Are plantations changing the tree species composition of New Brunswick's forest?

by Thom Erdle¹ and Jason Pollard²

Forest plantations are viewed by some as a means to meet the world's escalating demand for wood, and by others as a threat to forest diversity and ecological function. With the purpose of improving planting practices, we analysed recently available data on 15- to 30-year-old plantations on public land in New Brunswick to identify tree species composition differences between plantations and the natural forest they replaced. Presently, 9% of the public forests in the province has been planted; at current planting rates, this will increase to 17% by the year 2030. Plantations established between 1967 and 1982 differ little from the natural forest they replaced in terms of total softwood content, but differ markedly by having much higher jack pine and much lower red spruce contents. There is evidence of reduced diversity evenness in plantations at the landscape level, but at the stand level few plantations are true monocultures and the abundance of high single-species dominance in plantations is very similar to that of the natural forests they replaced. All species composition comparisons between plantations and replaced natural forest vary strongly by ecoregion. To reduce the degree of difference between plantations and the natural forest, planting practices and prescriptions should (a) broaden the mix of species used, and use less jack pine and more red spruce and cedar, (b) employ a mix of species at the stand level, and (c) consider more fully the site conditions and natural species composition of ecological zones.

Key words: plantations, tree species composition, forest simplification, tree species diversity, forest management

Les plantations forestières sont perçues par certaines personnes comme un moyen de répondre à la demande mondiale sans cesse croissante de bois, et par d'autres comme une menace à la diversité forestière et aux fonctions écologiques. Dans le but d'améliorer les pratiques de plantation, nous avons analysé les données disponibles depuis peu sur les plantations de 15 à 30 ans des terres publiques du Nouveau-Brunswick afin d'identifier les différences dans la composition des espèces d'arbres entre les plantations et la forêt naturelle qu'elles ont remplacées. Actuellement, 9 % des forêts publiques de la province a été planté; selon les taux actuels, cette proportion devrait passer à 17 % d'ici l'an 2030. Les plantations réalisées entre 1967 et 1982 diffèrent peu de la forêt naturelle qu'elles ont remplacée en terme de contenu total de résineux, mais diffèrent de façon marquée en ayant un contenu plus important de pin gris et moins d'épinette rouge. On constate de façon évidente une réduction de la régularité de la diversité dans les plantations au niveau du paysage, mais au niveau du peuplement, peu de plantations sont de vraies monocultures et l'abondance de la dominance élevée d'une seule espèce dans les plantations est très semblable à ce qu'on retrouve dans les forêts naturelles qu'elles ont remplacées. Toutes les comparaisons sur la composition des espèces entre les plantations et les forêts naturelles remplacées varient fortement selon l'écocorégion. Pour réduire le niveau de différence entre les plantations et la forêt naturelle, les pratiques et les prescriptions de plantation devraient (a) accroître le mélange des espèces utilisées, et utiliser moins de pin gris et plus d'épinette rouge et de thuya, (b) employer un mélange d'espèces au niveau du peuplement, et (c) étudier plus en détail les conditions de la station et la composition des espèces naturelles des zones écologiques.

Mots-clés : plantations, compositions des espèces d'arbres, simplification forestière, diversité des espèces d'arbres, aménagement forestier

Introduction

Opinions vary about the use of tree plantations as a tool for managing forests. From one perspective, plantations are viewed as an essential part of the intensive forest management deemed necessary to meet the upward spiral in world demand for wood products (Binkley 1997, South 1999, Sedjo 2001). From another perspective, tree plantations are viewed as a potentially serious threat to the biological diversity of forested ecosystems (Forest Stewardship Council 2000, Conservation Council of New Brunswick 2001). Behind this latter view is the notion that the forest is changed, often simplified, when natural forests are harvested and "converted to plantations," resulting in a loss of important elements that contribute to biological diversity. Logical arguments have been made in sup-

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port of both views (Moore and Allen 1999). Many foresters and ecologists recognize both the opportunity and risk posed by plantation forestry and seek ways to capture the production benefits of plantations while avoiding undesirable impacts on the diversity of forests (Seymour and Hunter 1992, Kohm and Franklin 1997, Norton 1998, Moore and Allen 1999).

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Designing plantations that meet the dual but potentially conflicting goals of high wood productivity and biological diversity maintenance requires a good understanding of how plantations affect forest diversity. Of course, the nature of this effect will vary with specific plantation management practices and the forests in which they are employed (Palik and Engstrom 1999). Replacement of native *Nothofagus* spp. forests with exotic *Eucalyptus* spp. plantations in Chile may have very different effects on forest diversity than planting native spruces (*Picea* spp.) and pines (*Pinus* spp.) in the Acadian forest of eastern Canada. Similarly, extensive use of exotic *Pinus radiata* (D. Don) in New Zealand may have very different effects on forest diversity than planting native Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and lodgepole pine (*Pinus contorta* Dougl. ex Loud.) in British Columbia. Given the importance of particulars about practice and context, there seems little utility in general statements about the “goodness” or “badness” of plantations; of more use to forest managers are specifics about alternative plantation practices and how they may affect the forest in which the manager operates.

In an attempt to provide some such specifics to forest managers in the Canadian Maritimes, we examine here the effects of plantations on the tree species composition of Crown (public) forests in New Brunswick. Specifically, our objective is to quantify the impact of past planting practices in terms of (a) current and future coverage of plantations in the forest and (b) tree species composition of plantations relative to that of forests they replaced. Both issues have arisen in public debate about forestry in the region (Betts and Coon 1996, Anonymous 2001, Conservation Council of New Brunswick 2001) and both represent potentially significant impacts of plantations on the forest condition.

We hope to help paint a clear picture of the forest change caused by use of plantations, contribute to a more informed debate about the role of plantations in forest management, and most importantly, aid forest managers in design of plantations which meet the dual goals of wood production and diversity maintenance.

Background

Much of New Brunswick’s forest falls in the Acadian forest region. It is a transitional forest exhibiting traits of both the Boreal and Great Lakes-Saint Lawrence regions (Rowe 1972). The Acadian region includes all the forests of Nova Scotia and Prince Edward Island, and all but the extreme northwest corner of New Brunswick (which is classified in the Great Lakes-Saint Lawrence and Boreal regions). It has a very rich species composition, which likely has triggered much of the concern and criticism about plantation establishment in the region (Betts and Coon 1996). Representative tree species include the eastern spruces (*Picea rubens* Sarg., *P. mariana* (Mill.) BSP, *P. glauca* (Moench) Voss), eastern pines (*Pinus strobus* L., *P. banksiana* Lamb., *P. rubra* Ait.), balsam fir (*Abies balsamea* (L.) Mill.), eastern hemlock (*Tsuga canadensis* (L.) Carriere), eastern cedar (*Thuja occidentalis* L.), red and sugar maple (*Acer rubrum* L., *A. saccharum* Marsh.), yellow and white birch (*Betula alleghaniensis* Britt., *B. papyrifera* Marsh.), beech (*Fagus grandifolia* Ehrh.), and trembling aspen (*Populus tremuloides* Michx.). These species grow in various proportions and associations depending upon local climate, fertility, and disturbance conditions within the region.

Fig. 1. Ecoregions of New Brunswick.

Fig. 2. Relative temperature and moisture regimes of New Brunswick ecoregions (from NB Department of Natural Resources and Energy 1998).

Many of these factors are reflected in the New Brunswick ecological land classification system (NBDNRE 1998) which recognizes seven ecoregions, defined largely in terms of climatic differences in precipitation and temperature (Fig. 1 and 2). These factors partly govern natural species occurrences, and since our interest here is to gauge the effect of plantations on species composition, we employ these ecoregions in the analysis that follows.

The present forest condition has been shaped by a long history of natural and man-caused disturbances. Timber harvesting began over 200 years ago, and today approximately 5 million m³ are harvested per year from the 3 million ha of Crown forest. Natural disturbances vary across the province. They range from stand-replacing disturbance caused by fire, spruce budworm outbreaks, and severe windstorm, to gap-creating events caused by various insects, diseases, and localized wind gusts.

Fifty percent of New Brunswick’s forest is on publicly owned Crown land. Crown forests are managed under evergreen licenses by six large forest products companies under objectives and regulations established by the Provincial Department of Natural Resources and Energy (NBDNRE 2000a). Our

analysis of plantations pertains only to these public forests and results cannot be extrapolated to the other 50% of the land that is privately owned. Private forests are managed under very different regimes for very disparate objectives.

Methods

Concept

We view the effect of plantations on forest diversity as having two dimensions, namely, extent and degree. Extent addresses “how much,” that is, the amount or proportion of the forest that is planted. Degree addresses “how different,” that is, the nature and degree of difference between planted stands and the natural stands they replace. The overall effect of plantations on forest diversity is a combined function of the two dimensions (Fig. 3). A given area planted can have quite different effects depending upon the degree of difference at the stand level (A vs. B in Fig. 3). Similarly, a given stand-level planting regime can have quite different effects depending upon the total area planted (X vs. Y in Fig. 3).

The extent of plantation coverage is readily defined from existing data sources; however, the degree of difference at the stand level is much more difficult to address because it introduces at least three questions: “different compared to what?”; “different in terms of what?”; and “different at what stage of stand development?” Respectively, in recognition of these questions we compare (a) tree species composition (defined by merchantable volume), (b) between plantations and the mature, natural³ stands harvested and replaced by plantations, (c) at stand harvest age. Comparing tree species composition focuses on the overstory which, by way of physical dominance, strongly influences within-stand processes and the distribution and abundance of other taxa (Palik and Engstrom 1999). Comparing plantations to the stands they replaced examines specific differences between conditions removed from the forest and those created. Comparing these conditions at age of harvest recognizes that harvest timing is an important element of plantation strategy, and it reduces the confounding effect of variation among stages of development. Harvest age may differ in plantations and natural stands; it nonetheless represents the terminal state to which stands will be allowed to mature and therefore constitutes a meaningful comparison.

Tree species composition is but one important facet of biological diversity in forests; genetics, structure (Duvall and Grigal 1999), and understory vegetation (Roberts and Zhu 2002) are but a few of the others. By examining only one facet of diversity, our analysis is limited in scope; however, it provides an extensive geographic view which we believe contributes to painting the full picture of plantation effects on biological diversity in eastern forests.

Data Sets

The “how much” aspect of plantations was addressed using two data sources. Present extent of plantation coverage was determined from provincial planting and forest inventory records (NBDNRE 2000b) and future extent was approximated from

Fig. 3. Conceptual representation of plantation impacts on forest diversity. Low impact results when little area is planted (X) or stand-level differences between plantations and natural forest are low (A). High impact results when much area is planted (Y) or stand-level differences between plantations and natural forest are great (B).

the 2002 25-year forest management plans required by law for all Crown forests in the province (personal communication, R. Dick, NBDNRE).

The “how different” aspect of plantations, as we approach it, first requires knowledge of species composition at time of harvest of the natural stands that were subsequently planted, and second, of species composition at time of harvest of plantations that replaced the natural stands. The ideal data sets for this would contain pre-harvest species composition on each planted site and plantation species composition at maturity for those same sites. Unfortunately, this ideal data set is not available for New Brunswick Crown land; forest inventory records do not contain pre-harvest species composition for plantations established prior to 1984, and no plantations have yet reached maturity.

Nonetheless, we believed insight into the effects of plantations on forest diversity could be gained by careful analysis of three data sets that are available. First is a set of 423 temporary sample plots (each comprising 5 to 10 prism points) established in 1998 in 15- to 30 year old plantations (created between 1967 and 1982). The sampling provided stand tables that characterize 77 000 ha of the oldest operational-scale plantations on Crown land. To estimate plantation species composition at maturity, stand table projections were made to age 60 using the STAMAN growth model (Erdle and MacLean 1999).

The second data set contained a summary of pre-harvest natural stand types for 41 000 ha of plantations established in the period 1984–1990. These data were derived by digitally clipping plantation areas out of the mapped forest inventory that represented the forest before harvest. The data show how much area of each natural stand type was harvested and planted. This time period was used because pre-harvest stand conditions were first available with creation of the digital forest inventory in 1984, and because after 1990 the mix of stand types harvested and available for planting changed as a result of increased industrial hardwood demand. The key assumption here is that the general distribution of stand types cut and planted between 1984 and 1990 (characterized in the mapping) is representative of the general distribution of stand types cut and planted

³Although little of New Brunswick’s forest is truly natural (*i.e.* entirely escaping the influence of man), we use the term “natural” here in reference to stands which originated before 1940. These represent the mature existing condition in which harvest and planting decisions must be made. Unless otherwise noted, the term natural stand will refer to the pre-harvest state of areas that are now plantations.

between 1967 and 1982 (characterized in the plantation ground samples). Foresters whose careers spanned these years have indicated this to be a reasonable assumption (personal communication, T. Spinney, NBDNRE).

The third data set contained detailed mensurational information for 7194 temporary sample plots. These plots are part of the New Brunswick Forest Development Survey database and were used to characterize species composition of pre-harvest natural stand types.

Process

Using these three data sets, estimates of pre-harvest species composition in natural stands and plantation species composition at maturity were derived on an ecoregion basis as follows:

- distributions of plantation area by pre-harvest natural stand type were constructed (using data set 2);
- these distributions were related to natural stand inventory plots (data set 3) and area-weighted species composition calculated for each pre-harvest natural stand type;
- plantation species composition was forecasted (using data set 1) to age 60 and area weighted species composition calculated for the plantation area.

The result is a data set with which forecasted plantation species composition can be compared to pre-harvest species composition in the 77 000 ha of natural forest cut and planted in the period 1967–1982. These data and process allow an approximate comparison only and the results are not amenable to rigorous statistical testing. However, we believe they paint a useful and informative picture about overall trends and patterns of plantation impacts on species composition which can provide guidance in evaluation and design of plantation practices.

Results

“How Much?” – The Extent of Plantations

The planting program on Crown land in New Brunswick began in the early 1960s (NBDNRE 2000b). It escalated rapidly in the late 1970s with a nation-wide concern about reforestation in Canada (which prompted the 1977 National Forest Regeneration Conference), fell off with an increased emphasis on natural regeneration in the late 1980s, and has increased over the last few years as part of an expanded silviculture effort in the province (with more extensive use of fill-planting) aimed at increasing long-term wood supply. The current forest management plans for Crown land propose planting levels of 10 000 ha/year into the near future (Fig. 4).

Plantations on Crown land today cover land approximately 257 000 ha, which represents 9% of the productive forest and 19% of the softwood-dominated forest. At forecasted planting rates of 10 000 ha/yr, the total area in plantations will increase by the year 2030 to 490 000 ha, representing 17% of the productive forest and 36% of the softwood dominated forest (Fig. 5).

These percentages do not suggest a wholesale conversion of the forest to plantations, as even by the year 2030 only one forested hectare in six will support a plantation, assuming continuation of current planting levels. However, plantations do and will occupy a significant portion of the landbase; the proportions are sufficiently high to warrant closer inspection of the nature and degree of differences between plantations and the natural forest they replace.

Fig. 4. Area planted per year on Crown land in New Brunswick (from NB Department of Natural Resources and Energy 2000a).

Fig. 5. Area planted as a percent of productive and softwood-dominated forest on Crown land in New Brunswick.

“How Different?” – Species Composition Across Plantations

Species composition control is an obvious production advantage of plantations, and one compelling reason for their use. But this same control has the potential to modify forest composition in ways that may be undesirable with respect to diversity maintenance. Such modification may simply be change in relative species abundances, or change in abundance resulting in simplification. We examined both possibilities.

In very coarse terms, plantations can be compared to natural forest on the basis of softwood content. Overall, softwood volume content increased from 80% in natural stands to 90% in the plantations that replaced them (Fig. 6). The greatest shift occurred in ecoregions with the highest natural hardwood content, namely the Northern Uplands, Southern Uplands, and Continental Lowlands. In the Highlands and Eastern Lowlands, where softwood content is naturally high, plantations show only marginal softwood increases relative to the stands they replaced. There is little to suggest that plantations are causing a wholesale conversion of the New Brunswick forest to softwood, but this is only viewing species composition in very coarse terms.

Imprecision inherent in the data sets and methodology precludes inference of subtle changes; however, some noteworthy trends are apparent when composition is examined with finer

Fig. 6. Softwood content (% volume) in plantations and the natural forest they replaced.

species resolution. One of the most striking is the upward shift in abundance of jack pine, which, at the provincial level, is three times more abundant in plantations than in the replaced natural forest (Fig. 7a). This increase occurs partly in the Highlands, Northern Uplands, and Eastern Lowlands, where jack pine naturally makes up between 2 and 15% of the volume. The balance of the increase occurs in the Continental Lowlands and Southern Uplands, where jack pine is virtually non-existent in the natural forest.

The unnaturally high jack pine content resulted partly from attempts to create a “budworm-resistant” new forest by extensive planting of jack pine in the 1970s and early 1980s when New Brunswick was in the midst of a severe spruce budworm outbreak (Clowater and Andrews 1981). Most forest managers today would challenge the ecological wisdom of planting jack pine in such large proportions where it does not naturally occur; however, if one lived through the budworm control controversy of the 1970s, it is not difficult to understand the attempt at that time to reduce budworm-vulnerable forest area by planting non-susceptible species.

A second salient trend is the decline in red spruce, which, across all ecoregions, comprises 1% of plantation volume in contrast to the 14% it made up in natural forest replaced by plantations (Fig. 7a). This decline is not ubiquitous; in the Northern Uplands, the scarcity of red spruce in plantations differs little from the natural condition of low red spruce abundance (Fig. 7c). Elsewhere, however, red spruce occurs naturally in significant proportions (Continental Lowlands 28%, Southern Uplands 25%, and Eastern Lowlands 13%), but makes up less than 5% of plantation volume (Fig. 7d–f). The dearth of red spruce in plantations is attributable both to its poor establishment and survival as natural regeneration in open conditions created by clearcutting (Seymour 1992) and to its almost complete exclusion from the planting mix employed in the province in the 1970s and 1980s (Craig Frame, NBDNRE, unpublished data).

Similarly, eastern cedar appears in only trace amounts in plantations of all ecoregions (Fig. 7), although its decline is less pronounced given its status as a relatively minor, albeit locally abundant, overall component in the natural forest (between 2% and 8%, depending upon ecoregion). Like red spruce, cedar was not planted in the period studied and can fare poorly against other species in open, post-clearcut conditions (Zelazny and Veen 1997).

Across all ecoregions, black spruce content differs little between plantations and the natural forest they replace (Fig. 7); however, no net change at the provincial level masks significant shifts within ecoregions. A halving of black spruce abundance in the Eastern Lowlands (Fig. 7d) is offset by a doubling of black spruce in the Northern Uplands and Continental Lowlands (Fig. 7c and 7e).

Despite the fact that it is not planted, balsam fir appears as a significant component of plantations in all ecoregions (Fig. 7). In the Highlands and Northern Uplands, the fir content in plantations remains very near the 40% it constitutes in the replaced natural forest. In the other three ecoregions, the fir content in plantations is somewhat higher than in the natural forest. This is likely due to the combined effect of prolific fir regeneration and persistence as advance regeneration in plantations, and relatively low fir content in natural stands as a result of severe losses sustained in the 1970s budworm outbreak (Clowater and Andrews 1981).

The 20% hardwood content of pre-harvest stands reveals that, for the period of study, planting was targeted largely to softwood-dominated stands. The hardwood content drops to 10% in plantations, with over half the reduction occurring in the tolerant hardwood species (sugar maple, yellow birch, and beech) and most of the balance in red maple (Fig. 7). There is relatively little change in white birch and aspen content. These hardwood reductions may be explained by competition control measures; approximately two-thirds of the 1969–1982 plantations were treated with herbicides (NBDNRE 2000b). As might be expected, the largest downward shift in hardwood content occurs in ecoregions where hardwoods are naturally more abundant, namely the Northern Uplands, Southern Uplands, and Continental Lowlands (Fig. 7c–e–f).

Fig. 7 reveals that plantations have changed species composition from that of the replaced natural forest—large change in some ecoregions, little change in others—but it does not clearly reveal if such change is simplifying the forest. We view simplification as an increased concentration of volume in fewer species. Volume concentration can be illustrated by plotting the cumulative frequency distribution of species ranked by abundance (Fig. 8). The steeper the slope of that distribution near the origin, the greater the concentration of volume in few species; the flatter the slope, the more even the composition (a straight line would result from all species being equally abundant).

By this measure, planting has simplified tree species composition; the cumulative frequency distributions of plantations are steeper near the origin than those of the replaced natural forest (Fig. 8). Simplification appears greatest at the provincial level because this scale includes the natural variation of all ecoregions; the three predominant tree species comprise 80% of the total volume in 1969–1982 plantations, but only 60% of the volume in the natural forest they replaced (Fig. 8a).

At the ecoregion level, simplification of plantations relative to natural forest is apparent, but much less pronounced. In the Highlands, for example, two species make up two-thirds of the total volume in both plantations and the replaced natural forest (Fig. 8b). In fact, the general case is that the natural forest replaced by plantations was dominated by few species prior to harvest; the four most abundant species in each ecoregion make up at least 65% of the total species volume in the replaced natural forest, and as much as 80% in the Highlands and South-

Fig. 7. Species composition (% merchantable volume) in 1967–1982 plantations and the natural forest replaced by plantations (bf=balsam fir; bs=black spruce; ws=white spruce; rs=red spruce; wp=white & red pine; jP=jack pine; eC=cedar; oSW=larch & hemlock; wB=white birch; tA=trembling aspen; rM=red maple; TH=sugar maple, beech & yellow birch).

ern Uplands. Planting has accentuated this concentration, as the four dominant species make up at least 80% of the plantation volume in each eco-region (Fig. 8).

“How Different?” – Species Composition Within Plantations

It is not uncommon to hear of plantations referred to as unnatural monocultures, devoid of the variety common in the natural forest (Conservation Council of New Brunswick

2001). This concern relates to species simplification at the stand scale and suggests, first, that plantations are monocultures, and second, that monocultures are not found in the natural forest.

We examined both matters by comparing species dominance within plantations to that within the natural stands they replaced. Our simple measure of dominance was the proportion of stand volume made up by the most dominant tree species in each sampled stand. A pure monoculture would have

Fig. 8. Cumulative frequency distribution of species sorted by abundance in 1967–1982 plantations and the natural forest replaced by plantations.

100% of its volume in the most dominant species; the lower that percentage, the less the stand is dominated by a single species, and the less it is like a monoculture. This is a stand-level measure and with it can be constructed an area distribution by percent volume in the dominant species. This provides a forest-wide picture of stand-level species composition.

Not surprisingly, given the past practice of planting single species per site, these area distributions clearly reveal a tendency towards single-species dominance in plantations (Fig. 9). However, for two reasons, it is erroneous to generally label New

Brunswick plantations as unnatural monocultures. First, pure monocultures in plantations are the exception. Less than 10% of the surveyed plantations across all ecoregions has more than 90% of the volume contributed by one species; less than 25% has more than 80% of the volume contributed by one species (Fig. 9). Second, monocultures existed in the natural forest that was harvested and planted, and in roughly the same proportion as they do in plantations. Cases of extreme single-species dominance (>90% in one species) are found in the same abundance in the natural forest as they are in plantations that

Fig. 9. Percent area distribution of 1967–1982 plantations and the replaced natural forest by % stand volume in the dominant species. Pure monocultures would appear in the 90-100 category on the x-axis.

replaced it (Fig. 9a). Even cases of less extreme dominance (>70% in a single species) are of similar abundance in plantations (35%) and the replaced natural forest (29%).

This similarity in single-species dominance between plantations and natural stands is strongest in the Highlands and Eastern Lowlands, areas that have the least natural within-stand variability (Fig. 9b and 9d). The differences between plantations and the natural forest are more pronounced in the Northern Uplands (Fig. 9c) and most pronounced in the Southern Uplands and Continental Lowlands, which are ecoregions with the most natural species variability (Fig. 9e and 9f).

A greater difference between plantations and natural stands is in the abundance of area with low single-species dominance. Plantations clearly do not provide the highly mixed compositions found in some of the replaced natural stands, as evidenced by the distinct differences in percent area where the dominant species comprises 4% or less of stand volume. Such cases exist in 22% of natural stands and only 10% of plantations (Fig. 9).

Discussion

We acknowledge some methodological shortcomings in our approach to assessing the effect of plantations on

forest diversity. First, we have examined only tree species composition, which is just one of many characteristics that must be examined to obtain a comprehensive picture of plantation effects on forest diversity. Second, we used merchantable volume as the measure of abundance, which could underestimate the presence of species that occupy smaller diameter classes; however, such error should be tempered given that our comparison was a relative one between plantations and replaced natural forest. Third, by using stand table projection to forecast future plantation composition, trees less than 1.3m in height at time of sampling in 1998 will not influence estimated species composition at stand maturity. This potential source of error we deem quite small given that all plantations were 15 to 30 years old at time of sampling. Any net error in our approach would likely be an underestimate of the abundance of slow-growing, shade-tolerant species in plantations.

Despite these methodological concerns, we believe a number of findings from our analysis are clear, strong, and noteworthy. Salient ones can be summarized as follows:

- [1] Today, plantations comprise 9% of New Brunswick's productive Crown forest and this is forecast to increase to 17% by 2030.
- [2] Plantation species composition differs most strikingly from replaced natural forest by increased jack pine and reduced red spruce content.
- [3] Overall hardwood content in plantations is approximately 10% by volume, down from 20% in the natural forest. Most of the reduction is in tolerant hardwoods.
- [4] Approximately the same volume proportion made up by the four most abundant species in the natural forest is made up by two to three species in plantations, which suggests reduced diversity evenness at the landscape level.
- [5] Few plantations are true monocultures and the abundance of high single-species dominance in plantations is very similar to that of the natural stands they replaced.
- [6] Plantations have a much lower abundance of highly mixed species composition than natural stands they replaced.
- [7] All species composition comparisons between plantations and replaced natural stands varied strongly by ecoregion. Species composition differences were least in the ecoregions with least natural species variation and most in those with most natural variation.

We believe these findings provide important guidance with respect to improving forest management in New Brunswick. In our view, the findings do not validate the view that plantations (as established on Crown land) create a completely alien forest condition. They do not support some of the arguments against use of plantations in forest management and they do not suggest that the New Brunswick planting program, implemented as a means of meeting society's wood demands, is necessarily inimical to forest diversity.

However, by exposing species composition characteristics that vary most between plantations and natural forest, the findings do highlight opportunities to modify practices to reduce potential negative ecological consequences of plantations. If one adopts the increasingly popular approach that minimizing departure from natural conditions is a wise approach to safeguarding diversity and integrity of forests (Patch 1997), then reducing the differences between plantations and the natural forest they replace should become a management objective.

Some opportunities for reducing such differences are clearly evident from our analysis; the most obvious are to carry out the following:

- [1] Significantly reduce the amount of jack pine planted to keep it closer to its natural proportions and plant no jack pine in the Continental Lowlands and Southern Uplands.
- [2] Secure much more abundant regeneration of red spruce, by modifying harvesting to foster natural regeneration, by increasing red spruce in the planting mix, or both.
- [3] Broaden the mix of planted species at the forest level, and include more minor species like eastern cedar.
- [4] Broaden the mix of planted species at the stand level, by salting stock trays with other species.
- [5] Consider more fully the biogeophysical site conditions in selection of planting sites, design of plantation tactics, and choice of species (noting especially the natural presence and abundance of species in the ecological zones for which planting decisions are being made).
- [6] Better target and concentrate plantation establishment into ecological zones that are naturally most similar to plantations (e.g., Eastern Lowlands). Favour alternate harvesting and silviculture practices in those zones that are naturally least similar (e.g., Continental Lowlands). In fact, should New Brunswick consider triad or other forms of forest zoning (Seymour and Hunter 1992), this criterion could partially form the basis for defining intensive and extensive management zones.

It is encouraging that some changes in these respects are already underway. For example, the proportion of jack pine in the Crown land planting program has decreased significantly, from almost 50% twenty years ago to less than 15% today. Over the same time frame the proportion of other species planted (including red spruce, white pine, and cedar) has increased markedly, from 2% to 16%. Further, some companies routinely salt plantations with red spruce, eastern cedar, or white pine (personal communication, G. Adams, JD Irving), which results in greater within-stand species diversity.

Even with progress in implementing the above recommendations, challenges to improving plantation practices remain. Prominent among them is the matter of structural retention within planted stands. Variability in horizontal and vertical structure is believed to have an important ecological function (Kohm and Franklin 1997, Hunter 1999), which may be compromised with structural simplification as can occur in plantations (e.g., Duvall and Grigal 1999). Unpublished analysis of the data used here clearly reveal plantations to have much simpler tree size structures than the natural stands they replace, but plantation practices on New Brunswick Crown land are generally not designed to retain within-stand structural variation. An effort to develop well-founded structural retention objectives seems a logical next step to improving plantation practices.

Society expects much from its forest, including high production of wood and maintenance of diversity and ecological function. Continued refinement of plantation practices, based on careful and thorough consideration of the character of the natural forest, holds promise as an effective and prudent way to employ plantations in management strategies to meet society's dual goals of commodity production and environmental protection.

Acknowledgements

We would like to thank Craig Frame, Tom Spinney, John Upshall, Bob Dick, Hilary Veen, and Vince Zelazny of the New Brunswick Department of Natural Resources and Energy for providing data and information used in this study. We would also like to thank Jamie Simpson of the New Brunswick Nature Trust and two anonymous reviewers for providing helpful suggestions on the manuscript.

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