Triad forest management: Scenario analysis of forest zoning effects on timber and non-timber values in New Brunswick, Canada

by Michael K. Montigny¹ and David A. MacLean²

ABSTRACT

Triad forest management is a form of zoning under which land is allocated into extensively managed, intensively managed, and reserve zones, with management tailored in each zone such that all objectives are met collectively across the landbase. We evaluated the utility of triad management on the privately-owned, industrial, 190 000-ha Black Brook District in New Brunswick, Canada. Scenario planning was used to simulate effects of 64 allocation scenarios (0–15% reserve area, 39–64% intensively managed softwood, and 21–61% extensively managed) on forest species composition, age class distribution, timber growing stock, harvest levels, and old forest habitat. Softwood harvest in the short term (30 years) was insensitive to reserve and intensive management allocations but doubled in the long term as the intensive management zone was increased from 39% to 64%. Hardwood harvest was sensitive only to area in reserves, declining as the area allocated to reserves was increased. Abundance of old forest generally increased with the amount of reserve area, but varied by species composition. Management of this landbase is focused on timber production, and intensive management clearly provided major increases in timber yield. It also could permit setting aside additional reserve area; old mixed-wood habitat in particular is in short supply. These were hypothetical scenarios, and the landowner is not necessarily pursuing any of modeled strategies. Although the range of desired values may differ on other landbases, a scenario analysis of alternative zoning is an effective means to select a management strategy.

Key words: scenario planning, intensive forest management, reserves, extensive forest management, triad, land allocation, forest zoning

RÉSUMÉ

L'aménagement forestier en triade est une forme de zonage selon laquelle le territoire est divisé en zone sous aménagement extensif, aménagement intensif et zone de réserve, pour lesquelles l'aménagement est fait sur mesure pour chaque zone de telle sorte que tous les objectifs sont atteints collectivement sur l'ensemble du territoire. Nous avons évalué l'utilité de l'aménagement en triade sur 190 000 ha de forêt privée industrielle du district de Black Brook au Nouveau-Brunswick, Canada. Une simulation de planification a été utilisée afin de simuler les effets de 64 scénarios d'allocation (0 à 15 % de réserve, 39 à 64 % de résineux aménagés intensivement et 21 à 61 % d'aménagement extensif) sur la composition en espèces forestières, la distribution des classes d'âge, le volume de bois en croissance, les niveaux de récolte et l'habitat sous les vieilles forêts. La récolte de résineux à court terme (30 ans) était sans effet sur les allocations de réserve et d'aménagement intensif, mais a doublé à long terme suite à l'accroissement de la zone sous aménagement intensif passant de 39 à 64 %. La récolte de feuillus a été affectée seulement par la superficie dans les réserves et a décliné selon l'augmentation du territoire sous réserve. L'abondance des vieilles forêts s'est généralement accrue selon la superficie sous réserve, mais a varié en fonction de la composition en espèces. L'aménagement de ce territoire est centré sur la production de bois et l'aménagement intensif a permis clairement des accroissements marqués du rendement en matière ligneuse. Cela a également permis de mettre de côté d'autres territoires sous réserve, en particulier l'habitat de vieilles forêts mélangées étant sous représenté. Il s'agissait seulement de scénarios hypothétiques et le propriétaire ne suit pas nécessairement l'une des stratégies élaborées. Même si l'ensemble des valeurs désirées peut différer sur d'autres territoires, une analyse de scénario de zonage alternatif constitue un moyen efficace de choisir une stratégie d'aménagement.

Mots clés : planification par scénario, aménagement forestier intensif, réserves, aménagement forestier extensif, triade, allocation du territoire, zonage forestier

¹University of New Brunswick, Faculty of Forestry and Environmental Management, P.O. Box 44555, Fredericton, New Brunswick E3B 5A3. Present address: New Brunswick Department of Natural Resources, Forest Management Branch, P.O. Box 6000, Forestry Complex, Fredericton, New Brunswick E3B 5H1.

²University of New Brunswick, Faculty of Forestry and Environmental Management, P.O. Box 44555, Fredericton, New Brunswick E3B 5A3. E-mail: macleand@unb.ca. Corresponding Author.

Michael K. Montigny

David A. MacLean

Introduction

The triad forest management concept (Seymour and Hunter 1992) involves designating forest reserves and intensively managed areas within a landscape matrix managed by silvicultural systems patterned after natural disturbance regimes (Franklin 1989, Gillis 1990). The triad concept is based on earlier work of Clawson (1974, 1977), furthered by Seymour and McCormack (1989). These authors argued that concentrating timber production in selected areas would allow increased non-timber value availability from the remaining forests. More recently, many authors (e.g., Binkley 1997, Sahajananthan *et al.* 1998, Messier and Kneeshaw 1999, Taylor 1999) have explored the single-use zoning concept under various naming conventions.

Triad zoning results in management specialization where a specific and different set of values is managed for in each zone, with the purpose of adequately providing a full set of values at the forest level through the collective outcomes across all zones. Part of the rationale for triad management rests on economic theory, which suggests that management for multiple values, on every hectare of forest, is inefficient (Sahajananthan *et al.* 1998) and that specialized management under zoning avoids this inefficiency. A further supporting argument is that intensive management on some lands reduces the area required to achieve wood supply targets, and could thereby allow an increase in reserves (Seymour and McCormack 1989, Binkley 1997, Sedjo and Botkin 1997). Triad zoning is based on the assumptions that protection of biodiversity values need not be the focus of management on every hectare of the forest, a view supported by some in the conservation community (e.g., Woodley and Forbes 1997), and that possible negative environmental consequences of intensive management are acceptable on some areas, a view questioned by others (e.g., Franklin 1989, 1998).

No consensus exists regarding the superiority of triad zoning relative to other land allocation alternatives and given this, we felt it productive to quantitatively study triad-based forest management outcomes for an extensive industrial forest holding. Our objective was to gain insight into the timber and non-timber consequences of various land allocation options under the triad concept. From this we hope to better reveal how triad zoning influences forest outcomes.

The general forest management question in any context is "what allocation of treatments in time and space will likely result in forest conditions best able to provide the values sought for the forest in question?" Answering this requires measuring management strategy outcomes in comprehensive

and meaningful terms that reflect the breadth of economic, environmental, and social dimensions that characterize contemporary values sets. To this, the triad concept introduces an additional specific question, namely, "how much area should be allocated to each of the three types of zones to produce the best overall provision of values from the forest as a whole?" In this context, "best" is clearly dependent upon the values desired by the landowner, or society in the case of publicly-owned lands.

Key to answering this latter question is an understanding of objectives for the zones into which area is allocated and the actions that can be implemented in those zones. Intensive management zones are managed primarily for the production of timber products; other values may be obtained, but are secondary (Seymour and Hunter 1992). Careful stocking and density control, genetically improved stock, and short rotations or frequent harvest entries may all be employed to produce high yields. Extensive management zones are managed less intensively for timber production and in some cases with priority also given to non-timber values such as habitat or water quality. Natural disturbance-based silviculture may be implemented to protect these other values (Bergeron *et al.* 1999, Seymour and Hunter 1999). This frequently involves longer harvest rotations or cutting cycles, and structural retention than is generally consistent with the natural disturbance dynamics of the stand types in question. Such practices result in lower timber production than that resulting from intensive management. Reserves are managed to provide ecological benchmarks and to represent forest conditions unaffected by timber management practices. As such, no timber is extracted from reserves and, ideally, natural ecological processes are allowed to occur (although major natural disturbances may be controlled depending upon the specific forest management plan).

We defined 64 combinations of land allocation into these three zones and used scenario planning (Schoemaker 1995) to examine the long- and short-term consequences of each on a set of economic and environmental indicators. Across these 64 scenarios, we varied reserve area from 0–15%, intensively managed areas from 39–64%, and extensively managed areas from 21–61%. In each case, we characterized forest-level outcomes in terms of species composition, age class distribution, timber growing stock, harvest levels, and old forest habitat.

Study Area

The study area was the 188 584-ha Black Brook District, owned by J.D. Irving, Ltd. (JDI), in northwestern New Brunswick, Canada (Fig. 1). As a result of reforestation programs initiated in the mid 1950s, the Black Brook District is one of the most intensively managed forests in Canada, with over 60 000 hectares of primarily spruce (*Picea* spp.) plantations. Management strategies, including uneven-aged management of tolerant hardwood and even-aged intensively managed softwood plantations, have resulted in a bimodal age-class distribution (Fig. 2). The large area contained in 65–105 year old stands is primarily uneven-aged hardwood (yellow birch [*Betula alleghaniensis* Britton], sugar maple [*Acer saccharum* Marsh.], and American beech [*Fagus grandifolia* Ehrh.]), while 5- to 40-year-old stands are intensively managed even-aged softwood plantations.

Currently, JDI has allocated over 7000 hectares of benchmark scientific reserves (Fig. 1). Reserves were selected with

Fig. 1. Map showing initial reserve network on J.D. Irving, Ltd. Black Brook District in New Brunswick, Canada, including watercourse buffers, deer wintering areas, adaptive management areas (areas undergoing a single research harvest, based on removing trees that would be killed by a spruce budworm outbreak), and core reserves.

Fig. 2. Initial age-class structure of forest in the Black Brook District.

input from World Wildlife Fund, with emphasis on large, unharvested, and unroaded areas on the landbase, and include 2600 ha designated as adaptive management areas where natural disturbance-based silviculture treatments are being developed and tested. These treatments are based on the main natural disturbances in the area, which result from spruce budworm (*Choristoneura fumiferana* (Clem.)) (Porter *et al.* 2004) and localized disease and wind-driven mortality resulting in gap replacement. To act as a control, JDI established 4750 ha of core reserve areas (Fig. 1), which will not receive any intervention.

In this analysis, we will categorize intensive management as softwood plantation management, and all natural stand

treatments as extensive management. Although multiple-entry, single-tree selection harvests in tolerant hardwood stands are also intensive, we concentrated on plantation establishment intensity in this study, as it is currently under examination in the region (e.g., Erdle and Pollard 2002, Erdle and MacLean 2005). Given these zone definitions, the study area was initially 39% intensive, 56% extensive, and 5% reserve.

Methods

Indicators

Several indicators were selected to enable scenario evaluation with respect to important timber and non-timber values: softwood and hardwood inventory volume, softwood and hardwood harvest volumes (total and by product), harvest and silviculture treatment levels, area of old softwood, mixedwood, and hardwood forest habitat, and age-class structure at the end of the 80-year forecast horizon. The old forest habitat types were defined using criteria developed by the New Brunswick Department of Natural Resources and Energy (NBDNRE) (2000) reflecting species composition and the presence of structural features (e.g., standing dead trees with cavities) associated with stand decline. Typically in New Brunswick, softwood stands first exhibit “old stand” structural characteristics between 60–80 years, mixedwood between 60–90 years, and hardwood stands between 90–120 years (NBDNRE 2000). Due to good site quality and silvicultural treatments on the Black Brook District, stands produce old forest habitat structures faster than in other areas of New Brunswick. Thus, plantations, precommercial thinnings and commercial thinning were deemed suitable as old forest habitat at age 50 years by NBDNR staff. Similarly, stands that receive partial harvest prescriptions, specifically single-tree selection harvest, patch harvest, and shelterwood harvest, as

Table 1. Summary of treatment descriptions, ages eligible, contribution to old forest habitat, and triad zone assigned for eight treatments used in a triad forest management analysis on the Black Brook District. Treatments used were consistent with J.D. Irving, Ltd. management plan targets (J.D. Irving, Ltd. 2002) and were used to reflect operational reality.

Treatment	Treatment description		Ages eligible (years)	Contribution to old forest ^a	Triad zone
Clearcut	removal of all merchantable stems; all species	Managed	25–75	Yes	Intensive
		Natural	50–150	Yes	Extensive
Single-tree harvest	uneven aged management in tolerant hardwood and cedar; 35% volume removal		50–150	Yes	Extensive
Patch cut	small patches (0.01–0.1 ha) created; encourage natural regeneration		50–150	Yes	Extensive
Shelterwood	40% removal of standing volume (low quality species) to promote quality regeneration		50–150	Yes	Extensive
Salvage	removal of dead and dying stems		50–150	Yes	Extensive
Plant	establish fully stocked plantation		0–10	Yes	Intensive
Precommercial thin	control density and species composition		10–25	Yes	Intensive
Commercial thin	removal of 30% standing volume; short-term volume and promote volume and increased piece-size		25–50	Yes	Intensive

^aold forest habitat windows varied by stratum and treatment

Table 2. Triad management scenarios applied aspatially to the Black Brook District, New Brunswick, Canada. Scenarios varied from the initial allocation of 5% reserve, 39% intensively, and 56% extensively managed area. Each value represents the extensively managed area associated with one of 64 scenarios, as a function of specified reserve and intensively managed areas.

Reserve area (%)	Extensively managed area (%), as a function of specified levels of intensively managed softwood area (%)					
	39	44	49	54	59	64
0	61	–	51	46	–	36
1.3	59.7	54.7	49.7	44.7	39.7	34.7
1.5	59.5	54.5	49.5	44.5	39.5	34.5
2.6	58.4	53.4	48.4	43.4	38.4	33.4
3.0	58	53	48	43	38	33
4.0	57	52	47	42	37	32
5.0	56	51	46	41	36	31
6.0	55	50	45	40	35	30
7.0	54	49	44	39	34	29
10	51	46	41	36	31	26
15	46	41	36	31	26	21

well as untreated stands, are suitable as old habitat area if they meet NBDNR requirements (e.g., $\geq 40\%$ crown closure and $\geq 16 \text{ m}^2$ basal area, minimum 10 trees $\geq 30 \text{ cm dbh}$ for old, and minimum five trees $\geq 45 \text{ cm dbh}$ for large) (Beaudette 2003).

Forest and treatment characterization

Stand development patterns (merchantable volume by species and product vs. stand age) were built for strata defined by stand type, site class, and silviculture prescription. Stands were categorized by reserve designation and operability, resulting in 446 stand types (324 managed and 122 natural) (J.D. Irving, Ltd. 2002). Stand development forecasts were constructed for each using the STAMAN 5.0 stand table pro-

jection model (Vanguard Forest Management Services Ltd. 1993). Generally, intensively managed areas reach peak merchantable volumes of $365 \text{ m}^3/\text{ha}$ at age 75, while extensively managed areas achieve $180 \text{ m}^3/\text{ha}$ at age 75.

Eight silviculture interventions were used: planting, pre-commercial thinning, commercial thinning, shelterwood harvesting, patch cutting, single-tree selection harvesting, salvage harvesting (fire or insect damaged), and clearcut harvesting. Gains of 5–25% in predicted yield were applied to plantations to reflect JDI's 20-year genetic tree improvement program (J.D. Irving, Ltd. 2002). Planted species included black spruce (*Picea mariana* [Mill.] BSP), white spruce (*Picea glauca* [Moench] Voss), red spruce (*Picea rubens* Sarg.) and Norway spruce (*Picea abies* [L.] Karst.), with the latter being planted only on the highest quality sites and limited to $< 25\%$ of the planted area. The major characteristics (timing, volume harvested, and old forest suitability, applicability to each type of zone) of each treatment and stand type are summarized in Table 1. Stands that develop from natural regeneration, regardless of the pre-harvest management (e.g., intensively or extensively), were considered to be extensively managed. However, once a post-cut area was planted or precommercially thinned, the stand was considered intensively managed. Decisions regarding how stands were regenerated were made using linear optimization in a wood supply model.

Some areas such as watercourse buffers and deer wintering areas had primary values other than production of timber and others were inoperable because of terrain features. These were assigned special operability codes and included in the extensive management zone. Specific management prescriptions were in place for each (excluding inoperable areas), including single-tree selection, patch cutting, and shelterwood harvesting. Such areas were eligible but did not receive priority when allocating additional area to the reserve network. However, if they were selected as reserves (Montigny and MacLean 2005), they were no longer eligible for the above management prescriptions.

Table 3. Description of area and % by ecosite for the current reserve network on the Black Brook District (5% of the area), and for proposed additional reserves to attain scenario targets of 6, 7, 10, and 15% of the total area. Montigny and MacLean (2005) described the selection method and locations of proposed additional reserves.

		Area	Current reserves		Proposed additional reserves (ha) by % landbase target				Proposed total reserve area (%) by % landbase target			
			ha	%	6%	7%	10%	15%	6%	7%	10%	15%
Ecosite description		(%)	ha	%	6%	7%	10%	15%	6%	7%	10%	15%
2	coniferous moist poor	9.4	737	4.2	208	231	440	1043	5.4	5.4	6.7	10.1
2c	coniferous calcareous moist poor	5.4	372	3.7	10	173	418	468	3.7	5.3	7.8	8.2
3o	bog	0.4	167	23.3	0	0	23	23	23.3	23.3	26.5	26.5
4	coniferous or mixedwood dry moderate	1.3	22	0.9	11	33	228	281	1.4	2.3	10.3	12.4
5	mixedwood moist moderate	24.2	1811	4.0	353	969	1808	4600	4.7	6.1	7.9	14.0
5c	mixedwood calcareous moist moderate	19.3	1881	5.2	176	193	1946	3230	5.7	5.7	10.5	14.1
6	coniferous or mixedwood wet slope	7.1	1854	13.8	73	89	514	663	14.4	14.5	17.7	18.9
6c	coniferous or mixedwood wet calcareous	6.0	1165	10.3	0	12	728	1498	10.3	10.4	16.7	23.5
7	mixedwood upper ridge slope	14.5	1015	3.7	460	1272	2170	4612	5.4	8.4	11.7	20.6
7c	mixedwood calcareous upper slope	9.1	3476	2.0	410	478	999	1872	4.4	4.8	7.9	13.0
8	hardwood ridge dry rich	3.3	229	3.8	79	241	441	797	5.0	7.6	10.9	16.7
Total		100	9479	5.0	1780	3691	9715	19 087	6.0	7.0	10.2	15.1

Reserve network

Currently, reserves cover 5% of the District area. We were interested in testing the effect of reserves over a range of 0 to 15% and Montigny and MacLean (2005) conducted a gap analysis of ecosite representation by ecodistrict in current reserves to determine what areas should be added in scenarios where reserve area exceeded 5%. Montigny and MacLean (2005) tested two methods, based upon heterogeneity of forest features vs. targeted ecosite representation (10% of each ecosite), in order to spatially identify and rank candidate reserve areas. The heterogeneity method used an additive equation that scored 100-ha cells for heterogeneity of soils, vegetative community, and elevation class, with an objective to maximize heterogeneity of enduring ecosite features within selected reserves. The representation method targeted specific ecosites to build a reserve network with 10% coverage of each ecosite. Montigny and MacLean (2005) concluded that the heterogeneity method was superior, in that with a 10% area target, it resulted in larger reserves (29 vs. 42, ranging from 490–2000 ha and 50–1500 ha, respectively), 10% more core area, 30% larger mean patch size, and 30% less edge.

Thus, the heterogeneity method was used to select potential reserves for scenarios ranging from 0 to 15% of the area (Table 2). For increased reserves over the current 5% level, additional potential reserves were targeted to represent a given level of each ecosite, but with priority given to aggregate proposed reserves to make them as large and round as possible, to increase core area and reduce the amount of edge (Diamond 1975). Table 3 shows areas added as reserves and coverage by ecosite and broad stand type, for the current 5% reserves and for increased scenarios of 6, 7, 10, and 15%. In total, 47 reserves were identified and each was given a unique

identifier in the GIS. This allowed for reserves to be incorporated using a spatially explicit modeling constraint. In scenarios that required the reserve network to be increased by a specified percent, reserves totalling that area were removed from the landbase eligible for harvest.

Scenario modeling

Management strategy formulation, forest development forecasts, and calculation of indicators over an 80-year time horizon were performed using the linear programming formulation of the Remsoft (2003) Woodstock model. The objective function was a weighted linear equation:

$$[1] \quad 2 \times (\text{discounted softwood harvest}) + \text{discounted hardwood harvest.}$$

Equation [1] defined softwood harvest volume to be twice as important as hardwood but still maximized total projected harvest level. Discounting at 4% was used to place higher value on volume yield earlier in the management plan.

A set of constraints (Table 4) was used that reflected JDI-specified timber and non-timber values, including non-declining softwood and hardwood yields, non-declining total growing stock, and a 160 000 m³ per five-year period limit on softwood yield from watercourse buffers. Other constraints limited areas of planting and precommercial thinning per period, amount of Norway spruce used in plantations, required application of commercial thinning to plantations to limit natural, within-stand tree mortality and increase piece-size, set area targets for seven forest communities throughout the planning periods, and set a minimum softwood volume to be obtained from softwood-dominated deer wintering area (DWA) (Table 4).

Table 4. Summary of the model constraints that reflected J.D. Irving, Ltd. specified timber and non-timber values, and were used in all scenario model runs. Constraints and area targets were consistent with management plan targets (J.D. Irving, Ltd. 2002) and were used to ensure that management did not liquidate natural stand types on the landbase.

Model Constraints
<ul style="list-style-type: none"> • Non-declining softwood and hardwood harvest volume • Non-declining total growing stock • A limit of 160 000 m³ per five-year period of softwood projected yield obtained from watercourse buffers • Planting and precommercial thinning maximum of 15 000 ha per period (reflecting operational limitations owing to workforce and nursery stock availability) • Norway spruce less than 25% of the plantation area (it might otherwise be scheduled for more extensive planting due to its high growth rates) • 90% of eligible plantations receive a first commercial thinning intervention • 70% of commercially thinned plantations receive a second commercial thinning (consistent with the JDI plantation management strategy to use commercial thinning to limit natural, within-stand tree mortality and increase piece-size) <ul style="list-style-type: none"> • Minimum area targets for forest communities of: <ul style="list-style-type: none"> • 1500 ha balsam fir • 1000 ha black spruce • 9000 ha mixedwood (mixed hardwood-softwood) • 1000 ha of old mixedwood • 40 000 ha of tolerant hardwood (including 6,000 ha of old tolerant hardwood) • 9500 ha old eastern white cedar (<i>Thuja occidentalis</i> L.) • Softwood-dominated deer wintering area to provide a minimum of 2000 m³ of softwood volume at year 35 and at least 4000 m³ in years 36–80

Triad zone constraints

Areas were sequentially added to the reserve network to fulfill the percent area defined in each scenario (Table 3). A no-harvest constraint was applied to each reserve. The unique reserve identifier in the forest description allowed control of the treatment eligibility in specific pre-determined locations on the landbase. We needed a method to control either the amount of intensively or extensively managed areas (the other would be controlled by default as the remaining area). For operational reasons, the area of plantation establishment was limited to 15 000 ha per five-year period (Table 4). Due to this plantation establishment operational constraint, intensively managed area targets were applied only after period 5, to allow time to attain the area target. After period 5, a constraint controlled the area intensively managed for each scenario to within ± 100 ha per period. Unlike candidate reserve areas, intensively managed areas were not spatially delineated, but rather were selected by linear optimization in Woodstock; choices were constrained by treatment, stand eligibility for treatment, and timing of treatments. To determine how specified levels of intensively managed area influenced timber and non-timber values, a constraint was set to maintain the level tested in each scenario. Extensive management areas were controlled by default as the remaining (not intensive management or reserve) area.

Results

Softwood and hardwood growing stock

Softwood total growing stock increased in proportion to the area of intensive management after period 6, using five-year periods (Fig. 3). There was a generally similar trend of softwood volume across scenarios, increasing to period 8, and then declining in periods 11 to 16; however, the level reached was directly proportional to the area intensively managed (Fig. 3). In period 1, softwoods made up 52% of the operable growing stock, but by periods 10 to 16, it increased to 64% to 75%. Softwood growing stock peaked at 12–19 million m^3 in period 8 and declined slightly thereafter (Fig. 3). In all scenarios, hardwood growing stock declined slightly over time, from 7.8 million m^3 in period 1 to 6.0–6.5 and 5.8–6.2 million m^3 in period 16 with 39–54% and 59–64% intensively managed area, respectively (Fig. 3). Total growing stock, which included other softwood and hardwood species (e.g., eastern white cedar, *Thuja occidentalis* L.) was limited by a non-declining inventory constraint (Table 4).

Softwood and hardwood total growing stocks in period 12 (year 60) are presented in contour plots as a function of % intensively managed area and % reserves in Fig. 4. With 64% intensively managed areas, the total growing stock was higher with increasing reserves due to lower harvest level combined with increased growing stock contained in reserves. Softwood total growing stock in period 12 was relatively insensitive to increased reserves, except when reserve and intensive management areas were both maximized (upper right of Fig. 4a). However, softwood growing stock was directly related to the area of intensive management, increasing by 4 million m^3 as intensively managed area increased from 39% to 64% (Fig. 4a). The lack of sensitivity of softwood growing stock to increased area of reserves resulted from the make-up of this landbase, as: 1) much of the area added as reserves was in mixedwood or hardwood ecosites (Table 2); and 2) most future softwood timber supply was coming from plantations

(39–64% of the landbase in various scenarios), which provided the majority (82%) of the softwood growing stock. In 2002, natural softwood made up only 6% of the District, 4% of which was in riparian buffers (Etheridge *et al.* 2006); the landbase included roughly 25 000 ha softwood-cedar, 79 000 ha softwood (only 1140 ha of natural stands > 50 years old), 32 000 ha mixedwood, and 46 000 ha hardwood (Etheridge *et al.* 2005). Model constraints (Table 4) mandated the maintenance of 12 000 ha of softwood (9500 ha of old cedar, 1000 ha of black spruce, and 1500 ha of balsam fir), as well as at least 9000 ha of mixedwood and 40 000 ha of hardwood.

In contrast, higher hardwood total growing stock generally resulted from more reserves and less intensive management (Fig. 4b). Higher volume with increased reserves occurred because of hardwood stands in reserves. With 0–10% reserves and increasing intensively managed area, hardwood volume decreased due to conversion to softwood dominated plantations. With 15% reserves, the increase in hardwood total growing stock with increased intensively managed area was due to a lower harvest level combined with the previous point.

Softwood and hardwood harvest levels

Projected softwood harvest remained constant for the first six periods, regardless of the area of reserves or intensive management (Fig. 5). Some intensively managed areas remained unharvested in periods 1 to 6, to meet the intensive management area constraint. Managed stands that were harvested and regenerated naturally (i.e., post-harvest silviculture had not yet been applied) were assigned to the extensive zone. The area of intensive management was reduced whenever these stands regenerated naturally, and the model would reduce harvest to maintain the required area of intensive management. For scenarios with 64% intensive and 10% and 15% reserves, we broadened the description of intensive management to include recently clearcut intensively managed stands, thus allowing for a harvest level comparable to other scenarios.

Natural softwood was harvested primarily in the first 15 years: period 1, 1.4–2.3 million m^3 from natural vs. 0.4–0.5 million m^3 from intensively managed stands; period 2, 0.8–1.4 million m^3 natural vs. 1.3–1.6 million m^3 intensive; and period 3, 0.1–0.5 million m^3 natural and 2.2–2.5 million m^3 intensive. After period 3, natural stands contributed only about 10% and 2% of the total softwood harvest with 39% and 64% intensively managed area, respectively. By period 12, softwood harvest was 50% greater as intensive management increased from 39 to 64%, but it was relatively insensitive to reserve area (Fig. 6b). As intensive and reserve area increased (Fig. 6b), natural softwoods were limited to the required minimum of 2500 ha of balsam fir and black spruce (Table 4).

Due to lower hardwood volume available in periods 10 to 16 (Fig. 3), the non-declining constraint resulted in constant hardwood harvest across all periods (Fig. 5e–h). As reserves increased from 0 to 15% of the landbase, hardwood projected harvest declined from 0.96 to 0.71 million m^3 per period (Fig. 5e–h). Hardwood harvest from intensively managed area made up 7–14% per period up to period 9, and thereafter, hardwood harvest was a combination from intensively managed softwood and natural stands. Projected hardwood harvest was insensitive to increased intensively managed area but declined by almost 20% as reserves increased (Fig. 6a).

Fig. 3. Softwood and hardwood total growing stock (million m³) on the Black Brook District, projected for 80 years, for 24 scenarios with differing areas allocated to reserves, intensively managed, and extensively managed forest.

Fig. 4. Contour plots for the Black Brook District showing a) softwood total growing stock and b) hardwood total growing stock, in period 12 (year 60) with 0–15% reserves, 39–64% intensively managed area, and the remainder extensively managed.

Fig. 7 shows both the increased total harvest over time, and the distribution of products (hardwood logs and pulpwood and softwood logs, studwood and pulpwood), for four scenarios. Softwood volume accounted for the majority (64–84%) of the projected harvest in all scenarios (Fig. 7). The harvested product mix varied little among these scenarios, at about 72% softwood (22% pulpwood, 17% studwood, 33% logs) and 28% hardwood (23% pulpwood, 5% logs). However, by period 16, not only had the total harvest volume increased substantially from period 1 (by 35, 67, 76, and 139% in Figs. 7a–7d, respectively), there were more high-value products: up to 88% more softwood studwood, and 57% more softwood logs, while hardwood logs doubled (Fig. 7). Softwood logs increased due to maximized softwood volume and forced commercial thinning of plantations to increase piece size. In all scenarios, 80–90% of plantations were commercially thinned, allowing volume to accumulate on fewer stems.

Projected silviculture

Projected areas to be clearcut (Fig. 8a) and partially harvested (Fig. 8b) had offsetting peaks in area harvested. This translated into the majority of projected harvest in even-aged and uneven-aged silviculture in off-setting periods (Fig. 8). Partial harvesting reached maxima of 17 000–20 000 ha in a four-

period cycle — periods 1, 5, 9, and 13 (Fig. 8b). This resulted from single-tree selection and patch cutting harvests removing treated areas from operability for four planning periods (20 years), and then all these stands becoming operable in the same period (Fig. 8b). In period 1, area clearcut ranged from 16 000 to 19 000 ha as intensively managed area increased from 39% to 64%. The area clearcut decreased to a minimum of 6000–10 000 ha in period 5, corresponding to the first major partial harvest (Fig. 8b).

The total area planted in periods 1 and 2 was proportional to the required intensively managed area (Fig. 8c). The area planted in these periods increased from 2350 to 15 000 ha for scenarios with 2.6% reserve and intensive management increasing from 39% to 64% of the area (Fig. 8c). Clearly, with maximal intensively managed area (64%), the optimal solution was to maximize planting in periods 1 to 3 (Fig. 8c). As the intensively managed area increased from 39 to 64%, the average area planted increased from 4000 to 9600 ha per period, which would result in increased silviculture costs. At average costs of \$600/ha for plantation establishment, \$250/ha for competition control, and \$550/ha for precommercial thinning (G. Pelletier, JDI, personal communication), there would be \$4.2 million per period difference in plantation establishment costs alone with increased intensively managed area. Although no allowable cut effect is realized as intensively managed area increased from 39% to 64%, this increased silviculture cost results in the 1.4 million m³ per period higher harvest available after period 5.

Projected deer wintering area and old habitat

Total growing stock contained in deer wintering areas was largely unaffected by the amount of intensively managed area in the District for the first eight periods (Fig. 8d). In all scenarios, total growing stock in the current DWA stands increased from the 3500 m³ initially to 7900 m³ in period 5 (Fig. 8d), regardless of the amount of intensively managed area. In addition, due to the influx of commercially thinned plantations that eventually met DWA eligibility standards, the total area eligible as DWA increased from 35 000 ha initially to 72 000 ha by period 4. To help maintain sufficient DWA in the future, it would be in the interest of JDI to ensure that managed stands are able to provide non-timber values as well as timber values.

NBDNR has differentiated old softwood, old hardwood, and old mixedwood habitat, linked them structurally to wildlife species use, and proposed area targets. Old softwood habitat declined from an initial 42 000 ha to 9000–13 000 ha in period 16, with the range in proportion to the area of reserves (Fig. 9a–d). Old softwood habitat was insensitive to the amount of intensively managed area but was directly related to area of reserves (Fig. 10c).

Old mixedwood habitat declined from an initial 21 000 ha to about 5000 ha in period 16 (Fig. 9e–h). Increasing the reserve area from 0–15% increased the area in old mixedwood by 7500 ha, on average, in periods 3 to 14 (Fig. 9e–h). Old mixedwood habitat was relatively insensitive to increasing intensively managed area (Fig. 10b). In period 16, there were 2600 ha of old mixedwood with no reserves versus 4600 ha with 15% reserves. Old mixedwood was the most constraining habitat, is limiting for some wildlife in the District (Higdon *et al.* 2005), and has decreased from 28% of the landbase in 1945 to 18% in 2002 (Etheridge *et al.* 2005).

Fig. 5. Projected softwood and hardwood harvest level per 5-year period, with 0–15% reserves, 39–64% intensively managed areas, and the remainder extensively managed.

Fig. 6. Contour plots for the Black Brook District showing a) hardwood and b) softwood harvest level (m^3) in period 12, with 0–15% reserves, 39–64% intensively managed area, and the remainder extensively managed.

Although old hardwood habitat decreased over time, it was still quite plentiful. The initial 51 000ha declined to about 20 000–35 000 ha in period 16, depending upon levels of reserves and intensively managed area (Fig. 9i–l). Both reserves and intensively managed area influenced old hardwood level, with reserves having more influence at < 50% intensively managed area, but intensively managed area having more influence at > 50% (Fig. 10a). As the intensively managed area increased, more hardwood stands were harvested to allow creation of additional managed softwood stands. However, old hardwood habitat was clearly the least constraining of the three types (Fig. 9), because of extensive all-aged management of tolerant hardwoods and the assumption that such treatment will leave stands with old forest characteristics.

Generally, reserves provided additional areas of old softwood, mixedwood, and hardwood habitat that were not provided in the general forest. Old hardwood habitat occurred in both reserves and also in stands managed by single-tree selection in the extensively managed forest. With 15% reserves, one-half (9000 of 18 000 ha) of old softwood habitat was in reserves, while the rest was in the extensively managed buffer or DWA.

Age-class structure

We selected the four most contrasting examples to represent the period 16 (end) age-class structure of the forest under differing scenarios (Fig. 11). To permit broad comparison, we

defined young, mature and old forest as aged 0–60, 61–120, and 121–200 years, respectively. As reserves increased from 0–15%, the area of old forest increased from 8000 to 35 000 ha (Fig. 11). By period 16, at higher levels (10–15%) of reserves, the forest had a tri-modal age structure (Fig. 11c–d). Apart from this, there was relatively little difference in the age distributions among scenarios. All four scenarios in Fig. 11 ended with 104 000–131 000 ha of young, 37 000–55 000 ha of mature, and 8000–35 000 ha of old forest.

With 1.3% reserves, there was 8000–9000 ha of old forest (Fig. 11a, b), and with 15% reserves, this increased to 28 000–35 000 ha (Fig. 11c, d). Clearly, reserves played a major role in maintaining old forest conditions. Intensively managed area increasing from 39% to 64% had no effect (< 1%) on the area of old forest, but there was 1000–18 000 ha more young (0–60 year) forest with more intensive management (Fig. 11).

Discussion

Our purpose in this paper was primarily to demonstrate the value of scenario planning analyses and contour plot data display in evaluating the potential of triad forest management. This particular landbase is unique and among the most intensively managed in Canada. Nevertheless, the analysis method is applicable to other Crown or privately owned landbases. Results showed that increasing the area zoned for intensive softwood management from 39% to 64% increased softwood harvest by 1.4 million m^3 per period after period 5. Softwood harvest level was relatively insensitive to the area of reserves, but increases from the current 5% reserves to 15% increased old softwood and mixedwood habitat by 4000 ha and 2000 ha, respectively, or nearly 50%. More area under intensive management could permit setting aside of more unharvested reserves while still increasing timber value. Intensive softwood and high-quality hardwood management also doubled the proportion of hardwood sawlogs and increased softwood studwood and logs by 88% and 57% over the 80-year forecast period. It is important to note that these were hypothetical scenarios, and the landowner, J.D. Irving, Ltd., is not necessarily pursuing any of modeled strategies.

Scenario analysis provided an effective framework for assisting in land-use decisions by identifying trade-offs between forest values and by helping to elucidate forest dynamics trends. Forests provide a wide variety of timber and non-timber values, and selecting the appropriate mix of zones is a function of desired values (Erdle 1999). This becomes more difficult when one value occurs at the expense of others, as occurred in many instances among scenarios as intensively managed and reserve areas increased. For example, as the intensively managed area increased from 39% to 64%, the amount of old hardwood habitat declined. As the reserve area increased, so did the area of old forest habitat, but at the cost of lower projected harvest levels. Before a land manager can decide how much area to allocate to intensive forest management or reserves, the influence on forest values should be clear. Contour plots of indicators such as volume, harvest level, and habitat, as a function of intensive and reserve areas, provide a clear, succinct decision aid, and the relative distance between contours (e.g., in Fig. 6) indicates sensitivity. However, triad zone allocation is clearly driven by desired values.

Fig. 7. Distribution of projected products (hardwood [HW] logs, hardwood pulpwood, softwood [SW] logs, softwood studwood, and softwood pulpwood) for the Black Brook District for four scenarios with reserves ranging from 2.6–15%, intensively managed area from 39–64%, and the remainder extensively managed.

Fig. 8. Area projected to be clearcut, partially harvested, planted, and softwood volume in current deer wintering habitat (DWA) on the Black Brook District for scenarios with intensively managed area ranging from 39–64%, reserve area 2.6%, and the remaining area extensively managed.

Fig. 9. Projected areas of old softwood, old hardwood, and old mixedwood habitat on the Black Brook District, defined using New Brunswick Department of Natural Resources wildlife habitat classes for scenarios with 0–15% reserves, 39–64% intensively managed area, and the remainder extensively managed.

Advantages and disadvantages, depending upon the value of interest, are associated with both increased reserves and increased intensively managed area, and their joint use had offsetting benefits. Increased intensive forest management can actually aid land managers in establishing a larger reserve network, by concentrating the silviculture investment in intensively managed zones (Seymour and Hunter 1992). In recent years, triad management has become an attractive concept for industrial forest companies, due to the protection of all values at a landscape level while maximizing forest productivity (Binkley 1997, Sahajananthan *et al.* 1998). In our analysis, increasing the intensively managed area generally also increased the projected harvest level.

As more demand is placed on forests to produce timber and non-timber values, the opportunity to establish representative reserve networks may be lost. Land managers have asked whether private land owners should be responsible for

establishing reserves and, if so, at what level? Proposals for appropriate size of reserve networks have ranged from 10% (World Wildlife Fund 2004), 12% (World Commission on Environment and Development 1987), 20% (Taylor 1999), and 50% (Soulé and Sanjayan 1998). Although at a provincial scale, there are many reasons why at least 10–12% protected areas may be reasonable, they may not apply to a privately owned industrial forest like the Black Brook District. The cost of establishing a representative reserve network on a private landbase may be higher than a forest products company is willing to bear, yet many companies are committed to maintaining biodiversity as part of sustainable forest management. Increased reserves reduce the landbase eligible to provide operable volume, yet, as was shown in several of our scenarios, modest increases in the intensively managed area, which require capital investment in silviculture, can more than offset the harvest level that could have been obtained in reserves.

Fig. 10. Contour plots for the Black Brook District showing a) old hardwood habitat, b) old mixedwood habitat, and c) old softwood habitat in period 12 (year 60) with 0–15% reserves, 39–64% intensively managed area, and the remainder extensively managed.

Fig. 11. Projected age-class distributions for the Black Brook District, after 80 years of forest management for scenarios with 2.6–15% reserves, 39–64% intensively managed areas, and the remainder extensively managed.

We controlled intensively managed areas in this analysis by applying a per-period area constraint after period 5. Feasible solutions were calculated, but our results were influenced by periods 1 to 5 not having any area constraints applied. An intensively managed stand that was harvested by clearcutting and regenerated naturally would automatically switch to extensively managed, which, depending upon definitions and ecosystem processes, may not accurately reflect the “true” area intensively managed. Another approach to area control could spatially identify areas similarly to the way that reserve areas were controlled, and thus select the sites most suited for intensive management (e.g., high site productivity, proximity to processing facility). Norfolk and Erdle (2005) described a framework to spatially select potential intensive management sites.

This study is timely given recent controversy about intensification of forest management in New Brunswick. A report commissioned by NBDNR and the New Brunswick Forest Products Association explored the feasibility of doubling the long-term wood supply on public lands (Jaakko Pöyry Management Consulting 2002). This was contentious and prompted the establishment of a Legislative Select Committee on Wood Supply, which held far-reaching public hearings into Crown land management (Erdle and MacLean 2005). Our study provides a rigorous, quantitative analysis of possible zoning scenarios for an industrial forest. The Jaakko Pöyry report suggested that increased intensive forest management was necessary to allow for increased projected wood supply. Unfortunately, little quantitative analysis was provided regarding the implications of increased intensive management on timber and non-timber values. A more informed society is now demanding evidence that actions carried out on public and private lands will not jeopardize forest values for future generations. Triad management may satisfy both forest industry and environmentally conscious citizens (not mutually exclusive), and scenario planning analyses provide a good means of providing information on costs and benefits of zoning strategies.

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