climate change
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The Carbon Sequestration Potential from Afforestation in Ontario

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1.0 Introduction

Afforestation involves the establishment of forests on previously non-forested lands. The Kyoto Protocol defines afforestation as the conversion of land that has not been forested for a period of at least 50 years to forested land through planting, seeding, and/or the active promotion of natural regeneration. Increased interest in afforestation in recent years follows the inclusion of forest carbon sequestration opportunities in Kyoto Protocol commitments. Previous studies by ArborVitae et al. (1999) and Bogdanski (2002a,b) suggest that carbon sequestration opportunities exist in Ontario. This note provides an estimate of the carbon sequestration potential from afforestation on private farmlands and non-farmlands in Ontario.

2.0 Methods

The maximum land area available for afforestation was estimated using the Ontario Land Cover Database (OMNR 1998) and agricultural census data published by Statistics Canada (1996, 2002). The estimated amount of available land was then refined using results from the Environics (2000) survey of farmers and rural landowners. Most of these data are spatially aggregated by county and MNR administrative district. County and district boundaries were superimposed on the map of Ontario ecoregions (Crins 2002) to generate ecologically meaningful estimates of land available for tree planting (Fig.1). In cases where a county or district straddled two ecoregions, the jurisdiction was assigned to the ecoregion in which most of its area is located. For example, although a portion of Frontenac County is in Ecoregion 5E, most of the non-forest lands are located in Ecoregion 6E. The number of hectares (ha) available for tree planting was based on the number of farmers willing to participate if their tree planting costs were paid. Accordingly, the area of farmland available for tree planting was estimated using the following formula:

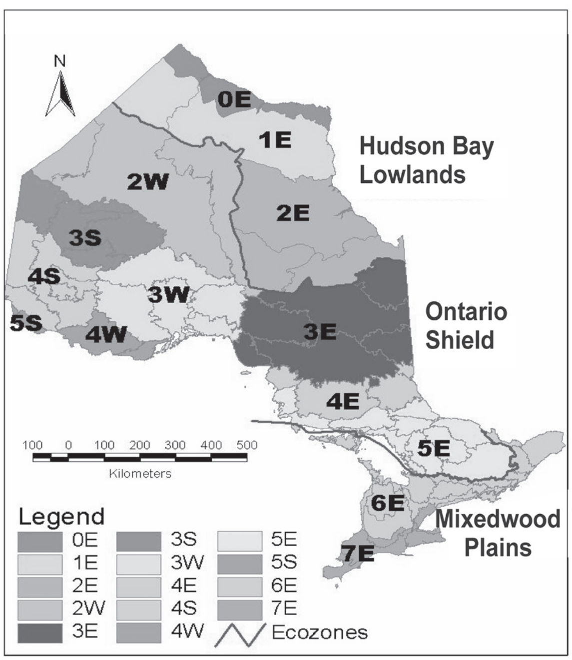

Figure 1. Ecozones and ecoregions of Ontario (Crins 2002).

$$\mathbf{Area}_{region} = \mathbf{N\ farms}_{region}\ (\mathbf{N\ planters}_{region} / \mathbf{N\ survey}_{region})\ \mathbf{Mean\ area}_{region}$$

Where,

Area_{region}	= total area available for tree planting
N farms_{region}	= number of farms in an ecoregion
$\text{N planters}_{region}$	= number of responses in an ecoregion
N survey_{region}	= number of people surveyed in the ecoregion
$\text{Mean area}_{region}$	= mean area available for planting in each ecoregion

The estimated area of available farmland was then used to determine the carbon sequestration potential from afforestation on a portion of land identified as available. The potential carbon benefits and costs of a large-scale afforestation program in Ontario were evaluated through a case study based on a business plan prepared by the Trees Ontario Foundation for the Ontario Private Land Afforestation Program (OPLAP) (for details see FORMAC 2002). OPLAP proposed a large 20-year afforestation program, from 2006 to 2025, and described a practical planting schedule. This note applies the business plan's methods to calculate potential costs associated with an afforestation program. For the purposes of analyzing sequestration costs associated with the afforestation program, costs of seeds, planting, operations, and inflation-induced impacts were examined. We assumed that the cost of greenhouse gas emissions during the Kyoto Period will approximate C$11.80 per tonne of CO_2e[1] (Natsource 2002).

[1] CO_2 equivalent (CO_2e) is a standard unit that expresses the energy-trapping properties of any greenhouse gas and the length of time it remains in the atmosphere. The measure is used to compare the emissions from various greenhouse gases with varying magnitudes of effect based upon their global warming potential.

The carbon sequestration estimate for the variety of species considered in the OPLAP case study was calculated using GORCAM, which is a stand-based algorithm that allows users to model the flow of carbon in a forest ecosystem (Schlamadinger and Marland 1996). Model input data included yield tables, expansion factors to convert from total volume to tree volume, basic densities, ratio of root to aboveground biomass, and litter decay rates. The input data were estimated on the basis of work completed by Alemdag (1983, 1984), Moore et al. (1999), and Siltanen et al. (1997). The biomass yield tables used to support this model were developed by Plonski (1981).

3.0 Results and Discussion

Land Available for Afforestation in Ontario

It is estimated that 309,878 ha of private land are available for afforestation if planting costs are paid to landowners as an incentive to participate (Table 1). Most of the farmland and non-farmland available for afforestation is located in ecoregions 6E and 7E, where soil and growth productivity are highest. The amount of available farmland and non-farmland increases significantly if an additional incentive of C$25 ha yr^{-1} is provided. However, increasing the incentive to C$125 ha yr^{-1} has minimal effect on available area.

By 2025, OPLAP proposes reforesting 84,000 ha, which is about 25% of the total land available if planting costs are paid (Table 2). The plan proposes that the first 200 ha of planting be completed in 2006 and the planting increase to 5,000 ha yr^{-1} by 2010 and remain at that level until the end of the planting program in 2025 (Fig. 2).

Table 1. The eco-geographical distribution of available planting areas on farmland and non-farmland properties in Ontario in response to incentive programs.

Ecoregion	Area (ha) Available by Incentive Program		
	Planting costs paid	Planting costs + C$25 ha^{-1} yr^{-1}	Planting costs + C$125 ha^{-1} yr^{-1}
3E, 4W, 4E, 4S, 5E	28,679	36,904	31,029
6E	257,374	353,134	388,641
7E	23,825	25,394	38,551
Total	309,878	415,432	458,221

Table 2. The ecoregional distribution of the species planting mix proposed in Ontario, 2006-2025.

Ecoregion	Hectares Available (and % of mix) for Afforestation by Species and Species Group							
	Hardwoods	Hybrid poplar	Jack pine	Red pine	White pine	Black spruce	White spruce	Total
3E, 4W, 4E, 4S, 5E	0	2,337 (30%)	2,337 (30%)	0	779 (10%)	2,337 (30%)	0	7,790
6E	6,994 (10%)	13,988 (20%)	0	20,982 (30%)	20,988 (30%)	0	6,994 (10%)	69,940
7E	1,941 (30%)	1,941 (30%)	0	0	2,588 (40%)	0	0	6,470
Total	8,935	18,266	2,337	20,982	24,355	2,337	6,994	84,206

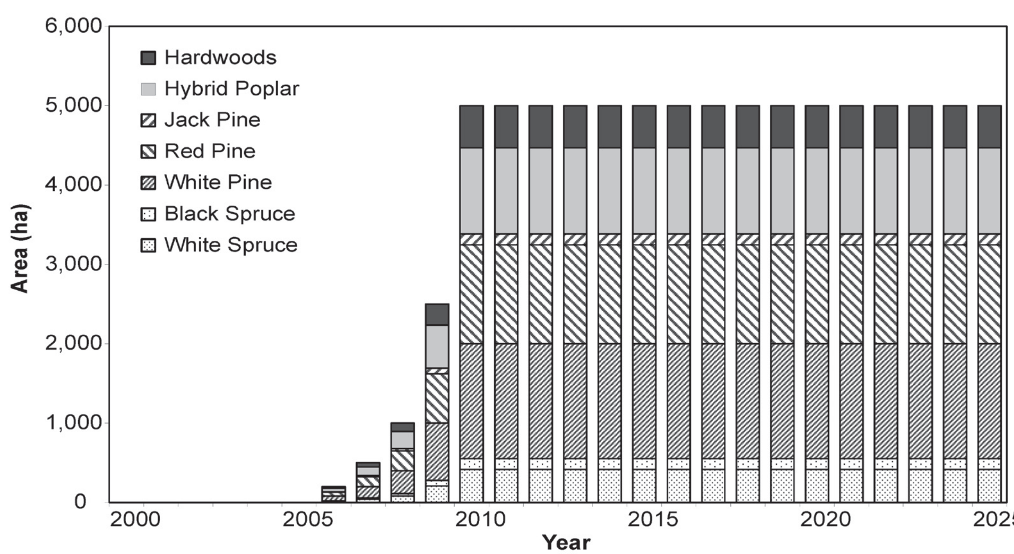

Figure 2. The proposed planting schedule and species mix composition for 2006-2025, developed for the Ontario Private Land Afforestation Program.

The area planted, the species used, and the planting timeframe are important factors in the calculation of the carbon sequestration potential. A balanced species mix was described using six species [white pine (*Pinus strobus*), red pine (*Pinus resinosa*), jack pine (*Pinus banksiana*), black spruce (*Picea mariana*), white spruce (*Picea glauca*), and hybrid poplar (*Populus berolinensis*)] and one species group [tolerant hardwoods such as sugar maple (*Acer saccharum*), yellow birch (*Betula alleghaniensis*), and red oak (*Quercus rubra*)] to maximize forest productivity and in turn rates of carbon sequestration.

Cherry (2001) suggests that regional afforestation projects should anticipate the impacts of climate change, and recommends less emphasis on hybrid poplar due to the need for intensive management. As well, Cherry (2001) recommends extensive planting of white pine in areas where blister rust (*Cronartium ribicola*) is absent, and specific hardwoods such as northern red oak in southern ecoregions. Species mix allocations in this study were somewhat arbitrary, where northern areas were assigned higher proportions of black spruce and jack pine while southern areas were assigned higher proportions of hybrid poplar.

OPLAP's basic program costs include cost of seeds and planting, assuming 2,000 seedlings per hectare for planting (Table 3). In addition to tree planting costs, operation costs are assumed to be C$400,000 in the first year of the program and C$300,000 in subsequent years with an inflation rate of 3%.

Table 3. Ontario Private Land Afforestation Program tree planting costs.

Activity	Cost/tree ($)	Cost/ha ($)
Planting stock - Hardwood	0.40	800
Planting stock - Hybrid Poplar	0.50	1,000
Planting stock - Softwood	0.40	800
Planting - Hardwood	1.35	2,200
Planting - Hybrid Poplar	0.50	2,700
Planting - Softwood	1.10	1,000

Carbon Sequestration Potential of Afforestation in Ontario

Species diversity is an important consideration in the design of an afforestation program. For example, use of a diverse mix of indigenous tree species reduces the risk of loss to insects and diseases, and may provide increased adaptability to a changing climate. As described in Table 2 and Figure 2, diverse assemblages of afforested species can be planted.

Given that planting does not begin until 2006 in the case study, the OPLAP will sequester little carbon during the first Kyoto commitment period (2008 to 2012) (Table 4). But over time, the number and size of planted trees increases, resulting in significant carbon sequestration. Over 50 years during and following the planting program, the 84,210 ha of forest will cumulatively account for more than 14 Mt CO_2e (Fig. 3).

Table 4: The Ontario Private Land Afforestation Program case study: Net sequestration of carbon dioxide on 84 210 hectares, 2008-2052.

Sequestration period	Amount (t CO_2e) sequestered	Cumulative amount (t CO_2e) sequestered
2008 to 2012	15,000	15,000
2013 to 2017	166,000	181,000
2018 to 2022	553,000	734,000
2023 to 2027	1,143,000	1,877,000
2028 to 2032	1,805,000	3,682,000
2033 to 2037	2,338,000	6,020,000
2038 to 2042	2,693,000	8,713,000
2043 to 2047	2,885,000	11,598,000
2048 to 2052	2,947,000	14,545,000

Afforestation Project Costs: A Case Study

While the Ontario Private Land Afforestation Project is not cost-effective during the first Kyoto commitment period, cost effectiveness increases with time (Table 5). OPLAP's initial planting regime sequesters very little carbon at great cost; however, by 2052 costs are reduced to C$8.01 t^{-1} CO_2e. Based on the assumed cost of greenhouse gas emissions during the first Kyoto period of C$11.80 t^{-1} CO_2e, the long-term cost effectiveness of OPLAP is significant.

The predicted average market value of greenhouse gas emission reductions ($NPV_{10\%}$ - net present value at 10% discount rate) to 2052 approximates C$6.97 t^{-1} CO_2e. This value assumes that the demand for emission reductions increases 3% per year and the inflation rate is 3%. Within the first Kyoto period, the predicted average market value of greenhouse gas emission reductions is C$13.50 t^{-1} CO_2e. Accordingly, OPLAP could be a useful and cost-effective long-term method for meeting greenhouse gas emissions targets.

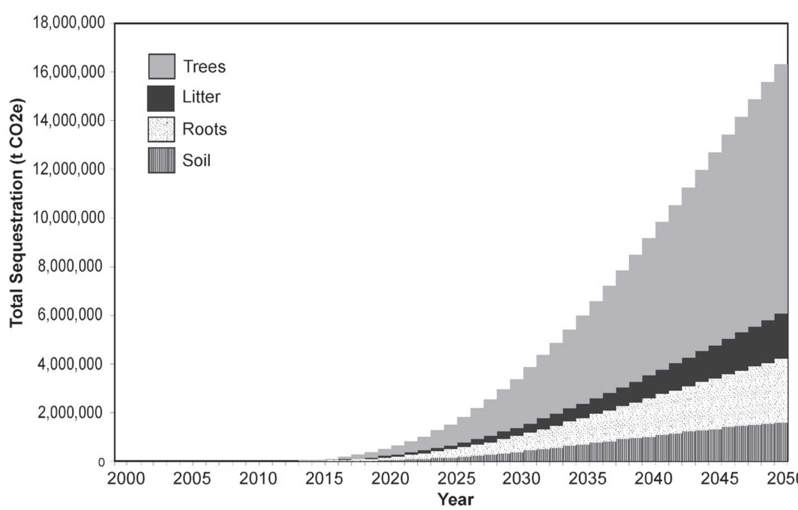

Figure 3. Ontario Private Land Afforestation Program total carbon sequestration by forest pool (trees, litter, roots, and soil), 2006-2052.

In addition to the value of stored carbon, when other benefits are considered such as improved atmospheric quality, oxygen generation, wildlife habitat, a strengthened economy in affected communities through increased recreational opportunities, as well as the economic benefits of timber production after 2052, OPLAP has merit.

Conclusion

Significant area is available for afforestation on private farmland and non-farmland across Ontario. Carbon sequestration is one of many benefits of planting trees on land that has not been forested in a long time. Others include ecosystem health, economic health, and ultimately human health. Afforestation requires a long-term commitment and investment by both management agencies and private landowners to maximize benefits to society and to the environment.

Table 5. Ontario Private Land Afforestation Program financial summary.

Sequestration period	Cost[1]	
	Total cost per tonne (C$/tonne CO_2e)	Net present value ($NPV_{10\%}$/Tonne CO_2e)
2008-2012	5,156	2,628
2013-2017	1,326	459
2018-2022	651	147
2023-2027	374	62
2028-2032	237	32
2033-2037	183	19
2038-2042	159	13
2043-2047	148	10
2048-2052	145	8

[1]The total required funding for 2008-2052 = C$427,586,000, which = C$116,562,000 NPV10%.

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Le potentiel de fixation du carbone que créerait le boisement en Ontario

Comme technique de gestion des gaz à effet de serre, le boisement contribue à la lutte contre le changement climatique, en plus d'offrir d'autres avantages, dont l'enrichissement de la biodiversité, l'amélioration de la qualité de l'air et l'élargissement des possibilités de loisir. La présente étude donne une estimation du potentiel de fixation du carbone que pourrait créer le boisement en Ontario. Il est estimé que plus de 300 000 hectares pourraient être boisés en Ontario, si les propriétaires terriens se faisaient rembourser les dépenses liées à la plantation d'arbres, pour les encourager à boiser leurs terrains. L'utilisation de plusieurs essences forestières bien choisies pourrait potentiellement fixer 14 millions de tonnes d'équivalent CO_2 d'ici à 2052. Il est estimé que les premiers régimes de boisement (p. ex., durant la première période du protocole de Kyoto, de 2008 à 2010) fixeraient très peu de carbone à un coût énorme, mais que le coût serait ramené, en 2025, à 8,01 $ par tonne d'équivalent CO_2. On voit donc que les travaux de boisement aptes à donner des résultats en Ontario nécessitent des investissements de longue durée.

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