City of Victoria

Vegetation Canopy Change Detection Analysis 2013-2019

Phase 02 Project

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Submitted to:
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terra remote sensing

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Above Ground Vegetation and Plantable Area Assessment Using Multiple LiDAR Datasets, 2013 – 2019

Terra Remote Sensing, August 31, 2020

EXECUTIVE SUMMARY

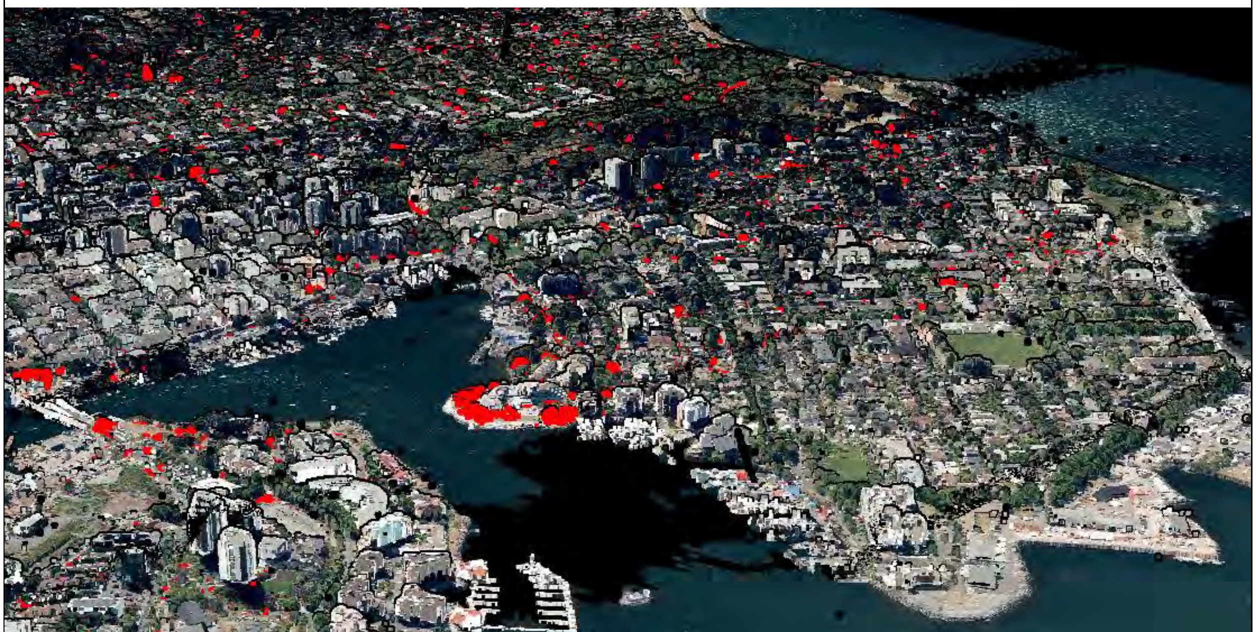
In 2019 and 2020, Terra Remote Sensing (Terra) compared three LiDAR datasets collected over the City of Victoria with the goal of quantifying changes in above ground vegetation in the city. The first LiDAR dataset is from 2007, the second dataset from 2013 and the third from 2019. The goal of the study was to quantify the change in vegetation area and volume between the two datasets over each interval period (2007-2013 and 2013-2019). Change was observed and characterized by comparing the measured area of vegetation coverage by subtracting the two different years and by using image (raster) processing techniques to detect vegetation object removal as well as the introduction of new vegetation objects.

The overall project was undertaken in two phases. The first phase of the project had the goal of assessing change between 2007 and 2013, as the 2019 dataset was not yet available at the time of the first study, and there was good value in assessing a baseline year for ongoing change detection work. A finding in Phase 01 was, due to the sampling differences between the 2007 and 2013 LiDAR datasets, meaningful comparisons were difficult to make as uncertainties existed around the accuracy of using a 1m pixel size for both years of data. Therefore, it was concluded that 2013 would serve as the most reliable baseline dataset to use going forward. One encouraging aspect of this report is that the measured change between 2013 to 2019 were similar to what was observed between 2007 to 2013. It should also be noted that a comparison of the Habitat Acquisition Trust (HAT) analysis was not undertaken in the second project phase and therefore has not been referenced in this report.

Between 2013 and 2019 there was an 8.97% increase of above ground vegetation area (2.37% net increase of city area coverage, *table 2*) and a net increase of 17% in vegetation volume (*table 4*). Consistent with the findings of the Phase 01 report, the horizontal growth of existing vegetation offsets the effect of vegetation loss from urban development or die off. Vegetation gain from new plantings was present in several locations, which did not represent a significant contribution to vegetation fill in between 2013-2019.

This Phase 02 Project Report summarizes the datasets used, the methodology used to determine the area and volume of vegetation, results in terms of area and volume of vegetation change, as well as identifying areas of potential vegetation planting to increase the urban vegetation cover of the city.

Figure 1



Oblique view of 2019 City of Victoria LiDAR Data. LiDAR data has been colorized with color from orthophotos. Areas of vegetation loss between2013 and 2019 LiDAR data are identified in red.

INTRODUCTION

The City of Victoria's Urban Forest Master Plan (UFMP) was approved by Council in 2013, following extensive consultation with community members, staff and industry experts. The plan provides guidance on the long-term management and enhancement of the urban forest, with 26 recommendations relating to trees on public and private lands to be completed over the next few decades. At present, the City has direct control over roughly one-third (33,000ha) of the urban forest inventory. The other two-thirds consists of trees on private land. The City's overall tree canopy coverage when last measured from 2013 LiDAR data was assessed to be 26% (Phase 01 Project, 2019 Terra Remote Sensing).

The City's plan for the results provided in this report, as well as the associated data deliverables, is to:

- Establish an accurate baseline assessment of tree canopy and impervious surface across the entire City from which to benchmark changes over time
- Assess above ground vegetation cover across the entire City
- Identify areas of the City with significant changes in tree canopy
- Establish a robust program to assess tree canopy and impervious surface change on an ongoing and regular basis
- Inform the City's management of the urban forest

This report is the second phase of the overall project that was completed for the City of Victoria. The first project phase compared LiDAR data from 2007 and 2013, which had highly different LiDAR densities due to sensor advancements during that period of time. The 2007 dataset was not dense enough to support a 1m pixel size for vegetation cover, so various techniques (which were not required for this report) were employed in order to investigate changes to vegetation between the 2007 and 2013 datasets as the 2019 LiDAR data was not available at the time of the first phase of the project. The focus of this Phase 02 project was to assess the change in vegetation between 2013 and 2019, as well as detect plantable areas to further add to the city's vegetation coverage. The results from the Phase 02 project provide confidence to the results reached in the Phase 01 project as the increases and loss of vegetation is relatively similar between the three datasets covering 2007 – 2019.

DESCRIPTION OF LIDAR DATASETS

LiDAR is an active remote sensing technology that emits laser pulses at a high sampling rate (current sensors sample up to 2 million pulses/second) and measures the range to target from the sensor of the returned laser pulses based on the speed of light. Based on range to target, the 3D position, time, and orientation of the sensor, the 3D position of each laser return can be determined and contribute to a "point cloud" representing objects scanned by the sensor. Each of these points are georeferenced and generally accurate within 20cm of the object's real-world position. In 2007, 2013, and 2019, LiDAR sensors were deployed on aircraft and flown over the City of Victoria by different vendors and for different purposes.

The 2007 LiDAR dataset was initially flown with the purpose of geologic fault mapping and was collected at an average pulse spacing of 1 pulse/m². The 2013 LiDAR dataset was flown with urban inventory in mind, at a higher pulse density of 10 pulses/m², and the 2019 LiDAR dataset was flown under the National Disaster Mitigation Program (NDMP) for sea level rise and tsunami studies around the circumference of Vancouver Island with a targeted pulse density of 8 pulses/m². All LiDAR datasets were classified into ground, vegetation ≥2m from ground elevation, buildings, and a 'catch all' non-vegetation class, which includes distribution wires, signs, traffic lights, and other above ground features that are not vegetation or buildings. Vegetation ≥2m above ground elevation was only considered in this analysis, which allowed low 'clutter' to be ignored as potentially false vegetation. Objects under 2m in height from ground elevation such as mail boxes, cars, umbrellas, trampolines, barbeques, etc. are difficult and time consuming to accurately distinguish from vegetation in the same height class. Distribution lines, lamp standards, high trucks, shipping containers etc. were removed from the ≥2m vegetation class through manual classification methods in order to achieve a high level of classification accuracy of a 'clean' vegetation class.

Following the LiDAR data classification, a quality control (QC) process that involved reviewing the classified points overlaid on orthophotos was conducted to ensure significant vegetation wasn't missing from vegetation class, or significant non-vegetation features were included in the vegetation class. After the LiDAR classification QC, the LiDAR vegetation class was rasterized (vector to image process), and each year was compared using the three methods to summarize different aspects of change (gain and loss of vegetation area, and change in volume). In order to test the quality of the data classification, 154 random points were placed on vegetation, solely identified using the 2019 CRD orthophotos, and then these points were overlaid on the vegetation raster image created from the classified LiDAR and assessed if the LiDAR was classified as vegetation. The assessment passed at 98.7%. These validation points were provided to the City as part of the project deliverables, and the tabulated results have been included in Appendix A of this report.

The 2013 and 2019 datasets were rasterized at 1m grid size, which was used to determine the area of 2013 and 2019 above ground vegetation cover. As an initial measure of change, the area of vegetation between two datasets was measured and summarized (Table 1). These numbers do not provide a measure of how much vegetation has been lost or gained, rather are the total area of the classified vegetation cover for each year's dataset.

In order to gain a better idea of where the changes have occurred the datasets were compared to assess loss and gain areas. It can be asserted that horizontal vegetation growth between 2013-2019 again offset the effect of vegetation removal, as was the case between 2007-2013. An imbalance between large observable bodies of vegetation added and removed is observed once the effect of horizontal growth is removed.

Vegetation Area Calculation

Table 1

Year	2m+ Vegetation Area (ha)	% of City Area	Comment
2007	**512**	**26.41%**	Measured at 2m cell size
2013	**513**	**26.46%**	Measured at 1m cell size
2019	**559**	**28.83%**	Measured at 1m cell size

Vegetation Area Change Calculation

Table 2

Description	Area (ha)	% of City-Wide Vegetation Area	Comment
Vegetation Added between 2007-2013	**+53.4**	**+10.43%**	Based on 2007 vegetation area of 512ha
Vegetation Loss Between 2007-2013	**-52.38**	**-10.23%**	Based on 2007 vegetation area of 512ha
Vegetation Added between 2013-2019	**+113.10**	**+22.14%**	Based on 2013 vegetation area of 513ha
Vegetation Loss Between 2013-2019	**-65.70**	**-12.81%**	Based on 2013 vegetation area of 513ha
Net Vegetation Area Change 2007-2013	**+0.19%**		Based on the city area of 1,939 ha
Net Vegetation Area Change 2013-2019	**+2.37%**		Based on the city area of 1,939 ha

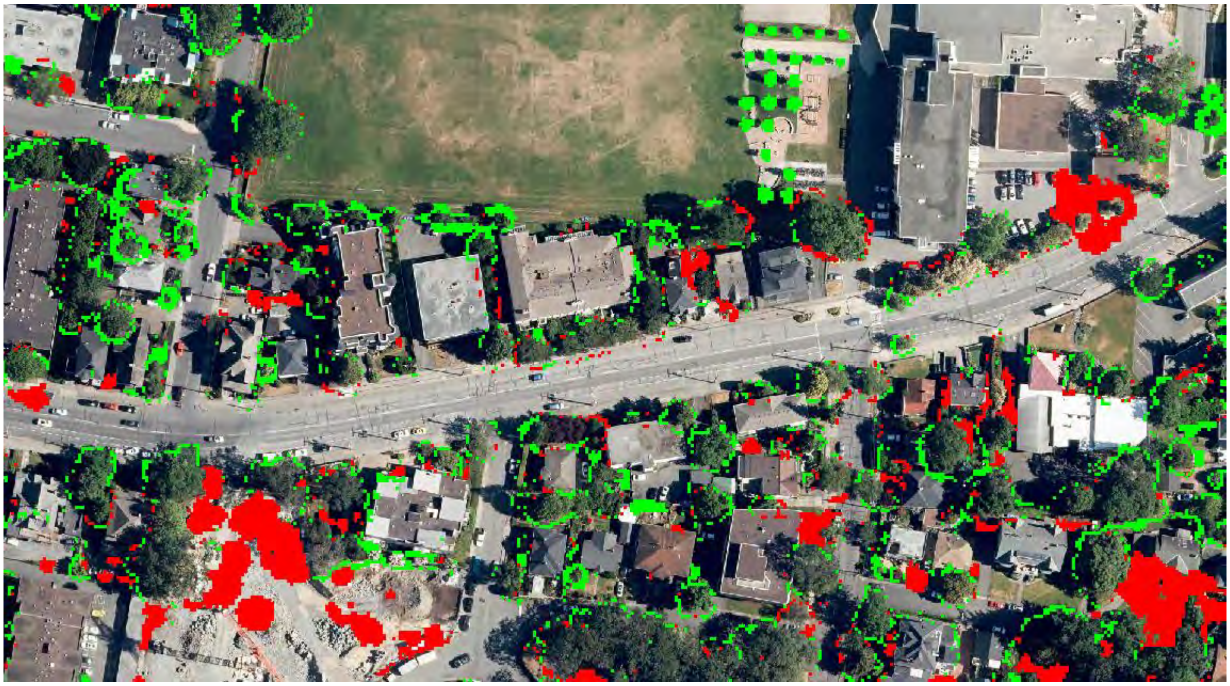
Vegetation area coverage was also broken down by neighborhood areas (table 3).

Table 3

Neighbourhood	Vegetation Cover 2013 (ha)	Vegetation Cover 2019 (ha)	% change from 2013-2019
Burnside	31.24	34.48	10.37%
Downtown	5.76	7.13	23.78%
Fairfield	87.78	92.06	4.88%
Fernwood	51.40	55.92	8.79%
Gonzales	50.28	53.27	5.95%
Harris Green	3.91	4.16	6.39%
Hillside Quadra	50.45	57.15	13.28%
James Bay	55.19	62.88	13.93%
North Jubilee	17.11	18.90	10.46%
North Park	10.58	11.56	9.26%
Oaklands	49.29	53.82	9.19%
Rockland	57.49	60.02	4.40%
South Jubilee	9.87	10.68	8.21%
Victoria West	30.49	36.22	18.79%
Total	**510.82**	**558.24**	**9.28%**

Figure 2

Vegetation gain (green) and vegetation loss (red) around Peter Pollen Park (2013-2019)

Figure 3

New vegetation plantings at Central High School to the North of Fort Street, and losses at Bellewood Park development
Figure 4

New vegetation on the corner of Douglas and Courtney Street, and tree loss at Government and Humboldt streets' scramble cross walk.

Vegetation Volume Calculation and Change

An additional benefit of using LiDAR data is that vegetation change can be measured in the vertical dimension as well as the horizontal. As with the horizontal area measurements, it is possible to compare the differences between years. By subtracting the two gridded vegetation layers where they overlap (using a 1m grid size for each dataset), a net vegetation volume *gain* of 6,569,487m^3 is observed between 2013 and 2019. The gain represents 2.85% per year of increased vegetation volume (which is consistent with the results observed between 2007-2013). This increase in volume is consistent with generalized canopy growth rates in the Pacific Northwest, which ranges widely based on a number of factors. Further discussion of canopy growth is presented in the conclusion.

It should be noted that the volume discussed in this study is not representative of actual biomass. The volumes presented are based on a 3D surface above the ground and is not indicative of the actual vegetation volume (tree branches, understory etc.) that exists between the modeled vegetation surface and ground level. The volume is representative of the space from the top of the vegetation canopy to the ground surface.

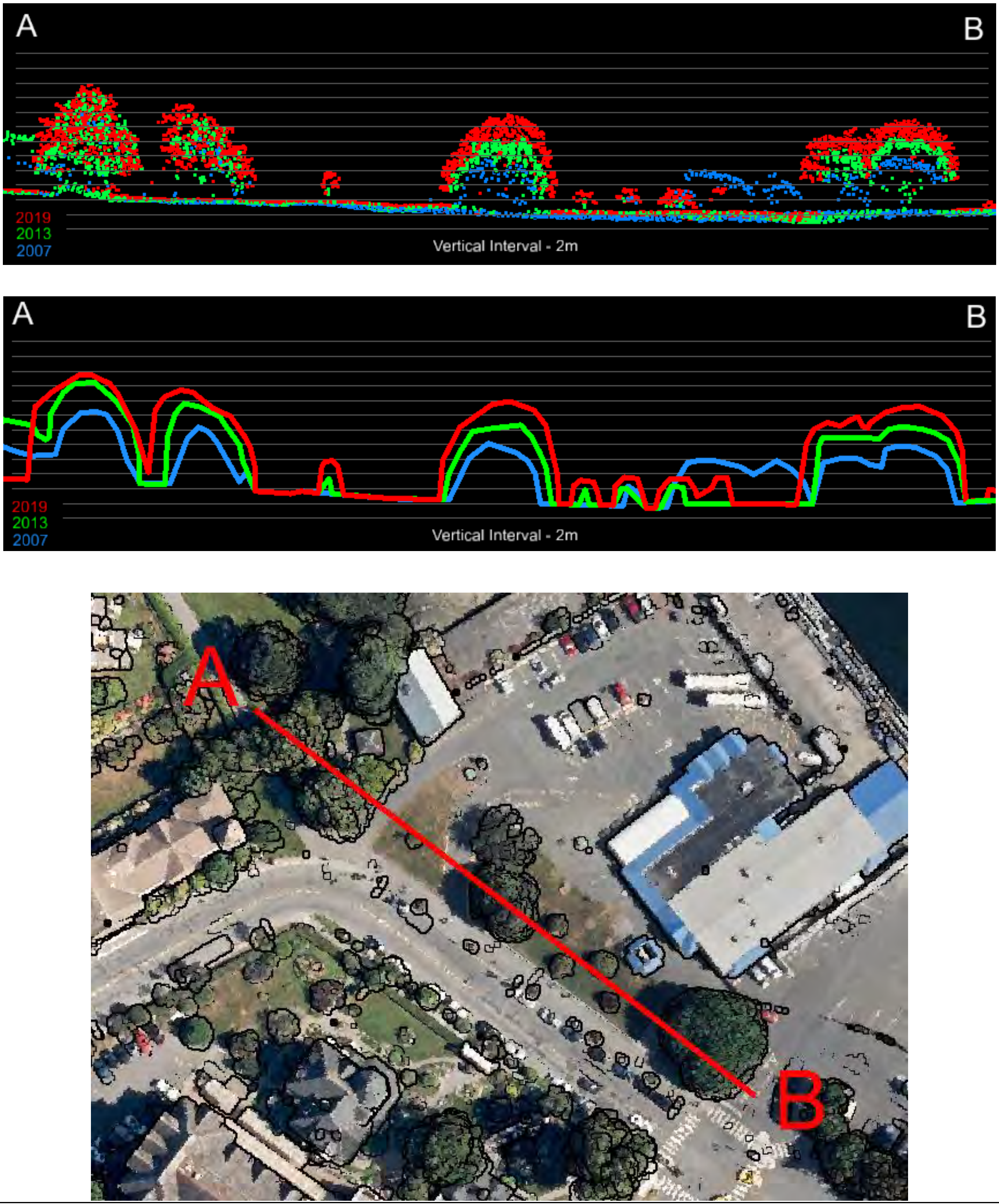
Table 4

Description	Vegetation Volume (m^3)	Comments
Vegetation Canopy - 2007	**32,815,587**	Measured on a 2m grid.
Vegetation Canopy - 2013	**38,412,445**	Measured on a 1m grid.
Vegetation Canopy - 2019	**44,981,932**	Measured on a 1m grid.
Vegetation Volume Change between 2013-2019	**+17%**	17% net increase in vegetation volume from 2013 to 2019.

Figure 5

Sample area showing vertical vegetation change between 2013 - 2019, Beacon Hill Park.

Figure 6



Sample 2m cross section profile(s) and plan view showing transect of the LiDAR cross section images showing vertical vegetation change between 2007 - 2019, near the Clipper Terminal Building. Blue points in top images are 2007 LiDAR data, Green points are 2013 LiDAR data, and Red points are 2019 LiDAR. Middle image shows profile of Digital Surface Model (DSM) comparing 2007 (blue) with 2013 (green) and 2019 (red).

PLANTABLE AREAS FROM 2019 LIDAR DATASET

Following the classification of the vegetation in the 2019 LiDAR dataset, areas for hypothetical vegetation planting were identified using a combination of LiDAR and orthophoto in the City of Victoria. Plantable areas were assumed to be flat, contiguous areas consisting of an unpaved surface (mostly grass in various states).

Figure 7

Plantable areas shown in light green with the colorized 2019 LiDAR overlaid.

The process of classifying the plantable areas are described below and the results are provided in table 5 on the following page.

- LiDAR point cloud was colorized by coincident orthophotos.
- A support vector machine (a supervised machine learning technique) was used to distinguish impermeable from permeable, plantable surfaces directly on the LiDAR point cloud.
- The classified surfaces were rasterized, and image processing techniques were employed to erase small edges and dangles from the classification.
- Road right-of-ways were masked out using a roads dataset supplied by the City of Victoria.
- The classification was finally polygonised, and areas less than $50m^2$ were removed.

Table 5			
Neighbourhood	**Plantable Area 2013 (ha)**	**Plantable Area 2019 (ha)**	**% change from 2013-2019**
Burnside	6.62	10.88	64%
Downtown	0.99	0.84	-15%
Fairfield	25.33	29.81	18%
Fernwood	9.75	14.86	52%
Gonzales	9.73	15.90	63%
Harris Green	0.48	0.38	-21%
Hillside Quadra	14.82	18.96	28%
James Bay	25.82	30.81	19%
North Jubilee	2.28	3.92	72%
North Park	3.81	4.62	21%
Oaklands	9.73	16.26	67%
Rockland	8.71	11.17	28%
South Jubilee	1.42	2.21	56%
Victoria West	12.02	19.08	59%
Total	**131.52**	**179.70**	**37%**

It should be noted that these numbers do not take into account plantable areas that would likely be unsuited to tree planting due to competing land uses such as recreation sports fields, underground or above ground utilities corridors, or other aspects such as security or general aesthetics. The 50m² minimum size was arbitrarily selected to minimize the number of small invalid sliver areas, as well as to account for the size of a mature tree canopy. Plantable areas would also be highly subject to varying levels of quality based on their adjacent environment such as spacing from adjacent vegetation, adjacent buildings, slope, aspect and soil conditions, which are not in the scope of this study.

Based on the total plantable area, it appears that the vegetation loss observed from 2013 – 2019 of 65.70 ha, could be compensated by new plantings. The maximum potential canopy coverage across the entire City for 2019 is assessed at 38% (based on the total vegetation area coverage and plantable areas, which include the planting of sports fields and other potential areas that are likely unfeasible for planting significant vegetation).

Comparing plantable areas between years is subject to inaccuracies as the process relies on supervised classification from a combination of LiDAR point cloud heights and color, derived from the orthophotos. Differences such as green paint on impermeable surfaces, and shadows, especially due to differing light and time conditions between the different years, make yearly comparisons of plantable areas subject to a greater deal of variability than the comparisons from LiDAR data. A detailed description of the challenges / errors associated with using orthophotos for change detection were described in the phase 01 report.

CONCLUSION

The results from the Phase 02 project (2013-2019) generally supported the overall trends of vegetation gain/loss, area and volume change, as well as plantable areas, which were observed in the Phase 01 Project (2007-2013). Assessing the accuracy of either dataset with actual measurements on the position and height of above ground vegetation is not possible without having field verifications conducted at or near the time of each survey. However, the inherent accuracy of LiDAR data, in terms of being able to measure spatial objects above ground surface, lends a high degree of confidence in the measurement of the position and height of vegetation. Additionally, as previously mentioned the LiDAR classification accuracy was assessed at 98.7% (see appendix A).

Assessing whether the horizontal and vertical vegetation growth detected in this study is on 'trend' with what is 'normal' is a complex question. Victoria, BC, is situated in the Pacific Northwest (PNW), a broad geographic region whose nominal boundaries are the Pacific Ocean to the West and the Rocky Mountains to the East. Due to its geographic extension and diversity, the PNW is home to many different types of forests, in particular the costal temperate rainforest, subalpine and montane forest. The predominant species in the coastal temperate rainforest are Douglas-fir, Western redcedar and Western hemlock. There are a number of factors affecting the growth of natural forests, which can be summarized in site conditions, age class, climatic conditions, and forest disturbances. Landscapes and ecosystems are dynamic both in space and time, therefore it is very difficult to obtain reliable data about yearly growth that can be generalized to a small region, especially an urban area where there are abundant non-native species of trees, site-specific pollution, areas of intense irrigation and vegetation management, and areas of unnatural shade from buildings. Coniferous trees typical of the coastal PNW region also have growth rate that vary according to age. In ideal conditions, seedlings and young Douglas-fir and Western redcedar can grow at 2 to 4 inches per year, while at the age of 8 to 10 years, the growth rate can be close to 2-3 feet/year. Climate change is expected to be a primary driver in change of structure and composition of plant species.

Vegetation across an urban environment plays an important role by providing many ecosystem services, so gaining an understanding of the asset in terms of how much exists, where, and how it changes over time, is extremely valuable. Based on both phases of the project, multi-temporal LiDAR data represents an important tool that can help facilitate informed policy and management decisions regarding the City's vegetation assets. The results of the comparison between the 2013 and 2019 LiDAR datasets verify the trends of vegetation growth identified in the Phase 01 Project Report, which lends credibility to the potential of using 2007 values for additional context of a legitimate baseline dataset. As the three datasets (2007, 2013 and 2019) span approximately 12 years, the actual time of vegetation removal or new plantings can't be determined. It will be of importance to monitor the continual changes in the city's vegetation canopy to assess whether the fill in growth of existing and new plantings will continue to outstrip the vegetation loss. Further to on-going monitoring, determining age class, distribution, and species composition will help to forecast vegetation growth trends and potentially predict when vegetation growth will cease to offset losses.

APPENDIX A – CLASSIFICATION ACCURACY ASSESSMENT

Easting	Northing	Vegetation Point ID	Test Result
473122	5365823	0	Pass
473174.4	5365804	1	Pass
472957.7	5366085	2	Pass
472872.8	5366006	3	Pass
472828.2	5366069	4	Pass
473142.6	5366078	5	Pass
473314.8	5366159	6	Pass
473267.6	5366196	7	Pass
473425.9	5366164	8	Pass
474080.2	5365368	9	Pass
474039.3	5365402	10	Pass
473913.7	5365374	11	Pass
474313.1	5365374	12	Pass
474298.6	5365282	13	Pass
474519.6	5365435	14	Pass
474425.7	5365471	15	Pass
474586	5365450	16	Pass
475057.9	5364939	17	Pass
475180.8	5364908	18	Pass
475181	5364866	19	Pass
475116.8	5364835	20	Pass
475057.5	5364876	21	Pass
475037.2	5364825	22	Pass
475057.3	5364815	23	Pass
474752.4	5364843	24	Pass
474778.8	5364900	25	Pass
474670.1	5364827	26	Pass
474633.4	5364746	27	Pass
474478.8	5364764	28	Pass
474481.2	5364792	29	Pass
474582.7	5364630	30	Pass
474877.1	5364644	31	Pass
474951.3	5364642	32	Pass
475039.4	5364682	33	Pass
475038.2	5364650	34	Pass
475208.8	5364611	35	Pass
475248.2	5365582	36	Pass
475148.1	5365541	37	Pass
475377.4	5365487	38	Pass
475330.9	5365468	39	Pass
474736.9	5365539	40	Pass
475619.8	5364154	41	Pass

475627.8	5364145	42	Pass
475558.8	5364102	43	Pass
475763.8	5364110	44	Pass
475739.1	5364115	45	Pass
475763	5364093	46	Pass
475677.8	5364117	47	Pass
475686	5364157	48	Pass
475756.3	5364249	49	Pass
475694.2	5364223	50	Pass
475854	5363684	51	Pass
475829.1	5363761	52	Pass
476003.3	5363740	53	Pass
475968.2	5363615	54	Pass
475794.1	5363620	55	Pass
475656.9	5363596	56	Pass
475684	5363584	57	Pass
474762.6	5363760	58	Pass
474691.1	5363824	59	Pass
474622.2	5363798	60	Pass
474641.1	5363720	61	Pass
474954.8	5363784	62	Pass
474534	5363637	63	Pass
474428.5	5363636	64	Pass
474375.5	5363694	65	Pass
474312.7	5363658	66	Pass
474289.4	5363663	67	Pass
473889.2	5364266	68	Pass
473810.6	5364369	69	Pass
473921.5	5364341	70	Pass
473925	5364293	71	Pass
473546.4	5364477	72	Pass
473567.4	5364412	73	Pass
473519.4	5364490	74	Pass
473504.5	5364396	75	Pass
473426.2	5364405	76	Pass
473407.9	5364407	77	Pass
473447.4	5364238	78	Pass
473402.9	5364244	79	Pass
473486.7	5364231	80	Pass
473535.1	5364130	81	Pass
473445.6	5364096	82	Pass
473905	5363824	83	Pass
473767.6	5363826	84	Pass

473703.3	5363846	85	Pass
473905.3	5363787	86	Pass
473728.9	5363720	87	Pass
473770	5363713	88	Pass
473794.5	5363709	89	Pass
473737.4	5363735	90	Pass
473850.3	5363624	91	Pass
473841.6	5363566	92	Pass
473882.4	5363591	93	Pass
473929	5363604	94	Pass
473485.5	5363659	95	Pass
473400.7	5363674	96	Pass
473426.3	5363661	97	Pass
473366.6	5363676	98	Pass
473260.4	5363716	99	Pass
473030.5	5363733	100	Pass
473108	5363643	101	Pass
473207.8	5363601	102	Pass
473184.6	5363605	103	Pass
473173.5	5363544	104	Pass
473029	5363545	105	Pass
472964.2	5363457	106	Pass
472954.1	5363398	107	Pass
472817.8	5363330	108	Pass
472645.3	5363394	109	Pass
472667.8	5363135	110	Pass
472571.1	5363078	111	Pass
472576.5	5363123	112	Pass
472690.3	5363001	113	Pass
472673	5362970	114	Pass
472615.9	5362864	115	Pass
472547.8	5362894	116	Pass
472648.2	5362912	117	Pass
472430.2	5362850	118	Pass
472452.8	5362876	119	Fail
472406.5	5362771	120	Pass
472316.3	5362651	121	Pass
472573.3	5362705	122	Pass
472636.3	5362555	123	Pass
472581.9	5362553	124	Pass
472702.7	5362527	125	Pass
472586.8	5362478	126	Pass
472731.9	5362439	127	Fail

472523.1	5362407	128	Pass
472517.7	5362390	129	Pass
474785	5361996	130	Pass
474770.8	5362073	131	Pass
474745.5	5362118	132	Pass
474987.6	5362059	133	Pass
474603.9	5361898	134	Pass
474594.2	5362031	135	Pass
475043.8	5361987	136	Pass
475106	5362001	137	Pass
475106	5362024	138	Pass
475453.4	5361916	139	Pass
475454.1	5361962	140	Pass
475537.8	5361838	141	Pass
475452.1	5361820	142	Pass
475378.6	5361822	143	Pass
475101.8	5361923	144	Pass
475419.7	5362118	145	Pass
475527.8	5362168	146	Pass
475528.2	5362204	147	Pass
475645.3	5362271	148	Pass
475512.2	5362273	149	Pass
475657	5362335	150	Pass
475634	5362336	151	Pass
475057.3	5363624	152	Pass
474985.4	5363587	153	Pass
Test Result		**152/154 Passed**	**98.7%**