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Carbon stock and change from woody biomass on Canada's cropland between 1990 and 2000

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ABSTRACT

Accurate estimation of greenhouse gas emissions and detailed monitoring of the carbon cycle are important for mitigation of and adaptation to climate change. On agricultural land, annual herbaceous vegetation is not considered a carbon sink, whereas perennial woody vegetation accumulates biomass over multiple years and does represent a carbon sink. This paper presents a study to estimate aboveground woody carbon stock in 1990 and its annual change from 1990 to 2000 on Canada's cropland. The cropland was stratified into zones according to soils, climate and cropping systems, within which sample plots were randomly selected and paired aerial photographs corresponding to circa 1990 and 2000 were interpreted to detect changes in perennial woody vegetation such as trees, shrubs, orchards and vineyards. Woody biomass volumes lost as a result of land use change and gained as a result of planting and growth were estimated using species composition and growth rates typical of each zone, as obtained from published literature, forest reports and charts and forestry expert knowledge. Census of agriculture data was used to scale up the sample level results to zone and national levels. Results showed that on Canada's cropland, the aboveground woody carbon stock in 1990 was 33.7 ± 8.8 Tg. Between 1990 and 2000, the area covered by woody vegetation was affected negatively by removals and positively through planting and natural regeneration, leading to a net reduction in area. There was an annual increase of about 78.3 Gg over all cropland in Canada, with a net decrease in some ecozones. Although this is a comparatively small increase with a large uncertainty, it indicates that changes in woody carbon on cropland in Canada over the 1990–2000 period were relatively insignificant. Further studies may be needed to refine the carbon estimates and reduce uncertainties.

1. Introduction

It is a scientific consensus that global warming and associated climate change can be significantly attributed to enhanced anthropogenic greenhouse gas (GHG) emissions (Oreskes, 2004; Intergovernmental Panel on Climate Change, 2007). Mitigation of and adaptation to climate change have thus become a research and policy focus in recent decades (Atmadja and Verchot, 2012; Bierbaum et al., 2013; Huesemann, 2006; Sathaye and Andrasko, 2007), and this has generated a demand for techniques that allow for accurate, timely and affordable characterization of various aspects of the carbon cycle (Cihlar, 2007). Reliable estimates of terrestrial CO_2 sources and sinks at regional and local spatial scales are required to quantify their spatial variability in order to improve our understanding of the carbon cycle (Crevoisier et al., 2006; Gerbig et al., 2003).

Under Canada's commitment to the United Nations Framework Convention on Climate Change (UNFCCC) and according to interdepartmental agreements, Agriculture and Agri-Food Canada (AAFC) is responsible for estimating annual GHG emissions on agricultural land, while Canadian Forest Service (CFS; Natural Resources Canada) is responsible for estimates relating to forestry, and Environment Canada currently develops annual estimates for trees in urban areas (settlement land remaining settlement land) which are included in the national inventory report (NIR; Environment Canada, 2013). Since Canada has elected 1 ha as the minimum area to be considered as a forest, there is a considerable area of woody vegetation on managed land that is not included, such as individual, rows and clumps of trees and shrubs within agricultural land. Orchards could meet the area

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requirement to be defined as forest but Canada has decided to consider this cropland for purposes of reporting to the UNFCCC. Currently, AAFC estimates of GHG sources and sinks on agricultural land includes estimated woody biomass changes for orchards and vineyards but does not include carbon fluxes related to changes in other woody vegetation associated with cropland, and such areas are the subject of this study.

Although herbaceous crops occupy the majority of the cropland area in Canada, biomass accumulated by these cover types in a single year is assumed to be equal to biomass losses from harvest and mortality in the same year, thus there is no net accumulation of carbon stock (IPCC, 2003). On the contrary, woody cover types on cropland can accumulate biomass over many years. The cropland cover types with woody biomass include trees and shrubs in farmyards, shelterbelts (windbreaks of trees or shrubs), hedgerows (field borders of trees and/or shrubs), riparian areas, orchards and vineyards. Three types of biomass change can be anticipated with these land cover types: (1) loss due to removal, (2) accumulation through growth of existing vegetation and (3) addition through areal extension of woody vegetation through planting or natural colonization. Complete removal of trees and woody shrubs can occur due to the expansion of cultivated land through the removal of hedgerows and small groups of trees within agricultural fields, the removal of shrubs and small trees from previously idle fields which are being brought back into production, the conversion of orchards and vineyards to herbaceous crops and harvesting of woody crops such as Christmas trees and nursery stock. Biomass accumulation occurs through the growth of existing trees and shrubs and through the establishment (planting) of shelterbelts, orchards and vineyards.

This paper outlines a study conducted to quantify the woody biomass stock on Canada's cropland and monitor its change over time. The objective of the study was to investigate and quantify the contribution that agricultural land makes to the national carbon balance. The cropland area of Canada was first stratified into regions with distinctive climatic, soil, landform and agricultural production conditions, and historical aerial photographs were then used to identify typical woody cover types and their areal changes at random sample plots within each zone. Woody biomass associated with forests was not considered because such estimates fall under the domain of CFS, but observed changes relating to forest conversions are included in discussions on land cover change.

2. Material and methods

2.1. Spatial stratification

A national eco-stratification framework for Canada in which the entire landmass is divided into a hierarchical classification with ecozones as the highest class (largest units), followed by ecoregions and ecodistricts, was developed between 1991 and 1999 by the Ecological Stratification Working Group (1996). This framework has provided a common basis to report on the state of the environment and the sustainability of ecosystems in Canada in a variety of programs such as the reporting of carbon stock changes by Canada for the UNFCCC and reporting of national agri-environmental indicators (Eilers et al., 2010). Ecozones were used as the basis for spatial stratification in this study, and agricultural activities occur in 7 ecozones: the Atlantic Maritime, Mixedwood Plains, Boreal Shield, Boreal Plains, Prairie, Montane Cordillera, and Pacific Maritime. Due to differences in the local scale and nature of agricultural production activities, five sub-zones were further segregated on the basis of ecodistricts and treated as independent stratification units: (1) the Lower Mainland portion of Pacific Maritime; (2) the Okanagan Valley of Montane Cordillera; (3) the Niagara Region of Mixedwood Plains; (4) the Annapolis Valley of Atlantic Maritime and (5) the grassland portion of the Prairies. In the first four of these subzones agricultural production activities are generally focused on specialty crops such as vegetables, fruit, berries and grapes as opposed to the general field crop orientation of the remainder of the ecozone, while the grassland portion of the prairie ecozone is by definition essentially devoid of trees and would not naturally regrow to forest if abandoned (Ecological Stratification Working Group, 1996; Environment Canada, 2013). The stratification resulted in a total of 12 study zones (Fig. 1).

2.2. Aerial photography and interpretation

Medium resolution satellite imagery, particularly the Landsat series of sensors that has been in operation for several decades, is an indispensable resource for studying land use and land use change, and thus has been used in biomass accounting studies (Asner et al., 2003; Lunt et al., 2010). However, Landsat data is not adequate for a study such as this, as the dimensions of the target land cover classes are generally too small to be confidently detected using 30 m imagery. For example, a hedgerow may cover a significant area by virtue of its length, but it is difficult to detect due to its width being less than a 30 m Landsat pixel. Individual or clumps of trees or shrubs inside a crop field may also be indistinguishable on the long-term, medium resolution satellite imagery available. Low altitude (large-scale) historical aerial photography was selected as the information source for this study. Suitable aerial photos were identified and purchased through online searches of the National Air Photo Library (NAPL) and provincial data repositories using the following criteria: (1) plot sizes were either 1 km × 1 km (for 'specialty crop' (orchards, berries, vegetables, vineyards) zones of Annapolis, Niagara, Okanagan and Lower Mainland) or 2 km × 2 km (for 'field crop' (wheat, canola, corn, soybeans) zones); (2) each sample site must contain paired aerial photos corresponding to circa 1990 and circa 2000 at a scale of 1:10 k or larger. A target of 30 sample sites per stratification zone was adopted, and photo plots were selected by randomly choosing intersection points of the 20 km × 20 km National Forest Inventory (NFI) grid (Gillis et al., 2005) and searching for suitable imagery at the site. The availability of suitable photography was a limiting factor in identifying sites in

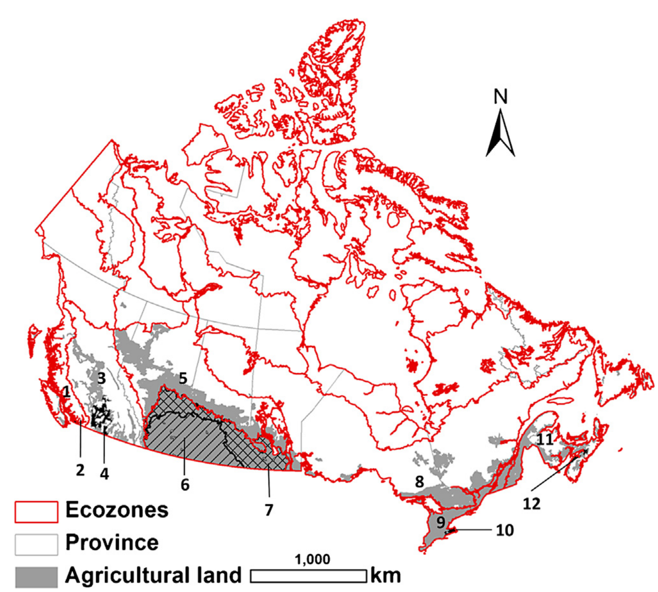

Fig. 1. Distribution of cropland in Canada and spatial stratification; specialty zones are denoted in black.