GEOLOGICAL SURVEY OF CANADA
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Abstract

This document describes the production and assessment of peak season leaf area index estimates over the Nanaimo Aquifer and surrounding regions from satellite imagery using standard Canada Centre for Remote Sensing algorithms. A 30m resolution map of 2011 peak season leaf area index for the Nanaimo Aquifer was created using a combination of in situ LAI estimates, vegetation indices from remotely sensed spectral data and land cover information from SPOT 5 satellite imagery. A total of 104 ground plots were sampled across the study area between July 15-30, 2011for the purposes of calibration and validation of the leaf area index product.

Introduction

The Nanaimo Aquifer is one of the key regional aquifers being mapped within the Natural Resources Canada Earth Sciences Sector Groundwater Geoscience Programme (http://ess.nrcan.gc.ca/gg-ges/proj2_e.php). Leaf Area Index (LAI) is defined as half the total foliage area per unit horizontal ground surface area (CCRS, 2005). This document describes the production of a 30m LAI map for the Nanaimo Aquifer and surroundings followed by a limited accuracy assessment.

Study Area

The Nanaimo Aquifer Region is 837 square kilometres and consists of 25 watersheds located in southeastern Vancouver Island (Figure 1). The aquifer lies in the Pacific Maritime ecozone. The region is characterized by 105 cm of average annual precipitation and 16.5 (°C) mean summer and 3.1 (°C) mean winter temperatures. Topography ranges from 30 m to 1870 m with extensive mountainous areas. Vegetation includes Douglas Fir and Spruce in alpine areas and Cedar, Red Alder and Balsam in valleys, and mixed land cover driven by human land use along the coastal areas. Detailed Land Cover mapping was also conducted in this study and discussed in this document.

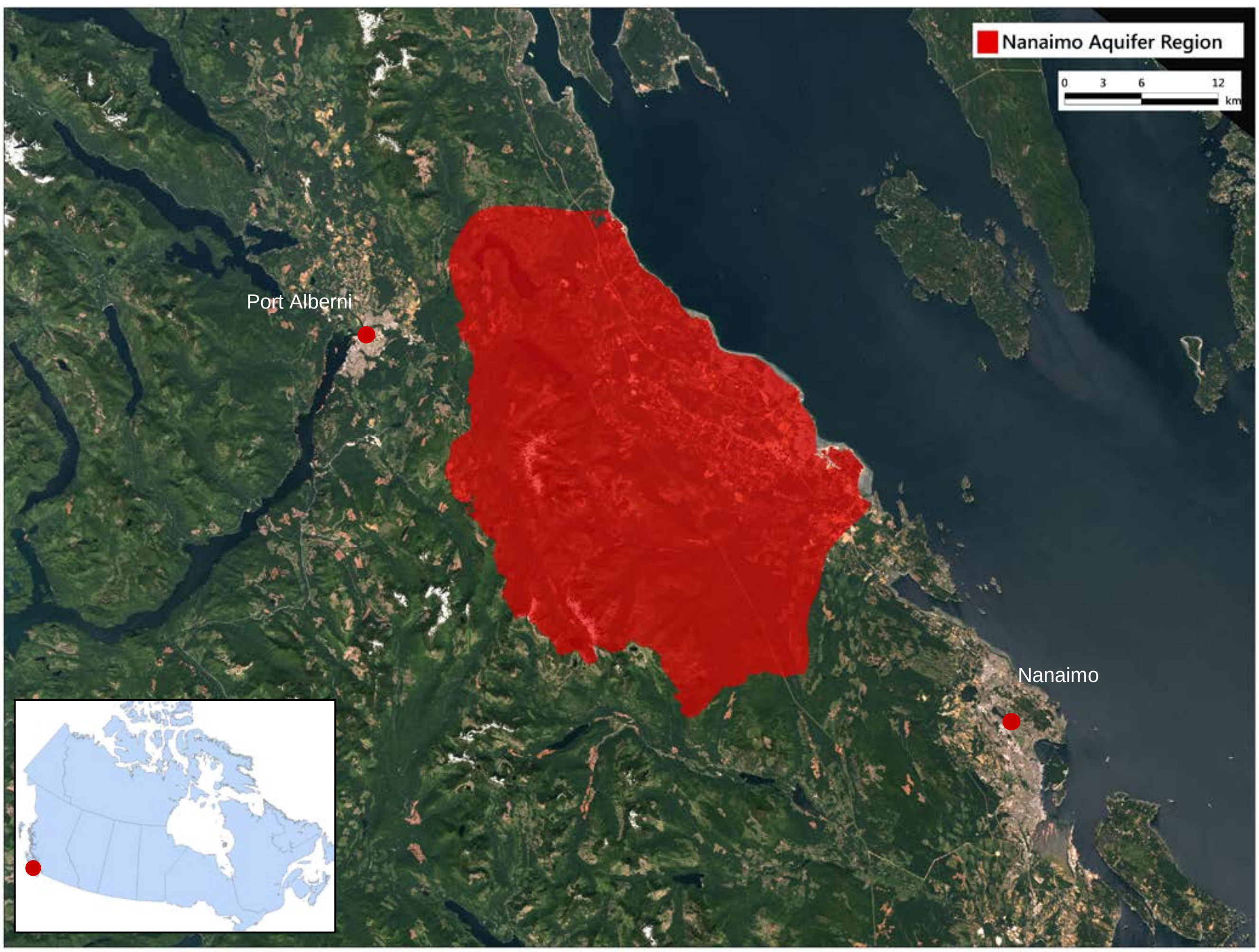


Figure 1: Location of Nanaimo Aquifer Region delineated by the red polygon, within South Eastern Vancouver Island.

Methodology

A 30m resolution map of 2011 peak season LAI for the Nanaimo Aquifer was created using a combination of in situ LAI estimates, vegetation indices from remotely sensed spectral data and land cover information.

Field Measurements

In situ LAI was estimated using digital hemispherical photography. A total of 104 ground plots were sampled across the study area (Figure 2) between July 15-30, 2011 using the CCRS LAI measurement protocol (Appendix I). This corresponds to upward and downward digital hemispheric photographs spaced within each plot together with notes on stand characteristics (e.g. tree heights, DBH, slope) .The ground plots in which LAI were measured are generally 50-120 m in size, depending on the stand homogeneity. The majority of plots were on forested areas, with 32 primary forest plots and 60 secondary or recently harvested forest plots. The remaining 12 plots were on agricultural or urban areas. Normally separation of LAI from total plant area is performed using a leaf-off survey or by destructive or allometric estimation of non-foliage area. This was not performed here due to both access and time restrictions. In addition, nominal values for needle to shoot ratios were used from Frazer et al. 2000 (Appendix II). The location of each ground plot was determined using global positioning systems (GPS), which have an accuracy of about ±5 m.

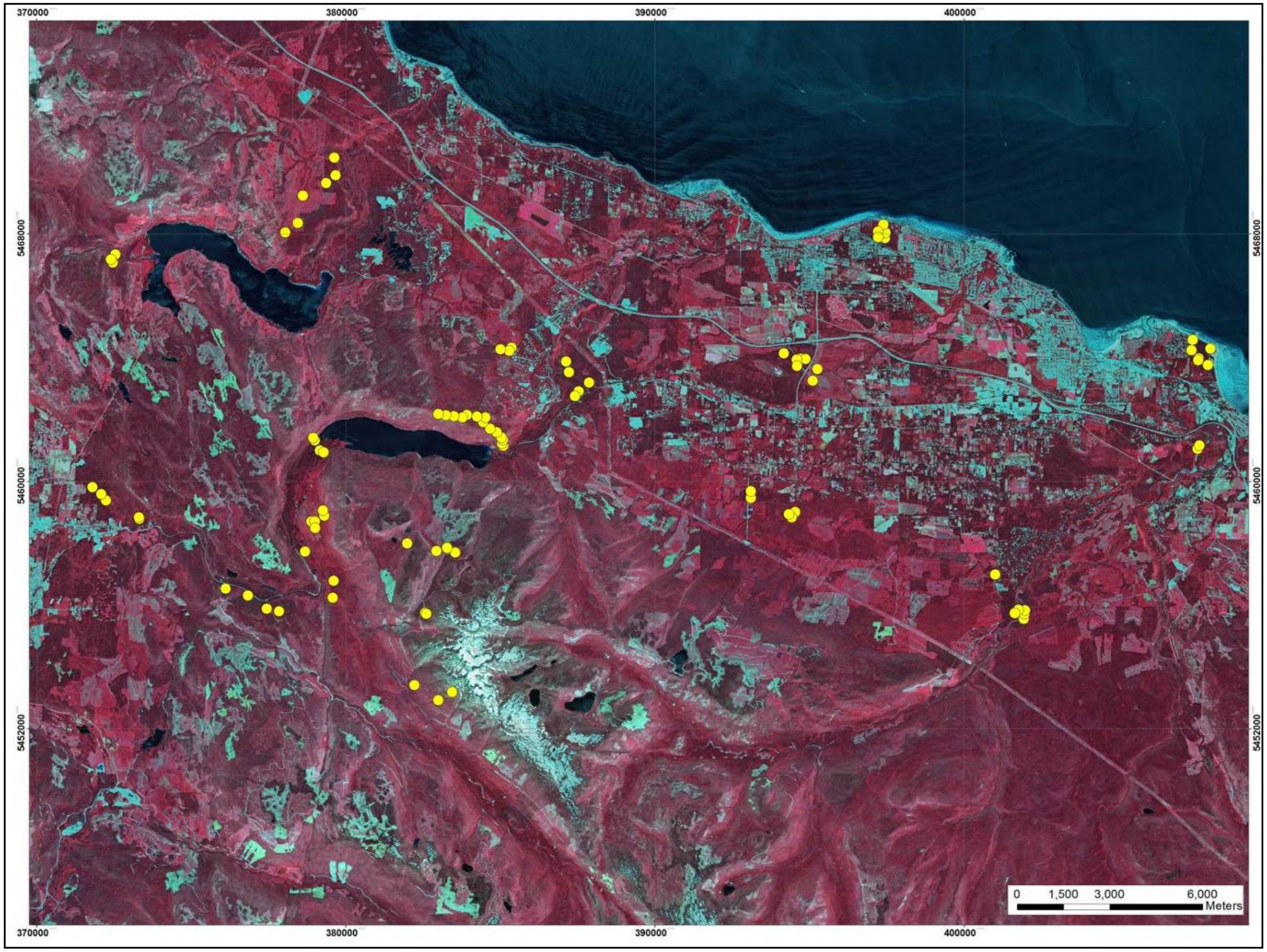


Figure 2: Location of field measurement plots within South Eastern Vancouver Island.

Understory vegetation is a recognized problem that limits the accuracy of satellite-estimated forest LAI. A negative linear relationship (r^2=0.3) was observed between Nanaimo Aquifer Region field measurements of upward and downward LAI (Figure 3).

The influences of understory LAI on the relationship between total LAI and reflectance data has been studied extensively (Chen & Cihlar, 1996; Chen et al., 2002; Eriksson et al, 2006). Typically the greater the crown closure and denser the forest stand, the lower the understory LAI, the better the performance of spectral reflectance data in estimating LAI. Frazer et al. 2000 discuss the increases in canopy openness and heterogeneity in old growth forests when compared to immature forests found within the study area. It is expected that in the complex primary forest stands of this study area, the ability to accurately measure spectral reflectance in shaded understories may lead to underestimation of LAI.

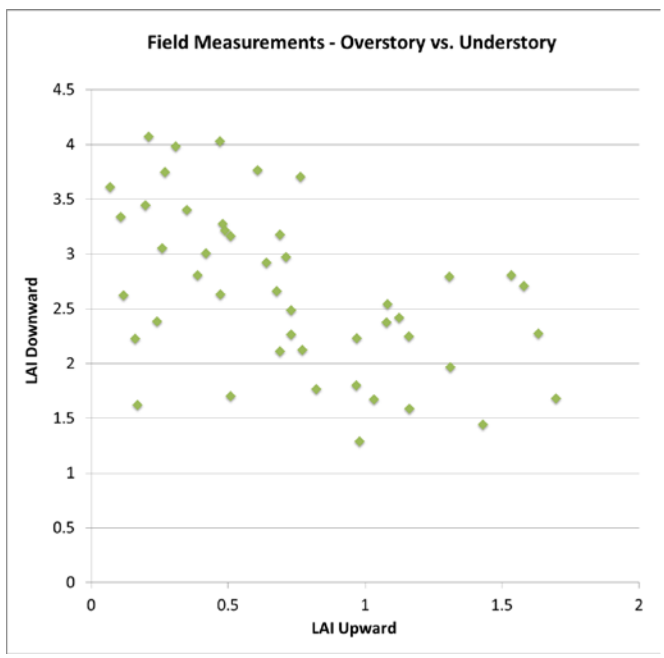


Figure 3: Field measured overstory and understory LAI.

Land Cover Mapping

Multi-date remote sensing imagery was used to produce a land cover map for the study area as described in Pouliot et al. 2012. The land cover product at 10m spatial resolution has an overall accuracy of 87%, and the Kappa Coefficient of 0.83. The land cover classes were used to determine the approach to model LAI. For all forested, shrub and wetland areas, which represent 57% of the land for the study area, remotely sensed imagery would be used to produce vegetation indices which would then be calibrated by the field measurements to determine LAI. Different calibrations would be applied to primary forests (class 1) and secondary forests (all other forest and shrub classes), based on complexities in understory and gap dynamics observed in the field measurements of primary forests. In the case of agricultural areas, where field measurements were considered insufficient, LAI would be estimated using peak season means from similar studies. For urban, barren and water land cover classes, these areas would be assumed to have no leaf cover.

The methodology used to produce the land cover is discussed in Pouliot et al. 2012. The land cover classes used are as follows:

1. Coniferous - Predominantly coniferous “old growth” forests or treed areas. Dense forest with structural variability and gap dynamics.
2. Deciduous - Predominantly broadleaf/deciduous forests or treed areas. Moderate to dense predominately deciduous forest.
3. Mixed - Mixed coniferous and broadleaf/deciduous forests or treed areas. Moderate to dense mixed forest.
4. Coniferous recent disturbance origin ~last 50 years. More dense canopies with reduced vertical structural variability.
5. Mixed Regeneration (shrub and conifer) young 3-8 years. Regeneration from disturbance typically after tree planting creating a mixed forest condition, generally dominated by shrub.
6. Mixed Regeneration (shrub and conifer) old 8 -16 years. Older regeneration from disturbance, conifer trees > 2 m.
7. Shrub - Predominantly woody vegetation of relatively low height (±2 meters).
8. Wetlands - Land with a water table near/at/above soil surface for enough time to promote aquatic processes.
9. Low Vegetation – Grass and other low lying herbaceous covers.
10. Cropland high biomass - Agricultural land with cultivated crops.
11. Cropland low biomass - Agriculture land where crops have not be cultivated, typical pasture and fallow post harvesting.
12. Barren - Predominately non-vegetated and non-developed. Includes: exposed lands, snow, glacier, rock, sediments, burned areas, rubble, mines
13. Urban - Land that predominantly built-up or developed. This includes road surfaces, railway surfaces, buildings and paved surfaces, urban areas, industrial sites, mine structures.
14. Water - Exposed water

Satellite Product

SPOT5 imagery for the study area was acquired on August 1, 2011. The imagery was atmospherically corrected to produce surface reflectance using the ATCOR3 model with PCI Geomatica v12.0. A 25m digital elevation model (CTI-NRCAN) was used in the correction for terrain effects and atmospheric information was collected from neighbouring Environment Canada climate stations. For the purpose of extracting reflectance data to match the in situ plots, which typically covered a minimum area of 50m, the 10m SPOT imagery was resampled to 50m using a bilinear method.

Vegetation Indices derived from SPOT5 Imagery

Once resampled, the SPOT5 reflectance bands were used to produce vegetation indices for regression analysis with the field LAI estimates. A Reduced Simple Ratio (RSR) was compared with a Simple Ratio (SR) and a standard Normalized Difference Vegetation Indices (NDVI).

The RSR is an indices found to be accurate for vegetation over various cover types and also sensitive to vegetation water content (Chen et al. 2002). RSR is defined as $\rho_{NIR} / \rho_{Red} (1 - (\rho_{SWIR} - \rho_{SWIRmin} / \rho_{SWIRmax} - \rho_{SWIRmin})$, where ρNIR, ρred, and ρSWIR are the reflectance in NIR, red, and SWIR band, respectively. ρSWIRmin and ρSWIRmax are the minimum and maximum SWIR reflectance found in the image (Brown et al., 2000).

SR is the ratio between ρNIR and ρSWIR and NDVI is (ρNIR - ρSWIR/ ρNIR + ρSWIR).

The comparisons between the forested LAI estimates, which represent the majority of the sites, and the vegetation indices indicate that although the correlation coefficients are similar, the RSR responds more dynamically to LAI than NDVI or the SR.

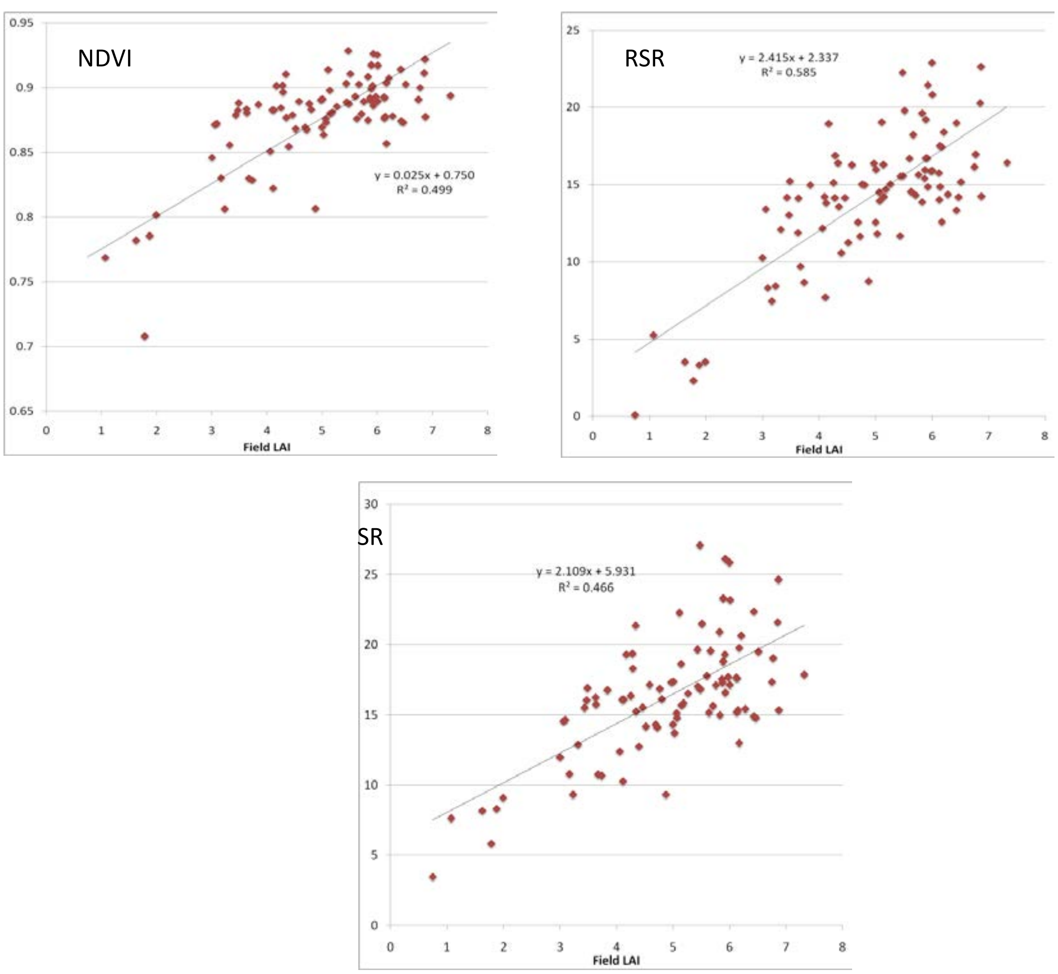


Figure 4: Vegetation Indices plotted against Field LAI.

LAI Estimation – Forested Areas

The RSR was selected as the optimal vegetation indices for forest cover types and subsequently regressed with the field LAI estimates using a Theil-Sen regression. Separate regression equations were developed for primary and secondary forests based on the complex forest dynamics and subsequent spectral responses observed in the primary old growth forests.

The Theil-Sen regression technique has been used to develop statistical regression relationships and normalisations for remote sensing imagery (Fernandes and Leblanc, 2005; Olthof et. al. 2005). This regression approach is robust up to 29% of the outliers in the data and accounts for unknown measurement errors in both the x- and y-axis. Both of these two factors are critical if unbiased LAI estimates are important. In the absence of major outliers, the Theil-Sen regression will be similar to that of a traditional linear fit.

By incorporating the Land Cover map, the following regression equations for the two forest classes were applied to the entire image/study area:

Primary Forest LAI = 3.34079 + 0.16863 * RSR
Secondary Forest LAI = 1.13095 + 0.23746 * RSR

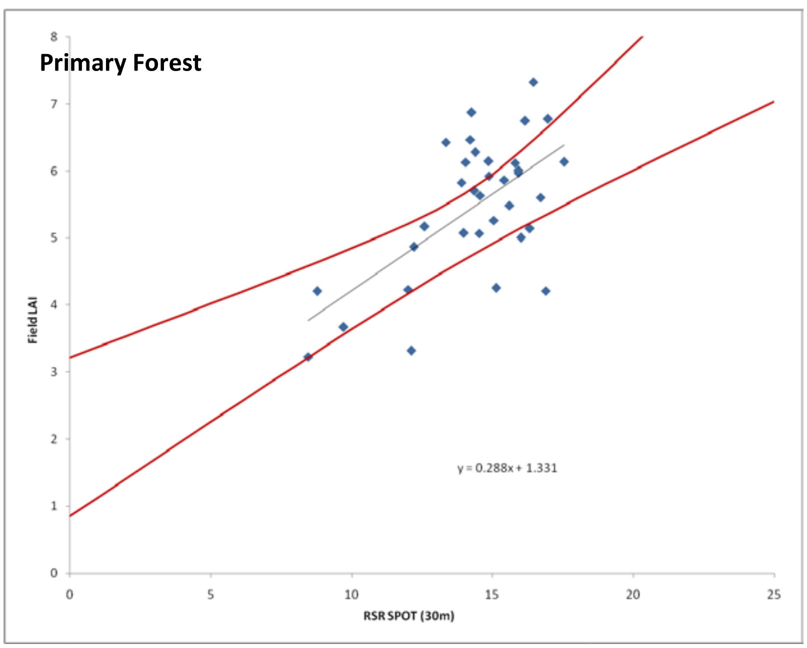


Figure 5: Primary forest field estimated LAI compared with SPOT5 RSR. Red lines indicate regression confidence intervals.

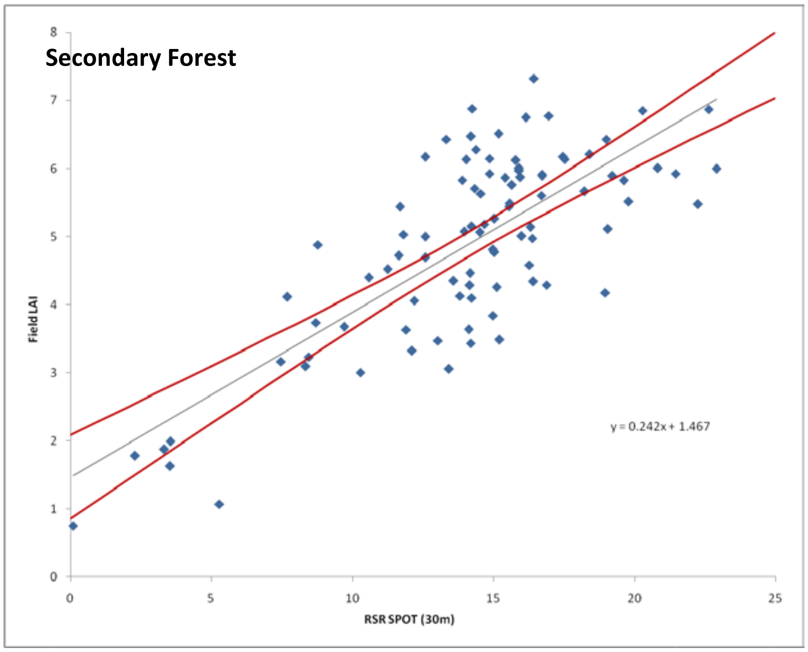


Figure 6: Secondary forest and disturbance area field estimated LAI compared with SPOT5 RSR. Red lines indicate regression confidence intervals.

LAI Estimation – Agricultural Areas and Low Vegetation Areas

Insufficient field measurements were made over agricultural and other herbaceous covers, therefore the LAI estimates would be derived from land use dependent retrieval algorithms from Fernandes et al. 2003. While low vegetation covers represented 7.72% of the total study area land cover, both high and low biomass croplands represented less than 1% of the total area.

Based on recent field measurements of peak season LAI of cultivated high-biomass crops from Ottawa (Eastern Ontario), Richelieu (Southern Quebec) and Grand River (Southern Ontario), estimates of LAI were used to set maximum LAI values. Low biomass crops (i.e. wheat) were estimated to have $LAI_{max} = 6.25$ with uncertainties on average less than ±0.10 units in peak season. High biomass crops (i.e. soybean) were estimated to have $LAI_{max} = 8.5$ with uncertainties on average of ±1.0 units at peak season. The following land cover dependent retrieval algorithms were used:

Low vegetation LAI = -0.20750 + (0.22880*SR)
Cropland high biomass LAI = 0.15050*exp(3.97030*NDVI)
Cropland low biomass LAI = 0.00280*exp(8.09717*NDVI)

Post Processing

The final product was filtered using a 3x3 median filter to remove any artefacts between the Land Cover product and the RSR processing. All LAI values were then multiplied by 10 and stored in an 8-bit geotiff file at 30m resolution

Results

The final LAI product was produced with spatially explicit per pixel estimates of LAI, as seen in Figure 6, but also allowing regional descriptive LAI statistics to be compared, as in Table 1. Coniferous areas accounted for almost 60% of the land cover for the study area, with a mean LAI of 52.61 and reasonably low variation ($\sigma = 11.30$). Low vegetation areas such as grasslands and pastures accounted for approximately 10% of the area, with a considerably lower mean LAI of 15.21. Mixed regeneration areas had the highest mean LAI of 80.78 and significant variability ($\sigma = 24.36$), however only covered 6% of the study area.

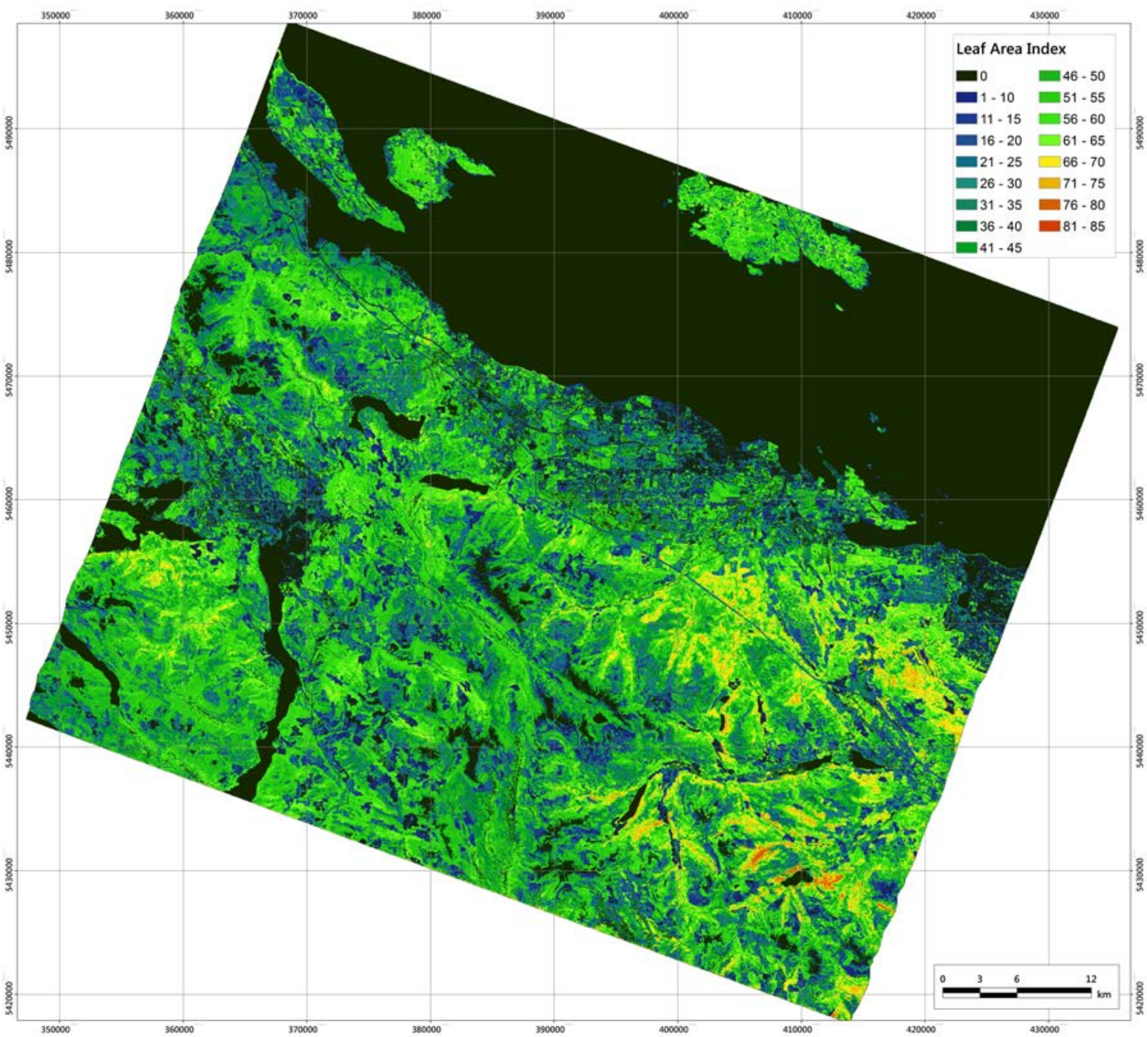


Figure 7: LAI (*10) for Nanaimo Aquifer Region for August 1, 2011.
Reference as: Fernandes, R.A., Maloley, M., Canisius, F., Butson, C.; August 1, 2011 Leaf Area Index for Nanaimo Aquifer Region from SPOT5 Imagery, Canada Centre for Remote Sensing, Natural Resources Canada.

Land Cover Class	AREA (m^2)	MEAN	STD (σ)	MEDIAN	RANGE
Coniferous	969473000	52.61	11.30	54	125
Deciduous	40941800	30.42	21.34	39	90
Mixed	162149000.	21.26	22.17	18	82
Coniferous recent disturbance (origin ~50 years)	893250000	49.47	12.23	51	103
Mixed Regeneration	197877400	80.78	24.36	83	183
Shrub	231714000	24.58	8.54	24	88
Wetlands	3495000	27.14	12.03	27	90
Low Vegetation	330305000	15.21	9.24	13	80
Cropland high biomass	13978500	33.05	8.12	32	140
Cropland low biomass	10499800	21.58	5.64	22	65
Barren	120691000	2.93	7.90	0	71
Urban	82285500	1.39	5.01	0	58

Table 1: LAI statistics by Land Cover class.

Uncertainty

Spatially errors due to ortho-correction are estimated to be +-10m and should have negligible impact on the LAI analysis

Insufficient field measurement data was available for a comprehensive validation, however uncertainties can be inferred from the Root Mean Square Errors (RMSE) of the land cover specific regression analysis. Based on the Theil-Sen regression analysis of field measurements and RSR values, primary forests cover had substantial uncertainty with RMSE = 0.912, whereas secondary forest covers had slightly improved accuracy with RMSE = 0.755.

LAI RMSEs observed in Fernandes et al. 2003 using SPOT VGT data were 15% of LAI+ 0.68 for the low vegetation (grassland) class, 0.44+15% for the high biomass crop class and 0.78+15% for low biomass crop class.

Users of this product for local rather than regional LAI trends should consider uncertainties over in situ plots reported in Figures 4 and 5 as well as conduct local in situ measurements.

Appendix I: Digital Hemispherical Photography Manual for In-situ Measurements

Summary: A methodology for acquiring in-situ estimates of leaf area index (LAI) based on digital hemispherical photographs for a plot of approximately 1ha is presented. The method includes plot criteria and set up, camera operation within the plot, required ancillary information and post processing steps.

Plot Selection

The chief goal of plot selection is to acquire measurements in vegetated areas that satisfy the assumptions of the DHP analysis software a priori. The theory is discussed in some detail in Leblanc et al. 2005 however, for the purpose of plot selection the most important considerations are:

1. The spatial footprint corresponding to the field of view of each DHP image when it is processed by the software.
2. The assumption in the theory that the vegetation follows a statistical pattern that is stationary (not necessarily random). For example, that the area samples in a plot looks at least similar if one were to subdivide a plot in half randomly.
3. The assumption that there is sufficient sampling in at least the zenith angle around 57.5° (but preferably all angles from 60° to nadir) such that there is little likelihood of no gaps or all gaps for a given zenithal field of view.
4. The assumption that each image taken is sufficiently different from the others such that no dominant gap or vegetated patch in the plot is overemphasized.
5. The assumption that the plot does not have topography that causes shadows to be cast within the camera when it is looking upwards (e.g. cliffs).

Spatial footprint or Field of view

The DHP has a spatial field of view that corresponds to a single pixel at nadir and infinity (assuming the horizon is not blocked by the ground surface) at 180°. In most cases, only the range of zenith angles from 0 to 60° in used to estimate LAI and (Leblanc et al. 2005) the zenith angle at 57.5° may be the best single angle of all of these based on theoretical considerations.

The field of view diameter of a given zenith angle ring looking at a flat vegetation surface is:

FOV = 2*h_camera * tan(theta)

Where theta is the zenith angle and h_camera is the height of the camera above (down looking) or below (up looking) the vegetation.

For example, if taking downward looking images from of 20cm grasses from a camera at 1m height gives a FOV at 57.5° of approximately 2.5m in diameter.

Another example: taking upward pictures of a 11m canopy from a camera at 1m height has a FOV_up of ~30m at 57.5°.

The implications of this are:

1. vegetation near the camera will reduce the field of view so that more sampling is required to cover a reasonably representative area of the plot.
2. vegetation far from the camera will extend the field of view to the point it may go past the intended plot

Generally speaking these assumptions mean that a plot should be selected such that:

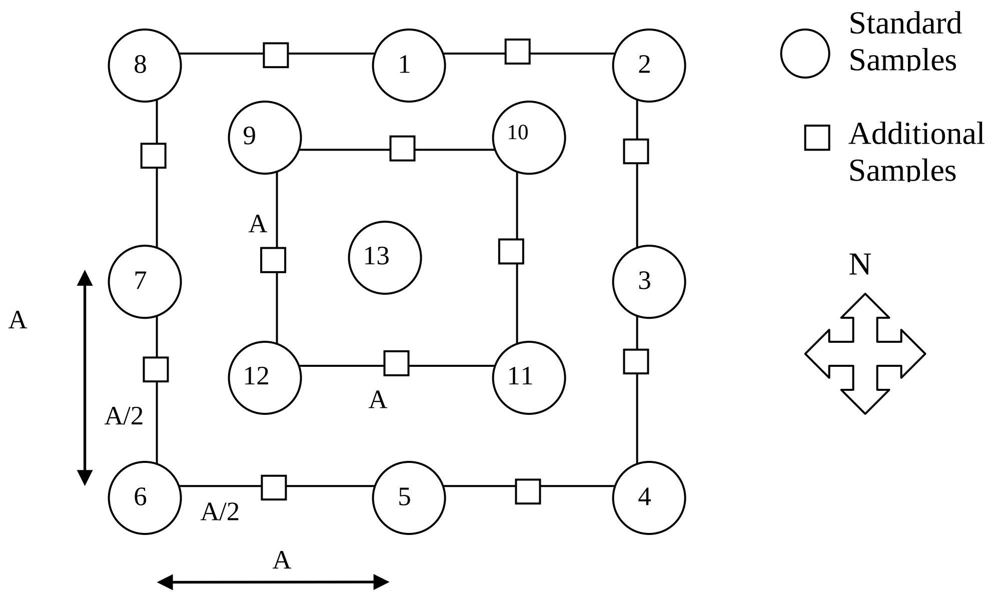
1. There is no visible boundary (e.g. clear cut edge) within a plot.
2. There should be no walls, cliffs, large trees etc. near the plot unless the plot itself has very tall trees in it.
3. The plot corresponds to at least 30m on each edge and perhaps larger if possible for very tall (>20m) trees.
4. The footprint of each DHP image falls within the plot out to 57.5 ° (at least make notes for images where this is in doubt)

VALERI Sampling Plan

Plots should be sampled using a nested rectangular grid oriented north south. Use table 1 to determine the sample spacing for best-case conditions. Of course, one could default to a smaller spacing where the plot size requirement would conflict with the needs for consistent vegetation density within a plot.

Table A1: Plot sampling requirements as a function of vegetation height.

Vegetation height	A	Sampling mode	Plot Size Required	Approximate 57.5 ° FOV Diameter
H<50cm	10m	Down, camera at 1m, additional samples	22m	2m
50cm<h<1m	10m	Up with camera placed at ground level, additional samples	22m	2m
2m<h<5m	10m	Up and down	30m	10m
5m<h<15m	10m	Up and down	50m	30m
15m<h<25m	20m	Up and down	100m	60m
25m<h<35m	20m	Up and down	130m	90m



Figures A1. CCRS VALERIE PLOT

Appendix II: In-situ LAI estimates over Nanaimo Aquifer Region.

Site Name	UTMx	UTMy	Date	Species	Elevation (m)	Final PAI	Final LAI
ARR01A1	378895.031	5458685.190	2011-07-18	Fd	420	1.79	6.43
ARR01A2	378879.215	5458706.608	2011-07-18	Fd	430	3.76	6.01
ARR02A2	378988.251	5458704.990	2011-07-18	Fd	382	4.02	6.43
ARR03A2	379003.967	5458489.395	2011-07-18	Fd	369	3.68	5.89
ARR04A1	379292.806	5458889.315	2011-07-18	Fd	311	3.42	5.48
ARR04A2	379292.806	5458889.315	2011-07-18	Fd	311	4.29	6.87
ARR05A1	379252.063	5459060.935	2011-07-18	Fd	291	3.70	5.92
ARR05A2	379252.063	5459060.935	2011-07-18	Fd	291	3.75	6.00
ARR06A1	379596.748	5456784.708	2011-07-18	Fd	309	3.44	5.51
ARR06A2	379596.748	5456784.708	2011-07-18	Fd	309	4.28	6.85
ARR07A1	379571.021	5456234.840	2011-07-18	Hw	313	3.64	5.83
ARR07A2	379571.021	5456234.840	2011-07-18	Hw	313	4.50	6.21
ARR08A2	378676.144	5457736.193	2011-07-18	Fd	225	4.47	6.17
ARW03A1	383431.290	5453191.919	2011-07-19	Bl	1400	2.02	3.23
BIGQ01A2	378039.805	5468050.032	2011-07-25	Regenerative	160	1.51	1.85
BIGQ02A2	378440.393	5468364.760	2011-07-25	Regenerative	146	3.85	4.69
BIGQ03A2	378610.224	5469243.224	2011-07-25	Regenerative	100	3.94	5.43
BIGQ04A2	379352.966	5469646.503	2011-07-25	Fd/Hw	106	2.77	4.13
BIGQ05A2	379660.320	5469901.504	2011-07-25	Fd/Hw	97	3.38	5.03
BIGQ06A2	379620.544	5470472.025	2011-07-25	Mixed/Fd	92	4.29	5.91
CAT1A2	379153.091	5460999.179	2011-07-13	Hw	208	4.91	6.77
CAT2A2	379278.531	5460941.719	2011-07-13	Fd/Cw/S	195	4.61	6.88
CAT3A2	378995.228	5461325.871	2011-07-13	Fd/Cw/S	202	3.94	5.87
CAT4A2	378940.581	5461408.504	2011-07-13	Fd/Cw/S	236	3.45	5.14
ENGPP1A2	401920.725	5455552.545	2011-07-17	Fd/Hw	164	4.12	6.13
ENGPP2A2	401942.171	5455723.330	2011-07-17	Fd/Hw	162	3.76	5.60
ENGPP3A2	401960.965	5455835.644	2011-07-17	Fd/Hw	150	4.34	6.47
ENGPP4A2	401748.402	5455856.483	2011-07-17	Fd/Hw	131	4.32	6.43
ENGPP5A2	401627.623	5455744.024	2011-07-17	Fd/Hw	156	5.31	7.33
ENGREG1	*400999.986*	*5456993.267*	2011-07-17	Cut	34	3.74	1.63
ENGREG2	407548.281	5461057.731	2011-07-17	Fd/Hw	20	4.53	6.75
ENGREGEN1A2	407604.403	5461168.513	2011-07-17	Fd/Hw	136	4.37	6.51
HILL01A2	395100.092	5463261.461	2011-07-27	Regenerative	97	3.09	3.09
HILL03A2	395252.861	5463637.163	2011-07-27	Regenerative	96	2.27	3.63
HILL04A2	394162.496	5464147.462	2011-07-28	Dr/Fd	94	3.22	5.15
HILL05A2	394706.653	5463965.904	2011-07-28	Fd/Hw	107	2.87	4.28
HILL06A2	394866.494	5463959.541	2011-07-28	Fd/Hw	109	3.20	4.77
HILL07A2	394580.669	5463941.338	2011-07-28	Fd/Hw	102	2.99	4.46
HILL08A2	394591.273	5463740.177	2011-07-28	Fd/Hw	92	3.86	5.76
HILL09A2	387120.766	5463876.843	2011-07-28	Fd/Hw	107	2.75	4.10
HORN01A2	372542.805	5467339.823	2011-07-21	Hw	150	3.05	4.88
HORN02A2	372462.533	5467077.736	2011-07-21	Fd	252	2.68	4.29
HORN03A2	372396.186	5467177.494	2011-07-21	Hw	255	3.43	5.49
LITQ010A2	387216.177	5463532.963	2011-07-28	Fd	133	3.12	5.00
LITQ011A2	387216.177	5463532.963	2011-07-28	Fd	142	2.93	4.69

LOON01A2	376107.774	5456534.355	2011-07-20	Fd	398	3.83	6.13
LQ3T3A2	387531.663	5462917.403	2011-07-12	Fd/Ra	166	3.27	4.25
LQ4T4A1	387405.872	5462765.363	2011-07-12	Fd/Ra	176	3.90	5.07
LQ5T5A1	387858.346	5463195.732	2011-07-12	Fd/Ra	143	3.85	5.01
LQRVREG1	385355.339	5464324.204	2011-07-15	Cut	140	1.24	1.99
LQRVREG2	385283.668	5464221.670	2011-07-15	Cut	148	1.17	1.88
LQRVREG3	384995.262	5464271.471	2011-07-15	Cut	156	1.11	1.78
LREG04A2	377832.272	5455799.245	2011-07-20	Fd	457	2.71	3.73
LREG05A2	377439.950	5455879.282	2011-07-20	Cw	440	0.00	
LREG06A2	376826.576	5456305.494	2011-07-20	Fd	406	0.00	
MILN01A2	397430.761	5467876.971	2011-07-27	Fd/Hw	38	4.14	6.17
MILN02A2	397455.348	5468044.591	2011-07-27	Fd/Hw	29	3.91	5.83
MILN03A2	397382.524	5468311.784	2011-07-27	Broadleaf Mix	23	3.45	4.58
MILN04A2	397207.776	5468088.852	2011-07-27	Fd/Hw	31	4.01	5.97
MILN05A2	397213.676	5467900.173	2011-07-27	Fd/H	42	3.40	5.07
OLD01A2	373307.696	5458783.379	2011-07-21	Fd	217	3.70	5.92
OLD02A2	373301.205	5458835.828	2011-07-21	Fd	224	3.75	6.00
OLD03A2	372234.612	5459387.021	2011-07-21	Fd	121	3.92	6.28
OLD04A2	372086.089	5459592.719	2011-07-21	Fd	112	3.29	5.26
OLD05A2	371797.138	5459815.222	2011-07-21	Fd	103	3.57	5.71
PASS01A2	383532.578	5457704.881	2011-07-22	Fd	1012	2.29	3.67
PASS02A2	383266.154	5457855.902	2011-07-22	Bl	1043	0.54	0.75
PASS03A2	382922.168	5457752.749	2011-07-22	cut	1039	2.61	3.47
PASS04A2	381983.835	5457995.308	2011-07-22	Bl	1073	2.21	3.05
PASS05A2	382562.741	5455748.136	2011-07-22	Hw	1110	2.41	3.32
PASS06A2	382601.278	5455716.123	2011-07-22	Hw	1122	2.94	4.06
RATH01A2	407957.737	5464295.925	2011-07-26	Fd/Hw	6	2.80	4.17
RATH02A2	407392.212	5464582.297	2011-07-26	Fd/Hw	5	3.34	4.97
RATH03A2	407354.310	5464243.182	2011-07-26	Fd/Hw	5	4.12	6.15
RATH04A2	407582.613	5463981.331	2011-07-26	Fd/Hw	3	2.01	3.00
RATH05A2	407566.236	5463919.858	2011-07-26	Fd/Hw	5	3.78	5.63
RATH06A2	407880.154	5463762.777	2011-07-26	Fd/Hw	5	4.11	6.12
WES10A2	383910.545	5462148.666	2011-07-14	Fd/Hw/Ra	671	2.59	3.43
WES11A2	383763.665	5462065.387	2011-07-14	Fd/Hw/Ra	674	3.91	5.18
WES12A2	383488.517	5462107.198	2011-07-14	Fd/Hw/Ra	677	3.28	4.35
WES13A2	383232.913	5462142.233	2011-07-14	Fd/Hw/Ra	662	2.90	3.84
WES14A2	382986.340	5462182.773	2011-07-14	Fd/Hw/Ra	647	3.56	4.72
WES1A1	385091.005	5461158.245	2011-07-14	Fd/Hw/Ra	317	2.63	3.48
WES2A2	385046.232	5461226.094	2011-07-14	Fd/Hw/Ra	359	0.81	1.07
WES3A2	385074.470	5461346.845	2011-07-14	Fd/Hw/Ra	443	2.39	3.16
WES4A2	385028.663	5461423.114	2011-07-14	Fd/Hw/Ra	468	3.10	4.11
WES5A2	384876.496	5461588.276	2011-07-14	Fd/Hw/Ra	509	3.62	4.80
WES6A2	384658.604	5461700.998	2011-07-14	Fd/Hw/Ra	543	4.10	5.44
WES7A2	384442.966	5461916.744	2011-07-14	Fd/Hw/Ra	600	2.74	3.64
WES8A2	384508.495	5462073.334	2011-07-14	Fd/Hw/Ra	587	3.41	4.52
WES9A2	384234.139	5462098.490	2011-07-14	Fd/Hw/Ra	655	3.31	4.40
WIN01A2	394523.919	5459008.818	2011-07-23	Fd	147	3.54	5.67
WIN02A2	394411.365	5458834.892	2011-07-23	Fd	147	3.19	5.11

WIN03A2	394329.052	5458942.129	2011-07-23	Mb	144	4.34	4.34
WIN04A2	393095.640	5459464.624	2011-07-23	Hw	167	3.68	5.89
WIN05A1	393098.515	5459687.142	2011-07-23	Fd	158	3.67	5.87

Appendix III: In-situ LAI estimates over Nanaimo Aquifer Region.

Species		Tree Code	Needle-Shoot Area Ratio
Western red cedar	*Thuja plicata*	Cw	1
Douglas-fir	*P. menziesii*	Fd	1.6
Subalpine fir	*A. lasiocarpa*	Bl	1.38
Western hemlock	*T. heterophylla*	Hw	1.38
Arbutus	*Arbutus menziesii*	Ra	1.38
Bigleaf maple	*A. macrophyllum*	Mb	1
Spruce	*Picea*	S	1.6
Red alder	*A. rubra*	Dr	1

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