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Canadian urban tree canopy cover and carbon sequestration status and change 1990–2012

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ABSTRACT

Urban trees provide numerous ecosystem goods and services by providing shade, habitat for wildlife, removal of air pollutants and the removal and storage of atmospheric CO_2. Carbon removal services provided by Canadian urban trees have previously been assessed using an IPCC 2006 guidelines approach based on the percentage of urban area covered by tree canopy (UTC) for the 2012 time period (Pasher et al., 2014). That work however provided only a single point in time assessment of the national scale UTC and carbon removal services. The research undertaken for this study was a continuation of this earlier work focusing on a 1990 national scale UTC assessment and carbon sequestration estimates for 1990. UTC estimates for 1990 were developed using a point sampling approach with circa 1990 air photos covering a large portion of Canadian urban areas. In total almost 179,000 points were sampled for the 1990 time period, reassessing 83% of the points used for the previous 2012 assessment. Based on the urban area boundary layers for 1991 and 2011, Canada's urban areas grew by an estimated 6% for this time period. Most of this growth occurred through conversion of agricultural and forested lands to urban. At the national scale the UTC for 1990 was estimated to be 27.6%, as compared to the 2012 UTC estimate of 26.1%, the difference between estimates for the two time periods fell within the uncertainty range. Carbon removal estimates based on the UTC estimates were also very similar for the two dates with 660.2 kt C removed in 1990 and 662.8 kt C removed in 2012. It was noted that urban development in the Prairie regions resulted in an increase in tree cover as compared to the pre-conversion agricultural and natural landscapes and also that in most urban areas across the country UTC increases through time as tree cover matured in newly developed urban areas. These two assessments provide a time series of urban trees for 22 year time period, which will be useful for further studies and analysis.

1. Introduction

National scale assessments of urban trees provide an overall picture of urban tree status and are needed to estimate of the ecosystem goods and services provided by urban trees, they can play a critical role in the development and implementation of management programs and strategies for these valuable urban resources. Assessments have been made to estimate the national tree canopy coverage and carbon and air pollutant removals for the U.S.A. and Canada (Nowak et al., 2006, 2013; Pasher et al., 2014). While these estimates are useful they often only provide urban tree status for a single period in time making it difficult to determine changes and trends through time. Estimates made with comparable methodologies for additional time periods could provide value as indicators of overall changes in urban tree cover condition and the services provided by these trees.

A variety of factors and disturbances both anthropogenic and environmental in nature can result in negative and positive impacts on urban trees. Severe weather-snow, ice, wind and rain storms, insect infestations, disease and natural mortality can lead to tree and canopy loss (Sisinni et al., 1995; Beaudet et al., 2007; City of Kelowna, 2007). In addition arboricultural practices and indirect anthropogenic impacts such heat, air pollution and moisture stress can negatively affect tree growth and survival and result in reduce tree canopy area (Cregg and Dix, 2001; Nowak et al., 2006). New plantings, proper pruning and the nurturing of existing trees are all management tools which can improve tree stocks and result in an increase the tree canopy cover in urban areas. Newly developed urban areas often have a lower stock of trees as a result of

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land development disturbance activities such as construction of new roads, water, sewer, communication and electrical services and building site activities, also urban development often occurs on lands with a previous low tree cover particularly agricultural land. Tree planting activity and the growth of existing trees in these new urban areas can over time offset losses in other areas and help to maintain or increase the overall proportion of canopy cover in a particular city.

UTC is often defined as “the layer of leaves, branches and stems of trees that cover the ground when viewed from above” (Watershed Forestry Resource Guide USDA, 2008), and is often used when discussing the area of urban trees viewed in remotely sensed imagery or other earth observation data.

In an effort to help improve our current understanding of the ecosystem goods and services provided by urban trees and changes in urban tree status this research was undertaken with the following objectives: (i) development of an estimate of Canada’s urban tree canopy for 1990; (ii) based on the 1990 UTC estimates develop estimates of the associated carbon stored and CO_2 removed by these trees in urban areas.

2. Materials and methods

2.1. Study area

The spatial framework used for UTC sampling, estimation and the resulting estimates and reporting of the carbon storage and sequestration were the same as that used for Canada’s annual greenhouse gas (GHG) reporting (Environment Canada, 2016). This spatial framework is made up of sixty reconciliation units (RU), the RU represent the scale at which many of the GHG estimates for land use, land-use change and forestry (LULUCF) activities are made for United Nations Framework Convention for Climate Change (UNFCCC) reporting by Canada. The RU spatial layer was developed by intersecting the national ecozones of Canada and the provincial/territorial administrative boundary layers. UTC sampling and estimates were made at the RU scale to broadly capture provincial and regional variation while providing consistent national scale estimates suitable for GHG reporting under the UNFCCC reporting requirements. While Canada has an extensive land mass the population density is low with urban areas occurring in only 18 of the 60 RU in the southern regions of the country. Pasher et al. (2014) provides figures and further details on the areas sampled, sampling framework and the RU areas reported for.

To conduct sampling and estimation a high quality detailed spatial layer providing the boundaries of urban areas was needed. For the 2012 UTC estimation work the Statistics Canada vector file ‘2011 Population Centres’ (Statistics Canada, 2011) provided the best quality and nationally consistent delineation of urban areas. In total 947 population centres (cities, towns, villages) were identified and delineated by the SC for 2011 on a basis of population, dwelling and workplace density and urban non-urban boundaries were determined using a variety of geographic data sets. From an initial set of 947 population centres a subset of 86 were selected on a basis of the population class (class 3 or 4 having a total population >30,000 individuals). This subset was then used to represent population centres with sufficient urban area to be representative of Canada’s urban regions. Centres which did not fall into this subset were small communities having a small urban footprint composed of a mix of non-urban land uses mainly agriculture and forestry which are included in other national land use and GHG assessments (Environment Canada, 2016).

Determining equally representative urban boundaries for 1990 presented more of a challenge. A similar Statistics Canada product for 1991 (Statistics Canada, 1992) was available and was used but some editing was required to reduce known (Statistics Canada, 2010) over-bounding errors. These over-bounding errors occurred when large non-urban land areas were included in urban footprint due to the use of municipal administrative boundaries in developing the original 1991 product. The manual editing to 1991 SC layer was based on 1990 air photos and where no air photos were available the built-up land cover class from a 1990 Landsat manually interpreted satellite products was used (Koeln et al., 1999) to provide an improved representation of the urban built-up areas.

2.2. Point sampling

Pasher et al. (2014) provides a detailed description of the development of the point sampling system used to develop the 2012 UTC estimates, the same point sampling approach was employed to develop 1990 UTC estimates. The sample points used for the 2012 point sampling were re-sampled for the 1990 time period UTC estimates with the exception of points which fell outside of the 1990 urban areas or points for which no 1990 air photos were available. The objective was to estimate UTC at the RU scale to provide a nationally representative estimate.

In total 83% of the points used for the 2012 UTC estimates (178,709 from the original 215,863 points sampled in 2012) were sampled to provide 1990 UTC estimates. This group of points fell within 69 of the 86 urban centres used for the 2012 assessment and represented 79% of the total population and 62% of the total area for all of the 947 population centres identified by SC for 1991. The 1990 1 km by 1 km sampling grid cells covered 23% of the 1990 total urban boundary area this was very close to sampling cell coverage used for to the 25% cell coverage used for the 2012 sampling.

2.3. Photo interpretation

The 2012 sample point interpretation was made using high resolution color air photos data, while sample point interpretations for the 1990 time period using greyscale air photos. Acquisition dates for the 1990 air photos was generally within 2 years of 1990 (1988–1992), with the majority of photos during “leaf-on” conditions. The photo scales ranged from 1:40 000 to 1:5 000. The 1990 photos were georeferenced using recent high resolution Bing imagery (Microsoft Corporation, 2011) with manually collected ground control points used with an affine polynomial algorithm for image rectification (Lillesand et al., 2004). In total almost 1 000 photos were processed and used for the 1990 UTC sampling activity.

Each sampling point was interpreted by trained interpreters in a similar manner as the 2012 sampling. Sample point locations were classified into one of the following classes; agriculture, building, grass, other impermeable surface, shrub, tree canopy (coniferous, deciduous or unsure) or water. Interpreters also noted if no imagery was available or imagery was not interpretable due to clouds or haze or other issues. Quality control checks were carried out by having more than one interpreter interpret subsets of the same points as well as having the same interpreter reinterpret a random selection points to ensure consistent interpretation and maintain accurate interpretation.

2.4. Estimation of UTC and error calculation

Percentage tree coverage was calculated by dividing the total number of points interpreted as tree crown in a RU by the total number of points interpreted. If the point could not be classified due to lack of imagery, clouds or haze they were excluded from the UTC percentage calculation. This percentage value was then used as an estimate for all urban areas within each RU. Standard error