Can intensive silviculture contribute to sustainable forest management in northern ecosystems?

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In the midst of changing social, ecological, and technical realities, interest in intensive silviculture has resurfaced. Intensive silviculture could build on previous silvicultural approaches, simply intensifying use of the treatments or treatment combinations identified in this paper to increase timber production, but the costs and benefits for specific treatments or treatment combinations remains unclear. Or intensive silviculture could be based on new thinking, refocusing so that increasing amounts of fibre are produced on dramatically younger, agricultural-like *fibre farms* located in areas that have the longest possible growing season. If fibre farming, using either natural or artificial regeneration, becomes increasingly more important, emphasis will start to be placed as much on equipment and integration of fibre production with manufacturer needs as on previously standard silvicultural treatments. Regardless of the form taken, some reject the suggested advantages of intensive silviculture, recommending instead a *knowledge-intensive integrated approach* or a combination of approaches. Although integrated landscape management is increasingly becoming the foundation for forest management, silvicultural direction remains unclear. Silviculturalists and managers will reap rewards by increasing silvicultural intensity only if their plans are scientifically based and socially acceptable. Before reasonable silvicultural directions can be developed, responsible parties need to frame and agree on the most realistic approaches that address both social and ecological concerns. Calls for increased silvicultural intensity are based on the recognition that *status quo* management could result in increasing fibre imports to satisfy local producer and consumer needs. Still, much of our naturally less productive northern forested land base seems far from ripe for increasing silvicultural intensity dramatically. Even so, those who continue *status quo* forest management *solely* may become increasingly less competitive. In an increasingly interdependent world market-based economy it is unclear whether intensive silviculture in northern ecosystems can be competitive with production in other parts of the world.

Key words: economics, fibre production, forest management, integrated landscape management, intensive silviculture, social concerns, sustainable forest management

L'intérêt pour la sylviculture intensive semble refaire surface alors que les réalités sociales, écologiques et techniques changent. La sylviculture intensive pourrait s'appuyer sur les approches sylviculturales passées en intensifiant simplement l'usage des traitements ou des combinaisons de traitements identifiés dans ce papier pour accroître la production des bois. Cependant, le coût de traitements spécifiques ou de combinaisons de traitements restent incertains. La sylviculture intensive pourrait aussi se baser sur une nouvelle façon de penser, se concentrant sur une augmentation de la production de fibre sur des parcelles beaucoup plus jeunes, dans des fermes à fibre de type agricole, situées dans les régions qui ont les plus longues saisons de croissance. Si la culture de la fibre, utilisant la régénération naturelle ou non, devient de plus en plus importante, l'équipement et l'intégration de la production de fibre avec les besoins des manufacturiers deviendront aussi importants que les traitements agricoles standards. Quelle que soit sa forme, certains rejettent les avantages supposés de la sylviculture intensive, recommandant plutôt une approche de la gestion des ressources naturelles intégrée et basée sur connaissance intensive, ou une combinaison d'approches. Même si l'aménagement intégré du paysage devient progressivement la base de l'aménagement forestier, la direction que prend la sylviculture reste incertaine. Les sylviculteurs et les aménageurs ne récolteront les fruits d'une augmentation d'intensité de la sylviculture seulement si leurs plans sont scientifiquement fondés et socialement acceptables. Avant que des directions de sylvicultures ne soient développées, il faut que les parties responsables s'accordent sur une définition des approches les plus réalistes qui tiennent en compte les problèmes sociaux et écologiques. Les appels à une augmentation de l'intensité sylviculturale sont basés sur la reconnaissance qu'un *status quo* de l'aménagement actuel pourrait résulter dans l'augmentation des importations de fibre pour satisfaire le producteur local et les besoins du consommateur. Par ailleurs, la majeure partie des forêts du nord, moins productives, semblent loin d'être prêtes à une augmentation considérable de l'intensité sylvicultural. Quoiqu'il en soit, ceux qui continuent à pratiquer seulement un *status quo* de l'aménagement forestier deviendront de moins en moins compétitifs. Dans une économie de marché de plus en plus interdépendante à l'échelle mondiale, il n'est pas certain que la sylviculture dans les écosystèmes du nord puisse rester compétitive face à la production dans d'autres parties du monde.

Introduction

In 1999, Canada's Senate subcommittee report on the boreal forest (Taylor 1999) and Ontario's Living Legacy strategy (OMNR 1999a) catapulted intensive silviculture back into forest management prominence in Canada. The Senate report recommended 20% of the boreal forest be man-

aged intensively for timber and fibre production (Taylor 1999). Ontario's Living Legacy and the associated Forest Accord (OMNR 1999b) suggested that intensive silviculture (called *intensive forest management*) be practised in designated zones to maintain existing wood flows and costs for mills, increase the quanti-

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ty and quality of the wood fibre produced, and potentially increase the future supply of fibre from a land base where protected areas are being increased while areas for forestry are being reduced.

Forest Accord commitments to Ontario's forestry industry included that "there would be no net increase in the cost of wood delivered to the mill and there would be no long term reduction in the supply of fibre necessary for processing ... as the result of the establishment of new protected areas" (OMNR 1999b). In addition, all parties agreed to "Develop an Ontario forest science partnership in order to:

- develop and test a range of intensive (silvicultural) practices;
- assess the impacts of intensive (silviculture) on ... forest (fibre production);
- assess the environmental impacts of intensive (silviculture); and
- direct science activities in support of Ontario's forest management planning requirements under the Timber Class Environmental Assessment and Crown Forest Sustainability Act."

Following the signing of the Forest Accord the Ontario Ministry of Natural Resources (OMNR), the Canadian Forest Service (CFS), and Ontario's forest industry began to develop a coordinated response to address these and related commitments. This overview, part of that response, examines: 1) the foundations of intensive silviculture; 2) the increasing demands for wood fibre and associated increases in silvicultural intensity; 3) the role of silviculture within the timber management cycle; 4) costs, benefits, and concerns associated with specific silvicultural treatments; and 5) the sustainability of intensive silviculture. A more detailed analysis is being prepared.

Foundations of silviculture

Major components of modern forestry include policy (sociological and political), management (planning, economic analysis, harvest scheduling, and administration), and silviculture (Smith *et al.* 1997). *Silviculture* (literally tree or forest culture) is the art and science of producing and caring for (tending) stands, forests, and landscapes to meet present and future needs of landowners and society (a synthesis of definitions from Hartig 1795, Baker 1950, CFS 1995, Smith *et al.* 1997, Helms 1998). Although silviculture may be used to produce or maintain individuals or stands of specific tree species, as well as mosaics of successional stages, forest types, and the wildlife habitat associated with each stage (Lautenschlager *et al.* 1995, Smith *et al.* 1997), it is most commonly used to guide natural processes so that merchantable volume is produced more quickly than it would be produced naturally (Smith *et al.* 1997). *Extensive* and *intensive* (called *incremental* in British Columbia – CFS 1995) are the silvicultural extremes, and although Duerr (1960) provided economically based definitions, these extremes are more commonly defined as:

Extensive: Silviculture that relies on natural processes with minimal human input, i.e., low operating and investment costs/unit area (SAF 1983).

Intensive : Silviculture that involves natural and/or artificial processes that contribute to forest development and growth augmented (depending on the degree of intensity) by increasing inputs of labour and capital (intended to increase volume and/or quality/unit area) (SAF 1983). Lautenschlager (1999a) defined intensive silviculture as management that, in addition to maintaining specific tree species or forest cover types,

can increase the volume, value, or both of a variety of future forest components within a sustainable management context.

In practice, silviculture is a continuum from extensive to intensive. The degree and appropriateness of silvicultural intensity along that continuum varies with ownership, management objectives, proximity to mills and/or transport centres, accessibility to management unit(s), markets, and site quality (Smith *et al.* 1997).

Increasing Silvicultural Intensity

Globally, silvicultural intensity has increased slowly over the last 50 years and more rapidly during the last 20 years (Reed *et al.* 1978, Wernick *et al.* 1998). These increases, however, have been greater in some countries or regions and minimal or nonexistent in others. Although there are exceptions based on historical uses and economic need, the degree of silvicultural intensity being practised anywhere is as flavoured by local philosophy and government agenda as by the differences in productivity noted by Sedjo *et al.* (1998).

In northern North America, silvicultural intensity has changed through time, gradually shifting from non-existent 100 years ago to extensive (some protection from insects and wildfires) 70 years ago, to increasingly more intensive 50 to 30 years ago on both industrial and public lands (Widner 1968, Seymour and Hunter 1992, Perry 1998, Taylor 1999). These changes reflect changing conditions: management objectives, remaining untended forest, labour, technology, fibre requirements, and economics.

Historically, in Canada, standard practice involved little or no forest management (Reed *et al.* 1978), although varying degrees of silvicultural intensity have been practised since the early 1900s (Reed *et al.* 1978, Rowe 1992, Taylor 1999, Armson *et al.* 2000). Major regeneration efforts in Canada began only after World War II (Armson *et al.* 2000). The seriousness of those efforts is demonstrated by the associated development of a variety of physiographically based forest site classification systems [see *The Forestry Chronicle* 68(1) – 1992]. That development followed the realization that continued use of natural production in Canada was unlikely to be sustainable and that people would have to help reforest previously forested lands (Corns 1992). Reed *et al.* (1978) presented guidelines for increasing silvicultural intensity in Canada 20 years ago; however, by the early 1990s only 20% of managed Canadian forests were site prepared after harvesting (CCFM 2000), suggesting that roughly 80% continued to be managed extensively.

Classification systems that have been developed and refined were designed in part to help identify where silvicultural treatments could be integrated into the larger natural resource management picture (Carmean 1996). Once fully developed, these systems, in concert with other hierarchical or bio-physical approaches, should serve as the foundation for a variety of land-management decisions. These decisions will include placing all natural resource management, including silvicultural efforts, into context with a variety of other land uses – *integrated landscape management*.

Although Benson (1988) and Oliver (1999) outlined the benefits of extensive silviculture in northern forested ecosystems, silvicultural intensity has gradually increased in these ecosystems during the last 30 years (Seymour and Hunter 1992, Perry

1998). By the 1970s, intensive silvicultural approaches (site preparation, planting, and aerial herbicide conifer release) and programs (*prime site* and *hybrid poplar* management) were well underway or were being developed (genetic improvement). Reed *et al.* (1978) and Armson (1979) outlined incentives for intensive silviculture across Canada and Ontario, respectively. Others, representing most Canadian provinces and territories, also proposed increasing silvicultural intensity soon after this time [see *The Forestry Chronicle* 68(1) – 1992]. Over the last few years, there have been new calls for increasing silvicultural intensity across Canada (McColm 1986; Binkley 1997; Dietz 1997; Kryzanowski 1998; Lautenschlager 1999a; OMNR 1999a,b; Taylor 1999).

Historically, enthusiasm for increasing silvicultural intensity has been cyclic, and critics have been and continue to be sceptical. Oliver (1999), echoing Benson's (1988) arguments, outlined the long-term benefits of integrated forest management. Brown *et al.* (1999) suggested that the constantly changing mix of ecological, economic, and social constraints and opportunities associated with forested ecosystems makes longer-term decisions difficult and silvicultural investments risky. Brown *et al.* (1999) concluded that managerial expertise and manipulations of naturally occurring processes, rather than more intensive cultural inputs, are keys to economically and ecologically realistic forest management decisions. Smith *et al.* (1997) advised that "the most astute silviculture is the kind conducted at low intensity in which much is accomplished with a limited amount of treatment." Lautenschlager (1998a, 1999b) and Messier and Kneeshaw (1999) call for social-ly/ecologically based integrated management.

Boyle (1999) and others have identified general ecological and social benefits associated with intensive silviculture. More specifically, Seymour and McCormack (1989), Binkley (1997), and Sedjo and Botkin (1997) have argued that increasing the amount of intensively managed land will reduce the amount of land where silviculture will be practised and hence save associated ecosystems from potential management-related problems. Wernick *et al.* (1998) examined consumers, millers (producers), and foresters, and the potential of changes or improvements that each of these groups could make (e.g., millers could substitute materials or improve their use of existing materials) to conserve the world's forests. They concluded that changes in forest production (through silviculture) offered the greatest potential for conserving forests and noted (as did Seymour and McCormack 1989, Binkley 1997, and Sedjo 1999) that by growing trees faster, foresters could produce more on dramatically less land. Seymour and McCormack (1989) argued that, depending on the silvicultural options used, one third or less of the forest being used today would be needed to maintain the production of Maine's forest lands. Binkley (1997) argued that only 40% of the land now used for forest fibre production in British Columbia (18% of the province's total productive forest area) would be needed to meet fibre requirements if a system of zoning and intensively managed plantations was implemented.

Although production increases of eight or more times those presently obtained in Canada from intensively versus extensively managed forests have been suggested (Taylor 1999), production potential of intensively managed plantations varies greatly among forest types around the world (Sedjo *et al.* 1998). Because of its relatively short growing season (~ 4 months)

and soil nutrient (particularly nitrogen) limitations (Messier and Kneeshaw 1999), production potential of boreal forests is commonly considered to be limited (Benson 1988, Sedjo *et al.* 1998). Seymour and Hunter (1992), however, asserted that volume extracted from intensively managed stands in boreal spruce-fir forests on 30 to 50 year rotations are expected to be two to five times more (6–10 m³/ha/yr) than those from unmanaged stands. Similar results have been reported by Seymour and McCormack (1989), McCullough (1999), and Wagner *et al.* (1999).

Thus, if successful, increased silvicultural intensity could help avoid potential roundwood shortfalls, while reducing the land area required to produce that fibre. However, management-related gains on the productive but less fertile colder or wetter sites that are scattered throughout most northern forested ecosystems are approximately 30% less than on "better" quality sites (Meng and Seymour 1992, Lautenschlager 1995). Therefore, although increased silvicultural intensity may increase volume production in some places, it is questionable whether total volume production could triple, much less provide the eight-fold increase envisioned by the Canadian Senate (Taylor 1999). Indeed, recent projections, based on modelling in Maine, suggest at most a three-fold increase from applying the most intensive cultural practices to spruce plantations on the best sites (Birdsall and Gadzik 1995).

Silviculture Within the Timber Management Cycle

Silvicultural systems are closely linked to harvesting and regeneration, and the system chosen is one indication of the silvicultural intensity being practised. Harvesting is a major silvicultural tool and harvest-related specifics, including season of harvest, equipment used, residual biomass, residual species composition, basal area, the degree of biomass removed, and site disturbance set the stage for post-harvest regeneration success, post-harvest competition (amount and vigour), and future crop protection requirements. Silvicultural treatments have been divided into 1) methods to favour reproduction (direct regeneration and/or methods that favour establishment), and 2) tending, or intermediate, treatments that take place at other times during the rotation. For both plantations and naturally regenerated stands [gymnosperms (conifers) and angiosperms (hardwoods)] opportunities for intensive silvicultural treatments exist throughout the rotation or timber management cycle (Fig. 1, Table 1). This cycle includes pre-harvest, harvest, establishment, and growth phases; during each phase, forest crop growth increases have been documented following silvicultural treatments (Lautenschlager 1999a). A prerequisite to entering the timber management cycle, however, is to place stand-level treatments into appropriate broader scales. Sustainable forest management (SFM) requires that part of that placement include developing a holistic (hence integrated) landscape-based management plan. That plan must include reforestation and protection designed to address both stand- and landscape-level considerations and objectives and be appropriate for stands within forests, forests within landscapes, and landscapes within their broader contexts (regions, provinces, countries, etc.). [Bordelon *et al.* (2000) present a hierarchical framework for examining a variety of natural resource considerations when addressing stand, basin, district, and regional scales of landscape planning.]

Fig. 1. Timber management cycle(s) including treatments, for even- (solid line) and uneven-aged (dashed line) management.

During the last three decades in North America forest management plans have commonly had an integrated natural resource management focus (Oliver 1999). However, *zoning* as a way to maintain natural resource components and values, although questioned (Sherry and Johnson 1999), is being embraced by many (Seymour and Hunter 1992, Binkley 1997, Taylor 1999). At the fibre production level, management plans must be based on clearly identified objectives and associated outputs (product types), and depending on the objectives, maintaining other, commonly non-fibre forest components or conditions within managed stands, forests, landscapes, or zones.

Perry (1998) outlined the following silvicultural practices that have been used, primarily in association with artificial regeneration, to increase fibre production and growth: "(a) rapid establishment of a new stand following harvest (nursery and planting practices); (b) maximizing the flow of site resources to the crop (controlling competing vegetation); (c) improving soil resources (fertilization, bedding, and drainage on some sites);

(d) selecting and breeding fast-growing genotypes; and (e) minimizing losses due to insects, diseases, fire, and wind (stand protection)." An alternative outline, which I follow [similar to presentations by Walstad *et al.* (1987)], places silvicultural treatments within groups associated with operational timing within the timber management cycle (Fig. 1).

Table 1 outlines opportunities for intensive silvicultural treatments during a rotation or over several cutting cycles. Although interactions among silvicultural treatments are identified (footnotes in Table 1) the *appropriate* steps required to be considered *intensive silviculture* have not. Those steps will vary by forest type, management history, and management objectives, as well as site-specific resources and conditions. Therefore, appropriate steps will differ markedly among management units. Table 2 provides a synthesis of expected costs, growth responses, scientific concerns, and public concerns associated with specific treatments. However, an in-depth understanding of short- and longer-term costs, and biological and social consequences of individual treatments and treatment com-

Table 1. Opportunities for intensive silvicultural treatments and related considerations and activities during a rotation or cutting cycle(s) [plantations and/or naturally regenerated stands – gymnosperm (conifer) or angiosperm (hardwood)].

Pre-Harvest¹

- stand assessment (gene conservation, vertebrates, invertebrates, pathogens, succession, microsites), prescriptions, and marking
- seed collections²
- ground applied (manual, mechanical, herbicide, prescribed fire)
- aerial applied (herbicide)

Harvest³

- thinning, timber stand improvement, or the silvicultural system chosen [clearcut, shelterwood, selection (+ regeneration protection variants), etc.]
- stump treatments (herbicide/fungicide)
- residual (cut and uncut) distribution (clumped or scattered)

Establishment⁴

- site preparation [mechanical, herbicide (ground or aerial), mechanical + herbicide, prescribed fire]
- bedding (mounding) and/or drainage
- seeding or planting⁵ (genetic improvement⁶, stock type and testing, nutrient loading, mycorrhizal-inoculating)
- fertilization⁷
- minimizing losses caused by:
 - competing vegetation⁸ [herbicide (ground or aerial), mechanical, manual, combinations]
 - animals (insects and larger), wildfire, disease
 - environmental vagaries (wind, ice, floods, etc.)

Growth

- spacing and thinning⁸ [pre-commercial, commercial (potentially repeated⁹), timber stand improvement]
- fertilization⁷
- minimizing losses caused by:
 - competing vegetation⁸ [herbicide (ground or aerial), mechanical, manual, prescribed fire, combinations]
 - animals (insects and larger), wildfire, disease
 - environmental vagaries (wind, ice, floods, etc.)
- pruning (where stem quality is a major concern)

¹ Develop a reforestation plan based on desired product outputs through time. Assess potentials, concerns, and sites, and collect seed if appropriate.

² Including production, processing, and minimizing stress (biological, chemical, and physical). Consider certification class, management and accounting, storage, preparation and sowing, quality, pests, watering/nutritional regimes, weeding, seedling handling, pre-storage, storage, transportation, and on-site storage.

³ Harvest using an appropriate silvicultural system and prepare the site to optimize establishment success and growth potential of desirable species and/or individuals, and minimize risks to those from undesirable plants and animals (insects and larger), fire, disease, and environmental vagaries.

⁴ Monitor the establishment (survival 1-3 months, plus 1 and 2 years after planting) through to "free-to-grow," and use that information to adjust site-specific needs to ensure maximum production and refine future reforestation efforts.

⁵ Select the best site for the species being planted and match the seed source to planting macro- and micro-sites, but consider using species that may grow well but have been excluded from sites by competition or historical accident. Ensure a mix of genotypes within a plantation and use genetically superior seed sources where available. Prepare sites to "capture" natural seedfall and/or harvest to protect advance regeneration.

⁶ Realistically restricted to areas that are planted.

⁷ Fertilization has shown benefit on nutrient-poor sites, but in northern forested ecosystems it has commonly provided significant benefit only when combined with competition control. In many instances, competition control alone has provided benefits equal to those of fertilisation plus competition control.

⁸ Competition control [pre-release, release, and pre-commercial thinning (spacing)] may be via herbicides, machines, both, or manual while competition control later in the rotation [commercial thinning (even-aged), selection cutting (uneven-aged), etc.] is commonly a mechanical treatment that provides both biological and economic (increasing merchantable volume on residual stems) value. Control competition to optimize the seedlings' access to warm micro-environments, provide moisture and nutrients, secure establishment, and achieve growth potential and stature in the stand. In northern even-aged managed forested ecosystems, this is critical during the first 5 years after establishment (planting or natural regeneration). In addition, it can provide growth benefit in both even- and uneven-aged managed forested ecosystems throughout their rotations or cutting cycles.

⁹ Now commonly practised in Great Lakes-St. Lawrence tolerant hardwood forests, resulting in stands that are continuously improved.

binations is required before any treatment or treatment combination can be evaluated and the *best* for specific management units and objectives can be identified. [See McKenney (2000) for an analysis of the economics of intensive silviculture.]

Wood Quality Concerns

Increased silvicultural intensity is designed to increase growth rates of selected individuals, shorten rotations, and increase the potential for harvesting (potentially repeatedly) more young trees. Each of these variables could reduce wood quality. In conifers, the juvenile wood, commonly the bulk of production early in the rotation in more intensively managed plantations, has lower specific gravity, shorter tracheids, larger fibril angle, greater longitudinal shrinkage, lower percentage of latewood, more compression wood, thinner cell walls, larger

cell diameter, higher lignin content, and lower cellulose content (Bendtsen 1978). Thus, a greater volume of wood from intensively versus extensively managed stands will be required to produce fibre-based products.

Smith *et al.* (1997) noted, however, that during periods of active increase in size, including height, the specific gravity and strength of the wood laid down tends to increase and that juvenile wood (as opposed to the denser, stronger late-wood) is normally produced only in parts of the boles of trees that are covered with living branches. In addition, they stress that wood age, not growth rate, is responsible for the weaker juvenile wood. Therefore, if following release a conifer grows more rapidly, it creates a greater volume of the kind of wood that would have been laid down without release; it does not shift to production of weak wood (Smith *et al.* 1997). Much of the focus of the

Table 2. Overview¹ of expected costs, growth responses², scientific concerns, and public concerns associated with a single application of a variety of intensive silvicultural treatments. [NA = not applicable, ? = unknown, - = none, * = little (low), ** = moderate, *** = heavy (high), **** = severe (very high)].

Practice	Cost	Growth Response	Scientific Concern	Public Concern
<i>Pre-harvest</i>				
ground applied: manual	****	?	*	*
mechanical	***	?	**	*
herbicide	**	?	-	**
prescribed fire	***	?	*	** to ****
aerially applied: herbicide	*	?	*	****
<i>Harvest</i>				
thinning and/or stand improvement	**	-	**	*
silvicultural systems	-	NA	*	* to ****
stump treatments (herbicide/fungicide)	*	?	*	***
residual distribution	**	?	***	*
<i>Establishment</i>				
site preparation: mechanical	**	*	**3	*
herbicide	*	**	*3	****4
mechanical + herbicide	**	*	**3	***
prescribed fire	*	*	*	** to ****
bedding and/or drainage	** to ****	**	* to ***	- to ****
seeding/planting	**	**5	**	*
stock type and testing	*	*	-	-
genetic improvement	*	**6	*	* to ****
nutrient loading	*	*	-	-
mycorrhizal inoculation	**	*	-	-
fertilization	* to ***	*6	**	*
Minimizing losses caused by:				
1) competing vegetation				
herbicide (ground or aerial)	*	* to ****5	*	****
mechanical	**	*	*	*
manual/motor-manual	****	*	*	*
combinations (ground-based)	****	* to **	**	**
2) animals				
insects	**	**7	***	****4
mammals	**	**7	*	**8
3) wildfire	* to ****	**7	*	**9
4) disease	***	?	***	**
5) environmental vagaries	**10	NA	-	-
<i>Growth</i>				
spacing and thinning				
pre-commercial	*	** to ****	*	*11
commercial (once or repeated)	*	*12	*	*
stand improvement	*	* to ****	*	*
fertilization and minimizing losses ¹³				
pruning	**	**14	*	*

¹A synthesis of views provided by R. A. Lautenschlager, Tom Sullivan, Bob Wagner, John Zasada, and Steve Colombo.

²Short-term responses only; many of these treatments have both short- and long-term consequences.

³Depends on percentage of area treated – full-site treatments (e.g., blading) of great concern; limited treatment (patch scarification) of limited concern.

⁴Less concern if ground applied; greater concern if aerially applied.

⁵May mean the difference between having a gymnosperm (conifer) crop quickly and not having that crop within the next century.

⁶Growth responses often require or are improved by competition control.

⁷May be required to ensure that there is a forest crop to harvest

⁸Variable (* to ****) depending on the problem species and the control method(s) used.

⁹Public concern is associated with NOT controlling fires.

¹⁰Silvicultural treatments may help reduce losses.

¹¹Minimal if mechanical treatments are used. Much greater if herbicides are used.

¹²Increase merchantable volume but total volume/unit area generally decreases.

¹³As suggested under Establishment (above).

¹⁴Reduces one wood quality concern (knots).

juvenile wood/wood quality issue has been the on effects of thinning; however, all of the treatments outlined under *Establishment and Growth* in Table 1 and the often-required combinations of treatments designed to increase fibre production are likely to affect wood quality.

Increased taper associated with planting at wider spacings is another concern associated with increasing silvicultural intensity. Shepard and Shottafer (1990) and Shepard *et al.* (1991) reported that dominant 77-year-old black spruce trees from a natural stand contained nearly twice the merchantable volume

of dominant trees from a 29-year-old stand that had been released with a herbicide application and pre-commercially thinned, even though the average dbh of both was approximately 18 cm. The younger trees simply had much greater taper. Still, early stand management, over time, seems capable of producing volumes like those from untreated areas in 25% less time.

Wood quality also affects interactions between the pulping process and the desired products: "In general, the farther the wood is from the pith, the greater the length, density, strength, cellulose content, and anatomical structural quality of the fibers" (Smith *et al.* 1997). Although used, low-density and knotty woods are not desirable for pulpwood. With its lower specific gravity, short-rotation wood produces lower chemical pulp yields per unit volume (Gladstone *et al.* 1970); however, it is not as undesirable as higher density wood (Haygreen and Bowyer 1989) and may actually be preferable for mechanical pulping (Carpenter 1984).

Pugel *et al.* (1990a,b) found that composites (flakeboard, particleboard, fibreboard) produced from loblolly pine juvenile wood were comparable to composites from mature wood in a number of strength and functional characteristics. However, juvenile wood composites had a higher compaction ratio, and 20% more juvenile wood was required to obtain a panel of equal density. Wood properties change during the juvenile period, and specific gravity is one property of interest to many manufacturers. When grown naturally specific gravity differs among the common northern gymnosperm species, obtaining acceptable levels in 30 years for balsam fir (*Abies balsamea*), 50 years for black (*Picea mariana*) and white spruce (*Picea glauca*), and 60 years for red (*Picea rubra*) spruce (Shepard, personal communication). Thus, if higher specific gravity from shorter-rotation conifers is an objective, managers should consider both the potential for genetic improvements of and appropriate cultural practices for fir, a common native northern species that regenerates naturally and abundantly and grows rapidly across a variety of northern forest ecosystems.

For solid wood, density is probably the most important property affecting the strength of clear lumber, while size and frequency of knots is the most important characteristic controlling the grade for structural lumber (Kellogg and Kennedy 1986). Solid-wood products from intensively managed forests commonly have strength and structural weaknesses, will likely be valued less than those cut from naturally regenerated, untended stands. Thus, solid wood will likely continue to lose market share to composites (Balter and Berg 1999), which are increasingly convincingly covered with either visually appealing paper-thin wood or "wood-like" veneer. Wood quality concerns seem to be less serious with diffuse-porous hardwoods, soft pines, true firs, and spruces, which show little contrast between early and late wood (Smith *et al.* 1997). These species groups, therefore, provide the best opportunities to grow desirable highly homogeneous wood on shorter rotations.

Unresolved Questions

The silvicultural treatments identified in Table 1 could be manipulated at various times during a rotation to adjust species composition and stocking, increase survival, increase merchantable volume, shorten rotations, and increase the quality of fibre coming from managed stands. However, only site preparation, genetic improvements, stock type and testing conifer release with herbicides, and thinning have been inves-

tigated in detail or with rigour. Furthermore, treatments with potential, like fertilization and exotics, are not approved for some northern jurisdictions. Therefore, the following questions remain:

1) Will intensive silvicultural treatments (single, repeated, or combined) increase forest crop growth? If so, at what cost, for what species, and for how long?

2) In what order, or in what combination, should intensive silvicultural treatments be implemented to provide the greatest economic return (i.e., what are the biological and economic consequences of an intensive silviculture version of Liebig's law of the minimum)? How does Liebig's law, which suggests that production is limited by the lowest stage in the barrel (Fig. 2), vary with repeated treatments or combinations?

3) Could the benefit of early and repeated competition control, which has dramatically increased gymnosperm volume production, be achieved by a single strategically timed treatment or by appropriate combinations of earlier treatments (e.g., site preparation immediately after harvest followed by planting with stock that is larger, genetically improved, tested inoculated with mycorrhizae, and/or nutrient-loaded)?

4) How do potential economic advantages vary by plant groups, species, forest types, site types, latitude, and predicted changes in climate and pollution?

Other Concerns

Fibre production and markets

Global wood use has increased over 40% in the past 25 years (McCullough 1999), with production from 11 major industrial wood-producing nations increasing 70% between 1977 and 1995, up 25% in the US and Canada, 58% in New Zealand, and 195% in Chile (Campinhos 1999). With expected continual increases in the global standard of living, wood fibre demand could increase seven fold over the next 50 years (Sutton 1999).

Much of the world's fibre supply now comes from intensively managed plantations in the warmer parts of the world (Sedjo 1999), where timber growth rates commonly exceed 20 m³/ha/yr (Wilson and Arthur 1998). In cooler northern ecosystems, growth rates are commonly less than 5 m³/ha/yr (Wilson and Arthur 1998). In Canada and elsewhere, intensive silviculture has been touted as a way to address the increasing demand for fibre (Taylor 1999), yet forest industry seems to have adapted to the increased demand, to this point, by developing new technologies that use lower-cost fibre, producing *reconstituted* or *composite* wood products.

Over the last 20 years, composites (plywood, panelling, particleboard, chipboard, oriented strandboard, etc.) have rapidly gained an increasing share (30 – 60%) of previously solid wood markets (Wernick *et al.* 1998, Balter and Berg 1999). Therefore, fibre-based products of the future are likely to increasingly differ from those produced two decades ago. Due primarily to price but also to strength and structural characteristics, fibre for most construction uses will increasingly be some form of composite, coming from dramatically younger, lower-valued trees and forests that are common, often naturally occurring throughout the world (Cohen, D., Associate Prof., Forest Products Marketing and Management, Faculty of Forestry, University of British Columbia, Vancouver, BC., personal communication, 1999). Cohen believes that although solid wood will likely continue to have a place in world markets,

Fig. 2. An intensive silviculture version of Liebig's law (which suggests that production is limited by the lowest stave in the barrel) relative to hypothetical biological consequences of individual treatments.

that place will soon be limited to certain niches. If markets increasingly favour low- or lower-cost fibre, an oversupply of previously desirable fibre (timber) may result, reducing prices for what many foresters concentrate on growing today.

Sutton (1999) stated that economic realities will lead to a greater emphasis on agricultural approaches to gymnosperm and/or angiosperm fibre production. Concerned foresters should consider adjusting their silvicultural strategies and inputs (i.e., reconsider treatments and approaches outlined in Table 1) to address this reality. They may also want to start to emphasize economically justifiable agricultural approaches to culturing and harvesting dramatically younger stands for fibre as opposed to producing timber.

Any increased use of an agricultural approach will eventually lead to a greater emphasis on maintaining and/or augmenting site productivity, minimizing biotic and abiotic damaging agents, and securing optimal site occupancy and growth in both space and time. In Oregon, Washington, California and elsewhere around the world (South America, Africa, Australia, New Zealand), hybrid poplar (*Populus* spp.) and eucalyptus (*Eucalyptus* spp.), the most widely planted angiosperm species in the world (Turnbull 1999), provide wood fibre in 5 to 10 years (Boyle 1999). Balter and Berg (1999) state that as North American fibre demands become tighter industry should expect intense competition from offshore producers.

Fibre productivity data concerns

Depending on the markets, which are opportunistic, traditional forest production information may be inappropriate or inadequate. If future markets primarily pay only for inexpensive fibre it will likely come from early successional species managed for maximum production during one or a few decades. However, no information is available about the productivity potential for former non-crop species in northern forest ecosystems. Nor has sufficient information been gathered about species and/or genotypes that can produce quickly and abundantly during short rotations on available, potentially productive northern sites.

In addition, even if more traditional silvicultural approaches continue, retrospective production analysis consistently fails

to document their production potential. Retrospective analysis has not (and cannot) capture the elimination of species that may have been on a site but were out competed (Kotar and Coffman 1982, Newton *et al.* 1992), the growth lost to competition even if the desired species survive (Newton *et al.* 1992), or species (natives or exotics) that could grow well but do not because they have never been actively cultured on those sites. Newton *et al.* (1987) noted that because site index curves are based on breast height-over-age relationships, potential yields of conifers in the northeast and lake states/provinces, particularly those growing on good sites and free of competing vegetation, tend to be greatly underestimated.

In Ontario, forest scientists have been recording the growth of several gymnosperm species on a variety of sites where competition has been controlled annually (Wagner *et al.* 1995). Those studies have demonstrated a two- to six-fold (depending on sites and species) increase in conifer volume growth associated with release from competition alone. However, conifer release is only one of several silvicultural treatments commonly used to increase growth (Table 1). To document maximum growth potential associated with specific treatments, those treatments must be examined in greater detail both on their own and in combination with other treatments (site preparation, bedding, fertilization, genetic improvement, etc.), with different genotypes and species on a variety of sites and latitudes. In addition, research must be conducted to determine the fibre production potential, wood quality, milling possibilities, etc., for non-traditional species such as willow (*Salix* spp.), alder (*Alnus* spp.), aspen (*Populus* spp.), and others (Evers *et al.* 1983) when planted and cultured, on their own or in combinations, across a range of potentially productive northern sites.

Binkley's (1997) statements that the site-index curves in current use consistently understate stand productivity and that in some places the actual site index is 85% higher than the figures used for current timber supply analysis suggest serious problems with existing forest production information. Those statements also suggest that forest managers in British Columbia, and other northern jurisdictions (Fraser and Furnival 1999), have a limited understanding of fibre resource availability as well as the connection between their inventory and productivity. Simply improving and updating the fibre resource inventory might help elevate current forest fibre shortfall fears. Without an accurate, appropriately updated fibre resource inventory directly coupled with growth and production predictions, forest managers at all levels will have difficulty predicting stand, forest, or regional production potential, regardless of the degree of silvicultural intensity employed or planned.

Is Intensive Silviculture Sustainable?

If intensive silviculture is to contribute to human welfare, it must be an ecologically/socially sustainable component within a larger, ecosystem management, context. With the advent of "ecosystem management" (Grumbine 1994, Lautenschlager and Browning 1997), increasing emphasis has been placed on blending ecological (including biological) and social (including economic and cultural – Jakes 1996) realities and values to assure that managed ecosystems meet present and future public needs (WCED 1987; Lautenschlager 1996, 1998a; Messier and Kneeshaw 1999). Chapin *et al.* (1996) stated that "A sus-

tainable ecosystem is one that, over the normal cycle of disturbance events, maintains its characteristic diversity of major functional groups, productivity, and rates of biogeochemical cycling... determined by a set of *interactive controls* that both govern and respond to ecosystem processes." *Sustainability* has been called a quest, a process, a set of ideas and actions in gestation, development and evolution (Boyle 1999); more a philosophy than a definable condition or set of acceptable management practices (Flasche 1997, Lackey 1998). The term sustainable forest management (SFM) has been used loosely (Sims *et al.* 1996), but it is my belief that the foundation for SFM is the integration of specific social and ecological concerns and knowledge to direct management *at that time*.

Certification

Certifying the sustainability of forest management and related production is one approach to quantifying SFM (i.e., integrating social and ecological needs), and will likely be required to document that any intensive silvicultural approach is sustainable. Certification approaches are commonly linked to broad-scale, internationally recognized criteria and indicators of SFM (CCFM 1995, 1997). Companies meeting standards become certified and with one approach their products are identified (*labelled*) in the marketplace. Certification addresses the realities of the global market, reassuring consumers that their purchases come from forests that are managed sustainably. North America presently has four forest certification approaches: International Organization for Standardization (ISO), Sustainable Forestry Initiative (SFI), Forest Stewardship Council (FSC), and the Canadian Standards Association (CSA). All except SFI have third-party review, and only FSC, which is performance- as opposed to systems-based is intended for product labelling (Mater *et al.* 1999). Although ISO and FSC are being examined or have been used to monitor and then certify SFM in some Canadian forests, only the CSA, which was developed by a coalition of 23 forest industry associations from across Canada and the Canadian Standards Association (Lapointe 1998), has a clear Canadian focus.

Until there is broad-based agreement about exactly what constitutes SFM, which I have argued will be tied to local specifics integrated with cultural and ecological concerns across increasingly broader scales (Lautenschlager 1998a), forest management certification may continue to flounder. Even if certification becomes the norm, it remains unclear whether the majority of consumers will pay a premium for certified products (Sedjo *et al.* 1998, Spinazze and Kant 1999). In addition, because certification is primarily a means for foresters and sometimes millers to attempt to satisfy the environmental concerns of consumers, it is unlikely that anything less than a performance-based approach will ever be judged acceptable. Environmentally astute consumers, or groups representing them, will want to know exactly what foresters hoped to accomplish with specific management practices, if that was achieved during the designated management period, and what independent auditor verified the results. In addition, they will also want to know if the goals and objectives were reasonable (if components *they* care about were protected) and therefore will increasingly want to contribute to specific objectives for the next round of management (Lautenschlager 1999b). If intensive silviculture is to be judged to be SFM, and hence

certifiable, it will be because it will be practised as part of a broader scale integrated landscape management approach.

Intensive silviculture and landscape management

Fifty years ago, Aldo Leopold recognized and advocated silvicultural manipulations in enlightened land management. He stated, "A land ethic of course cannot prevent the alteration, management, and use of ... soils, waters, plants, and animals, but it does affirm their right to continued existence, and at least in spots, their continued existence in a natural state" (Leopold 1966). Environmentalists who accept Leopold's view do not advocate managing for natural forests everywhere; rather they believe that management should be directed at ensuring that forests continue to exist everywhere and that some are natural (Lautenschlager 1998b). Implementing intensive silviculture in some places across the landscape could easily be viewed as ecosystem management because having everything everywhere (stand-level, multiple resource management) is not desirable, practical, or possible (Lautenschlager 1999b).

Placing intensive silviculture into an ecosystem management context could involve partitioning the land base into different use types or *zoning* (Hunter 1990, Seymour and Hunter 1992, Binkley 1997, Taylor 1999). In New Zealand, forests are divided into natural or intensively managed plantations. Hunter (1990) and Seymour and Hunter (1992) suggest that forest land should be partitioned into high yield (intensive management), general management (extensive), and special value and protected areas, similar to recent suggestions for Ontario (OMNR 1999a) and Canada (Taylor 1999). Binkley (1997) suggests that zoning in British Columbia should include intensive timber production, integrated use, and protected zones. In 1999 the Canadian Senate suggested that 20% of the boreal forest should be intensively managed, 60% managed less intensively, and 20% be set aside as protected areas (Taylor 1999). Although Sherry and Johnson (1999) suggested that Binkley's strategy has serious flaws from ecological and aboriginal standpoints, others believe that with proper placement, zoned intensive silviculture should be compatible with maintaining all desirable ecological components across the managed landscape (Messier and Kneeshaw 1999). Indeed, Seymour and McCormack (1989) argue that production increases from high-yield silviculture will dramatically decrease the need to manage most of the land base, leaving the bulk of the land available for multiple uses. Experience, however, has shown that when new fibre sources are identified mills use them as additions to, rather than replacements for, established sources.

Although timber and fibre provide significant economic benefits to local and broader scale economies, other values such as ecotourism (Theophile 1995) and non-timber products (Emery 1999), including pharmaceuticals (Mohammed 1999), fur, fish, and wildlife (McKenney and Sarker 1994, Legg 1997), as well as environmental services (*ecological life-support systems* – Costanza *et al.* 1997) both enrich and help maintain related economies and ecosystems. Even excluding the high cost calculated for environmental services (which are *literally irreplaceable* – Costanza *et al.* 1997), other non-timber, or speciality, forest products may provide economic value as great or greater than that available from timber or fibre production (Burton *et al.* 1992).

Mohammed (1999) categorized non-timber products as foods, health and personal care, materials and manufacturing supplies, environmental, landscape and garden, and decorative and aesthetic and suggested that collectively these have high personal and economic value. Emery (1999) simply suggested that speciality forest products have livelihood, cultural, and recreational values. Livelihood values have both non-market and market uses, cultural values include the continued ability to observe special practices and transfer knowledge among generations, and recreational values combine the peace and pleasure of being outdoors with a practical and useful activity.

Consumptive and non-consumptive wildlife use, fishing, and trapping fall into this recreational values category, and their collective contributions to the health and well-being of participants as well as local economies can be large (McKenney and Sarker 1994). For instance economic information for Ontario for the mid-1990s (Legg 1997) indicate that although forest product shipments exceeded \$11 billion/year, wildlife pursuits and recreational fishing contributed \$4 billion/year, while fur harvesting contributed \$16 million. McKenney and Sarker (1994) provide similar figures for the early 1990s; however, they caution that those figures should be weighed against current and future benefits, services, and values. They go on to say that statistics like those provided above do not, as a general rule, help decision-makers, and non-wood services are difficult to define and quantify (McKenney and Sarker 1994). Emery (1999) also noted that livelihood, cultural, and recreational values are qualitatively and quantitatively different from those that are captured by standard macroeconomic calculations. Costanza *et al.* (1997) calculated the value of *natural capital* and ecosystem services provided by the environment, and although their results have been questioned, the values predicted outweigh the value associated with timber, fibre, forest plants, fish, wildlife, and recreational use.

Silvicultural Intensity and Production

Increasing silvicultural intensity has costs and benefits (McKenney 2000). For angiosperms (hardwoods) in southern ecosystems, great benefits have come from short rotations (Turnbull 1999), while in northern ecosystems benefits have come from systematic rigorous pre-harvest assessments, prescriptions, and marking followed by judicious periodic thinnings (Nyland 1996). In tolerant hardwoods, thinnings are commonly designed to improve the quality of intermediate age classes, with benefit increasing with thinning intensity and decreasing with dbh (Nyland 1996). To date, conifer fibre production benefits have consistently come from treatments during the establishment phase. Not surprisingly, techniques with proven operational benefits, site preparation and conifer release, are now standard silvicultural practice across much of Canada's forests and in other northern boreal and boreal mixedwood ecosystems (CCFM 1996, Puettmann and Ek 1999). In conifer plantations, the growth associated with competition control has increased in direct proportion to the degree and duration of control (Lautenschlager 1999a). Across forested landscapes, habitat changes caused by controlling competitive vegetation can also help reduce browsing of forest crops by a variety of mammals (Walstad *et al.* 1987, Black 1992, Newton *et al.* 1992, Lautenschlager and Voigt 2000). In addition, although a single release treatment sometimes provides only a marginal growth

increase, it often ensures that conifers survive (Newton *et al.* 1992) and are maintained within harvested northern landscapes.

In planted northern forests, dramatic conifer growth increases have followed repeated release treatments, and *critical application periods*, generally one to four years after establishment – have been identified (Wagner *et al.* 1999). Impressive growth responses by naturally regenerated northern conifers following release are also common (Newton *et al.* 1992), as are growth increases by both gymnosperm and angiosperm species across North America and throughout the world (Stewart *et al.* 1984, Walstad and Kuch 1987, Wagner and Thompson 1998).

Repeated applications of any silvicultural treatment have repeated costs, and for conifers the early and repeated herbicide treatments have both financial and social consequences. In North America most publics are opposed to herbicide use in general and aerial herbicide use in particular; however, they are much less opposed to mechanical vegetation control treatments, such as those commonly used in site preparation (Wagner *et al.* 1998). Therefore, any form of herbicide application will lead to conflicts with concerned publics, and repeated applications will likely lead to repeated conflicts. However, for many publics the psychological value of land use designations (knowing the location of specific use areas) could reduce some or many of these conflicts. Finally, and importantly, it remains unclear whether post-treatment conifer crop tree volume increases will continue throughout the rotation without additional inputs (Perry 1998).

Conclusions

The successful management of northern forested ecosystems via increased silvicultural intensity will require cooperation among governments, industry, and individuals, leadership, action, social acceptance, and adherence to national and international treaties and agreements. It will require the integration of cultural and ecological knowledge plus communications among interested parties as they collectively identify desirable outputs from a combination of unmanaged, occasionally managed, and more intensively managed forest ecosystems. The foundation for the integrated landscape management that will be required for intensive silviculture to be successful must include a thorough social and ecological analysis, synthesis, and consensus about potential management scenarios. Economically unjustifiable choices, once made, could make it difficult, if not impossible, to obtain true value from forests grown under other less intensive approaches (Oliver 1999), and difficult to justify less intensive approaches with time (Benson 1988).

So, what are the choices? First, intensive silviculture could simply be part of the knowledge-intensive integrated management outlined by Oliver (1999) – more thoughtful multiple use management. Second, and more likely, intensive silviculture could build on existing silvicultural approaches, focussing on testing, understanding, increasing biological efficacy, and minimizing costs of treatments already developed and frequently used. This would require improving our understanding of the value of *standard* treatments, potentially repeated or in combination with others, and the effects of the most promising when applied to a variety of species (potentially genetically improved and fertilized), on a variety of site types where competition was controlled. The two- to six-fold volume increases seen to date following repeated conifer release treatments may be modest relative to what could be achieved with integrated inten-

sive silviculture. Indeed, for some sites the eight-fold increases suggested by the Canadian Senate could be conservative. However, the cost of potential incremental increases remains unclear, as do the effects of specific treatment-related increases on wood quality and damage from animals, disease, and other biotic and abiotic stressors.

Third, the way silviculture is practised in northern ecosystems could change dramatically. New approaches could use new or existing treatments or techniques and integrate field-focussed efforts with knowledge and needs of wood technologists, harvesters, and millers. This could easily lead to focussing on producing low-cost fibre for composite markets and dramatically reducing efforts to culture larger trees. If fibre, as opposed to timber, production becomes the focus, emphasis will increasingly be placed on the equipment used throughout the rotation and less on historical silvicultural treatments and systems. Silvicultural practices under this scenario will likely be much more like agriculture than traditional forestry. (Unfortunately, like the watchmakers who had difficulty adapting to the digital world, traditional silviculturists and related researchers may be reluctant to examine fibre- rather than timber-based approaches to production for the future.)

Fourth, and more realistically, intensive silviculture could involve increased attention to integrated landscape management and include some components of the first three approaches, but with an increasing emphasis on fibre as opposed to timber production. Even if increased silvicultural intensity produces the predicted gains, however, the remaining forest (40–80% of that in use) will continue to require some degree of *management* to maintain the variety of values society expects. Therefore, in addition to identifying and zoning areas for specific uses, foresters should start to reconsider where (sites, forests, regions) the greatest gains from intensive silviculture will likely be achieved and how the economics of intensive silviculture and alternative land uses compare among these areas. For example, in much of the productive forest region of northern Ontario, the average growing season is 170 days; in southeastern Ontario it averages 210 days; and in much of southwestern Ontario, it averages 230 days. Although the choice may seem obvious, focussing intensive silviculture in southwestern Ontario may not be economically viable, due to greater land costs, increased need for vegetation control, and the historic agricultural use of that area. As energy costs increase, advantages associated with producing fibre close to mills or related infrastructure also increase. Therefore, at local and broader scales, the productive ability of potential fibre-producing species on less-than-prime sites, near roads, mills, and transportation centres and markets, as well as production on better sites across latitudes, needs to be thoroughly investigated.

The variety of silvicultural treatments examined in this paper either have been or could be used to increase timber or forest fibre production in northern forested ecosystems. Still, physiological, climatic, and social constraints, as well as previously established higher uses suggest that much of our naturally less productive northern forested land base is far from ripe for economically justifying increasing silvicultural intensity. Even so, those who continue *status quo* forest management *solely* may become less competitive. Calls for increased silvicultural intensity are based on the recognition that *status quo* management could result in the need to increase fibre imports to satisfy pro-

ducers and consumers and that selective increases in intensity in the north could provide economic and ecological benefits (Lautenschlager 1994). Although the bold could reap great rewards by selectively increasing silvicultural intensity, unless their plans are scientifically based and socially acceptable, they could suffer the greatest losses. Before reasonable silvicultural directions and associated integrated landscape management plans can be developed, responsible parties need to agree on the most realistic and favourable (ecologically/socially responsible) approach(es) that are predicted to be economically competitive with production in other parts of the world. Price has been and will continue to be a major factor influencing forest product consumption, and that alone suggests that composites will increasingly dominate forest fibre markets and that SFM certification will only influence consumption if product choices have a similar price.

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