Beautiful Plantations: can intensive silviculture help Canada to fulfill ecological and timber production objectives?

by Andrew Park[1] and Edward R. Wilson[2]

ABSTRACT

There is growing international agreement that intensive silviculture will play a major role in meeting future demand for wood and wood fibre worldwide. In Canada, however, extensive forest management continues to be the dominant paradigm. Driven by low growth rates in primary forests and the consequent long rotations, current policies support only basic management, with little or no silvicultural intervention between stand initiation and final harvests. By contrast, native conifers and hybrid poplars (*Populus* spp.) grown in plantations have been shown to achieve increments of 6 to 29 m^3 ha^{-1} yr^{-1} in Canada. In this paper, we argue that increased production, economic, and environmental benefits can be realized in Canada by intensifying silvicultural practices over designated parts of the landbase. Indeed, the shift to intensive management may be essential to sustain Canada's competitiveness in the international forest products sector. In reviewing past work, we demonstrate that intensive silviculture may yield outputs that are competitive with many other regions, even those in the tropics. Achieving wide support for intensive silviculture will require integration of a broader range of silvicultural, environmental, and social objectives into management planning than has traditionally been the case. Such a broad-based strategy, especially where it has gained the support of communities, may be the most balanced and effective means of resolving many of the key forest management issues that face Canada in the 21st Century.

Key words: conventional intensive silviculture, super-intensive silviculture, plantations, foreign competition, multiple-use forests, native conifers, roads, CO_2 emissions, incentive

RÉSUMÉ

On s'accorde sur la scène internationale pour affirmer que la sylviculture intensive jouera un rôle déterminant en réponse à la demande future de bois et de matière ligneuse à l'échelle mondiale. Au Canada, cependant, l'aménagement forestier extensif continue d'être le paradigme dominant. À la suite des taux de croissance faibles dans les forêts primaires et par les longues révolutions qui en découlent, les politiques actuelles sanctionnent seulement l'aménagement de base, accompagné de peu ou pas d'intervention sylvicole entre l'établissement du peuplement et la récolte finale. D'autre part, les conifères indigènes et les peupliers hybrides (*Populus* spp.) en plantation ont démontré qu'ils atteignaient des accroissements de 6 à 29 m^3 ha^{-1} an^{-1} au Canada. Nous faisons la preuve dans cet article qu'une production ainsi que des bénéfices économiques et environnementaux accrus peuvent être atteints par l'intensification des pratiques sylvicoles sur certaines zones désignées du territoire. En effet, le passage vers l'aménagement intensif pourrait être essentiel pour maintenir la compétitivité du Canada dans le secteur international des produits forestiers. En révisant les travaux antérieurs, nous démontrons que la sylviculture intensive pourraient engendrer des retombées de niveau compétitif avec plusieurs régions, incluant les tropiques. L'atteinte d'un appui généralisé pour la sylviculture intensive nécessitera l'intégration d'un ensemble plus complet d'objectifs sylvicoles, environnementaux et sociaux au niveau de la planification de l'aménagement, contrairement à ce qui été le cas jusqu'à date. Cette stratégie générale, spécialement lorsqu'elle a reçu l'appui des communautés, pourrait être le moyen le plus équilibré et le plus efficace pour résoudre plusieurs enjeux cruciaux d'aménagement forestier auxquels le Canada fait face au XXIe siècle.

Mots clés : sylviculture intensive conventionnelle, sylviculture plus qu'intensive, plantations, compétition étrangère, forêts à usages polyvalents, conifères indigènes, chemins, émissions de CO_2, mesures incitatives

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[1] Department of Biology / Centre for Forest Interdisciplinary Research (CFIR), University of Winnipeg, 515 Portage Avenue, Winnipeg, Manitoba R3B 2E9. E-mail: a.park@uwinnipeg.ca (corresponding author).

[2] Institute of Atmospheric and Environmental Science, School of GeoSciences, The University of Edinburgh, Crew Building, The King's Buildings, West Mains Road, Edinburgh, EH9 3JN, Scotland. E-mail: ted.wilson@yahoo.co.uk

Andrew Park

Edward R. Wilson

Introduction

For much of the 20th Century, it made economic sense in Canada to leverage the comparative advantage of having an enormous forest landbase to keep silvicultural costs down. Benson (1989) advocates this approach: "Instead of trying to emulate the intensive management strategies of the Scandinavians and Americans, it may be to our competitive advantage to consider extensively managing our larger, but less productive, forests to produce a second forest at the lowest regeneration cost possible." Canada's forests have therefore been managed with minimal silvicultural interventions, using extensive and basic forest management (EFM or BFM). Silvicultural practices under EFM include the use of clearcut, shelterwood or selection systems, together with reliance on natural regeneration. Basic forest management extends EFM to include site preparation, artificial regeneration, and practices designed to secure free-to-grow status, but with little further intervention prior to the final harvest (Bell *et al.* 2006), (Table 1).

In recent years, concerns about sustainability and biodiversity conservation have prompted the development of a new generation of EFM/BFM strategies. The new approaches share the goal of emulating the landscape patterns, stand age distributions, and habitat attributes that are produced by native natural disturbance regimes. They are variously known as "natural forest management"(Booth *et al.* 1993), "natural disturbance based management" (Harvey *et al.* 2002), "disturbance pattern emulation" (Anon 2001), or multicohort management (Groot *et al.* 2004). All involve the active management of stand habitat using varying levels of residual tree retention, active retention of senescent trees for wildlife, or even the development of future wildlife trees by girdling large live stems.

A strong counter-current to EFM/BFM philosophies is the idea that forest management should be intensified on parts of the landbase to ensure long-term timber supplies and to sustain a competitive Canadian forest industry (Binkley 1999, Messier *et al.* 2003, Anderson and Luckert 2007, Carmean 2007). Intensive practices potentially include a wide spectrum of silvicultural treatments and interventions that continue from stand initiation to the final stages of target crop removal (Table 1). Arguments in favour of intensive forest management (IFM) have focused on the impacts of new protected areas on timber supply (Binkley 1999), incipient and current wood supply crises (OMNR 1996, Atherton & Associates 1999, Messier *et al.* 2003, Coulomb Commission 2004), the potential of plantations to relieve pressures on primary forests (reviewed in Clapp 2001) and the use of afforestation/reforestation to help Canada fulfill its Kyoto Protocol commitments (Natural Resources Canada 2000).

Proponents of intensive forest management (IFM) envisage using creative land use zonation to resolve the competing demands on Canada's industrial forest. The well known "Triad" approach would divide the forest into strictly protected, extensively managed and intensively managed zones (Seymour and Hunter 1992, Binkley 1999, SSBF 1999). The "Quad" approach of (Messier and Kneeshaw 1999) further divides the intensively managed zone into "conventional" intensive silviculture (CIS) and "super-intensive" silviculture (SIS) areas (Table 1). Some forestry companies have initiated

Table 1. Definitions and acronyms. Definitions and detailed descriptions are adapted from (Bell *et al.* 2006) and (Messier *et al.* 2003).

Term	Acronym	Silvicultural activities	Rotation
Extensive Forest Management	EFM	Forestry carried out over economic rotations that occur with minimal silvicultural intervention. Employs the Clearcut System or shelterwood without tree marking. Relies on natural regeneration.	Long; natural economic rotation.
Basic Forest Management	BFM	Harvest systems include clearcut, variable retention, strip and seed-tree cuts, harvest with advanced regeneration protection (HARP). Site preparation (including prescribed burn) and artificial regeneration may be used. Juvenile spacing or precommercial thinning may be employed.	Long; planting/ spacing may shorten somewhat.
Intensive Forest Management	IFM	Forest practices exceed basic free-to-grow requirements that are current in most Canadian provinces. IFM may include use of "plus" seedling stock, large planting stock, juvenile spacing, vegetation management, commercial thinning, pruning, and deployment of herbicide, insecticide or biological control agents. Timber objectives include both increased wood volume and quality.	May be shorter than economic rotation, or repeated entries if thinning or shelterwood
Super-intensive silviculture (also called "Elite").	SIS	Super-intensive or "Elite" silviculture is synonymous with high density plantations of fast growing hybrids grown primarily for fibre or biomass. Inputs may include fertilizers, herbicides, insecticide, and biocontrol of pests.	Short: 40 years or less, depending on species and climate.

planning processes to introduce TRIAD zonation into their tenures (e.g., Boyland *et al.* 2004, D'Eon *et al.* 2004).

Internationally, it is widely assumed that much of the future global demand for wood can and should be met from tree plantations managed with varying degrees of intensity (Matthews and Hammond 1999, Bazett 2000). Some major environmental groups (Elliott 2003) and think-tanks (Victor 2005) have endorsed plantation forests as part of a global forest conservation strategy. Canada's forest industry also faces a new breed of foreign competitors whose strategies for securing future timber supplies depend on intensively managed tree plantations (Brown 2000, Lu 2004, FAO 2005a). Many of these competitors enjoy lower costs, higher labour productivity, and fewer environmental constraints than Canada (FPAC 2007). In Canada, however, CIS is only practiced on a large scale in New Brunswick, and relatively few super-intensive forest plantations have been established, most of them in Québec, Alberta, and British Columbia.

In this paper, we place Canadian plantation forestry in a global context, review the potential production and environmental benefits of silvicultural intensification, and assess some of the challenges of moving forward. The idea that intensive silviculture can coexist with purposes other than fibre supply runs counter to many preconceptions (e.g., Binkley 1999, Natural Resources Canada 2000). We argue that future planning for intensive silviculture must move beyond the narrow goal of intensifying fibre production to embrace a wide range of silvicultural, environmental, and social objectives. We also maintain that objections to and stereotypes about intensive silviculture will only be overcome once CIS and SIS are viewed as integral components of sustainable forest management.

The Future in Plantations

Global demand for wood

The global demand for wood rose steeply during the 20th Century and is likely to increase steadily into the foreseeable future. From 1960 to 1995 world roundwood consumption increased by 40% to 60% and fuelwood harvesting rose by 250% (Best *et al.* 1999). During the same period, the use of paper products increased by 80% to 350% in industrialized and rapidly industrializing nations (Matthews and Hammond 1999). Global demand for industrial roundwood, averaged across all available wood supply scenarios, is projected to rise from 1.5 billion m^3 in 2003 to between 2.3 and 3.1 billion m^3 by the year 2050 (Brown 2000, Weiner and Victor 2000). Much of the increased demand comes from newly industrialized countries, particularly China, where imports of unprocessed roundwood rose by 72% (15.7 to 27.0 million m^3) between 2000 and 2004 (FAO 2005b).

Wood supply from plantations

From 1995 to 2005, between 2.2 and 4.5 million hectares of plantation forests were established each year (Brown 2000, FAO 2005a). Plantations occupied about 3.5% of global forest lands in 1998, but accounted for about 16% of global wood supply. Nine countries with major forest products industries or large forest landbases account for over 70% of the global area devoted to plantations as they are defined by the FAO (Table 2). Chile and New Zealand obtain about 95% and 93% of their wood from plantations that cover, respectively, 16.1% and 17.1% of their forest lands (Best *et al.* 1999).

Among major timber producers, China is noteworthy in making timber self-sufficiency an explicit forest policy goal (Lu 2004). Plantations will be fundamental to realizing this goal because most of China's indigenous forests were protected under the Natural Forest Protection Program of 1998 (Lu 2004), and timber imports are constrained by rapid depletion of natural forests in neighbouring countries (Katsigris *et al.* 2004). The annual rate of plantation establishment for industrial wood and wood fuel in China was 1.8 million ha yr^{-1} between 2000 and 2003, or about 64% of the world total (FAO 2003).

Table 2. Best estimates of total forest and plantation area in a selection of countries that source a significant proportion of their wood supply from plantations, and Canada (FAO 2003).

	Forest Area (2000)			Plantations (2000)		Change (1990–2000)	
Country	Total land area (000 ha)	Forest area (000 ha)	% Forest	Area (000 ha)	% total forest area[a]	Total Forest (000 ha)	% Change in Forest Cover
India	297 319	64 113	21.6	32 578	50.8	38	0.06
Japan	37 652	24 081	64.0	10 682	44.4	3	0.01
China	932 743	163 486	17.5	45 083	27.6	1 806	1.10
New Zealand	26 799	7 946	29.7	1 542	19.4	39	0.49
Chile	74 881	15 536	20.7	2 017	13.0	-20	-0.13
USA	915 895	225 993	24.7	16 238	7.2	388	0.17
Argentina	273 669	34 686	12.7	926	2.7	-285	-0.82
Russian Federation	1 688 851	851 392	50.4	17 340	2.0	135	0.02
Brazil	845 651	543 905	64.3	4 982	0.9	-2 309	-0.42
Canada	922 057	244 571	26.5	0	0.0	ns[b]	ns

[a] Estimates of the percentage of the forest landbase in plantations vary somewhat depending on the time period over which data are estimated.
[b] "Not significant"

How does Canada compare?

Recent years have seen a decline in tree planting on harvested forest lands in Canada, but a parallel increase in spacing and thinning. Between 1990 and 2004, the area planted was reduced from 481 292 ha to 420 385 ha, a decline from 52.6% to 42.6% of the total area cut. During the same period, the area of stand tending increased from 385 791 ha to 422 346 ha (Canadian Council of Forest Ministers 2006). In 2004, 224 032 ha received conifer release treatments and 185 926 ha were precommercially thinned. Large areas of private forest in New Brunswick are intensively managed conifer plantations (Montigny and MacLean 2006). In spite of the evidence for intensive practices, FAO forestry statistics do not report any plantations for Canada[3]. Moreover, regrowth from primary forests and plantations are not distinguished in Canadian forest inventory data (van Oosten 2004), which makes international comparisons of difficult to make.

Populus is one of the most important temperate hardwood genera employed in plantation systems. In this case, some comparisons between Canada and other countries are possible. China and India are poplar powerhouses, with a million hectares in India devoted to agroforestry and wood production on farms, and 4.9 million ha in China divided between wood production in tree plantations (1.5 million ha), wood production in agroforestry systems (0.5 million ha), and environmental protection (2.9 million ha). Turkey, China, France, Italy, and India respectively harvested 3.8, 1.9, 1.8, 1.4 and 1.2 million m^3 annually from poplar plantations between 2000 and 2003 (FAO 2004; van Oosten 2004), (Fig. 1). By comparison, Canada's removals amounted to 25 000 m^3 from planted forests and 18 000 m^3 from agroforestry systems and trees planted on farms (FAO 2004).

Worldwide, *Pinus* species are the most important softwoods used in intensive silviculture. They collectively account for over 37 million ha (or 20%) of the global plantation estate (Varmola and Lungo 2003). For example, New Zealand reported over 1.8 million ha of plantations to the FAO (2005b) (22.3% of her total forest area). The majority of these are intensively managed *Pinus radiata* plantations grown on 25- to 40-year rotations. The USA reported 8.3 million ha. of plantations, an increase of 3.5% to 5.6% over 15 years. The greatest concentration of softwood plantations is in the southeast of the country, where *Pinus taeda* (loblolly pine) grown on 30- to 36-year rotations account for 60% of the timber produced in the USA (Wear and Greis 2007). There are no nationwide data on the area of intensively managed softwood plantations in Canada, and it is likely that only certain forest operations in New Brunswick match the intensity of silviculture in New Zealand or the US southeast. For example, J. D. Irving Ltd. maintains 60 000 ha of intensively managed softwood stands in its Blackbrook and Deersdale forest units (Montigny and MacLean 2006).

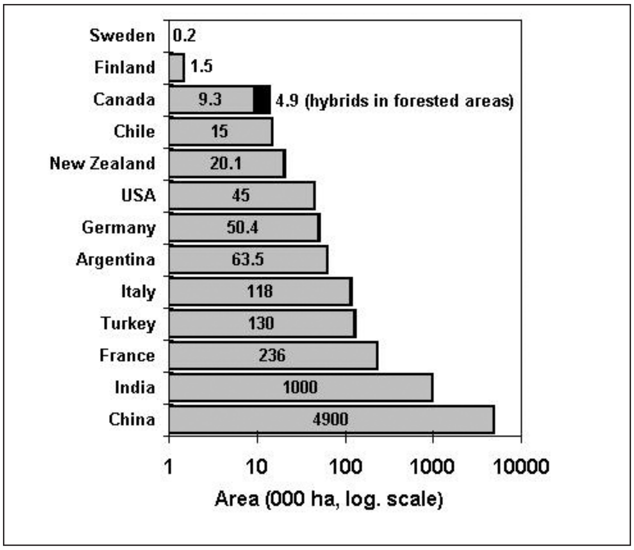

Fig. 1. Area of poplar plantations in selected countries, as reported to the International Poplar Commission in 2004. Statistics are combined areas planted for wood production, agroforestry, and protection (adapted from FAO 2004), except for Canada, where the grey bar indicates hybrid poplar grown on intensive (13- to 18-year) rotations, and the black bar indicates hybrid poplar grown on 20- to 25-year rotations (van Oosten 2004).

Resolving Wood Supply Challenges

It has been known for some time that several Canadian provinces will experience declining wood quality and supply in the absence of improved silviculture and planning (e.g., Innes 1994). In Ontario, demand for softwood is projected to fall short of supply by 4 to 8 million m^3 yr^{-1} over the next twenty years, while the average diameter of harvested conifers has declined from 20 to 15 cm dbh (OMNR 1996). In Quebec, overharvesting the long-run sustained yield (LRSY) in northern forests, and severe high-grading of southern hardwood stands have led to a 20% short-term reduction in the annual allowable cut (AAC). This measure will almost certainly result in a smaller Québec forest industry in the future (Commission for the study of public forest management in Québec 2004). In New Brunswick, softwood growing stock is projected to decline by over 40% by 2032, and current softwood processing capacity exceeds supply by about 29% (Select Committee on Wood Supply 2004).

Intensive silviculture is being actively promoted in at least two provinces with recognized wood supply problems. Even though CIS is practiced more widely in New Brunswick than in other provinces, a recent report by Jaakko Pöyry Consulting suggested that modest increases in planting and precommercial thinning could double wood supply over 50 years (Ashton and Anderson 2005). The BC Ministry of Forests is actively sponsoring research into "Incremental Silviculture" to offset imminent reductions in the Provincial AAC (BC MOF 1999). Without such measures, BC's AAC is projected to decline from about 71 to 58 million m^3 over the next forty years (Atherton & Associates 1999).

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[3] The absence of Canadian plantations in FAO statistics results form the definitions used. The FAO defines plantations as "intensively managed stands of introduced or of indigenous species" with "one or two species, even-aged, regular spacing." Importantly for Canada, this definition excludes plantations that have been without intensive management for a significant period. These are classified as semi-natural forests. Any natural forest is counted as semi-natural if it has natural characteristics like mixture of natural regeneration, diversification of age classes, layered canopies, enriched species diversity or random spacing (Varmola and Lungo 2003).

The potential contributions of SIS and CIS

Preliminary analyses of plantation growth rates and projections from simple models suggest that intensive silviculture could contribute substantially to future wood supply. Volume yields from hybrid poplar on the BC coast compare favourably with growth rates in some intensively-managed warm-temperate and tropical plantations (Fig. 2). Furthermore, the high yields reported from the tropics are often derived from experiments in which the trees received optimal silvicultural treatments. Growth rates in commercial tropical plantations are more modest, with mean annual increments (MAIs) as low as 1.0 to 3.1 m^3 ha^{-1} yr^{-1} in some teak plantations, and mortality rates of 50% or greater are not uncommon (Pandey 1995).

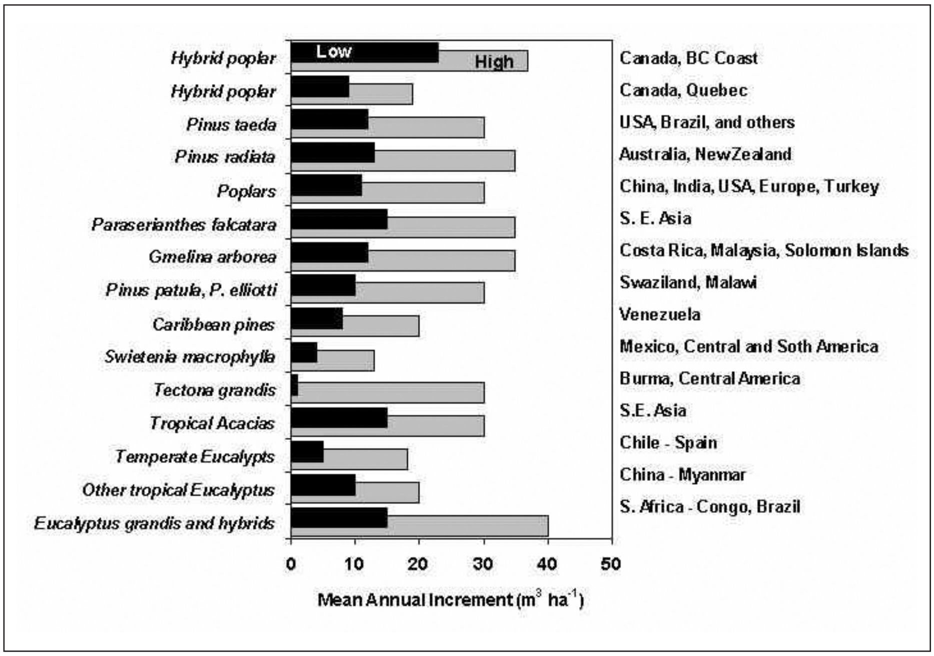

Fig. 2. High and low mean annual increments (in m^3 ha $^{-1}$yr^{-1}) of intensively managed plantations by species (left hand axis) and location (right hand axis). Data from CSIRO (1995), Cossalter and Pye-Smith (2003) and Messier *et al.* (2003).

Native Canadian trees have a great, but largely unrealized potential for increased yield under intensive and basic silviculture. Using a simple site index-based model with MAIs of 6 to 9 m^3 ha^{-1} yr^{-1} for SIS and 1.5 to 5.0 m^3 ha^{-1} yr^{-1} for CIS, Messier *et al.* (2003) projected that these strategies might respectively supply 23.1% and 22.3% of Canada's wood supply from 10% and 3% of the productive forest landbase. At the stand scale, data from spacing and thinning trials of native Canadian conifers show that much higher yields than those anticipated by Messier *et al* (2003) are possible (Table 3). Red pine (*Pinus resinosa*) on average to good sites in Ontario and the Maritimes achieved MAIs of 9.2 to 16.0 m^3 ha^{-1} yr^{-1} in spacing trials and thinning operations (Government of PEI 1997; Nicholson 2006; C. Bowling[4], personal communication). Spacing trials of white pine (*Pinus strobus*) and red spruce (*Picea rubens*) planted in old fields in Nova Scotia accrued 10.8 to 11.0 and 6.1 to 11.0 m^3 ha^{-1} yr^{-1}, respectively (Nicholson 2006). White spruce spacing trials exhibited more modest, but still substantial gains in gross MAI of 1.43 to 8.6 m^3 ha^{-1} yr^{-1} over 20 to 52 years of growth (Pollack *et al.* 1992; Nicholson 2006; C. Bowling, personal communication).

Studies from coastal British Columbia suggest that high wood volume production and increased wood quality can be compatible with the creation of complex stand structures and wildlife conservation. Combining growth and yield projections from the PROGNOSIS model with financial analysis, Howard and Temesgen (1997) found that positive net present values (NPVs) could be generated using shelterwood systems, thinning followed by clearcutting after 30 years, and even single-tree selection cuts at 15-year intervals. Volume increments were projected to range from 3.9 m^3 ha^{-1} yr^{-1} over the last 15 years of a shelterwood in a Douglas fir (*Pseudotsuga menziesii*) stand to 19.1 m^3 ha^{-1} yr^{-1} in a sequentially thinned western hemlock / Sitka spruce (*Picea sitchensis*) / amabilis fir (*Abies amabilis*) site.

Copland (2003) describes a strategy called sequential thinning that has the goals of enhancing wood quality and creating complex, multilayered canopies in second-growth stands. An experimental 38-ha stand in southeast Vancouver Island was stratified into 11 management units based on species composition, soil and topography. Eleven tree species occupying six identified canopy layers were to be managed using a combination of thinning from below, patch cuts with retention and reserves. Under sequential thinning, gross MAIs of 8.72 m^3 ha^{-1} yr^{-1} were projected for dominant and co-dominant trees. If understory trees and advance regeneration were counted, MAIs increased to 9.28 m^3 ha^{-1} yr^{-1}.

Some of the most important early silvicultural decisions involve provenance selection and breeding from genotypes with desirable silvicultural qualities. Matching the latitudinal origins of provenances to that of sites explained much of the growth variation in 25 provenance trials of white spruce (*Picea glauca*) planted at the Petawawa Research Forest (Morgenstern *et al.* 2006). Programs of seed selection from superior stock produce early growth gains that are magnified in the progeny of second and third generation parent trees from seed orchards (Penty *et al.* 2005). Selective breeding may be the most cost-effective means of increasing productivity and stem quality in the long run (Samuel *et al.* 2007).

To realize gains from such work, however, requires an ongoing commitment to stand management. The correct timing of early thinning operations is critical to generate growth in residual trees rather than losing it by thinning too late and having growth sacrificed in the cull trees (Reukema

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[4] Forest Science Specialist, Stand Management, Ontario Ministry of Natural Resources

Table 3. Productivity of native Canadian conifers in plantation trials and silvicultural experiments.

Species	Province	Treatment	Age at treatment	Age when measured	MAI ($m^3\ ha^{-1}\ yr^{-1}$)	Notes	Citations
Black spruce	NW Ontario	ST/SP	0	52	6.0	Spacing trial at 1.8 × 1.8 m spacing	C. Bowling, Ontario MNR, personal communication
	Nova Scotia	ST/SP	0	38	6.1	Established in old fields (1.8 × 1.8 m)	Nicholson 2006
Jack pine	Ontario	Pl/SP	0	Various	3.1[a]	Basic silviculture, including planting (2000 sph), and scarification	Penner 2004
	Ontario	P/SP/VC/W in various combinations	0–2	15–16	0.13– 7.0	Plantations established at 1.8 × 1.8 m spacing. Best results achieved using windrow, and 2nd best using windrow and bare root stock	Winters and Bell 2002
Lodgepole pine	Alberta	PCT	7–40	40–64	3.5–7.2	Merchantable volume change was -5 - 538%	Stewart 2005a
	Alberta	CT	22– 85	70–135	2.9–4.3	MAI based on residual growth plus thinnings	Stewart 2005b
Red pine	NW Ontario	ST/SP	0	52	16.0	Spacing trial at 1.8 × 1.8 m spacing	C. Bowling, Ontario MNR, personal communication
	Prince Edward Island	PCT/CT/P/CC	25–60	NA	10.4–12.4	Growth data from SI50 stands used as basis for use in CFS investment analysis program	Government of PEI 1997
	Nova Scotia	ST	0	18-70	9.2–13.3	Established in old fields (1.5 × 1.5 m)	Nicholson 2006
White pine	Minnesota	CT	80–94	125	4.2–5.6	MAI is net of natural mortality and includes 3 thinnings between 1953–1964	Anderson *et al.* 2002
	Nova Scotia	ST	0	20–70	10.8–11.0	Established in old fields (1.9 × 1.9 m)	Nicholson 2006
White spruce	Ontario, Petawawa	PT/VC/PCT	0	44	4.3–6.5	Unthinned trials of 25 white spruce provenances from 44.1 deg N to 49.7 deg N.	Morgernstern *et al.* 2002
	NW. Ontario	ST	0	52	7.30	Spacing trial at 1.8 × 1.8 m spacing	C. Bowling, Ontario MNR, personal communication
	Northern BC	ST	0	32	1.43–7.0 4.9–6.7	Spacing trials at 420–6727 trees ha^{-1} (1.2–4.9 m inter-tree spacing). Volume growth estimates were based on TIPSY model projections.	Pollack *et al.* 1992
White spruce	Nova Scotia	ST	0	12–40	5.2 - 8.6	Established in old fields (1.5 × 1.5 m)	Nicholson 2006
Red spruce	Nova Scotia	ST	0	20–45	6.1–11.0	Established in old fields (1.5 × 1.5 m)	Nicholson 2006
Douglas fir/mixed conifer-hardwood	Coastal British Columbia	CT/SW/PC	65–65	64	8.7– 9.3[b]	64 year old stand in Coastal Western Hemlock very dry (CWHxm1) subzone of Vancouver Island. Volume equations were based on BC-MOF volume tables	Copland 2003
Douglas Fir	Coastal British Columbia	9 treatments, including CC, CT, SW, and SC in various combinations	60–90	53–60	3.9–14.7 [b]	Growth and yield of 9 different silvicultural prescriptions modelled using PROGNOSIS program. Minimum cut of $50m^3\ ha^{-1}$ with a diameter limit of 15 cm.	Howard & Temesgen 1997
Western hemlock / Sitka spruce			60–90	53–60	5.7–12.8 [b]		
W. hemlock / W. red cedar, Douglas fir			60–90	53–60	6.7–19.1 [b]		

Acronyms: PCT – Precommercial thinning; CT – Commercial thinning; ST – Spacing trial; JS – Juvenile spacing; PT – Provenance trial; VC – Vegetation control; SW – Shelterwood; PC – Patch Cut; SC – Selection cut; CC – Clearcut; P – Pruning; Pl – Planting; SP – Site preparation; W – Windrowing.

[a] Growth extrapolated from graph. The MAI is for merchantable wood.

[b] Growth extrapolated using timber supply or stand table models.

1975). Delayed thinning in dense stands can also adversely affect future wood quality and threaten crop tree survival through increased susceptibility to windthrow (Wilson and Oliver 2000).

The inability to control the timing of silvicultural treatments may explain the inconsistent response to thinning in some old plantation trials. For example, precommercial and commercial thinning of lodgepole pine (*Pinus contorta*) in Alberta resulted in MAIs between –26% and +99% of those in unthinned control plots (Stewart 2005a, b). In these trials, commercial thinning between 22 and 85 years of age generally produced worse results than precommercial thinning between seven and 40 years after stand establishment. Nevertheless, even in precommercially thinned stands, half of the treatments realized lower MAIs than unthinned controls, pointing to the need to integrate density management, site factors and timing into treatment decisions.

Conserving Ecosystems, Deforestation Avoided, and Reducing Carbon Emissions

By alleviating current pressures to expand logging northwards, CIS and SIS could contribute to strategic conservation goals. Indirect benefits of CIS and SIS would almost certainly include a reduction in greenhouse gas emissions by industry, reduced costs of road construction and maintenance, and potentially industry-saving fuel economies.

Enhancing forest conservation

Managed temperate and boreal forests are vulnerable to the loss of older stands, reduction of habitat quality, and fragmentation by roads. The loss of large-dimension coarse woody debris (CWD) during the first and subsequent rotations of clearcut harvesting dramatically reduces habitat supply for many species (McRae *et al.* 2001, Kuuluvainen and Laiho 2004). Roads produce avoidance behaviour in some mammals, potentially alter carnivore-prey relationships, and increase access for legal and illegal hunters (Henschel 2003, Noss 2003, Park *et al.* 2004). Where roads and landings are not deactivated and replanted, they contribute to net deforestation (Robinson *et al.* 1999).

Two major initiatives are intended to institute large-scale conservation measures in Canada's boreal forests. The Canadian Boreal Conservation Framework (CBCF) calls for the protection of "at least 50% of the (boreal) region in a network of large interconnected protected areas" (Canadian Boreal Initiative 2003). The Senate Subcommittee on the Boreal Forest (SSBF) suggests a lower, but still substantial figure of 20%. The SSBF also called for guidelines on maximum road densities (SSBF 1999). Given provincial wood supply deficits and the current pressures to move the harvesting frontier further north (e.g., OMNR 2001), CIS and SIS will be needed to achieve these protection goals.

Deforestation avoided and reducing carbon emissions

The annual extension of forest roads to access new timber results in increased carbon emissions during wood transport. Increased haul distances imply higher fuel costs, despite measures to improve the mechanical efficiency of logging trucks (Feng 1993, FORINTEC 2003) and the behavioural efficiency of drivers (Clemence 2004). Rising fuel costs act as a multiplier on increased distance. The average price of diesel fuel rose by 47% in Canada between 1993 and 2004 (Transport Canada 2004). Moreover, the peak in economically viable global oil production (Hubbert's peak) may be imminent (Duncan and Youngquist 1998, Campbell 2002, Vidal 2005). Fuel supplies will be progressively constrained after Hubbert's peak occurs, which will lead to long-term, irreversible oil price increases.

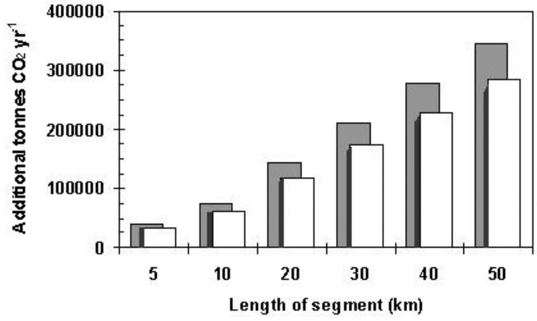

Fig. 3. High and low estimates of the additional carbon dioxide released into the atmosphere from logging trucks as a result of the annual extension of forest roads. Grey bars are high estimates assuming diesel consumption of 1.7 l / km, and white bars are low estimates based on diesel consumption of 1.4 l / km. See Appendix I for details of assumptions and calculation.

Deforestation in Canada due to road construction is estimated to release 9.4 megatonnes of CO_2 yr^{-1} from above- and below-ground sources (Robinson *et al.* 1999). Reducing this type of deforestation could potentially sequester more carbon than current reforestation and afforestation combined (Nelson and Vertinsky 2003). There are no centralized data for the total length of forest roads in Canada, the annual extension of the road network, or haul distances from wood supplies to mills. Estimates of incremental fuel consumption during logging must therefore rely on scattered data sources, expert opinion (e.g., Robinson *et al.* 1999), and extrapolation from reasonable assumptions.

Our estimates of incremental CO_2 emissions that accrue as a result of the annual extension of forest roads are shown in Fig. 3 (see Appendix I). Incremental CO_2 emissions depended heavily on the average length of new road segments. If many roads were extended by only 5 km per road, between 33 442 and 40 608 additional tonnes of CO_2 yr^{-1} could be released. On the other hand, if a few roads were to be extended by 50 km, between 284 255 and 345 166 additional tonnes CO_2 yr^{-1} might be generated. These projected emissions comprise 0.24% to 2.47% of Environment Canada's 1999 estimates for total CO_2 emissions by off-road diesel transport (Environment Canada 2001).

Failure to restrict the future extension of forest, mining and oil supply roads will produce adverse impacts on road-sensitive species in the future. As an example of such impacts, the cumulative length of roads in Alberta Pacific's (AlPac's) 59 054 km^2 FMA is projected to increase from 17 774 km to 162 000 km over a 50-year period (Schneider 2002). Among other effects, this planned extension of the road network would reduce the proportion of the landbase deemed suitable for woodland caribou from about 43% to less than 10% over 20 years[5].

Carbon sequestration

Deforestation to create new agricultural land continues to occur near the southern edge of the boreal forest (Fitzsimmons 2002, Hobson *et al.* 2002), a process that releases between 1.89 and 5.66 megatonnes of CO$_2$ annually (Robinson *et al.* 1999). Arresting deforestation and providing opportunities to raise profitable carbon-absorbing tree crops therefore comprise a dual challenge in and around Canada's agricultural regions.

Hybrid poplars, and native conifer and hardwood plantations managed using CIS or SIS, are alternative farm crops that may qualify for carbon credits if they are established on land that was bare of trees in 1989. Additionally, emerging carbon markets may create opportunities to profit from carbon sequestration in growing trees. In Canada, however, afforestation on private land has historically been small in scale. Between 1990 and 2002, 52 000 afforestation projects were initiated with an average area planted of 2 ha (White and Kurz 2005). More recently, the Forests 2020 Plantation Demonstration Assessment established about 6000 ha of carbon sequestration demonstration trials across all of Canada's ecozones (Canadian Forest Service 2006). White and red pine, white spruce, larch (*Larix* spp.), and yellow birch (*Betula alleghaniensis*), as well as Norway spruce (*Picea abies*) and hybrid poplars have been planted, and MAIs of up to 20 m^3 ha^{-1} are anticipated.

Managed forests may also qualify for carbon credits. In 2002, Canada's first large-scale carbon sequestration project was approved under the Greenhouse Gas Emission trading (GERT) pilot project (Lemprière *et al.* 2002). Twelve forest carbon reserves (FCRs) composed of mature and overmature forest stands that are reserved from harvesting will cover 206 000 ha of Crown land. White spruce plantations will also be established on 3300 ha of insufficiently restocked lands (NSR) lands. Under a 50-year agreement, about 1.54 million tonnes of carbon sequestered by these reserves and plantations will be sold by Saskatchewan Environment to the Saskatchewan Power Corporation.

Beyond Timber and Carbon: Multiple Purpose Plantations

In Canada, there are opportunities to establish structurally complex or species-rich plantations to serve a wide variety of silvicultural and environmental objectives. Diverse plantations may gain greater acceptance where non-timber products and ecosystem services equal or exceed wood products in value (Kanowski 1997). Boundaries between plantation and non-plantation forest uses also become blurred as a greater variety of end-uses for tree cover are desired. Such blurring is already evident in Europe, where the adoption of continuous cover silviculture is an increasingly important option for plantations near the end of their rotation (Wilson *et al.* 1999).

Wildlife habitat

The relative value of tree plantations to wildlife depends on the size of the plantations and the character and complexity of the surrounding vegetation (Schiller and Tolbert 1996, Hanowski *et al.* 1997). A general finding from semi-agricultural landscapes is that bird and small mammal diversity in plantations is intermediate between that of row crops and natural forests (Schiller and Tolbert 1996, Tolbert and Schiller 1996). Rates of species turnover can be high during the early years of plantation development, reflecting the rapid growth of the trees and accelerated progression through successional stages (Hanowski *et al.* 1997). Maintaining short-rotation plantations at all stages of development could therefore contribute to landscape habitat and species diversity.

Even relatively young, structurally homogeneous plantations provide valuable habitat if they enhance landscape-scale habitat diversity. Hybrid poplar plantations embedded in an agricultural and shrub-steppe matrix in Oregon were used preferentially during the winter by up to six owl species (Moser and Hilpp 2004). Optimal habitat for the endangered Kirtland's Warbler (*Dendroica kirtlandii*) depends on the creation and maintenance of young (£ 22 years old) monocultured jack pine (*Pinus banksiana*) stands in lower Michigan (Kashian and Barnes 2000). In intercropped fields of arable crops and hybrid poplar in Ontario, bird diversity approached levels found in nearby forests stands in an old-field successional sere (Thevathasan and Gordon 2004).

Ecosystem restoration

Plantations managed using CIS have an established role in the restoration of ecosystem services and aesthetic values. In Canada, the classic examples of such restoration are the red pine plantations that were established to restore degraded agricultural land on Ontario's Oak Ridges Moraine. The oldest plantations were established during the 1920s, and are now developing understories of native broadleaved trees (McPherson and Timmer 2002; A. Park, personal observation). This transformation is now being encouraged in the younger plantations using row thinning and group selection combined with underplanting of bare root white ash (*Fraxinus americana*), white pine, and red oak (*Quercus rubra*) (Parker *et al.* 2001).

Shade-tolerant hardwoods (USDA 2000) and conifers (Morford and Hutton 2000) have also been successfully planted beneath hybrid poplar stands. In a Canadian example of using hybrid poplar as a nurse crop, sugar maple (*Acer saccharum*), white pine, red oak, basswood (*Tilia americana*), white ash, European alder (*Alnus glutinosa*), and black walnut (*Juglans nigra*) were interplanted among a variety of poplar clones (Ontario Stewardship Centre undated). Planted or naturally regenerated white pine growing beneath an aspen overstory thinned to provide 45% to 50% of full sunlight may be partially protected from attacks by the white pine weevil (*Pissodes strobi*) (Heckman 1985, Stiell 1985).

In a British Columbia context (Douglas *et al.* 2004) summarizes projects in which CIS was used to restore reference landscape conditions and enhance timber production. Group selection was used to restore open forests and meadows in Kootenay National Park to provide winter habitat for bighorn sheep and to lower fire hazards near the town of Radium. A shelterwood cut of 10- to 30-cm diameter trees followed by a

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[5] Estimate includes roads created for all industrial activity, including logging, oil sands development, and mining.

heavy thinning of the advance regeneration was used to increase stem growth of Douglas fir, encourage understory development, and reduce fire hazards. Understory burns were prescribed as post-harvest treatments in both of these examples to improve seedbed conditions and remove fine and coarse fuels.

Challenges to Silvicultural Intensification

Challenges to the establishment of plantations in Canada can be grouped into three categories: (1) achieving profitable levels of growth and yield, (2) economic and biological risks of plantation establishment, and (3) opposition by interests groups and citizens on environmental and social grounds.

Achieving profitable growth and yield

For companies, investment in increased timber production must be accompanied by positive long-term cash flows. Specifically, net present value (NPV), the discounted value of future cash inflows minus the costs of current and future silvicultural investments, should be positive. Mean annual increments for unmanaged mature forests (70 to 110 years of age) vary from 1.65 $m^3 ha^{-1} yr^{-1}$ in the boreal to 2.53 $m^3 ha^{-1} yr^{-1}$ in coastal BC (Gray 1995). If they were to continue into second-growth stands, such slow growth rates would be serious disincentives to invest in CIS at any conceivable discount rate.

Table 3 shows that MAIs of three to 12 times the average rates for unmanaged forests can be achieved for a variety of native Canadian conifers and hardwoods. Silvicultural practices used in these examples varied from the manipulation of inter-tree spacing to deploying the full panoply of intensive practices. In the few cases where treatment costs and potential revenues are projected, returns appear to be sensitive to harvesting technology, the size of trees harvested, and stand-specific growth responses to specific treatments. Harvesting costs and gross returns reported by Howard and Temesgen (1997) varied inversely, with costs declining exponentially with tree size and log value. Net returns were contingent on the harvesting system employed, and ranged from \$173.84 m^{-3} for sequential thinning and cable yarding to \$100.46 for a uniform shelterwood with line skidding.

Net present values are also extremely sensitive to discount rates and rotation age. Insley *et al.* (2002) used a Faustman approach to predict optimal rotations for jack pine and black spruce (*Picea mariana*) at discount rates of 3% to 7% under silvicultural regimes that ranged from "natural" (no intervention) to "intensive" (planting, thinning etc). Optimal rotations of 45 to 114 years were reported, and yields for the most intensive treatment were projected to increase by 25% to 300% over basic and natural options. Nevertheless, only "basic" silviculture was economically justified under most circumstances at discount rates higher than 3%. Future profitability is thus heavily impacted by unpredictable economic trends as well as the immediate costs of silviculture and stand responses to treatment.

A solution that has been proposed to the challenge of achieving profitability under CIS is to invoke the Allowable Cut Effect (ACE) (Insley *et al.* 2002, Weetman 2002). The ACE involves permitting companies to harvest mature forest stands on an accelerated schedule in return for their agreement to invest in CIS. Economic projections suggest that positive returns from the ACE will only occur when most of a concession comprises mature forest and when AAC ignores wood from deciduous stands. Furthermore, positive returns were higher for extensive than for intensive treatments (Hegan and Luckert 2000). Employing the ACE may also lead to harvesting decisions becoming divorced from price signals, and treatments that improve wood quality being undervalued or ignored altogether (Luckert 1996).

Risk

Insect infestations, disease, and extreme climatic events could nullify potential economic gains from CIS and SIS. The use of hardwood nurse crops and high density plantings are established strategies to reduce the risk of losses from pests such as white pine weevil, and are compatible with CIS practices (Stiell 1985). Early pruning of weevil-infected leaders, removal of balsam fir (*Abies balsamea*) to minimize the attractiveness of stands to spruce budworm, planting mixed stands, and careful site selection to avoid environmental stress are among the many additional measures that can minimize the loss of timber values (de Groot *et al.* 2003).

The successful practice of SIS in boreal and sub-boreal regions is contingent on identifying or developing genotypes that grow rapidly over short rotations, and which are well-adapted for the local climate (Weih 2004). The growth rates of clones in current use vary widely. Clones planted by the Prairie Farm Rehabilitation Administration (PFRA) achieved a maximum MAI of 17.65 $m^3 ha^{-1} yr^{-1}$ in 15-year-old stands, but average MAIs were much lower at 7.78 ± 3.78 $m^3 ha^{-1} yr^{-1}$ and 7.45 ± 2.72 $m^3 ha^{-1} yr^{-1}$ in 15- and 25-year-old stands, respectively (Anderson and Luckert 2007). The NPVs realized from these growth rates proved highly sensitive to stumpage values, land rents, and interest rates. To place these figures in perspective, MAIs of at least 14 $m^3 ha^{-1} yr^{-1}$ are required before investing in carbon-storing plantations is justified at current market prices for CO_2 (McKenney *et al.* 2004).

There are no direct financial incentives to practice CIS in Canada, and only limited inducements for SIS. For example, British Columbia and Alberta classify on-farm plantations as primary farm land, which facilitates certain tax deductions (van Oosten 2004). In Ontario, property tax relief is available for private land that is classified as forest (OMNR 2006). The lack of more direct subsidies and the need for appropriate crop risk insurance (Conference Board of Canada 2002) may be partly responsible for the low area of carbon plantations that have been established on private land (2650 ha between 1990 and 2000, Hall *et al.* 2004). This small area contrasts with an estimated potential of 36 500 $ha yr^{-1}$ if direct subsidies were to be provided (de Marsh 1999). Even where subsidies or cost-sharing agreements exist, as in the United States, uncertainty about emissions trading rules and liability issues may contribute to low uptake rates of opportunities by small landholders (Griss 2005).

Additional barriers to investment in CIS and SIS by industry include outdated tenure arrangements, declining competitiveness, low labour productivity and product prices, and capital depreciation (FPAC 2007). Each of these factors merits a paper in itself, but their full treatment of each of these factors lies beyond the scope of the present paper.

Opposition to CIS and SIS

Environmental non-governmental organizations (ENGOs) and certification organizations have often opposed CIS and

SIS. Intensive practices are often portrayed as replacing "diverse native forests," moving us away from an "ecological approach to forestry" (Conservation Council of New Brunswick 2001, Peaceful Parks Coalition 2002). High yield plantations are typified as "having little in common with forests" (World Rainforest Movement 1998). This stereotype is reinforced by some segments of the forestry community: "…plantations dedicated to timber production need not mirror the natural forest, since they would not be managed or viewed as natural forest" (Natural Resources Canada 2000).

Starting from a normative goal that intensive practices should be used to create more protected areas, von Mirbach (2001) asks a series of wide-ranging questions about intensive land zonation. Von Mirbach asks whether intensification is able to facilitate an increase in protected areas, and whether such areas will be ecologically significant. He is concerned that industry will request increased logging rates (ACE) to compensate for CIS and SIS investments, that intensification will exacerbate the tendency to produce large volumes of low-value products, and that regulations may be relaxed to accommodate intensive practices. Finally, von Mirbach questions whether lands targeted for intensive production will be put to their best use, citing biodiversity conservation and farming as potential alternative practices.

If the views held by ENGOs about intensive forestry are easily accessed and frequently stated, data on the opinions of the general public are elusive. We are aware of no public opinion surveys that are dedicated to gathering views about CIS or SIS, although some touch upon elements of intensive forestry. In a comparative survey of 1501 members of the public and 201 forestry professionals, Wagner *et al.* (1998) found that the opinions of non-foresters consistently diverged from those of foresters. Relative to forestry professionals, the public saw little need to use insecticides or herbicides in forestry operations, and felt that clearcutting was not acceptable in many situations. Rural and urban Nova Scotians were more ambivalent about elements of intensive forestry. Here, 65% of respondents felt that clearcutting on public lands was unacceptable. Narrow majorities felt that properly applied insecticides and herbicides were acceptable, but disapproved of their use for vegetation control (Sanderson *et al.* 2000). These data suggest that members of the public would be suspicious of the widespread introduction of intensive forestry practices. More research is needed to clarify levels of public knowledge to provide a basis for balanced education programs about intensive forestry.

Discussion and Conclusions

Intensive silviculture and comparative advantage

Contrary to Booth *et al.* (1993), the multiple ecological and amenity values embodied in Canadian forests imply that very high opportunity costs would be attached to the continuing dominance of EFM (Binkley 1999). It is therefore surprising that governments and industries have been slow to embrace the opportunities for improved land use zonation and stabilization of fibre supply that CIS and SIS could potentially supply. Canada also lags many of her major industrial competitors in forest management research expenditures (Binkley 1995, Natural Resources Canada 2000). This research deficit, which exists in both the natural and social sciences, translates into a limited capacity to respond to the challenges of transforming forest management strategies.

The slow pace of development in Canada can be contrasted with rapid rates of plantation establishment in countries such as China and Brazil. These countries are now challenging Canada and the USA in their traditional areas of manufacturing dominance (Bowyer 2004). Pulp supply from the efficient, low-wage mills of Latin America has increased by 40% in recent years, and is contributing to a global supply surplus that will depress future prices (ALPAC 2006). The Canadian market share enjoyed by Chinese furniture manufacturers rose from 2% in the early 1990s to 36% by 2003 thanks to both competitive cost and quality with their Canadian equivalents (Industry Canada 2005).

Technological advances have enabled Canadian manufacturers to process smaller trees (OMNR 1996) and to reduce carbon emissions (Nelson and Vertinsky 2003). New technologies and increasing efficiencies have also allowed companies to reduce the carbon intensity of manufacturing and transport. Yet in the long run, continuing reliance on extensive, low-input forestry will lead to increased carbon emissions as log haul distances increase and fuel prices inevitably rise, a situation that the industry is well aware of (ALPAC 2006). In the approaching world of constrained fuel supplies, forestry in the far north of Canada appears to have a limited future. In particular, silvicultural investments to secure second and subsequent harvests in the north are unlikely to be substantial.

A CIS/SIS strategy for Canada

The advantages of silvicultural intensification and creative land use zonation have been discussed in Canada for a number of years (SSBF 1999, Messier and Bigué 2002, Arseneau and Chiu 2003). Pilot projects on intensification have been initiated (D'Eon *et al.* 2004), but the future character and competitiveness of CIS/SIS-managed forests remains unclear. In our view, CIS/SIS managed Canadian forests will have the following characteristics:

1. There will be large areas of CIS-managed plantations of native conifers and hardwoods that achieve MAIs of 8 to 20 m^3 ha^{-1} yr^{-1}. These will be established on average to good sites using appropriate provenances, improved stock, and close attention to initial spacing, early vegetation control and precommercial thinning.
2. Smaller areas will be devoted to high yield plantations of hybrid poplar, birch and larch grown on 12- to 25-year rotations at 10 to 40 m^3 ha^{-1} yr^{-1}. Most likely, these will be planted on marginal agricultural land or other areas in southern Canada specifically zoned for hybrid cultivation. Hybrid poplars may provide transitional income if they are used as nurse crops in longer rotations.
3. There should be an increased emphasis on improving wood quality in stands managed using CIS. High-quality logs command higher prices, are more economical to harvest, and are necessary to provide feedstock for some value-added industries. In Copland's (1993) projections, the value of individual logs in sequentially thinned stands increased by a factor of four as residual trees grew into higher log grades. Future research will need to go beyond biomass production as the key selection criteria to embrace a wider array of stem quality and wood chemical properties.
4. As timber supply becomes localized, road networks will be reduced in length, and transport costs should stabilize. In

a parallel process, the timber industry is also likely to be increasingly consolidated around major CIS/SIS timber supply areas. Increased protection of forests not designated for CIS or SIS will be facilitated.

5. Plantation research will establish precise production functions for species–site combinations based on site evaluation that are more sophisticated than those that are currently available (Carmean 2007).

Overcoming challenges

The realization of such a vision is not without its challenges. As Carmean (2007) points out, much of the standing stock in boreal and sub-boreal forests is small, low in value, and suitable mainly for pulp production, which has one of the lowest added values among forest products. Such a resource makes a poor foundation for a future of high-volume, high-quality production. The first step in realizing a vision for CIS may therefore be to institute a series of juvenile spacing, precommercial thinning and commercial thinning treatments in naturally regenerated stands that have the potential to grow rapidly and realize positive NPVs. Modelling the physical and economic consequences of silvicultural interventions (as done by Howard and Temesgen 1997 or Insley 2002) needs to become common practice in all forest ecozones. In this way, treatments may be targeted towards maximum stand response and improved profitability.

Constrained timber supplies in the coming decades combined with 40- to 80-year rotations may necessitate new policies or incentives from governments to encourage investment in silviculture. Reluctance to make long-term silvicultural investments is a global phenomenon, and leads private investors to pursue plantation projects with the shortest rotation periods (Kanowski 2003). Although SIS rotations as short as 12 years can be achieved in Canada, longer rotations under CIS may require compensating incentives. These could include tax exemptions[6], tree crop insurance or direct subsidies. Incentives might also take the form of payments for environmental services (Kanowski 2003), which in Canada potentially include carbon storage in old-growth forests (harvesting and deforestation foregone), carbon sequestration, watershed protection, and biodiversity conservation.

Sites chosen for intensive management will not always be in the same areas as current processing facilities. The centre of gravity for manufacturing will therefore experience a geographical shift over time. This locational shift may devalue fixed capital and disrupt some timber-dependent communities. Although these communities would have been vulnerable to the synergy of wood shortages, increased energy costs and climate change anyway, mechanisms to deal with social disruption will have to be developed.

An accelerated program of plantation research is needed to address everything from wood production functions to the potential risks of climate change. As part of this program, there is an urgent need to locate and revive the numerous provenance and spacing trials that have been established in the past, but subsequently abandoned. Data on silvicultural interventions in many of these trials exist but have not been analyzed (C. Bowling, personal communication). Young trials could be used for juvenile spacing experiments, while older trials would yield useful information on the effects of commercial thinning.

Final Thoughts

Our forests are now valued for a wider array of attributes than at any time in history. Traditionally valued services, such as recreation, wildlife habitat, and watershed protection are now augmented by an appreciation of the global value of Canadian forests for the conservation of migratory birds and for their role as carbon reservoirs and sinks. Canada's large forest endowment has not, however, prevented the onset of wood supply shortages and long-term declines in wood dimension and quality. The many competing demands on forest resources have raised concerns about the future viability of the forestry sector in many regions of the country, and this is only exacerbated by the emergence of other forestry powers who are currently investing heavily in intensive silvicultural systems.

The weight of evidence presented in this paper demonstrates that plantations can serve a wide variety of ecosystem protection and commercial purposes for multiple beneficiaries. A greater role for intensive silviculture will be essential if Canada is to maintain a competitive position in international markets. A viable program of CIS and SIS, backed by policy, research, and appropriate incentives would go a long way towards solving some of the structural issues and resource conflicts that beset forest management in this country.

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[6] There are worries that tax breaks will create the impression that afforestation is not viable without government assistance, or that they will work mainly in favour of wealthier investors (Griss 2005).

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Appendix I

Assumptions

Estimates for distance travelled are based the assumption that each kilometre of new road accesses about 50 ha of forest. The 50 ha figure is based on a maximum skidding distance of 250 m to either side of the road (J. Michaelsen, FERIC, personal communication. To calculate the additional distance travelled due to road extensions, we broke road segments into 1 km sub-sections, and allocated truck loads of logs travelling these sub-sections according to the following calculations and assumptions:

1. British Columbia creates 8,400 linear km of road yr^{-1} (Robinson *et al.* 1999). The rest of Canada (ROC), by extension, is expected to construct 11 100 km yr^{-1}.
2. Biomass per ha in BC was estimated independently of the rest of Canada because of the very different characteristics and growth rates of forests in this province, and because the length of additional roads is more precisely known. Biomass for (BC) ~ 120 metric tonnes ha^{-1}.
3. For the rest of Canada we calculated a weighted average woody biomass (forest types x proportion of area in each province). Yukon, the Northwest Territories and Nunavut were excluded form these calculations because their timber industry is either non-existent or in the early stages of exploitation. Weighted average biomass for ROC was 78.6 metric tones ha^{-1}.
4. Logging truck capacity and diesel consumption were estimated from Feng (1993) and FORINTEC (2003). Capacity was set at 35 metric tonnes. Minimum and maximum diesel consumption were set at 1.4 and 1.7 litres km^{-1}, respectively.
5. Log utilization was assumed to be about 70% of total biomass.
6. Carbon dioxide (CO_2) intensity was set at 2.73 kg CO_2 l^{-1} diesel (Environment Canada 2001).

Calculations

1. A 35 tonne load implied 93 trips per km of new road in BC, and 61 trips per km in ROC. Each truckload requires the truck to travel into the site empty, returning full. The total distance travelled to collect one load of wood from each km of road is therefore:

   $$D = n \times (n + 1) \qquad [1]$$

   where n = the length of the segment. Thus, a single trip to each km of a 5-km segment would involve $5 \times (5 + 1) = 30$ km of travel. The total distance travelled per segment is equal to the number of loads per km multiplied by D.
2. Diesel consumption and carbon emissions are then obtained by simple multiplication, with the lower values assuming higher fuel efficiency.

The emissions scenarios shown in Fig. 3 are undoubtedly rough estimates of additional carbon emissions by logging trucks. Until more accurate data on road construction become available, however, we believe that our figures provide a reasonable first estimate of the additional emissions incurred during the annual expansion of the forest road network. In fact, our estimates must be conservative, since we made no attempt to calculate the additional emissions due to the transport of heavy equipment, the operation of skidders, and the traffic generated by administrative duties, such as free-to-grow surveys.