The Canadian Ecology Centre – Forestry Research Partnership: Implementing a research strategy based on an active adaptive management approach

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ABSTRACT

Between April 2000 and March 2007, the Canadian Ecology Centre – Forestry Research Partnership funded, directed, or catalyzed approximately 145 projects. Most of these focused on knowledge and data acquisition, providing a solid foundation for a series of sensitivity and gap analyses to determine whether a long-term goal of enhancing productivity on 6 forest management units in Ontario was achievable, and more importantly, sustainable. A research strategy provided the focus for knowledge and data acquisition and the partnership facilitated integrated research, development, transfer, and implementation. Here we provide an overview of this effort, which is expected to position forest managers of the 6 forests to apply an adaptive management process to increase understanding of the response of their forests to various forest management policies and practices in the future. The strategy and approach described could be useful to other jurisdictions aiming to more closely integrate forest research and operations as well as those interested in implementing adaptive management.

Key words: forest ecology, forest economics, forest inventory, forest management

RÉSUMÉ

D'avril 2000 à mars 2007, le Centre écologique du Canada – Partenariat pour la recherche forestière a financé, dirigé ou catalysé près de 145 projets. La plupart d'entre eux étaient centrés sur l'acquisition de connaissances et de données, afin de constituer une base solide d'une série d'analyses de sensibilité et des écarts pour déterminer si un objectif à long terme d'accroissement de la productivité de 6 unités d'aménagement forestier de l'Ontario était atteignable et, plus important encore, durable. Une stratégie de recherche a été au cœur de l'acquisition de connaissances et de données et le partenariat a facilité la recherche intégrée, le développement, le transfert et l'implantation. Nous présentons ci-après un sommaire de ce travail, lequel devrait permettre aux aménagistes forestiers des 6 unités forestières de mettre en pratique un processus d'aménagement adaptatif visant à accroître la compréhension des réactions de leur forêt face aux différentes politiques d'aménagement forestier et aux diverses pratiques utilisées dans un proche avenir. La stratégie et l'approche décrites pourraient être utiles à d'autres juridictions cherchant à intégrer plus étroitement la recherche forestière et les opérations, ainsi qu'à tous ceux intéressés par l'implantation de l'aménagement adaptatif.

Mots clés : écologie forestière, économie forestière, inventaire forestier, aménagement forestier

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Introduction

Forest research in Ontario is designed to serve sustainable forest management goals and legislative responsibilities (Baker 2000a) and the research conducted by the Canadian Ecology Centre-Forestry Research Partnership (CEC-FRP[6]) is no exception. Initiated in 1999, the goal of the CEC-FRP is to enhance productivity on 6 forest management units in Ontario by 10% in 10 years (the 10/10 goal) (Bruemmer 2008, this issue). By applying existing knowledge and acquiring new knowledge within an adaptive management framework, the likelihood of achieving this goal could be evaluated. In Ontario, such an adaptive management approach has been used to develop and test provincial forest management policies (Baker *et al.* 2000a, b), but has yet to be used to develop and test goals and objectives at the level of a sustainable forest licence.

The CEC-FRP considers adaptive management as a formal process to deal with uncertainties in implementing policies and management practices in the "real" world of operational management. It can be broadly described as a sequence of 4 to 9 steps (Appendix A); however, the following 6-step sequence is being used by the CEC-FRP:

1. Assess sustainability by defining the management problem clearly, and in terms of ecosystem function rather than preconceived management solutions,
2. Design, plan, and formulate best management practices by exploring the potential effects of alternative policies (solutions),
3. Implement management policies and best management practices,
4. Monitor responses of key indicators over appropriate time frames and spatial scales using sampling designs that will provide reliable information and will enable tests of alternative hypotheses about forest ecosystems,
5. Evaluate the effects of policy options by analyzing and evaluating data, and
6. Revise goals and objectives using the resulting information (Fig. 1).

Adaptive management approaches can be considered as a continuum from reactive to active (Baker 2000b, Duinker and Trevisan 2003, McAfee *et al.* 2006). Active adaptive management, which is the level intended by the CEC-FRP, is the deliberate, experimental evaluation of several policy/practice alternatives, accomplished by implementing them simultaneously and comparing their outcomes (McAfee *et al.* 2006). This formal process requires the use of existing knowledge to pose potential alternative strategies/policies/practices that might achieve a specific management outcome such as the CEC-FRP's 10/10 goal.

The objective of this paper is to introduce a 2-phase research strategy implemented by the CEC-FRP towards achieving the 10/10 goal and reducing major risks and uncertainties related to managing forests in Ontario. In Appendix A, we provide brief reviews of adaptive management, knowledge synthesis, controlled experimentation, and monitoring for those who may not be familiar with these research approaches and to define our use of these terms.

[6]The CEC-FRP is a partnership between Tembec Inc., the Ontario Ministry of Natural Resources (OMNR), Natural Resources Canada (NRCan) and the Canadian Ecology Centre (Bruemmer 2008, this issue). Its mission is to identify, develop and implement ecologically sustainable and scientifically defensible leading edge forestry practices required to maintain and enhance an economically viable supply of quality fibre to Tembec mills, and to the communities those mills support, over the long term. (CEC-FRP 2000).

The CEC-FRP Approach to Achieving the 10/10 Goal

Holling (2001) suggested that "*Science had become narrowed by publishing traditions, by bureaucracy, by traditions of granting agencies, and by politics. Not really useful fun any more. Lots of bricks but not much architecture to develop an understanding of interrelationships. Good biology, good physics, good economics, good social science, but not sufficient integrative science and integrative experience*." The CEC-FRP approach was a sharp deviation from that norm. Rather than requesting, screening, and funding $1 million worth of project proposals annually, after 6 months of careful deliberation, the CEC-FRP chose to develop a focused, integrative approach to advancing knowledge based on the concept of adaptive management as defined by Baker (2000b).

The first initiative, funded in part by the CEC-FRP, was the *Intensive Forest Management (IFM) Science Workshop* held December 1999. The impetus for the workshop was the provincial government's decision to increase the area in parks and protected areas in the province (OMNR 1999a), which necessitated a reduction in the landbase available for forest management. The goal of the workshop, organized in response to commitments made in the 1999 Ontario Forest Accord (OMNR 1999b), was to explore the assumption that more intensive silviculture could be used to offset those reductions by identifying what was known about IFM and what additional knowledge was needed to adapt it for use in Ontario's forests (Bell *et al.* 2000).

Workshop participants recommended establishing clear definitions for IFM and provincial forest resource objectives and developing wood supply, silviculture, protection, monitoring, and science and information strategies. Both the workshop participants and the CEC-FRP partners recognized that extensive general knowledge and experience related to intensifying forestry existed, and strongly recommended working towards implementing this knowledge. They also recognized that this could be accomplished using a research strategy embedded in an adaptive management cycle (Bell *et al.* 2000). The premise was to identify current knowledge and knowledge gaps related to assessing the effects of intensifying forestry on wood supply, economics, and/or biodiversity. Thus, the CEC-FRP developed a framework for science and information needs that would capture existing knowledge, provide direction and linkages to acquire new knowledge, identify sources of critical uncertainty, and thereby determine future research foci (Fig. 2).

As the partners developed the framework, they recognized that impediments to achieving the 10/10 goal might in the end not be due to a lack of knowledge but rather, for example, to policy barriers or failure to operationally implement the available knowledge. Although these potential impediments were not explicitly identified in the framework, it was expected that they would emerge during the course of implementing the research strategy and as products were produced from the research plan. Also recognized was that other factors

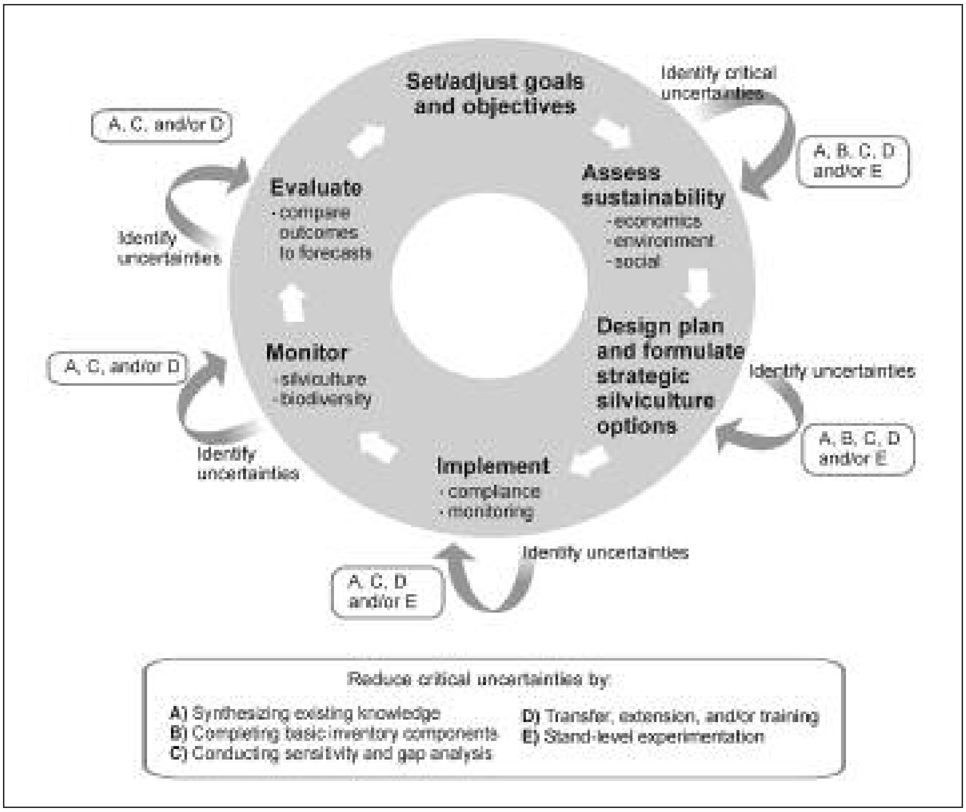

Fig. 1. An active adaptive management cycle indicating points of critical uncertainty and means by which those uncertainties can be reduced (adapted from Bell and Baker 2006).

not considered within this framework, such as climate change, social values, and markets, would influence the outcomes related to the 10/10 goal.

The 2 phases of the research strategy are (1) the FRP projects phase and (2) the IFM process phase (Fig. 2). The first phase focused on projects that involved synthesizing knowledge, completing basic inventory components, conducting sensitivity analyses, identifying critical uncertainties, initiating new research, and transferring knowledge. During this phase, researchers focused on addressing true knowledge gaps and maximizing returns on research investments. During the second phase, researchers will focus on incorporating what has been learned during the project phase into the forest management planning process and management plans through active adaptive management and will help to develop monitoring and evaluation programs.

Phase 1: Forestry Research Partnership Projects

Based on the strategy, the CEC-FRP funded, directed, or catalyzed approximately 145 projects between April 2000 and March 2007. Most were focused on data and knowledge management to provide a solid foundation for a series of sensitivity and gap analyses that would help to determine whether the CEC-FRP 10/10 goal was achievable from the 6 partner sustainable forest licences (SFLs) and, more importantly, sustainable. The following is a brief description of select projects undertaken within each component of the framework identified in Fig. 2.

Synthesize knowledge

During the decades preceding the signing of the 1999 Ontario Forest Accord, substantial changes occurred in forestry in Ontario (Armson 2001, Wagner and Colombo 2001). More effort was focused on fire, insect, and disease control with the rationale that increased investments warranted additional protection. Utilization standards increased to the point where most fibre was useable. The development of aspen (*Populus* spp.) markets and the implementation of full-tree logging with roadside chipping operations were but 2 examples. Nurseries expanded, were privatized, and forest industry now custom orders a broad array of stock types. Nursery stock survival and performance also increased (Greene *et al.* 1999). Gains were made in tree improvement with the first generation becoming the standard for the basic silvicultural program across most SFLs (Joyce *et al.* 2001) and mixed-species plantations became far more common (Légaré *et al.* 2005). Efforts were also made to increase growth by ensuring that crop trees received a much greater proportion of site resources through site preparation (Ryans and Sutherland 2001), vegetation management (Thompson and Pitt 2003), and density regulation (Bell *et al.* 1990; Sharma *et al.* 2008, this issue).

During the same period, extensive research programs were carried out by the Ontario Ministry of Natural Resources (OMNR) and Natural Resources Canada (NRCan) (see D'Eon 1999). Under these programs, substantial efforts were made to improve forest protection, utilization, and silviculture. Participants of the 1999 IFM science workshop noted that a plethora of research results existed in filing cabinets, computer files, and publications. Journal articles, technical reports, file reports, and well-documented older field trials all contained information and experiences that were used to build the foundation for the CEC-FRP research strategy.

The need to "inventory" this new knowledge and make it available to forest managers in an accessible, useful format was deemed critical. The intent of conducting such an inventory would support the objectives of the research strategy in many ways. It served to (i) accelerate the incorporation of existing knowledge into operational best management practices, (ii) identify management options supported by "weight of evidence", (iii) enhance awareness of environmental issues associated with preferred practices, (iv) provide data and informa-

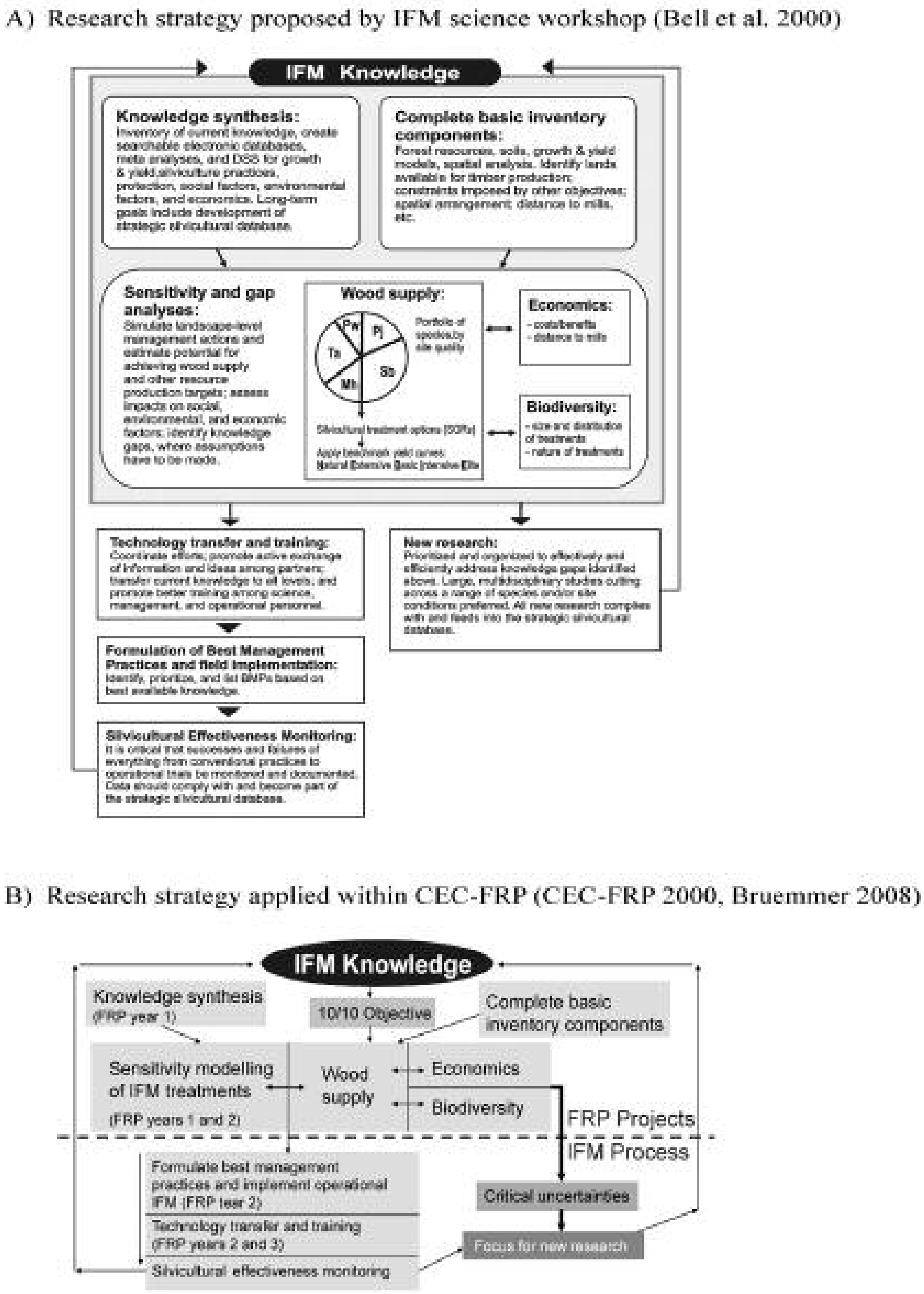

Fig. 2. The research strategy proposed at an intensive forest management workshop (a) evolved into the general research strategy (b) applied within the CEC-FRP (CEC-FRP 2000).

tion for meta-analyses (e.g., growth-response, crop tolerance), (v) identify data gaps and research opportunities, (vi) provide the basis for decision support and future artificial intelligence systems, (vii) provide direct links to related data and information sources, and (viii) facilitate forest certification.

Thus, the initial focus of CEC-FRP efforts was to generate inventories of available knowledge and create searchable electronic databases, meta-analyses, and decision support systems (DSS). Knowledge syntheses focused on information related to enhancing fibre yields through protection, harvesting, and silviculture and the effects of these practices on ecosystem sustainability. Since much of the information was not synthesized, simply gathering and compiling it was a monumental task. Several reviews were completed, including a synthesis of yield response of 4 conifers to tree improvement (Newton 2003), a meta-analysis of tolerant hardwood research (Cole *et al.* 2005), and a synthesis of historic data on major insects and diseases of spruce, pine, and aspen in eastern Canada (De Groot *et al.* 2005). The synthesis of tree improvement programs indicated that first-generation selection strategies could increase merchantable productivity by approximately 13% at 50 years for black spruce, 28% at 40 years for jack pine, and 20% at 45 years for white spruce, and second-generation selection strategies could increase merchantable productivity by approximately 31% at 50 years for black spruce (Newton 2003).

Information pertaining to the effects of intensive forest management on wildlife was also synthesized. Thompson *et al.* (2003) reviewed approximately 50 papers that reported studies of the long-term effects of post-harvest silviculture on vertebrate wildlife.

Interactive online databases were also initiated. For example, the Ontario Research Sites (ORS) database stores metadata about research studies in Ontario. As of May 2005, approximately 480 studies were in the ORS system (Verkley *et al.* 2006). Over 50% of these studies focused on silviculture and/or forest management. The Canadian Forest Management Database[7], one of the repositories for partnership products, stores scientific literature citations and abstracts related to efficacy, environmental acceptability, and cost-benefit analyses of techniques used to control competing vegetation, insects, and diseases in Canadian forestry (Thompson and Pitt 2003).

All of these initiatives helped to consolidate the available knowledge related to enhancing forest productivity and make it more accessible to resource managers.

Complete basic inventory components

Rotherham (1999) stated "*If I were king, I would do two things: Fund a forest inventory program across Canada in cooperation with provincial governments and industry to obtain excellent, up-to-date information on the forest. …. Fund growth and yield studies on stands of all ages to validate the present stand yield tables.*" These 2 basic inventory components are key for forest managers preparing forest management plans, which require an inventory/statement of the forest's current condition and a forecast of how stands are expected to develop over time (Erdle and Sullivan 1998).

[7]http://www.glfc.cfs.nrcan.gc.ca/cfpm/CFPMAbout.cfm; accessed April 2, 2008

Participants of the IFM science workshop (Bell *et al.* 2000) and a more recent wood supply workshop in Ontario (Sobze *et al.* 2006) echoed Rotherham's statement and suggested that inventories of forest condition (i.e., forest age structure and composition), soils, streams and riparian areas; wildlife habitat; visual quality; cultural heritage and archaeology sites; and wilderness areas are lacking. Concurrent with synthesizing existing knowledge, the CEC-FRP focused on improving basic inventory components (forest and spatial analysis), both to develop a wood supply strategy for selected forests and to identify knowledge gaps to maximize returns on research investments. This included (i) identifying possible areas in which to apply intensive forestry; (ii) improving forest and soil inventories; and (iii) improving protection, forest productivity and yield, and succession models.

Identifying possible intensive forestry areas

The OMNR has developed a series of manuals and guides, each designed for a specific purpose, including forest management planning (OMNR 2004), identifying cultural heritage values (OMNR 2007), protecting resource-based tourism (OMNR 2001a), maintaining wildlife habitat (e.g., OMNR 1988, Naylor *et al.* 1996, Watt *et al.* 1996, Voigt *et al.* 1997, Racey *et al.* 1999), emulating natural disturbances (OMNR 2001b), and applying silviculture (e.g., OMNR 1997, 1998). The effect of applying these guides on options for implementing the 10/10 goal was analyzed through a detailed land use and regulation study. Areas with potential for enhancing productivity were identified on partnership forests by eliminating those with known and likely policy and regulatory conflicts (McPherson *et al.* 2008, this issue).

Improving forest and soil inventories

Forest resource inventory (FRI) was identified as a primary challenge at the outset of the partnership when it became clear that the configuration of available data sets did not permit direct comparisons among management units, impairing the CEC-FRP's ability to compare and evaluate forest management options. For several SFLs, the FRI could best be described as resulting from an ad hoc approach, undertaken for reasons that seemed appropriate at the time.

Forest resource inventories in Ontario have traditionally focused on the minimum number of variables needed to predict wood supply (i.e., forest composition, stand age, site class, and stocking). Black and white 1:15 840 and more recently 1:20 000 scale photographs were adequate for planning under the Crown Timber Act, but did not meet requirements set out in the Crown Forest Sustainability Act. For example, inventories of intermittent streams, estimates of within-stand variability of stem size, and estimates of slope, aspect, or soil type are now necessary. Thompson *et al.* (2007) tested the accuracy of FRI in 2 study areas, 1 near Ear Falls in northwestern Ontario at 2 locations—Trout Forest and Whiskey Jack Forest—and the second near Kapuskasing, Ontario, on the Gordon Cosens Forest. Their observations indicate that approximately 30% of stands were misclassified when broad forest categories of conifer, mixed or deciduous were used. Species identification was even less accurate, with 83 of 129 stands incorrectly classified by species composition. Common boreal species, including jack pine, black spruce, and trembling aspen were incorrectly classified in about half of the cases and the rate of misclassification of species among forest types was inconsistent. Clearly, a more accurate inventory is needed.

New enhanced forest resource inventories (eFRI) include a mix of remote sensing technologies and a range of field inventory techniques. To learn more about eFRI, the CEC-FRP engaged inventory specialists from across Canada to identify ways to improve the accuracy of their forest inventory and initiated projects to investigate and evaluate technology that integrates both LiDAR and high-resolution digital photography. As a result, the CEC-FRP committed to supporting research (Lim and Treitz 2004; Hopkinson *et al.* 2005, 2006; Chasmer *et al.* 2006a, b; Thomas *et al.* 2006) and the acquisition of new eFRI across all of Tembec's SFLs to facilitate comparisons and analyses within and among management units. In addition, all the silviculture treatments on 2 sustainable forests (i.e., Gordon Cosens and Nipissing; McPherson *et al.* 2008, this issue) were compiled into a spatial database that could be used to assess future fibre production and undertake economic analyses.

Soils mapping was also identified as an urgent need for IFM and eFRI is being evaluated to determine its effectiveness for assessing site types. Lack of adequate soil inventories to support intensive forestry practices increases the risk, for example, of compacting or rutting fine-textured or wet soils, depleting nutrients on shallow or coarse-textured soils, planting or seeding inappropriate species, and inaccurate predictions of growth rates and final yields.

Developing protection, wood supply, and succession models

Models that estimate a long-term response to forest management inputs are commonly used in strategic forest planning. Models can be categorized by function (protection, wood supply, succession) and/or scale (landscape, stand, tree). To get a sense of future influences and resulting potential constraints on wood supply, the risk of fire and insect and disease infestations were investigated for partnership forests, primarily by modelling risk scenarios. For example, the *Forest Fire Level of Protection Model for Protection of Wood Supply and Analysis of Climate Change in Ontario* and *Spruce Budworm Decision Support System* were designed to assist forest managers in reducing fibre losses.

The CEC-FRP recognized the need to improve many of the stand-level wood supply models used by forest managers (for details see Sharma *et al.* 2008, this issue). Accurate yield predictions were needed to replace Plonski's (1956) curves for a range of species, on different soil types, and under various silvicultural intensities, resulting in sponsorship of plantation yield curves dubbed the *Benchmark Yield Curves* (Penner *et al.* 2008, this issue).

The CEC-FRP also sponsored development of forest succession models, because many forest management decisions are based on information about these models. Due to a high level of uncertainty about the knowledge base used to develop the models, a workshop was held to investigate potential approaches to improve that knowledge. For example, *Modelling Ontario's Stand Succession and Yield (M.O.S.S.Y.)* project uses existing empirical data from growth and yield projects to provide forest managers with better methods to incorporate some aspects of succession into forest planning models (FRP n.d.). However, the need for a more fundamental approach to improving succession knowledge was recognized. Although not linked to the CEC-FRP, OMNR science programs are working to improve succession knowledge (Drescher *et al.* 2008).

While many aspects of forest inventory remain a challenge, all of the above initiatives have helped to improve the base from which forest managers develop their management plans as well as supporting improved forest operations.

Conduct sensitivity analysis and modelling

A key feature of active adaptive management is to simulate potential alternative models of the managed system and potential alternative responses to policies (Baker 2000b). Uncertainty exists in all models, including those used for forest management such as to predict wood supply or to assess social, economic, and environmental effects (O'Neil and Rust 1979, Andison 2003). Knowledge is never perfect and thus the assumptions used in both forest management and modelling need to be evaluated. These assumptions could affect (1) the precision with which the management system can be implemented and measured in time and space, (2) the functional realism of actions invoked in the plan relative to their function in the target system, and/or (3) the level of generality expected in applying the plan (Baskerville 1994, 1997). Baskerville (1994, 1997) professes that in the management of natural systems these 3 characteristics of models are mutually exclusive. That is, anything gained in the way of precision in a model used to forecast the management design for a forest reduces the generality of application in the forest and the functional realism of the plan relative to the forest. Similarly, gains in making a model more generally applicable to an array of conditions decreases its functional realism with respect to forest dynamics and precision relative to any particular forest estate to which the model might be applied. Sensitivity and gap analyses are essential if forest managers wish to adequately evaluate the interrelationships between multiple values and to understand the tradeoffs required to meet social, economic, and ecological sustainability objectives. Through simulations of alternative management practices, the CEC-FRP sought to gain insight about the 10/10 goal to determine if it was plausible and, more importantly, sustainable. These projects, described briefly below, were used to identify knowledge gaps with respect to future wood supply, the economics of intensive management, and possible effects on biodiversity.

Until recently, forest managers have been restricted to the use of non-spatial models, but geographic information systems (GIS) now provide a ready template for assembling models that use physiographic and topographic databases, natural history observations, scientific measurements, and social and economic data (Lee 1999). No longer restricted to non-spatial models, the CEC-FRP was free to test both spatial and temporal hypotheses about how selected practices would affect forest ecosystems. Several key projects were undertaken, using the Strategic Forest Management Model (SFMM; Davis 1999), a non-spatial model, and Patchworks, a spatial sustainable forest management optimization model (Rouillard and Moore 2008, this issue; Moore and Tink 2008, this issue), to evaluate various scenarios. The Patchworks model provided a mechanism to evaluate the interrelationships and interactions among the different values at play on the forest landscape, determine appropriate tradeoffs among them, and project both a sustainable allowable cut volume over time and a spatial allocation of where that allowable volume should come from, both at the stand and the forest management unit scale.

The above represent initial efforts to understand the effects and effectiveness of implementing IFM on these forests. As additional information and data become available, more detailed analyses can be conducted during Phase II of the partnership to evaluate new opportunities and assess effectiveness of treatments being implemented within the adaptive management framework.

Assessing wood supply

In Ontario, wood supply is predicted using models that project for periods of 150+ years based on information about current forest condition, natural disturbances, harvest rates, silviculture activities, forest growth, and succession.

Wood fibre volume required to achieve the 10/10 goal for major commercial tree species harvested on Tembec's licence areas and on the Nipissing Forest (McPherson *et al.* 2008, this issue) was determined by the CEC-FRP using SFMM (Davis 1999). This analysis contrasted what was desired (the 10/10 goal) against what is possible (potential increased yield on a defined landbase). Different combinations of landbase size and treatment yields by different species and renewal intensities were evaluated through multiple iterations of SFMM runs and the following best bets were identified for increasing wood volume:

1. Use more precise managed stand growth and yield curves,
2. Use spatial planning to more specifically delineate forest reserves and other broad requirements on the landscape,
3. Establish elite plantations with genetically improved stock,
4. Apply precommercial and commercial thinning regimes,
5. Protect high-value stands against natural losses, and
6. Stratify the landbase more precisely to apply appropriate renewal intensities.

A second wood supply project, the *Northeastern Ontario Enhanced Forest Productivity Pilot*, was initiated to examine (1) elements of a long-term business plan that would project supply and demand imbalances over time and assess the levels of investment effort and resources required to enhance forest productivity, (2) candidate enhanced wood supply areas for 2 pilot forest management units, (3) effects of a suite of treatments on forest productivity and sustainability of conifer and poplar programs, and (4) potential application of enhanced forest productivity to implement the Room to Grow framework (OFAAB 2002).

Additional studies included an analysis of volume losses to fire and insects. For example, the Spruce Budworm Decision Support System Protection Planning System (PROPS) was applied to the Romeo Malette forest to determine the effects of "normal" and "severe" outbreaks of spruce budworm. The analysis indicated that losses exceeding 3 million and 7 million m^3 could be expected in the absence of protection treatments for normal and severe outbreaks, respectively (BioForest Technologies Inc. 2002).

Evaluate economics

One of the biggest uncertainties in forest planning is the length of time involved in growing timber (Williams 1995, Allen 2001). The fastest growing boreal stands may be harvestable in 40 to 50 years but it is difficult to forecast timber prices that far into the future with any accuracy. The uncertainty inherent in predictions for 100 years or more is enormous. Nonetheless, to estimate economic sustainability, the CEC-FRP conducted several analyses.

The first analysis involved a theoretical evaluation of net present value (NPV) using different discount rates and expected costs and revenues. As with most analyses of this type, the economic returns were bleak. The only silvicultural strategy with positive returns was based on growing hybrid poplar plantations, with its short rotations (<20 years) and high yields (>350 m^3/ha); however, very few sites within Tembec's licence areas would support these plantations (CEC-FRP 2005).

The second analysis was an evaluation on returns on forest investments for various harvesting policies, ranging from complete flexibility to strictly applied allowable cut requirements. Stumpage prices, however, vary from year to year and forest managers need to adapt their timber harvests in response to these changes (Thomson 1992) and consider how forestry firms and communities can benefit from explicit recognition of uncertainty due to price and other risks in forest management plans. Insley and Rollins (2005) demonstrated that returns can be improved somewhat using a "real options" analysis, which builds better estimates of probability into calculations.

A third project involved an applied analysis and projection of actual costs and revenues on the Romeo Malette Forest (T. Moore, Spatialworks, unpublished). This landscape-level analysis was conducted using Patchworks to provide insight into the relationship between volume of wood delivered to the mill and its value through time. Any substantial increases in annual allowable cut above current levels, when coupled with other constraints, exert immediate downward pressure on product value. Patchworks is being refined to incorporate the harvesting and transportation cost outputs of FERIC's Interface Map program, which is a spatial model that determines the cost of harvesting forest biomass. The addition of biomass harvesting as revenue is expected to add significant precision to the long-term projection of wood supply costs.

The fourth study was a business case analysis for enhanced forest productivity within the Gordon Cosens Forest area. Several harvest levels and silviculture expenditures on timber, non-timber, and socio-economic values were assessed to highlight trade-offs and key sources of risk to industry and government (HLB Decision Economics Inc. 2005). The study suggests that it is possible for the public and private sectors to engage in a win-win investment partnership if the regional socio-economic gain from increased harvest levels is truly incremental and not just a regional transfer of economic resources.

Results from these projects concurred with earlier economic analyses in boreal forests: Ontario's slow-growing forests provide little financial incentive to invest in reforestation, in part because of the long time intervals between investment and return (Benson 1988, Willcocks *et al.* 1990). Size of harvest area, piece sizes, and haul distances are also important factors (Nautiyal *et al.* 2001). Results to date suggest that woodlands managers need to draw their operations closer to mills to be cost-effective with or without more intensive practices.

Understanding effects on biodiversity

Long-standing concerns about the effects of forest management on biodiversity, and wildlife in particular, are amplified when more intensive practices are considered. Thus, effects of IFM on biodiversity were identified by the CEC-FRP as an area of uncertainty and included in the framework.

Three projects were undertaken in partnership with the

CEC-FRP with the goal of (1) examining the effects of more intensive silviculture on forest songbirds, (2) evaluating effects of intensive silviculture on American marten (*Martes americana*) habitat (see Thompson *et al.* 2008, this issue), and (3) assessing the effects of conifer release treatments on tree species diversity and richness (Dampier *et al.* 2007). Forest birds are an obvious choice for examining management effects because they use a variety of habitat types, structures, and age classes of forests; marten are an indicator of forest condition and habitat for this species must be considered during forest management planning (Watt *et al.* 1996); and trees support habitat needs of most forest-dwelling plants and animals. Although examining the effects of intensive silviculture on forest songbirds, marten, and trees does not cover the full spectrum of biodiversity concerns, results for these species provide some "clues" about whether and to what degree ecosystem processes might be affected by intensive silviculture.

Other related projects included a knowledge synthesis of forest management effects on caribou and mapping of wetlands and historic forest conditions in the forests of interest.

Transferring results

To implement active adaptive management, the CEC-FRP required 3 different types of experts: (i) forest management planning experts to initiate and lead the 6-step adaptive management cycle, (ii) research experts to assist planning experts in identifying critical uncertainties and conducting appropriate research to reduce the uncertainties, and (iii) knowledge transfer, extension, and training experts to coordinate knowledge transfer and extension (Fig. 1). To ensure that these experts worked together effectively, the CEC-FRP initiated *core teams* for each forest management unit. A description of how the core teams function is provided in Smith *et al.* (2008, this issue).

Phase II: Intensive Forest Management Process

The second phase of the partnership, the IFM process phase, emphasized operational implementation through an active adaptive management approach (Fig. 1). Progress has been made towards completing the following:

1. The 10/10 years goal has been proposed and corporately accepted (Bruemmer 2008, this issue) and core teams established to ensure knowledge is transferred to resource managers as it becomes available (Smith *et al.* 2008, this issue),
2. Sustainability of the 10/10 goal is being assessed on selected forest management units (McPherson *et al.* 2008, this issue, Moore and Tink 2008, this issue; Thompson *et al.* 2008, this issue), and
3. Strategic silvicultural options are being formulated (Bell *et al.* 2008, this issue) and operational tools improved. For example, Thompson *et al.* (2007) assessed the potential for integrating a suite of modern technologies with a view to optimizing efficacy, cost-effectiveness, environmental protection, and post-spray monitoring of aerial herbicide applications to spray blocks typical of Northern Ontario.

The next steps in the adaptive management cycle are to continue to assess sustainability, to implement and monitor strategic silvicultural options, and to evaluate outcomes to determine whether the 10/10 goal is sustainable and/or identify necessary adjustments (Baker *et al*. 2008, this issue).

Summary

The 2-phase research strategy (consisting of *FRP projects* and *IFM process phases*) adopted by the CEC-FRP was recommended by the participants of an IFM science workshop funded by the partnership (Bell *et al.* 2000). During the *FRP projects phase*, the CEC-FRP invested in 145 research projects. These projects were sponsored because they reduced critical uncertainties related to fibre supplies on 6 sustainable forest licences in northeastern Ontario. During the *IFM process phase*, more emphasis will be on implementing an adaptive management strategy and researchers will be required to become more actively involved in transfer, extension, and monitoring programs (Baker *et al.* 2008, this issue; Smith *et al.* 2008, this issue). During this phase, the partners will shift from relying on existing knowledge to evaluating outcomes of new or modified practices on the forest management units, and the means to achieve the 10/10 goal and/or address any impediments should become more evident.

Although the partners originally envisioned becoming engaged in an active adaptive management strategy in 2000, they realized that was not realistic. The 2-phase approach enabled them to first develop an understanding of adaptive management. Although the CEC-FRP science partners had a strong research background and thus familiarity with literature, experimentation, monitoring, transfer, and extension, they were relatively unfamiliar with using these approaches in combination with an adaptive management strategy. We recommend this 2 phase approach to other organizations that are considering engaging in adaptive management.

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Appendix A - Research Approaches

Most empirical research belongs clearly to 1 of 2 general categories: correlational and experimental. In forestry, these approaches are commonly used to test hypotheses related to effects of natural or anthropogenic disturbances on forest ecosystems. More recently, adaptive management has been considered as another approach to testing hypotheses related to management policies. In combination with syntheses of previously acquired knowledge, a powerful research program, such as the CEC-FRP, can be established using a combination of adaptive, correlational, and experimental approaches. Here we provide a brief description of each approach to acquiring knowledge as applied within the research strategy of the CEC-FRP.

Adaptive management

An adaptive management approach was adopted by the CEC-FRP because it encourages a disciplined approach to management, without constraining the creativity that is vital to dealing effectively with uncertainty, risk, and change. This was considered vital to success and to ensuring that government and industry partners could move forward together.

Adaptive management is a formal, systematic, and rigorous approach to learning from the outcomes of historic, current, or simulated management actions, accommodating change, and improving future management of our forest resources (Holling 1978; Baskerville 1985; Walters 1986; Haney and Power 1996; Stankey and Shindler 1997; Lee 1999; Stankey *et al.* 2003, 2005; Morghan *et al.* 2006). It is used to reduce uncertainty by developing alternative management strategies and monitoring and evaluating how different indicators within a system will respond, and implementing the more favourable option(s) (Holling 1978, 2001; Gunderson 1999; Kneeshaw *et al.* 2000; Harvey *et al.* 2003). The concept and approach has been described and used in a range of resource management contexts from fisheries, to wildlife, to forestry (MacDonald *et al.* 1997, 1998). It has been described as *reflection before action* (Boothroyd 1978), *management by experimentation* (MacNab 1983), *probing* (Walters 1986), and *learning by doing* (Walters and Holling 1990).

Adaptive management can be considered as a continuum from reactive to active approaches (Baker 2000b, Duinker and Trevisan 2003, McAfee *et al.* 2006). Often, reactive management occurs when a policy change results from public criticism, legal challenge or simply recognition that the current policy/practice is not achieving desired results; this precipitates a change but with no formal monitoring process to evaluate the effectiveness of that change. Passive and active adaptive management are largely distinguished by the extent of learning they offer, the resources they require to be successfully carried out, and the degree to which management goals are incorporated into the design (Stankey *et al.* 2005, McAfee *et al.* 2006). Passive adaptive management is most frequently adopted by management agencies professing to be using an adaptive management approach (Baker 2000b). Passive adaptive management is characterized by the implementation of a single policy or hypothesis formulated on the basis of available data and knowledge as an appropriate means to reach management goals (McAfee *et al.* 2006). This "best" management scenario is often selected from a set of scenarios tested through computer simulation models, and then implemented and evaluated through formal monitoring. This approach has been criticized for its limited ability to accelerate learning while managing and to reduce uncertainty (Baker 2000b) but it is better than reactive management in terms of inference about change of policy/practice to achieving desired outcomes.

Active adaptive management is the deliberate, experimental evaluation of several policy/practice alternatives by implementing them simultaneously and comparing their outcomes (Baker 2000b, McAfee *et al.* 2006). Multiple stakeholders are convened to establish a deliberate learning and experimentation process around the system being managed. The system is seen as a moving target, which is continuously evolving because of the human influences on it (Walters and Holling 1990). The active adaptive approach is based on the premise that knowledge of the system is always incomplete and is ideal for accelerated learning in the face of uncertainty. Evaluation of alternative silviculture practices through field trials could be classified as active adaptive management (Taylor *et al.* 1997, MacDonald and Rice 2004); it is probably the most frequent application where alternative practices are evaluated, although examples from fisheries and wildlife management also exist (Walters 1986, 1997; Walters and Holling 1990; Lancia *et al.* 1996).

In the northwest United States, the adaptive management concept was a central tenet of the Northwest Forest Plan developed in the early 1990s to deal with constraints on logging old-growth forests. The expectations for adaptive management have not been met due to a variety of reasons discussed thoroughly by Stankey and Shindler (1997) and Stankey *et al.* (2005). They assert that adaptive management, although conceptually attractive, is not a panacea and cannot be easily implemented due to a variety of complexities usually involving stakeholders, the public, and resource management institutions.

Nonetheless, movement towards adaptive management encourages scientists and resource managers to actively engage in reducing uncertainty by building an evaluation process into operational management. This process involves posing questions and discovering answers through, for example, knowledge synthesis in literature reviews, controlled experimentation, and monitoring, as described briefly below.

Correlational research/monitoring

In correlational or monitoring approaches researchers do not deliberately influence any variables, they simply measure them and look for relations (correlations) among variables. Forest researchers often refer to correlational research as monitoring. However, data from correlational research can only be "interpreted" in causal terms, but cannot conclusively prove causality (StatSoft, Inc. 1984–2008).

Monitoring programs, which can be classified as compliance, exceptions, effects, or effectiveness monitoring (Taylor *et al.* 1997, OMNR 2001c), are essential to successful adaptive management because they provide empirical data that can be used to reduce dependence of forest managers on professional opinions. In forestry, types of monitoring are distinguished as follows: *compliance monitoring* documents whether or not and/or to what degree the intended treatments in a forest management plan were implemented. *Exceptions monitoring* programs are required when the treatment differs from those listed in a forest management or silviculture guide (OMNR 2001c). *Effects monitoring* determines how a particular treatment, group of treatments, or operation interacts with, or affects, other organisms or ecological processes (OMNR 2001c). *Effectiveness monitoring* measures the status and trends of known pressures to evaluate the success of forest management plans or guides in meeting stated objectives (OMNR 2001c), for example, the degree to which management prescriptions and practices protect non-timber environmental values or how well silviculture efforts (harvest, renewal, and maintenance) support forest regeneration (OMOEE 1994).

Monitoring programs are necessary at both provincial and local levels (OMOEE 1994) and are key to successful implementation of an adaptive management approach. Thus, the CEC-FRP incorporated monitoring in its research strategy along with knowledge synthesis and experimentation.

Experimental research

In experimental research, researchers manipulate specific variables and then measure the effects of this manipulation on other variables; for example, they may artificially control stand densities or add nutrients. Similar to correlation research, described above, the associated data analysis involves calculating "correlations" between variables, specifically, those manipulated and those affected by the manipulation (StatSoft, Inc. 1984–2008). However, experimental data may provide qualitatively better information than correlational data: only experimental data can conclusively demonstrate causal relations between variables. For example, if whenever variable A is changed, variable B also changes, the conclusion is that "A influences B."

Controlled experimentation includes laboratory and field experiments, which can be further classified as screening or comparison trials and demonstration areas (Miller and Glover 1991). *Screening trials* are used to evaluate previously untested treatments on crop performance prior to operational use. They are based on small plots (usually <0.2 ha) and large numbers of treatments (up to 25), including a control (no treatment) and a standard treatment, with many replicates (4 to 6); in Ontario forest conditions they are usually assessed for less than 10 years. *Comparison trials* are used to confirm the results of screening trials, assess potential operational problems, and demonstrate characteristics of promising treatments to field staff. More detailed objectives are developed to test for specific effects on, for example, human health and safety, yield response, economics, and environment. Comparison trials use medium to large operational plots (i.e., 0.5 ha to 2 ha), no more than 4 to 6 treatments including a control (no treatment) and a standard, fewer replicates (typically 3 or 4) installed at several locations covering the range of soil and vegetation conditions that might be expected in operational use, and they are typically monitored for 10 or more years. *Demonstration areas* are established to show potential users differences in treatment (in a given situation) costs, results, and effects, and should be located on typical sites and designed to facilitate visitor access and viewing. They might be 1 replicate of a large trial that is monitored accordingly, or stand alone and thus not monitored but usually maintained for as long as they serve a purpose.

Knowledge syntheses/literature reviews

Literature reviews provide the reader with a state-of-the art summary of available information on a specific subject. Since the table of contents is essentially the design, both it and a series of questions to be addressed should be prepared prior to initiating the review. Literature reviews differ primarily in the level of information collected and how it is presented. For example, they may include only information available in peer-reviewed journals or also include unpublished reports and personal communications. Information collected can be presented as a summary or a synthesis of knowledge to identify knowledge gaps and formulate hypotheses. The review and synthesis by Perera *et al.* (2007) illustrates how a synthesis can be used to develop hypotheses for research that are relevant to policy/practices issues. No original data are collected for literature reviews.