Land cover trends in Metro Vancouver, Canada over 45 years: mapping, analysis, and visualization

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Abstract

The Metro Vancouver region has experienced significant changes in land use and land cover (LULC) over the past 5 decades, in particular the urbanization of forest and agricultural land. In this study, 45 years of historical LULC data from 1966-2011 were mapped, analyzed and visualized to examine trends in land cover change and to highlight where sensitive ecosystems are being impacted. Historical land cover data for the years 1966, 1976 and 1986 that had originally been mapped by the Canada Land Use Monitoring Program (CLUMP) were reclassified into a simplified classification scheme and converted to a raster format. Land cover rasters for 1993, 2000, and 2011 were created by classification of Landsat satellite into the CLUMP data classification scheme. Overall land cover change was then visualized and quantified using single and multi-date land cover maps. These map layers were also draped over satellite imagery that had been rendered into 3D using a digital elevation model. To highlight amounts and rates of change in important ecological area, changes in a number of watersheds with different topography (flat to mountainous) and different amounts of historical land cover over the time period (from urban to forested in 1966) were also analyzed. Visualization and analysis of change over time provided important information on the nature of change that is occurring within Metro Vancouver over time.

Introduction

The Metro Vancouver region (Figure 1) is one of the fastest growing areas in Canada and has experienced significant land use and land cover change over the past 5 decades, in particular the urbanization of forest and agricultural land. It is home to more than half of the province's population, which grew from 950, 000 people in 1967 to 2.1 million in 2006 (Metro Vancouver 2010). Unfortunately, the increase of urban land cover can have adverse impacts on ecological systems, such as our water resources. Stream water quality, for example, can be impacted with increased loading of nutrients, metals, pesticides, and other contaminants (for reviews see Paul and Meyer (2001), Walsh and others (2005)). Historical land cover mapping of land cover in the Metro Vancouver area on a watershed basis has been done to study the long term affects of land cover on water quality within a subset of regional watersheds (Shupe, 2013). Ongoing mapping of Metro Vancouver land cover is being performed as part of a longer term analysis of the relationship between stream water quality and land cover. The main objective of this study was to create current and historical land cover data sets covering the entire Metro Vancouver region, and to quantify and visualize changes of land cover in different parts of the region, in particular on a watershed-basis.

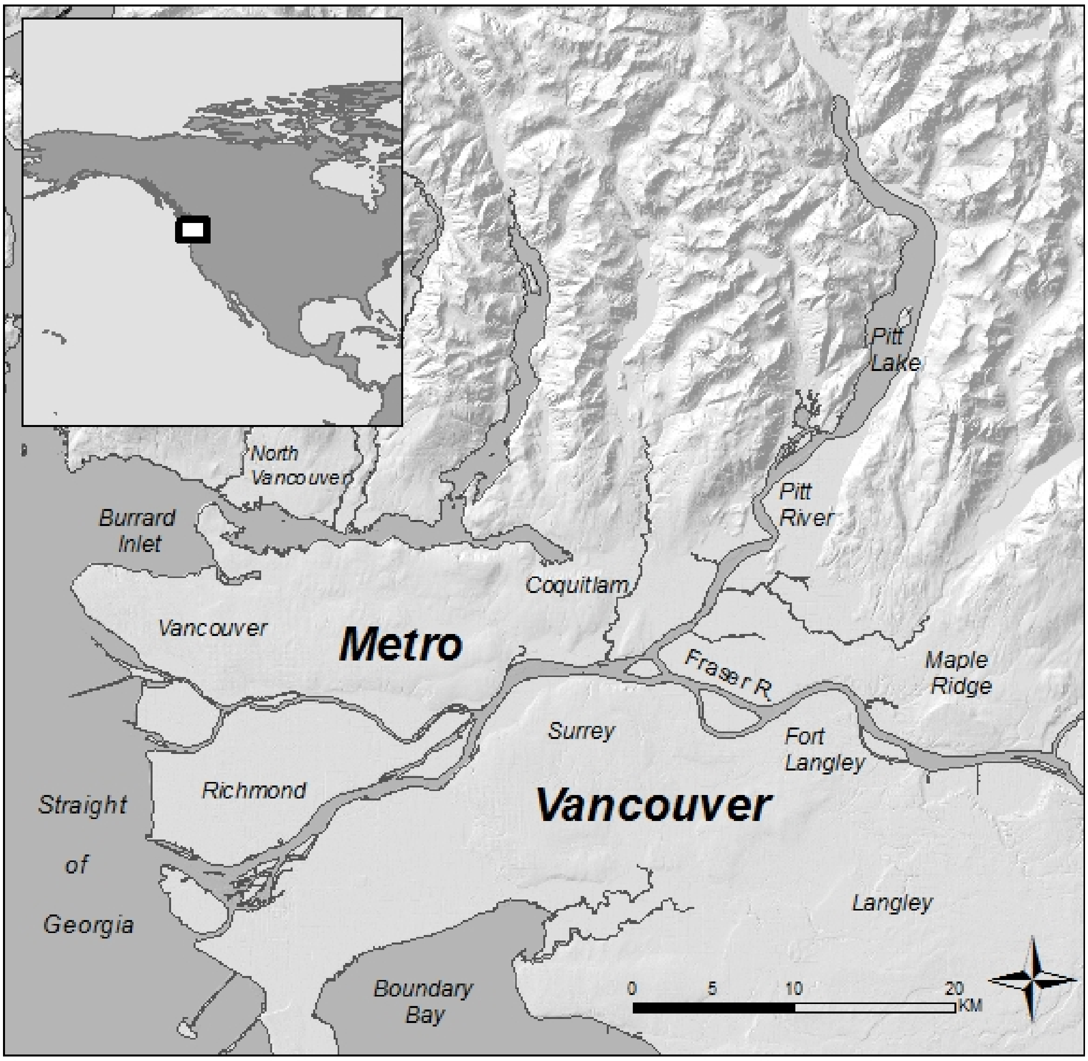

Figure 1 – Location of Metro Vancouver

Methods

Multi-Temporal Image Classification

Canada Land Use Monitoring Program (CLUMP) data: years 1966-1986

Historical land cover data for the years 1966, 1976 and 1986 that had originally been mapped by the Canada Land Use Monitoring Program (CLUMP) using the pioneering Canada Geographic Information System (Government of Canada 2002) were imported into ArcGIS and linkages created between polygon and attribute data. The CLUMP datasets were originally created using air photo interpretation, field surveys, and census information and contained detailed land information. To efficiently compare changes over the entire time period a land cover rather than land use approach was taken in this study. This was particularly the case because many CLUMP polygons had mixed land use and land cover designations that would be difficult to compare in different years (e.g. 1986 polygons with an improved grass and legumes land cover designation were also attributed with urbanized land uses such as dwelling activities and institutional services). CLUMP polygons for 1966, 1976 and 1986 were thus reclassified into a simplified classification scheme including urban, agriculture, forest, grassland, disturbed/bare, scrub, snow, wetland, and water land cover classes and then converted into a raster format.

Landsat satellite data classification: years 1993-2011

Land cover maps for 1993, 2000, and 2011 were created by classification of Landsat satellite imagery obtained from the U.S. Geological Survey (USGS, 2013). Initial classification of these data layers involved an unsupervised classification of 2011 Landsat 5 Thematic Mapper imagery. These classes were manually labeled and merged where appropriate into the classification scheme used for the CLUMP layers. Spatial modeling using NDVI, Tassled Cap layers (brightness, greenness, and wetness) was then used to refine the classification, in particular by helping to separate forest, agricultural and grassland classes. The classification was then visually inspected for any remaining major errors in ArcGIS using high resolution Bing Maps and other ArcGIS online imagery as a base layer. Major errors were flagged and then edited using a tool that was created to more efficiently handle localized thematic editing of discrete rasters in ArcGIS as well as through editing in Erdas Imagine. The 2011 classification was then accuracy assessed using a stratified random sampling technique. Bing imagery and local knowledge and field checking were used as reference data. The 1993 and 2000 imagery were then classified using unsupervised classification, followed by cluster merging and spatial modeling similar to that done with the 2011 layer. Next, classification changes from 1993 to 2012 were mapped and compared to spectral changes between the 2000 and 2011 Landsat imagery. Land cover changes that did not correspond to spectral change over a given threshold were then visually inspected and manually reclassified where necessary.

Land cover analysis and visualization

Overall land cover change was then visualized and quantified using single date land cover and composite change maps. These map layers were also draped over satellite imagery that had been rendered into 3D using a digital elevation model. Land cover change was also analyzed within important ecological areas, specifically watersheds with different topography (flat to mountainous) and different amounts of historical land cover over the time period. Visualization and analysis of change over time provided important information on where and what kinds and amounts of change are occurring in Metro Vancouver over time. These data are also being used in ongoing studies evaluating the effects of historical land cover on historical water quality in the lower Fraser River Valley of British Columbia.

Results

Figure 2 shows changes in the extent of the three major categories of land cover over the 45 year period from 1966 to 2011: urban/built up, forest, and agricultural land. While refinement and reconciliation of each of the land cover classes between each date is ongoing (e.g. in 1966 many of the small urban parks were not mapped separately) Figure 2 is indicative of both general and specific types of changes that are occurring. The overall trend is an increase in urban land cover, and a decrease in both agricultural land

and forest. Another major category (not shown in Figure 2) is disturbed/bare land. This class included clear cuts, clearing of land for urban structures, and sand and gravel operations. This class was small in extent compared to the main three land cover types and variable between each of the years analyzed in this study. Land cover trends on a watershed basis provide data for use in understanding potential or measured ecological impacts. **Figure 3** provides a visualization of the general land cover surfaces in the region and their relationship to watersheds. North of the Fraser River more forest is present (particularly in the mountainous areas) and less agriculture than south of the Fraser River. The northern portions of the Capilano and Lynn Watersheds are protected land, though the southernmost areas are heavily urbanized. Still, Stoney, Como and Scott Watersheds have undergone heavy urbanization. Within a number of Metro Vancouver watersheds such increases in urban land cover have been shown to be inversely associated with forest land (i.e. 1976 to 2000; r = -0.90) and positively associated with a number of contaminants in stream water (e.g. ammonia, coliform bacteria, and cadmium) (Shupe, 2013). The northern portions of the easternmost watersheds in Metro Vancouver also include protected land; however, North Alouette, Alouette, and Kanaka Watersheds are all experiencing increasing pressures due to urbanization. **Figure 4** Shows the encroachment of urban land cover into Scott Creek and Hyde Creek Watersheds between 1966 and 2006. The 2006 is a false colour SPOT image obtained from geobase.ca which had been pansharpened to 10 m for visualization. In-between the two watersheds in Figure 4 one can see sand and gravel quarries which are used to produce materials for construction within the region. **Figure 5** shows at a larger scale changes in the Serpentine watershed (refer to Figure 3 for location). The Serpentine Watershed resides in the extensive agricultural floodplain south of the Fraser River. Conversion of forest and agricultural land to urban land in the Serpentine Watershed is indicative of similar urbanization trends extending eastward from Metro Vancouver well into the communities of the eastern Lower Fraser Valley. This is most pronounced in the areas south of the Fraser River and is clearly visible over time on the historical satellite imagery.

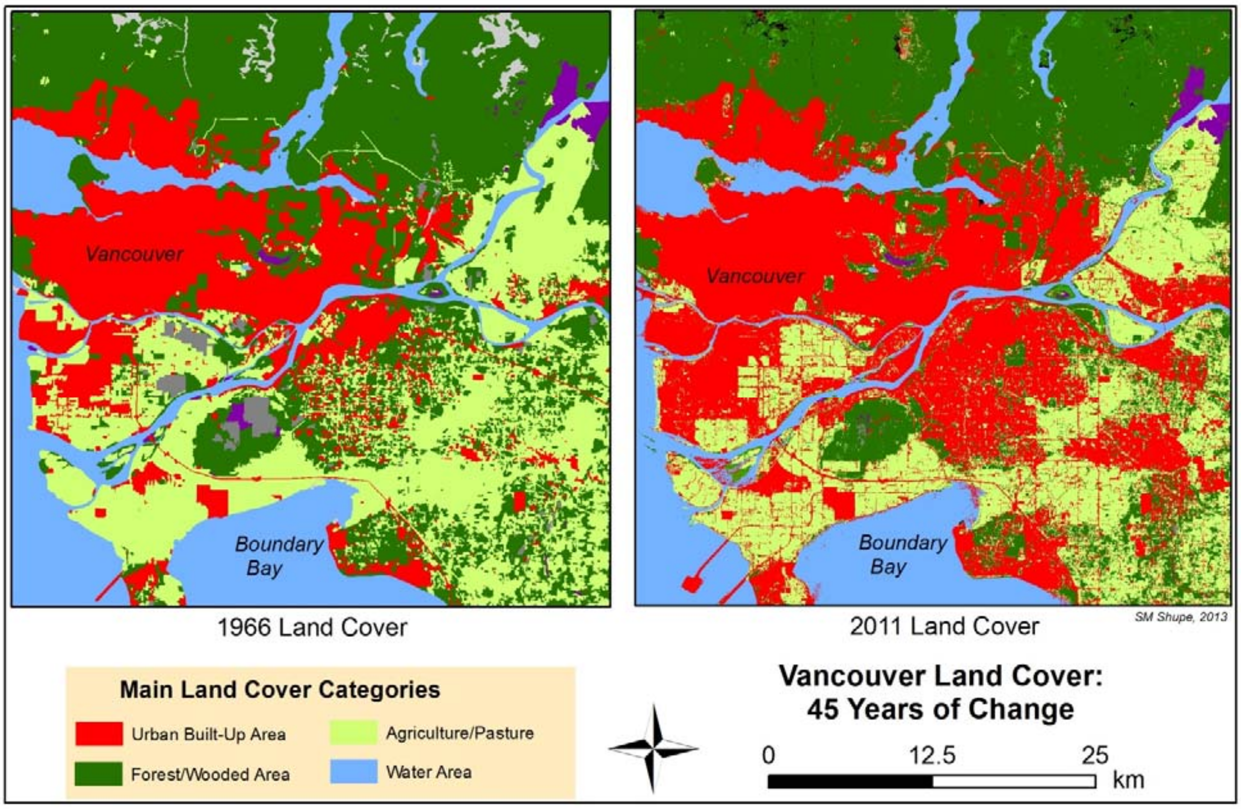

Figure 2 – Land cover change from 966 to 2011 in Metro Vancouver

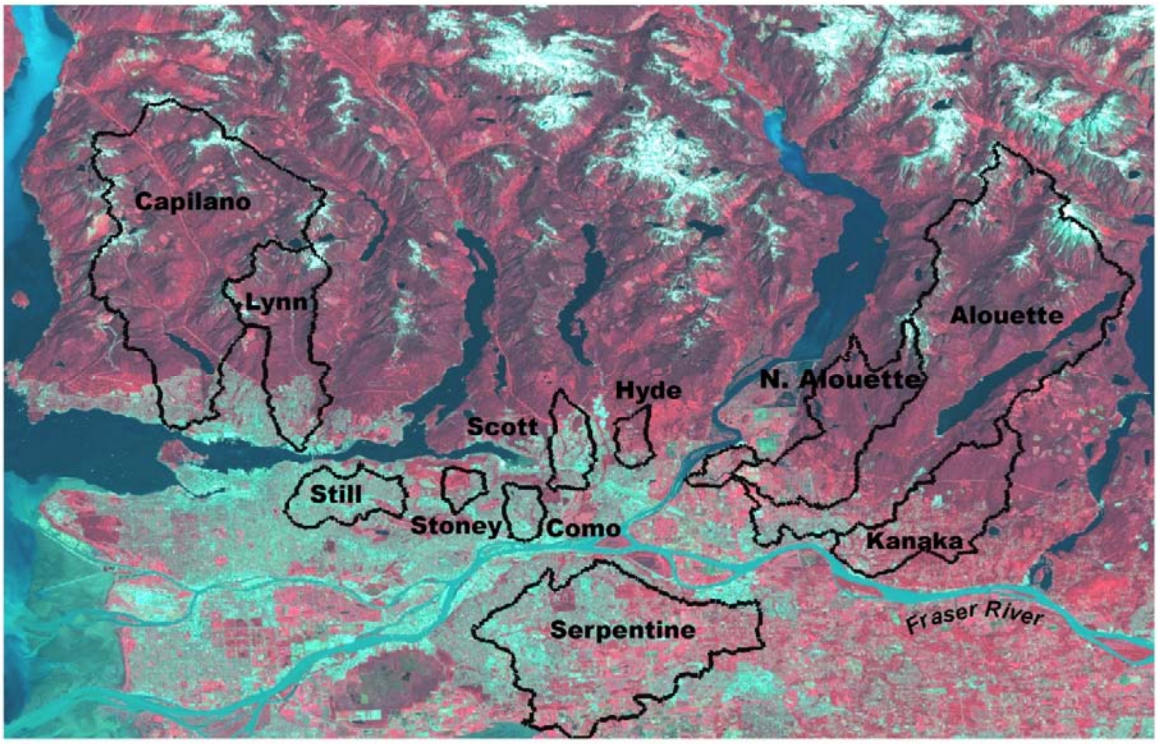

Figure 3 – Selected Watersheds north and south of the Fraser River superimposed on a pan-sharpened 2000 Landsat Thematic Mapper false color composite image. North is towards the top of the image.

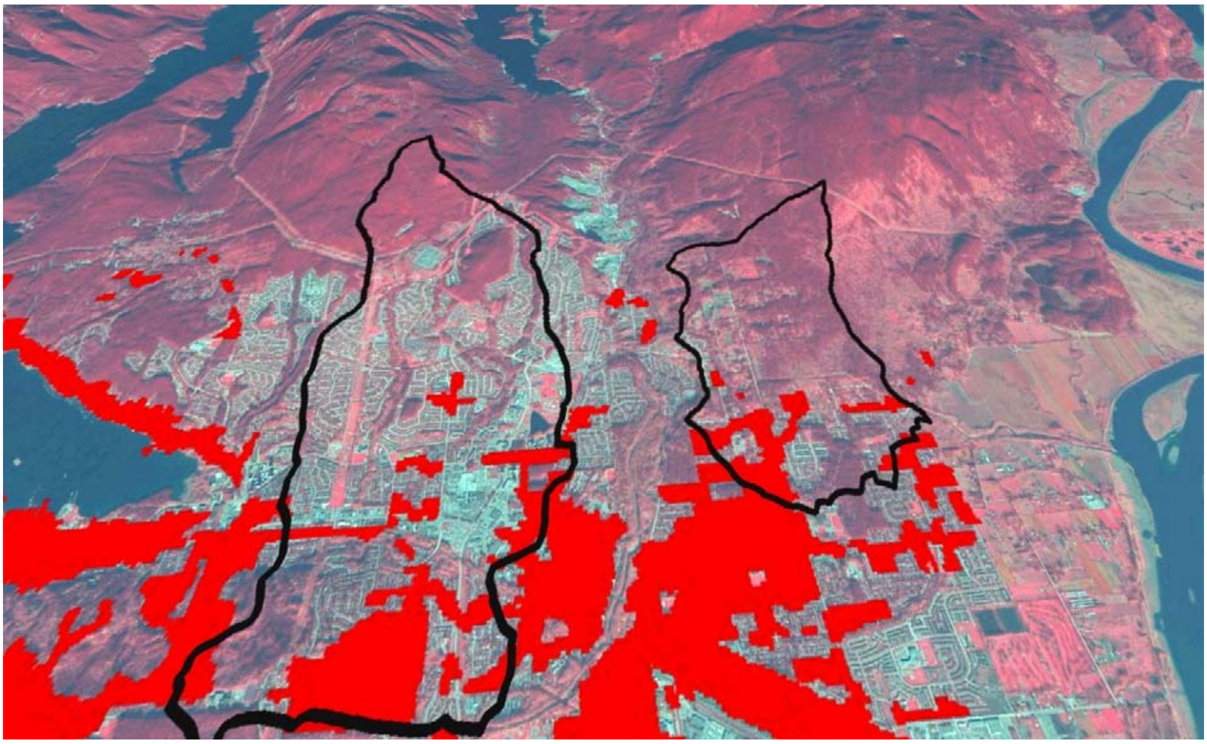

Figure 4 - The encroachment of urban land cover into Scott Creek (left) and Hyde Creek (right) Watersheds in 1966 (thematic red overlay) and 2006 (continuous urban data from a pan-sharpened 2006 false color composite SPOT image). North is towards the top of the image.

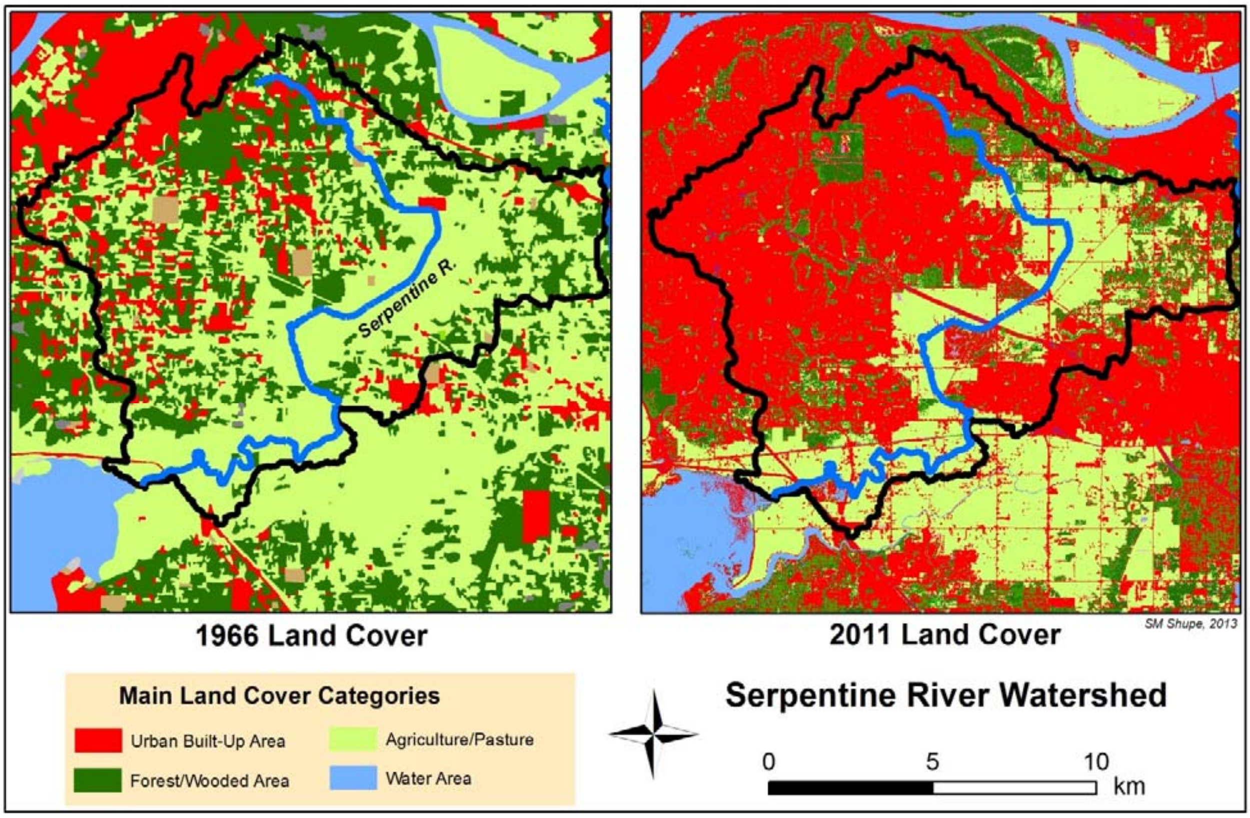

Figure 5 - Land cover change from 1966 to 2011 in the Serpentine Watershed

Discussion

As with many urbanizing cities in North America and other parts of the world, much of the growth of Metro Vancouver is primarily outwards into rural land rather than inwards towards increased densification. Core urban areas within the cities of Vancouver and North Vancouver, for example, are relatively unchanged over 45 years. Much of North Vancouver on the north side of the Fraser River is comprised of relatively wealthy residential neighborhoods surrounded by protected forested mountainous parkland leaving little room for expansion. As one travels eastward in Metro Vancouver, still on the north side of the Fraser River, more recent land cover change become evident. The most significant change is the transition of forest into built up land. In the early 20th century heavy logging occurred within the northeaster part of Metro Vancouver, However, much of this forest was able to grow back given the rapid growth of Douglas fir and Western Red Cedar trees, which are dominant species in this area. In fact, many people are surprised that some of these areas were completely clear cut in this time period. However, the more recent loss of forest due to urbanization has a more permanent character which can impact the ecosystem services forests provide such as wildlife habitat and diversity, carbon storage, interception of rainfall and regulation of runoff, and provision of scenic landscapes. South of the Fraser River there has been forest loss due to urbanization as well, in addition to the transition of agricultural land into urban land. Land change here is more complex, given that forest cover is less contiguous and more interspersed with agricultural land than most areas north of the Fraser River. A key technique in understanding this complexity was the visualization of medium and high resolution satellite imagery in

ArcMap in conjunction with the thematic raster land cover data. This visualization was also used to refine of the mapping of the land cover data layers themselves. Future studies will use visualization and re-mapping techniques to improve the classification and quantification of riparian and other land cover in a number of Metro Vancouver watersheds.

Conclusion

The mapping and monitoring of urban and other land cover provides essential data for understanding long term human-induced landscape change. Automated and semi-automated methods of mapping land cover are used to simplify complex landscapes into discrete land cover categories which are then used for quantification. In Metro Vancouver, quantitative amounts of (and changes in) land cover are being used on an ongoing basis to study and monitor effects of land cover on stream health. In addition to quantification of land cover, the visualization of land cover is also important. Visualization of both mapped thematic land cover and continuous multi-temporal satellite land cover data in Metro Vancouver is used as an analytical tool to help understand where change is occurring and the drivers of change, in particular with respect to urban expansion. Visualization can provide detailed information on the accuracy of mapping, integrity of riparian corridors, and the nuances of character in different landscapes.

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