CAPITAL REGIONAL DISTRICT
URBAN LAND COVER CLASSIFICATION
2017/2019
SUMMARY REPORT

Submitted to:

Jennifer Tyler
Capital Regional District
Environmental Protection
625 Fisgard Street, PO Box 1000
Victoria, B.C., V8W 1R7

Submitted by:

Caslys Consulting Ltd.
Unit 10 – 6782 Veyaness Road
Saanichton, B.C., V8M 2C2

Contact: **Luanne Richardson**
Tel: (250) 652-9268; Fax: (250) 652-9269
Email: lrichardson@caslys.ca

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1.0 EXECUTIVE SUMMARY

Periodic mapping of land cover provides current data to support various planning and policy decisions for local and regional governments and also supports the on-going monitoring of landscape changes for tree cover and impervious surfaces. This report outlines the methods and results of the most recent updates to land cover mapping and change trends for portions of the Capital Regional District (CRD). The most significant objectives of this current work include:

- Mapping land cover and updating tree canopy and impervious surface trends with orthophotos that were predominantly acquired in the summer of 2019 for areas that had previously been mapped using 2011 imagery.
- Leveraging LiDAR terrain and point cloud data to enhance the classification in the following ways:
  - Mapping of a larger study area that includes Salt Spring Island and the southern Gulf Islands (using 2017 orthophotos);
  - Increasing the number of classes mapped to separate out features such as deciduous and coniferous trees as well as a unique shrub and small tree class;
  - Increase the precision and accuracy of land cover map results;
  - Develop a Canopy Height Model (CHM) that provides insight into building and vegetation heights; and
  - Improve upon riparian area mapping with better terrain model inputs.
- Modeling tree planting potential to assist in planning future tree planting initiatives.

Study Area

To achieve the above objectives, areas that were previously mapped have been updated with consistent mapping methods that do not use the available LiDAR. This was particularly important for quantifying changes over time. The LiDAR enhanced methods were developed and implemented as a second set of map products that cover the Core Municipal Area, combined with Salt Spring Island, the southern Gulf Islands, the areas near Port Renfrew and a series of smaller islands that had not been mapped previously such as the Trial Islands, Chatham Islands and Discovery Island.

Tabular Reporting

The results of mapping have been tabulated using two separate methods (as completed in past years) to support decision-making and operational efforts that are guided by these datasets. First, areas are tabulated based on the precise 1 m^2 pixels that have been mapped and summarized across reporting areas for municipalities, First Nation lands, parks, and watersheds. These table summaries are reported across each of the unique land cover classes and also aggregated to form major land cover classes that may be more easily applied to certain decisions. Reporting is also summarized for tree canopy cover types and again for impervious surface classes to apply directly to the operational efforts such as storm water management.

In addition, the second approach to tabular reporting involves the generalization of areas per hectare across the study area. Both the tree canopy and imperious cover types are reported using this method, which down-samples some of the precision and mapping errors to provide a clear picture of change trends for canopy cover and impervious surfaces. Through this approach, the proportion of tree canopy, and separately the proportion of impervious cover types, are calculated for the same hectare grid cells that we mapped previously. This provides insight into more significant changes on the landscape and is not hindered by fine-scale details or small inconsistencies in mapping approaches that result from variability in data sources between years.

Overview of Methods

To support the tabular reporting described above, the same orthophoto classification methods applied in past years were re-applied for areas that had been mapped in 2011. The following additional techniques were applied to leverage the value of LiDAR and other technologies that can improve mapping precision or accuracy.

- Use of the Digital Elevation Model (DEM) that was derived from the LiDAR supplied by the Province to better model the ground surface with much more detail than was previously available. This surface was applied to modeling the terrain as it influences surface water and the potential for riparian habitat.
- Use of the LiDAR point cloud dataset to create a pair of Canopy Height Models (CHM) that contain the heights of features relative to the ground. The first CHM includes all vegetation and built features such as buildings, bridges, large signs, vehicles, and industrial equipment. This canopy height model provided the height details to very accurately isolate taller trees from lower trees and shrubs, and also separate even lower vegetation types such as grass. A second CHM is refined from the land cover datasets to only include the heights of tree and shrub features. Either of these CHM files can be used to refine the tree and shrub class breaks using a different set of height thresholds. The current thresholds that define the shrub and small trees class include heights between 0.5 and 3 metres above ground elevation.
- The LiDAR point cloud was also used to model the location of each individual tree stem and assign a series of tree metrics that include dimensions and the separation of deciduous and coniferous species. This dataset could act as an important initial input towards an urban forest inventory database.
- Multi-date Satellite imagery was used for two purposes to improve upon the separation of certain land cover classes. Although coarse in terms of pixel resolution, multi-date imagery provides insight into ground covers that change seasonally (in the case of agricultural areas) or those that were once treed but are now cleared or developed.
    - Areas where vegetation appeared to be removed since 1984 were used to limit the classification of bedrock and move those pixels into the more likely classes of bare ground, gravel or pavement; and
    - Areas with agricultural land where the bare ground was evident in the satellite imagery over the past few years was applied to help assign pixels into the agricultural land cover class instead of grass, herbaceous or shrub classes.
- When mapping with LiDAR, a classification algorithm is required that leverages both the spectral characteristics of the orthophotos and the various details that are contained within the LiDAR. Although an unsupervised classification was used in previous years for the mapping approach, a Random Forest supervised classification technique was applied for the LiDAR enhanced mapping. The Random Forest algorithm required the delineation of training sites for each land cover class and iterations of classification analysis are then run to best fit each location into the most appropriate class. Additional masks were then applied to constrain or separate further classes. The following example illustrates how masks are used to enhance classification results: The road linework available from the Province was used to create a binary image where roads exist or do not exist; this binary mask is then used as an overlay on the land cover map to force paved or gravel classes into

the road class. Similar masks were used to assign areas into the agricultural class, based on the use of parcel zoning information or to separate shoreline bedrock from upland bedrock, based on the proximity to the ocean.

- In addition to land cover mapping, this project also applied LiDAR and orthophotos towards the mapping of riparian habitat areas and a model for tree planting potential to support specific objectives.
    - Riparian Potential Model: In past years, a simple model was applied to determine the location of land that was lower and more likely to contain hydric soils, and therefore more likely to support riparian habitat. These riparian tree and riparian herbaceous classes were previously integrated into the land cover mapping but suffered from the use of a coarse DEM as the lone model input. The LiDAR enhanced mapping methods applied the more detailed LiDAR DEM and the more detailed hydrography dataset (streams, lakes, ponds and wetlands) to more precisely map existing riparian areas and also areas that have potential for riparian habitat restoration. CRD elected to have the riparian data delivered as a standalone dataset to support a broader range of end uses; therefore the riparian land cover classes are not identified in the LiDAR enhanced classification results. The riparian model results, however, can be used independently to support decisions, or be used as a mask to overlay and adjust land cover types if desired.
    - Tree Planting Potential Model: An updated tree planting potential model was developed to identify places where more suitable conditions exist for future tree planting initiatives. This model relies upon the presence of suitable non-treed cover types as the starting point for further constraints such as steeper terrain and setbacks from buildings, Ministry of Transportation and Infrastructure (MOTI) highway jurisdiction, sports fields and playgrounds. This model provides improved detail over past years for some municipalities, but still suffers from a lack of detail in areas such as golf courses and cemeteries, where tree planting opportunities may exist in certain locations but not others, for more specific aesthetic or functional reasons. As well, underground and overhead utilities are not factored into the tree planting potential model and therefore the results can be refined for use by municipalities that have access to these datasets to further constrain the model.

<u>Results Overview</u>

This report includes a series of map figures that illustrate the broad results of various map outputs; however, the various digital files provided through this project provide the best way to view the detail, generate operational maps or explore specific geographic areas. GIS practitioners can aggregate the results to suit specific follow-up analysis or clip the data to more practical files sizes or extents to share with municipal or First Nation partners or other users.

The following deliverables are included digitally:

- Land cover map layers for the Core Municipal Area (CMA) and Port Renfrew / Pacheedaht area from traditional mapping methods;
- Land cover mapping for the full study area from LiDAR enhanced mapping techniques;
- Digital Elevation Model (DEM) that was produced by the Province from the LiDAR dataset to best represent the ground surface.
- Full featured Canopy Height Model (CHM) that includes vegetation and built feature heights;
- Vegetated CHM that only included height for tree and shrub features;

- Digital Surface Model (DSM) that presents the upper surface of the LiDAR point cloud. The primary purpose of the DSM is to subtract the ground elevation (DEM) to create the Canopy Height Model (CHM).
- Riparian Potential Model layer that shows existing riparian habitat and areas where potential exists for habitat restoration;
- Topographic Position Index (TPI) surface derived from LiDAR that shows areas of upland and lowland terrain which can inform other terrain-based analyses;
- Tree Planting Potential map layer that identifies low, medium and higher potential areas where planting could be considered; and
- Tree Points geodatabase which includes over seven million tree locations derived from the LiDAR point cloud within the study area as points with various attributed tree metrics.

In most cases, the files above are split into two separate and appropriately named files to cover the portion of the study area around and north of Victoria, and the additional study extents located near Port Renfrew.

Section 4.0 (Table 5) provides a detailed listing of all file names and more detailed descriptions of each map layer output to support further use of the data.

Mapping Without LiDAR:
During the project, it became evident that the imagery captured in 2019 has a lower sun angle than images captured in 2005 and 2011 for similar mapping. The effects of increased shadow, both on the ground and within tree canopies, created challenges for achieving similar mapping accuracies with the traditional mapping approach. Assessed map accuracy, when mapping without LiDAR, dropped by approximately 4% from values achieved in 2011, down to about 90% user accuracy. This value poses some challenges when trying to understand trends in tree canopy and impervious cover types which have tended to change by no more than a few percent between mapping periods.

LiDAR Enhanced Mapping:
LiDAR data does not suffer from parallax or sun shadow issues and provides a significant improvement to the ability to discern new land cover classes and increase accuracy. LiDAR, combined with orthophotos, allowed for the mapping of these additional classes:

- Shrub (and small trees)
- Deciduous Forest
- Coniferous Forest
- Emergent Aquatic Vegetation

Accuracy was assessed at 91.2% with all classes included and over 95% when considering the similar classes that have been mapped in the past. The separation of vegetation heights with LiDAR is quite accurate and therefore significant confidence can be placed in the separation of ground level vegetation classes from shrubs and also taller trees. The separation of deciduous from coniferous trees is assessed with about 10% error. The most significant issue with the current mapping is derived from vehicles in driveways and parking lots throughout the study area. The current methods do not deal well with the fact that cars have a height from the LiDAR data and a variety of colours from the imagery. This is compounded by the fact that the vehicles in the imagery are not in the same locations as the vehicles in the LiDAR as they two dataset were not captured in the same flight mission.

Manual efforts were taken to resolve misclassifications in many larger parking lots in the core study area but not across the full study area.

When comparing the results between the two mapping methods across the study area, the application of LiDAR provides a more accurate result with about 2% less tree cover and 4% less impervious cover types. This results from more accurate mapping of smaller patches of ground that can include a matrix of trees, shrub, lawn and driveways, without the influence of shadow. In addition, the ability to accurately separate trees and shrubs from lower vegetation with a high degree of certainty has a positive impact on results. This report describes an approach that can be used to adjust past and future results to account for changes in mapping methods.

As completed on past iterations of tree canopy and impervious surface trend mapping for the CRD, the results have been reported per square metre and also as a proportion across a one hectare grid. The hectare-based reporting approach continues to be a robust technique that identifies more significant changes on the landscape without suffering from the details and shifts that can result from changes in image quality or mapping method.

Within the Core Municipal Area (CMA) that was mapped previously, we see two key trends slowing:

- The 0.5% increase in the pavement and buildings class reflects a slowing of the trend of increasing impervious surfaces. Between 2005 and 2011, impervious surfaces showed a trend increasing almost 3%. When reported per municipal jurisdiction, we see some higher values in Langford (4.3%), Sidney (4.7%), Port Renfrew (3.1%), East Saanich – Tsawout First Nation (5.7%), and Esquimalt First Nation (6.4%)
- Likewise, treed classes show only small changes in this most recent time period when compared to past rates of decline in canopy. Overall, tree cover saw an increase of 0.2% in the study area. In the past time period (2005-2011), the trend saw a decrease of 2%. Changes in tree cover are influenced not only by the removal and planting of trees, but also by the incremental growth of larger canopies as trees mature and mask out the various cover types below. Certain jurisdictions saw more significant reductions in tree cover: Esquimalt First Nation (11.7%), New Songhees First Nation (11.4%), Langford (3.5%), and Esquimalt (5.2%). Smaller jurisdictions can show higher rates of change where a development project can cover a much high proportion of the relatively small land base.

Appendix C provides a table with the most detailed breakdown of areas per land cover class broken down by each of the municipal and First Nation jurisdictions across the full study area, including the CMA, the southern Gulf Islands and the Port Renfrew / Pacheedaht area. This table has been provided digitally as well to support further calculations or analysis.

<u>Summary of Key Limitations and Recommendations</u>

Orthophoto Land Cover Mapping:

- This report highlights the issues when dealing with lower sun angle and increased shadow present in the 2019 orthophoto. The reduced accuracy provides a strong case for relying on the LiDAR enhanced results to support decisions.
- The 2011 image was taken in the spring, and therefore not all trees were in full leaf. As a result, tree cover values in areas where deciduous species are dominant may be underestimated. Although this

does not directly influence 2019 mapping, it does influence the trends in cover change between these time periods.

LiDAR Enhanced Land Cover Mapping:

- Since the LiDAR enhanced mapping process also relies on the orthophotos, the limitations above can influence results, but to a significantly lesser degree.
- Temporal data differences between LiDAR and orthophotos create some inconsistencies in places where ground features have changed (i.e., building construction, vehicle positions, and agricultural vegetation heights). These changes can increase mapping error, but not in a significant manner when pertaining to overall tree cover or impervious surfaces trends. In future, it is recommended to capture orthophotos coincidentally during the LiDAR flight mission.
- Although efforts have been made to align the LiDAR enhanced cover classes with past mapping, there was value in adding a shrub, and small trees less than 3-metres tall, class, which has not been mapped previously. This new class helps define the tree extent and area of deciduous and coniferous trees for tree canopy calculations. The most significant issue with the shrub class is that it draws from both the herbaceous and tree classes in past mapping, making it difficult to make direct comparisons for past trends. This improved mapping approach does, however, mean that future mapping (when LiDAR is used) will allow for much more accurate comparisons to this 2019 dataset. Conversion factors are presented in Section 4.1.4.1 to assist in making more accurate comparisons between future and previous mapping methods.
- The land cover classification process is developed to semi-automate mapping in a replicable manner and does not include significant levels of manual delineation of classes. The accuracy assessment provides a quantitative evaluation of the degree of error in the mapped results and, depending on the level of class aggregation, the error can be as high as 5% for the LiDAR enhanced land cover mapping. Although this error is recognized, it is important to understand the types of errors that can exist. The accuracy assessment error matrix provides some insight into classes that demonstrate confusion. Based on further visual review, some additional types of error include:
    - Confusion between various non-vegetated classes such as bare soil, gravel, pavement or bedrock which all share similar spectral characteristics.
    - Confusion between some areas of low vegetation and non-vegetated areas due, in part, to LiDAR data, suggesting that vegetation heights are very low in some areas.
    - Tall features such as buildings, bridges and signage can influence the classification of features creating false areas of tree or shrub in the map. Capturing LiDAR at the same time as future orthophotos will resolve this issue, but additional manual data edits would be required to make additional corrections to the current deliverables.
    - The LiDAR data does not cover the full extents of all small islands and features offshore from major land areas. As a result, some small islands may have been missed (e.g., McCarthy Island in Esquimalt Harbour).

LiDAR-Based Tree Metrics:

- Software developed for use in identifying tree parameters are largely designed for the forest resource industry, but apply well to more urban and rural forest management applications. The degree of species variation, pruning or other modifications to urban trees for utilities, safety, or aesthetic reasons creates additional challenges for tree classification tasks which rely heavily on comprehensive training data. The point dataset developed through this work could act as a good starting dataset for a tree inventory dataset but suffers from these issues:

- Large hedges are often mapped as trees and do not reflect the positions of the individual stems that comprise the hedge.
- Some large trees species can be mapped with multiple stems (typically associated with each large branch separated by open areas within the tree canopy).
- Mapping is focused on the canopy that is visible from above and therefore misses trees located below the upper canopy or factors some understory trees into the delineation of a larger tree.
- Tree points are ideally located as close as possible to the actual stem for inventory purposes; however, the tree points are calculated based on the tallest point of the tree canopy.

Regardless, the tree points remain a valuable dataset to start a tree inventory database.

LiDAR Enhanced Riparian Potential Model:

- The riparian potential model is derived almost entirely from terrain characteristics in the LiDAR dataset and is intended to reflect the potential for riparian habitat commonly associated with low land adjacent to existing hydrographic features like wetlands, streams, ponds and lakes. This model does not infer the actual existence of riparian habitat, nor does it include hydraulic modeling or detailed inspections to infer flood hazard or risk.
- The precise alignment of the source features (streams in particular) relative to elevation model channel location plays an important role in determining the slopes that water must travel across in this cost-distance modeling approach. Misalignments in the location of a stream centreline, relative to the terrain model, create inaccuracies in the riparian potential model results.

Tree Planting Potential Model:

- The tree planting potential model is based on a variety of factors that are more comprehensive than past results for some muncipalities, but do not account for all considerations associated for a tree planting site. Various localized conditions must be accounted for via local knowledge, more detailed desktop analysis or actual field visits. In particular, the model does not account for underground or overhead utilities or fire hydrants. These data should be included by municipalities to further constrain the model results for operational purposes.

Additional Recommendations:

The following recommendations should be considered to ensure a high level of confidence can be placed in future interpretations of the data.

- The LiDAR allows for accurate determination of tree heights. As a result, it may be useful to report trees by height classes. This information could be useful from an urban forest management perspective. This data would come directly from the LiDAR derived Canopy Height Model (CHM) dataset.
- Mapping Impervious Surfaces is complicated by the presence of impervious surface that are sometimes covered or partially covered by tree canopy. This consideration could be important from a storm water management perspective and could be mapped as individual classes if required. This would be done by overlaying the tree canopy class with the building footprint polygons and polygonal representations of the roads. The new classes could be termed "Tree covered Buildings" and "Tree covered Roads".

- This report documents that the LiDAR enhanced mapping approach is more accurate and develops additional useful classes when compared to past mapping. The costs associated with acquiring LiDAR can be higher than capturing orthophotos alone and could be a consideration in future updates, as LiDAR costs have been dropping over the past decade. LiDAR does serve other important uses and could be sourced in collaboration with other stakeholders (in various levels of government and government departments).
- The use of modeled stream channel locations developed from flow accumulation calculations may provide a more accurate manner of precisely aligning streams with the LiDAR terrain modeling to improve riparian potential. This approach would require significant efforts to account for engineered water management infrastructure, which is not reflected in the terrain surface (i.e., culverts and other water diversion structures), but could be a valuable approach if deemed important for engineering purposes.

2.0 INTRODUCTION

2.1 Background

In 2013, Habitat Acquisition Trust (HAT) sponsored a project to map the density of the Capital Regional District's (CRD) urban forest and impervious surfaces[1]. The trends in land cover change were focused on the Core Municipal Area stretching from North Saanich to Sooke, including the municipalities and First Nation jurisdictions in between. Land cover change trends from this work were based on the classification of aerial photographs acquired in 1986, 2005 and 2011. In 2017, the CRD completed a satellite-based image classification project to map land cover that also covered the Juan de Fuca Electoral area that was primarily used to inform park planning activities in this region. Unlike past classification work, the Juan de Fuca project used 3-metre resolution satellite imagery to map similar land cover classes but with less detail.[2]

This report provides an update to land cover mapping, to document trends in tree cover and impervious surface changes using the most recent aerial photography from 2017 and 2019. The current work goes a step further to also use available LiDAR data available from the Province to complete a new mapping method that generates more detailed cover classes (e.g. shrub and coniferous versus deciduous trees) with improved accuracy. In areas where past aerial photograph mapping had been completed, a common approach was followed using the 2019 imagery to allow for updated tree cover and impervious surface change trend reporting. The improved approach was also completed to explore the utility of LiDAR towards improving mapping of a larger study area that includes the following areas: (See Figure 1)

- Core Municipal Area with 2019 imagery (previously mapped from North Saanich to Sooke)
- Salt Spring and southern Gulf Islands (Galliano and south) with 2017 imagery (not previously mapped)
- Chatham and Discovery islands with 2017 imagery (not previously mapped)
- Trial islands with 2015 imagery (not previously mapped)
- Port Renfrew and Pacheedaht lands with 2019 imagery

Together these two mapping approaches provide the data to support:

1. A comparison of tree cover and impervious surface trends where they had been mapped previously; and
2. Mapping with LiDAR enhanced classification results across a wider region that can be used as a baseline to evaluate trends in the future and support operational tasks such as tree planting strategies.

Through this project, land cover is described in terms of the total area of each class based on the 1-metre resolution land cover classification results; while the long-term trends continue to be monitored using the same approach applied in past years. This approach first defined the percent tree cover and percent impervious surface cover over the one-hectare grid across the full study area. The tree cover class includes more natural forests, trees in urban parks and along trails, boulevards or trees found on other public or private property. LiDAR point cloud data is leveraged to further separate taller trees from shrubs based on a threshold height of 3-

[1] Blyth, C. A. 2013. Capital Regional District Land Cover Mapping 1986, 2005 and 2011 Summary Report. Prepared by Caslys Consulting Ltd. for CRD / Habitat Acquisition Trust.

[2] Blyth, C. A. 2018. Capital Regional District Land Cover Mapping 2017 Summary Report. Prepared by Caslys Consulting Ltd. for CRD.

metres. Additionally, a riparian habitat potential model has been developed with the use of the LiDAR DEM and tree planting potential has been modeled to help guide future tree planting initiatives.

This report summarizes the methods used to conduct the mapping and presents key findings pertaining to landscape change and potential for tree planting. Accounting for the changed mapping methods that incorporate LiDAR (which was not previously used), requires some additional effort to maintain statistically valid datasets for comparison across time periods. A discussion at the end of this report (Section 4.1) shows how this has been completed.

2.2 Study Area

The study area (Figure 1) shows the areas mapped, along with a listing of the municipal and First Nation jurisdictions that have been tabulated for land cover area summaries.

Figure 1. Study Area Map

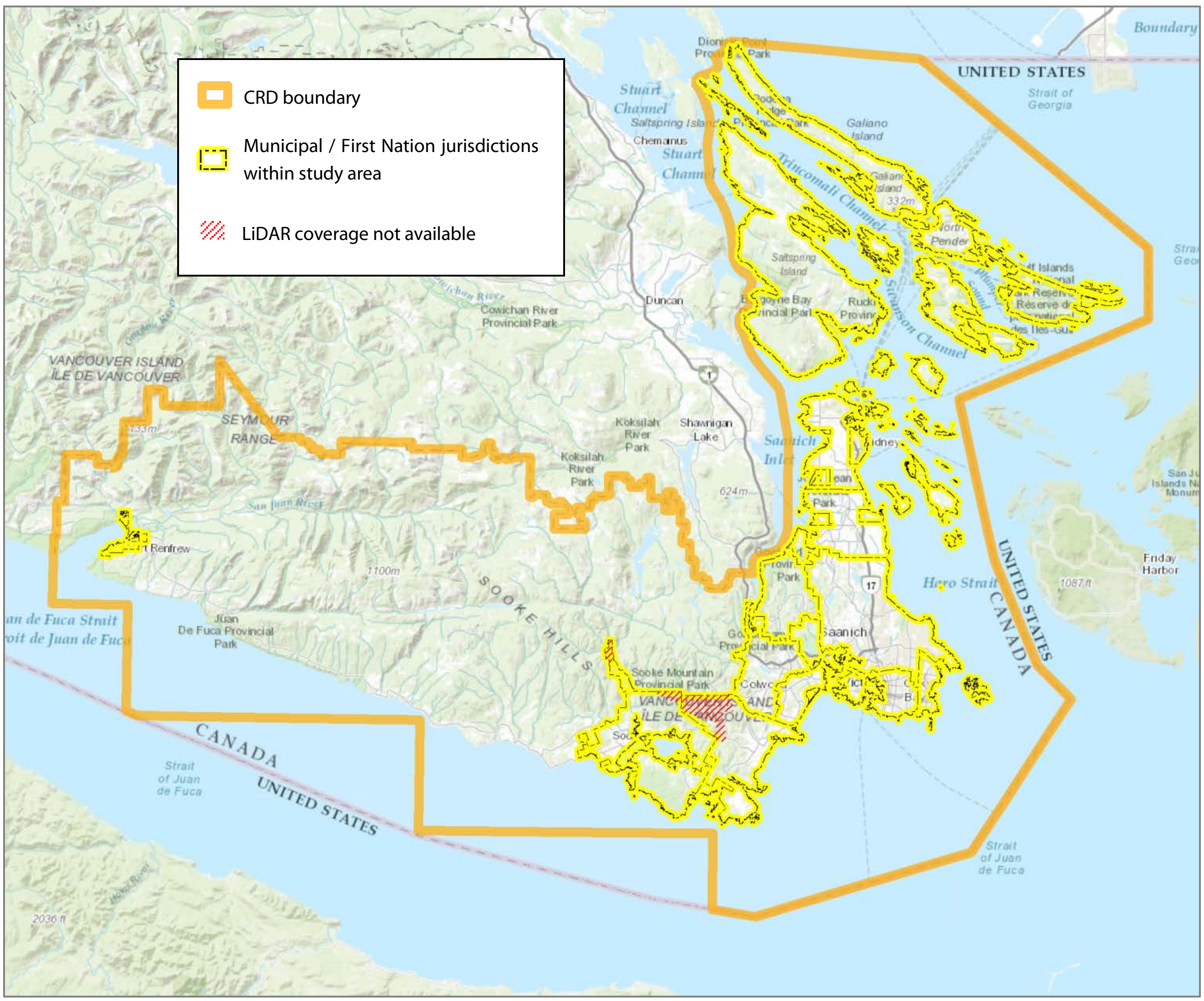


Table 1 lists the areas that have been mapped during this project (note the year of the source imagery) and also identifies which jurisdictions have had land cover mapping completed in previous project iterations. Where noted, land cover for certain areas in the Core Municipal Area had been mapped in 1986, 2005 and 2011. For these previously mapped areas, comparisons in land cover change are calculated to inform change trends over time through to 2019. The trends include tree cover and impervious surface density.

Table 1. Municipal and First Nation Jurisdictions

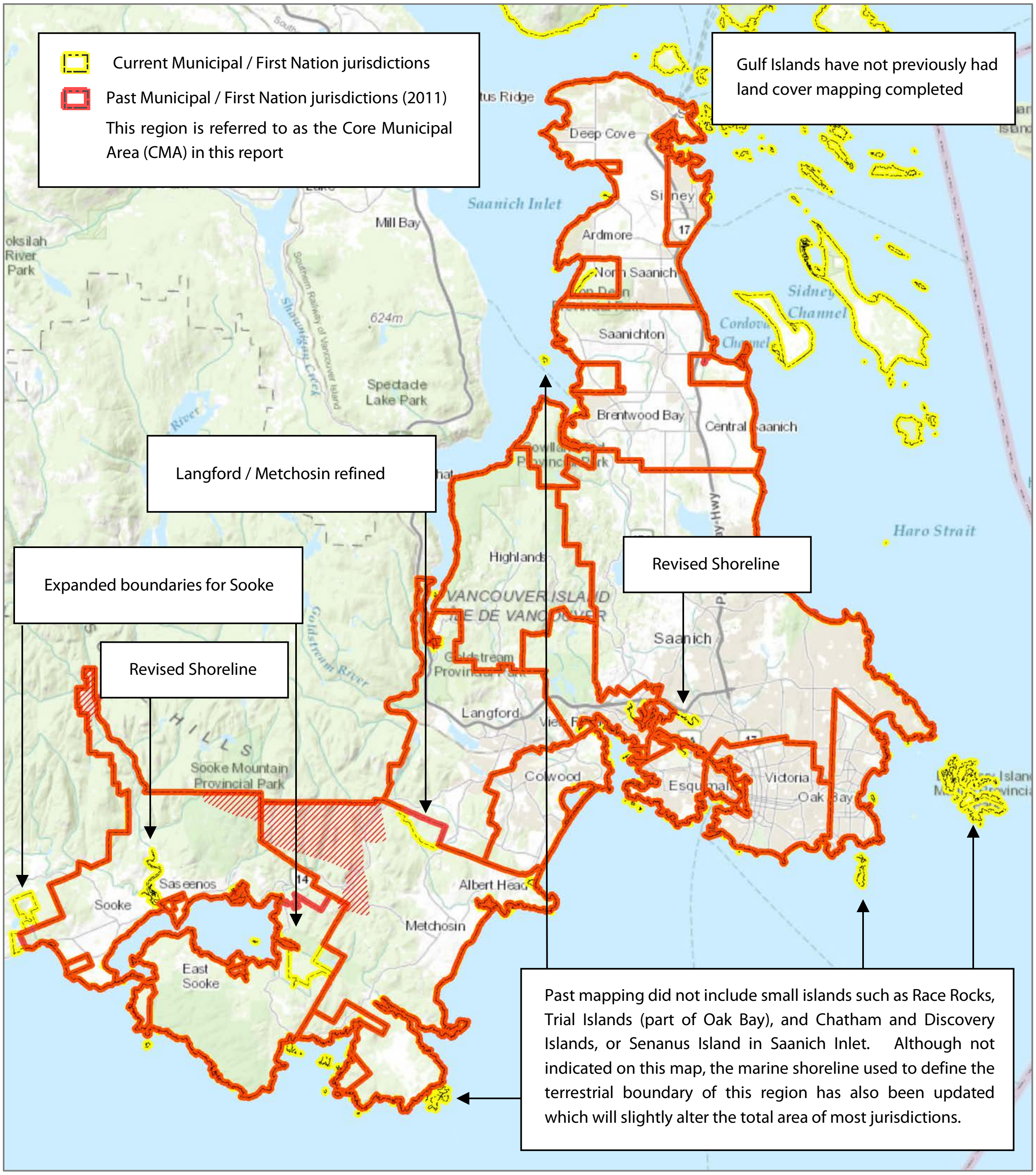
Mapped using 2019 Imagery	Past Mapping
Central Saanich	Yes
Colwood	Yes
East Sooke	Yes
Esquimalt	Yes
Highlands	Yes
Langford	Yes
Malahat	Yes
Metchosin	Yes
North Saanich	Yes
Oak Bay (revised to include Trial Islands)	Yes
Saanich	Yes
Sidney	Yes
Sooke	Yes
Southern Gulf Islands (Saanich Inlet)	No
Victoria	Yes
View Royal	Yes
Beecher Bay 1 & 2 First Nation	Yes
Cole Bay 3 (Pauquachin First Nation)	Yes
East Saanich 2 (Tsawout First Nation)	Yes
Esquimalt First Nation	Yes
Goldstream 13 (Various First Nations)	Yes
Long Neck Island 9 & Whale Island 8 FN	Yes
New Songhees 1A First Nation	Yes
Senanus Island 10 (Tsartlip First Nation)	Yes
South Saanich 1 (Tsartlip First Nation)	Yes
T'Sou'ke 1 & 2 First Nation	Yes
Union Bay 4 (Tseycum First Nation)	Yes
Port Renfrew *	Yes
Pacheedaht First Nation *	Yes

Mapped using 2017 Imagery	Past Mapping
D'Arcy Island	No
Discovery Island	No
Galiano & Parker Islands	No
James Island	No
Mayne Island	No
Moresby Island	No
North Pender Island	No
Piers Island	No
Portland Island	No
Prevost Island	No
Salt Spring Island	No
Samuel Island	No
Saturna & Tumbo Islands	No
Secretary & Wallace Islands	No
Sidney Island	No
South Pender Island	No
Southern Gulf Islands (Sidney Area)	No
Bare Island 9 (Tsawout, Tseycum FN)	No
Chatham 4 & Discovery 3 (First Nation)	No
Fulford Harbour 5 (Tsawout First Nation)	No
Galiano Island 9 (Penelakut First Nation)	No
Mayne Island 6 (Tsartlip First Nation)	No
S.Pender Island 8 (Tsawout, Tseycum FN)	No
Mayne Island 6 (Tsartlip First Nation)	No
Saturna Island 7 (Tsawout, Tseycum FN)	No

* *These locations have been mapped in a separate file for data management purposes. Past mapping may exist from 2009 aerial photography but has not been used for comparisons for this project.*

For the purposes of this report, the portion of the study area that has previously been mapped will subsequently be referred to as the Core Municipal Area (CMA). It is also important to note that some jurisdictional boundaries have changed slightly in the official legal survey data maintained by the Province (Figure 2). Significant changes include added portions of Sooke adjacent to the Juan de Fuca Electoral Area and the inclusion of Trial Islands into the Oak Bay reporting summaries.

Figure 2. Core Municipal Area



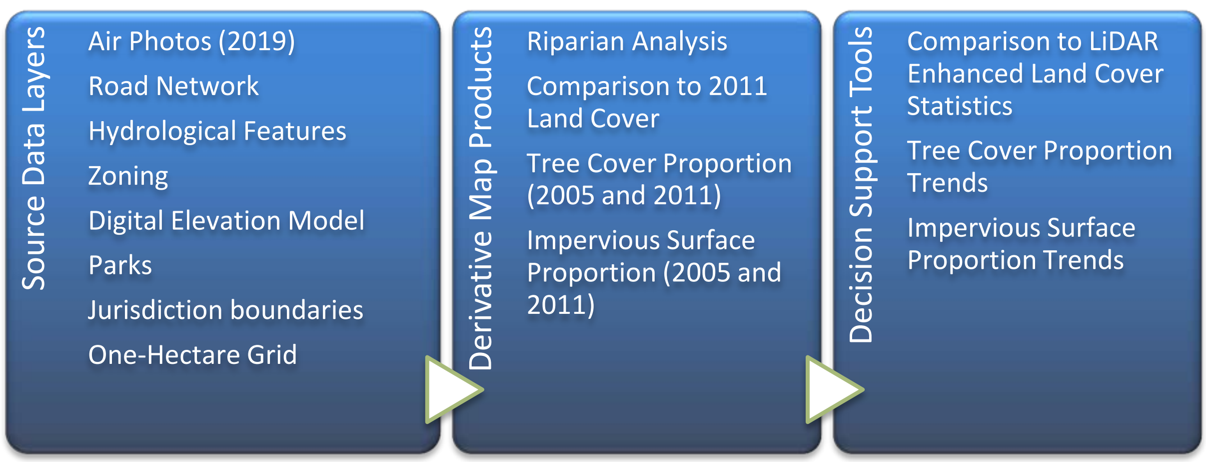
3.0 METHODS

Mapping was completed using past methods in areas where comparisons can be made to previous iterations of mapping. This approach does not involve the use of LiDAR data. A second method has been applied across the full study area to also leverage the LiDAR and enhance the classification with additional classes and improved mapping accuracy. These methods are presented herein under individual sections within Section 3.1 (Previous Land Cover Mapping Approach) and Section 3.2 (LiDAR Enhanced Land Cover Mapping Approach).

3.1 Previous Land Cover Mapping Approach

Previous methods have been applied for the CMA and also for the Port Renfrew region. These methods are described in detail in "Capital Regional District Land Cover Mapping 1986, 2005 and 2011 Summary Report" (Caslys, 2013). This method is summarized below, with attention given to any slight modifications that have been applied through this project. The analysis work was conducted using ESRI's ArcMap, with the use of the isoclustering (grouping of like pixel colours) unsupervised classification algorithms. The raster-based components of the analysis were conducted using ArcMap's Spatial Analyst extension. Figure 3 summarizes the various source data layers, derivative map products and the resultant decision support tools.

Figure 3. Land Cover Mapping Overview (Orthophoto Method)



3.1.1 Source Data Layers

3.1.1.1 <u>Air Photos</u>

The 2019 orthophoto was provided by the CRD to facilitate land cover mapping. Although this imagery is adequate for land cover mapping, a comparison to 2005 and 2011 imagery shows increased shadow and reduced image contrast, giving the images more green tones throughout. The raw images include portions at 10cm and 20cm resolution, which is resampled to 1-metre for consistent classification purposes. (Although some 2017 and 2015 imagery was used to cover other parts of the study area, the entire area mapped using the previous methods had been covered by the 2019 images.)

3.1.1.2 Road Network

A dataset identifying highways, roads and many trails within the Region was downloaded from the Provincial data warehouse. This data was used to assist in the identification of paved surfaces.

3.1.1.3 Hydrological Features

The CRD supplied a dataset mapping hydrological features. These included polygonal features such as lakes, ponds and wetlands; and linear features delineating streams. The data were used to refine the land cover datasets and included improved details when compared to past years. These features are used as an input towards modeling the riparian habitat potential.

3.1.1.4 Zoning

The CRD supplied a zoning layer that was used to refine the land cover information. This assists in defining urban and suburban areas, as well as agricultural parcels.

3.1.1.5 Digital Elevation Model

A Digital Elevation Model (DEM) was generated from a Triangular Irregular Network (TIN) dataset supplied by the CRD. The DEM was used to derive a hillshade, which was only used to derive the riparian potential areas for this classification. The LiDAR DEM was used for all other project tasks associated with the LiDAR Enhanced classification and modeling.

3.1.1.6 Parks and Open Space

A dataset specifying the locations of parks and open space was supplied by the CRD. Impervious surfaces and tree cover densities are summarized per park.

3.1.1.7 Municipalities

Table 1 and Figure 2 highlight the jurisdictions that have been mapped using the 2019 images for the CMA region. These polygons are defined by updated boundaries sourced from the Province, combined with First Nation lands, and were also downloaded from the Provincial data warehouse. Although not pertinent to the CMA, the Gulf Island boundaries were defined to match designations used by Islands Trust (islandstrust.bc.ca). In addition, CRD has applied a revised shoreline delineation to define boundaries along the coastline. These regions are used to support reporting for the land cover and density values.

3.1.1.8 One-Hectare Grid

The provincial government has developed a mapping product entitled Hectares B.C., which is a grid-based dataset that summarizes biodiversity and land use information using a one-hectare cell size for the entire province. The one-hectare grid cell dataset used to generate the tree cover and impervious surface density statistics was identical to the one used for the previous project (Caslys, 2013). It uses the same origin points as those used by Hectares B.C. to allow data to be exchanged seamlessly between the two datasets. The origin points (in B.C. Albers NAD 83) are as follows:

Easting: 159,587.5m Northing: 173,787.5m

3.1.2 Derivative Map Products

3.1.2.1 Riparian Potential Analysis

Riparian zones are moist and densely vegetated areas adjacent to streams, rivers, lakes and wetlands. They provide transitional green belts that separate areas that are perennially covered by surface water from drier upland regions. Although the riparian land cover classes had been part of past mapping, CRD has chosen to remove riparian classes from the LiDAR enhanced land cover classification, while still modeling riparian potential as a stand-alone dataset that can be applied to broader types of analysis. When mapping without LiDAR, the riparian classes remain integrated into the land cover mapping to maintain continuity with past methods. The riparian potential model is described in more detail in Section 3.2.6 as it now uses the LiDAR DEM as a more precise input to the model.

3.1.2.2 2005, 2011 and 2019 Land Cover Classifications

An unsupervised classification was conducted using 2019 orthophotos supplied by the CRD. This type of classification is performed when there is no prior knowledge of the classes in a scene. In this project, it was used to detect and extract unique land cover features. Unsupervised (isocluster) classification algorithms compare the spectral signatures of individual pixels to the signatures of computer-determined classes and assign each pixel to one of these classes. The classifications yielded ~175 unique classes, each of which was assigned a preliminary land cover attribute. This classification was subsequently refined through the integration of various ancillary datasets available for the study area, such as the zoning data or building footprints. The integration of these datasets allowed the classes to be refined based on land use. The unsupervised classes are manually assigned into one of the applicable 'Land Cover Classes' as presented in Table 2. A sample of this land cover map is presented in Figure 4.

Table 2. Land Cover Classes

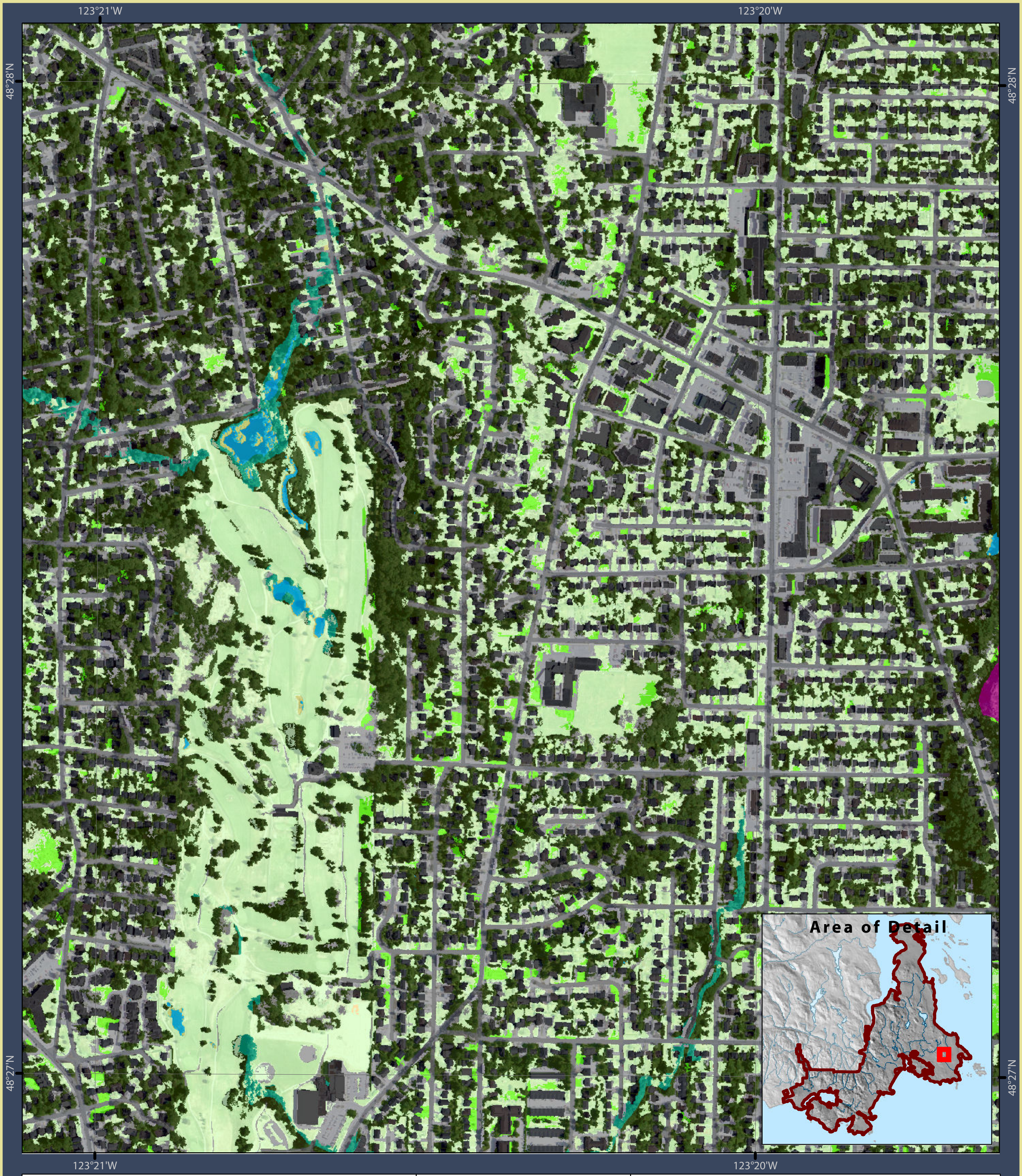
Value	Class	Description
1	Shadow	Areas in the land cover classification unresolved due to shadows in the source imagery that were unable to be classified.
2	Ocean	Ocean water features.
3	Lake	Water within polygons identified in the hydrological features GIS dataset as being lakes.
4	Pond	Water within polygons identified in the hydrological features GIS dataset as being ponds.
5	River	Water within polygons identified in the hydrological features GIS dataset as being rivers.
6	Sand and gravel shoreline	Sand and gravel beaches or tidal mudflats. The extent of this land cover will vary between time periods as a function of the height of the tide at the time the image was taken.
7	Bedrock shoreline	Bedrock shoreline. The extent of this land cover will vary between time periods as a function of the height of the tide at the time the image was taken.
8	Exposed soil	Areas of exposed soil and bare land (e.g., construction sites, cleared areas) falling outside of agricultural land uses.
9	Grass	Grass land cover falling within residential and urban land uses, including lawns, gardens, playing fields and institutional grounds. These areas represent lands subject to regular maintenance.
10	Herb	Areas of natural herbaceous vegetation (i.e., not manicured). Typically, these are areas of grasses, reeds, ferns, flowers or low-lying vegetation.
11*	Riparian herb	Areas of natural herbaceous vegetation (i.e., not manicured) falling in riparian habitats. Note that this class can be aggregated with Class 10 (Herb) since CRD has decided to omit riparian potential classes in the Land Cover results. The riparian model now forms a standalone deliverable that is derived using the LiDAR dataset.
12	Tree	Treed land covers (woody vegetation over 3m).
13	Docks	Dock structures present along lake and marine shorelines.

Value	Class	Description
14*	Pavement/Packed gravel	Paved areas (e.g., roads, sidewalks, driveways and parking lots) that are generally considered impervious surfaces. (In past editions of this land cover mapping, buildings were included in this class.)
15	Agriculture	Grass, crop and shrub land covers falling within agriculture and rural residential land uses. The agriculture class includes areas of exposed soil as these are assumed to be fallow fields.
16	Exposed bedrock	Areas of exposed bedrock. Exposed bedrock is found in areas of rugged upland terrain.
17*	Riparian tree	Treed land cover falling in riparian habitats. Note that this class can be aggregated with Class 12 (Tree, i.e., woody vegetation over 3m) since CRD has decided to omit riparian potential classes in the Land Cover results. The riparian model now forms a standalone deliverable that is derived using the LiDAR dataset.
20*	Road	The available road network linework is used to differentiate roads from other impervious surfaces.
23*	Buildings	Building footprints as defined through other mapping initiatives have been incorporated into this edition of land cover mapping. (In past editions, buildings were included in Class 14 with other impervious surfaces.)

Note that class values marked with an * in Table 2 have been modified or added since past mapping editions. For example, roads and buildings have been separated from a single previous class that included other paved or packed gravel (impervious) surfaces. The new classes are not sequentially numbered to better align with the additional classes that are part of the LiDAR enhanced land cover mapping approach.

3.1.2.3 Tree Cover and Impervious Surface Proportion Statistics

In past years (up to 2011), statistics were calculated for each one-hectare grid cell to report the proportion of tree cover and impervious surface datasets. This approach summarizes the percent cover per hectare cell. The percentage values were then divided by the percentage of land within each cell to determine the percentage of the land base within each cell that is treed and the percentage that is covered by impervious surfaces (i.e., Class values 14, 20, or 23). This approach was completed for this most recent iteration of mapping using the LiDAR enhanced mapping approach. The hectare-based reporting method is described in Section 3.2.6. Figures 5 and 6 provide illustrated examples of the structure of the hectare-based statistics for tree cover and impervious surface proportions.



Land Cover

- Shadow
- Ocean
- Lake
- Pond
- River
- Shoreline Gravel / Sand
- Shoreline Bedrock
- Bare Surface
- Grass
- Herbacious
- Seasonally Flooded Herb / Agri
- Tree
- Dock
- Paved / Packed Gravel
- Agricultural
- Bedrock
- Tree (Riparian)
- Road
- Building

0 100 200 300
Meters

Projection: UTM Zone 10 North (NAD83)

Data Sources:
Capital Regional District
Province of British Columbia

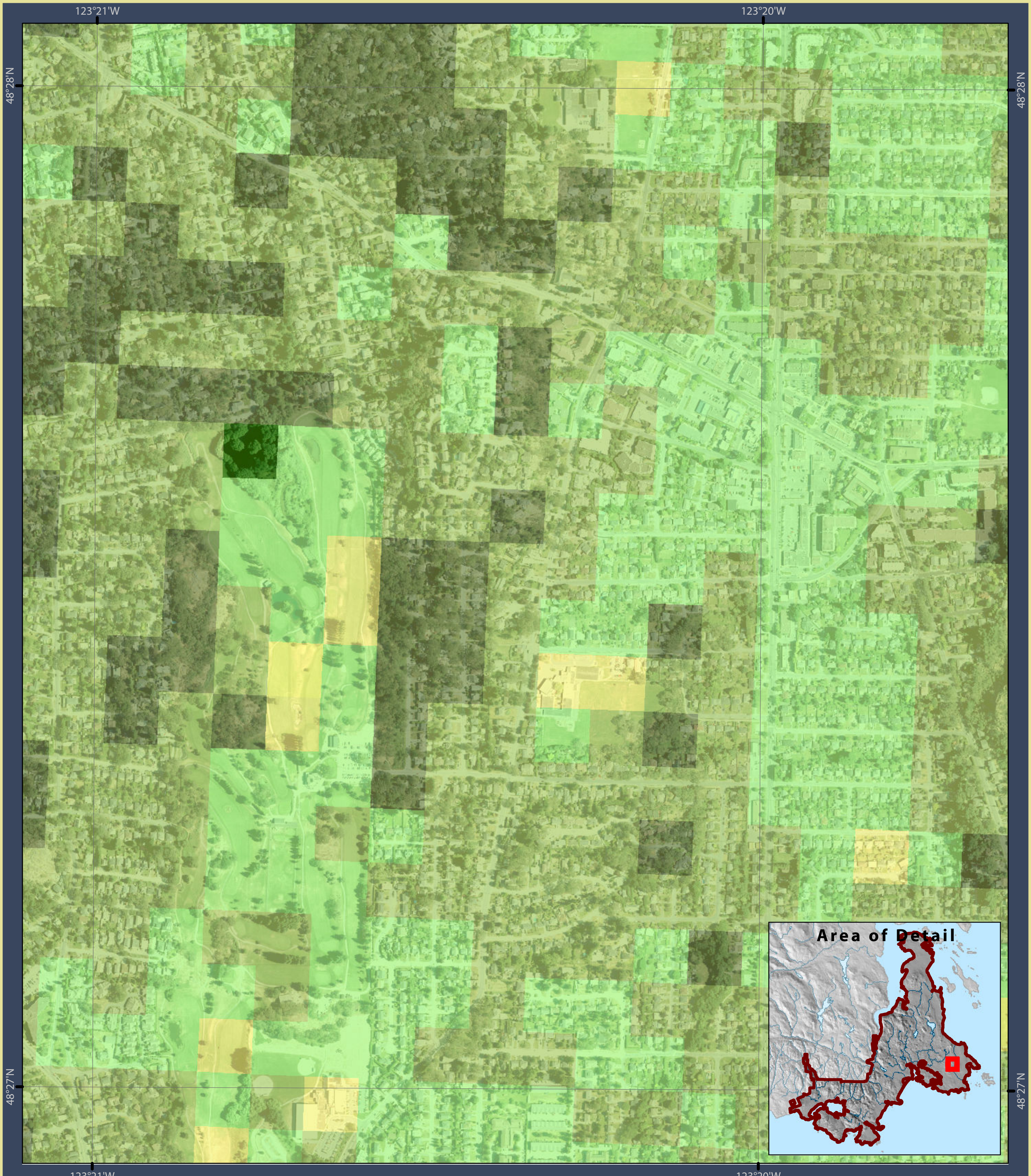
Figure 4. 2019 Land Cover Mapping Detail

Core Municipal Area

Urban Land Cover Mapping
CRD (2017/2019)

Prepared for: CRD Making a difference...together

By: CASLYS CONSULTING



Tree Cover Proportion

Percent (%)

- 0 - 5
- >5 - 10
- >10 - 25
- >25 - 50
- >50 - 75
- >75 - 100

0 100 200 300

Meters

Projection: UTM Zone 10 North (NAD83)

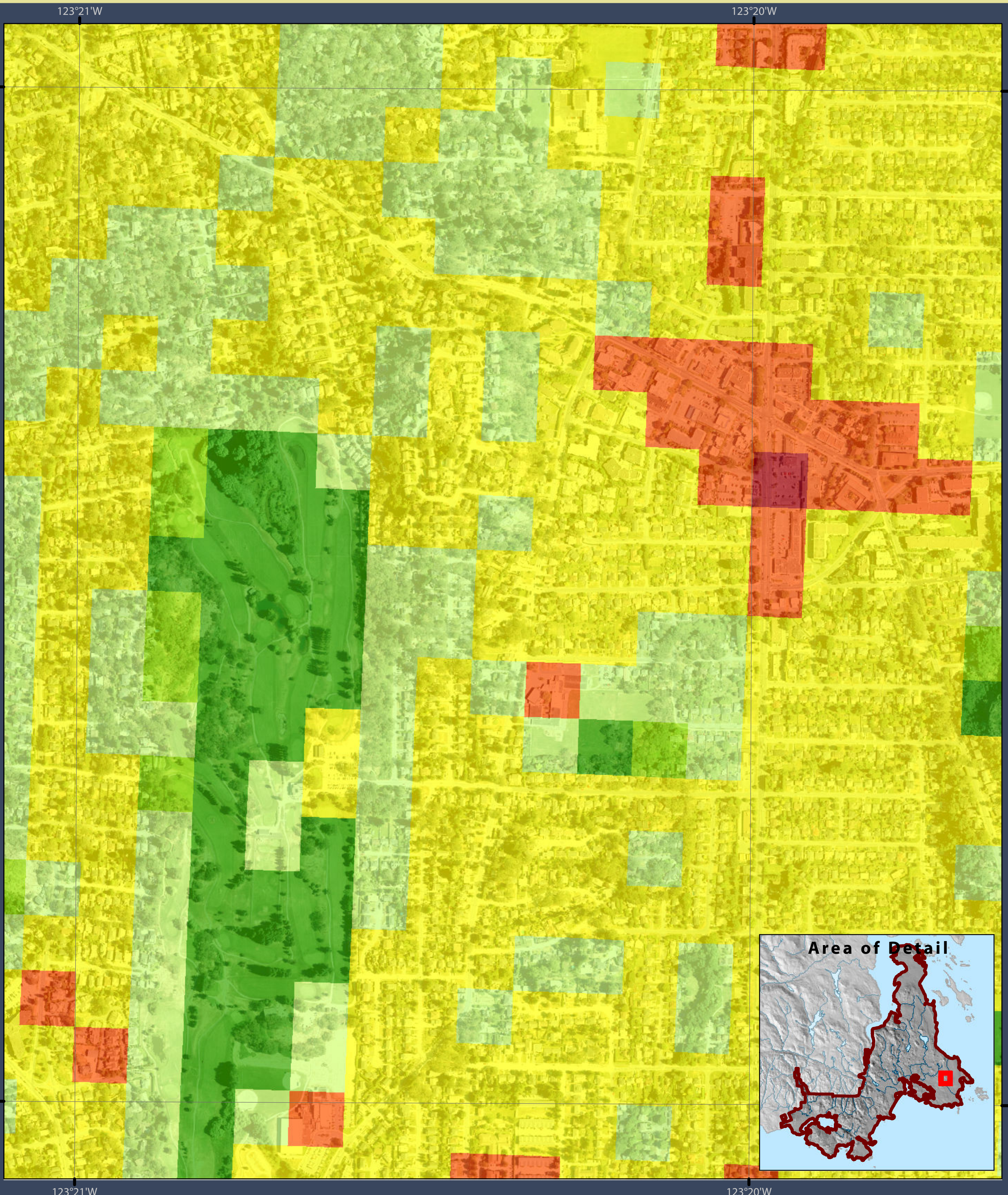
Data Sources:
Capital Regional District
Province of British Columbia

Figure 5.
Tree Cover Proportion per Hectare (1:10,000)
Core Municipal Area

Urban Land Cover Mapping
CRD (2017/2019)

Prepared for: CRD Making a difference...together

By: CASLYS CONSULTING



Impervious Surface Proportion

Percent (%)

- 0 - 5
- >5 - 10
- >10 - 25
- >25 - 50
- >50 - 75
- >75 - 100

0 100 200 300

Meters

Projection: UTM Zone 10 North (NAD83)

Data Sources:
Capital Regional District
Province of British Columbia

Figure 6. Impervious Surface Proportion per Hectare (1:10,000)
Core Municipal Area

Urban Land Cover Mapping
CRD (2017/2019)

Prepared for: CRD Making a difference...together

By: CASLYS CONSULTING

3.1.3 Decision Support Tools

3.1.3.1 Land Cover Statistics

Summary statistics were generated to quantify the following land cover changes:

- A summary of the 2019 land cover class areas for the CMA.
- A comparison of land cover changes between 2005, 2011 and 2019 for the CMA.
- Percent tree cover and impervious surface in 2019 for the CMA.
- Percent tree cover and impervious surface changes between 2005, 2011 and 2019 by municipality for the CMA.

3.1.4 Quality Control

3.1.4.1 Land Cover Accuracy – Core Municipal Area

In comparison to past years of land cover mapping using this same approach, the orthophotos available in 2019 suffer from two issues that impact land cover mapping:

1. The sun angle was lower at the time of image acquisition in 2019 when compared to previous years. This issue impacts the amount of shadow cast by trees and buildings and increases unknowns related to mapping areas in those shadows. By comparison, 2019 has double the amount of shadow compared to previous years. Notice the shadows within the tree canopy, as well as the larger shaded areas beside the trees.
2. The image contrast in 2019 is lower than in past mapping years, meaning that the many different shades of vegetation in past years is not as clearly defined in 2019. Notice the clarity of the tree foliage in the right image below.

The overall accuracy of the land cover classification is, therefore, degraded from past years as a result of the reduced clarity to define clear breaks between tree cover and other green ground cover types and the increased percentage of the image that is classified as shadow. This results in less precise comparisons for tree canopy and impervious surface trends. (Section 3.1.4.1 presents the results of orthophoto classification accuracy assessment.)

3.2 LiDAR Enhanced Land Cover Mapping Approach

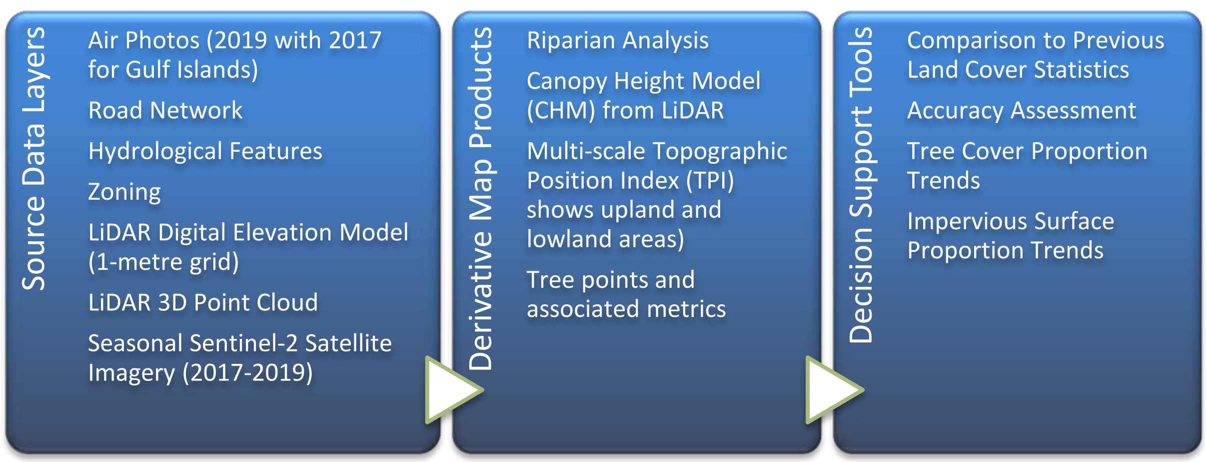
Using available Provincial LiDAR elevation and 3D point cloud data, land cover mapping was completed for a larger study area that includes the southern Gulf Islands, the CMA and the areas near Port Renfrew. LiDAR allows for added classes such as shrub, and the separation of trees into deciduous and coniferous classes. These refined mapping methods are presented in this section.

Although some steps remain similar to previous methods, all steps for the LiDAR enhanced land cover are outlined below. Figure 7 summarizes the various source data layers, derivative map products and the resultant decision support tools. The advantages of LiDAR towards land cover mapping are as follows:

- Significantly more accurate terrain elevation data with a 1-metre grid surface and sub-metre vertical precision.
- Ability to identify building and vegetation heights, as well as LiDAR intensity, helps to define different surface textures.
- Ability to define tree geometry to produce a series of tree metrics that can separate different types of trees.
- Corrected for vertical distortions such as parallax which exist in orthophotos (resulting in more precise location information).

A second enhancement applied to this classification is the use of multi-temporal Sentinel-2 satellite imagery at 10-metre resolution. Although this imagery lacks the spatial resolution of orthophotos, the use of monthly data across spring, summer and fall allows for improved separation of grounds features that are seasonally variable. For example, an agricultural crop undergoes distinct changes in land cover throughout a year, while a managed lawn has much less variability. Multi-date imagery can also be used to locate areas of development which allows for differentiation between natural bedrock and many paved or concrete features.

Figure 7. Land Cover Mapping Overview (LiDAR Enhanced Method)



3.2.1.1 <u>2017/2019 LiDAR Enhanced Land Cover Classes</u>

A series of additional classes are added to the LiDAR Enhanced classification which take advantage of improved abilities to separate some useful land cover types that are not effective without these added data inputs. Table 3 lists all classes mapped in this version of the classification. Since LiDAR data does not suffer from the effects of shadow that are associated with orthophotos, there is no need for the undesirable "shadow" class that exists in previous classifications. As well, riparian potential has been removed from the classification and delivered as a standalone dataset. Although this removes riparian classes, it provides the ability to overlay riparian potential on any future land cover map products. New classes include separation of trees into deciduous and coniferous species (Classes 11 and 12) and the ability to easily isolate vegetation by height to create the Shrub (and small trees <3m in height) Class number 10. Emergent aquatic vegetation and larger loose gravel areas are also mapped (Classes 22 and 24 respectively).

Table 3. LiDAR Enhanced Land Cover Classes

Value	Class	Description
	Shadow	Not mapped with LiDAR Enhanced classification
1	Ocean	Ocean water features.
2	Lake	Water within polygons identified in the hydrological features GIS dataset as being lakes.
3	Pond	Water within polygons identified in the hydrological features GIS dataset as being ponds.
4	River	Water within polygons identified in the hydrological features GIS dataset as being rivers.
5	Sand and gravel shoreline	Sand and gravel beaches or tidal mudflats. The extent of this land cover will vary between time periods as a function of the height of the tide at the time the image was taken.
6	Bedrock shoreline	Bedrock shoreline. The extent of this land cover will vary between time periods as a function of the height of the tide at the time the image was taken.
7	Exposed soil	Areas of exposed soil and bare land (e.g., construction sites, cleared areas) falling outside agricultural land uses.
8	Grass	Grass land cover falling within residential and urban land uses, including lawns, gardens, playing fields and institutional grounds. These areas represent lands subject to regular maintenance.
9	Herb	Areas of natural herbaceous vegetation (i.e., not manicured). Typically, these are areas of grasses, reeds, ferns, flowers or low-lying vegetation.
10*	Shrub (and small trees)	Shrub and/or small trees that are between 50 centimetres and 3-metres in height. This class does not include tall hedges or other shrubs that are taller than 3-metres.
11*	Tree (Deciduous)	Deciduous treed land covers that can also include shrubs that are taller than 3-metres.
12*	Tree (Coniferous)	Coniferous treed land covers that can also include shrubs that are taller than 3-metres.
13	Docks	Dock structures present along lake and marine shorelines. (Often includes boats adjacent to the docks that may be present at the time of imagery or LiDAR acquisition.)
14*	Pavement/Packed gravel	Paved areas (e.g., roads, sidewalks, driveways and parking lots) that are generally considered impervious surfaces. (In past editions of this land cover mapping, buildings were included in this class.)
15*	Road	The available road network linework is used to differentiate roads from other impervious surfaces. (In past editions, roads were included in Class 14 with other impervious surfaces.)
16*	Buildings	Building footprints as defined through other mapping initiatives and LiDAR processing have been incorporated into this edition of land cover mapping. (In past editions, buildings were included in class 14 with other impervious surfaces.)
17	Agriculture	Grass, crop and shrub land covers falling within agriculture and rural residential land uses. The agriculture class includes areas of exposed soil as these are assumed to be fallow fields.
18	Exposed Bedrock	Areas of exposed bedrock. Exposed bedrock is found in areas of rugged upland terrain.
22*	Aquatic Vegetation	Areas within lakes and ponds that have emergent aquatic vegetation at the surface.
24*	Loose Gravel	Larger regions of exposed loose gravel which are often associated with vacant or industrial lands where development may be in progress.

Note that class values marked with * in Table 4 have been modified or added since past mapping editions.

3.2.2 Source Data Layers

3.2.2.1 Air Photos

In addition to the 2019 orthophoto that covers the portion of the study area on Vancouver Island, 2017 imagery was provided for the Gulf Islands and a small portion of 2015 imagery was used to map the Trial Islands south of

Oak Bay. This 2015 imagery was not deemed to be out of date due to the minimal level of change anticipated on these islands.

3.2.2.2 Road Network

A dataset identifying highways, roads and many trails within the Region was downloaded from the Provincial data warehouse. This data was used to assist in the identification of paved surfaces, as well as to contribute to riparian potential modeling and setbacks for tree planting potential.

3.2.2.3 Building Footprints

CRD provided a consolidated building footprint polygon file that was derived from the best available inputs from municipalities within the study area. NRCAN produced a publicly available buildings dataset that was derived from LiDAR and processed to form regular shaped building footprint. Although the NRCAN building footprints are less precise than CRD municipal data, they are used to fill gaps in the CRD dataset.

3.2.2.4 Hydrological Features

The CRD supplied a dataset mapping hydrological features. These included polygonal features such as lakes, ponds and wetlands; and linear features delineating streams. The data were used to refine the land cover datasets and included improved details when compared to past years (e.g., low vegetation found within the boundary of lake polygons is classified as aquatic vegetation, and non-vegetated features found within lakes or the ocean are mapped as docks). These features are also used as an input towards modeling the riparian habitat potential. The level of detail in the hydrological features is improved over past years; however, separation between lakes and ponds is not ideal, and many small ponds are missing from the data. Caslys captured an additional 115 ponds across the study area from the most recent air photos. Based on input from CRD, it was also deemed appropriate to group lakes with a surface area smaller than one hectare with the ponds and only use streams attributed as 'primary' for the purposes of mapping riparian potential.

3.2.2.5 Zoning

The CRD supplied a cadastral parcel-level zoning layer that was used to refine the land cover information. This assists in defining urban and suburban areas as well as agricultural parcels. This layer also provides separation of private and public lands, as well as schools and sporting facilities used for tree planting potential.

3.2.2.6 LiDAR DEM and Point Cloud Data

The CRD supplied two formats of LiDAR data acquired by the Province. The Digital Elevation Model (DEM) of the ground surface was included with a 1-metre grid cell size and sub-centimetre vertical precision. This dataset excludes bridges and generally denotes the lower ground level or water surface where bridges exist. The LiDAR dataset was also acquired as a 3D point cloud in tiled .LAS format with X, Y, Z coordinates, and the intensity for each laser pulse return reading. This DEM and LiDAR point cloud dataset was not available in the red hatched area shown in Figure 1 near the Sea-to-Sea Regional Park; therefore, mapping in this region was completed without elevation and vegetation height data.

3.2.3 Derivative Map Products

3.2.3.1 Terrain-based Datasets

Using the LiDAR DEM grid, the following derivative datasets are developed to aid in mapping and data visualization tasks (each dataset is produced at a 1-metre cell size):

- Slope (in percent).
- Aspect (in degrees from North).
- Multiscale Topographic Position Index (TPI) is the measure of deviation of a pixel elevation compared to the average elevations across an area defined by a search radius. A pixel that is higher than average has a relatively high topographic position; while a pixel that is lower than average is downslope. The search radius used has a significant influence on the results, and the combined result from iterations with different distances creates a realistic representation of upland and lowland areas. The multiscale TPI is derived from the following search tolerances:
    - 100m, 250m, 500m, 1000m
- Hillshade is a cartographic shading of the DEM based on a modeled sun illumination that brightens slopes that face the sun and darkens areas that are shaded by terrain. The result is displayed as a semi-transparent grid over top of the DEM or other layers to help assist in visualizing the terrain. This layer is not used formally in any spatial models, but does assist in visualizing terrain for interpretation of features such as upland bedrock, coastal bedrock and beaches, and riparian potential.

3.2.3.2 Canopy Height Model (CHM)

The LiDAR point cloud is used to derive two versions: the first return surface at 25cm; and 1-metre resolution. The first return is the highest elevation point within each pixel and represents the top of canopy and building roofs. The DEM is subtracted from the first return surface to provide the Canopy Height Model (CHM), which forms an accurate height of vegetation, buildings, and other features on the landscape. This can include features such as cars, trucks and buses, which are not located in the same positions as in the orthophoto (acquired at a different time). The CHM serves to provide valuable information about the height of vegetation to classify trees from shrubs and other low vegetation types such as grass, herbaceous covers, or agricultural crops. This allows for the accurate separation of small trees and shrubs that are less than 3 metres tall, from trees and tall shrubs that are 3-metres or taller. The 1-metre version is used for the initial land cover classification, while the 25 cm version is used for tree type classification and tree metrics that help define coniferous and deciduous classes.

3.2.3.3 LiDAR Point Cloud Derived Datasets

The LiDAR point cloud provides two other key datasets that aid in classification of land cover.

- Each return point is attributed with a return intensity. When the LiDAR pulse hits water, a large portion of the signal enters the water, while only a small portion returns to the sensor; resulting in low intensity. Conversely, low vegetation tends to reflect a strong signal back to the sensor, while trees and non-vegetated surfaces have a range of moderate intensities. The average of all intensity values with each grid cell is produced to aid in classification.
- A LiDAR pulse can refract and/or reflect off the various cover types in different manners that return few or several signals back to the sensor. A second grid is produced with the ratio of LiDAR returns per pulse for each grid cell. In general, water has the lower ratio of returns (e.g., less than 1) as the pulse

passes into the water; trees tend to have the highest ratio of returns per square metre (e.g., approximately 10); and other features are found between these values.

3.2.3.4 Satellite Image Derivatives

Two satellite image products are developed to assist with project mapping tasks:

- Publicly available Sentinel-2 satellite imagery was acquired with 10-metre multispectral resolution for several cloud-free dates through spring, summer and fall between 2017 and 2019. These images provide insight into vegetated land covers that change or remain relatively consistent over time. Normalized Vegetation Difference Index (NDVI) is an image combination that uses infrared and red wavelengths to measure the level of photosynthetic activity in vegetation. NDVI is calculated for each image date and the variance of these values is calculated across all dates. Trees and shrubs tend to have low values when leaves are off, and higher values when leaves are on. Grass and herbaceous cover types can also see periods of green and dryness. Agricultural croplands see the highest range when fields are plowed to have zero NDVI, and later irrigated with very high levels of growth resulting in very high NDVI values. These characteristics allow for separation of cropland areas from other areas that could potentially be candidates for tree planting within agricultural zoned parcels.
- Publicly available Landsat satellite imagery was acquired for the last 35 years and processed to identify pixel locations that have seen the removal of vegetation at some point in time. A location where trees are removed and impervious surfaces are developed sees a dramatic reduction in greenness as measured by the Landsat multispectral sensor. An area where upland bedrock exists will have consistently low greenness, while an intact forest will have consistently higher greenness over the 35-year period. The areas where greenness drops dramatically are selected and converted to a binary grid that identifies human development. This binary grid can later be used a mask to better differentiate natural bedrock from human development (pavements, concrete, gravel, roofs, etc.).

3.2.3.5 Other Derivatives

Orthophoto imagery contains the red, green, and blue bands; and in order to highlight various feature combinations of these bands, were used to produce indices (e.g., Green Leaf Index, luminance, redness, blueness).

3.2.4 LiDAR Enhanced Classification

Using the orthophotos and various derivative products identified above, the enhanced classification approach is applied for the extended study area that covers areas that have not previously been mapped for land cover in the CRD. The classification methods applied across this region are presented below, with the only differences being that 2017 orthophotos are used for the southern Gulf Islands, and 2015 orthophotos are used for the Trial Islands. The 2019 vintage photos are used for all portions of Vancouver Island proper. To clearly differentiate this classification from past methods, use of the term “Enhanced Classification” is applied throughout this report.

3.2.4.1 Enhanced Classification

A key advantage of LiDAR is the geometric precision and lack of distortion resulting from airphoto geometry – primarily the parallax that results in tree and building features appearing to lean over. Although the orthophoto correction process places the ground level of features in the correct location, tree canopy and building roofs are offset by varying distances depending on height and the offset distance from directly under the plane during acquisition. The location of a tree canopy in the LiDAR dataset is accurate, while the location of that same canopy in the orthophoto can be offset by as much as 5-metres. The added precision of the LiDAR forms the primary rationale for conducting the first level of image classification using LiDAR parameters as inputs to a Random Forest Model approach.

STEP 1: The Random Forest (RF) machine learning algorithm uses a collection of decision trees to produce a robust classification built from a set of independent predictor variables relative to supervised training sites. Each individual decision tree produces a class prediction based on a series of binary choices for a random selection of the predictor variables. The information generated from the individual decision trees is merged together to produce a final classification that is more stable and accurate than any one of the individual trees. A Random Forest classification is completed using the following input layers:

- Canopy Height Model
- Digital Elevation Model
- LiDAR Average Intensity Grid
- LiDAR Maximum Intensity Grid
- LiDAR Minimum Intensity Grid
- LiDAR Pulse Return Ratio Grid
- Combined Building Footprints

The initial segmented classes generated through this approach are as follows:

- Water
- Buildings
- Bare surfaces without vegetation
- Grass / herbaceous or similar low vegetation types less than 50 cm tall
- Shrub or small tree vegetation between 50 cm and 3-metres tall
- Tree or tall shrub vegetation taller than 3-metres

Upon inspection, the results of this first level classification have a very high level of accuracy and precision and are then used as the basis for further refinements into the 19 final land cover classes presented in Table 4.

STEP 2: The initial classes are then refined using the orthophoto, various derivative layers, and polygonal datasets. The goal of this step is to improve upon the segmentation of the initial classes before introducing more refined land cover classes. The following masking steps (a dataset defining which of the inputs will be considered in the execution of the tool) were applied:

1. Confusion between the bare and water classes within lakes is improved by reclassifying the areas that fall under water feature polygons using the orthophoto.
2. The orthophoto is used to refine the shrub class.
3. The orthophoto is used to refine the herb class.
4. The orthophoto is used to refine the bare class.
5. The coastline polygon is used to improve the water class.

STEP 3: New classes are introduced to the classification using various derivative layers and masks often built from polygonal datasets to achieve more detailed classes. The following masking steps were applied:

1. Lawns and other more manicured grasses are differentiated from various other herbaceous ground covers based on a masked derived from the Canopy Height Model. Lawns have a defined height of less than 20cm, while herbaceous vegetation ranges from 20cm to 50cm. This mask is applied to generate Classes 8 (Grass) and 9 (Herb) from areas that were previously defined as low vegetation.
2. The hydrology polygon file with lakes, ponds, wetlands and wide rivers was augmented with the addition of additional ponds interpreted from the orthophotos. Additionally, a polygon derived from the values in the DEM at or below 0-metres, corresponds to the extent of the ocean at the time of LiDAR acquisition. The ocean file was compared to the Canadian Hydrographic Service high tide linework to ensure its validity. These masks were then applied as an overlay to the classification to force water classed areas into the specific Ocean, Lake, Pond, and River classes.
3. The Provincial Digital Road Atlas linework was buffered by 4-metres to create a mask of paved roads. This mask is applied to the classification to force ground level classes to Class 15 – Road. It is common for tree canopy to extend over portions of a road, and in these cases, the land cover is mapped as Tree (coniferous or deciduous).
4. Masks were generated to define areas with higher potential to be upland bedrock, and higher potential to be bare soil. This also differentiates these areas from other non-vegetated areas in urban areas such as gravel and concrete. At this stage, shoreline classes for bedrock and beach gravels / sands are not captured. The bedrock mask was defined as areas with upland topographic position from the multiscale TPI layer and not within 10-metres of a building or road. This mask was further refined by excluding areas where the Landsat Long Term Change derivative layer identified development over the past 35 years. Lastly, a series of manual edits were made in urban areas to remove bedrock potential in places where the landscape is heavily developed but not within 10-metres of a road or building. This mask was applied to generate the first iteration of the upland bedrock class. A separate urban mask was defined as a 5-metre buffer around buildings, and a dynamic buffer around roads (DRA) based on a function of the speed limit. In some cases, buildings that were missing in the original file were manually added. In addition, the masks used to limit bedrock mapping factored in cadastral dataset parcels with attributes for civic institutions, industrial facilities, residential and agricultural areas. This step introduced the Bedrock, Bare Soil, Loose Gravel, and Pavement/Packed Gravel Classes.
5. An agricultural mask is applied to force various bare and vegetation types lower than 3-metres to Agriculture (Class 17). This includes the Shrub, Herb, and Grass vegetation Classes. The 3-metre height threshold for the Shrub Class coincides with the maximum elevation of some tall crop types (e.g., corn fields) found within the study area. Agricultural areas can be defined through three optional source files; this includes the Provincial Agricultural Land Reserve (ALR) polygons which are far too coarse for this purpose. Instead, two more detailed datasets were combined:
    a. The Cadastral layer provided by CRD includes a parcel-level agriculture designation which is the primary source. This layer is used to delineate agriculture within the full study area. Manual review and edits were conducted to improve this layer for the purpose of agricultural mapping – resolving larger regions of forest that are sometimes found within agriculturally zoned parcels.
    b. The Agricultural Land Use Inventory completed by the Province also includes sub-parcel mapping of agricultural classes which delineates portions of parcels that have active agriculture. This layer is used in conjunction with the CRD cadastral layer to delineate agriculture on the Saanich Peninsula and through parts of Metchosin and Sooke.
6. Docks found in lakes and ocean are classified based on spectral characteristics in the orthophotos and elevation parameters seen in the LiDAR. A manual digitization and reclassification approach was used

to map docks found within lakes. For docks found in the ocean, the LiDAR data was employed along with a cost surface approach. This allowed for the capture of elevated features found in the ocean, but connected to the shore. In some cases, shallow shores, estuaries, and spits resulted in misclassifications. As a result, an additional mask was created to manually fix areas that were misclassified as docks. These manual masks are applied to convert missed pixels into Docks (Class 13), as well as to convert misclassified pixels back to the appropriate Water classes (1 through 4).

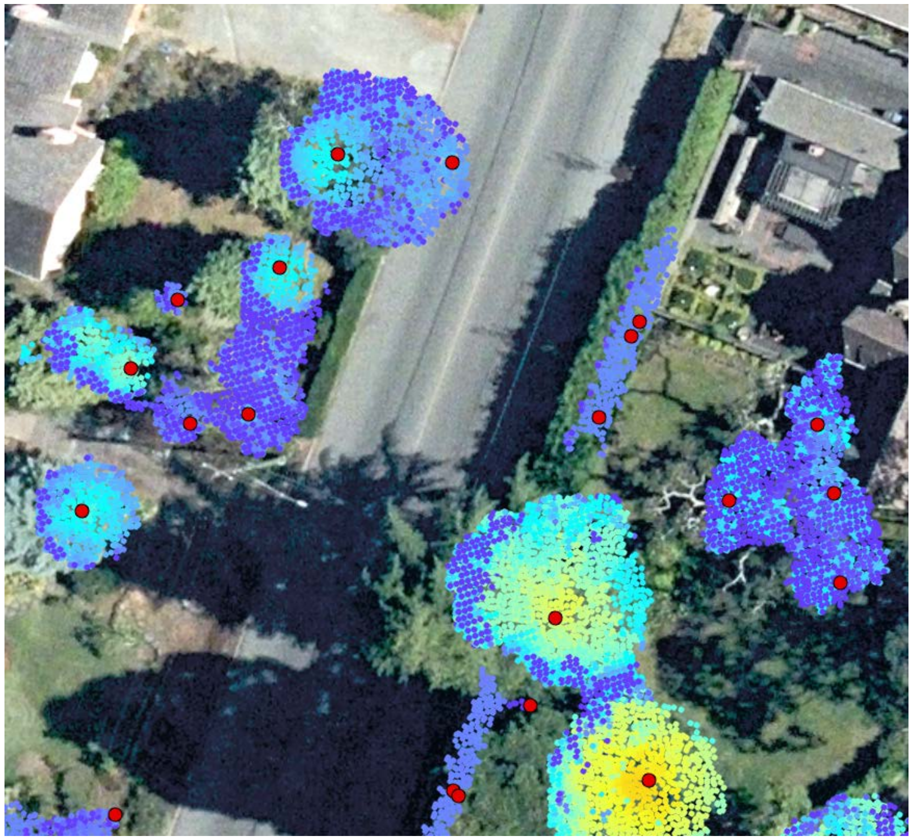
7. The non-vegetated shoreline is characterised by Gravel, Sand and Mudflats (Class 5), Bedrock (Class 6), and in certain developed areas, the shoreline can be developed Impervious Surfaces (Class 14). An approach was used to convert bare areas adjacent to the shoreline to their respective shoreline class. The LiDAR DEM is used to define bedrock as an area with upland topographic position and/or slopes greater that 30 percent. This differs from beach areas which are characterized by lower slopes and generally low topographic position relative to the surrounding land. Areas that were classified as bedrock will therefore become bedrock shoreline, and non-bedrock bare classes will become sand/gravel shoreline. This generates errors in more developed coastal areas such as harbours and areas with waterfront development. An additional mask is mapped manually across these developed areas to convert Non-Vegetated classes to Class 14 (Pavement / Packed Gravel).

STEP 4: Vegetation taller than 3-metres is refined into deciduous and coniferous classes. This approach relies on the use of the bare earth DEM and the LiDAR point cloud data to define tree stems, and crown parameters.

The LiDAR is processed tile-by-tile (based on the 1:2500 scale BCGS) to generate a seamless point layer that is attributed with LiDAR based tree statistics. This process is described in more detail in Section 3.2.5. The results of this analysis were twofold:

1. LAS point cloud files that only included the points that are assigned to trees. An example is shown with the yellow to purple elevation coloured gradient in Figure 8.
2. Approximately 7.5 million tree points with statistics generated from LiDAR points that were associated with each tree. These are shown as the red points in Figure 8.

Figure 8. LiDAR Tree Point Clouds and Tree Crown Location Points



Using these two analysis results, classified tree polygons were developed. The tree point layer was loaded into an ArcGIS Map for visual inspection. For the purposes of classifying the tree points, a sample of them was manually labelled as coniferous or deciduous trees. Additionally, tree points that were not identified correctly during the lidR processing (i.e. using the digital orthophotos, it could be seen that they were not trees) were assigned to classes such as pole (power, streetlight, etc.), power line, built, bridge, dock and hedge. 'lidR' is an open-source package developed though University of British Columbia (Prof. Nicholas Coops), Laval University and the Quebec Ministry of Forests, Wildlife and Parks between 2015 and 2021. User support is available via GitHub authored by Jean-Romain Roussel et al. For example, in Figure 8, it is evident that hedges are sometimes identified as trees. A random forest classification was trained on the manually labelled points. The classifier was then applied to the entire dataset. The result was a point layer with a probability of assignment for each class. The assigned class was based on the class with the highest probability.

The derivative LAS point cloud datasets, with only the tree points (described above), were then used to delineate crown polygons for each tree (each polygon will have the Tree ID to which it belongs). While tools exist to delineate vector polygons, the approach is too computationally expensive to perform on such a large study area. An alternative approach was developed that was raster based. In this approach, LiDAR points are converted to pixels and each pixel is assigned the value of the unique tree ID that it belongs to. By joining to the classified tree point layer, attributes generated in previous steps (i.e., statistical and predicted class attributes), based on the unique tree ID, the pixels of each tree could be assigned to a deciduous or coniferous class.

A Random Forest classification is completed using training data derived through orthophoto interpretation to classify each tree point into a deciduous or coniferous tree type. The classification is based on a long series of tree geometry and intensity parameters defined by the 'lidR' tree classification software built on the 'R' analytical platform. The tree classification is then assigned back to the canopy area as defined by the LiDAR points that belong to each tree and used as a mask to convert the land cover classification values into Deciduous (Class 11) and Coniferous (Class 12). More details related to tree metrics and the tree point dataset are presented in Section 3.2.5.

STEP 5: Trees and shrubs are misclassified in two cases that require specific post-processing corrections. This issue is complicated by the fact that the date of the LiDAR collection is different from the orthophotos, and therefore the position of vehicles is different in both datasets. The following post-process corrections have been applied:

1. In cases where building footprints a slightly misaligned with pixels that have been assigned vegetation classes, we see a single pixel "halo" around certain buildings where trees have been mapped incorrectly. Essentially, the classification finds features that are not mapped under the building footprint, but the LiDAR indicates that these vegetated areas of lawn are at the height of the building. It is also common for some trees to be correctly mapped directly adjacent to a building or to have canopy above a roof. The mask is generated to locate misclassified tree pixels that have a 1-pixel (1-metre) width adjacent to buildings, but no other mapped tree areas adjacent. This mask converts the misclassified pixel to Buildings (Class 16) and leaves pixels as trees where the patches are larger than 1-pixel in width.
2. Cars, buses, trucks and airplanes are found throughout the study area on paved and gravel surfaces. When these objects are located on mapped roads, they have already been appropriately forced to the Road Class (Class 15). In parking lots and on airport tarmac, the features are often misclassified as trees (when taller than 3-metres) and shrub (when less than 3-metres in height). In cases where the Shrub Class is found fully surrounded by impervious surfaces, any adjacent shrub pixels (to a distance of 1-metre) are converted to Class 14 (Paved / Packed Gravel). Since cars are approximately 2-metres wide, this resolves the vast majority of misclassified cars from the land cover map. A mask is created manually to deal with planes and taller vehicles in parking lots throughout the study area. This mask is applied to remove many of the misclassified vehicles. Other similar features such a heavy machinery at industrial facilities may not be captured.

STEP 6: Review and manual fixes are applied where mapped features do not align with orthophoto interpretation. A series of issues that persist are rectified through manual fixes. This includes:

1. Misclassification of bridges, which tend to be classed as trees because they exhibit a height from the LiDAR that falsely assigns these taller features to the tree classes.
2. Some agricultural areas with greenhouses or plastic materials on the ground surface are resolved.
3. Areas with significant numbers of buses or trucks are also resolved to the Pavement Class. There is no significant spectral difference between areas with loose gravel and areas with pavement/packed gravel; this resulted in the implementation of a manual digitization approach.
4. A review of the Dock Class resulted in manual edits to areas of shoreline misclassified as docks.
5. Misclassifications in the Bedrock Class were also manually fixed.

3.2.5 LiDAR Derived Tree Data

The LiDAR point cloud is used to derive tree stem points and a series of canopy metrics per stem based on vegetation that is taller than 3-metres. This may also include some hedges and shrubs that are taller than 3-metres. Caslys has applied the 'lidR' package to process the .LAS files and conduct tree segmentation, tree stem identification, and to assign each stem a series of metrics that describe the geometry and form of each tree.

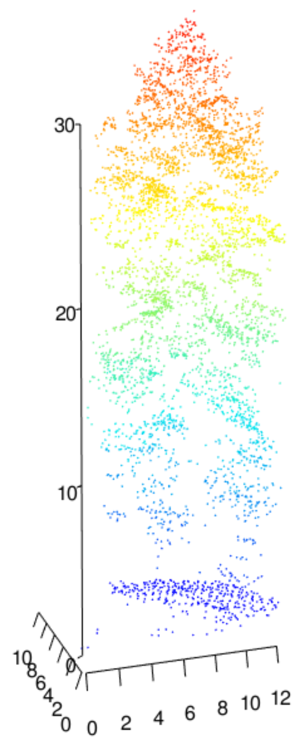
LiDAR processing was computationally expensive and also consumed a vast amount of disk storage. Each step in the process generated a new set of LiDAR LAS files. Much of the processing was conducted using an Intel Core-i9 processor (8 physical cores, 16 logical cores), with 64 GB of RAM. In many cases, memory limitations were encountered and tiles had to be subdivided to accommodate the intensive processing. Approximately 35 billion LAS points were processed for the study area over hundreds of hours of processing.

LiDAR was processed primarily with R using the lidR package developed by Laval University (https://github.com/Jean-Romain/lidR). The process, at a high level, followed these steps:

1. Classify buildings in the LAS. This step uses ArcGIS LiDAR geoprocessing tools. This is important because removal of buildings during downstream processing reduces false identification of tree points from roof-tops and chimneys.
2. Normalize the LiDAR point elevations heights using the bare earth DEM. This produces LAS datasets of relative heights where the effects of actual surface elevation have been removed. During this phase, points classified as buildings or (outlier) noise are dropped from the output. As stated in the previous step, this reduced false tree identification.
3. A noise filter was run on each LAS file to remove extreme outliers based on height (Z value). These values would negatively impact downstream processing.
4. A Canopy Height Model (CHM) raster is computed for each LAS file based on the point heights (Z value). The goal is to produce a surface that can be used to identify high points that represent individual tree crowns.
5. Where building footprint polygons were available, they were used to set the CHM elevation to zero-metres. A buffered version of the buildings was used for this to ensure that any edge effects were minimized. The purpose of this step was to exclude roof-tops and chimney objects from influencing the tree crown identification process. While earlier steps included filtering out LAS classified as building, that process often left a halo of tree points around a building footprint that would create a negative impact on the CHM processing.
6. The CHM is smoothed using a mean filter with a 5x5 moving window. This step helps when attempting to identify the true tree crowns in a forested area. Without smoothing, many false crowns are identified in the next steps.
7. A tree point identification algorithm is used on the CHM to identify individual tree points. A 3-metre threshold is used in an attempt to exclude shrubs from the output. Without this threshold, many smaller features such as hedges and cars can be included. The output of this step is a point (geometry) for each tree identified, with a unique Tree ID assigned.
8. Using the tree points and CHM, the LAS is segmented into individual trees. Each individual LAS point is examined to see if should be assigned to a tree from the collection of individual tree points determined in the previous step. If a LAS point is associated with a tree point, it will be assigned the Tree ID. With a collection of LAS points representing a tree, tree based statistics can be calculated. An example of a LAS point cloud tree is shown in Figure 9.

9. Tree metrics are calculated using the LAS tree points for each tree and these are assigned to a point geometry for each tree. The output is a point GIS layer with a field for each statistic. The lidR R package provided a function called 'tree_metrics' for computing some standard metrics. These statistics are described in Appendix A and are documented by the author at: https://github.com/Jean-Romain/lidR/wiki/stdmetrics.

Figure 9. Example of 3D LAS Point Cloud for an Individual Tree



3.2.6 Hectare-based Decision Support Tools

Zonal statistics were calculated for each one-hectare grid cell as summarized previously for 2005 and 2011 datasets using the tree cover and impervious surface datasets. This approach summarizes the percent cover per hectare cell. The percentage values were then divided by the percentage of land within each cell to determine the percentage of the land base within each cell that is treed and the percentage that is covered by impervious surfaces. The cells were then grouped into the following classes based on the land-based percentage value. The generalization down to the hectare-level makes this approach a useful tool to compare past results to the updated LiDAR-enhanced approach. Figure 5 illustrates the resolution of the tree cover proportion classification using these classes:

- 0 - 5 % (primarily non-forested [e.g., an urban area or agricultural field with little to no trees]);
- >5 – 10% (very low proportion of urban forest [e.g., an agricultural area with hedgerow trees or a high density residential area with a few street trees]);

- >10 – 25% (low proportion of urban forest [e.g., a moderate density residential area or a golf course with some treed areas]);
- >25 – 50% (medium proportion of urban forest [e.g., a low to moderate density or well established residential area, parks with playing fields and trees]);
- >50- 75% (high proportion of urban forest [e.g., rural residential areas or cells fringing on forested areas]); or
- >75% (very high proportion of urban forest [e.g., undeveloped areas or heavily treed parks]).

The proportion of impervious surface present in each time period was determined and assigned to the following classes as illustrated in Figure 6:

- 0 - 5 % (primarily undeveloped or permeable [e.g., treed areas or grass areas, agricultural fields, golf courses]);
- >5 – 10% (very lightly developed [e.g., rural residential areas, agricultural areas with a few associated buildings and paved surfaces]);
- >10 – 25% (lightly developed [e.g., low density residential areas, or areas on the fringe of green space]);
- >25 – 50% (moderately developed [e.g., suburban residential areas]);
- >50 – 75% (heavily developed [e.g., highways with grass covered boulevards, apartment complexes with limited grass/treed areas]); or
- > 75% (very heavily developed [e.g., parking lots, large buildings, downtown core]).

Summary statistics were generated (and provided in Esri Shapefile format) to quantify the following tree cover and impervious surface proportion changes:

- Tree cover and impervious surface proportion in 2019 (summarized by one-hectare grid) for the CMA.
- A comparison of tree cover and impervious surface proportion (summarized by one-hectare grid) change between 2005, 2011 and 2019 for the CMA.
- A summary of tree cover and impervious surface proportion change trends by municipality between 2005, 2011 and 2019.

Table 4 provides a list of attributes and a data structure for the file. It should be noted that as additional mapping is conducted in the future, the data can easily be stored within the file by simply adding new year-specific attributes.

Table 4. Data Structure for the Hectare Grid Coverage

Field Name	Description	Field Type	Attributes
Feature ID	A unique identifier allowing the polygon to be linked to other datasets (e.g., land cover, zoning, Hectares B.C.), as required.	Numeric	Numeric ID
BinFor86	Cells are assigned to one of six classes (bins) to indicate the percentage of tree cover present in the 1986 time period.	Character	0 – 5 >5 – 10 >10 – 25 >25 – 50 >50 – 75 >75 - 100
BinImp86	Cells are assigned to one of six classes (bins) to indicate the percentage of impervious surface present in the 1986 time period.	Character	Same 6 class bins (as above)
BinFor05	Cells are assigned to one of six classes (bins) to indicate the percentage of tree cover present in the 2005 time period.	Character	Same 6 class bins
BinImp05	Cells are assigned to one of six classes (bins) to indicate the percentage of impervious surface present in the 2005 time period.	Character	Same 6 class bins
BinFor11	Cells are assigned to one of six classes (bins) to indicate the percentage of tree cover present in the 2011 time period.	Numeric	Same 6 class bins
BinImp11	Cells are assigned to one of six classes (bins) to indicate the percentage of impervious surface present in the 2011 time period.	Numeric	Same 6 class bins
BinFor19	Cells are assigned to one of six classes (bins) to indicate the percentage of tree cover present in the 2019 time period.	Numeric	Same 6 class bins
BinImp19	Cells are assigned to one of six classes (bins) to indicate the percentage of impervious surface present in the 2019 time period.	Numeric	Same 6 class bins

3.2.7 Riparian Potential Model

In previous years, a simplistic riparian potential model was integrated into the land cover classification to define tree and herbaceous areas that were likely to include riparian habitat characteristics in areas adjacent to lakes, ponds and streams. The previous model was based on a geospatial cost-distance model that used available hydrology features as the source locations for a cost-distance (slope) surface derived from the available TRIM DEM.

Through collaboration with CRD and some other key stakeholders for this project, the riparian potential map has been separated from the LiDAR enhanced land cover classification and included as a stand-alone dataset. In this manner, riparian potential can be applied independently for various end-user requirements, including acting as a land cover class modifier. In addition, the riparian potential model is improved through the application of more detailed hydrology source data, the availability of the LiDAR DEM, and improved logic related to stream types, vegetation heights, and connectivity to the storm water drainage system and other engineered water management infrastructure. The previous '2-class' approach of mapping riparian potential or absence is enhanced to show existing riparian habitat as well as potential for existing or future riparian habitat restoration with the following '3-class' approach:

1. Non-Riparian: Little to no riparian potential
2. Riparian Potential Zone: Areas that may include riparian cover types or have potential through riparian restoration efforts
3. Existing Riparian Zone: Areas that likely include riparian cover types

The LiDAR Enhanced riparian potential model uses a cost-weighted distance surface that determines the cost water would incur to flow or permeate through the surrounding terrain. In this usage, "cost" refers to the friction for water to move or exist further away from an original source location. The source data layers were the CRD's hydrological data layers and the 1-metre LiDAR DEM. A cost-weighted distance analysis calculates a value for each raster cell based on the least accumulated cost of travelling upslope from each cell to the source (i.e., streams, lakes and ponds). Distances are not in geographic units but rather determined in cost units. The surface was developed by calculating a cost-weighted distance to determine the difficulty (the cost) of the streams to move through the surrounding terrain. A slope map was used as the terrain component of the model – flatter terrain (lower slopes) to offer less resistance and therefore have a lower associated cost; whereas steeper slopes have a higher cost. Riparian habitat surrounding a stream will, therefore, be more extensive in flatter areas and narrower in steeper terrain.

The cost-surface grid is defined by the slopes generated from the LiDAR DEM with additional (significant) costs added where roads and buildings exist. The riparian source locations are defined with individual model parameters from the following source features:

- Lakes supplied by CRD in the hyd_Poly shapefile
- Wetlands from hyd_Poly shapefile
- Ponds from hyd_Poly
- Additional ponds captured by Caslys through orthophoto interpretation
- Streams and ditches from hyd_Line shapefile

The above features are separated into the following groups for analysis:

- Primary classed streams
- Primary classed ditches (further excluding ditches found within close proximity to roads)
- Large lakes urban (larger than 10,000m^2)
- Large lakes non-urban (larger than 10,000m^2)
- Small lakes urban
- Small lakes non-urban
- Ponds urban
- Ponds non-urban

In addition, pond, stream and ditch source files were separated into two classes as follows:

- Source features that connect directly (within 10m) to storm water linework in the hyd_Line file (i.e., Gravity Mains, Lateral Lines, and Pressurized Mains) or other engineered features in the hyd_Point shapefile (i.e., Service Connections, Manholes, Interceptors, Clean Outs, and Catch Basins). These features are expected to manage the water flow in a manner that reduces the potential for riparian habitat. These source features are termed 'More Natural' to differentiate them from the feature below.
- Source features that exist in a more natural or rural setting, where they are not in proximity to the engineered water management features described above. These source features are termed 'Urban' to differentiate them from those above.

Individual cost-distance models are run from each of the above source (seed feature) map layers. The cost threshold that is applied to each feature type is based on aligning the distances in the model to the general location of riparian shrub and tree features interpreted in the orthophotos at selected locations.

In addition, in more urban environments (as defined by the proximity to engineered water management features), the riparian potential model is restricted to only extend into adjacent areas where shrub or treed vegetation exists (as mapped in the land cover classification). This approach limits riparian potential to only those areas along streams where taller vegetation exists.

The following thresholds (or cumulative costs) are applied to each source feature type:

- More Natural Source Features
    - Lakes 150
    - Wetlands 100
    - Ponds 10
    - Primary Streams 150
    - Primary Ditches 30
- Urban Source Features
    - Lakes 30
    - Selected Ponds* 5
    - Primary Streams 100
    - Primary Ditches 0 (i.e., no riparian potential)

  * *Note that a small number of ponds found in urban areas have been selectively removed from riparian modelling in areas where they are maintained by engineered flows or concrete walls or landscaping that limit riparian potential.*

To better comprehend the cost-distance model thresholds listed above, consider these examples. The cost to travel across:

- 5 pixels with a constant slope of 5% = 25;
- 100 pixels with a constant slope of 1% = 100;
- 2 pixels with a constant slope of 50% = 100;
- 1 pixel with a slope of 50% and 10 more pixels with a slope of 2% (= 50+20) = 70.

Each individual model defines an area where riparian potential exists. The various source file models are overlaid to derive a single map layer that delineates the riparian potential zone. The model is run a second time with the same settings outlined above plus an additional limitation to derive the existing riparian vegetation zone. The existing riparian vegetation zone model only allows the cost-distance model to extend into adjacent treed or shrubby areas as mapped in the land cover classification results. The results of the riparian potential zone are merged with the results of the existing riparian vegetation zone to form a single raster layer.

The riparian model results can be used in conjunction with land cover mapping, tree planting potential or other land management map products when applicable to support decision-making.

3.2.8 Potential for Tree Planting

The addition of LiDAR and additional datasets applied through the enhanced land cover mapping approach increased the detail that can be applied to mapping potential for tree planting. Tree planting has the ability to reduce or reverse some of the impacts associated with development in the Region. The tree planting potential map layer should be used in conjunction with operational knowledge or field specific judgement to determine precise logistics. Specifically, the tree planting model does not account for underground utilities, street lamps, fire hydrants, or overhead powerlines which should be factored into planning. Residents should be encouraged to follow municipal guidelines where available. Municipal users with access to utility GIS data could refine the model to limit potential near utility infrastructure. Please note that "some areas included in the model may not be appropriate to plant trees including sensitive grassland ecosystems".

Overall tree planting potential is scored as a having one of the following values:

- 0 – Not Suitable
- 1 – Low Potential Areas
- 2 – Moderate Potential Areas
- 3 – High Potential Areas

In all cases, local knowledge and field circumstances may alter the tree planting plans. Larger areas of suitability may provide more ideal sites for planting, but a large area of suitability does not infer that planting could or should cover the full area mapped. For example, a larger open park may be identified as having planting potential, but perhaps only a few trees should be planted across the larger area in locations planned through further desktop planning or field visits.

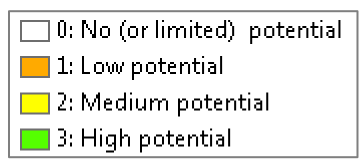
Planting Potential Model Ruleset:

1. Land Cover classes with ‘Bare’, ‘Grass’, ‘Herbaceous’ or ‘Shrub’ cover types are allocated with some level of potential, while other classes are assigned as not suitable.
2. Areas within 2-metres of a building are assigned as not suitable.
3. Highways attributed as Ministry of Transportation responsibility are isolated from the DRA roads file and the right-of-way is defined from the adjacent linework in the cadastral parcels. In cases where those parcels are not differentiated from other adjacent land ownership (e.g., stratas), a distance of 50-metres from the road centreline is applied to define the right-of-way. The Ministry of Transportation and Infrastructure (MOTI) land is set to ‘Not Suitable’ since specific safety and maintenance concerns exist and a formal permitting process is needed.
4. Caslys manually interpreted and delineated sports fields and playground areas within associated cadastral parcels and set the tree planting potential as ‘not suitable’ with 5-metres of these areas. There may be additional sports fields not captured that exist on lands zoned other than schools, parks or other civic lands. Golf courses and cemeteries are also treated as lands that have low potential, but actual planting opportunities must consider functional restrictions to determine if and where there may be suitable areas within the larger portions that have been modelled. In other words, planting on fairways

and greens is not expected, but portions of the property may have specific planting opportunities of other limitations.

5. The LiDAR DEM is used to determine the average slope value (in percent) over a 5-metre radius to locate flatter areas and steeper slopes, which may restrict planting from an operational standpoint. The landscape is divided into the following slope classes to adjust tree planting potential:
   a. 0-30% No adjustment based on slope
   b. >30-60% Limited to Moderate Potential
   c. >60-100% Limited to Low Potential
   d. >100% Set to Not Suitable for tree planting
6. The Cadastral dataset is used to define agricultural parcels. These parcels are further separated into areas mapped as having active cultivation or ploughing, where multi-date Sentinel-2 imagery shows signs of bare fields and green areas at different times of year. The red:green satellite image band ratio is used to identify ploughed fields between 2016 and 2020. Areas of cultivation are assigned to the Not Suitable class, while other areas of the farm may remain as having tree planting potential. Smaller parcels or hobby farms may not be captured in this process and some larger agricultural areas that do not appear to be actively ploughed may also remain as having planting potential. Pasture is typically not captured unless the areas appear very bare in some seasons. This constraint is further modified to allow higher planting potential within 2.5-metres of the farm parcel boundaries. This allows for planting in the form of hedge rows or trees between farmed areas. One limitation of this approach includes the creation of higher potential in areas where land is being worked across the parcel boundary (which is often the case where a land owner owns or leases adjacent parcels and works these parcels as one field).
7. The multi-scale Topographic Position Index (TPI) dataset derived from LiDAR is used to assign the landscape into upland (likely xeric or thin soils), lowland (likely hydric or seasonally saturated soils), and flat or mid-slope soils that are common or mesic soil types. These classes allowed for consideration to be given to the soil wetness when assigning planting potential. This layer could also be used to inform planting logistics with respect to soil moisture but would not supersede field verification.

The tree planting model takes the above considerations into account to assign tree planting potential into the four classes illustrated here. Although there is potential to further modify these results by land ownership to assist with planning or operations, ownership is not currently applied to the model.



4.0 RESULTS

Land cover mapping was completed using traditional orthophoto classification methods to allow for consistency of comparison to past years, and then again with the benefit of LiDAR to leverage added data towards a more detailed and accurate land cover map. These results are presented in Section 4.1, along with accuracy assessment results and a comparison of the two methods. Comparisons are made by tabulating the areas of classes across various geographic regions, including municipalities and First Nation jurisdictions.

Section 4.2 presents the results of land cover trends by comparing the mapping results from this current project to the results from past mapping in 2011 and 2005, where available.

Section 4.3 highlights the results of other analysis completed during this project including the use of a one-hectare grid to report the proportion of treed and impervious cover types and the change in those cover types across the 2005, 2011 and 2019 reporting periods.

Table 5 lists and describes the uses for the digital files produced during this project.

Table 5. Digital Data File List

Item	Filename	Description
1	CRD LC no lidar.tif	1-metre raster file of land cover mapped without the use of LiDAR for the Core Municipal Area.
2	CRD LC no lidar_PR.tif	1-metre raster file of land cover mapped without the use of LiDAR for the Port Renfrew / Pacheedaht area.
3	CRD LC lidar-enhanced.tif	1-metre raster file of land cover mapped with the addition of LiDAR for the Core Municipal Area including Salt Spring and the southern Gulf Islands.
4	CRD LC lidar-enhanced_PR.tif	1-metre raster file of land cover mapped with the addition of LiDAR for the Port Renfrew / Pacheedaht area.
5	CHM.tif	1-metre raster file of the height of features on the landscape for the Core Municipal Area including Salt Spring and the southern Gulf Islands.
6	CHM_PR.tif	1-metre raster file of the height of features on the landscape for the Port Renfrew / Pacheedaht area.
7	CHM_Veg.tif	1-metre raster file of heights for features that are mapped as trees or shrubs for the Core Municipal Area including Salt Spring and the southern Gulf Islands.
8	CHM_Veg_PR.tif	1-metre raster file of heights for features that are mapped as trees or shrubs for the Port Renfrew / Pacheedaht area.
9	RiparianPotential.tif	1-metre raster file of existing and potential areas for riparian habitat for the Core Municipal Area including Salt Spring and the southern Gulf Islands.
10	RiparianPotential_PR.tif	1-metre raster file of existing and potential areas for riparian habitat for the Port Renfrew / Pacheedaht area.
11	TPI_Uplands.tif	1-metre raster file of multi-scale topographic position index which highlights upland and lowland areas for the Core Municipal Area including Salt Spring and the southern Gulf Islands.
12	TPI_Uplands_PR.tif	1-metre raster file of multi-scale topographic position index which highlights upland and lowland areas for the Port Renfrew / Pacheedaht area.
13	TreePlantingPotenital.tif	1-metre raster file with low, moderate and high tree planting potential for the Core Municipal Area including Salt Spring and the southern Gulf Islands.
14	TreePlantingPotenital_PR.tif	1-metre raster file with low, moderate and high tree planting potential for the Port Renfrew / Pacheedaht area.
15	Treepoints.zip contains treeclassifications_delivery.gdb	Esri Geodatabase with point feature class for over 7 million tree locations which also contain attributes modeled from LiDAR that define tree metrics and tree type (deciduous vs. coniferous)

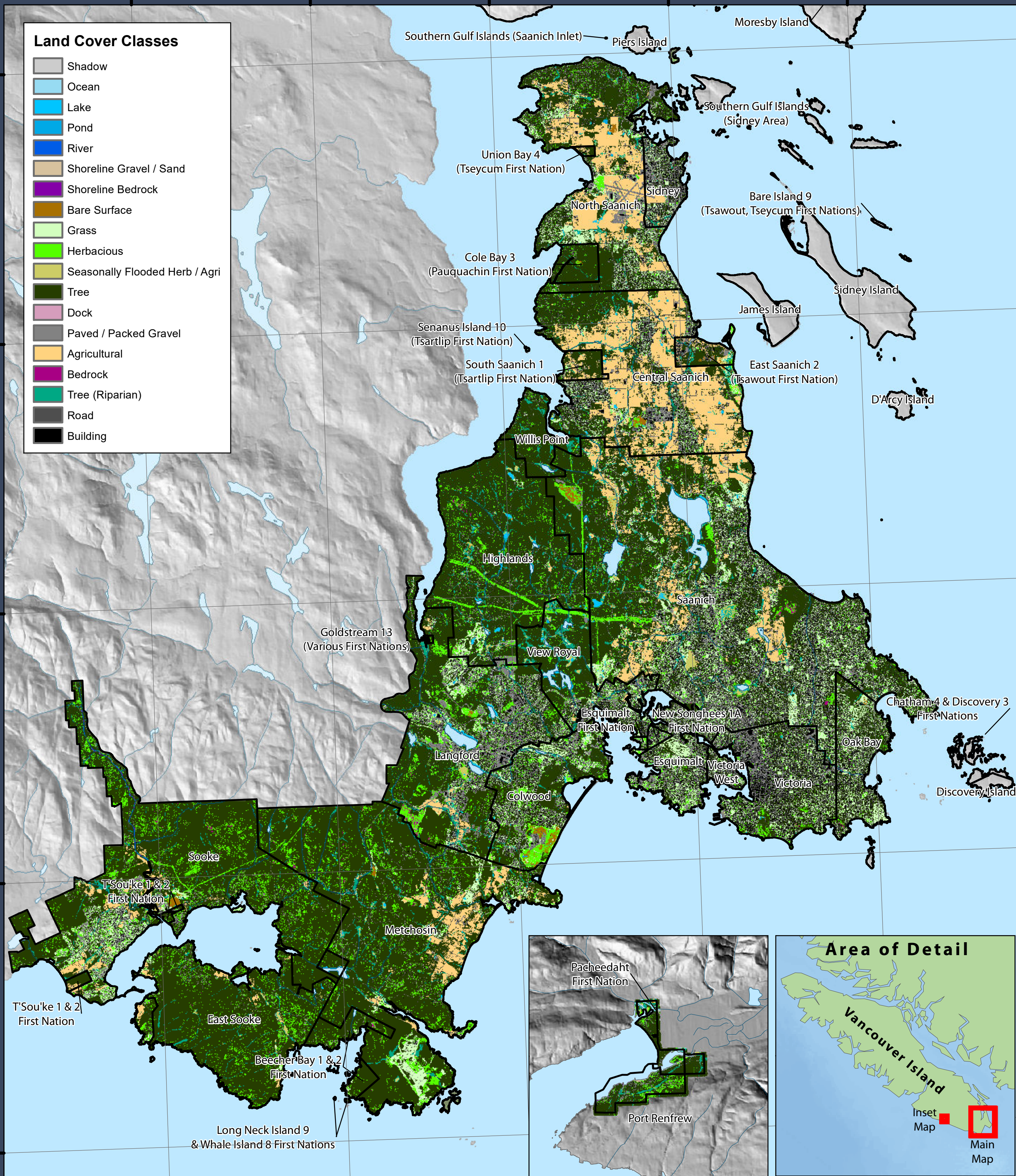
Item	Filename	Description
16	DSM.tif	1-metre raster Digital Surface Model derived from the top of features (or 1st return) from the LiDAR point cloud for the Core Municipal Area including Salt Spring and the southern Gulf Islands.
17	DSM_PR.tif	1-metre raster Digital Surface Model derived from the top of features (or 1st return) from the LiDAR point cloud for the Port Renfrew / Pacheedaht area.
18	DEM.tif	1-metre raster Digital Elevation Model (ground surface) derived by the Province from the source LiDAR point cloud for the Core Municipal Area including Salt Spring and the southern Gulf Islands.
19	DEM_PR.tif	1-metre raster Digital Elevation Model (ground surface) derived by the Province from the source LiDAR point cloud for the Port Renfrew / Pacheedaht area.
20	HectaresTrends.shp	Esri shapefile derived from the Hectares BC initiative that defines a one-hectare grid across the study area. Within each hectare cell, attributes are included to define the 2005, 2011 and 2019 proportions of tree cover and proportions of impervious surfaces as class bins. In addition to defined bins of percent cover, fields are also included that define the number of classes that a cell changed between the 2011 and 2019 time period. For example, A transition from the 0-5% bin in 2011 to the 10-25% bin in 2019 indicates a shift of 2 classes over this period.

Application of Canopy Height Model: The CHM provides a height value for features on the landscape. For this project, CRD chose to use a 3m threshold to differentiate tree and shrub in the land cover classification. The CHM can be used as a GIS overlay with the land cover results to redefine the threshold between trees and shrub with a different height value. For example: To locate trees taller than 5 metres, reclass the CHM to 2 classes (greater than 5 m and less than or equal to 5 m) with values 0 and 100 respectively; then use raster addition to add the reclassed CHM to the Land Cover results. The resulting raster file will have values above 100 where the tree heights are greater than 5 metres.

4.1 Land Cover Mapping Results

4.1.1 Land Cover Mapping Results (without LiDAR)

A set of figures provide an overview of the land cover mapping results. The digital files listed in the previous section should be used to review the data in more detail. Figure 10 presents land cover using the traditional mapping methods from the 2019 orthophotos (for the CMA and Port Renfrew). In addition, Figure 11 illustrates the same dataset aggregated by major land cover classes. The major land cover classes are simply a re-grouping of the land cover dataset into more generalized classes. These classes may serve to simplify certain decision support analyses where certain class separations are not required.



Jurisdiction Boundary
Lake
River

0 2 4 6
Kilometres

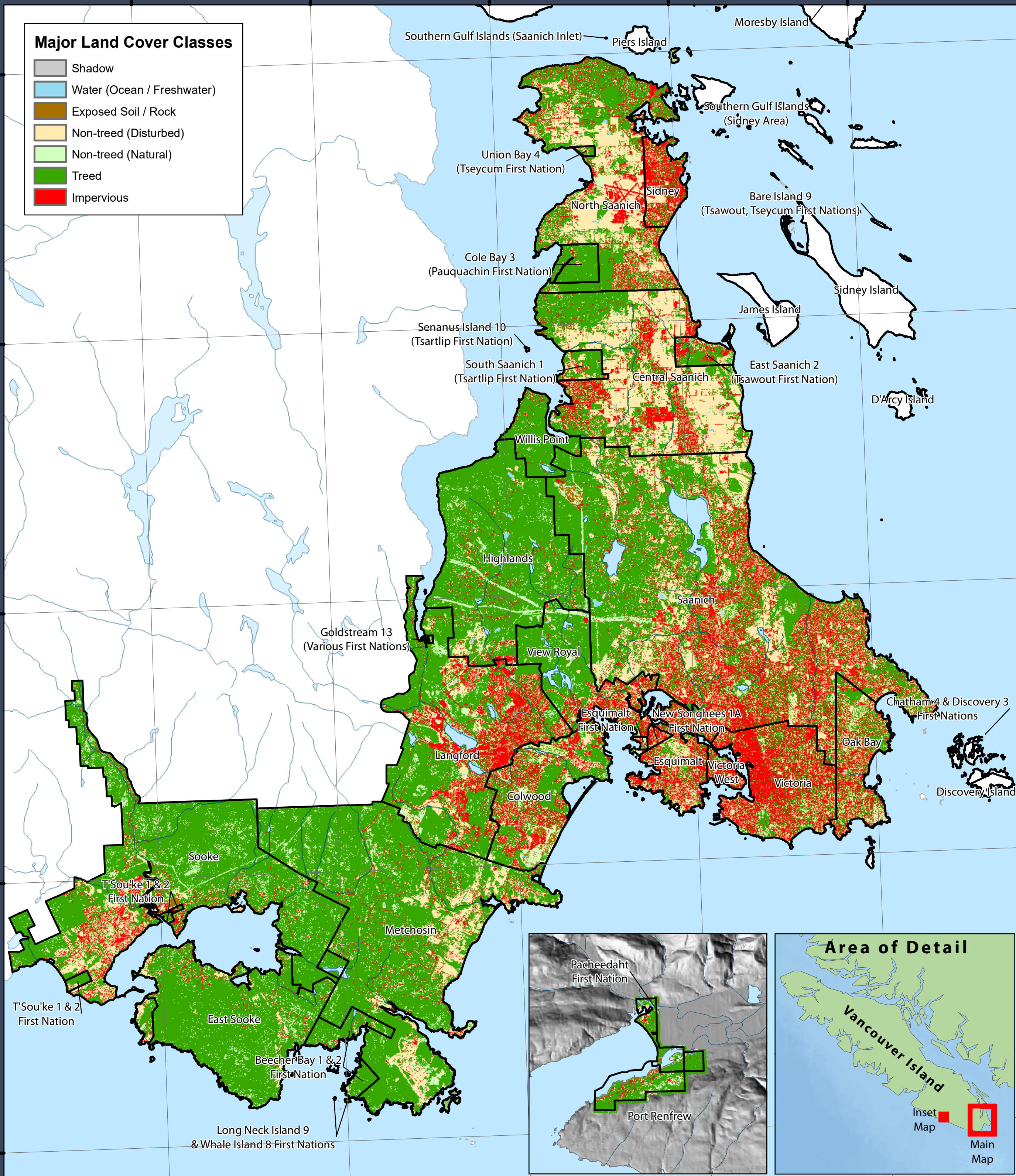
Projection: BC Albers NAD83

Data Sources:
Capital Regional District
Province of British Columbia

Figure 10. 2019 Land Cover (Orthophoto Method)
Core Municipal Area (includes Port Renfrew)

Urban Land Cover Mapping
CRD (2017/2019)

Prepared for: CRD Making a difference...together
By: CASLYS CONSULTING



Jurisdiction Boundary
Lake
River

0 2 4 6
Kilometres

Projection: BC Albers NAD83

Data Sources:
Capital Regional District
Province of British Columbia

Figure 11. 2019 Major Land Cover Classes (Orthophoto Method)
Core Municipal Area (includes Port Renfrew)

Urban Land Cover Mapping
CRD (2017/2019)

Prepared for: CRD Making a difference...together

By: CASLYS CONSULTING

4.1.2 Land Cover Mapping Results (LiDAR Enhanced)

This section presents the results of the more advanced land cover mapping that has also been completed by leveraging the available LiDAR DEM and point cloud towards the same mapping objectives. Descriptions include mapping across the broader study area that includes the CMA, Salt Spring Island, southern Gulf Islands, as well as a standalone portion of the study area near Port Renfrew that includes the Pacheedaht First Nation lands. This complete area is 89,622 hectares in size and represents a land base that is about twice the area of past mapping in the CMA. Mapping also covers much larger portions of ocean to ensure that smaller offshore islands and islets are mapped. Results for this same extent are broken down by municipalities and First Nation lands. Since the CMA portion of these reporting areas has been mapped previously, comparisons are provided along with discussion about conversion factors between years to account for methods adjustments or biases that make direct comparisons less reliable than when a common mapping method is being used to define change trends. Conversion factors are developed through comparisons of several municipal and First Nation areas that have been mapped with both methods (i.e., with and without LiDAR) using 2019 data. Conversion factors can be derived to better assess trends in future years regardless of the mapping methods used. Accuracy assessment for the LiDAR enhanced method is presented in Section 4.1.3.

Table 6 provides a general summary of aggregated cover types in the full study area. Refer to Appendix C to review the detailed tabulation of each land cover type summarized by each of the 53 municipalities and First Nation jurisdictions. Appendix C provides more detail about individual land cover types than the aggregated summaries by treed and impervious cover types reported previously. Values include the number of hectares of each class and the percent of the municipality covered by each class.

A series of figures provide an overview of the land cover mapping results enhanced through the addition of LiDAR data. The digital files listed in Section 4.0 should be used to review the data in more detail or produce maps at a more detailed scale. The following figures are provided to illustrate the LiDAR Enhanced land cover classes:

- Figure 12. 2019 Land Cover (LiDAR Enhanced Method) – CMA
- Figure 13. 2019 Land Cover (LiDAR Enhanced Method) – Gulf Islands and Port Renfrew

In addition, the following figures depict the same data as above aggregated into major land cover classes:

- Figure 14. 2019 Major Land Cover Classes (LiDAR Enhanced Method) – CMA
- Figure 15. 2019 Major Land Cover Classes (LiDAR Enhanced Method) – Gulf Islands and Port Renfrew

Table 6. Major Land Cover by Jurisdiction (LiDAR Enhanced Method)

Municipal and First Nation Areas	Areas in Hectares							Percent Cover	
	Water (Ocean / Freshwater)	Exposed Soil / Rock	Non-treed (Disturbed)	Non-treed (Natural)	Treed	Impervious	Total Area (ha)	% Treed	% Impervious
Bare Island 9 (Tsawout, Tseycum FN)	-	0.8	1.6	4.3	0.1	-	6.8	1.3%	0.0%
Beecher Bay 1 & 2 First Nation	1.5	9.8	21.9	38.7	316.6	8.5	397.0	79.8%	2.1%
Central Saanich	27.0	51.7	1,935.8	363.8	1,289.7	489.6	4,157.6	31.0%	11.8%
Chatham 4 & Discovery 3 (FN)	1.3	8.3	17.1	14.9	69.5	-	111.2	62.5%	0.0%
Cole Bay 3 (Pauquachin First Nation)	-	0.6	9.3	14.3	245.2	4.9	274.3	89.4%	1.8%
Colwood	8.3	80.2	355.0	251.0	710.7	357.3	1,762.4	40.3%	20.3%
D'Arcy Island	0.2	3.7	1.7	3.4	80.9	0.0	89.8	90.1%	0.0%
Discovery Island	1.7	6.2	8.8	6.7	58.8	-	82.2	71.6%	0.0%
East Saanich 2 (Tsawout First Nation)	0.8	9.6	48.3	32.1	117.2	41.3	249.4	47.0%	16.6%
East Sooke	18.0	10.8	188.5	233.4	2,630.2	38.0	3,118.9	84.3%	1.2%
Esquimalt First Nation	-	0.4	4.8	4.3	4.9	6.5	21.0	23.5%	30.9%
Esquimalt	1.1	20.6	154.8	92.9	182.7	251.6	703.7	26.0%	35.7%
Fulford Harbour 5 (Tsawout FN)	-	0.1	0.2	0.4	19.6	0.0	20.4	96.3%	0.0%
Galiano & Parker Islands	30.8	38.6	280.1	447.0	5,114.3	60.4	5,971.2	85.6%	1.0%
Galiano Island 9 (Penelakut FN)	-	0.4	0.6	1.2	22.2	0.1	24.4	90.9%	0.3%
Goldstream 13 (Various First Nations)	-	0.1	0.5	0.6	7.3	0.0	8.5	86.4%	0.1%
Highlands	42.3	36.0	226.0	393.0	3,023.2	93.6	3,814.1	79.3%	2.5%
James Island	7.5	18.0	120.3	28.9	134.5	6.8	316.0	42.6%	2.1%
Langford	102.7	98.6	479.1	585.1	2,246.8	716.2	4,228.6	53.1%	16.9%
Long Neck Island 9 & Whale Island 8 FN	0.0	1.3	0.3	0.6	1.7	0.0	3.8	44.3%	0.1%
Mayne Island 6 (Tsartlip First Nation)	-	0.8	1.8	5.2	131.4	0.0	139.2	94.4%	0.0%
Mayne Island	2.0	17.5	349.5	159.9	1,631.0	55.6	2,215.5	73.6%	2.5%
Metchosin	21.5	109.7	879.4	751.4	4,884.2	190.2	6,836.3	71.4%	2.8%
Moresby Island	0.6	11.6	64.5	23.0	500.2	0.2	600.1	83.4%	0.0%
New Songhees 1A First Nation	-	3.2	13.7	9.9	14.8	24.8	66.4	22.3%	37.4%
North Pender Island	33.9	43.6	314.5	189.9	2,028.4	77.8	2,688.2	75.5%	2.9%
North Saanich	14.9	44.6	1,218.3	351.0	1,547.1	520.4	3,696.4	41.9%	14.1%
Oak Bay	0.9	31.4	224.5	147.9	403.7	241.9	1,050.3	38.4%	23.0%

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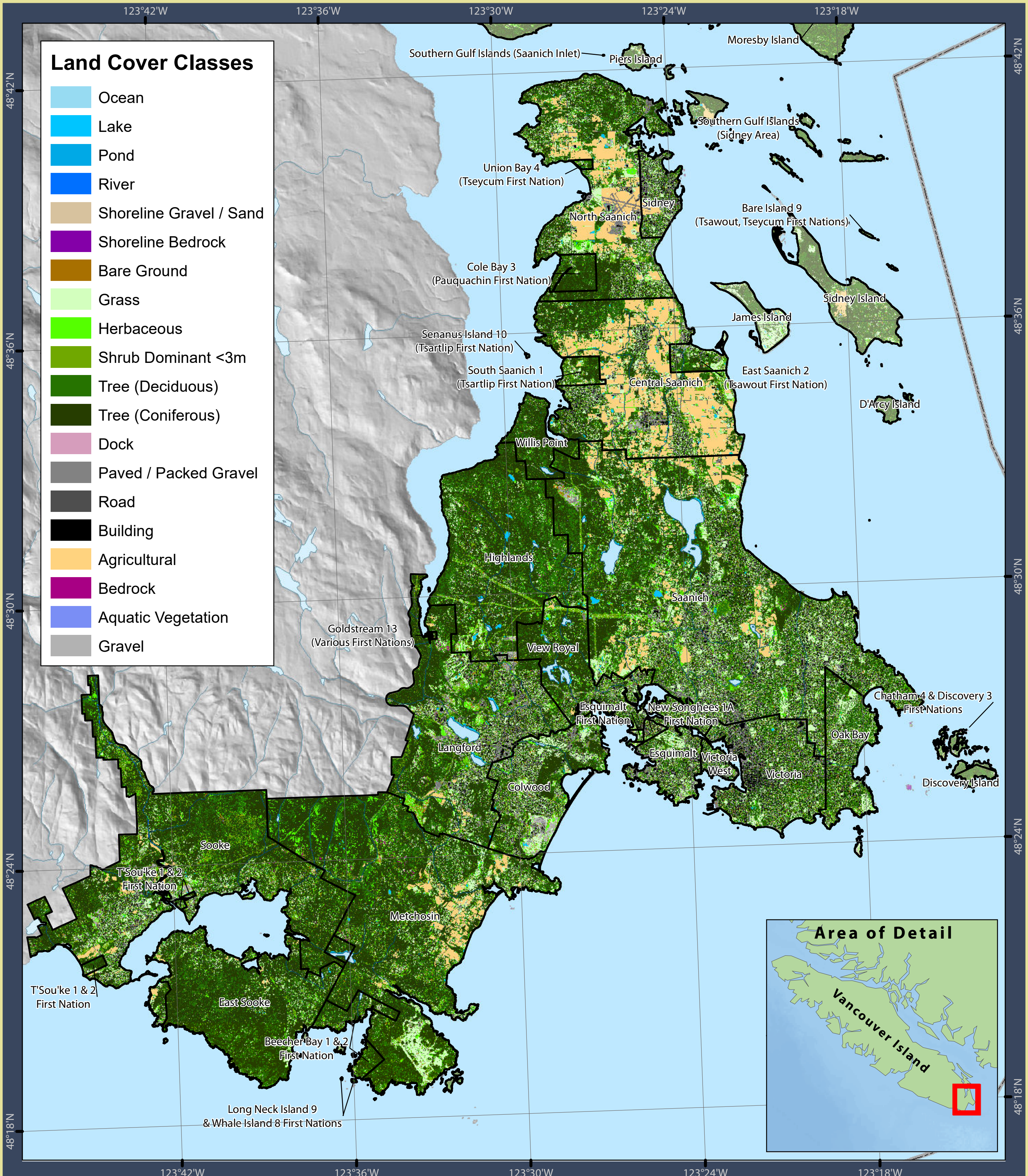
Municipal and First Nation Areas	Areas in Hectares							Percent Cover	
	Water (Ocean / Freshwater)	Exposed Soil / Rock	Non-treed (Disturbed)	Non-treed (Natural)	Treed	Impervious	Total Area (ha)	% Treed	% Impervious
Piers Island	0.2	0.9	8.5	4.2	82.9	2.6	99.3	83.5%	2.6%
Portland Island	1.0	1.5	3.6	9.1	215.0	0.0	230.2	93.4%	0.0%
Prevost Island	2.6	8.1	75.2	12.9	565.3	0.5	664.6	85.1%	0.1%
S.Pender Island 8 (Tsawout, Tseycum FN	-	0.1	0.1	0.1	2.7	-	2.9	90.6%	0.0%
Saanich	354.2	163.9	2,171.7	1,374.2	4,802.7	1,793.2	10,660.0	45.1%	16.8%
Salt Spring Island	322.5	160.9	2,281.6	1,698.3	13,636.0	333.5	18,432.8	74.0%	1.8%
Samuel Island	-	4.8	13.4	6.1	179.2	0.2	203.6	88.0%	0.1%
Saturna & Tumbo Islands	11.4	31.4	157.2	197.9	2,737.2	25.3	3,160.4	86.6%	0.8%
Saturna Island 7 (Tsawout, Tseycum FN)	-	1.3	17.0	34.5	92.3	0.0	145.1	63.6%	0.0%
Secretary & Wallace Islands	1.5	1.5	2.4	7.0	197.3	0.5	210.2	93.9%	0.2%
Senanus Island 10 (Tsartlip FN)	-	0.1	0.2	0.3	1.7	0.0	2.3	73.7%	0.1%
Sidney Island	0.2	9.0	121.2	56.1	97.6	221.2	505.2	19.3%	43.8%
Sidney	1.4	38.4	117.4	50.2	656.4	6.7	870.4	75.4%	0.8%
Sooke	15.3	106.2	561.8	739.0	3,996.6	333.6	5,752.5	69.5%	5.8%
South Pender Island	5.5	11.3	71.8	68.1	729.1	14.3	900.2	81.0%	1.6%
South Saanich 1 (Tsartlip First Nation)	0.3	1.3	30.4	29.7	123.5	17.4	202.7	61.0%	8.6%
Southern Gulf Islands (Saanich Inlet)	-	0.1	0.1	0.1	-	0.0	0.3	0.0%	0.1%
Southern Gulf Islands (Sidney Area)	4.7	12.1	32.2	14.9	245.0	2.3	311.1	78.7%	0.8%
T'Sou'ke 1 & 2 First Nation	-	0.7	9.4	6.1	52.7	6.6	75.6	69.8%	8.7%
Union Bay 4 (Tseycum First Nation)	0.2	0.7	4.1	5.3	15.8	2.2	28.3	55.9%	7.7%
Victoria	2.7	52.9	280.3	221.0	556.0	832.3	1,945.3	28.6%	42.8%
View Royal	49.2	15.4	125.4	191.7	923.6	185.3	1,490.6	62.0%	12.4%
Willis Point	8.0	2.8	12.7	23.5	511.9	11.3	570.3	89.8%	2.0%
Port Renfrew	-	2.2	6.3	15.9	104.9	9.5	138.8	75.6%	6.8%
Pacheedaht First Nation	-	3.3	9.8	87.5	228.8	32.6	362.0	63.2%	9.0%
Total (All Areas)	**1,097.9**	**1,289.3**	**13,034.7**	**9,008.5**	**58,171.3**	**7,016.6**	**89,618.2**	**64.9%**	**7.8%**
Total as percent cover	1.2%	1.4%	14.5%	10.1%	64.9%	7.8%	100.0%		



Jurisdiction Boundary
Lake
River
International Boundary

0 2 4 6
Kilometres

Projection: BC Albers NAD83

Data Sources:
Capital Regional District
Province of British Columbia

Figure 12. 2019 Land Cover
(LiDAR Enhanced Method)

Core Municipal Area

Urban Land Cover Mapping
CRD (2017/2019)

Prepared for: CRD Making a difference...together

By: CASLYS CONSULTING

Jurisdiction Boundary
Lake
River
International Boundary

0 2 4 6
Kilometres

Projection: BC Albers NAD83

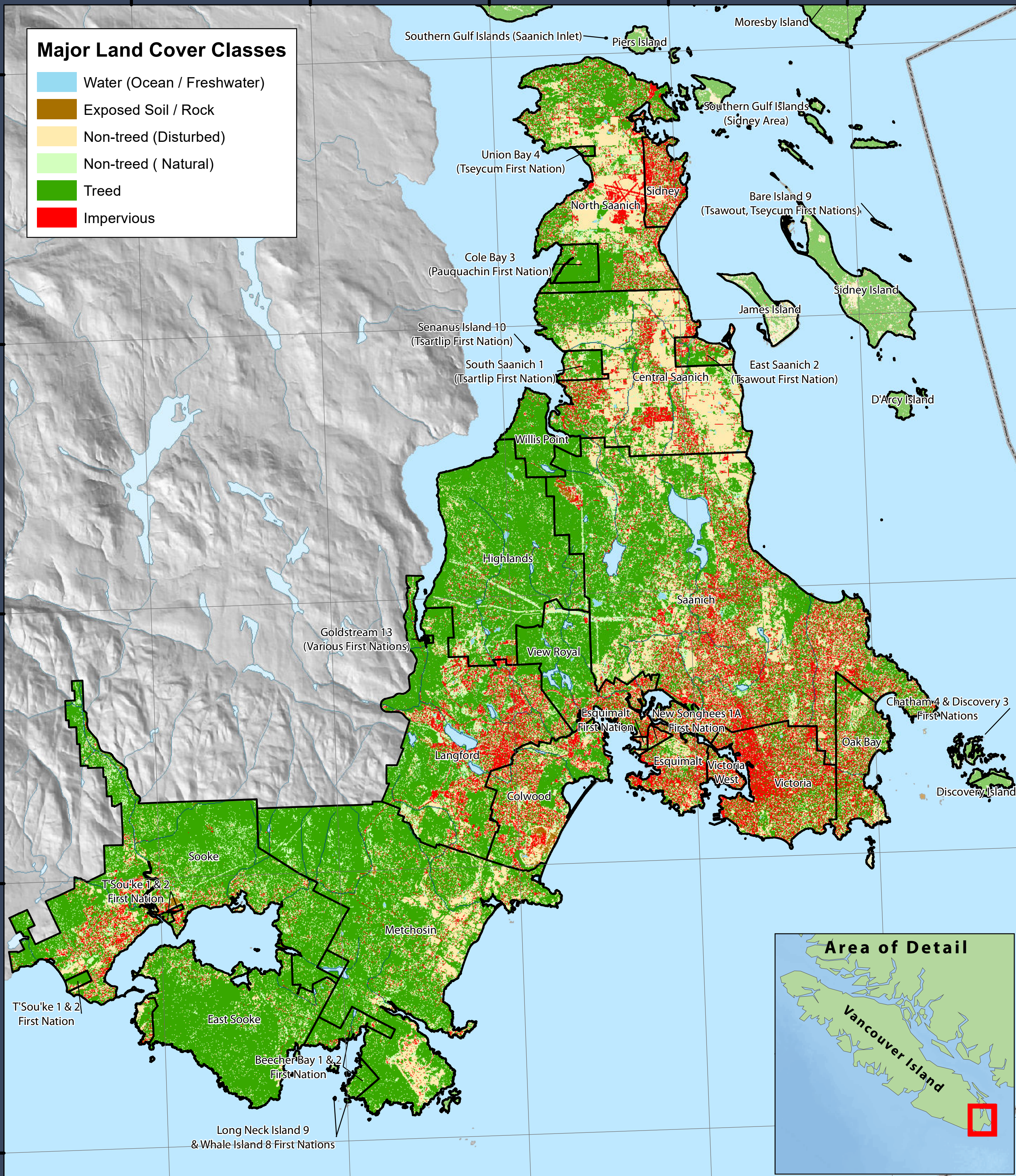
Data Sources:
Capital Regional District
Province of British Columbia

Figure 13. 2019 Land Cover
(LiDAR Enhanced Method)
Southern Gulf Islands and Port Renfrew

Urban Land Cover Mapping
CRD (2017/2019)

Prepared for: CRD Making a difference...together

By: CASLYS CONSULTING



Jurisdiction Boundary
Lake
River
International Boundary

0 2 4 6
Kilometres

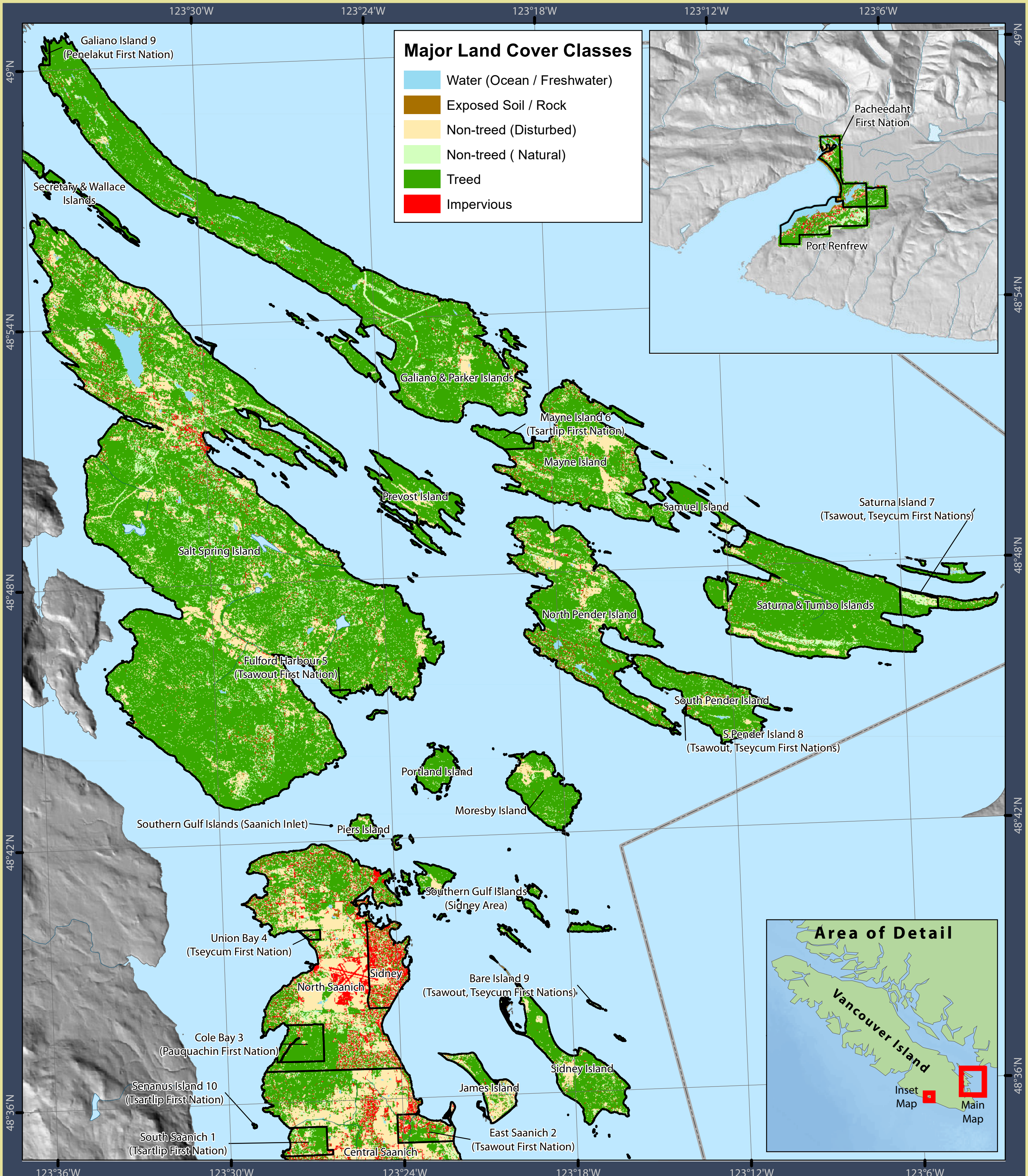
Projection: BC Albers NAD83

Data Sources:
Capital Regional District
Province of British Columbia

Figure 14. 2019 Major Land Cover Classes
(LiDAR Enhanced Method)
Core Municipal Area

Urban Land Cover Mapping
CRD (2017/2019)

Prepared for: CRD Making a difference...together
By: CASLYS CONSULTING



Jurisdiction Boundary
Lake
River
International Boundary

0 2 4 6
Kilometres

Projection: BC Albers NAD83

Data Sources:
Capital Regional District
Province of British Columbia

Figure 15. 2019 Major Land Cover Classes
(LiDAR Enhanced Method)
Southern Gulf Islands and Port Renfrew

Urban Land Cover Mapping
CRD (2017/2019)

Prepared for: CRD Making a difference...together

By: CASLYS CONSULTING

4.1.3 Quality Control and Accuracy Assessments

The primary purpose of mapping land cover without LiDAR for this project was to follow the same mapping method as completed in previous years and have a directly comparable result to support trends. As presented in Section 3.1.4 of this report, the orthophoto image contrast and the lower sun angle at the time of image acquisition have a negative impact on the ability to make direct comparisons to past request. Increased shadow within tree canopies and on the adjacent ground decrease the effectiveness of the traditional mapping approach. Mapping with LiDAR greatly reduces the influence of shadow since LiDAR data does not suffer from parallax or shadow issues. The one challenge that stems from the use of LiDAR is that the LiDAR acquisition date differs from the orthophoto image date. As a result, features can change due to any development and mobile features such as vehicles have different locations in the imagery versus the LiDAR. This discontinuity of information makes for challenges in mapping parking lots, driveways and industrial or commercial lots.

<u>Accuracy Assessment:</u>

Land cover classifications suffer from errors that stem primarily from challenges automating the separation of cover types that share similar characteristics in the source datasets that are used for mapping. With orthophoto classifications, the image colours and/or textures can be similar for different classes and classification is further complicated by various features on the landscape that are not associated with land cover (i.e., vehicles, various objects on a property or types of human development surfaces such as skylights, industrial equipment and outdoor storage, geotextiles used in agriculture, atypical crops or a wide variety of ornamental shrubs and trees). Classification accuracy assessment provides a quantification of the level of correctness associated with the land cover map relative to the real world land cover types. Best practices for accuracy assessment involve the selection of random sample points stratified by land cover classes. This approach provides a statistically valid sample per class and helps define not only an overall accuracy but identifies which classes tend to be mistaken (or confused) with each other. Each sample location is manually evaluated by a trained photo interpreter to populate an error matrix that tabulates an agreement and errors between each class.

User Accuracy refers to the percent chance that a random location on the map will be the best representation of the cover type on the ground, as verified manually in the orthophoto. The 2005 land cover map user accuracy was assessed at 94.0%. The 2011 land cover map was assessed at 94.4%. Without LiDAR, the overall user accuracy for this 2019 classification is 90.5% based on 385 samples. This lower accuracy is largely due to less spectral contrast and more shadow in the 2019 orthophoto. Refer to Appendix B to review the accuracy assessment error matrix. Producer Accuracy is also listed on the error matrix to quantify errors of omission to better understand which classes are misclassified.

The level of accuracy for the 2019 product suggests that tree cover and impervious surface trends are somewhat less accurate than in the past; however, confusion within the tree and impervious classes are only a fraction of the 9.5% overall error that exists, and confidence in tree and impervious cover trends remains strong enough to support reporting, operational and planning decisions. As well, the stratified random sampling performed for accuracy assessment for this project is a more stringent approach when compared to the unstratified random sampling completed in the past.

Improved Accuracy with LiDAR:

The same accuracy assessment error matrix approach with a stratified random sample of 531 locations was used for the LiDAR enhanced land cover map. The overall user accuracy when incorporating LiDAR is assessed at 91.2% which also includes a series of additional classes. Although this is less than 1% better than mapping without LiDAR, the accuracy rises to over 95% if we simply aggregate the deciduous and coniferous tree classes (which were not separated in past classifications). When comparing accuracy for similar classes, the LiDAR results are between 4% and 5% better. The error matrix results for each method are presented in Appendix B. A larger number of random samples are used to evaluate the LiDAR enhanced method since it covers a larger region and includes additional classes.

Specifically, the error between deciduous and coniferous trees is approximately 10%, meaning that about 9 out of 10 trees are properly classed. Improving this result would be difficult due to the wide range of tree types that are found in urban areas. Discerning deciduous and coniferous tree types in the forestry industry is typically higher for commercial timber management since there is only a fraction of the number of species that exist in more urban areas. Another challenge in the urban environment is tree canopy that is often modified for aesthetic reasons or to minimize interactions with powerlines. A significant percentage of trees in urban, residential and rural areas are modified; adding complexity to the mapping of tree types.

The accuracy assessment was completed prior to a series of manual edits applied to the classification results. These manual edits resolved issues in some areas where systematic error persisted and will result in the actual accuracy of the final LiDAR enhanced data being slightly higher than assessed.

4.1.4 Comparison of Mapping Methods

This section presents a comparison of both mapping methods for the CMA and Port Renfrew areas where both methods were completed. These comparisons highlight the improvements to results from the use of LiDAR. The LiDAR enhanced classification is superior in the following reasons:

1. Additional classes are mapped when LiDAR is incorporated into the classification. These include separation of taller trees from shrub and small trees, deciduous versus coniferous tree types and emergent aquatic vegetation (classes 10, 11, 12 and 22).
2. Orthophoto shadow is no longer a confounding element in the mapping process since the features are visible in the 3D point cloud and LiDAR intensity returns. This allows for accurate mapping of paved and vegetated surfaces in areas fully masked by tree or building shadow in the orthophoto.
3. In addition to having these added classes, the spatial precision at which various vegetated and non-vegetated cover types can be discerned is significantly improved as illustrated in Figure 4. Spatial precision is improved through more precise separation of ground cover types and removal of parallax offsets that are problematic with taller features, such as trees and buildings, in orthophotos.
4. Even with the additional class types, the classification accuracy is improved by as much as 5% (Roughly 90% without LiDAR, and 95% when using LiDAR). At this level, the ability to quantify total area of tree cover and impervious surfaces is significantly improved and future trends could be more reliable if updated LiDAR is made available.

Table 7 presents the side-by-side summaries of major cover types within the CMA. The difference for tree cover is 2.2% less and impervious surfaces are on average 4.2% less when mapping with LiDAR. In the last row of the table, the total area mapped differs slightly due to rounding of grid cell counts where cells align differently relative to the study boundaries.

Table 7. Comparison of Results Between Mapping Methods

	Mapping without LiDAR (T1)		LiDAR enhanced Method (T2)				
Major Land Cover Class	2019 Area (ha)	% of CMA	2019 Area (ha)	% of CMA	Difference in Area (ha)	% Change T1 to T2	Difference [%] T1 to T2
Shadow / no data	167.2	0.3%	-	0.0%	-167.19	-100.0%	-0.3%
Water	739.8	1.4%	715.2	1.4%	-23.53	-3.2%	0.0%
Exposed Soil / Rock	325.5	0.6%	959.0	1.9%	661.14	203.1%	1.3%
Non-Treed (disturbed)	8,229.0	15.9%	9,064.0	17.6%	837.08	10.2%	1.6%
Non-Treed (Natural)	3,902.6	7.6%	5,905.7	11.4%	2004.89	51.4%	3.9%
Treed	29,745.7	57.6%	28,609.6	55.4%	-1135.02	-3.8%	**-2.2%**
Impervious	8,524.5	16.5%	6,381.7	12.4%	-2176.59	-25.5%	**-4.2%**
TOTAL	**51,634.4**		**51,635.2**		0.8	0.0%	**0.002%**

Although the table above is informative, it is expected that differences vary depending on the level of cover type fragmentation or patterns of distribution in different land uses. For example, an urban setting includes isolated trees in small patches, while a park may include much larger patches of tree cover. The precision that trees are mapped with LiDAR suggests that those differences in area would be more pronounced in the urban setting; therefore, differences between the two method results are expected to vary depending on the composition of a municipality in terms of proportions of urban, residential, rural, agricultural, and natural areas. Table 8 and Table 9 illustrate how the results of the two methods vary when summarized in different municipal areas that vary in size and level of development. Table 8 displays differences in Tree Cover; Table 9 displays differences for Impervious Surfaces.

Table 8. Tree Cover Comparison Between Mapping Methods

Municipality and First Nation Areas	2019 Area (ha)	Mapping without LiDAR (T1) 2019 Treed Area (ha)	Mapping without LiDAR (T1) % Treed	LiDAR enhanced Method (T2) 2019 Treed Area (ha)	LiDAR enhanced Method (T2) % Treed	Difference Area (ha)	% Change T1 to T2	Difference [%] T1 to T2
Beecher Bay 1 & 2 First Nation	389.5	327.2	82.4%	310.4	79.7%	-16.8	-5.1%	-2.7%
Central Saanich	4,165.9	1,406.3	33.8%	1,290.7	31.0%	-115.6	-8.2%	-2.8%
Cole Bay 3 (Pauquachin First Nation)	277.5	254.9	93.0%	246.6	88.9%	-8.3	-3.3%	-4.1%
Colwood	1,768.6	772.9	43.9%	711.3	40.2%	-61.6	-8.0%	-3.6%
East Saanich 2 (Tsawout First Nation)	252.7	127.2	51.0%	116.4	46.1%	-10.7	-8.4%	-4.9%
East Sooke	3,727.1	2,650.7	85.0%	3,139.2	84.2%	488.5	18.4%	-0.8%
Esquimalt	706.8	160.9	22.9%	183.2	25.9%	22.4	13.9%	3.1%
Esquimalt First Nation	21.9	4.7	22.2%	5.0	23.0%	0.4	7.9%	0.8%
Goldstream 13 (Various First Nations)	5.7	7.8	91.8%	4.8	84.5%	-2.9	-37.9%	-7.3%
Highlands	3,819.4	3,176.7	83.3%	3,023.6	79.2%	-153.1	-4.8%	-4.1%
Langford	4,087.6	2,321.6	54.9%	2,160.1	52.8%	-161.5	-7.0%	-2.0%
Long Neck Island 9 & Whale Island 8 FN	3.1	1.7	45.4%	1.7	54.1%	0.0	-2.1%	8.7%
Metchosin	6,981.8	5,216.9	76.3%	4,959.4	71.0%	-257.5	-4.9%	-5.3%
New Songhees 1A First Nation	66.9	11.5	17.4%	14.9	22.2%	3.3	28.8%	4.9%
North Saanich	3,717.2	1,597.4	43.2%	1,552.2	41.8%	-45.2	-2.8%	-1.5%
Oak Bay	1,034.7	392.1	37.3%	404.4	39.1%	12.3	3.1%	1.8%
Saanich	10,699.4	4,979.3	46.7%	4,806.8	44.9%	-172.5	-3.5%	-1.8%
Sidney	506.4	98.0	19.4%	97.8	19.3%	-0.2	-0.2%	-0.1%
Sooke	5,073.9	4,172.2	72.5%	3,391.2	66.8%	-781.0	-18.7%	-5.7%
South Saanich 1 (Tsartlip First Nation)	204.1	130.0	64.1%	124.3	60.9%	-5.7	-4.4%	-3.2%
T'Sou'ke 1 & 2 First Nation	76.0	54.0	71.4%	51.7	68.0%	-2.3	-4.2%	-3.4%
Union Bay 4 (Tseycum First Nation)	29.3	18.0	63.8%	15.9	54.3%	-2.1	-11.7%	-9.5%
Victoria	1,944.7	478.5	24.6%	557.3	28.7%	78.7	16.5%	4.1%
View Royal	1,497.9	946.3	63.5%	926.3	61.8%	-20.1	-2.1%	-1.7%
Willis Point	577.0	518.6	90.9%	514.4	89.1%	-4.1	-0.8%	-1.8%

It is noted from Table 8 that the LiDAR method results in lower estimates of tree cover in more rural and natural settings (e.g., Central Saanich, Goldstream 13, Highlands, Union Bay 4), while more urban settings see higher estimates of trees when using LiDAR (e.g., Esquimalt, New Songhees First Nation, Victoria). This is expected since the precision at which individual trees are mapped with LiDAR is far improved and far more common in urban areas. Likewise, the small canopy gaps in forests are also mapped with LiDAR while more likely missed when only using the orthophotos.

Table 9. Impervious Surface Comparison Between Mapping Methods

		Mapping without LiDAR (T1)		LiDAR enhanced Method (T2)				
Municipality / First Nation Reserve	**2019 Area (ha)**	**2019 Impervious Area (ha)**	**% Impervious**	**2019 Impervious Area (ha)**	**% Impervious**	**Difference Area (ha)**	**% Change T1 to T2**	**Difference [%] T1 to T2**
Beecher Bay 1 & 2 First Nation	389.5	13.3	3.3%	8.5	2.2%	-5.4	-40.3%	-1.3%
Central Saanich	4,165.9	661.7	15.9%	489.5	11.8%	-173.0	-26.1%	-4.2%
Cole Bay 3 (Pauquachin First Nation)	277.5	7.4	2.7%	5.9	2.1%	-2.6	-34.8%	-0.9%
Colwood	1,768.6	442.1	25.1%	355.9	20.1%	-87.0	-19.7%	-4.9%
East Saanich 2 (Tsawout First Nation)	252.7	58.7	23.6%	41.5	16.4%	-16.1	-27.5%	-6.5%
East Sooke	3,727.1	87.4	2.8%	43.3	1.2%	-49.5	-56.7%	-1.6%
Esquimalt	706.8	305.0	43.3%	250.7	35.5%	-55.4	-18.2%	-7.9%
Esquimalt First Nation	21.9	6.9	33.1%	6.6	30.4%	-1.8	-26.5%	-8.8%
Highlands	5.7	145.7	3.8%	0.1	0.9%	-52.0	-35.7%	-1.4%
Langford	3,819.4	964.7	22.8%	93.8	2.5%	-248.9	-25.8%	-5.9%
Metchosin	4,087.6	302.7	4.4%	714.0	17.5%	-114.2	-37.7%	-1.7%
New Songhees 1A First Nation	3.1	32.9	49.5%	0.0	0.1%	-8.0	-24.4%	-12.1%
North Saanich	6,981.8	677.9	18.3%	191.9	2.7%	-160.9	-23.7%	-4.4%
Oak Bay	66.9	323.2	30.8%	24.8	37.1%	-84.2	-26.1%	-8.0%
Pacheedaht First Nation	3,717.2	9.8	7.0%	518.6	14.0%	-0.3	-2.7%	-0.2%
Port Renfrew	1,034.7	34.6	9.6%	242.0	23.4%	-2.0	-5.8%	-0.6%
Saanich	10,699.4	2,400.8	22.5%	1793.9	16.8%	-610.4	-25.4%	-5.7%
Sidney	506.4	284.0	56.2%	219.3	43.3%	-65.9	-23.2%	-13.0%
Sooke	5,073.9	439.4	7.6%	325.7	6.4%	-109.5	-24.9%	-1.9%
South Saanich 1 (Tsartlip First Nation)	204.1	24.3	12.0%	17.4	8.5%	-7.0	-28.9%	-3.5%
T'Sou'ke 1 & 2 First Nation	76.0	8.0	10.6%	7.2	9.4%	-1.4	-17.9%	-1.9%
Union Bay 4 (Tseycum First Nation)	29.3	2.6	9.2%	2.8	9.5%	-0.4	-16.9%	-1.6%
Victoria	1,944.7	1,068.8	54.9%	831.6	42.8%	-245.4	-23.0%	-12.6%
View Royal	1,497.9	244.5	16.4%	185.3	12.4%	-59.9	-24.5%	-4.0%
Willis Point	577.0	20.4	3.6%	11.4	2.0%	-9.3	-45.8%	-1.6%

Also note from Table 9 that the LiDAR method results in significantly lower estimates of impervious cover types in more urban areas (e.g., Esquimalt, Esquimalt First Nation, New Songhees First Nation, Sidney, Victoria), while more rural or natural urban settings see only see slightly lower estimates (e.g., East Sooke, Highlands, Pacheedaht First Nation, Port Renfrew, Sooke). This is also expected where there are urban or residential areas which have more driveways and interspersed impervious surfaces, which are more likely to be mapped precisely with LiDAR. The discussion of differences in mapping methods by land use leads directly to the discussion of conversions of values between methods so that more accurate comparisons can be made in future, regardless of the method used (See Section 4.1.4.1).

4.1.4.1 Conversion Factors

When mapping differences are accounted for, the difference (%) values displayed in the far right columns of Table 8 and Table 9 can be used as conversion factors to adjust percent tree and/or percent impervious values accordingly, from one method to the other, when making comparisons to past years of mapping across the different methods (now or in the future).

For example: Saanich has 22.5% impervious surfaces when mapped with orthophotos alone, and only 16.8% when mapped with LiDAR. This difference of 5.7% applied in future would allow for comparison between methods if LiDAR is available in some years, but not others, when mapping is completed. This becomes applicable if one was comparing future mapping with LiDAR to the previously reported 1986, 2005, or 2011 results.

These conversion factors apply to each of the municipal or First Nation areas listed but do not exist for areas that have never been mapped with both methods. Conversion factors can be estimated for other municipalities that display similar ratios of urban, rural, residential and natural landscapes. These ratios can be determined from the detailed class breakdowns per municipal or First Nation jurisdictions in Table 6 (Section 4.1.2).

A limitation with the use of conversion factors to compare cover types between mapping methods is that mapping errors associated with each method are factored into the conversion values. Other comparison techniques or recognition of limitations should be considered when comparing between methods.

4.2 Land Cover Trends

4.2.1 Core Municipal Area

Comparing the land cover results between time periods (2005, 2011 and 2019) allows for examination of change trends. Summary statistics from past years are taken directly from previous land cover reports for the CRD (Capital Regional District Land Cover Mapping 1986, 2005 and 2011 Summary Report - Caslys, 2013). Table 10 provides a comparison of the percentage of each class in each time period based on the same mapping method. Although this project involved mapping of areas outside of the CMA and Port Renfrew, cover type change trends discussed in this section of the report are limited to only those areas that have been mapped previously.

- While these data do not allow us to examine what classes are moving from and to over each time period, we can see differences in many classes ranging from a 2.6% reduction in grass cover types, up to a 2.3% increase in herbaceous cover types, with most classes moving within the +/- 0.5% range. Due to variations in orthophoto quality and the similarities across certain classes, it is difficult to suggest that more manicured lawns are transitioning to more rough herbaceous cover types as this difference is well within the mapped error between these classes.
- More importantly, a 0.5% increase in the pavement and buildings class reflects a slowing of the trend of increasing impervious surfaces.
- Likewise, treed classes show only small changes in this most recent time period when compared to past rates of decline in canopy. Overall, tree cover saw an increase of 0.2% in the study area. Changes in tree cover are influenced not only by the removal and planting of trees, but also by the incremental growth of larger canopies as trees mature and mask out the various cover types below. Changes in the proportion of trees that are classified as riparian are due primarily to improved source data that depicts stream, ponds and lakes compared to the available mapping a decade ago.
- The same 0.5% trend is seen for the agricultural class which may also be due, in part, to changes in land cover on agricultural properties, and also due to different parcels being reported as agricultural in the cadastral (zoning) data.

- Changes in water classes appear minimal, although variable in part due to improved mapping of the marine shoreline and the breaks between marine, estuary and inland fresh water.

Although there is an approximate 5 hectare increase in the overall area being reported in 2019, this is only due to rounding related to the alignment of mapped pixel relative to the same CMA reporting area polygon. Trends presented later in this report highlight the more significant details at the municipal level.

Table 10. Comparison of 2005, 2011 and 2019 Land Cover Classes in the Core Municipal Area

Land Cover	Major Land Cover Class	2005 Area (ha)	2005 % of CMA	2011 Area (ha)	2011 % of CMA	2019 Area (ha)	2019 % of CMA	Difference Area (ha) 2005 to 2011	% Change 2005 to 2011	Difference (%) 2005 to 2011	Difference Area(ha) 2011 to 2019	% Change 2011 to 2019	Difference (%) 2011 to 2019
shadow/no data	Shadow	460.8	0.9%	159.4	0.3%	167.2	0.3%	-301.4	-65.4%	-0.6%	7.8	4.9%	0.0%
ocean	Water	6.2	0.0%	8.4	0.0%	85.8	0.2%	2.2	34.0%	0.0%	77.4	921.1%	0.1%
lake		503.3	1.0%	496.3	1.0%	610.0	1.2%	-7.0	-1.4%	0.0%	113.7	22.9%	0.2%
pond		233.8	0.5%	214.9	0.4%	27.2	0.1%	-18.9	-8.1%	0.0%	-187.7	-87.4%	-0.4%
river		27.4	0.1%	29.3	0.1%	16.8	0.0%	1.9	6.9%	0.0%	-12.5	-42.6%	0.0%
sand/gravel shoreline	Exposed soil/rock	75.2	0.1%	103.4	0.2%	76.6	0.1%	28.2	37.5%	0.1%	-26.8	-26.0%	-0.1%
bedrock shoreline		76.1	0.1%	55.1	0.1%	54.6	0.1%	-21.0	-27.5%	0.0%	-0.5	-0.9%	0.0%
exposed soil		1,405.0	2.7%	630.9	1.2%	127.7	0.2%	-774.1	-55.1%	-1.5%	-503.2	-79.8%	-1.0%
exposed bedrock		64.8	0.1%	60.8	0.1%	66.7	0.1%	-4.0	-6.2%	0.0%	5.9	9.6%	0.0%
grass	Non-treed (disturbed)	4,903.8	9.5%	5,209.9	10.1%	3,862.6	7.5%	306.1	6.2%	0.6%	-1347.3	-25.9%	-2.6%
herb	Non-treed (natural	2,123.3	4.1%	2,385.8	4.6%	3,572.3	6.9%	262.5	12.4%	0.5%	1186.5	49.7%	2.3%
riparian herb		284.5	0.6%	287.5	0.6%	330.4	0.6%	3.0	1.0%	0.0%	42.9	14.9%	0.1%
tree	Treed	29,476.8	57.1%	28,424.8	55.1%	28,317.2	54.8%	-1052.0	-3.6%	-2.0%	-107.6	-0.4%	-0.2%
riparian tree		1,182.5	2.3%	1,196.6	2.3%	1,428.5	2.8%	14.1	1.2%	0.0%	231.9	19.4%	0.4%
docks	Impervious	0.5	0.0%	0.6	0.0%	2.7	0.0%	0.1	28.2%	0.0%	2.1	346.5%	0.0%
pavement/building		6,751.8	13.1%	8,253.9	16.0%	8,521.8	16.5%	1502.1	22.2%	2.9%	267.9	3.2%	0.5%
agricultural fields	Non-treed (disturbed)	4,053.8	7.9%	4,112.2	8.0%	4,366.5	8.5%	58.4	1.4%	0.1%	254.3	6.2%	0.5%
TOTAL		51,629.6		51,629.6		51,634.4							

*Negative numbers indicate a decrease and positive an increase in the number of hectares within each class over the indicated time period.

** Only ortho classification was used for trend analysis in table above.

To better visualize key changes at this regional level, Table 11 shows the same statistics as Table 10, aggregated by major land cover classes. For ease of interpretation, the colours behind the land cover types in both tables illustrate how the classes were grouped.

- Notice that the overall tree cover trend has shifted from decline, to a small (0.24%) increase across the CMA.
- As mentioned above, Impervious Surfaces (pavement, concrete, compacted gravel and buildings) show a slowing trend, but continue to increase in area (by 0.5%).
- Although water shows a slight decline in area, this may be, in part, attributed to tree canopy cover near water edges, increases in aquatic vegetation that can mask water, and even increases in shadow from trees due to the lower sun angle and broader shadows noted in the 2019 orthophotos.
- Although the difference (in percent) trends are greatest (>2%) for non-treed natural vs. disturbed classes, these also happen to be the most difficult class to separate, but may still indicate changes in agricultural areas or less irrigated lawns.

Table 11. Comparison of Major Land Cover Classes in the Core Municipal Area

Major Land Cover Class	2005 Area (ha)	2005 % of CMA	2011 Area (ha)	2011 % of CMA	2019 Area (ha)	2019 % of CMA	Difference Area(ha) 2005 to 2011	% Change 2005 to 2011	Difference % 2005 to 2011	Difference Area(ha) 2011 to 2019	% Change 2011 to 2019	Difference % 2011 to 2019
Treed	30,659.2	59.4%	29,621.4	57.4%	29,745.7	57.6%	-1037.8	-3.4%	-2.0%	124.3	0.4%	**0.2%**
Non-treed (natural)	2,407.8	4.7%	2,673.2	5.2%	3,902.6	7.6%	265.4	11.0%	0.5%	1229.4	46.0%	2.4%
Non-treed (disturbed)	8,957.6	17.3%	9,322.1	18.1%	8,229.0	15.9%	364.5	4.1%	0.7%	-1093.1	-11.7%	-2.1%
Exposed soil/rock	1,621.1	3.1%	850.2	1.6%	325.5	0.6%	-770.9	-47.6%	-1.5%	-524.7	-61.7%	-1.0%
Impervious	6,752.3	13.1%	8,254.5	16.0%	8,524.5	16.5%	1502.2	22.2%	2.9%	270.0	3.3%	**0.5%**
Water	770.7	1.5%	748.8	1.5%	739.8	1.4%	-21.9	-2.8%	0.0%	-9.0	-1.2%	0.0%
Shadow	460.8	0.9%	159.4	0.3%	167.2	0.3%	-301.4	-65.4%	-0.6%	7.8	4.9%	0.0%
TOTAL	**51,629.6**		**51,629.6**		**51,634.4**							

*Negative numbers indicate a decrease and positive an increase in the number of hectares within each class over the indicated time period.
** Only ortho classification was used for trend analysis in table above.

4.2.2 Port Renfrew / Pacheedaht Area

This section highlights the land cover trends for the area that includes Port Renfrew and the Pacheedaht First Nation. Mapping in this region was previously completed using 2011 imagery; however, it was not mapped with 2005 imagery. As presented in the previous section for the CMA portion of the study area, Table 12 provides a comparison of the percentage of each class during this time period and Table 13 presents the same information, consolidated into major land cover classes.

The relatively small difference (4.3 hectares) in the total study area size is due to changes in the mapped area near shoreline between the two mapping periods. Although there are mapping differences in the delineation of riparian areas, the data shows a 0.5% percent decrease in tree cover and 2.9% increase in impervious cover types. Attempts to reduce the influence of image shadows in the 2019 data are likely the reason for reduced areas of water and non-treed cover types.

Table 12. Comparison of 2011 and 2019 Land Cover Classes in Port Renfrew / Pacheedaht Area

Land Cover	Major Land Cover Class	2011 Area (ha)	2011 % of CMA	2019 Area (ha)	2019 % of CMA	Difference Area(ha) 2011 to 2019	% Change 2011 to 2019	Difference (%) 2011 to 2019
shadow/no data	Shadow	40.8	8.2%	2.1	0.4%	-38.7	-94.9%	-7.7%
ocean	Water	0.0	0.0%	0.0	0.0%	0.0	-90.0%	0.0%
lake		-	0.0%	-	0.0%	0.0	0	0.0%
pond		0.9	0.2%	-	0.0%	-0.9	-100.0%	-0.2%
river		0.1	0.0%	-	0.0%	-0.1	-100.0%	0.0%
sand/gravel shoreline	Exposed soil/rock	1.3	0.3%	4.7	0.9%	3.4	268.0%	0.7%
bedrock shoreline		-	0.0%	0.1	0.0%	0.1	0.0%	0.0%
exposed soil		4.6	0.9%	0.4	0.1%	-4.2	-91.8%	-0.8%
exposed bedrock		-	0.0%	-	0.0%	0.0	0.0%	0.0%
grass	Non-treed (disturbed)	3.1	0.6%	-	0.0%	-3.1	-100.0%	-0.6%
herb	Non-treed (natural	15.0	3.0%	53.5	10.7%	38.5	256.1%	7.7%
riparian herb		5.2	1.0%	2.4	0.5%	-2.8	-54.7%	-0.6%
tree	Treed	321.4	64.7%	365.7	73.0%	44.4	13.8%	8.9%
riparian tree		74.5	15.0%	27.5	5.5%	-47.0	-63.1%	-9.4%
docks	Impervious	0.0	0.0%	-	0.0%	0.0	-100.0%	0.0%
pavement/building		29.6	6.0%	44.3	8.9%	14.7	49.8%	2.9%
agricultural fields	Non-treed (disturbed)	-	0.0%	-	0.0%	0.0	0.0%	0.0%
TOTAL		**496.5**		**500.8**				

* Only ortho classification was used for trend analysis in table above.

Table 13. Comparison of Major Land Cover Classes in the Port Renfrew / Pacheedaht Area

Major Land Cover Class	2011 Area (ha)	2011 % of CMA	2019 Area (ha)	2019 % of CMA	Difference Area(ha) 2011 to 2019	% Change 2011 to 2019	Difference % 2011 to 2019
Treed	395.9	79.7%	393.2	78.5%	-2.6	-1%	**-0.5%**
Non-treed (natural)	20.2	4.1%	55.9	11.2%	35.7	176%	7.1%
Non-treed (disturbed)	3.1	0.6%	0.0	0.0%	-3.1	-100%	-0.6%
Exposed soil/rock	5.8	1.2%	5.2	1.0%	-0.6	-11%	-0.1%
Impervious	29.6	6.0%	44.3	8.9%	14.7	50%	**2.9%**
Water	1.0	0.2%	0.0	0.0%	-1.0	-100%	-0.2%
Shadow	40.8	8.2%	2.1	0.4%	-38.7	-95%	-7.7%
TOTAL	**496.5**		**500.8**				

* Only ortho classification was used for trend analysis in table above.

4.2.3 Impervious and Treed Land Cover Trends by Municipality

More detailed changes (that may also sometimes be more significant) are noted when comparisons are evaluated for each municipality or First Nations jurisdiction. Results are presented for areas that have been mapped and reported previously. The results in this section are based on the common mapping method without LiDAR. Tree cover is presented first and then followed by impervious cover types.

Since some jurisdictions have seen adjusted boundaries, some comparisons are biased by differences in land base. Table 14 lists the regions that have seen more significant adjustments in land base.

Table 14. Municipal and First Nation Jurisdictions with Revised Boundaries

Municipality / First Nation Area	2019 Area (ha)	2011 Area (ha)	Difference Area (ha)	Difference
Esquimalt First Nation	21.0	21.9	-0.9	-4%
Goldstream 13 (Various First Nations)	8.5	5.7	2.8	32%
Langford	4230.6	4089.8	140.9	3%
Long Neck Island 9 & Whale Island 8 FN	3.8	3.1	0.7	18%
Metchosin	6836.4	6981.9	-145.5	-2%
Sooke	5752.9	5075.6	677.3	12%
Union Bay 4 (Tseycum First Nation)	28.3	29.3	-1.0	-4%

Esquimalt First Nation, Long Neck and Whale Island First Nation and Union Bay First Nation have not changed significantly; however, their small size relative to changes in the delineation of marine shorelines has a small impact on the percent land mass being reported. The Goldstream First Nation extent change results from revised inland boundaries, combined with adjusted shoreline and changes in the mapping of a road allowance. A portion of the boundary between Langford and Metchosin has been revised and Sooke has seen extended jurisdiction into a portion of what was formerly part of the East Sooke Electoral Area, as well as new lands near Kemp Lake / Otter Point.

Accuracy assessments and comparisons between mapping methods can be considered when interpreting results of land cover trends. All of these changes should be weighed when making direct comparisons of changes or trends in tree and impervious cover types.

4.2.3.1 Tree Cover Trends

Detailed land cover statistics were generated for each of the municipalities and First Nation areas in the CMA. Table 15 summarizes the changes related to treed land cover. When interpreting the statistics, it is important to consider the percentage change values in the context of the absolute area values and vice versa. In municipalities with minimal tree cover, a small change in area may represent a large percentage change. Alternatively, municipalities with more trees can have significantly larger losses in terms of area that represent minimal percentage change values. The difference (expressed as a percent) columns display the results using the area of each municipality as the denominator. The results indicate the following:

- In past years, more municipalities saw decreases in tree cover, while between 2011 and 2019 approximate half of the municipalities show an increase in tree cover.
- Trends are not presented for areas that were either not mapped previously or were previously mapped and reported as Electoral Areas (i.e., East Sooke, Willis Point).

Table 15. Tree Cover Change Trends by Jurisdiction

Municipality and First Nation Areas	2005 Area (ha)	2011 Area (ha)	2019 Area (ha)	% Tree Cover in 2019	Difference % 2005 to 2011	Difference Area (ha) 2011 to 2019	% Change 2011 to 2019	Difference % 2011 to 2019
Beecher Bay 1 & 2 First Nation	338.5	335.5	327.2	82.4%	-1.0%	-8.30	-2.5%	-2.1%
Central Saanich	1,314.9	1,234.0	1,406.3	33.8%	-1.9%	172.31	14.0%	4.1%
Cole Bay 3 (Pauquachin First Nation)	258.1	256.3	254.9	93.0%	-0.6%	-1.35	-0.5%	-0.5%
Colwood	778.2	737.1	772.9	43.9%	-2.3%	35.79	4.9%	2.0%
East Saanich 2 (Tsawout First Nation)	125.0	121.7	127.2	51.0%	-1.3%	5.48	4.5%	2.2%
Esquimalt	209.5	197.4	160.9	22.9%	-1.7%	-36.52	-18.5%	-5.2%
Esquimalt First Nation*	7.5	7.1	4.7	22.2%	-1.9%	-2.44	-34.4%	-11.7%
Goldstream 13 (Various First Nations)*	5.4	5.4	7.8	91.8%	0.1%	2.38	44.2%	28.1%
Highlands	3,254.1	3,207.5	3,176.7	83.3%	-1.2%	-30.81	-1.0%	-0.8%
Langford*	2,587.1	2,468.5	2,321.6	54.9%	-2.9%	-146.89	-6.0%	-3.5%
Long Neck Island 9 & Whale Island 8 FN*	1.5	1.5	1.7	45.4%	-0.2%	0.24	15.9%	6.2%
Metchosin*	5,326.3	5,259.6	5,216.9	76.3%	-1.0%	-42.70	-0.8%	-0.6%
New Songhees 1A First Nation	20.0	19.1	11.5	17.4%	-1.3%	-7.56	-39.6%	-11.4%
North Saanich	1,657.0	1,587.2	1,597.4	43.2%	-1.9%	10.20	0.6%	0.3%
Oak Bay	386.9	362.4	392.1	37.3%	-2.4%	29.71	8.2%	2.8%
Pacheedaht First Nation	N/A	104.9	116.8	84.1%	N/A	11.86	11.3%	8.5%
Port Renfrew	N/A	291.0	276.5	76.4%	N/A	-14.51	-5.0%	-4.0%
Saanich	5,055.2	4,676.9	4,979.3	46.7%	-3.5%	302.39	6.5%	2.8%
Sidney	100.3	92.9	98.0	19.4%	-1.5%	5.10	5.5%	1.0%
Sooke*	3,703.5	3,621.4	4,172.2	72.5%	-1.6%	550.76	15.2%	9.6%
South Saanich 1 (Tsartlip First Nation)	128.3	127.1	130.0	64.1%	-0.6%	2.92	2.3%	1.4%
T'Sou'ke 1 & 2 First Nation	56.2	55.8	54.0	71.4%	-0.6%	-1.82	-3.3%	-2.4%
Union Bay 4 (Tseycum First Nation)*	20.5	20.3	18.0	63.8%	-0.6%	-2.26	-11.1%	-8.0%
Victoria	482.5	440.0	478.5	24.6%	-2.2%	38.53	8.8%	2.0%
View Royal	982.2	960.4	946.3	63.5%	-1.5%	-14.06	-1.5%	-0.9%

* These jurisdictions have modified boundaries that were not accounted for in the trend analysis. See Table 14 for revised boundaries.
** Only ortho classification was used for trend analysis in table above.

4.2.3.2 Impervious Surface Trends

Table 16 summarizes the changes related to impervious land covers by municipality. The results indicate the following:

- The changes at Goldstream First Nation are largely due to updated boundaries that reflect changes in a road allowance.
- Trends are not noted for areas that were either not mapped previously or were previously mapped and reported as Electoral Areas (i.e., East Sooke, Willis Point).

- More development is noted in East Saanich First Nation, Esquimalt First Nation, Langford, New Songhees First Nation, and Sidney.

Table 16. Impervious Surface Change Trends by Jurisdiction

Municipality and First Nation area	2005 Area (ha)	2011 Area (ha)	2019 Area (ha)	% Impervious in 2019	Difference % 2005 to 2011	Difference Area (ha) 2011 to 2019	% Change 2011 to 2019	Difference % 2011 to 2019
Beecher Bay 1 & 2 First Nation	7.6	10.3	13.3	3.3%	0.3%	3.0	29.0%	0.8%
Central Saanich	474.6	582.4	661.7	15.9%	2.6%	79.3	13.6%	1.9%
Cole Bay 3 (Pauquachin First Nation)	6.2	7.8	7.4	2.7%	0.6%	-0.4	-5.1%	-0.1%
Colwood	345.8	410.7	442.1	25.1%	3.7%	31.4	7.6%	1.8%
East Saanich 2 (Tsawout First Nation)	33.8	44.6	58.7	23.6%	4.3%	14.1	31.7%	5.7%
Esquimalt	281.8	309.2	305.0	43.3%	3.9%	-4.2	-1.4%	-0.6%
Esquimalt First Nation *	4.2	5.6	6.9	33.1%	6.5%	1.3	24.0%	6.4%
Goldstream 13 (Various First Nations)*	0.3	0.3	-	0.0%	0.1%	-0.3	-100.0%	-3.5%
Highlands	82.0	116.5	145.7	3.8%	0.9%	29.2	25.0%	0.8%
Langford*	597.7	781.1	964.7	22.8%	4.5%	183.6	23.5%	4.3%
Long Neck Island 9 & Whale Island 8 FN*	0.1	0.1	-	0.0%	0.3%	-0.1	-100.0%	-2.6%
Metchosin*	221.0	298.8	302.7	4.4%	1.1%	3.9	1.3%	0.1%
New Songhees 1A First Nation	28.3	31.1	32.9	49.5%	4.2%	1.8	5.7%	2.7%
North Saanich	529.3	634.1	677.9	18.3%	2.8%	43.8	6.9%	1.2%
Oak Bay	291.9	330.6	323.2	30.8%	3.7%	-7.4	-2.2%	-0.7%
Pacheedaht First Nation	N/A	6.1	9.8	7.0%	N/A	3.6	59.0%	2.6%
Port Renfrew	N/A	23.5	34.6	9.6%	N/A	11.1	47.3%	3.1%
Saanich	2,026.3	2,559.1	2,400.8	22.5%	5.0%	-158.3	-6.2%	-1.5%
Sidney	240.8	260.0	284.0	56.2%	3.8%	24.0	9.2%	4.7%
Sooke*	292.7	410.9	439.4	7.6%	2.3%	28.5	6.9%	0.5%
South Saanich 1 (Tsartlip First Nation)	15.4	18.8	24.3	12.0%	1.7%	5.5	29.1%	2.7%
T'Sou'ke 1 & 2 First Nation	6.2	7.4	8.0	10.6%	0.6%	0.6	8.0%	0.8%
Union Bay 4 (Tseycum First Nation)*	2.9	3.2	2.6	9.2%	1.1%	-0.6	-18.4%	-2.1%
Victoria	990.5	1,082.3	1,068.8	54.9%	4.7%	-13.5	-1.3%	-0.7%
View Royal	203.2	245.3	244.5	16.4%	2.8%	-0.8	-0.3%	-0.1%

* These jurisdictions have modified boundaries that were not accounted for in the trend analysis. See Table 14 for revised boundaries.

** Only ortho classification was used for trend analysis in table above.

4.3 LiDAR Enhanced Impervious and Treed Land Cover Proportions

Impervious and tree cover proportion statistics are based on the percentage of impervious or tree cover in each one hectare grid cell. This process aggregates the proportion of tree cover and impervious cover types within each one-hectare cell within the following classes: 0-5%, >5-10%, >10-25%, >25-50%, >50-75%, and >75%. Summary tables have been prepared for the full project study area using the same techniques that have been previously applied (see Section 4.2.3). In past editions of this analysis, the term 'density' was used, but has been updated to the more appropriate term 'proportion' of each hectare grid cell. In this section, the focus is on reporting tree cover proportion in a more accurate manner from the improved accuracy and precision of the LiDAR Enhanced mapping methods. Comparisons to past methods are omitted, in this case, since portions of the study area have either not been mapped previously. These summary statistics do however act as a baseline for future comparisons and trend calculations.

4.3.1 Enhanced Tree Cover Proportions

The following pages illustrate the results for tree cover proportions developed from the enhanced LiDAR mapping method and summarized per hectare. Table 17 presents the tree cover proportion classes for each municipal and First Nations jurisdiction. Appendix C includes additional tabulation of data for tree cover by area and percentage per jurisdiction. Figure 16 and Figure 17 show the mapped results across the full study area. The hectare-based polygon GIS files containing these results are provided as a single digital file that includes tree cover and impervious surface results. Although there are some biases introduced from the different mapping methods, Figure 18 shows the locations are areas that have seen more substantial reductions in tree cover within the CMA when compared against past mapping that was completed in 2011. On this map, change is noted where the proportion within a hectare grid cell drops by 2 or more classes. This type of change is typically the result of larger scale development in the area. Additional class changes can be mapped to reflect more detail using the hectare-based digital files.

Table 17. LiDAR Enhanced Tree Cover Proportion by Municipality and First Nations Jurisdictions

Municipal and First Nation Areas	0 - 5%		>5 - 10%		>10 - 25%		>25 - 50%		>50 - 75%		>75%		Total
	(ha)	%	(ha)	%	(ha)	%	(ha)	%	(ha)	%	(ha)	%	(ha)
Bare Island 9 (Tsawout, Tseycum FN)	5	83.3%	1	16.7%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	6
Beecher Bay 1 & 2 First Nation	5	1.3%	2	0.5%	9	2.3%	19	4.8%	81	20.3%	284	71.0%	400
Central Saanich	1,028	24.7%	422	10.1%	859	20.6%	787	18.9%	471	11.3%	596	14.3%	4,163
Chatham 4 & Discovery 3 (FN)	9	8.4%	3	2.8%	3	2.8%	21	19.6%	32	29.9%	39	36.4%	107
Cole Bay 3 (Pauquachin First Nation)	0	0.0%	0	0.0%	4	1.5%	10	3.7%	26	9.6%	230	85.2%	270
Colwood	229	13.0%	87	4.9%	334	19.0%	534	30.3%	257	14.6%	321	18.2%	1,762
D'Arcy Island	0	0.0%	0	0.0%	1	1.1%	2	2.2%	13	14.4%	74	82.2%	90
Discovery Island	8	9.9%	2	2.5%	7	8.6%	3	3.7%	6	7.4%	55	67.9%	81
East Saanich 2 (Tsawout First Nation)	30	12.1%	13	5.3%	42	17.0%	53	21.5%	40	16.2%	69	27.9%	247
East Sooke	6	0.2%	2	0.1%	24	0.8%	127	4.1%	566	18.1%	2399	76.8%	3,124
Esquimalt First Nation	56	8.0%	59	8.4%	267	38.0%	269	38.3%	42	6.0%	10	1.4%	703
Esquimalt	4	21.1%	2	10.5%	5	26.3%	5	26.3%	3	15.8%	0	0.0%	19
Fulford Harbour 5 (Tsawout FN)	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	19	100.0%	19
Galiano & Parker Islands	36	0.6%	16	0.3%	88	1.5%	233	3.9%	740	12.4%	4854	81.3%	5,967
Galiano Island 9 (Penelakut FN)	0	0.0%	0	0.0%	0	0.0%	2	9.1%	2	9.1%	18	81.8%	22
Goldstream 13 (Various First Nations)	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	7	100.0%	7
Highlands	32	0.8%	20	0.5%	81	2.1%	204	5.4%	749	19.7%	2722	71.5%	3,808
James Island	52	16.9%	20	6.5%	54	17.5%	66	21.4%	39	12.7%	77	25.0%	308
Langford	239	5.6%	186	4.4%	697	16.4%	889	20.9%	738	17.4%	1496	35.2%	4,245
Long Neck Island 9 & Whale Island 8 FN	1	33.3%	0	0.0%	0	0.0%	0	0.0%	2	66.7%	0	0.0%	3
Mayne Island 6 (Tsartlip First Nation)	69	3.1%	27	1.2%	81	3.7%	205	9.3%	527	23.8%	1306	59.0%	2,215
Mayne Island	0	0.0%	0	0.0%	0	0.0%	0	0.0%	3	2.1%	137	97.9%	140
Metchosin	185	2.7%	113	1.7%	342	5.0%	779	11.4%	1517	22.2%	3907	57.1%	6,843
Moresby Island	18	3.0%	8	1.3%	21	3.5%	27	4.5%	50	8.3%	478	79.4%	602
New Songhees 1A First Nation	6	9.2%	6	9.2%	32	49.2%	16	24.6%	5	7.7%	0	0.0%	65
North Pender Island	51	1.9%	22	0.8%	86	3.2%	241	8.9%	625	23.2%	1669	62.0%	2,694
North Saanich	675	18.3%	173	4.7%	494	13.4%	858	23.2%	821	22.2%	670	18.2%	3,691
Oak Bay	39	3.7%	16	1.5%	198	18.7%	536	50.7%	227	21.5%	41	3.9%	1,057

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Municipal and First Nation Areas	0 - 5%		>5 - 10%		>10 - 25%		>25 - 50%		>50 - 75%		>75%		Total
	(ha)	%	(ha)	%	(ha)	%	(ha)	%	(ha)	%	(ha)	%	(ha)
Pacheedaht First Nation	7	4.9%	3	2.1%	5	3.5%	8	5.6%	30	21.0%	90	62.9%	143
Piers Island	0	0.0%	0	0.0%	4	4.1%	5	5.2%	14	14.4%	74	76.3%	97
Port Renfrew	17	4.7%	13	3.6%	30	8.4%	63	17.6%	75	20.9%	160	44.7%	358
Portland Island	0	0.0%	0	0.0%	0	0.0%	3	1.3%	16	7.0%	210	91.7%	229
Prevost Island	12	1.8%	8	1.2%	19	2.9%	28	4.2%	73	11.1%	520	78.8%	660
S.Pender Island 8 (Tsawout, Tseycum FN)	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	3	100.0%	3
Saanich	646	6.1%	376	3.5%	2077	19.5%	3266	30.6%	1974	18.5%	2338	21.9%	10,677
Salt Spring Island	401	2.2%	220	1.2%	622	3.4%	1864	10.1%	3936	21.3%	11,417	61.8%	18,460
Samuel Island	5	2.5%	1	0.5%	9	4.5%	7	3.5%	11	5.5%	168	83.6%	201
Saturna & Tumbo Islands	29	0.9%	24	0.8%	64	2.0%	124	3.9%	312	9.9%	2,601	82.5%	3,154
Saturna Island 7 (Tsawout, Tseycum FN)	20	13.8%	3	2.1%	16	11.0%	13	9.0%	15	10.3%	78	53.8%	145
Secretary & Wallace Islands	1	0.5%	0	0.0%	0	0.0%	2	0.9%	20	9.4%	190	89.2%	213
Senanus Island 10 (Tsartlip FN)	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	2	100.0%	2
Sidney	70	13.9%	50	9.9%	242	48.1%	128	25.4%	13	2.6%	0	0.0%	503
Sidney Island	51	5.9%	14	1.6%	28	3.2%	69	7.9%	126	14.5%	581	66.9%	869
Sooke	94	1.6%	95	1.6%	354	6.1%	821	14.2%	1,372	23.8%	3,027	52.5%	5,763
South Pender Island	12	1.3%	14	1.6%	12	1.3%	47	5.2%	156	17.3%	661	73.3%	902
South Saanich 1 (Tsartlip First Nation)	6	2.9%	7	3.4%	18	8.7%	49	23.7%	45	21.7%	82	39.6%	207
Southern Gulf Islands (Saanich Inlet)	1	100.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	1
Southern Gulf Islands (Sidney Area)	13	4.1%	5	1.6%	9	2.8%	22	6.9%	71	22.3%	198	62.3%	318
T'Sou'ke 1 & 2 First Nation	0	0.0%	0	0.0%	6	8.1%	19	25.7%	14	18.9%	35	47.3%	74
Union Bay 4 (Tseycum First Nation)	0	0.0%	0	0.0%	4	13.3%	10	33.3%	7	23.3%	9	30.0%	30
Victoria	75	3.9%	97	5.0%	630	32.4%	1008	51.8%	126	6.5%	11	0.6%	1,947
View Royal	28	1.9%	29	1.9%	163	10.9%	315	21.1%	222	14.8%	738	49.4%	1,495
Willis Point	0	0.0%	0	0.0%	1	0.2%	7	1.2%	56	9.8%	509	88.8%	573
Total (All Areas)	4,271	4.8%	2,159	2.4%	8,042	9.0%	13,764	15.3%	16,266	18.1%	45,180	50.4%	**89,682**

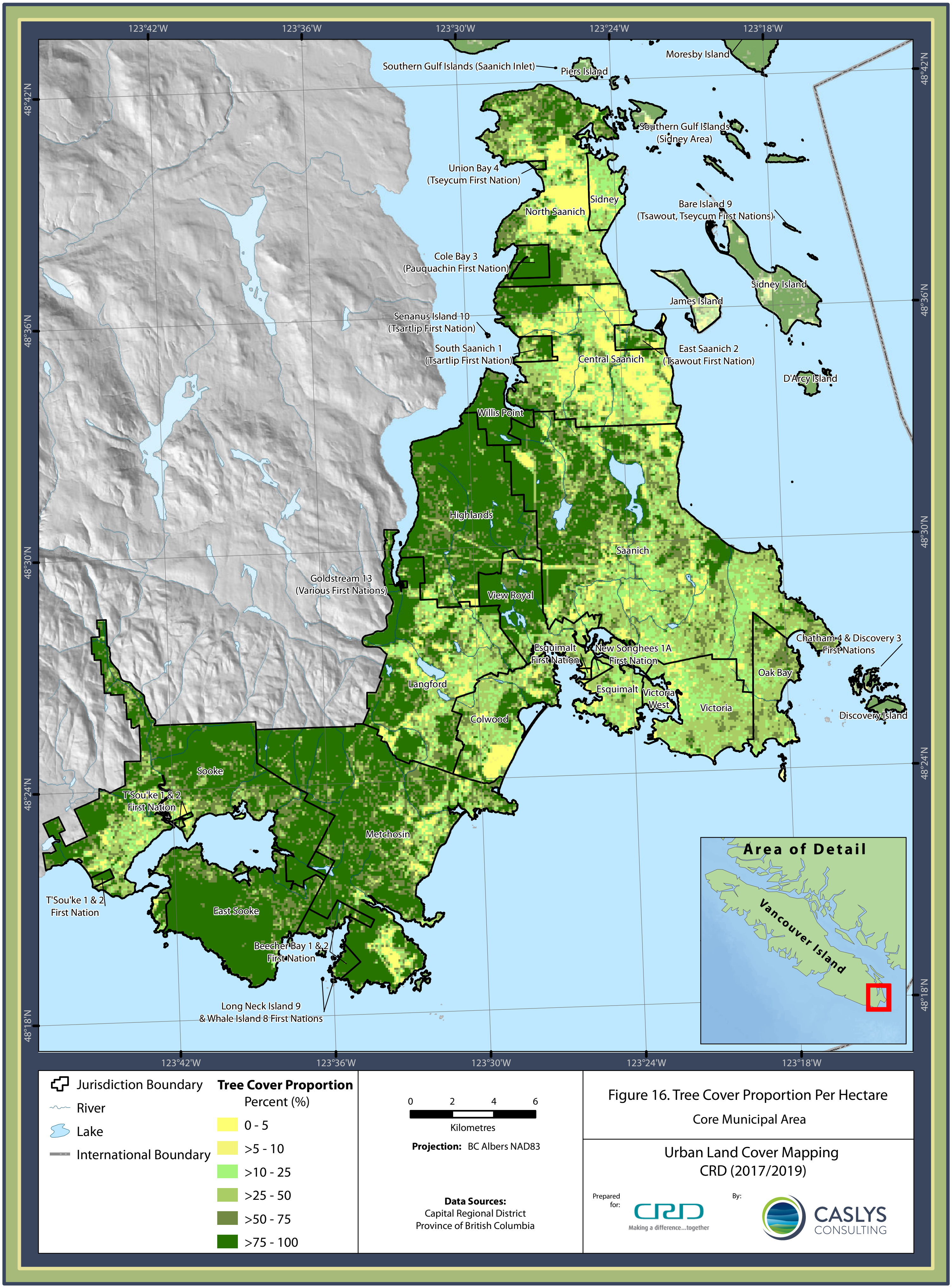
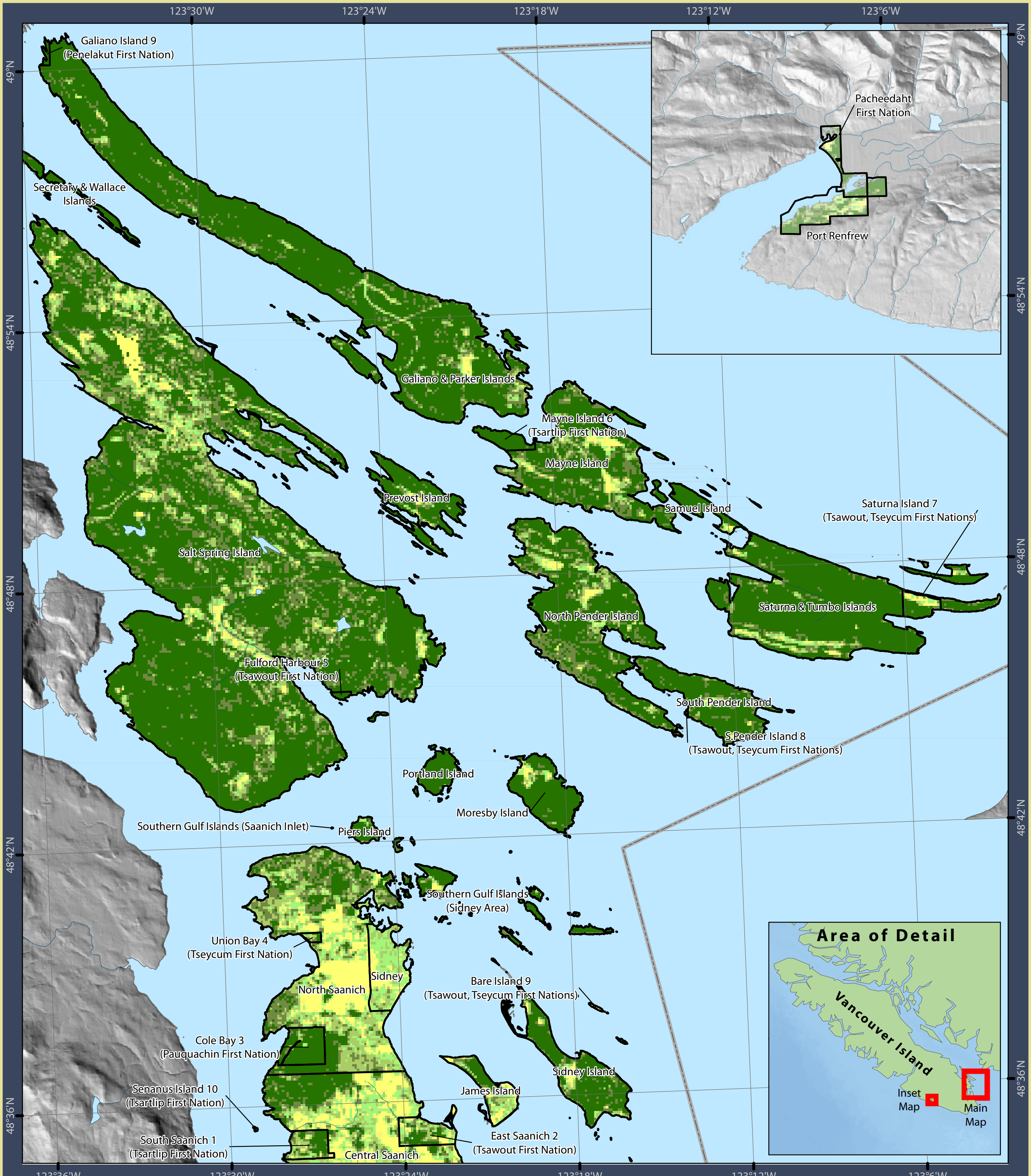


Figure 16. Tree Cover Proportion Per Hectare

Core Municipal Area

Urban Land Cover Mapping

CRD (2017/2019)



Legend	
Jurisdiction Boundary	
Lake	
River	
International Boundary	

Tree Cover Proportion

Percent (%)

- 0 - 5
- >5 - 10
- >10 - 25
- >25 - 50
- >50 - 75
- >75 - 100

0 2 4 6

Kilometres

Projection: BC Albers NAD83

Data Sources:
Capital Regional District
Province of British Columbia

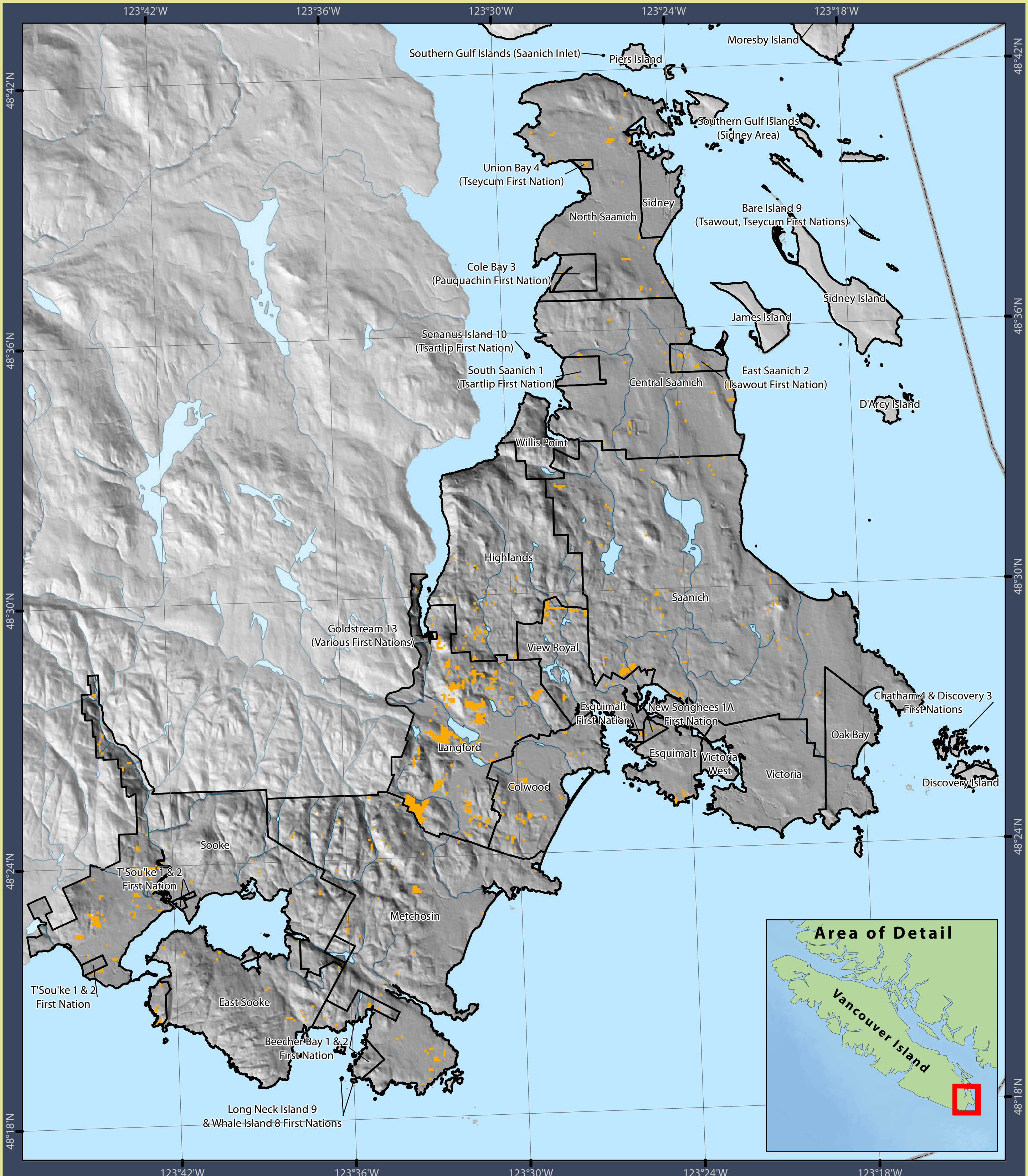
Figure 17. Tree Cover Proportion Per Hectare

Southern Gulf Islands and Port Renfrew

Urban Land Cover Mapping
CRD (2017/2019)

Prepared for: CRD Making a difference...together

By: CASLYS CONSULTING



Jurisdiction Boundary
Lake
River
International Boundary

Reduction in Tree Cover Proportion

> 2 Classes

0 2 4 6
Kilometres

Projection: BC Albers NAD83

Data Sources:
Capital Regional District
Province of British Columbia

Figure 18. Tree Cover Proportion Change Per Hectare

Core Municipal Area

Urban Land Cover Mapping
CRD (2017/2019)

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4.3.2 Enhanced Impervious Surface Proportions

The following pages illustrate the results for impervious surface proportions developed from the enhanced LiDAR mapping method and summarized per hectare. Table 18 presents the impervious surface proportion classes for each municipal and First Nations jurisdiction. Appendix C includes additional tabulation of data for impervious surfaces by area and percentage per jurisdiction. Figure 19 and Figure 20 show the mapped results across the full study area. The hectare-based polygon GIS files containing these results are provided as a single digital file that includes tree cover and impervious surface results. Although there are some biases introduced from the different mapping methods, Figure 21 shows the locations are areas that have seen more substantial increases in impervious surfaces within the CMA when compared against past mapping that was completed in 2011. On this map, change is noted where the proportion within a hectare grid cell increases by 2 or more classes. This type of change is typically the result of significant development in the area. Additional class changes can be mapped to reflect more detail using the hectare-based digital files.

Table 18. LiDAR Enhanced Impervious Surface Proportion by Municipality and First Nations Jurisdictions

Municipal and First Nation Areas	0 - 5%		>5 - 10%		>10 - 25%		>25 - 50%		>50 - 75%		>75%		Total
	(ha)	%	(ha)	%	(ha)	%	(ha)	%	(ha)	%	(ha)	%	(ha)
Bare Island 9 (Tsawout, Tseycum FN)	6	100.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	6
Beecher Bay 1 & 2 First Nation	349	87.3%	28	7.0%	16	4.0%	4	1.0%	3	0.8%	0	0.0%	400
Central Saanich	2064	49.6%	595	14.3%	755	18.1%	602	14.5%	104	2.5%	43	1.0%	4,163
Chatham 4 & Discovery 3 (FN)	107	100.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	107
Cole Bay 3 (Pauquachin First Nation)	224	83.0%	29	10.7%	13	4.8%	4	1.5%	0	0.0%	0	0.0%	270
Colwood	584	33.1%	133	7.5%	333	18.9%	595	33.8%	102	5.8%	15	0.9%	1,762
D'Arcy Island	90	100.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	90
Discovery Island	81	100.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	81
East Saanich 2 (Tsawout First Nation)	97	39.3%	33	13.4%	46	18.6%	50	20.2%	21	8.5%	0	0.0%	247
East Sooke	2812	90.0%	230	7.4%	81	2.6%	1	0.0%	0	0.0%	0	0.0%	3,124
Esquimalt First Nation	78	11.1%	32	4.6%	98	13.9%	343	48.8%	107	15.2%	45	6.4%	703
Esquimalt	0	0.0%	1	5.3%	5	26.3%	10	52.6%	3	15.8%	0	0.0%	19
Fulford Harbour 5 (Tsawout FN)	19	100.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	19
Galiano & Parker Islands	5579	93.5%	338	5.7%	45	0.8%	4	0.1%	0	0.0%	1	0.0%	5,967
Galiano Island 9 (Penelakut FN)	22	100.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	22
Goldstream 13 (Various First Nations)	7	100.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	7
Highlands	3185	83.6%	352	9.2%	228	6.0%	28	0.7%	10	0.3%	5	0.1%	3,808
James Island	272	88.3%	31	10.1%	4	1.3%	1	0.3%	0	0.0%	0	0.0%	308
Langford	2033	47.9%	296	7.0%	641	15.1%	866	20.4%	325	7.7%	84	2.0%	4,245
Long Neck Island 9 & Whale Island 8 FN	3	100.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	3
Mayne Island 6 (Tsartlip First Nation)	1755	79.2%	345	15.6%	111	5.0%	4	0.2%	0	0.0%	0	0.0%	2,215
Mayne Island	140	100.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	140
Metchosin	5450	79.6%	785	11.5%	538	7.9%	67	1.0%	3	0.0%	0	0.0%	6,843
Moresby Island	600	99.7%	2	0.3%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	602
New Songhees 1A First Nation	3	4.6%	2	3.1%	16	24.6%	21	32.3%	21	32.3%	2	3.1%	65
North Pender Island	2083	77.3%	372	13.8%	225	8.4%	14	0.5%	0	0.0%	0	0.0%	2,694
North Saanich	1366	37.0%	570	15.4%	1136	30.8%	443	12.0%	101	2.7%	75	2.0%	3,691
Oak Bay	152	14.4%	50	4.7%	346	32.7%	480	45.4%	26	2.5%	3	0.3%	1,057

Continued next page…

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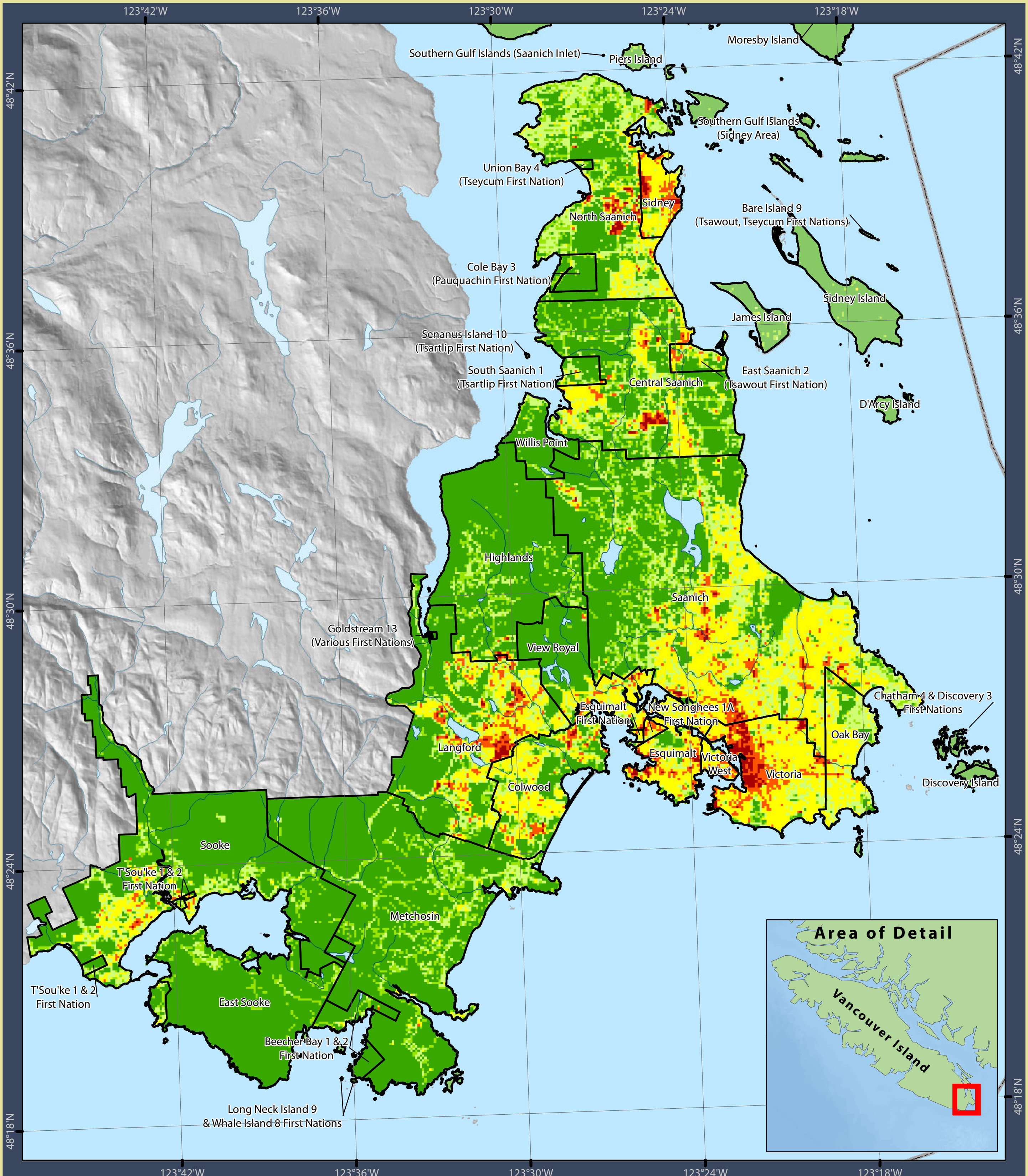
Municipal and First Nation Areas	0 - 5%		>5 - 10%		>10 - 25%		>25 - 50%		>50 - 75%		>75%		Total
	(ha)	%	(ha)	%	(ha)	%	(ha)	%	(ha)	%	(ha)	%	(ha)
Pacheedaht First Nation	96	67.1%	19	13.3%	15	10.5%	12	8.4%	1	0.7%	0	0.0%	143
Piers Island	78	80.4%	17	17.5%	2	2.1%	0	0.0%	0	0.0%	0	0.0%	97
Port Renfrew	190	53.1%	56	15.6%	69	19.3%	39	10.9%	4	1.1%	0	0.0%	358
Portland Island	229	100.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	229
Prevost Island	660	100.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	660
S.Pender Island 8 (Tsawout, Tseycum FN)	3	100.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	3
Saanich	4,163	39.0%	1061	9.9%	2035	19.1%	2966	27.8%	377	3.5%	75	0.7%	10,677
Salt Spring Island	16,084	87.1%	1590	8.6%	690	3.7%	78	0.4%	16	0.1%	2	0.0%	18,460
Samuel Island	201	100.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	201
Saturna & Tumbo Islands	3,003	95.2%	117	3.7%	31	1.0%	3	0.1%	0	0.0%	0	0.0%	3,154
Saturna Island 7 (Tsawout, Tseycum FN)	145	100.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	145
Secretary & Wallace Islands	211	99.1%	1	0.5%	1	0.5%	0	0.0%	0	0.0%	0	0.0%	213
Senanus Island 10 (Tsartlip FN)	2	100.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	2
Sidney	18	3.6%	10	2.0%	38	7.6%	280	55.7%	117	23.3%	40	8.0%	503
Sidney Island	854	98.3%	12	1.4%	2	0.2%	1	0.1%	0	0.0%	0	0.0%	869
Sooke	4,223	73.3%	437	7.6%	645	11.2%	383	6.6%	71	1.2%	4	0.1%	5,763
South Pender Island	791	87.7%	97	10.8%	12	1.3%	2	0.2%	0	0.0%	0	0.0%	902
South Saanich 1 (Tsartlip First Nation)	125	60.4%	16	7.7%	42	20.3%	21	10.1%	3	1.4%	0	0.0%	207
Southern Gulf Islands (Saanich Inlet)	1	100.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	1
Southern Gulf Islands (Sidney Area)	301	94.7%	14	4.4%	3	0.9%	0	0.0%	0	0.0%	0	0.0%	318
T'Sou'ke 1 & 2 First Nation	36	48.6%	14	18.9%	17	23.0%	6	8.1%	1	1.4%	0	0.0%	74
Union Bay 4 (Tseycum First Nation)	13	43.3%	6	20.0%	10	33.3%	1	3.3%	0	0.0%	0	0.0%	30
Victoria	61	3.1%	28	1.4%	210	10.8%	1064	54.6%	398	20.4%	186	9.6%	1,947
View Royal	909	60.8%	50	3.3%	167	11.2%	305	20.4%	56	3.7%	8	0.5%	1,495
Willis Point	486	84.8%	43	7.5%	39	6.8%	5	0.9%	0	0.0%	0	0.0%	573
Total (All Areas)	62,044	69.2%	7812	8.7%	8665	9.7%	8703	9.7%	1870	2.1%	588	0.7%	**89,682**



Jurisdiction Boundary
River
Lake
International Boundary

Impervious Surface Proportion

Percent (%)

- 0 - 5
- >5 - 10
- >10 - 25
- >25 - 50
- >50 - 75
- >75 - 100

0 2 4 6

Kilometres

Projection: BC Albers NAD83

Data Sources:
Capital Regional District
Province of British Columbia

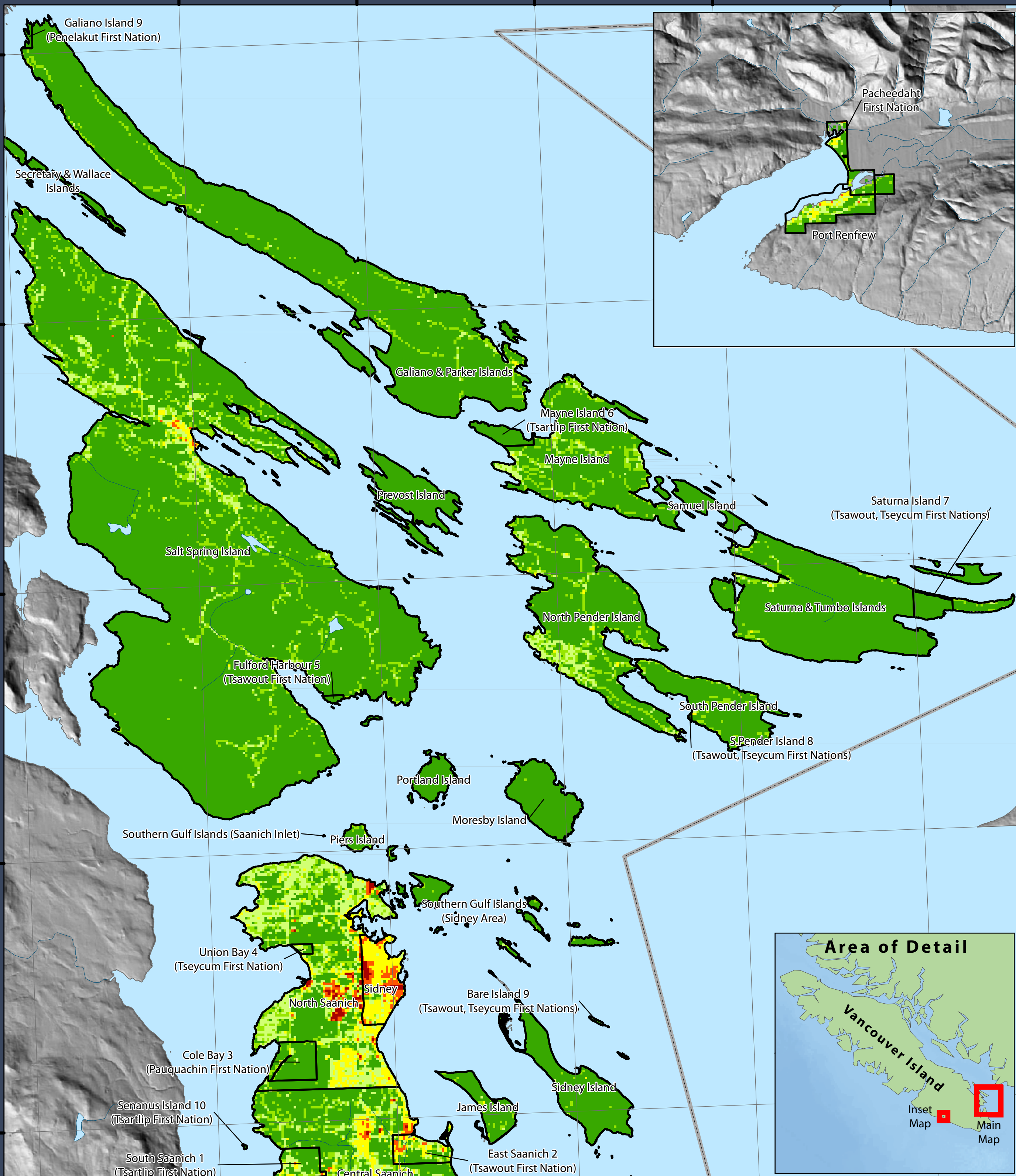
Figure 19. Impervious Surface Proportion Per Hectare

Core Municipal Area

Urban Land Cover Mapping
CRD (2017/2019)

Prepared for: CRD Making a difference...together

By: CASLYS CONSULTING



Jurisdiction Boundary
Lake
River
International Boundary

Impervious Surface Proportion
Percent (%)

- 0 - 5
- >5 - 10
- >10 - 25
- >25 - 50
- >50 - 75
- >75 - 100

0 2 4 6
Kilometres

Projection: BC Albers NAD83

Data Sources:
Capital Regional District
Province of British Columbia

Figure 20. Impervious Surface Proportion Per Hectare
Southern Gulf Islands and Port Renfrew

Urban Land Cover Mapping
CRD (2017/2019)

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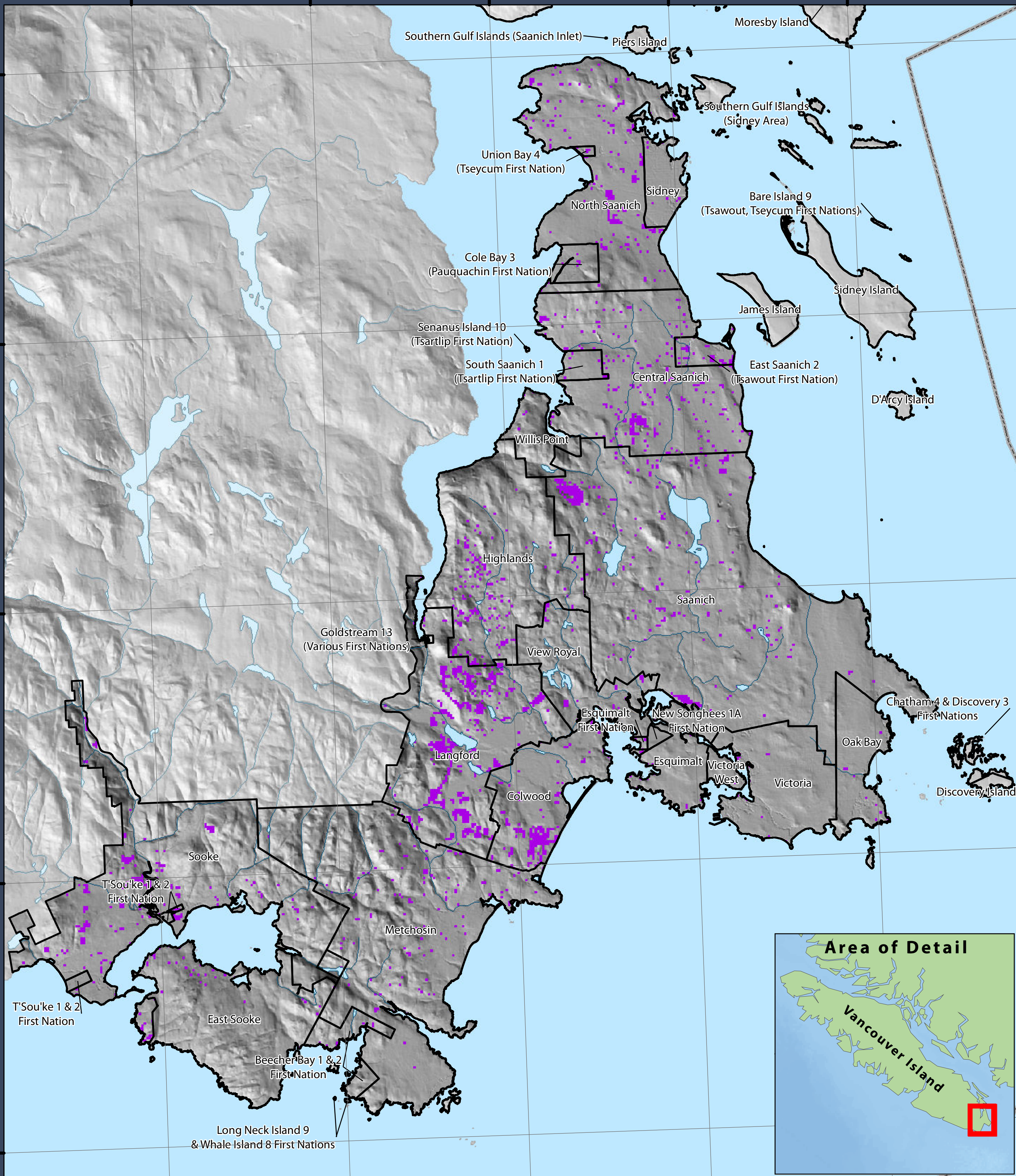


- Jurisdiction Boundary
- Lake
- River
- International Boundary

Increase in Impervious Surface Proportion

- > 1 Class

0 2 4 6

Kilometres

Projection: BC Albers NAD83

Data Sources:
Capital Regional District
Province of British Columbia

Figure 21. Impervious Surface Proportion Change Per Hectare

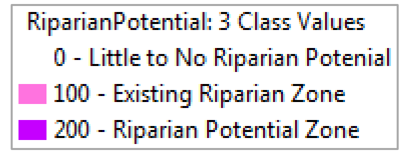
Core Municipal Area

Urban Land Cover Mapping
CRD (2017/2019)

Prepared for: CRD Making a difference...together

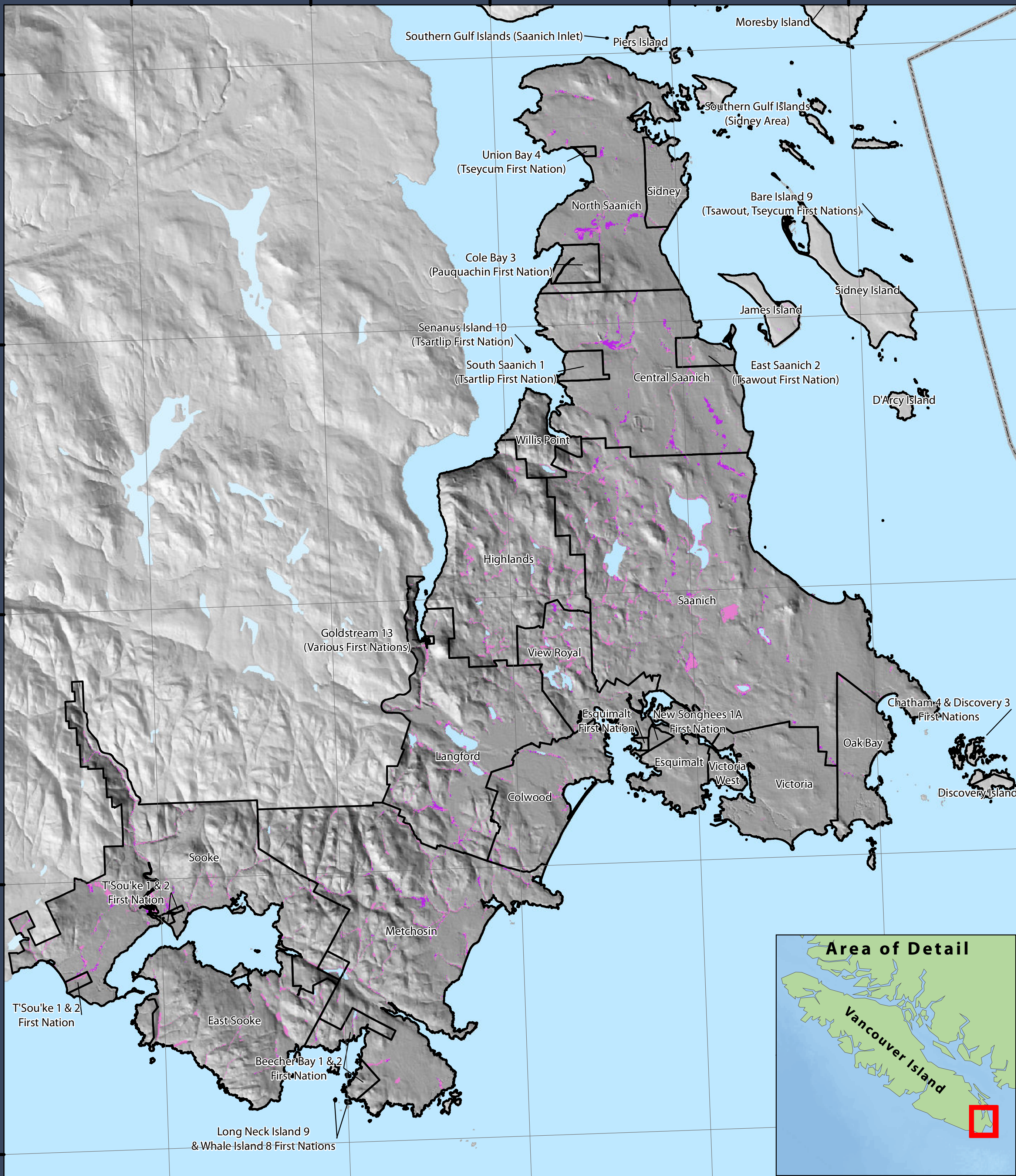
By: CASLYS CONSULTING

4.4 Enhanced Riparian Potential Mapping Results



The Riparian model results are a standalone dataset for the LiDAR enhanced portion of this project. The raster values and classes (right) can be integrated with other datasets to assist with decision-support. Class 100 includes areas where existing riparian vegetation types are probable, but this does not exclude them the benefits of further restoration efforts. Class 200 includes areas where riparian habitat has potential to exist or where restoration efforts could be focused as the model suggests that the ground is likely wetter into the summer months. The one-metre resolution raster output is presented in Figures 22 and 23.

Note that the riparian potential mapping excludes areas that that have been mapped as open water in the Land Cover Classification. This also excludes land cover areas mapped as emergent aquatic vegetation which is deemed to be more of an aquatic ecosystem than riparian.



Jurisdiction Boundary

Lake

International Boundary

Existing Riparian Zone

Riparian Potential Zone

0 2 4 6

Kilometres

Projection: BC Albers NAD83

Data Sources:
Capital Regional District
Province of British Columbia

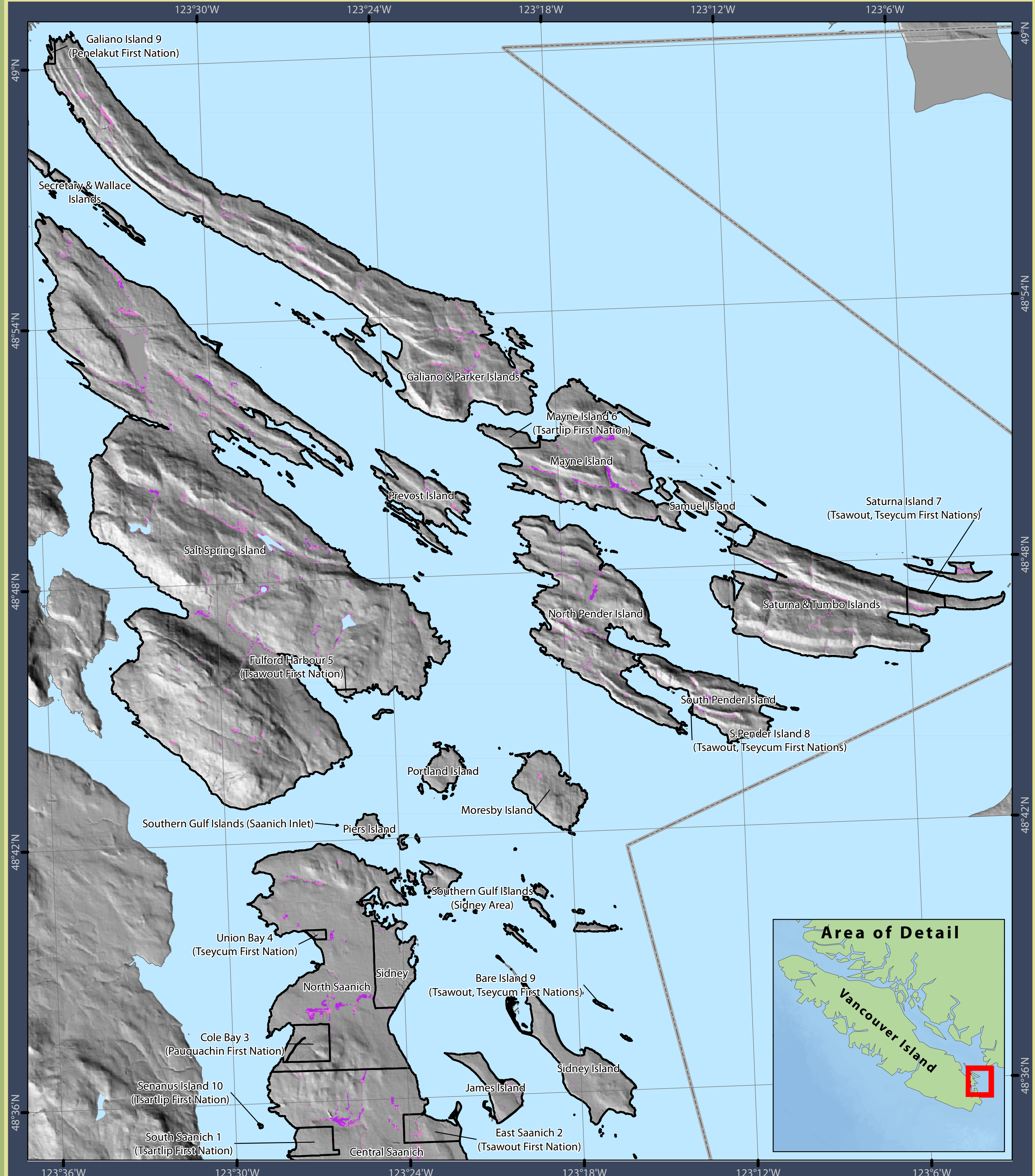
Figure 22. LiDAR Enhanced Riparian Potential Model

Core Municipal Area

Urban Land Cover Mapping
CRD (2017/2019)

Prepared for: CRD Making a difference...together

By: CASLYS CONSULTING



Core Municipal Area

Jurisdiction Boundary

Lake

International Boundary

Existing Riparian Zone

Riparian Potential Zone

0 2 4 6

Kilometres

Projection: BC Albers NAD83

Data Sources:
Capital Regional District
Province of British Columbia

Figure 23. LiDAR Enhanced Riparian Potential Model

Southern Gulf Islands

Urban Land Cover Mapping
CRD (2017/2019)

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4.5 Tree Planting Potential Mapping Results

The tree planting model allocates areas into the four classes based on the constraints described in Section 3.2.7. The results of this process have been provided as a grid format file with 1-metre resolution. These results could be further modified by land ownership if there is a desire to plan the planting initiatives with respect to different land ownership considerations. Samples of the results are illustrated in Figure 24 and Figure 25. Figure 26 demonstrates the detail of the model results.

Although the planting potential model highlights areas that are more likely to be suitable for planting and excludes areas that are likely not suitable for a variety of reasons, there are other constraints and unique property characteristics that cannot easily be modeled. As a result, there remains a need for localized planning to define actual planting suitability. One key example of this exists on golf courses, which have been modeled without the detailed location of fairways or greens. For this reason, tree planting potential does not differentiate greens and fairways from natural areas within the parcel where actual planting opportunities may exist. Additionally, underground and overhead utilities and fire hydrants have not been incorporated into the model.

Jurisdiction Boundary

River

Lake

International Boundary

Tree Planting

- No Potential
- Low Potential
- Medium Potential
- High Potential

0 2 4 6

Kilometres

Projection: BC Albers NAD83

Data Sources:
Capital Regional District
Province of British Columbia

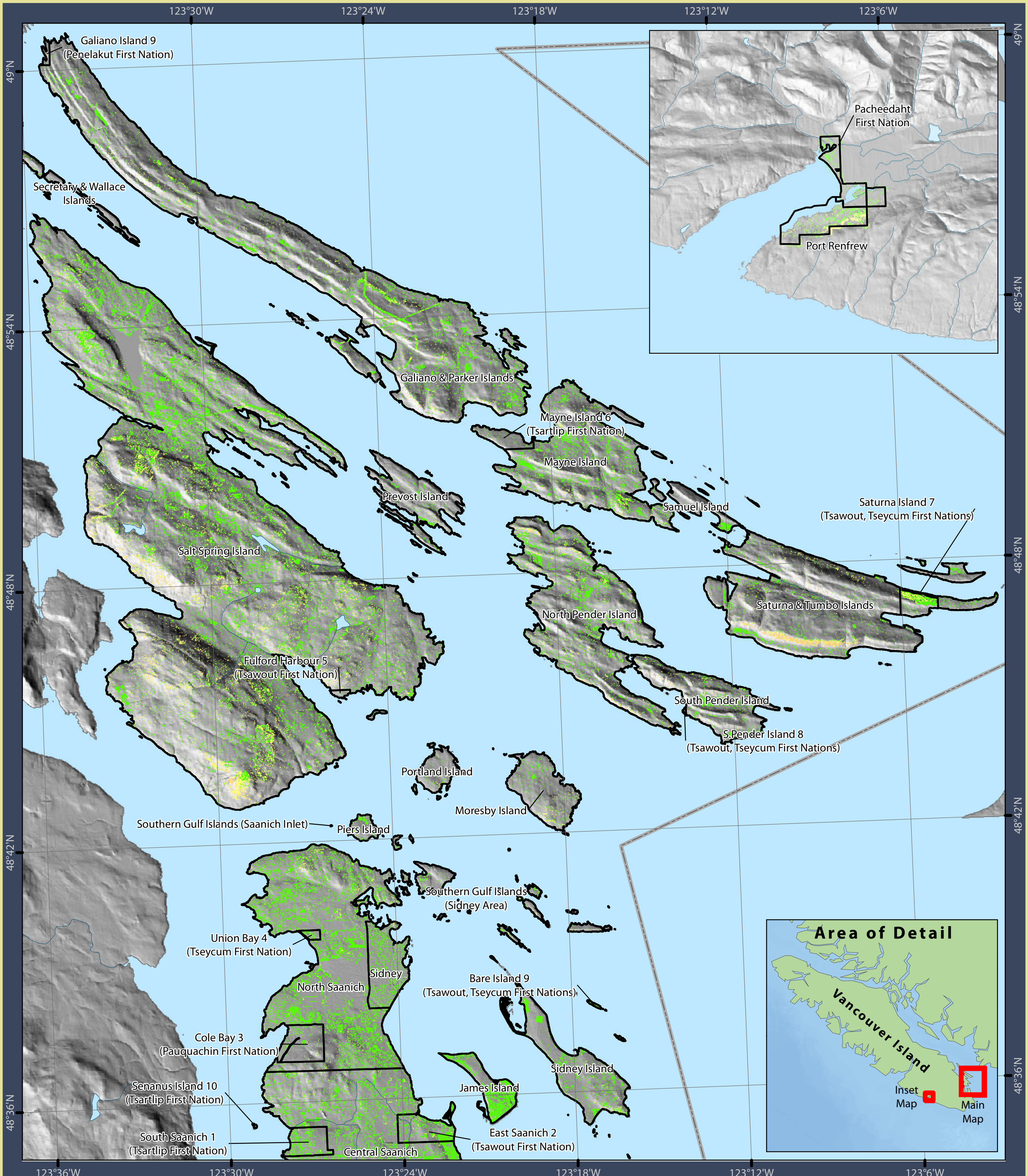
Figure 24. Tree Planting Potential Model

Core Municipal Area

Urban Land Cover Mapping
CRD (2017/2019)

Prepared for: CRD Making a difference...together

By: CASLYS CONSULTING



Jurisdiction Boundary

River

Lake

International Boundary

Tree Planting Potential

- No Potential
- Low Potential
- Medium Potential
- High Potential

0 2 4 6

Kilometres

Projection: BC Albers NAD83

Data Sources:
Capital Regional District
Province of British Columbia

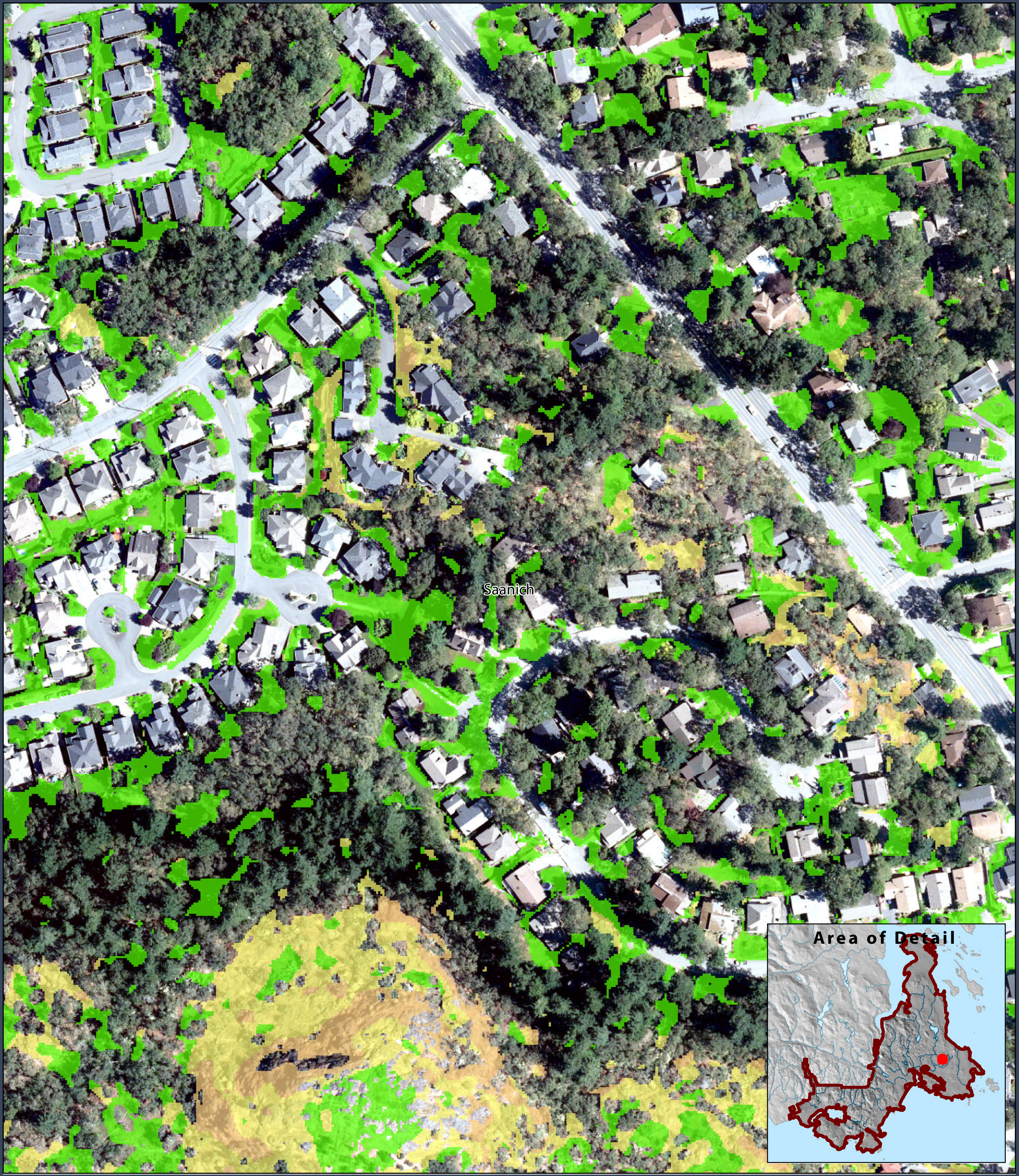
Figure 25. Tree Planting Potential Model

Southern Gulf Islands and Port Renfrew

Urban Land Cover Mapping
CRD (2017/2019)

Prepared for: CRD Making a difference...together

By: CASLYS CONSULTING



Jurisdiction Boundary

Tree Planting Potential

- No Potential
- Low Potential
- Medium Potential
- High Potential

0 25 50 75
Meters

Projection: UTM Zone 10 North (NAD83)

Data Sources:
Capital Regional District
Province of British Columbia

Figure 26. Tree Planting Potential

Core Municipal Area (Sample Area in Detail)

Urban Land Cover Mapping
CRD (2017/2019)

Prepared for: CRD Making a difference...together

By: CASLYS CONSULTING

5.0 DATA LIMITATIONS AND RECOMMENDATIONS

5.1 Data Limitations

Data limitations are presented under headings with respect to various datasets used or developed during this project. The following limitations are associated with the various data layers:

Orthophoto Land Cover Mapping:

- Previous CRD mapping of land cover included time periods for 1986, 2005 and 2011. More substantial limitations were identified for the 1986 dataset due to lower quality source imagery. This report omits 1986 results in part to focus on more recent change, but also due to those limitations. Refer to previous reports to review longer term trends in tree canopy and impervious surface coverage. This report presents 2005, 2011 and 2019 data in the same manner to previous reporting.
- Section 3.1.4 (Quality Control) highlights the lower sun angle and increased shadow present in the 2019 orthophoto, which limits the ability to map both the ground areas located in shadow, but also hinders the ability to classify as accurate on the shaded side of tree crowns. Although shadow makes up a small portion of the study area, it impacts mapping for an area approximately twice as significant when compared to 2005 and 2011 data. The 2019 image also suffers from reduced image contrast in comparison to past imagery.
- The 2011 image was taken in the spring and therefore not all trees were in full leaf. As a result, tree cover values in areas where deciduous species are dominant may be underestimated. Although this does not directly influence 2019 mapping, it does influence the trends in cover change between these time periods.

LiDAR Enhanced Land Cover Mapping:

- Since the LiDAR enhanced mapping process also relies on the orthophotos, the limitations above can influence results, but to a significantly lesser degree.
- Data difference between LiDAR and orthophotos create some inconsistencies in places where ground features have changed (i.e., building construction, vehicle positions, and agricultural vegetation heights). These changes can increase mapping error, but not in a significant manner when pertaining to tree cover or impervious surfaces. The most significant impact is the presence of a small percentage (<0.1%) misclassification between tree and pavement.
- Although efforts have been made to align the LiDAR enhanced cover classes with past mapping, there was value in adding a shrub (and small trees less than 3-metres tall) class which has not been mapped previously. This new class helps define the tree extent and area of deciduous and coniferous trees for tree canopy calculations. The most significant issue with the shrub class is that it draws from both the herbaceous and tree classes in past mapping, making it difficult to make direct comparisons for past trends. This improved mapping approach does, however, mean that future mapping (when LiDAR is used) will allow for much more accurate comparisons to this 2019 dataset. Conversion factors are presented in Section 4.1.4.1 to assist in making more accurate comparisons between future and previous mapping methods.

- The land cover classification process is developed to semi-automate mapping in a replicable manner and does not include photo interpretation and manual delineations in most cases. The accuracy assessment provides a quantitative evaluation of the degree of error in the mapped results and, depending on the level of class aggregation, the error can be as high as 5% for the LiDAR enhanced land cover mapping. Although this error is recognized, it is important to understand the types of errors that can exist. The accuracy assessment error matrix provides some insight into classes that demonstrate confusion. Based on further visual review, some additional types of error include:
    - Confusion between various non-vegetated classes such as bare soil, gravel, pavement or bedrock which all share similar spectral characteristics.
    - Confusion between some areas of low vegetation and non-vegetated areas due, in part, to LiDAR data suggesting that vegetation heights are very low in some areas and also due, in part, to features such as cars, buses, trucks and machinery on the landscape that is in the LiDAR (which is also acquired at a different date than the orthophotos). As a result, a car may be present in the LiDAR but not in the orthophoto creating false heights for ground features.
    - Tall features such as buildings, bridges and signage can influence the classification of features creating false areas of tree or shrub in the map.
    - The LiDAR data does not cover the full extents of all small islands and features offshore from major land areas. As a result, some small islands may have been missed (e.g., McCarthy Island in Esquimalt Harbour).
    - Various characteristic of imagery and LiDAR can create false readings that can be associated with water.
    - In some areas, a unique expression of a land cover type exists that is not well captured by the defined land cover classes. All attempts are made to ensure that all features are trained and classified to the best ability of the technology. This can include features such as sub-tidal areas being classified as herb or sand or bedrock shoreline areas being misclassified.

<u>LiDAR-Based Tree Metrics:</u>

- Software developed for use in identifying tree parameters are largely designed for the forest resource industry but apply well to more urban and rural forest management applications. The degree of species variation, pruning or other modifications to urban trees for utilities, safety, or aesthetic reasons creates additional challenges for tree classification tasks which rely heavily on comprehensive training data. The point dataset developed through this work could act as a good starting dataset for a tree inventory dataset but suffers from these issues:
    - Large hedges are often mapped as trees and do not reflect the positions of the individual stems that comprise the hedge.
    - Some large trees species can be mapped with multiple stems (typically associated with each large branch separated by open areas within the tree canopy).
    - Mapping is focused on the canopy that is visible from above and therefore misses trees located below the upper canopy or factors some understory trees into the delineation of a larger tree.
    - Tree points are ideally located as close as possible to the actual stem for inventory purposes; however, the tree points are calculated based on the tallest point of the tree canopy.

<u>LiDAR Enhanced Riparian Potential Models:</u>

- The riparian potential model is derived almost entirely from terrain characteristics in the LiDAR dataset and is intended to reflect the potential for riparian habitat commonly associated with low land adjacent to existing hydrographic features like wetlands, streams, ponds and lakes. This model does not infer the actual existence of riparian habitat, nor does it include hydraulic modeling or detailed inspections to infer flood hazard or risk.
- The precise alignment of the source features (streams in particular) relative to elevation model channel location plays an important role in determining the slopes that water must travel across in this cost-distance modeling approach. Misalignments in the location of a stream centreline, relative to the terrain model create inaccuracies in the riparian potential model results.

<u>Tree Planting Potential Models:</u>

- The tree planting potential model is based on a variety of factors that are more comprehensive than past results for some municipalities, but do not account for all considerations associated of a tree planting site. Various localized conditions must be accounted for via local knowledge, more detailed desktop analysis or actual field visits. Although the results of this model can help locate areas of the land base that have potential, some mapping inaccuracies and land use constraints may result in false positives. For example, parcel boundaries in agricultural areas are mapped with higher potential while croplands are restricted for planting; parcel boundaries may be intensively farmed in areas where a single operator is working land across parcel boundaries. As well, soil conditions are mapped entirely based on terrain position, and although this provides useful indicator of soil moisture, it is not a substitute for actual field sampling that can influence planting suitability.
- Although the model accounts for certain conditions, underground and overhead utilities and fire hydrants are not included as model constraints. Municipalities with this data could further constrain the results using these datasets.

5.2 Recommendations

The following recommendations should be considered to ensure a high level of confidence can be placed in future interpretations of the data.

- The LiDAR allows for accurate determination of tree heights. As a result, it may be useful to report trees by height classes. This information could be useful from an urban forest management perspective. This data would come directly from the LiDAR derived Canopy Height Model (CHM) dataset.
- Mapping impervious surfaces is complicated by the presence of impervious surface that are sometimes covered or partially covered by tree canopy. This consideration could be important from a storm water management perspective and could be mapped as individual classes if required. This would be done by overlaying the tree canopy class with the building footprint polygons and polygonal representations of the roads. The new classes could be termed “Tree covered Buildings” and “Tree covered Roads”.
- This report documents that the LiDAR enhanced mapping approach is more accurate and develops additional useful classes when compared to past mapping. The costs associated with acquiring LiDAR can be higher than capturing orthophotos alone and could be a consideration in future updates, even as LiDAR costs have been dropping over the past decade. LiDAR does serve other important uses and

could be sourced in collaboration with other stakeholders (in various levels of government and government departments).

- The use of modeled stream channel locations developed from flow accumulation calculations may provide a more accurate manner of precisely aligning streams with the LiDAR terrain modeling to improve riparian potential. This approach would require significant efforts to account for engineered water management infrastructure which is not reflected in the terrain surface (i.e., culverts and other water diversion structures), but could be a valuable approach if deemed important for engineering purposes.

6.0 LITERATURE CITED

Caslys 2013. Capital Regional District Land Cover Mapping 1986, 2005 and 2011 Summary Report. Prepared by Caslys Consulting Ltd. for CRD / Habitat Acquisition Trust

Caslys 2018. Capital Regional District Land Cover Mapping 2017 Summary Report. Prepared by Caslys Consulting Ltd. for CRD

Appendix A

LidR R Package Tree Metrics

LiDAR Derived Tree Point Metrics

For further information (including details for a broader set of tree metrics) refer to the lidR documentation repository below:
https://github.com/Jean-Romain/lidR/wiki/stdmetrics

n: number of points
area: approximative actual area of a raster (should be close to the square of the resolution but not on the edge)

$$(X_{max} - X_{min}) \times (Y_{max} - Y_{min})$$

angle: average absolute scan angle
zmax: maximum height
zmean: mean height
zsd: standard deviation of height distribution
zskew: skewness of height distribution
zkurt: kurtosis of height distribution
zentropy: entropy of height distribution (see function entropy)
pzabovezmean: percentage of returns above zmean
pzabovex: percentage of returns above x.
zqx: xth percentile (quantile) of height distribution
zpcumx: cumulative percentage of return in the ith layer according to Wood et al. 2008 (see metrics named d1, d2, ...)

$$d_i = \int_{z_{min}}^{i\frac{z_{max}}{10}} f(z)dz$$

with *f(z)* the probability distribution of elevations. is the lower bound and was hard coded to 0 in lidR < 3.1.3 and is now a parameter in from 3.1.3. is the elevation of the highest point
itot: sum of intensities for each return
imax: maximum intensity
imean: mean intensity
isd: standard deviation of intensity
iskew: skewness of intensity distribution
ikurt: kurtosis of intensity distribution
ipground: percentage of intensity returned by points classified as "ground"
ipcumzqx: percentage of intensity returned below the kth percentile of height
ip1st: percentage of intensity returned by 1st returns
ip2nd: percentage of intensity returned by 2nd returns
ip3rd: percentage of intensity returned by 3rd returns
ipxth: percentage of intensity returned by xth returns
pxth: percentage xth returns
pground: percentage of returns classified as "ground"

Appendix B

Land Cover Classification Accuracy Assessments

Accuracy Assessment for Task 1 Method – Without LiDAR

Value of 90.5% in lower right of table is derived from a comparable method to past accuracy assessments from 2011 and 2005 classifications. Producer Accuracy (along the bottom of the table) provides insight into errors of omission per class to better understand accuracy per class.

Mapped Class	Verified Class>	Shadow 1	Ocean 2	Lake 3	Pond 4	River 5	Shoreline-Gravel 6	Shoreline-bedrock 7	Bare 8	Grass 9	Herb 10	Flooded-Herb 11	Tree 12	Dock 13	Paved / Gravel 14	Agriculture 15	Bedrock 16	Tree (Riparian) 17	Road 20	Building 23	Total Count	Stratified User Accuracy	User Accuracy Weighted
Shadow	1	11				1							1		1						14	78.6%	0.2%
Ocean	2		8											1							9	88.9%	3.2%
Lake	3			11																	11	100.0%	1.1%
Pond	4				7																7	100.0%	0.1%
River	5					7															7	100.0%	0.0%
Shoreline-Gravel-Sand	6						10														10	100.0%	0.3%
Shoreline-Bedrock	7						2	8						1	3						14	57.1%	0.1%
Bare	8								9		2				1	1					13	69.2%	0.2%
Grass	9									15			6		1					1	23	65.2%	4.7%
Herb	10									8	34		6			2					50	68.0%	4.5%
Seasonally Flooded Herb	11								1			22									23	95.7%	0.6%
Tree	12												42						2		44	95.5%	50.5%
Dock	13													13							13	100.0%	0.1%
Paved/Gravel	14						1		1	2	4		2		31		1				42	73.8%	5.0%
Agriculture	15															42					42	100.0%	8.1%
Bedrock	16														1		10				11	90.9%	0.1%
Tree (Riparian)	17																	13			13	100.0%	2.7%
Road	20																		9		9	100.0%	3.9%
Building	23																			30	30	100.0%	5.1%
Total Count		11	8	11	7	8	13	8	11	25	40	22	57	15	38	45	11	13	11	31	385	**86.2%**	**90.5%**
Producer Accuracy		100%	100%	100%	100%	88%	77%	100%	82%	60%	85%	100%	74%	87%	82%	93%	91%	100%	82%	97%			

Accuracy Assessment for Task 2 Method – LiDAR Enhanced Classification

Value of 95.1% in lower right of table is derived from a comparable method to past accuracy assessments. Producer Accuracy (along the bottom of the table) provides insight into errors of omission per class to better understand accuracy per class.

Mapped Class	Verified Class>	Ocean	Lake	Pond	River	Shore Sand and Gravel	Shore Rock	Soil	Grass	Herb	Shrub	Tree Decid	Tree Conif	Dock	Paved / Gravel	Road	Built	Agriculture	Bedrock	Aquatic veg	Loose Gravel	Total Count	Stratified User Accuracy
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	22	24		
Ocean	1	29																				29	100.0%
Lake	2		18																			18	100.0%
Pond	3			11																		11	100.0%
River	4				11																	11	100.0%
Shore sand and gravel	5					24	2								2							28	85.7%
shore rock	6						26										1					27	96.3%
soil	7							11							2			1				14	78.6%
grass	8								32	3												35	91.4%
herb	9								1	25												26	96.2%
shrub	10										38								1			39	97.4%
tree decid	11											30	3									33	90.9%
tree conif	12											2	30									32	93.8%
dock	13					1								30						1		32	93.8%
paved gravel	14														41		1					42	97.6%
road	15															30						30	100.0%
built	16												2				36					38	94.7%
agri	17																	30				30	100.0%
bedrock	18										2				1				20			23	87.0%
aquatic veg	22																			22		22	100.0%
loose gravel	24																				11	11	100.0%
Total Count		29	18	11	11	25	28	11	33	28	40	32	35	30	46	30	38	31	21	23	11	531	**95.1%**
Producer Accuracy		100%	100%	100%	100%	96%	93%	100%	97%	89%	95%	94%	86%	100%	89%	100%	95%	97%	95%	96%	100%		

Appendix C

Detailed Tabulation of Land Cover by Municipality and First Nation Jurisdictions
(LiDAR Enhanced Mapping)

Municipal and First Nation Areas	Ocean	Lake	Pond	River	Sand/gravel shoreline	Bedrock Shoreline	Exposed Soil	Grass	Herb	Shrub (and small trees)	Tree (Deciduous)	Tree (Coniferous)	Docks	Pavement / Packed Gravel	Road	Buildings	Agriculture	Exposed Bedrock	Aquatic Vegetation	Loose Gravel	Total Area (ha)
Bare Island 9 (Tsawout, Tseycum FN)	-	-	-	-	0.0	0.8	0.0	1.6	1.7	2.6	0.1	-	-	-	-	-	-	-	-	-	6.8
Beecher Bay 1 & 2 First Nation	0.4	1.1	-	-	0.1	4.5	5.6	21.9	11.4	26.8	116.5	200.2	-	3.4	3.7	0.8	-	0.0	0.5	-	397.0
Central Saanich	0.1	22.9	4.0	-	8.0	3.1	34.6	490.3	113.4	248.0	635.2	654.5	0.1	206.6	107.6	174.5	1,445.6	0.5	2.5	6.4	4,157.7
Chatham 4 & Discovery 3 (FN)	1.3	-	-	-	1.3	5.7	0.1	17.1	1.1	13.8	53.7	15.8	-	-	-	-	-	1.3	-	-	111.2
Cole Bay 3 (Pauquachin First Nation)	-	-	-	-	0.0	0.0	0.6	9.3	1.7	12.7	69.0	176.2	-	1.9	1.6	1.4	-	0.0	-	-	274.3
Colwood	0.3	7.2	0.8	-	9.2	2.7	31.2	355.0	88.0	163.1	277.9	432.8	0.5	148.5	87.0	119.1	0.1	0.0	0.1	39.0	1,762.5
D'Arcy Island	0.2	-	-	-	0.3	3.2	0.3	1.7	0.9	2.5	42.2	38.7	-	0.0	-	0.0	-	-	-	-	89.8
Discovery Island	1.7	-	-	-	0.5	5.1	0.1	8.8	-	6.7	38.9	19.9	-	-	-	-	-	0.7	-	-	82.2
East Saanich 2 (Tsawout First Nation)	0.0	0.4	-	0.4	3.7	0.2	4.4	48.4	11.0	21.2	66.6	50.5	-	18.1	10.7	13.8	-	-	0.0	-	249.4
East Sooke	1.0	17.7	-	-	0.1	2.9	6.9	171.4	63.1	169.3	722.6	1,907.6	-	7.3	17.6	13.0	17.1	0.4	1.0	-	3,119.0
Esquimalt First Nation	-	-	-	-	0.8	0.7	0.4	4.8	1.3	3.0	3.7	1.2	-	2.8	1.4	0.9	-	-	-	-	21.0
Esquimalt	0.7	0.5	-	-	0.6	5.3	15.4	155.0	25.3	67.9	151.4	31.8	1.5	103.2	44.0	100.9	-	-	-	0.4	703.7
Fulford Harbour 5 (Tsawout FN)	-	-	-	-	0.0	0.1	0.0	0.2	0.1	0.4	5.4	14.3	-	0.0	-	-	-	-	-	-	20.4
Galiano & Parker Islands	0.7	30.2	-	-	1.1	11.5	25.1	197.7	117.7	328.4	1,987.6	3,126.7	0.1	8.8	31.8	19.5	82.4	1.0	1.0	-	5,971.4
Galiano Island 9 (Penelakut FN)	-	-	-	-	0.0	0.3	0.0	0.6	0.1	1.1	7.8	14.4	-	0.0	0.0	0.0	-	-	-	-	24.4
Goldstream 13 (Various First Nations)	-	-	-	-	0.0	-	0.0	0.5	0.1	0.5	1.5	5.9	-	0.0	-	-	-	0.0	-	-	8.5
Highlands	0.0	42.3	-	-	0.0	0.5	21.8	221.5	114.2	277.9	1,055.7	1,967.5	0.0	42.9	25.6	25.1	4.5	6.6	0.9	6.9	3,814.1
James Island	0.0	7.5	-	-	4.2	7.8	6.0	120.3	14.0	15.0	63.9	70.6	-	6.3	-	0.5	-	-	-	-	316.0
Langford	0.0	101.6	1.1	-	0.2	0.2	66.7	438.2	190.6	393.1	814.0	1,432.8	0.4	314.3	172.2	228.9	40.9	12.4	1.4	19.4	4,228.6
Long Neck Island 9 & Whale Island 8 FN	0.0	-	-	-	0.0	1.2	0.1	0.3	0.2	0.3	1.7	0.0	-	0.0	-	-	-	-	-	-	3.8
Mayne Island 6 (Tsartlip First Nation)	-	-	-	-	-	0.5	0.3	1.8	0.6	4.5	54.3	77.1	-	0.0	-	-	-	0.0	-	-	139.2
Mayne Island	0.2	1.8	-	-	0.4	3.3	13.5	175.3	48.3	111.6	613.7	1,017.4	-	9.1	26.1	20.5	174.2	0.3	0.0	-	2,215.6
Metchosin	0.3	21.2	-	-	3.8	21.7	67.6	588.5	340.5	409.7	1,384.5	3,499.6	0.2	82.7	56.5	49.1	290.9	16.6	1.1	1.9	6,836.4
Moresby Island	0.4	0.2	-	-	0.7	5.1	5.8	10.3	6.0	17.0	282.6	217.7	-	0.2	-	0.1	54.2	0.0	-	-	600.1
New Songhees 1A First Nation	-	-	-	-	0.0	0.2	3.0	13.7	2.7	7.2	11.9	2.9	-	7.5	6.0	11.3	-	-	-	-	66.5
North Pender Island	0.1	33.7	-	-	1.5	10.1	31.5	152.5	53.4	136.3	722.9	1,305.5	-	16.4	32.6	28.9	162.0	0.6	0.2	-	2,688.2
North Saanich	1.4	12.5	1.1	-	2.8	4.3	36.0	512.4	111.0	238.9	758.2	789.0	0.6	240.2	120.9	155.4	706.0	0.4	1.0	4.4	3,696.4
Oak Bay	0.2	0.7	-	-	3.2	11.3	19.0	224.5	27.2	120.7	359.9	43.8	0.0	48.2	57.6	133.1	-	0.9	0.0	-	1,050.3
Piers Island	0.1	0.1	-	-	0.1	0.4	0.4	7.9	0.7	3.5	44.6	38.3	-	0.4	0.6	1.6	0.6	-	0.0	-	99.3
Portland Island	1.0	-	-	-	0.1	1.3	0.1	3.6	1.8	7.3	117.8	97.3	-	0.0	-	0.0	-	-	-	-	230.2
Prevost Island	0.3	2.3	-	-	0.1	4.7	3.3	26.0	6.9	5.7	301.7	263.6	-	0.1	-	0.4	49.2	0.0	0.3	-	664.6
S.Pender Island 8 (Tsawout, Tseycum FN)	-	-	-	-	0.0	0.1	0.0	0.1	0.0	0.1	0.7	2.0	-	-	-	-	-	-	-	-	2.9
Saanich	1.2	351.7	1.3	-	4.6	11.6	131.2	1,584.3	412.4	954.8	2,565.1	2,237.7	0.4	570.0	414.2	805.8	587.5	7.1	7.0	12.3	10,660.1
Salt Spring Island	1.5	320.9	0.1	-	2.5	12.2	137.7	1,098.3	562.3	1,134.0	4,781.1	8,854.9	0.1	94.6	119.1	119.7	1,183.3	8.5	2.1	-	18,432.9
Samuel Island	-	-	-	-	0.1	2.2	2.4	13.4	1.0	5.1	76.8	102.4	-	0.1	-	0.1	-	0.0	-	-	203.6
Saturna & Tumbo Islands	0.4	11.0	-	-	1.3	9.4	17.6	68.4	82.2	115.8	764.2	1,973.0	0.0	4.5	13.6	7.2	88.8	3.2	0.0	-	3,160.4

Continued next page…

Municipal and First Nation Areas	Ocean	Lake	Pond	River	Sand/gravel shoreline	Bedrock Shoreline	Exposed Soil	Grass	Herb	Shrub (and small trees)	Tree (Deciduous)	Tree (Coniferous)	Docks	Pavement / Packed Gravel	Road	Buildings	Agriculture	Exposed Bedrock	Aquatic Vegetation	Loose Gravel	Total Area (ha)
Saturna Island 7 (Tsawout, Tseycum FN)	-	-	-	-	0.0	0.3	1.0	17.0	26.6	7.9	35.8	56.5	-	0.0	-	-	-	0.0	-	-	145.1
Secretary & Wallace Islands	1.5	0.0	-	-	0.0	1.1	0.3	2.4	0.8	6.2	108.5	88.8	-	0.1	-	0.4	-	-	-	-	210.3
Senanus Island 10 (Tsartlip FN)	-	-	-	-	-	0.1	0.0	0.2	0.1	0.2	1.0	0.7	-	0.0	-	-	-	-	-	-	2.3
Sidney Island	0.5	0.9	-	-	14.1	10.4	14.0	72.5	22.1	27.6	279.3	377.1	0.0	1.9	3.9	0.8	44.9	0.0	0.4	-	870.5
Sidney	0.1	0.1	-	-	1.7	2.5	7.9	90.3	10.4	45.7	83.4	14.2	0.3	81.5	47.0	89.3	30.8	-	0.0	-	505.2
Sooke	0.0	5.4	0.0	9.8	5.1	10.1	70.7	459.9	240.1	499.0	1,126.9	2,869.8	0.0	148.0	83.1	98.9	101.9	5.9	0.2	17.8	5,752.6
South Pender Island	0.0	5.5	-	-	0.3	4.2	6.5	32.1	16.1	52.0	255.5	473.7	-	2.3	7.6	4.4	39.7	0.3	0.1	-	900.3
South Saanich 1 (Tsartlip First Nation)	0.1	0.1	-	-	0.1	0.1	1.3	25.7	4.3	25.4	51.9	71.7	-	7.7	3.5	6.1	4.8	0.0	0.0	-	202.7
Southern Gulf Islands (Saanich Inlet)	-	-	-	-	-	0.1	0.0	0.1	0.0	0.1	-	-	-	0.0	-	-	-	-	-	-	0.3
Southern Gulf Islands (Sidney Area)	2.6	2.1	-	-	0.8	9.4	1.9	14.4	5.5	9.2	138.6	106.3	-	1.0	-	1.3	17.8	0.0	0.2	-	311.2
T'Sou'ke 1 & 2 First Nation	-	-	-	-	0.2	0.1	0.5	9.4	0.9	5.2	19.5	33.2	-	3.6	1.3	1.7	0.0	-	-	-	75.6
Union Bay 4 (Tseycum First Nation)	-	0.2	-	-	0.1	0.3	0.3	4.1	1.7	3.6	12.1	3.7	-	1.0	0.5	0.7	0.0	-	-	-	28.3
Victoria	0.6	2.2	-	-	3.0	5.7	49.6	282.3	39.4	182.7	522.6	34.0	0.3	246.2	165.9	411.0	-	-	0.0	-	1,945.4
View Royal	0.2	48.9	0.0	-	0.3	1.1	14.4	116.1	49.6	141.7	290.5	633.2	-	65.0	52.3	67.2	9.3	0.2	0.5	0.0	1,490.6
Willis Point	0.0	8.0	0.0	-	0.2	0.7	2.1	12.7	5.6	17.9	152.9	359.0	0.0	3.3	3.5	4.2	-	0.1	0.0	-	570.3
Pacheedaht First Nation	-	-	-	-	2.2	-	-	6.3	3.1	12.8	26.0	78.9	-	5.7	3.1	0.7	-	-	-	-	138.8
Port Renfrew	-	-	-	-	3.0	0.2	-	9.8	14.3	73.2	41.1	187.7	-	24.3	4.7	3.5	-	0.1	-	-	362.0
Totals per class	19.2	1,060.8	8.4	10.2	82.4	200.6	859.3	7,900.3	2,853.3	6,136.7	22,101.1	36,071.8	4.5	2,529.7	1,726.8	2,721.9	5,136.6	67.2	20.4	108.6	**89,619.8**

Summarized as percentages on the following pages

Municipal and First Nation Areas	Ocean	Lake	Pond	River	Sand/gravel shoreline	Bedrock Shoreline	Exposed Soil	Grass	Herb	Shrub (and small trees)	Tree (Deciduous)	Tree (Coniferous)	Docks	Pavement / Packed Gravel	Road	Buildings	Agriculture	Exposed Bedrock	Aquatic Vegetation	Loose Gravel	Total Area (ha)
Bare Island 9 (Tsawout, Tseycum FN)	0.0%	0.0%	0.0%	0.0%	0.5%	11.6%	0.2%	23.9%	24.4%	38.1%	1.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	6.8
Beecher Bay 1 & 2 First Nation	0.1%	0.3%	0.0%	0.0%	0.0%	1.1%	1.4%	5.5%	2.9%	6.8%	29.3%	50.4%	0.0%	0.9%	0.9%	0.2%	0.0%	0.0%	0.1%	0.0%	397.0
Central Saanich	0.0%	0.6%	0.1%	0.0%	0.2%	0.1%	0.8%	11.8%	2.7%	6.0%	15.3%	15.7%	0.0%	5.0%	2.6%	4.2%	34.8%	0.0%	0.1%	0.2%	4,157.7
Chatham 4 & Discovery 3 (FN)	1.2%	0.0%	0.0%	0.0%	1.1%	5.2%	0.1%	15.4%	1.0%	12.4%	48.3%	14.2%	0.0%	0.0%	0.0%	0.0%	0.0%	1.2%	0.0%	0.0%	111.2
Cole Bay 3 (Pauquachin First Nation)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	3.4%	0.6%	4.6%	25.2%	64.2%	0.0%	0.7%	0.6%	0.5%	0.0%	0.0%	0.0%	0.0%	274.3
Colwood	0.0%	0.4%	0.0%	0.0%	0.5%	0.2%	1.8%	20.1%	5.0%	9.3%	15.8%	24.6%	0.0%	8.4%	4.9%	6.8%	0.0%	0.0%	0.0%	2.2%	1,762.5
D'Arcy Island	0.2%	0.0%	0.0%	0.0%	0.3%	3.5%	0.3%	1.8%	1.0%	2.8%	47.0%	43.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	89.8
Discovery Island	2.0%	0.0%	0.0%	0.0%	0.6%	6.1%	0.1%	10.7%	0.0%	8.1%	47.3%	24.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.8%	0.0%	0.0%	82.2
East Saanich 2 (Tsawout First Nation)	0.0%	0.1%	0.0%	0.2%	1.5%	0.1%	1.8%	19.4%	4.4%	8.5%	26.7%	20.3%	0.0%	7.3%	4.3%	5.5%	0.0%	0.0%	0.0%	0.0%	249.4
East Sooke	0.0%	0.6%	0.0%	0.0%	0.0%	0.1%	0.2%	5.5%	2.0%	5.4%	23.2%	61.2%	0.0%	0.2%	0.6%	0.4%	0.5%	0.0%	0.0%	0.0%	3,119.0
Esquimalt First Nation	0.0%	0.0%	0.0%	0.0%	3.7%	3.2%	1.8%	22.8%	6.1%	14.5%	17.7%	5.8%	0.0%	13.4%	6.8%	4.2%	0.0%	0.0%	0.0%	0.0%	21.0
Esquimalt	0.1%	0.1%	0.0%	0.0%	0.1%	0.8%	2.2%	22.0%	3.6%	9.6%	21.5%	4.5%	0.2%	14.7%	6.3%	14.3%	0.0%	0.0%	0.0%	0.1%	703.7
Fulford Harbour 5 (Tsawout FN)	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%	0.2%	1.0%	0.3%	1.8%	26.3%	70.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	20.4
Galiano & Parker Islands	0.0%	0.5%	0.0%	0.0%	0.0%	0.2%	0.4%	3.3%	2.0%	5.5%	33.3%	52.4%	0.0%	0.1%	0.5%	0.3%	1.4%	0.0%	0.0%	0.0%	5,971.4
Galiano Island 9 (Penelakut FN)	0.0%	0.0%	0.0%	0.0%	0.0%	1.4%	0.1%	2.3%	0.6%	4.5%	32.0%	58.8%	0.0%	0.1%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	24.4
Goldstream 13 (Various First Nations)	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.5%	5.5%	1.0%	5.9%	17.2%	69.2%	0.0%	0.1%	0.0%	0.0%	0.0%	0.5%	0.0%	0.0%	8.5
Highlands	0.0%	1.1%	0.0%	0.0%	0.0%	0.0%	0.6%	5.8%	3.0%	7.3%	27.7%	51.6%	0.0%	1.1%	0.7%	0.7%	0.1%	0.2%	0.0%	0.2%	3,814.1
James Island	0.0%	2.4%	0.0%	0.0%	1.3%	2.5%	1.9%	38.1%	4.4%	4.7%	20.2%	22.3%	0.0%	2.0%	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%	316.0
Langford	0.0%	2.4%	0.0%	0.0%	0.0%	0.0%	1.6%	10.4%	4.5%	9.3%	19.3%	33.9%	0.0%	7.4%	4.1%	5.4%	1.0%	0.3%	0.0%	0.5%	4,228.6
Long Neck Island 9 & Whale Island 8 FN	0.0%	0.0%	0.0%	0.0%	0.1%	31.4%	1.8%	7.7%	5.7%	8.9%	44.0%	0.3%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.8
Mayne Island 6 (Tsartlip First Nation)	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	0.2%	1.3%	0.5%	3.3%	39.0%	55.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	139.2
Mayne Island	0.0%	0.1%	0.0%	0.0%	0.0%	0.1%	0.6%	7.9%	2.2%	5.0%	27.7%	45.9%	0.0%	0.4%	1.2%	0.9%	7.9%	0.0%	0.0%	0.0%	2,215.6
Metchosin	0.0%	0.3%	0.0%	0.0%	0.1%	0.3%	1.0%	8.6%	5.0%	6.0%	20.3%	51.2%	0.0%	1.2%	0.8%	0.7%	4.3%	0.2%	0.0%	0.0%	6,836.4
Moresby Island	0.1%	0.0%	0.0%	0.0%	0.1%	0.8%	1.0%	1.7%	1.0%	2.8%	47.1%	36.3%	0.0%	0.0%	0.0%	0.0%	9.0%	0.0%	0.0%	0.0%	600.1
New Songhees 1A First Nation	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	4.5%	20.7%	4.0%	10.8%	18.0%	4.3%	0.0%	11.3%	9.0%	17.0%	0.0%	0.0%	0.0%	0.0%	66.5
North Pender Island	0.0%	1.3%	0.0%	0.0%	0.1%	0.4%	1.2%	5.7%	2.0%	5.1%	26.9%	48.6%	0.0%	0.6%	1.2%	1.1%	6.0%	0.0%	0.0%	0.0%	2,688.2
North Saanich	0.0%	0.3%	0.0%	0.0%	0.1%	0.1%	1.0%	13.9%	3.0%	6.5%	20.5%	21.3%	0.0%	6.5%	3.3%	4.2%	19.1%	0.0%	0.0%	0.1%	3,696.4
Oak Bay	0.0%	0.1%	0.0%	0.0%	0.3%	1.1%	1.8%	21.4%	2.6%	11.5%	34.3%	4.2%	0.0%	4.6%	5.5%	12.7%	0.0%	0.1%	0.0%	0.0%	1,050.3
Piers Island	0.1%	0.1%	0.0%	0.0%	0.1%	0.4%	0.4%	7.9%	0.7%	3.5%	44.9%	38.6%	0.0%	0.4%	0.6%	1.7%	0.6%	0.0%	0.0%	0.0%	99.3
Portland Island	0.4%	0.0%	0.0%	0.0%	0.0%	0.6%	0.1%	1.6%	0.8%	3.2%	51.1%	42.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	230.2
Prevost Island	0.0%	0.3%	0.0%	0.0%	0.0%	0.7%	0.5%	3.9%	1.0%	0.9%	45.4%	39.7%	0.0%	0.0%	0.0%	0.1%	7.4%	0.0%	0.0%	0.0%	664.6
S.Pender Island 8 (Tsawout, Tseycum FN)	0.0%	0.0%	0.0%	0.0%	0.0%	1.8%	0.2%	3.1%	0.8%	3.5%	22.2%	68.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.9
Saanich	0.0%	3.3%	0.0%	0.0%	0.0%	0.1%	1.2%	14.9%	3.9%	9.0%	24.1%	21.0%	0.0%	5.3%	3.9%	7.6%	5.5%	0.1%	0.1%	0.1%	10,660.1
Salt Spring Island	0.0%	1.7%	0.0%	0.0%	0.0%	0.1%	0.7%	6.0%	3.1%	6.2%	25.9%	48.0%	0.0%	0.5%	0.6%	0.6%	6.4%	0.0%	0.0%	0.0%	18,432.9
Samuel Island	0.0%	0.0%	0.0%	0.0%	0.1%	1.1%	1.2%	6.6%	0.5%	2.5%	37.7%	50.3%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	203.6
Saturna & Tumbo Islands	0.0%	0.3%	0.0%	0.0%	0.0%	0.3%	0.6%	2.2%	2.6%	3.7%	24.2%	62.4%	0.0%	0.1%	0.4%	0.2%	2.8%	0.1%	0.0%	0.0%	3,160.4

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Municipal and First Nation Areas	Ocean	Lake	Pond	River	Sand/gravel shoreline	Bedrock Shoreline	Exposed Soil	Grass	Herb	Shrub (and small trees)	Tree (Deciduous)	Tree (Coniferous)	Docks	Pavement / Packed Gravel	Road	Buildings	Agriculture	Exposed Bedrock	Aquatic Vegetation	Loose Gravel	Total Area (ha)
Saturna Island 7 (Tsawout, Tseycum FN)	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.7%	11.7%	18.3%	5.4%	24.7%	38.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	145.1
Secretary & Wallace Islands	0.7%	0.0%	0.0%	0.0%	0.0%	0.5%	0.1%	1.1%	0.4%	3.0%	51.6%	42.2%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%	210.3
Senanus Island 10 (Tsartlip FN)	0.0%	0.0%	0.0%	0.0%	0.0%	4.6%	0.8%	8.5%	4.5%	7.8%	43.8%	29.9%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.3
Sidney Island	0.1%	0.1%	0.0%	0.0%	1.6%	1.2%	1.6%	8.3%	2.5%	3.2%	32.1%	43.3%	0.0%	0.2%	0.4%	0.1%	5.2%	0.0%	0.0%	0.0%	870.5
Sidney	0.0%	0.0%	0.0%	0.0%	0.3%	0.5%	1.6%	17.9%	2.1%	9.1%	16.5%	2.8%	0.1%	16.1%	9.3%	17.7%	6.1%	0.0%	0.0%	0.0%	505.2
Sooke	0.0%	0.1%	0.0%	0.2%	0.1%	0.2%	1.2%	8.0%	4.2%	8.7%	19.6%	49.9%	0.0%	2.6%	1.4%	1.7%	1.8%	0.1%	0.0%	0.3%	5,752.6
South Pender Island	0.0%	0.6%	0.0%	0.0%	0.0%	0.5%	0.7%	3.6%	1.8%	5.8%	28.4%	52.6%	0.0%	0.3%	0.8%	0.5%	4.4%	0.0%	0.0%	0.0%	900.3
South Saanich 1 (Tsartlip First Nation)	0.1%	0.1%	0.0%	0.0%	0.1%	0.0%	0.6%	12.7%	2.1%	12.5%	25.6%	35.4%	0.0%	3.8%	1.7%	3.0%	2.3%	0.0%	0.0%	0.0%	202.7
Southern Gulf Islands (Saanich Inlet)	0.0%	0.0%	0.0%	0.0%	0.0%	23.5%	0.2%	33.1%	16.1%	27.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3
Southern Gulf Islands (Sidney Area)	0.8%	0.7%	0.0%	0.0%	0.3%	3.0%	0.6%	4.6%	1.8%	2.9%	44.5%	34.2%	0.0%	0.3%	0.0%	0.4%	5.7%	0.0%	0.1%	0.0%	311.2
T'Sou'ke 1 & 2 First Nation	0.0%	0.0%	0.0%	0.0%	0.2%	0.1%	0.7%	12.4%	1.2%	6.9%	25.8%	44.0%	0.0%	4.7%	1.7%	2.3%	0.0%	0.0%	0.0%	0.0%	75.6
Union Bay 4 (Tseycum First Nation)	0.0%	0.9%	0.0%	0.0%	0.4%	0.9%	1.0%	14.6%	6.0%	12.6%	42.7%	13.2%	0.0%	3.4%	1.8%	2.4%	0.0%	0.0%	0.0%	0.0%	28.3
Victoria	0.0%	0.1%	0.0%	0.0%	0.2%	0.3%	2.6%	14.5%	2.0%	9.4%	26.9%	1.7%	0.0%	12.7%	8.5%	21.1%	0.0%	0.0%	0.0%	0.0%	1,945.4
View Royal	0.0%	3.3%	0.0%	0.0%	0.0%	0.1%	1.0%	7.8%	3.3%	9.5%	19.5%	42.5%	0.0%	4.4%	3.5%	4.5%	0.6%	0.0%	0.0%	0.0%	1,490.6
Willis Point	0.0%	1.4%	0.0%	0.0%	0.0%	0.1%	0.4%	2.2%	1.0%	3.1%	26.8%	63.0%	0.0%	0.6%	0.6%	0.7%	0.0%	0.0%	0.0%	0.0%	570.3
Port Renfrew	0.0%	0.0%	0.0%	0.0%	1.6%	0.0%	0.0%	4.5%	2.2%	9.2%	18.8%	56.8%	0.0%	4.1%	2.2%	0.5%	0.0%	0.0%	0.0%	0.0%	138.8
Pacheedaht First Nation	0.0%	0.0%	0.0%	0.0%	0.8%	0.1%	0.0%	2.7%	4.0%	20.2%	11.3%	51.9%	0.0%	6.7%	1.3%	1.0%	0.0%	0.0%	0.0%	0.0%	362.0
Total	0.0%	1.2%	0.0%	0.0%	0.1%	0.2%	1.0%	8.8%	3.2%	6.8%	24.7%	40.2%	0.0%	2.8%	1.9%	3.0%	5.7%	0.1%	0.0%	0.1%	**89,619.8**

Appendix D

Detailed Tabulation of Land Cover by Parks
(LiDAR Enhanced Mapping)

There are over 1000 Parks that have been summarized in the CRD and tabular results have been provided to CRD as MS Excel **Tables in Appendix-D-Parks.xlsx**. Refer to this file for full details which can be joined back to GIS datasets or other databases by Park name.

Notes: The first page of results are presented below. See the above XLSX for full details

- Reporting includes 4 mapping methods (per pixel and per hectare grid using the Past Mapping Method and the LiDAR enhanced method.
- Tables include columns for percent tree cover and percent impervious.
- Percent of Park Mapped column notes the amount of coverage for each park that has been mapped. Some parks extend beyond the mapping extent of this project. Percent mapped is calculated by a raster overlay of the park polygon and as a result the percentages can be off by a few percent in cases where parks are quite small. Consider numbers above 98% to be fully mapped. In cases where only a portion of the park has been mapped, the tree cover and impervious values only account for the portion that has been mapped.

Park Name	Percent Tree Cover	Percent Impervious	Percent of Park Mapped
Abbott Hill Park	94.7%	0.0%	99.9%
Adam Kerr Park	24.8%	0.4%	100.0%
Afriston Park	100.0%	0.0%	99.8%
Agate Park	50.7%	5.8%	100.0%
Albert Head Lagoon Regional Park	6.6%	0.7%	99.9%
Aldersmith Park	65.2%	0.1%	99.9%
Alexander Park	22.1%	7.8%	99.9%
Allenby Park	27.1%	10.1%	100.0%
Allman Park	88.4%	0.0%	99.9%
Alton Lane Park	56.3%	3.7%	100.0%
Alvin Indridson Nature Reserve	94.9%	0.1%	99.9%
Amanda Place Park	0.0%	0.0%	0.0%
Ambassador Park	20.7%	18.9%	99.9%
Amethyst Way Park	45.1%	1.6%	99.8%
Amwell Park	62.7%	0.1%	100.0%
Amy Pond Park / Turner's Bog	29.8%	18.8%	99.9%
Anderson Hill Park	27.5%	0.4%	99.9%
Anderson Park	17.7%	12.2%	99.7%
Andreas Vogt Nature Reserve	76.8%	0.0%	99.9%
Annie Park	91.2%	0.5%	99.9%
Arbutus Cove Park	54.5%	4.4%	99.9%
Arbutus Park	63.9%	0.0%	100.0%
Arm Street Park	72.3%	0.0%	99.9%
Arm Street Promenade	52.5%	9.5%	99.3%
Arncote Park	30.4%	10.6%	99.3%
Arngask Park	81.4%	0.8%	100.0%
Arngask South Park	77.1%	1.6%	99.8%
Arranwood Park	4.7%	19.5%	100.0%
ArtSpring Community Arts Centre (Mouat Park)	38.3%	31.0%	100.0%
Ashby Court Park	2.2%	1.8%	99.7%
Ashley Pl-Millstream Rd	60.4%	3.3%	100.0%
Aspen Road Park	0.0%	0.0%	0.0%
Atkins Park	72.6%	0.6%	99.6%
Autumnwood Park	91.8%	1.0%	100.0%
Avalon Green	52.4%	0.0%	99.7%

Appendix E

Detailed Tabulation of Land Cover by Watersheds
(LiDAR Enhanced Mapping)

There are over 1500 Watershed Areas that have been summarized in the CRD and tabular results have been provided to CRD as MS Excel **Tables in Appendix-E-Watersheds.xlsx**. Refer to this file for full details which can be joined back to GIS datasets or other databases by ID, CRDID or CRDDischargeID fields.

Notes: The first page of results is presented below. See the above XLSX for full details

- Reporting includes four mapping methods as described in the report (per pixel and per hectare grid using the Past Mapping Method and the LiDAR enhanced method).
- Tables include columns for percent tree cover and percent impervious.
- Percent Mapped column notes the amount of coverage for each watershed that has been mapped. Some watersheds extend beyond the mapping extent of this project. Percent mapped is calculated by a raster overlay of the watershed polygon and as a result the percentages can be off by a few percent in cases where watersheds are quite small. Consider numbers above 98% to be fully mapped. In cases where only a portion of the watershed has been mapped, the tree cover and impervious values only account for the portion that has been mapped.

Name	Percent Tree Cover	Percent Impervious	Percent Mapped	ID	CRDID
	13.3%	54.5%	100.0%		10892
	22.2%	31.7%	100.0%		10893
	32.0%	28.4%	99.9%		10908
	36.1%	30.3%	99.8%		10909
	44.7%	21.0%	99.9%		10910
	35.9%	28.5%	99.9%		10911
	16.1%	65.0%	99.9%		10858
Ten-Ten Creek Watershed	30.8%	11.1%	99.9%	TEMPID320	11153
Reay Creek Watershed (ḰEL¸SET)	19.3%	30.3%	99.9%	TEMPID322	11154
	51.1%	12.6%	99.9%		10944
Cripple Creek Watershed	75.7%	2.9%	99.9%	TEMPID379	11159
	30.0%	50.2%	99.9%		10977
	81.4%	3.2%	99.9%	TEMPID2031	11362
745	39.2%	14.8%	100.0%		10121
746	57.5%	10.2%	99.8%		10122
781	24.3%	42.1%	99.9%		10143
	28.1%	2.3%	99.9%	TEMPID2191	11435
Birdie Creek Watershed	53.9%	3.7%	99.9%	TEMPID2479	11438
822	0.5%	76.3%	99.7%		10208
821	0.9%	84.0%	100.0%		10209
Unnumbered	14.9%	5.1%	99.9%		10211
0835B	0.0%	94.1%	100.0%		10212
796	45.1%	28.4%	99.9%		10214
795	20.6%	64.1%	99.9%		10215
0818A	36.9%	23.5%	100.0%		10216
0820A	6.4%	91.4%	99.9%		10220
820	0.0%	93.8%	100.0%		10221
819	3.6%	94.2%	99.4%		10222
0818P	10.4%	82.9%	100.0%		10223
0818M	0.0%	85.4%	100.0%		10224
0818L	0.2%	89.4%	99.9%		10225
0818B	32.7%	37.3%	99.9%		10226