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Assessing carbon storage and sequestration by Canada's urban forests using high resolution earth observation data

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ABSTRACT

Urban trees are important components of the landscape and offer numerous benefits; both socio-economical and biophysical. Urban trees act as a sink for CO_2, helping to offset carbon emissions from urban areas by removing the greenhouse gas from the atmosphere through photosynthesis. Environment Canada develops estimates of Canada's greenhouse gas emissions and removals which are submitted annually to the United Nations as part of ongoing commitments under the United Nations Framework Convention for Climate Change. As part of these reporting commitments countries are required to develop estimates of emissions and removals of Greenhouse Gas that are the result of direct impact of human activities in the Land-Use, Land-Use Change and Forestry Sector. Here, we present an approach which involves sampling high resolution aerial photographs to determine urban tree coverage across Canada's major urban areas. Our results suggest Canadian urban areas have an estimated tree canopy cover of 27%. This tree cover is estimated to store approximately 34,000 kt C and annually sequester approximately 2500 kt of CO_2. These estimates show significant improvement over previous methods used to provide Canadian estimates. The methods developed here are easily repeatable which allow for temporal changes to be analyzed and assessed over time.

Introduction

Urban trees are important components of the landscape and provide numerous socioeconomic and biophysical benefits. The presence of trees within urban areas provides recreational opportunities as well as beautifying the urban landscape and improving the overall enjoyment and value of neighborhoods (Dwyer et al., 1992; Wolf, 1998; Kuo, 2003). Ecosystem services provided by urban forests are significant and impact the quality of life for millions of Canadians despite the relatively small area these urban forests cover. Urban trees have a direct impact on improving biodiversity by providing both a variety of habitats as well as nourishment to wildlife (Howenstine, 1993; Melles et al., 2003). From a physical perspective, urban trees have been shown to reduce air pollution (Yang et al., 2005; Nowak et al., 2006) and impact the urban climate by lowering temperatures and counteracting the urban heat island effect through shading, blocking wind and evapotranspiration (e.g. Akbari et al., 2001; Loughner et al., 2012; US-EPA, 2013a). Urban trees can act as a sink for CO_2, helping to offset carbon emissions from urban areas by removing the greenhouse gas from the atmosphere through photosynthesis (Rowntree and Nowak, 1991; Nowak and Crane, 2002). Trees capture CO_2 during photosynthesis (sequestration) at an annual rate based on the tree's biomass, which is directly related to species composition, age and growing conditions (McPherson, 1998).

In some countries urban areas make up a significant portion of the landmass; many European countries having more than 5% of their landmass classified as urban areas (Angel et al., 2012), and approximately 3% of the conterminous United States is considered urban (Nowak et al., 2008; United States Census Bureau, 2013). However in Canada, urban areas represent only a fraction of the total landmass, making up approximately 0.25% of Canada's landmass (Statistics Canada, 2009).

In many municipalities urban trees are counted and monitored for health. Some cities have programs to perform field plot sampling of urban trees to measure and monitor tree health, as well as estimate pollutant removal, carbon storage and annual sequestration. The most common methods used for these assessments

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following the i-Tree toolkit developed by the United States Forest Service (i-Tree, 2014). For example, using i-Tree estimates, urban forests in Toronto, Canada were estimated to reduce annual heating and cooling energy requirements by 41,200 MWh (a savings of \$9.7 million yr^{-1}) and remove 1430 t of air, improving air quality, and other benefits (City of Toronto, 2010).

Environment Canada (EC) develops estimates of Canada's greenhouse gas (GHG) emissions and removals that are submitted annually to the United Nations as part of Canada's commitments under the United Nations Framework Convention for Climate Change (UNFCCC). Estimates for the Land-Use and Land-Use Change and Forestry (LULUCF) sector are included as part of the reporting commitments under the Convention framework. Settlement lands are one of the six categories in the land use categorization recommended by the Intergovernmental Panel on Climate Change for national GHG inventories (IPCC, 2006). Settlement land for GHG reporting purposes are defined as all built-up land; urban, rural residential, land devoted to industrial and recreational use; roads, right-of-ways and other transportation infrastructure; and resources exploration, extraction and distribution land use and land-use change activity.

The 2006 IPCC guidelines provide specific guidance for estimation of emissions and removals of CO_2, related to changes in biomass (Chapter 8 Settlements Remaining Settlement Tier 2a and 2b). The approach currently used by EC however was developed prior to the publication of the IPCC (2006) guidelines. The current estimates are developed based on applying a constant stocking rate to all non-built-up areas within settlement boundaries in Canada (ESSA, 1996). Non-built-up area is defined as a sub-component of the Census Metropolitan Areas (CMA) (Statistics Canada, 2011a) and is determined by applying a provincial apportioning ratio to the total CMA area on a provincial basis (Statistics Canada, 1997). Increases in the coverage of urban areas are taken into account by applying a simple growth function based on the change between three periods for which the CMA and non-built-up area were available. Using the area estimates, an assumed stocking rate and an assumed above ground biomass estimate for the stock type, Environment Canada develops national scale carbon removal estimates for settlement land which is used in the annual inventory. Assumptions for both stocking rate and growth of urban areas have not been updated and verified for several years. In comparison to Canada, the United States uses an approach consistent with IPCC (2006) default approach (Nowak et al., 2013).

Here we propose a method for urban forest estimation that is consistent with the IPCC (2006) guidelines to provide a more accurate estimate of how management of these urban forest areas are contributing to Canada meeting its GHG reduction targets.

Earth observation data can provide a comprehensive assessment of the landscape and allows accurate estimation of land-use and land-use change activities. Among other applications, high resolution imagery has been used for mapping urban vegetation, as well as quantifying the proportional canopy cover within urban areas using various sampling approaches (e.g. Nowak et al., 1996; Nowak and Greenfield, 2012a,b). Regardless of availability of field based urban forest information, satellite imagery or aerial photographs can be used for mapping and assessing urban forests. There are two general approaches used; a mapping approach or a point-based photo interpretation sampling approach (Nowak et al., 1996; Walton et al., 2008). Previous studies have defined the term 'urban tree canopy' (UTC), as "the layer of leaves, branches and stems of trees that cover the ground when viewed from above" (USDA 2008), and use it when discussing the area of urban trees viewed in remotely sensed imagery.

UTC can be mapped through a variety of manual and automatic imagery processing methods including heads-up digitizing and image classification processes and the spatially continuous results can then be incorporated into other mapping or analyses. Several cities have employed this approach, for example, recent UTC estimation of Toronto, Ontario (City of Toronto, 2010) and Minneapolis, Minnesota (Bauer et al., 2011) were both based on maps generated from high resolution Quickbird data (60 cm resolution). Since the classification of optical imagery in urban areas can often be hampered by shadows, researchers have also tested LIDAR data (active laser sensor) to carry out detailed mapping and have been able to successfully map UTC as well as physical characteristics of individual trees in local areas (e.g. MacFadden et al., 2012). Unfortunately full coverage high resolution data is not always available and can be costly to acquire, especially airborne LIDAR data. It is difficult to apply such methods at a national scale due to inconsistent optical imagery including spectral characteristics, spatial resolution and temporal coherence. Coordination of individual municipalities to acquire consistent imagery suitable for standardized classification of UTC would be extremely difficult and therefore not suitable for GHG reporting and carbon sequestration estimates at a national scale.

The second approach typically used to measure UTC is through a technique based on photo interpreted point sampling (Nowak et al., 1996). While this does not result in a continuous landcover layer, it is significantly less time and resource demanding and has been shown to provide similar UTC measures to detailed landcover mapping (e.g. Nowak and Greenfield, 2010). Historically, Levy and Madden (1933) used a point based method to sample pasture vegetation on the ground, and over time the same methodology has been transferred to remotely sensed imagery. Point sampling to assess land-use/landcover as well as carry out wildlife population surveys has also been shown as a cost effective approach that provides valid results. Norton-Griffiths (1988) used point grids across high resolution aerial photos for assessing crop proportions and housing densities in Kenya, Africa. Corona et al. (2007) carried out photo interpretation of 1990 aerial photos to assess landcover changes in Italy using a point sampling strategy. Most recently, with respect to sampling UTC, Nowak and Greenfield (2012a,b) carried out a point-based assessment of United States cities, including examining changes over time, using Google Earth® imagery in addition to local aerial photographs.

The objectives of this research were to improve current estimates of urban forest carbon sequestration through; (i) development of a point-based sampling strategy for estimating UTC at the national scale; (ii) development of updated estimates of national urban tree cover; (iii) estimation of potential carbon and CO_2 removals based on estimated UTC. Using a sampling approach, methods were developed to estimate UTC through the interpretation and analysis of high resolution aerial photographs. This improved estimate of the total crown cover area within Canada's urban areas combined with IPCC methods and information from recent studies, a more accurate estimate for the total amount of carbon sequestered by urban forests can be produced. Here we present detailed estimates for Canada's urban tree cover, associated carbon storage and CO_2 sequestration using a methodological approach consistent with IPCC guidelines suitable for UNFCCC reporting.

Methods

The following sections have been structured into two parts. The first section describes methods used to develop and test an approach based on the IPCC (2006) guidelines to estimate UTC. These tests were carried out using subsets of imagery acquired over Canadian urban areas. The second section then demonstrates how these methods were then used to develop improved UTC estimates and estimates of carbon storage and sequestration by trees across Canada's urban areas.