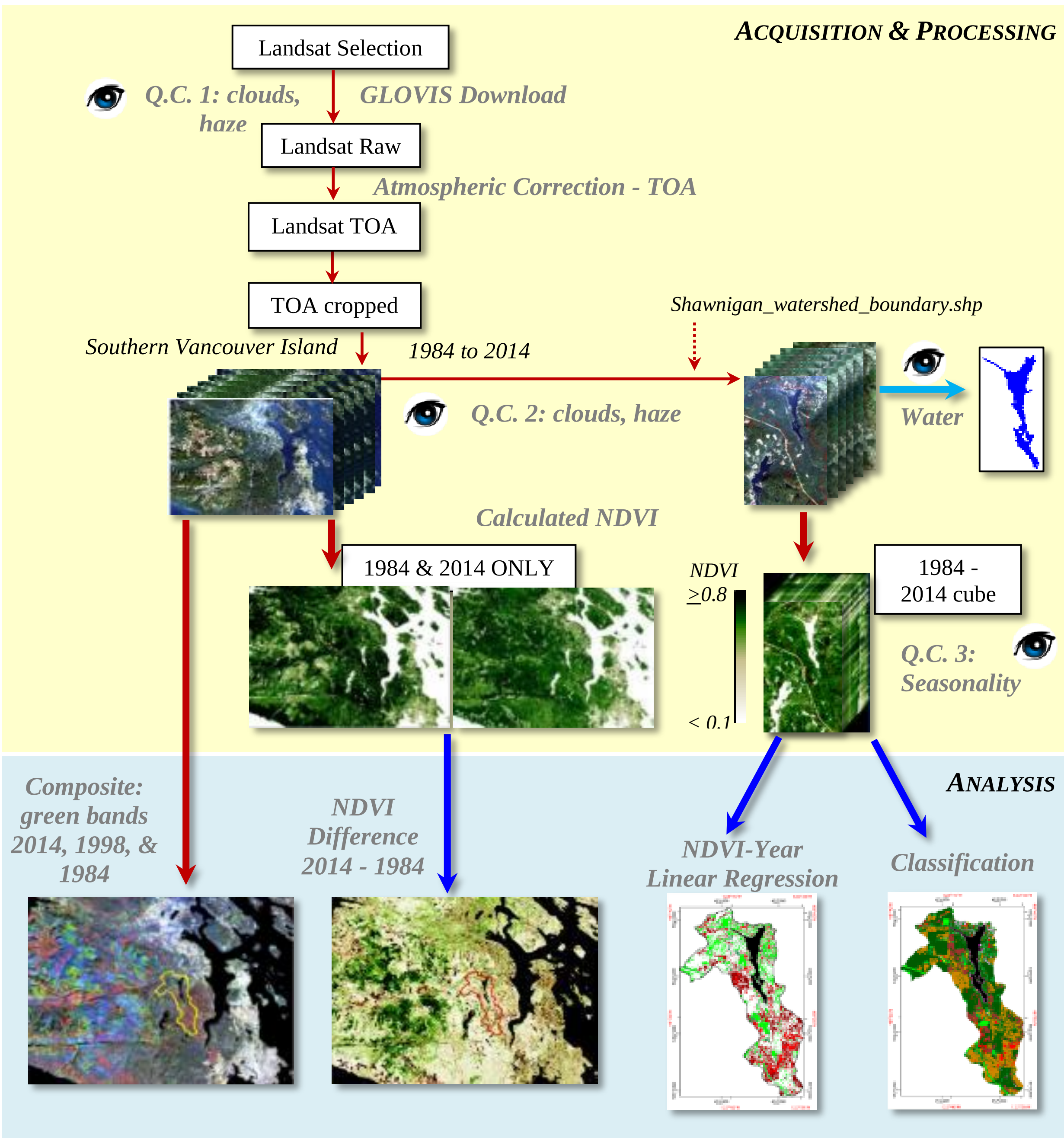


Appendix B: Greater Victoria Watersheds



Map of drinking water supply systems for Greater Victoria (CRD, 2012)

Appendix C: Overview of the Overall Remote Sensing Processing & Analyses

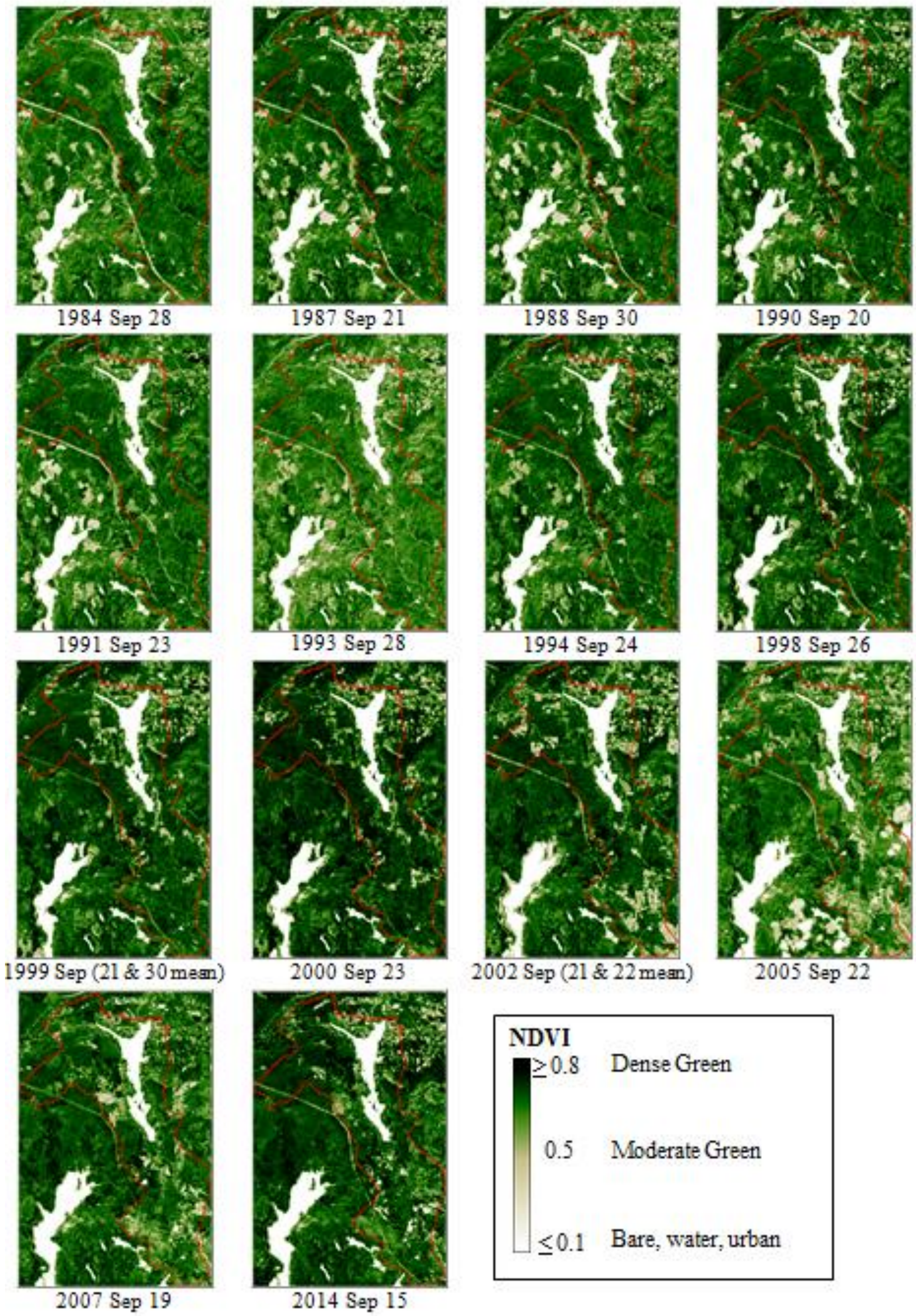


Appendix D: Landsat Scenes for 22 Aug – 11 Oct 1984-2014

Date	*Path*	*Row*	Sensor
28/09/1984	*47*	*26*	L5TM
11/10/1986	*48*	*26*	L5TM
05/09/1987	*47*	*26*	L5TM
21/09/1987	*47*	*26*	L5TM
29/08/1988	*48*	*26*	L5TM
14/09/1988	*48*	*26*	L5TM
30/09/1988	*48*	*26*	L5TM
10/09/1989	*47*	*26*	L5TM
03/10/1989	*48*	*26*	L5TM
28/08/1990	*47*	*26*	L5TM
04/09/1990	*48*	*26*	L5TM
20/09/1990	*48*	*26*	L5TM
22/08/1991	*48*	*26*	L5TM
23/09/1991	*48*	*26*	L5TM
10/10/1991	*48*	*26*	L5TM
24/08/1992	*48*	*26*	L5TM
09/09/1992	*48*	*26*	L5TM
05/09/1993	*47*	*26*	L5TM
12/09/1993	*48*	*26*	L5TM
30/08/1994	*48*	*26*	L5TM
24/09/1994	*47*	*26*	L5TM
02/09/1995	*48*	*26*	L5TM
07/09/1997	*48*	*26*	L5TM
03/09/1998	*47*	*26*	L5TM
26/09/1998	*48*	*26*	L5TM
13/09/1999	*48*	*26*	L5TM
21/09/1999	*48*	*26*	LE7
22/09/1999	*47*	*26*	L5TM
30/09/1999	*47*	*26*	LE7

Date	*Path*	*Row*	Sensor
22/08/2000	*48*	*26*	LE7
23/08/2000	*47*	*26*	L5TM
23/09/2000	*48*	*26*	LE7
26/08/2001	*47*	*26*	L5TM
10/09/2001	*48*	*26*	LE7
04/10/2001	*48*	*27*	LE7
28/08/2002	*48*	*26*	LE7
13/09/2002	*48*	*26*	LE7
21/09/2002	*48*	*26*	L5TM
22/09/2002	*47*	*26*	LE7
01/09/2003	*47*	*26*	L5TM
21/08/2005	*47*	*26*	L5TM
22/09/2005	*47*	*26*	L5TM
31/08/2006	*48*	*26*	L5TM
12/09/2007	*47*	*26*	L5TM
19/09/2007	*48*	*26*	L5TM
14/09/2008	*47*	*26*	L5TM
06/10/2010	*47*	*26*	L5TM
07/09/2011	*47*	*26*	L5TM
12/09/2013	*47*	*26*	L8
06/09/2014	*48*	*26*	L8
15/09/2014	*47*	*26*	L8

Appendix E: NDVI Images for 15-30 September 1984-2014



Appendix F: Areal Distribution of NDVI-year Trends in the CVRD Parcels

1984-2014 trends	22917		39496		25337		25339	
Slope & p groupings	**Ha**	**%**	**Ha**	**%**	**Ha**	**%**	**Ha**	**%**
Unchanged, slope >-0.002, < 0.002	39.78	*19.5%*	59.49	*37.6%*	12.0	*46.2%*	70.3	*46.8%*
Decreasing, slope ≤ 0.002								
p ≤ 0.05	30.24	*14.8%*	16.92	*10.7%*	2.8	*10.8%*	4.1	*2.8%*
p > 0.05	133.65	*65.6%*	58.5	*36.9%*	6.2	*24.0%*	6.2	*4.1%*
Increasing slope ≥ 0.002								
Increase, p ≤ 0.05	0.09	*0.04%*	12.87	*8.1%*	2.4	*9.4%*	47.3	*31.4%*
Increase, p > 0.05	0.09	*0.04%*	10.62	*6.7%*	2.5	*9.7%*	22.4	*14.9%*
Total area (ha)	203.9		158.4		25.9		150.3	

1984-2014 trends	21575		22586		36667		9323	
Slope & p groupings	**Ha**	**%**	**Ha**	**%**	**Ha**	**%**	**Ha**	**%**
Unchanged, slope >-0.002, < 0.002	228.2	*55.9%*	40.4	*57.3%*	87.2	*58.1%*	25.3	*64.6%*
Decreasing, slope ≤ 0.002								
p ≤ 0.05	9.3	*2.3%*	2.3	*3.2%*	6.5	*4.3%*	0.2	*0.5%*
p > 0.05	47.6	*11.7%*	14.7	*20.8%*	20.7	*13.8%*	2.0	*5.1%*
Increasing slope ≥ 0.002								
Increase, p ≤ 0.05	62.5	*15.3%*	7.2	*10.2%*	16.3	*10.9%*	9.5	*24.1%*
Increase, p > 0.05	60.5	*14.8%*	5.9	*8.4%*	19.4	*12.9%*	2.3	*5.7%*
Total area (ha)	408.0		70.5		150.1		39.2	

	27902		9321		41557	
	Ha	**%**	**Ha**	**%**	**Ha**	**%**
Unchanged, slope >-0.002, < 0.002	72.5	*66.8%*	36.3	*80.4%*	156.7	*84.0%*
Decreasing, slope ≤ 0.002						
p ≤ 0.05	0.0	*0.0%*	0.0	*0.0%*	3.4	*1.8%*
p > 0.05	0.0	*0.0%*	3.8	*8.4%*	2.1	*1.1%*
Increasing slope ≥ 0.002						
Increase, p ≤ 0.05	30.0	*27.6%*	4.0	*8.8%*	16.4	*8.8%*
Increase, p > 0.05	6.1	*5.6%*	1.1	*2.4%*	8.0	*4.3%*
Total area (ha)	108.6		45.1		186.6	

Appendix G: Areal Distribution of Temporal Classes in the CVRD Parcels

Temporal Class	22917		39496		25337		25339	
Weakly varying	Ha	%	Ha	%	Ha	%	Ha	%
Limited cover, NDVI < 0.3	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Moderate cover, NDVI 0.3-0.5	0	0.0%	0.45	0.3%	0.45	1.7%	0	0.0%
Dense cover, NDVI ≥ 0.5	23.2	11.4%	37.3	23.5%	10.8	41.7%	72.5	48.3%
Decreasing Trends: Disturbed areas								
Not recovered (Loss)	0.5	0.2%	0.4	0.2%	0.2	0.7%	6.8	4.6%
Disturbance before 2000; 2014 NDVI ≥ 0.5	3.0	1.5%	1.4	0.9%	2.1	8.0%	44.6	29.7%
Disturbance after 1999; 2014 NDVI ≥ 0.5	172.2	86.7%	101.6	64.1%	10.6	41.0%	1.7	1.1%
Increasing trends, 2014 NDVI ≥ 0.5								
1984 NDVI < 0.5	5.0	0.2%	12.1	7.6%	1.8	6.9%	6.0	4.0%
1984 NDVI ≥ 0.5	0	0.0%	5.31	3.4%	0	0.0%	18.3	12.3%
Total area (ha)	203.9		158		25.9		150	

	21575		22586		36667		9323	
Weakly varying	Ha	%	Ha	%	Ha	%	Ha	%
Limited cover, NDVI < 0.3	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Moderate cover, NDVI 0.3-0.5	0.09	0.0%	6.75	9.6%	0.54	0.4%	0.45	1.1%
Dense cover, NDVI ≥ 0.5	86.9	21.3%	22.2	31.5%	63.8	42.5%	31.0	79.1%
Decreasing Trends: Disturbed areas								
Not recovered (Loss)	0.3	0.1%	1.1	1.5%	2.6	1.7%	1.5	3.9%
Disturbance before 2000; 2014 NDVI ≥ 0.5	190.2	46.6%	0.2	0.3%	19.9	13.2%	0.0	0.0%
Disturbance after 1999; 2014 NDVI ≥ 0.5	88.3	21.6%	31.7	45.0%	32.8	21.8%	2.6	6.7%
Increasing trends, 2014 NDVI ≥ 0.5								
1984 NDVI < 0.5	31.2	7.7%	8.5	12.0%	13.7	9.1%	3.6	9.2%
1984 NDVI ≥ 0.5	11.07	2.7%	0.09	0.1%	16.8	11.2%	0	0.0%
Total area (ha)	408.0		70.5		150		39.2	

	9321		27902		41557	
Weakly varying	Ha	%	Ha	%	Ha	%
Limited cover, NDVI < 0.3	0	0.0%	0	0.0%	0.09	0.02%
Moderate cover, NDVI 0.3-0.5	0	0.0%	2.7	1.8%	0.81	0.2%
Dense cover, NDVI ≥ 0.5	37.0	82.0%	95.7	63.7%	164.5	40.3%
Decreasing Trends: Disturbed areas						
Not recovered (Loss)	2.3	5.2%	0.0	0.0%	0.1	0.0%
Disturbance before 2000; 2014 NDVI ≥ 0.5	0.0	0.0%	0.0	0.0%	10.2	2.5%
Disturbance after 1999; 2014 NDVI ≥ 0.5	4.1	9.2%	0.2	0.1%	2.0	0.5%
Increasing trends, 2014 NDVI ≥ 0.5						
1984 NDVI < 0.5	1.6	3.6%	10.1	6.7%	8.6	2.1%
1984 NDVI ≥ 0.5	0	0.0%	0	0.0%	0.27	0.1%
Total area (ha)	45.1		109		187	