Forest regeneration standards: are they limiting management options for Alberta's boreal mixedwoods?

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ABSTRACT

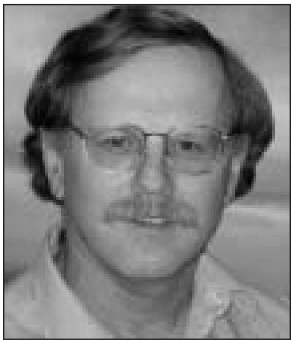
Regeneration standards in Alberta have developed incrementally over the last 40 years to ensure that cutover areas are regenerated with commercially valuable species that will contribute to timber yield. These standards have been controversial for the boreal mixedwood forest, because they do not appear to be producing forests that are similar in composition and structure to those found naturally. In this paper we discuss several components of the standards that are problematic: the issue of landbase designations that force relatively pure stands of spruce onto the landscape early in stand development compared to natural conditions where spruce establishes below deciduous canopies; the need for the free-to-grow standard, which requires removal of a large proportion of the deciduous trees in these mixedwood forests; and the overall philosophy that stands should be managed to maintain relatively simple composition and canopy structures. Regeneration standards need to be better-linked with forest management planning to allow managers to produce stands of a range of composition and structure.

Key words: policy, free-to-grow, competition, forest composition, succession

RÉSUMÉ

Les normes de régénération en Alberta ont été élaborées progressivement au cours des 40 dernières années afin de s'assurer que les superficies récoltées seraient régénérées avec des espèces commerciales recherchées qui contribueront au rendement en matière ligneuse. Ces normes ont fait l'objet de controverses dans le cas de la forêt boréale mélangée parce qu'elles semblent ne pas produire des forêts qui sont semblables en terme de composition et de structure à celles retrouvées en milieu naturel. Nous discutons dans cet article des différentes composantes de ces normes qui posent des problèmes : la question de la désignation du territoire qui insère de force des peuplements relativement purs d'épinette sous le domaine de la forêt résineuse dès le début du développement du peuplement tandis qu'en milieu naturel l'épinette s'établit sous des couverts de feuillus ; l'atteinte de la norme libre de croissance qui nécessite l'extraction de la majeure partie des feuillus retrouvés dans ces forêts mélangées et la philosophie générale qui veut que ces peuplements doivent être aménagés dans le but de maintenir une composition et une structure de couvert relativement simples. Les normes de régénération doivent être mieux reliées à la planification forestière afin de permettre aux aménagistes de produire des peuplements selon différentes compositions et structures.

Mots-clés : politiques, libre de croissance, composition forestière, succession



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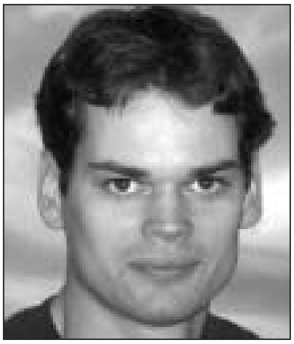

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Introduction

Over the last few decades, ecosystem management (EM) has emerged as a template for managing forests with the intention of retaining the natural species composition, structures, seral stages and ecological processes found in natural forests. These concepts are considered to be important for biodiversity and wildlife management at the landscape level (Burton *et al.* 2006). Most companies and jurisdictions have embraced this concept, as embodied in the Canadian Council of Ministers' criteria and indicators for sustainable forest management (CCFM 2005). Alberta is no exception; forest management plans are required to address CCFM criteria (ASRD 2006). The implementation of ecosystem management may vary, but there are three areas where it should be applied: 1) allocation of land to different intensities of management, frequently in some type of TRIAD approach (areas set aside for intensive management, extensive management and unmanaged reserves, (Messier *et al.* 2003, Burton *et al.* 2006)), 2) spatial harvest sequencing (e.g., ensuring connectivity of old-growth forest), and 3) silvicultural strategies to create stand structures representative of natural forests. This paper primarily addresses this third, silvicultural implementation of ecosystem management and the regulations that affect it, in the Alberta context.

There has been an increase in the level of intensive management on boreal forests (ASRD 2006; Table 1 in Bell *et al.* 2006). Plantation management, including site preparation, planting and vegetation control (herbicide or mechanical), is now considered to be "essential" practice to regenerate white spruce (ASRD 2006). Some of this increase in input levels is consistent with the allocation of land for intensive management to replace fibre lost to the withdrawal of land for other uses (reserves, petroleum industry infrastructure). However, these practices are also essentially mandated by current regeneration standards, which have strict goals for stocking, growth performance, species composition and levels of competing vegetation. These standards exert powerful regulatory control over forest management; the Alberta Timber Management Regulation (Section 142.1 and 142.2, Alberta 1973) authorizes the Minister of Sustainable Resource Development to penalize operators by curtailing their harvest operations if regeneration does not meet the standard.

Regeneration standards require Alberta forest managers to create juvenile stands that have a species composition similar to the previous stand at the time of harvest. Natural variation in regeneration and the successional trajectories of these stands are ignored, frequently resulting in an un-mixing of the mixedwoods. Thus, there is a disconnection between EM criteria and regeneration standards. In setting regeneration standards, we should consider how they affect the structure and composition of the entire managed forest and ask if this meets forest management goals.

Lieffers *et al.* (1996), Bergeron *et al.* (2002) and Comeau *et al.* (2005) identified stand level silvicultural strategies that could be consistent with ecosystem management. These include partial cutting to preserve old-growth structure, partial harvesting with understory protection of shade-tolerant species to mimic succession, or fine-scale density management of deciduous species to enhance conifer presence. At this time, these strategies are largely unused because regeneration standards have limited the options available for a given cutblock. This has largely been related to free-to-grow criteria and requirements restricting the compositional variation allowed in a given cutblock.

The objectives of this paper are to review some critical developments in the history of regeneration standards, discuss features of the standards in terms of their impact on forest management and suggest how regeneration standards could be better linked to forest management planning.

Alberta Boreal Mixedwoods

For this paper, we use Alberta boreal mixedwoods as a case study for discussion of regeneration standards. This forest is naturally a complex mixture of coniferous and deciduous trees; it is also an important source of fibre, and similar forests are found over a wide area of Canada (Rowe 1972). The productive upland forests are found on mesic to subhygric moisture regimes and medium to rich nutrient regimes in the boreal mixedwood and lower foothills natural subregions (ecosites BMd, BMe, LFe, and LFf of Beckingham and Archibald 1996, Beckingham *et al.* 1996) in the boreal mixedwood 18a and 19a sections (Rowe 1972). Early in development, fire-origin boreal mixedwoods are dominated by deciduous species (aspen, balsam poplar and paper birch), with lodgepole pine an occasional part of the overstory mix in the lower foothills. Shade-tolerant species such as white spruce, black spruce and/or balsam fir usually establish under the deciduous trees, and as the spruce attain greater maximum height and live longer than the deciduous species, they eventually dominate the stand (Lieffers *et al.* 1996). Because white spruce is a masting species, a seed source is not always available; as a result the spruce may recruit immediately after disturbance or some years later (Peters *et al.* 2006), depending on the timing of the mast. In rare cases, post-fire deciduous regeneration is sparse and spruce recruit at sufficient densities to develop juvenile spruce-dominated stands (Weir and Johnson 1998). Mixedwood ecosites are therefore capable of growing pure coniferous or deciduous stands, or stands containing intimate mixtures of coniferous and deciduous species. Due to succession, the composition of a stand growing on mixedwood ecosites can change greatly over time. The stochastic nature of white spruce seed dispersal and its slow juvenile growth rate has meant that it is usually regenerated through site preparation and planting after harvest, at considerable cost.

We focus on Alberta mixedwoods, but other provinces have similar forests, and have followed somewhat parallel paths in the development of their regeneration standards (B.C. Ministry of Forests 2000, Saskatchewan Environment 2004, Manitoba Conservation 2003, Pinto *et al.* 2003 [Ontario], New Brunswick Department of Natural Resources 2004). Further, in Alberta there is a long history of conflict between government and industry foresters, and between forestry companies interested in harvesting coniferous versus deciduous wood, over the goals and implementation of these standards.

History of Regeneration Standards

Up to about the first half of the 20^{th} century, Canada was in the exploitive phase of forest management (Kimmins 1991). The most valuable trees were cut first, with little concern for forest regeneration. An example of a consequence of unregulated management is the near elimination of white pine in eastern North America (Appelbaum and McCurdy 1993).

Eventually, timber shortages affected the mills and the communities that depended upon them. Stewards of public lands acted to institute regeneration rules and standards to ensure that economically important species were regenerated to sustain the timber supply.

Up until 1954, reforestation of harvested areas in Alberta was not required. With the implementation of the first forest management agreement in Alberta in 1954, and the implementation of the timber quota system in 1966, rights to harvest timber on public land began to be tied to requirements for reforestation. Since this time, reforestation has increasingly been the responsibility of private forest companies operating on public forest land (Murphy *et al.* 2006).

Over the following decades, increasingly complex regeneration standards were developed through negotiations between Alberta government and industry foresters, supplemented with expert opinion. The focus of the standards has largely been to maintain conifer and, to a lesser degree, deciduous fibre production. Concurrently, forest planners have increasingly addressed non-fibre concerns in their management plans, but at the stand level, this has been difficult as the fundamental goals dictated by the regeneration standards (Fig. 1) are aimed primarily at fibre production with little connection to other values.

The following describes the components of the standards approximately in the chronological order of their development:

Stocking

Stocking surveys focused on ensuring that trees (initially conifers) were growing on cutover areas by some specific time after logging. Early (1971) stocking surveys laid out mil-acre plots (subsequently increased to mil-hectare (10 m^2) plots) on a grid. Stocking was defined as the percentage of plots in which an acceptable tree was tallied. These early standards required acceptable conifer trees to be a minimum age but there were no size requirements. Since 1979, a minimum of 80% stocking of milhectare plots on most stand types is required before a cutover is considered successfully regenerated (AB Energy and Natural Resources 1979).

Defined layout of plots

Since 1979, the survey grid has required a control line with perpendicular survey lines to facilitate quality control. In large cutovers, plots are typically spaced 60 m apart, though the line and plot spacing is allowed to vary somewhat. This grid provided a systematic layout of plots that could be checked for accuracy. The regular network of plots also provided some ability to delineate larger unstocked areas in a cutover.

Landbase designations

Until the development of oriented strand board plants, and later hardwood pulp mills, deciduous trees had little commercial value in Alberta. Regeneration standards evolved in anticipation of this "new" resource in 1979. Lands could be designated as part of either a coniferous or deciduous landbase, with different reforestation requirements. In 1991 a mixedwood landbase was recognized and, by 2000 (AB Environment 2000), conifer (C), conifer–deciduous (CD), deciduous–conifer (DC) and deciduous (D) standards were created. The current management standard (ASRD 2006) recommends these categories be further subdivided by key species (e.g., white spruce-deciduous or pine-deciduous rather than CD). This gradual increase in complexity of landbase designation was an attempt to recognize mixedwoods; however, as we argue below, it does not recognize the expected changes in species composition and stand structure between juvenile and mature stands.

Growth performance criteria

Early regeneration standards only required conifers older than a specific age criterion (two to three years), regardless of size. In the 1980s, a series of surveys was commissioned in juvenile stands that had passed the regeneration standard a decade earlier. These "Regenerated Yield Standards Initiative" surveys indicated a loss of conifer stocking in these stands (AB Regeneration Standards Science Council 2001). Since deciduous trees were growing well in these stands, this mortality was attributed to competition from deciduous trees, and to the fact that very small conifer seedlings were acceptable in the early stocking surveys. In response to these concerns, the 1991 regeneration standards (AB Forest Lands and Wildlife 1992) called for an Establishment Survey to be performed within eight years following harvest, and a Performance Survey conducted in years 8 to 14 for mixedwood and conifer stands. Minimum height requirements were introduced to improve the odds of "acceptable" trees surviving and contributing to fibre yield at rotation.

Free-to-grow standards

The revision of the standards in 1991 introduced free-to-grow (FTG) criteria at the time of the Performance Survey

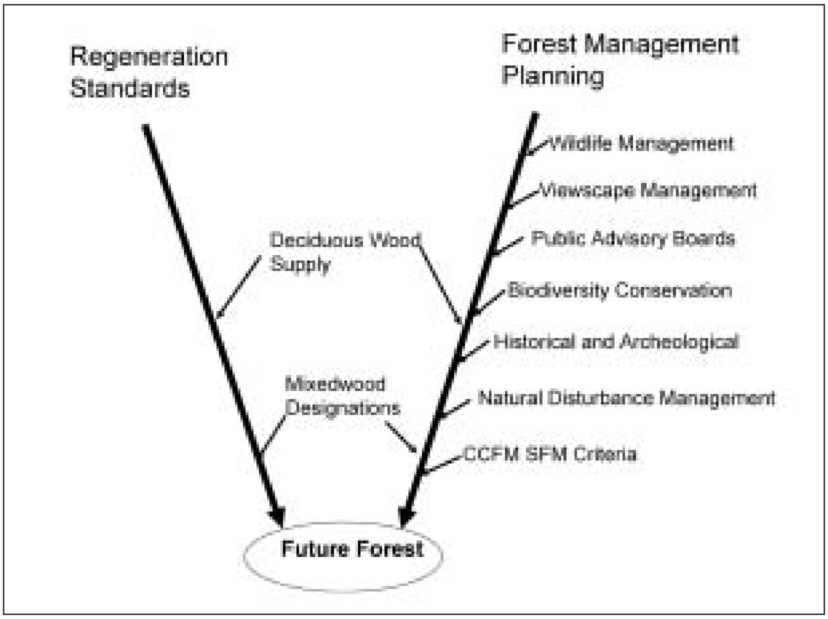

Fig. 1. Factors influencing the development of regeneration standards and forest management planning over the last decades. Note that the regeneration standards have remained focused on wood supply and have had little influence from other values.

(years 8 to 14). The principles of FTG were developed in the 1970s (Brand and Weetman 1986) but the final versions of the standards sprang from concepts that were built into competition indices used in assessing intraspecific competition (reviewed by Lorimer 1983) and then applied to interspecific competition in juvenile conifer plantations (Brand and Weetman 1986). The current principle of FTG (AB Sustainable Resource Development 2003) is that for a conifer tree to be "acceptable", it should be free of overtopping deciduous species within 1.78 m for cutblocks designated as coniferous, or have overtopping deciduous species in only one quadrant of the spruce-centred plot for cutblocks designated as mixedwood. Since the enactment of these FTG standards, there has been a large increase in mechanical brushing and herbicide use in Alberta (CCFM 2006). Aerial spraying of herbicides appears to be the most economical way to meet current FTG requirements.

A One-Size Fits All Strategy for Regeneration Standards

Developers of the current regeneration standards for the boreal mixedwoods have focused on establishment and growth of white spruce, largely because stocking and growth of planted spruce has been difficult to achieve. Unfortunately the methods used to meet the current standard (site preparation, planting, aerial spraying) produce a structurally simple forest. Simple forests fit into traditional principles of forest management, i.e., even flow of timber from a fully regulated forest. Also, simple forests are easier to categorize as "regenerated" than complex forests. Simplified structures and composition may be reasonable and necessary for lands designated for intensive management, but this should not be the only option, especially for land designated for extensive management. There are two policies under the current regeneration standards that enforce this simple forest structure: the fixing of yield strata designations, and free-to-grow standards.

While white spruce are more likely to be found naturally on moister positions on the landscape (Beckingham *et al.* 1996, Bridge and Johnson 2000), the composition of mixedwood forests at maturity on a site of a particular moisture and nutrient class can vary widely. Mature stands may vary from pure conifer to pure deciduous or have various mixtures of deciduous and coniferous trees, as illustrated by the different phases of mixedwood ecosites (BM d and e and LF e and f; Beckingham and Archibald 1996, Beckingham *et al.* 1996). The phases are largely related to the conditions for spruce recruitment, including availability of seed trees, availability of seedbeds, masting and moisture conditions in the years following germination (Peters *et al.* 2006), as well as succession. In contrast, the regulations for assigning stands to a conifer, deciduous or mixedwood landbase are based on interpretation of aerial photographs taken at the last inventory update. There is little recognition of succession in this designation.

Further, it is important to recognize that the photo classification of the yield strata of a mature stand at harvest may be quite different from the classification of the same stand when it was juvenile, since the interpreter has difficulty seeing understory spruce in juvenile stands. Although this is a seemingly obvious technical limitation of a photo inventory of a multi-storied stand, the current regulations force cutblocks to have a similar overstory type at the time of the regeneration survey as the pre-harvest condition. As an example, there is virtually no pure conifer (C) component in the young age classes of forests of management units that have had relatively little management in the past (Fig. 2). White spruce is in the understory of many of the younger stands, but as it was not visible in the aerial photo, its presence was not noted. Succession over the life of a stand results in a gradual shift from deciduous-dominated stands with a conifer understory, to a co-dominant deciduous-conifer stand, to a conifer stand in old age (Lieffers *et al.* 1996, OMNR 2003), a transition that is evident in any primarily natural-origin mixedwood inventory summary (Fig 2). A similar scenario is seen in data from Saskatchewan, where after fire, pure white spruce stands form a starting point for only a small portion of the successional pathways (Weir and Johnson 1998). The manipulation of forest-level composition as a result of the regeneration standards is evident in a management unit (P13) in northwestern Alberta that has had more than 20 years of active management, including spruce planting and tending (Fig. 3). This unit is in a slightly moister region of the province than L1. Nonetheless, there is now a substantial land area with pure

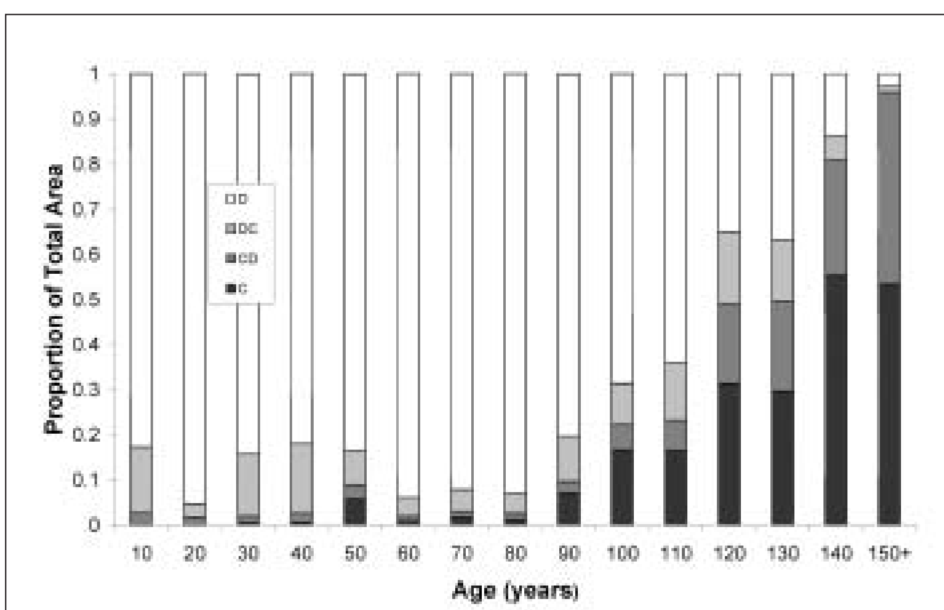

Fig. 2. Proportion of the land area in each age class designated to the four landbases, for the L1 management unit. Categorization of land was based upon aerial photo analysis by the Alberta Vegetation Inventory. Data were selected from stand polygons that had a species composition dominated either by white spruce or aspen. D is > 75% deciduous species, C is > 75% coniferous species. The DC is 75% to 50% deciduous and 25% to 50% conifer and the CD, the inverse. This unit is in the boreal forest NE of Lac La Biche, Alberta and has had little management for conifer.

stands of juvenile spruce compared with the more natural chronosequence seen in Fig. 2. Two other areas with a more than 20 years of conifer management were examined: the Drayton Valley area of Alberta and Fort St. John area of British Columbia have similar forest structures to that depicted in Fig. 3. While current regeneration standards that demand the regeneration of spruce-leading juvenile stands will ensure that spruce is regenerated, this is at odds with the natural structure of the majority of mixedwood forests where the spruce grow under the aspen in the juvenile phase.

It is the FTG standard that primarily leads to the creation of an unnaturally large area of simple single-species stands. One, or often two, herbicide treatments are needed to meet this standard, effectively reducing deciduous species to a minor presence. This is also true for stands designated as mixedwoods, as the most cost-effective way to achieve sufficient FTG spruce in mixedwoods is herbicide treatment of half of a cutblock. This results in cutblocks that are two spatially separate areas, one with aspen dominance and one with pure white spruce, an "un-mixed mixedwood." Mechanical brushing, spot herbicide treatment, strip or pulsed application of herbicides might allow more intimate mixtures to pass FTG (Comeau *et al.* 2005), but costs are generally higher and the timing often difficult.

If treatments are made simply to pass FTG and there are conflicts with broader forest management goals, the FTG standard needs to be critically evaluated. The efficacy of the FTG assessment in terms of predicting spruce growth has recently been called into question; Lieffers *et al.* (2007) demonstrated that white spruce trees that were FTG at year 14 did not grow faster after year 18 compared to trees that were not FTG. While it may be true that well-established white spruce will eventually grow faster when overtopping deciduous trees are removed (Yang 1991), the gain in conifer volume needs to be compared against the loss of deciduous fibre. And, as noted above, the forest-level implications of FTG are significant, through their effect on early structure and successional dynamics (Fig 2 vs. Fig. 3). Broad application of FTG standards are very much a barrier to ecosystem-based management of boreal mixedwoods.

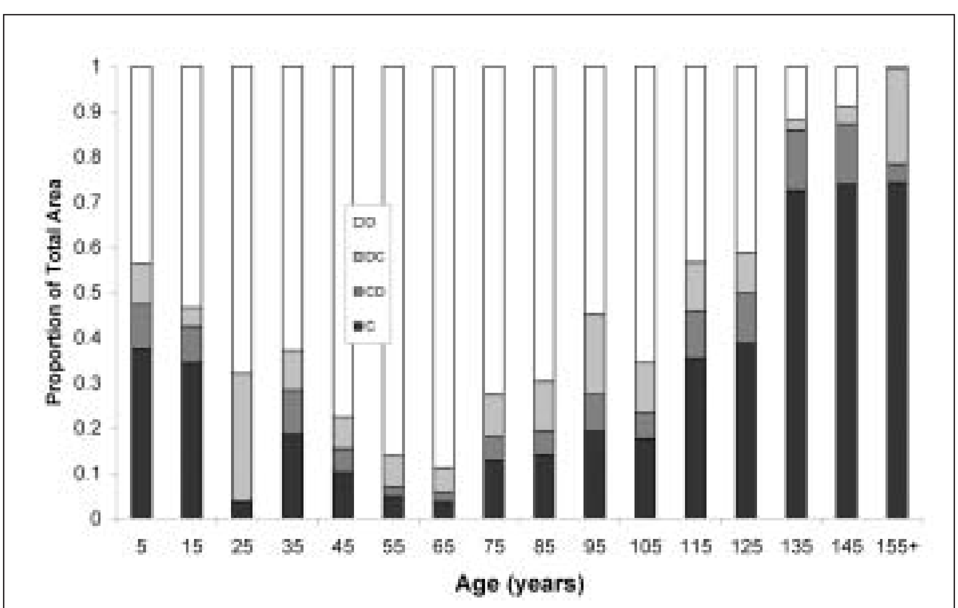

Fig. 3. Proportion of the land area in each age class designated to the four landbases, for the P13 management unit. Categorization of land was based upon aerial photo analysis by the Alberta Vegetation Inventory (see Fig. 2). This unit is in the boreal forest N of Hines Creek, Alberta. There has been active conifer management on this unit for approximately 20 years prior to inventory—note the pure conifer stands established in the early phase of stand development.

Linking Regeneration Standards to Management Objectives

The regeneration standards need to have the flexibility to allow the initiation and development of a variety of stand types with different intensities of management—for example, as under a TRIAD approach to management. The current standards force intensive management on a large part of the landscape—thereby limiting opportunities for stands to follow more natural successional pathways or stands that focus on values other than timber. Some lands should be managed extensively using systems of management that produce the composition and structures found in forests under natural development and disturbances. These forests are necessary to achieve the criteria and indicators of sustainable forest management related to biodiversity and landscape integrity (CCFM 2005). Other lands might be managed with more restricted goals of wood production, producing simple forests of coniferous or deciduous stands. As mixtures of shade-tolerant conifers with intolerant hardwoods may be more productive than single species stands (Kelty 1989, MacPherson *et al.* 2001), however, mixed species stands should not be eliminated as an option for increasing overall yield.

Meeting a specific measure of stocking with reasonably well-performing trees after an establishment period is probably sufficient to classify a managed stand as "regenerated." The juvenile growth rates of the species within the stand could also be used to place a stand on a particular yield stratum (including deciduous and coniferous components), though with recognition that the error in estimation of juvenile site index is large (Feng *et al.* 2006). Intervention to reduce aspen should be undertaken in the context of a company's overall management plan, and with due assessment of its financial value and goals for stand structure, rather than as a regulatory requirement. Further, instead of policies that require wide-scale removal of hardwoods from stands with conifers, there needs to be more careful evaluation of when broadleaf competition has a large impact on growth (Simard *et al.* 2004) so that managers only act when it is a good financial investment or when the additional conifer is required under the forest management plan (e.g., to achieve a desired landscape compositional structure).

Ecosite should be the primary identifier of mixedwood sites in Alberta. These sites offer considerable opportunity to create a range of different stand composition and structure (Lieffers *et al.* 1996, Bergeron *et al.* 2002, Comeau *et al.* 2005) and there should be allowance for a considerable shift in composition from one generation to the next. It must be recognized that in the juvenile phase of these forests there is naturally a significant deciduous component and it usually requires a significant expenditure on vegetation control to change this. In some situations there will be a need to regenerate pure spruce in the juvenile phase to meet timber supply needs or a specific management goal. Managers may wish to identify those lands with higher potential for conifer yield to apply these high-cost treatments. It should, however, be the management plan that is the main vehicle for prescribing the level of conifers regenerated in mixedwood forests. In this way the regeneration surveys will be the tool to monitor success of the forest management planning, instead of being largely independent of management planning as they are now (Fig. 1).

Final Remarks

In 2005, following prolonged discussions and concerns about the current regeneration standards, the provincial government passed the responsibility for further development of regeneration standards to industrial operators with a proposal for *Alternative Regeneration Standards* (ARS) (ASRD 2005). The primary criterion in developing an ARS is that targets and thresholds be linked to the expected yield at rotation age for each yield stratum used in the timber supply analysis. While recent modeling efforts with MGM (Bokalo *et al.* 2007) and GYPSY (Huang *et al.* 2001) have improved estimation of yields in mixed stands, there are significant gaps in data at mid-rotation age and for young white spruce-dominated stands that must be closed before these models can solidly link data from regeneration surveys to future yield. A cost-effective regeneration survey protocol that adequately stratifies and measures the variation in juvenile performance, density and composition across cutblocks also needs to be developed to improve this link. Also, a full analysis of the error in estimation of yield (sampling error, error in estimate of site index and error in model projection) should be done to determine the level of confidence we have in the forest level projections of yield.

The first tentative steps in approval of proposals for ARS have produced standards with a preliminary linkage to yield but the process is constrained to follow the current system for designation of landbase-yield strata; secondly, there is still a focus only on timber yield (ASRD 2005). Following the theme of this paper, we believe that ARS offers managers an opportunity to integrate regeneration monitoring into forest management planning, and consider all values of the future forest. The targets/standards should be flexible enough to allow managers to develop stands of a range of composition and structure that will meet *all* management goals; regeneration standards should not act as a barrier that frustrates the legitimate goals of managers.

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References

Alberta. 1973. Timber management regulation. AR 60/73 s1; 163/85.
Alberta Department of Lands and Forests. 1971. Regeneration survey manual. Alberta Forest Service, Timber Management Branch, Edmonton, AB. 6 p.
Alberta Energy and Natural Resources. 1979. Alberta Forest Regeneration Survey Manual. Alberta Forest Service, Edmonton, AB. 43 p.
Alberta Environment. 2000. Alberta Regeneration Survey manual. Forest Management Division, Edmonton, AB. 77 p.
Alberta Forest Lands and Wildlife. 1992. Alberta Regeneration Survey Manual. Alberta Forest Service, Edmonton, AB. 82 p.
Alberta Regeneration Standards Science Council. 2001. Linking Regeneration Standards to Growth and Yield and Forest Management Objectives. Alberta Regeneration Standards Science Council. Edmonton, AB. 57 p.
Alberta Sustainable Resource Development (ASRD). 2003. Alberta Regeneration Survey Manual. Forest Management Branch, Edmonton, AB. 96 p.
_____. 2005. Alternative Regeneration Standards Interpretive Bulletin. Public Lands and Forests, Forest Management Branch. 28/11/2005. Edmonton, AB.
_____. 2006. Alberta Forest management planning standard. Public Lands and Forests Division, Forest Management Branch. Edmonton, AB. Version 4.1.
Appelbaum, D.K. and M. McCurdy. 1993. Giants in the land. Houghton Mifflin, Boston, MA.
B.C. Ministry of Forests. 2000. Establishment to free growing guidebook. Prince George Forest Region. Rev. ed., Version 2.2. For. Prac. Br., B.C. Min. For., Victoria, B.C. Forest Practices Code of BC Guidebook.
Beckingham, J.D. and J.H. Archibald. 1996. Field guide to the ecosites of northern Alberta. Canadian Forest Service, Northern Forestry Centre, Edmonton, AB Special Report 5.
Beckingham, J.D., I.G.W. Corns and J.H. Archibald. 1996. Field guide to ecosites of west-central Alberta. Edmonton, AB: Canadian Forest Service, Northwest Region, Northern Forestry Centre, Special Report 9.
Bell, F.W., D.G. Pitt and M.C. Wester. 2006. Is intensive management a misnomer? An Ontario-based discussion of terminology and an alternative approach. For. Chron. 82: 662–674.
Bergeron, Y, A. Leduc, B.D. Harvey and S. Gauthier. 2002. Natural fire regime: a guide for sustainable management of the Canadian boreal forest. Silva Fennica 36: 81–95.
Bokalo, M., K.J. Stadt, S.J. Titus and P. Comeau. 2007. Mixedwood Growth Model [online]. Available at http://www.rr.ualberta.ca/research/mgm/mgm.htm
Bridge, S.R.J. and E.A Johnson. 2000. Geomorphic principles of terrain organization and vegetation gradients. J. Veg. Sci. 11: 57–70.
Burton, P.J., C. Messier, W.L. Adamowicz and T. Kuuluvainen. 2006. Sustainable management of Canada's boreal forests: Progress and prospects. Ecoscience 13: 234–248.
Brand, D.G. and G.F. Weetman. 1986. Standards for regeneration establishment in Canada: A case study for Douglas-fir. For. Chron. 62: 84–90.
Canadian Council of Forest Ministers (CCFM). 2005. Criteria and indicators of sustainable forest management in Canada. Available at www.ccfm.org/ci/rprt2005/C&I_e.pdf.
Canadian Council of Forest Ministers (CCFM). 2006. Compendium of Canadian Forestry Statistics [online]. Available at http://nfdp.ccfm.org/compendium/index_e.php [Accessed Nov. 20, 2006].
Comeau, P.G., R. Kabzems, J. McClarnon and J.L.Heineman. 2005. Implications of selected approaches for regenerating and managing western boreal mixedwoods. For. Chron. 81: 559–574.

Feng, Z., K.J. Stadt, V.J. Lieffers S. and Huang. 2006. Estimation of site index of juvenile white spruce stands. For. Chron. 82: 819–824.

Huang, S., D. Morgan, G. Klappstein, J. Heidt, Y. Yang and G. Greidanus. 2001. GYPSY, a growth and yield projection system for natural and regenerated stands within an ecologically based, enhanced forest management framework. Alberta Sustainable Resource Development, Edmonton, AB. Pub No. T/485.

Kelty, M.J. 1989. Productivity of New England hemlock/hardwood stands as affected by species composition and canopy structure. For. Ecol. Manage. 28: 237–257.

Kimmins, J. P. 1991. The future of forest landscapes of Canada. For. Chron. 67: 14–18.

Lieffers, V.J., R.B. Macmillan, D. MacPherson, K. Branter and J.D. Stewart. 1996. Semi-natural and intensive silviculture systems for the boreal mixedwood forest. For. Chron. 72: 286–292.

Lieffers, V.J., K.J. Stadt and Z. Feng. 2007. Free-to-grow regeneration standards are poorly linked to future growth of spruce in boreal mixedwoods. For. Chron. 83: 840–851.

Lorimer, C.G. 1983. Test of age-independent competition indices for individual trees in natural hardwood stands. For. Ecol Manage 6: 343–360.

MacPherson, D, V.J. Lieffers and P.V. Blenis. 2001. Productivity of aspen stands with and without a spruce understory in Alberta's boreal mixedwood forests. For. Chron. 77: 351–356.

Manitoba Conservation. 2003. Regeneration surveys [online]. Available at http://www. gov.mb.ca/conservation/forestry/forest-renewal/techniques/fr4-silvisurvey.html [Accessed 12 August, 2005].

Messier, C., B. Bigue and L. Bernier. 2003. Using fast-growing plantations to promote forest ecosystem protection in Canada. Unasylva 54: 59–63.

Murphy, P., B. Stevenson, S. Ferdinand and D. Quintilio. 2006. The Alberta Forest Service, 1930–2005. Protection and management of Alberta's forests. Alberta Sustainable Resource Development, Government of Alberta, Canada.

New Brunswick Department of Natural Resources. 2004. Forest management manual for New Brunswick crown land: interim manual. Forest Management Branch [online]. Available at http://www.gnb.ca/0078/reports/Interim_Forest_Management_Manual-e.pdf [Accessed 17 November, 2006].

OMNR. 2003. Silvicultural guide to managing spruce, fir, birch and aspen in mixedwoods in Ontario's boreal forest. Version 1.0. Ont. Min. Nat. Resour., Queen's Printer for Ontario. 286 p.

Peters, V.S., S.E. Macdonald and M.R.T. Dale. 2006. Patterns of initial versus delayed regeneration of white spruce in boreal mixedwood succession. Can. J. For. Res. 36: 1597–1609.

Pinto, F., D. Pearce and D. Nesbitt. 2003. Silviculture treatment assessment and reporting system (STARS): background and field manual. Ont Min of Nat Res Nat Res Information Centre, Peterborough, Ontario.

Rowe, J.S. 1972. Forest Regions of Canada. Department of the Environment, Canadian Forestry Service, Pub. No. 1300.

Saskatchewan Environment. 2004. Regeneration assessment [online]. Available at http://www.se.gov.sk.ca/forests/forestmanagement/Regeneration_Assess.pdf [Accessed 17 November, 2006].

Simard, S.W., D.L. Sachs, A. Vyse and L.L. Blevans. 2004. Paper birch competitive effects vary with conifer tree species and stand age in interior British Columbia forests: implications for reforestation policy and practice. For. Ecol. Manage. 198: 55–74.

Weir, J.M.H. and E.A. Johnson. 1998. Effects of escaped settlement fires and logging on forest composition in the mixedwood boreal forest. Can. J. For. Res. 28: 459–467.

Yang, R.C. 1991. Growth of white spruce following release from aspen competition: 35 year results. For. Chron. 67: 706–711.