The development and application of a decision support system for sustainable forest management on the Boreal Plain[1]

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Abstract: Millar Western Forest Products Ltd. manages a forest in west-central Alberta under a Forest Management Agreement (FMA) with the Government of Alberta. Part of Millar Western's planning process brought researchers together to develop a decision support system (DSS) for forest management planning and monitoring programs. Four modules — timber supply, biodiversity, FIRE, and WATER — were built to evaluate, with the help of indicators of sustainable forest management, current and future forest conditions predicted from computer simulations of alternative management scenarios. In the first round of assessment four management scenarios, distinct by their level of silviculture intensification and by the spatial clearcut layout pattern, were compared. Such comparison has demonstrated that (1) the current forest management scenario improved moose habitat at the expense of timber supply, (2) all scenarios had similar fire risk, (3) generated increases in peak flow and water yield of selected watersheds, and (4) slightly impoverished forest biodiversity. All scenarios were examined in light of a computer-simulated natural disturbance benchmark. This led to landscape design scenarios to reduce fire risk and balance biodiversity indicators with timber supply objectives, one of which was eventually selected for implementation. The company's monitoring and research program is also highly focused on improving DSS modules and the underlying data, hence its association with the Forest Watershed and Riparian Disturbance (FORWARD) project, which considers the effects of forest management on aquatic ecosystem indicators.

Key words: decision support system, ecosystem management, forest management, natural disturbance, indicators, sustainable forest management, adaptive management.

Résumé : La compagnie Millar Western Forest Products Ltd. a un contrat d'aménagement forestier avec le gouvernement albertain pour une forêt publique du centre-ouest de l'Alberta. Pour l'élaboration du plan d'aménagement forestier stratégique de cette forêt, la compagnie a rassemblé plusiers chercheurs afin de développer un système d'aide à la décision combinant planification et système de surveillance. Quatre modules (approvisionnement en bois, biodiversité, feu et eau) ont été instaurés par des groupes d'études d'impacts afin d'évaluer, à l'aide d'indicateurs de foresterie durable, les conditions actuelles et futures de la forêt, telles que prédites par des simulations présentant différentes scénarios d'aménagement. Une première évaluation a comparé quatre scénarios se distinguant par l'intensité de la sylviculture et la répartition spatiale des coupes à blanc. Cette comparaison a permis de démontrer que (1) la pratique actuelle (statu quo) permettait d'améliorer l'habitat de l'orignal au détriment de l'approvisionnement en bois, (2) tous les scenarios présentaient des risques de feu similaires, (3) tous les scénarios généraient des augmentations du débit de pointe et de l'apport en eau dans les bassins hydrographiques sélectionnés et (4) tous les scénarios avaient des impacts légers négatifs sur la biodiversité forestière. Les conditions forestières obtenues sous ces scènarios d'aménagement ont aussi été examinées en les comparant à celles obtenues sous un régime de perturbations naturelles, tel que simulé par ordinateur.

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Cette première série d'évaluations a mené à la création de nouveaux scénarios visant à équilibrer les risques de feu et les indicateurs de biodiversité avec les objectifs d'approvisionnement en bois. La comparaison de cette deuxième série d'evaluation a permis de raffiner les fonctions de compromis entre les valeurs forestières et ainsi de choisir le scénario à mettre en oeuvre. Il en résulte donc que le programme de surveillance et de recherch de la compagnie cible l'amélioration des modules de systèmes d'aide à la décision et les données sous-jacentes d'où son soutien pour le projet FORWARD « Forest Watershed and Riparian Disturbance » et sa participation à ce projet qui tient compte des effets de l'aménagement forestier sur les indicateurs des écosystèmes aquatiques.

Mots clés : système d'aide à la décision, gestion écologique, aménagement forestier, perturbation naturelle, indicateurs, développement durable des forêts, gestion adaptative.

[Traduit par la Rédaction]

Introduction

Millar Western Forest Products Ltd. (the Company) manages a publicly owned forest in west-central Alberta, Canada, approximately 120 km northwest of Edmonton. The forest (296 367 ha) is managed under a Forest Management Agreement (FMA) with the Government of Alberta. One requirement of the FMA calls for the Company to complete a government-approved detailed forest management plan (DFMP). The Company adopted the Government of Alberta's planning philosophies of sustainable forest management (SFM) and adaptive management into its DFMP.

Sustainable forest management builds upon traditional forest management and expands the time horizons (from one to many rotations), the spatial dimension (from stands and small forests to large landscapes), and the value array (from timber and selected wildlife habitat to biodiversity and social values). Thus, SFM has a larger scope of practice compared to the core of traditional forest management (Fig. 1). This demands that planning teams become larger and more interdisciplinary than planning teams of the past.

The desired outcome of SFM is a balance among conditions that are economically feasible, ecologically viable, and socially acceptable (Salwasser et al. 1993; Fig. 2). A broad-level goal of SFM in Canada is the long-term maintenance of forest ecosystem health (CSA 1996*a*, 1996*b*). Hence, SFM and its related concept of ecosystem management in the U.S. are associated with greater complexity and require trade-offs among value arrays. The large scope of SFM requires a commitment to continuous learning and improvement through a system known as adaptive management (Walters 1986; Noss 1993). Adaptive management begins with the selection and forecasts of measurable indicators of ecosystem health that can be monitored over time. An adaptive planning process is aided by computer simulations that occur over a period of hours (by an analyst), months (by a planning team), or years (by stakeholders). These virtual and real-world feedback loops illustrate how adaptive management nests within a SFM planning cycle (Fig. 3). The SFM cycle sets the strategic direction through the implementation of a selected management scenario based on information gained from the forecasting tools. Monitoring programs track the performance of the indicators and complete the loop by allowing for adjustment and re-calibration where required. Adaptive management forms a sub-level cycle within the forecasting component of the main planning cycle. Researchers generate knowledge to calibrate models that facilitate the adaptive planning loop of the virtual world and harness information gathered from the real world of the adaptive management loop. Model development and data collection reinforce one another in successive cycles of improvement.

Adaptive forest management, although it has scientific foundations, nests within other management systems that are more about politics than they are about science. Lee (1993) suggested that science is a compass and the politics of "bounded conflict" within democratic institutions is a gyroscope. A balance is defined by the nature of trade-offs made through scientific analysis and political process. The trade-offs between competing indicators such as old growth and timber supply become complex when the number of indicators increases under SFM. These trade-offs require the development of effective multi-objective decision support systems (DSS) (Rauscher 1999) designed to assist individuals and groups in their decision-making processes, support rather than replace the judgment of the decision-makers, and improve the quality, reproducibility and explicability of the decision process. Many of these models can be described as forecasting tools or DSS modules (Fig. 4).

This paper describes the development of a DSS for use in west-central Alberta. It provides an example of an approach that utilizes ecological data to manage forests and surface waters. The results generated from the application of the DSS are summarized and the implications for forest management and future DSS module development are discussed. This work is the basis from which new approaches will be devised by industry as part of the Forest Watershed and Riparian Disturbance (FORWARD) project.

Methods

Indicator assessment groups and decision support system modules

A group of specialists were commissioned by the Company to develop DSS modules to predict environmental responses to forestry activities over long planning horizons. The groups of specialists, called indicator assessment groups (IAGs), consisted of academic and other researchers, and practitioners assembled through an extensive personal solicitation process initiated by the Company.

The primary goal of the Company is to increase timber production from the forest without unduly compromising other forest values and forest use patterns. One IAG thus executed the

Fig. 1. The scope of sustainable forest management is based upon traditional forest management that is expanded outward on three axis: temporal, spatial, and values.

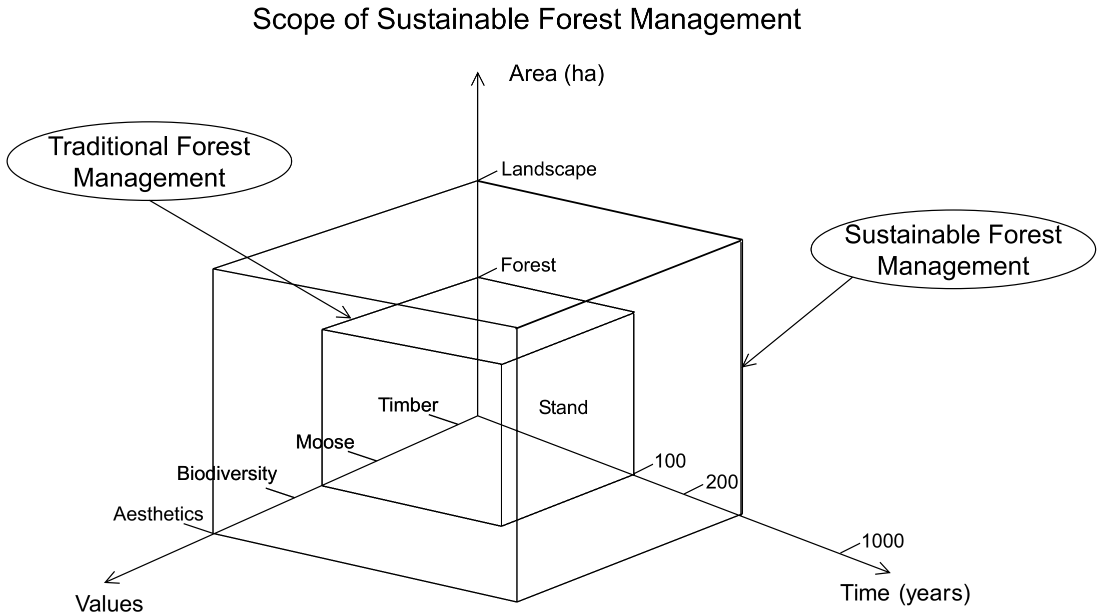
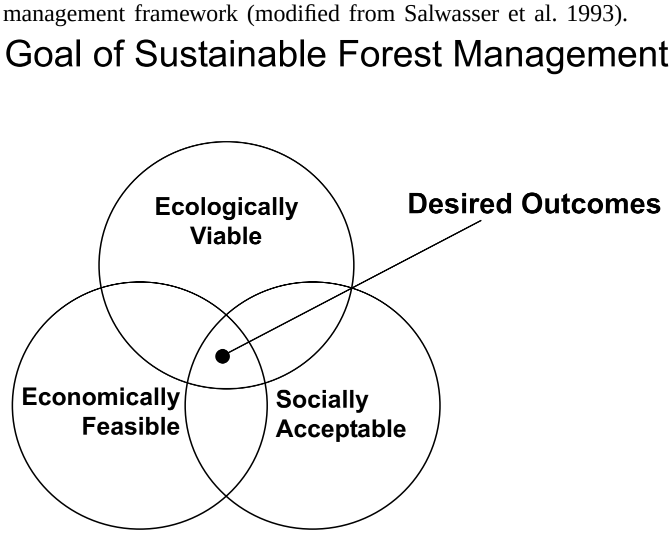


Fig. 2. The solution space defined within a sustainable forest management framework (modified from Salwasser et al. 1993).



timber supply analysis (TSA). The TSA evaluated the impact of forest management activities on existing and future wood supplies and was also responsible for making forecasts of future forest conditions, which were then evaluated by three other main IAGs. These included the biodiversity assessment project (BAP), the fire behaviour IAG (FIRE), and the water yield IAG (WATER).

The IAGs worked independently yet concurrently to develop their DSS modules (Fig. 5). The various simulation or forecast models received information from an assortment of biological and physical sources (e.g., climate, forest inventory, etc.), which helped to generate the range of biological and physical indicators. All DSS modules used input data describing the current forest environment and "snapshots" of future forest conditions produced from the TSA. The primary source of input data for each IAG was the current forest inventory, based on interpretation of aerial photography following the Alberta Vegetation Inventory (AVI) standard (Alberta Environmental Protection 1996). In addition to the AVI, the growth-and-yield program of the Company provided data to IAGs from approximately 600 temporary sample plots and a grid of permanent sample plots.

The harvest simulation tools used in the TSA were commercial harvest scheduling and forest growth projection models (i.e., COMPLAN; http://www.ormcanada.com and WOODSTOCK/STANLEY; http://www.remsoft.com). The remaining IAG process simulators and indicator models were either custom made (e.g., BAP) or adapted from existing non-commercial software (e.g., WATER and FIRE).

Development of management scenarios

A management scenario is a collection of rules and strategies regarding harvest scheduling and forest regeneration that drive the harvest simulator. These strategies were refined through successive rounds of indicator assessment until a single preferred strategy was identified to form the basis of the forest management program for the 10-year planning term. During each assessment round, preliminary assessments of forest process indicators were made and expert opinion was used to guide the development of successive management strategies until a preferred strategy was identified. Workshops and newsletters were used to facilitate development of successive assessment rounds. These rounds represent in practice the adaptive planning loop (Fig. 6).

For the purposes of this paper, only the first round of indicator assessments by all three IAGs (i.e., BAP, FIRE, and WATER)

Fig. 3. The concept of adaptive management is integrated within the sustainable forest management (SFM) planning cycle.

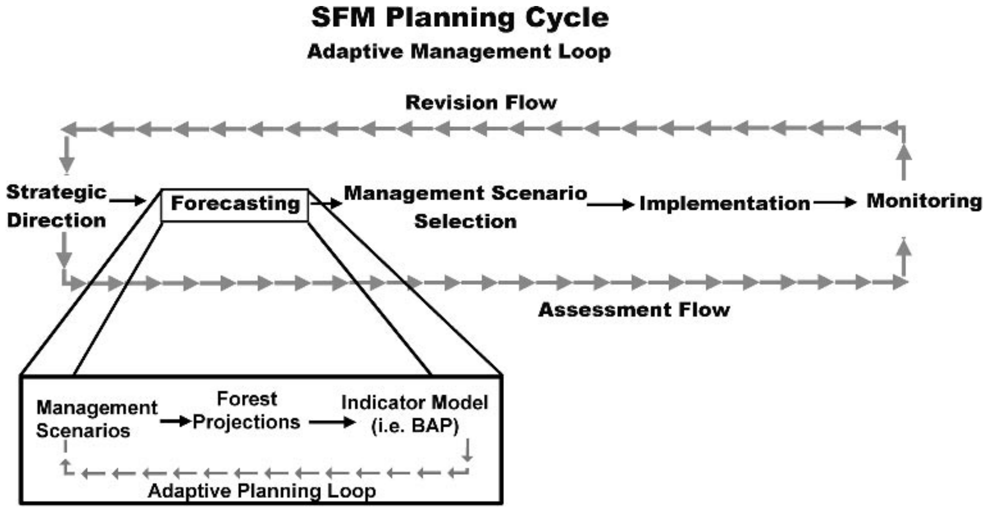
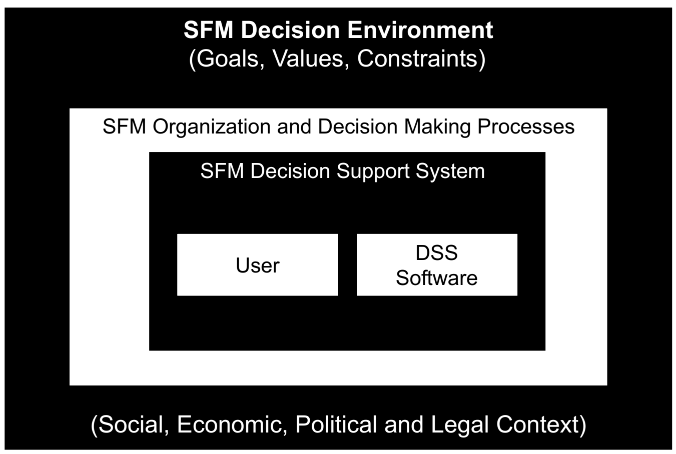


Fig. 4. A decision support system used within a sustainable forest management context fits within a management system that supports the broader management decision-making process (modified from Rauscher 1999).



are described. This round of assessment evaluated four management scenarios as follows: (1) business-as-usual (BAU), (2) adjusted spatial pattern (ASP), (3) intensive two-pass (I2P), and (4) enhanced timber production (ETP). The BAU scenario reflects the traditional timber harvesting and silviculture practices of the Company, which include a maximum cutblock-size of 50 ha. The ASP scenario was developed to determine the effect of eliminating cutblock size restrictions on the selected indicators. The silviculture practices used in this scenario are identical to those used in the BAU scenario. The I2P and ETP scenarios both include implementation of enhanced silviculture strategies. An enhanced silviculture strategy consisting of conifer tree planting, spacing, and thinning activities is expected to increase the conifer volume of timber available for harvest over the near and long term (Millar Western Forest Products 2000). However, in the I2P scenario cutblock size is restricted (as in BAU), whereas in the ETP scenario it is unrestricted (as in ASP). All of the strategies were to be implemented such that harvest levels were sustainable over the long term. The DSS was designed to explore the trade-offs associated with increased timber supply from larger cutblock size and intensive silviculture against biodiversity conservation, water yields, and fire risk reduction goals all under the constraints of sustained yield policies.

Biodiversity assessment project

The BAP included three levels of analysis: ecosystem, landscape, and species. The first two levels represented a coarse-filter and the species level represented a fine-filter approach to SFM as described by Hunter (1990). All levels involved the use of computer simulation models (Duinker et al. 2000). The ecosystem diversity and landscape configuration analyses were considered coarse-filter indicators, since they predict the condition of a set of forest features thought to consider broadly the basic habitat requirements of all forest species (Table 1). The ecosystem diversity statistics track changes in forest composition that may occur as a consequence of forest management. The landscape configuration indicators show the potential impacts of forest management on connectivity and fragmentation. Each of these configuration indicators was used to assess pat-

Fig. 5. Structure of Millar Western's management planning decision support system (DSS) showing the relationship between the DSS modules and impact assessment groups. Inputs are shown across the top and include historical weather/climate, topography, soil inventory, and forest inventory (AVI) data. Process simulators (dashed boxes) use input data to generate forest health assessment indicators (ovals) directly or by the application of indicator assessment group models (heavy outlined boxes).

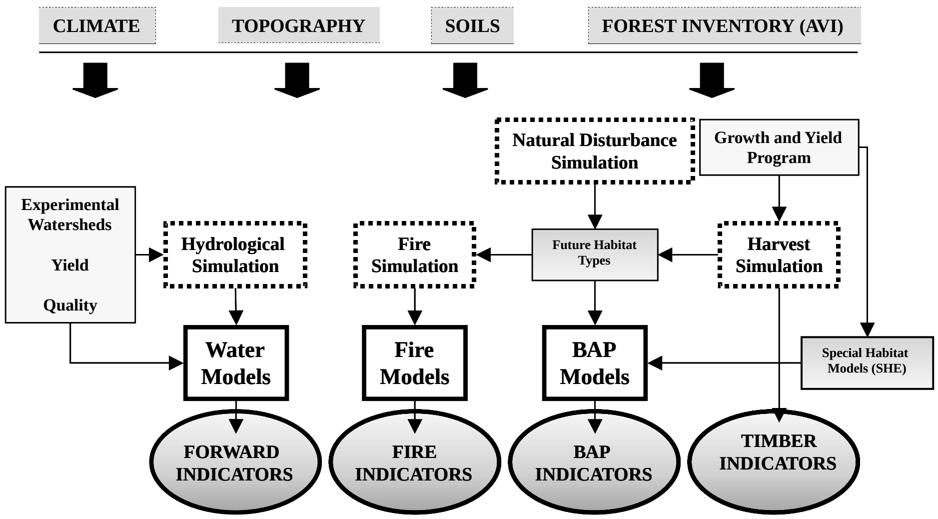


Fig. 6. Forecasting of indicators that measure ecosystem health, followed by plan implementation and monitoring of selected indicators, form the basis of an adaptive management cycle.

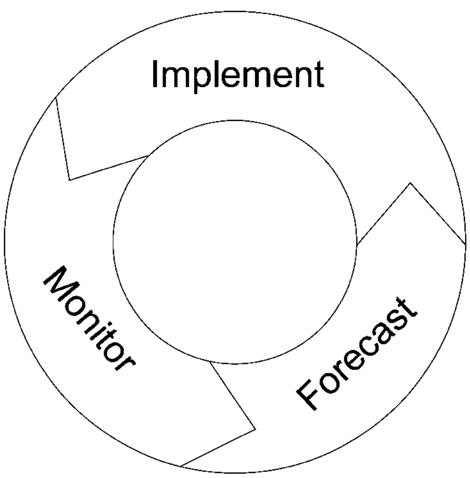


Table 1. Coarse-filter indicators.

Ecosystem diversity	Landscape configuration
Area-weighted age	Patch area
Tree species presence	Patch shape
Tree species dominance	Mean edge contrast index
Habitat diversity	Contrast weighted edge length
	Core area
	Patch adjacency
	Mean nearest neighbour

terns associated with each combination of forest habitat type and developmental stage (Doyon 2000*a*). At one scale of analysis, broad habitat types included hardwood, hardwood mixed, conifer mixed, and pure conifer stands. Developmental stages were classed as open, developing forest, or old. A more detailed analysis was also conducted based upon more refined habitat types (19 forest cover types) and six developmental stages.

Detailed (i.e., fine-filter) analyses were based upon wildlife species habitat supply models (HSMs). Such models have been used frequently in Canada to identify the potential impacts of forest management activities on the spatial and temporal distribution of wildlife habitat (Higgelke et al. 2000). In selecting the species to be studied under BAP, each terrestrial vertebrate on a preliminary list of 76 species was given a ranking describing its suitability as an indicator (Doyon and Duinker 2000*a*). This process allowed the BAP team to select a group of 17 species for which HSMs were created (Table 2). The HSMs are based on habitat suitability index models (HSIs) that provide a quantitative ranking (from 0.0 to 1.0) of the habitat capability for a particular wildlife species for a given time. Habitat suitability index models are spatially limited and provide only a snapshot in time of habitat capability. The HSMs used in this work expand on the basic principles of HSIs, with the addition of both spatial (using geographic information systems (GIS) techniques) and temporal (using simulation techniques) dimensions to facilitate long term, home range size interpretations of wildlife habitat capability. The inclusion of spatial considerations permits wildlife species–specific distance dependent relationships while the temporal dimension incorporates forest growth and time-dependent habitat changes (Higgelke et al. 2000).

The natural range of variation for each coarse-filter (i.e., broad scale) indicator was estimated with the use of the computer model LANDIS (Mladenoff et al. 1996; Doyon 2000*b*). LANDIS simulates the effects of natural succession and disturbance on forest composition and structure in the absence of human interference. It was assumed that the coarse- and fine-filter models would be correlated so that lessons learned from

Table 2. Species list of habitat supply models developed for BAP.

Birds	Mammals
Barred owl (*Strix varia*)	Canada lynx (*Lynx canadensis*)
Brown creeper (*Certhia americana*)	Elk (*Cervus elaphus*)
Least flycatcher (*Empidonax minimus*)	Marten (*Martes americana*)
Northern goshawk (*Accipiter gentilis atricapillus*)	Moose (*Alces alces*)
Pileated woodpecker (*Dryocopus pileatus*)	Northern flying squirrel (*Glaucomys sabrinus*)
Ruffed grouse (*Bonasa umbellus*)	Snowshoe hare (*Lepus americanus*)
Three-toed woodpecker (*Picoides tridactylus*)	Southern red-backed vole (*Clethrionomys*) *gapperi)*
Varied thrush (*Ixoreus naevius*)	Spruce grouse (*Dendragapus Canadensis*) *franklinii)*
	Woodland caribou (*Rangifer tarandus caribou*)

Note: BAP, biodiversity assessment project.

comparisons of the coarse-filter results to the natural range of variation could be applied to the fine-filter models. In addition, a "snapshot" of simulated landscapes projected to occur after a 200-year period of natural fires was used as a benchmark value for fine-filter indicators. The 200-year period was designed to "erase" the current forest management legacy imprint on the landscape pattern shown in the forest inventory data (Doyon and Duinker 2000*b*).

Fire behaviour impact assessment group

The dynamic indicator assessment for wildfire considered the risk of catastrophic fires emanating from landscape patterns associated with alternative management strategies. For each forest management scenario, a "snapshot" of the landscape was obtained at 10-year intervals. Based on the Fire Behaviour Prediction (FBP) System, each stand was classified in terms of its fuel type according to species composition and average stand height. An evaluation of how each of the four round 1 forest management scenarios would influence the fire behaviour potential of the landscape was conducted based on the fuel type maps for each scenario at 50-year intervals over the 200-year simulation. The area of each fuel type within the FMA area was calculated. An assessment of each fuel type map was conducted to determine the distribution and continuity of highly flammable fuels. In addition to knowledge of fire incidence, fire weather, and fire behaviour patterns, this information was used to assess qualitatively how each scenario might influence the potential size of escaped wildfires.

Water yield impact assessment group

The WATER assessed impacts on water resources for three watersheds, unlike BAP and FIRE, which assessed impacts on the entire forest landscape. Watersheds, as opposed to the FMA area administrative boundary, are a more logical unit of study in terms of impacts on water resources and are of a scale more appropriate for the assessment tools used in this study.

The effects of timber harvesting on water flows were assessed using the Water Resource Evaluation for Non-Point Silvicultural Sources – Model Forest version (WRENSS-MF) (U.S. Environmental Protection Agency 1980; Swanson 1997). This procedure was initially developed by the U.S. Forest Service and the U.S. Environmental Protection Agency, and later adapted for use in Canada. A WRENSS-MF uses long-term monthly precipitation and annual stream flow data from representative watersheds. GIS-generated harvest data, watershed characteristics, and forest-tree growth functions were used to estimate changes in annual water yield and peak flow due to timber harvesting for the 2-, 10-, 20-, 50-, and 100-year return periods. Simulations of the harvesting effects on water flows were done for three basins fully within the FMA area (Chickadee, Hurdy, and Bessie creeks) (Fig. 7). These basins all form tributaries to the Athabasca River and are upstream of the town of Whitecourt.

Two management scenarios (BAU and ETP) were simulated on each of the three watersheds. All cutblocks (i.e., past, present, and future) were identified and categorized based on size, aspect, and species. In the simulations, WRENSS-MF calculated seasonal water balances for each cutblock, thus determining the change in evapotranspiration with timber harvesting for each year of the simulation period. These values were then area-weighted and summed to give an annual change in water yield. Relative changes in water yield were based on comparisons to a gauged representative basin in the region (Chickadee Creek).

Results

A small sample of IAG findings for the first round of assessments is reported here to illustrate their application in the evolving DSS. For example, BAP models produced more than 2000 indicator-by-parameter combinations. An indicator such as patch area has associated descriptive statistical parameters that include the mean or standard deviation of patch area.[5]

Biodiversity assessment project

After an 80-year period of implementing the selected strategies associated with each scenario, the area-weighted age of I2P- and ETP-managed forest exceeded that of BAU- and ASP-managed stands (Fig. 8). It is expected that a greater volume of timber could be removed from smaller areas of the forest through intensive management, maintaining a higher overall average age. These enhanced-silviculture-intensity strategies

[5] A complete listing of indicators/parameter combinations produced by the BAP models is available from http://www.kbm.on.ca/bap.

Fig. 7. Map of watersheds showing Chickadee (220 km^2), Hurdy (74 km^2), and Bessie (73 km^2) creek basins.

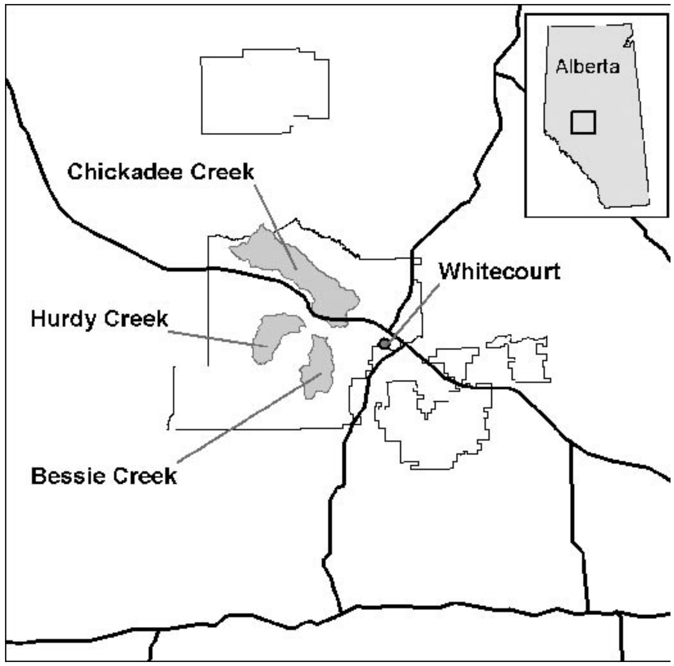


Fig. 8. Area-weighted age comparison under BAU, ASP, I2P, and ETP scenarios.

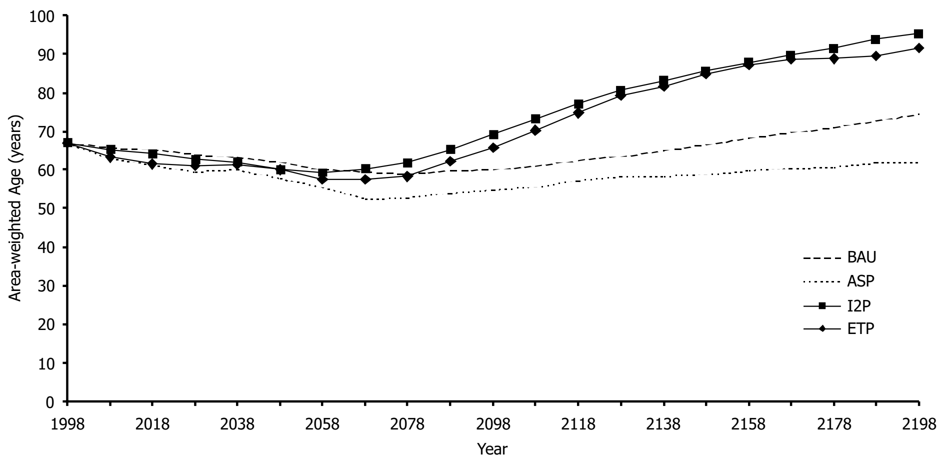
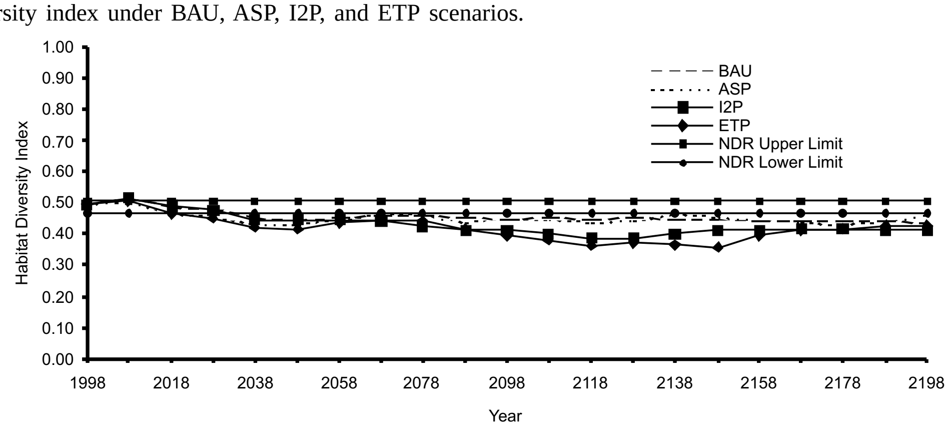


Fig. 9. Habitat diversity index under BAU, ASP, I2P, and ETP scenarios.



would benefit plant and animal species that require older forest structures, provided that harvest levels are not increased in the future. Over time, habitat diversity falls below the range of natural variation as derived from LANDIS in all scenarios (Fig. 9). The I2P and ETP systems tend to replace mixedwood forests with conifer-dominated stands that contribute to a lower habitat diversity index. Conversely, stands managed under the BAU and ASP scenarios maintain a relatively more constant tree species composition over time.

Total edge length is dependent on cutblock size – smaller cutblocks result in more edge. As expected, the restricted cutblock size of the BAU and I2P systems resulted in higher edge density than the unrestricted ASP and ETP scenarios. Edge statistics also take into account the contrast between two adjacent habitat types. Mean edge contrasts due to species differences decreased with use of the I2P and ETP systems. The proposed silvicultural practices favour conifers, and therefore increase forest uniformity in terms of species composition. When these effects were combined, BAU clearly created more edge and contrast compared to the other scenarios (Fig. 10). This condition is favourable to species like moose.

The current policy that has been in effect for the last 30 years (BAU) has been successful at increasing edge by limiting cutblock size and incorporating a two-pass system to improve moose habitat. However, the trends show that the footprint from these policies will last another 60 years before the effects from implementing new strategies become detectable (Fig. 10). In the fine-filter analysis, the HSMs for moose forage under severe winter conditions indicate that BAU supplies more suitable habitat than expected under natural disturbance regimes (NDR) and ETP (Fig. 11). The effects of the different management scenarios on moose cover are less apparent (Fig. 12). However, the TSA found that BAU produces 16% less timber than does ETP (Millar Western Forest Products 2000). Thus, one of many quantifiable trade-offs has been identified and management decision-making becomes better informed through the application of the DSS.

The LANDIS simulations indicated that from 0.5 to 1.4% of the landscape burned every year (Doyon 2000*c*). The projected harvest levels of all management scenarios is approximately 1% of the landscape, due to the long-run even flow of timber or sustained yield constraint associated with each scenario. This constraint has been the backbone of forest policy in Canada for many decades and the results for the BAP analyses seem to support the policy in terms of limiting forest management impacts on biodiversity. Of course, the assumption is that the harvest disturbance rate replaces fire. Given the complexity of modeling stochastic events like wildfire in a deterministic environment associated with harvest scheduling, the Company made a commitment to initiate a new plan if fire and harvest combined to generate a total disturbance area that exceeded 3% of the forest area during the planning term.

Fire behaviour impact assessment group

None of the scenarios in round 1 reduced fire risk. Fire behaviour research suggests that fire risk differs with tree species composition and geographic position of the stand (e.g., Hely et al. 2000; Wang 2002). In general, coniferous stands are thought to burn more readily than deciduous or mixedwood forests. Prevailing winds and topography-related microclimatic variations, none of which change with forest management, also influence burn patterns. Forest management activities associated with Round 1 did not change species composition and arrangement enough to affect fire risk.

Water yield impact assessment group

The WATER modeling results showed increases in annual water yield and peak runoff following timber harvesting. Maximum increases in annual water yield on the three basins for the BAU scenario ranged from 11 to 19%, generating an extra 17–28 mm of runoff over a 150-year period. Increases in annual water yield for the ETP scenario were larger. Annual water yields were increased by 23–29%, which produced an extra 35–44 mm of runoff. The increases in annual water yield for the ETP scenario exceed the 15% provincial guideline. This result is a reflection of more frequent and extensive timber harvesting on the watersheds despite the increase in conifer cover that usually reduces water yield through increased interception. These simulations, however, were based only on the final harvest cut and do not reflect the effects of planned thinning. Incorporation of the effects of intensive management into the simulations is expected to reduce the impacts on water yield. These expectations are based on the assumption that intensive silviculture will increase growth rates and shorten the time for hydrologic recovery of the watersheds.

Maximum increases in peak runoff for both timber harvest scenarios ranged from 2 to 20%, with the greatest changes coinciding with the period of maximum harvesting. The largest increases occurred with the shorter-return-period events (2 year) and the smallest increases with the longer return periods (10–20 year). Increases for the ETP scenario were 4–5% greater than increases in the BAU scenario. The difference is a reflection of more timber harvesting in the ETP scenario. The magnitude of these increases falls within the normal range of variability for streams in the region.

Discussion

Together, the coarse- and fine-filter biodiversity statistics and models assisted the planning team to determine the potential long-term effects of alternative management strategies on forest biodiversity. The results are also being used to help set priorities for research and monitoring to reduce the uncertainty associated with biodiversity conservation.

Forest management practices in Alberta over the last 30 years consisted of two-pass cutting and restricted clearcut sizes aimed at creating more edge to favour selected species like moose. Relaxing these restrictions decreased edge and moose habitat values as determined by the HSMs, but significantly improved

Fig. 10. Contrast-weighted edge length index under BAU, ASP, I2P, and ETP scenarios.

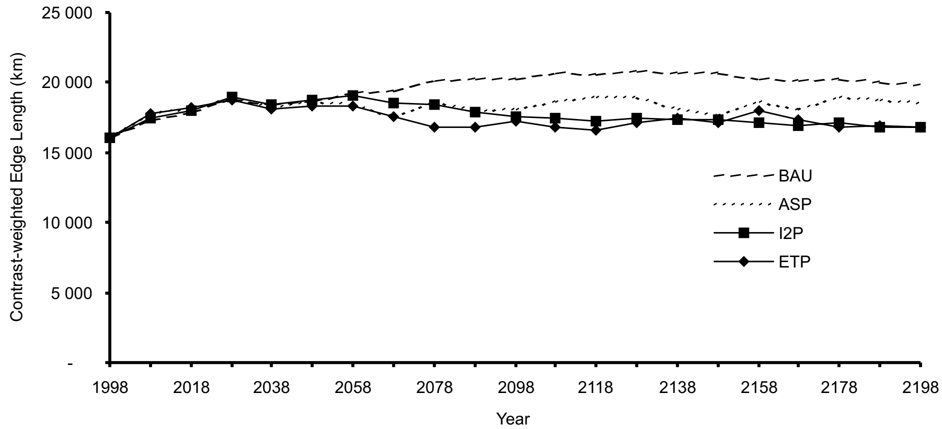
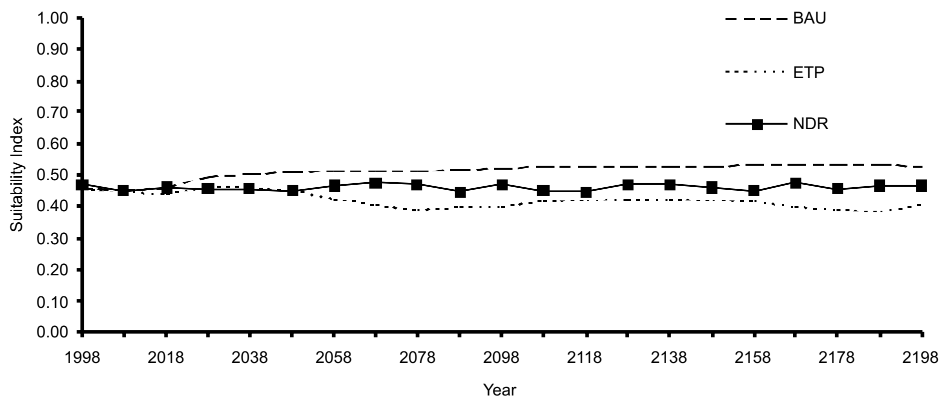


Fig. 11. Mean moose forage habitat suitability under severe winter conditions among BAU, ETP, and NDR scenarios.



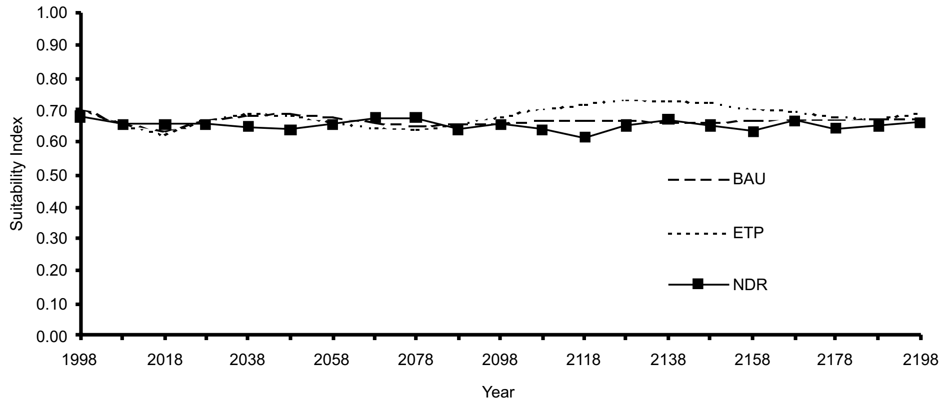
wood supply. Intensive silviculture practices had a greater negative effect than did relaxing cutblock-size restrictions. In addition, intensive silviculture had less immediate effects upon wood supply than did relaxing the cutblock restrictions. The planning team in successive rounds of analysis found a level of silviculture effort and cutblock-size restrictions that allowed for increased harvest levels without a significant deterioration of wildlife habitat. Although this example describes moose habitat, the same care was extended to include all 17 selected species. The above trends guided the development of new scenarios eventually leading to one selected for implementation that tended to balance wood supply goals with favourable impact assessment indicator trends.

Some important scientific questions remain unanswered through the analyses that were used to make management decisions. For example, at what point does an increase in edge density become important in terms of moose carrying capacity or population density? These relationships deserve further study. Nonetheless, the management questions and the analytical framework used here help better define research agendas for the future compared to past practices where natural science initiatives were separated from management practices. Perhaps a new linkage between science and practice will prove to be the legacy of the adaptive management paradigm.

The HSMs allowed the planning team to generate maps of current and future wildlife habitat quality. These maps engaged the public in meaningful discussions at open houses to allow input to the planning process. Other indicators were more meaningful to resource professionals and scientists but were beyond the understanding of the public. During model development, each HSM was peer reviewed by two independent experts. A series of independent model validation projects are currently underway. The preliminary findings are testing both the knowledge of these species' life history and habitat requirements and the integrity of the models. Improved models will be applied during the next planning exercise.

The large scope of BAP generated a tremendous volume of output. Multivariate analyses of these outputs are underway to reveal which coarse- and fine-filter indicators are most responsive to forest management practices. These indicators will be the focal point of future monitoring and research efforts. The BAP team is also developing landscape design ideas that may further conserve biodiversity in a forest managed primarily to increase timber production. These ideas will be transformed in the next planning process into forest structure targets such as the appropriate amount and distribution of old growth. For example, the LANDIS simulations indicate that under natural fire regimes, about 15% of the landscape forest cover should

Fig. 12. Mean moose cover habitat suitability under severe winter conditions among BAU, ETP and NDR scenarios.



be old growth (>150 years). Forest planners should consider either conserving or managing 15% of the forest under long or extended rotations (Doyon 2000*b*). This strategy of emulating natural disturbance regimes is becoming a dominant theme in SFM and is predicated on the assumption that by following nature's lead, most of the known and unknown biological pieces will be conserved (Andison 2000).

Fire indicators were simple and easily interpreted in terms of relative value compared to the BAP indicators. That is, most agree that lower fire risk is preferred; however, it was harder to reach consensus on the appropriate amount of habitat for a particular species. These conditions allowed landscape design ideas to be developed and tested early in the planning process in response to round 1 results.

Since no management scenario in round 1 reduced fire risk, the FIRE group created a "fire-smart" strategy, called the landscape fire control (LFC) scenario. This scenario helped identify the best patch distribution and changes in species composition on the forested landscape to create natural firebreaks. It was found that to reduce the spread potential of large wildfires without completely eliminating the coniferous forest, there is a need to locate fuel treatments strategically (mainly species conversion from conifer to aspen or mixedwood and fuel reduction) to create barriers to fire spread. This approach compartmentalizes the forest into distinct fire units. It is analogous to having fire doors in a building, which block fire spread to other parts of the building. This fire door effect could be accomplished by creating large cutblocks (in strategic locations and with adequate islands, edge effects, etc.) in conifer areas and converting the conifer to less flammable deciduous and mixedwood forests. Thinning of conifer stands as a fuel conversion process would also be beneficial. The southeast portion of the FMA area has a relatively low fire risk because of the large deciduous component. This means that it may be possible to manage the interior of this block for more conifers while maintaining deciduous stands around the perimeter that serve as fire breaks.

Subsequent computer simulations demonstrated that LFC reduced fire spread. The Canadian Forest Service is continuing the research inspired by this DSS module (e.g., Hirsch et al. 2001). Fire-smart ideas influenced the development of the final management strategy. In addition, a working relationship between the Canadian Forest Service and the Company staff identified practices to reduce the risk of catastrophic wildfire events.

A comparison of the relative increase in water yield that resulted from each of the two timber harvesting scenarios illustrates the effect of timing and area harvested on water yield. If harvesting is concentrated in time, water yield responses will be greater than if the same area is harvested over a longer period. More time allows greater hydrologic recovery by regeneration. The spatial arrangement of harvest blocks is also important but not accounted for in the modules within the existing WATER DSS module. Large cutblocks can promote snow loss, whereas smaller cutblocks will enhance snow accumulation and water yield response. Harvesting blocks located on lower slopes have a greater potential than those on upper slopes to increase yield and peak flow responses. The temporal and spatial planning and arrangement of timber harvesting are the primary tools used to manage the effects of harvesting on water yield and peak flows. This is especially important if water-yield increases are constrained by specific limits set by regulatory bodies such as the Alberta Government.

Simulations showed that the BAU scenario has a smaller effect on water yield than the ETP scenario. However, the magnitudes of the increases in water yield were judged to be modest and comparable to the findings of watershed research studies done in the region. The addition of the increases to existing flow regimes were well within the normal range of variation for annual flows in the region.

The relationship between water yield and peak flow after harvest and the proposed management scenarios were described in a due-diligence fashion. However, the selected indicators, although easy to model and monitor, were insufficient to suggest landscape designs or threshold values related to risks to aquatic ecosystem health as was the case in the biodiversity assessment. Given the magnitude of water yield response to forest management relative to other indicators evaluated, it became clear to the planning team that this DSS module needed further development. This realization led to the research initiative FORWARD, as described elsewhere in this journal (see Smith et al. 2003).

All of the DSS modules used a limited amount of data for initial calibration of the models. The data were either collected from field samples as part of the growth-and-yield work to support the TSA or from sources that were readily available from other agencies such as the Government of Alberta. The emphasis on model building as a starting point allowed results to be generated in time for use in strategic planning and helped guide future data collection priorities.

In general, scientists prefer data-guided model development rather than model-guided data collection. Although the former is arguably more objective, it rarely can contribute to real-time planning needs. As better data are collected, all of the DSS modules are expected to evolve over time through successive planning cycles. This process is a good example of adaptive management in action.

Despite the advances made through the planning process, the results of the indicator assessments viewed in isolation of the larger landscape and other resource sectors such as oil and gas will limit the effectiveness of the resulting forest management program in protecting important forest values. Despite efforts made by the planning team, companies on adjoining license areas chose not to participate in the indicator assessment activity and DSS module development. The Government of Alberta is now leading an integrated resource management initiative and the Company is bringing its experience to the table in an effort to overcome these limitations.

Conclusions

The Company developed a DSS and applied it successfully in a real-time detailed forest management planning exercise to find a balance between environmental concerns and timber supply goals. Four DSS modules evaluated indicators related to timber supply, terrestrial biodiversity, fire risk, and water quantity of forest streams. Forecasts of future forest conditions made in the timber supply module were evaluated by applying the other modules through successive rounds of scenario design and testing until a balanced program could be identified and selected for implementation, although only selected portions from the first round are reported here.

The design and application of the DSS represents an interpretation of SFM and adaptive management, the current paradigms espoused by government agencies across Canada. The advances reported here were made possible through the support and leadership displayed by the Company, cooperation from the Alberta Provincial Government, and by the mixture of skills assembled in the IAGs that created the modules and interpreted the outputs. The experiences gained from the planning process are focusing the research and monitoring program of the Company. A focal point of this program is the FORWARD project as discussed in the special edition of this journal (see Smith et al. 2003). In turn, the focus of FORWARD is to enhance the management program of the Company. This interplay is a concrete example of adaptive management in action.

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