TRIAD zoning in Quebec: Experiences and results after 5 years

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ABSTRACT

The TRIAD approach to forest management involves dividing the forest into 3 zones, each with its own management objectives, but with the overall goal of increasing the ecological and economic sustainability of the forest. For the past 5 years, we have been experimenting with TRIAD zoning in central Quebec, incorporating social interests into the original concept of TRIAD management. Results generally indicate that this approach is economically viable, socially acceptable, and preferable ecologically in this area. Although much remains to be done, thus far the consensus among the various project participants is that this approach may be a good fit for the public forest of Canada.

Key words: TRIAD, functional zoning, sustainable forest management, ecosystem management, natural disturbance based management, intensive forestry, mixed plantations, partial cuts, eco-efficiency, conservation, new forestry, green accounting

RÉSUMÉ

Dans le cadre d'un aménagement forestier TRIADE, la forêt est divisée en trois zones ayant chacune ses propres objectifs d'aménagement. L'objectif global est cependant toujours l'atteinte d'une gestion durable au niveau écologique et économique. Depuis 5 ans, nous expérimentons avec le concept de zonage TRIADE au centre du Québec, incorporant les intérêts sociaux dans le concept original de la TRIADE. Nos résultats indiquent que cette approche est viable au niveau économique, acceptable au niveau social et préférable au niveau écologique. Il nous reste beaucoup à faire, mais le consensus général des nombreux participants est que cette approche pourrait nous aider à mieux gérer les forêts publiques du Canada.

Mots clés : TRIADE, zonage fonctionnel, aménagement forestier durable, aménagement écosystémique, aménagement simulant une perturbation naturelle, foresterie intensive, plantations mélangées, coupes partielles, éco-efficience, conservation, nouvelle foresterie, comptabilité verte

Introduction

The forest sector in Canada is going through a difficult transitional period. These difficulties are driven by many factors, including (1) a high and fluctuating Canadian dollar (particularly at the time this article was written) (NRCan 2008), (2) increasing global competition from fast-growing plantations in more favourable climatic conditions and/or socio-political conditions (e.g., Sedjo 1999, ALPAC 2006, Park and Wilson 2007), (3) increasing energy costs, (4) concerns about the loss of biodiversity and the last primary forests in the world (e.g., FAO 2005), (5) concerns about homogenization of the forest due to the systematic use of clearcutting in all forest types, (6) an aging industrial infrastructure (e.g., NRCan 2007), (7) over-dependence on the US market, which was in decline at the time this article was written (e.g., NRCan 2008), and (8) an unsatisfactory softwood lumber arrangement with the US. In addition, the forest industry in Quebec is facing a shortage of mature and accessible timber.

In 2003, combined with a critical evaluation of forestry practices by the auditor general of Québec, these factors inspired the provincial government to appoint an independent commission to provide guidance on the management of the province's forests. Among other things, the Coulombe Commission recommended a reduction of approximately 20% in the annual allowable cut (Commission d'étude sur la gestion de la forêt publique québécoise 2004), a recommendation that the newly appointed chief forester of Quebec acted on in 2005. Another recommendation of the Commission was to implement some form of functional zoning for the province, and to include 12% of the boreal forest in a network of protected areas. The Commission also recommended developing some form of ecosystem management for the forest.

Faced with the challenge of addressing these recommendations, discussion of a TRIAD functional zoning approach to forest management emerged in Quebec. This zoning approach was first proposed by Seymour and Hunter (1992)

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to facilitate the creation of conservation areas and the implementation of ecosystem management in Maine, and by Thompson and Welsh (1993) as a way to incorporate the conservation of biodiversity into forest management across Canada. In 2003, a group of stakeholders from the Mauricie area in central Quebec agreed to work in collaboration with scientists to develop and implement a new management strategy based on the TRIAD approach. In 2005, to show support for the approach and facilitate the implementation process, the Quebec Minister of Natural Resources and Wildlife recognized the Mauricie TRIAD project as a special provincial pilot project.

What is the TRIAD Approach to Forest Management?

As the name suggests, the TRIAD zoning approach divides the territory into 3 zones, each one designed to address a specific set of objectives and priorities. Management in each zone is then focussed on these objectives (Binkley 1997).

In the *conservation zone*, the goal is the conservation of native biodiversity and ecosystem processes and functions. No industrial activity is carried out here, and human activities should be limited to those that do not interfere with the overarching goal of conservation.

In the *ecosystem management zone*, the goal is to preserve the resiliency and adaptability of the forest and its native biodiversity while accommodating human use (Grumbine 1994). Logging is thus permitted, as long as it is in keeping with the preservation of native biodiversity. Ecosystem management practices are often designed to mimic patterns created by natural disturbances (Kuuluvainen 2002, Bergeron *et al.* 2004, Gauthier *et al.* 2008a). Under many circumstances, the use of partial cutting in the ecosystem management zone helps to support timber production. These practices rely mostly on natural regeneration and offer multi-entry harvesting opportunities that help to regulate long-term logging schedules.

In the *wood production zone*, the main goal is timber production. This zone is set up to compensate for merchantable timber not harvested from the other 2 zones so as to maintain the timber supply, and thus the economic viability of the forestry sector. The more timber that can be extracted from this zone, the larger the area that can be set aside for conservation and the less timber need be extracted from the ecosystem management zone. To achieve productivity gains, various types of traditional silvicultural practices such as thinning and vegetation management are implemented. Genetically improved native tree species and fast-growing hybrids may also be planted (Messier *et al.* 2003), although care must be taken to select strains that will not interfere with the functioning or species composition of the rest of the forest through invasion or hybridization.

Since ecosystem management involves preserving native biodiversity and ecosystem functions and processes while accommodating human use, the whole TRIAD approach could be called ecosystem management. Biodiversity and ecosystem functions and processes are to be preserved in the conservation zone and, to a large extent, in the ecosystem management zone. Human use in terms of timber is to be accommodated in the wood production zone and, to some extent in the ecosystem management zone. Less destructive human uses like berry-picking are to be accommodated in the ecosystem management zone, and the least destructive human uses (e.g., bird-watching) may also be accommodated in the conservation zone.

Although only time will tell what the results of long-term application of the TRIAD approach will be, properly applied, we hypothesize that it will allow us to address many of the challenges facing the management of today's forests. In theory, it could help to reduce the shortage of mature and accessible wood, while at the same time providing for increased conservation and multiple uses. As such, the TRIAD approach should be economically and ecologically beneficial, and, according to our interpretation, also socially beneficial. Economically, transportation and silvicultural costs should be reduced by locating the wood production areas close to the mills and to the transportation infrastructure, although the ecological consequences of such planning must also be examined. Ecologically, biodiversity should be preserved through ecosystem management and the setting aside of relatively large unharvested conservation areas, counterbalanced economically by high returns from the wood production zone. Furthermore, plantations in the wood production zone and replanting in the ecosystem management zone may allow for native tree species that do not easily regenerate on their own (e.g., white pine, *Pinus strobus* L.) to prosper, thus contributing to the overall biodiversity of the managed forest. Socially, the less intensive timber harvesting of the ecosystem management zone should provide better opportunities for recreational and other non-timber uses while still providing timber for the forestry sector and habitat for wildlife.

When the 3 zones are examined as complementary parts of a whole management unit, there may be even more benefits. Conservation areas should act as controls by which the state of the present and future managed forest may be gauged, facilitating the creation of guidelines for sustainable forest management in the ecosystem management zone. Conservation areas should also provide source habitat for plant and wildlife species (*sensu* Pulliam 1988), thus helping to maintain higher levels of biodiversity than might otherwise be found in the surrounding managed forest. In turn, high levels of biodiversity may have economic as well as environmental and social value (e.g., Ehrlich and Ehrlich 1992). Intensive management in the wood production zone should also take the pressure off the rest of the forest, allowing for less intensive management in the ecosystem management zone and for more area to be set aside for conservation.

For the conservation zone to properly fulfill its role as a control by which to gauge management and as a refuge for all kinds of biodiversity, natural disturbance must be allowed to occur here. Thus, although particular emphasis was placed on the conservation of old-growth stands in the Mauricie, the age structure of the zone will fluctuate. The recommended conservation areas were spread out as much as possible so as to minimize the possibility that a single natural disturbance event would affect the entire zone, resulting in all conservation areas being of the same age. However, there is still the possibility that a single fire could affect the entire forest management unit. This highlights the need for this and any other conservation network to reach beyond the confines of geopolitical and management units.

The question of global change is also one that should be considered in any long-term management plan. By favouring the maintenance of complex stands in the ecosystem management zone (Puetmann *et al.* 2008) and mixed species plantations in the intensive zone (Paquette and Messier 2009), we feel we are minimizing the possible negative impacts. Although the management process (described below) is one that may allow for the delineations of the 3 zones to be changed as conditions change, it will likely be prudent to maintain the conservation areas as established, relatively well spread across the forest management unit, regardless of climate change or natural disturbance. In this way, the conservation zone can serve its purpose as a control, to provide an idea of the effects of climate change and natural disturbance in the absence of management, and thus a meter-stick by which to measure the impacts and minimize the negative effects of management.

Although the TRIAD concept has attracted a lot of interest recently (Burton *et al.* 2003, MacLean *et al.* 2009), it remains largely theoretical. Most studies on the concept have been simulations (Bos 1993, Krcmar *et al.* 2003, Boyland *et al.* 2004, Montigny and MacLean 2006). The approach has only been applied in the forest a few times. In 1994, after a long and intensive public involvement initiative, the TRIAD approach was applied in Maine by Champion International Corporation, a large industrial landowner. The company set aside some conservation areas and subdivided the remaining land territory into a "general management" zone and a "specific value" zone (Redelsheimer 1996). By the end of the 1990s, the project had been abandoned due to a lack of interest from the company, but it left a legacy of large protected areas that are still in place today. In New Brunswick, J.D. Irving Ltd. established spruce plantations on their privately-owned land and set aside some protected areas on Crown land and on their private land in collaboration with the government (MacLean *et al.* 2009). This was before the TRIAD concept had been fully developed, but it was nonetheless in keeping with the concept of the 3 zones. In the early 2000s, Riverside Forest Products planned to apply the TRIAD zoning concept to a 145 000-ha Tree Farm License (TFL 49) near Kelowna, British Columbia, and funded research to decide how best to divide the landscape (D'Eon *et al.* 2004). Based on an analysis of vulnerability to climate change and potential for timber production, Nitschke and Innes (2008) recommended setting aside 17% of the landscape for conservation, 34% for intensive management, and 49% for extensive management. Unfortunately, the zoning plan was abandoned in 2004, when the company was bought out by Tolko Industries. A similar zoning strategy has also been proposed by Binkley (1997) for the whole of British Colombia and by Lieffers *et al.* (2003) for the whole of Canada's boreal forest, although these proposals have not been acted upon as yet.

The Mauricie TRIAD Project

The Mauricie TRIAD project is being implemented on a 0.86 million-ha forest management unit (FMU 042-51) in the Mauricie in central Quebec (Fig. 1). This management unit covers 2 large ecological zones (Fig. 1b): the boreal mixedwood, composed mainly of balsam fir (*Abies balsamea* L.), jack pine (*Pinus banksiana* Lamb.), white birch (*Betula papyrifera* Marsh.), yellow birch (*B. alleghaniensis* Britt.), trembling aspen (*Populus tremuloides* Michx.), white spruce (*Picea glauca* [Moench] Voss), and white pine (*Pinus strobus* L.); and the northern temperate deciduous forest, composed mainly of sugar maple (*Acer saccharum* Marsh.), yellow birch, white birch, red maple (*A. rubrum* L.), red spruce (*Picea rubens* Sarg.), and white pine. The area is typical of much of Canada, with a low population density, a few small cities and villages that depend heavily on forestry, and a well-developed network of logging roads that also facilitate recreation, trapping, hunting, and fishing. The main natural disturbances of the area are wildfire, insect outbreaks (especially eastern spruce budworm, *Choristoneura fumiferana* [Clemens]), and windthrow.

Large-scale timber harvest began in the south of the FMU in the late 1920s or early 1930s and in the north in the 1940s to 1950s. Currently, the FMU includes 6 zones of controlled fishing/hunting (ZEC), where forestry operations and recreation activities coexist; 14 fishing/hunting outfitters; 4 sugar-shack operations; 2 native communities (the Atikamekw of Wemontaci and Montagnais of Lac St-Jean), 2 regional county municipalities (Domaine-du-Roy and the City of La Tuque); and 22 mills with procurement rights. In addition, many trappers, hunters, fishers, and vacationers use the FMU. The management regime in place in 2003 included 2% of the

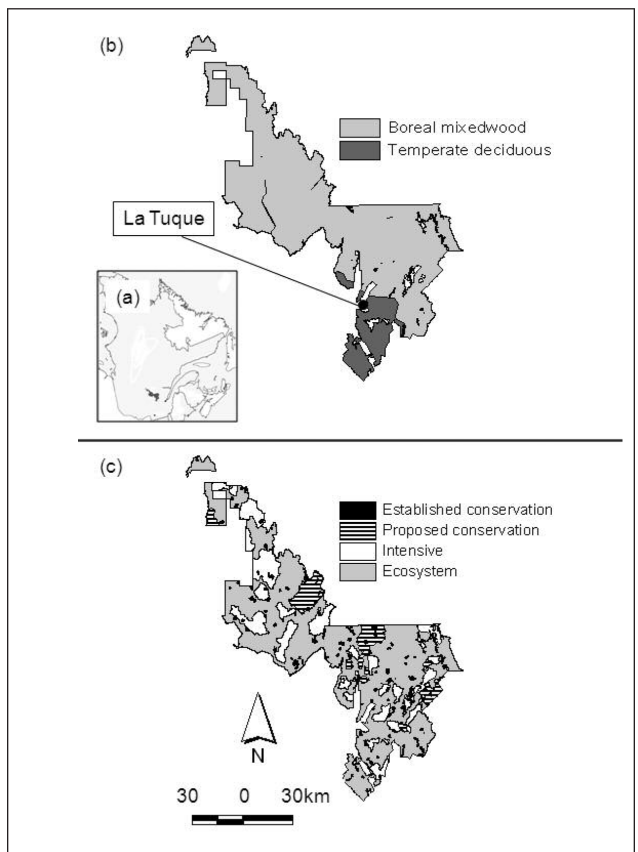

Fig. 1. Location of (a) the Mauricie TRIAD forest management unit in the Mauricie region, Quebec, (b) its main ecological units, and (c) the wood production, ecosystem management, and conservation zones (both proposed and established). Note that 4 of the proposed conservation areas are from the provincial government and 10 from the TRIAD scientific committee.

total forest area set aside for conservation, 5% for wood production and 93% for extensive management (where clearcutting was sometimes but not always followed by planting, and some measures were taken to protect against fire and insects).

The initial goal of the stakeholders involved in the Mauricie TRIAD project was to have the zoning concept fully implemented into the 5-year management plan set in place on the FMU in April 2008. To reach this overall goal, many specific objectives had to be fulfilled. The primary goals were: (1) to reduce the socio-economic impacts associated with the 20% reduction in annual allowable cut announced by the government, (2) to develop a strategy that was more acceptable than the status quo to the various stakeholders within and outside of the region, and (3) to restore the ecological integrity of the forest to some extent. Secondary goals were (1) to develop new silvicultural practices based on ecosystem management for the various forest types in the area, (2) to significantly increase the proportion of land set aside for conservation in the FMU, (3) to develop and implement new intensive forest management practices to complement ecosystem management and conservation strategies, and (4) to accommodate the spatial component of the zoning strategy using new simulation models.

To achieve all these objectives in less than 5 years, a comprehensive multidisciplinary team of scientists was assembled. The scientific and field expertises of the researchers and forest managers involved were used to develop the first 5-year management plan. The first implementation phase of the TRIAD zoning strategy in the field was set up as a series of experiments to be followed by the scientific team. Simulation models are being developed and used to evaluate various ecological, silvicultural, and economical scenarios and to further improve field practices for the 2013–2018 forest management plan (Fall *et al.* 2004, James *et al.* 2007, Sturtevant *et al.* 2007, Côté *et al.* in prep.).

Implementing the TRIAD Plan

Establishing the 3 zones

Step 1: Set aside conservation areas

As stated above, one of the objectives of the Mauricie TRIAD project was to significantly increase the proportion of the landscape allocated to conservation. Although the actual designation of protected areas is in the hands of the provincial government, the scientific team set out to make specific recommendations as the first step to implementing the TRIAD approach.

Although it is not necessarily the case in this part of the Mauricie, in general, there is potentially great conflict in the allocation of conservation and wood production zones, since areas of conservation importance may also tend to be particularly productive. For this reason, we were particularly careful to set aside conservation areas based on conservation goals before considering areas for the wood production zone.

Rather than limiting conservation to areas unsuitable for timber harvest (e.g., ridge tops, swamps, and other unproductive or inaccessible areas), the main goal in deciding which areas should be set aside was the preservation of biodiversity. Although the proportion of land dedicated to conservation is still a subject of debate, the team aimed for approximately 10% and ended up recommending 11%.

In deciding which specific areas should be recommended for conservation, we first excluded areas that had been seriously degraded by mineral extraction or other anthropogenic disturbance and evaluated the FMU and surrounding areas for existing protected areas. We also considered the presence of large parks near the FMU (e.g., Mauricie National Park) in judging the contribution of small reserves to strategic conservation planning. About 2% of the FMU had already been set aside as wildlife refuges by the provincial government. These are relatively small patches of mature and old-growth stands.

Considering the above, we proceeded to evaluate remaining sites for their contribution to the ecological and structural diversity of the FMU. Specifically, we examined the contribution of surface deposits, slope, geographical position, and stand age structure to the heterogeneity of the FMU. We divided the FMU into 3 broad zones based on the dominant climate, soils, and vegetation. In planning for the conservation areas, we recognised that forest management had already greatly altered many elements of the natural forest, such as age structure and tree species composition. We thus sought to preserve rare elements that were once common (e.g., old-growth stands).

We also considered the size and frequency of natural disturbances and attempted to ensure that protected areas would either be larger than known disturbances or far enough apart that not all protected areas would be affected at the same time. Since the largest historically known fires were as large as the FMU itself, the best we could do was to minimize the chance that the entire conservation zone would be affected by the same fire by distributing conservation areas throughout the FMU rather than establishing a singe large area (Fig. 1c). We also considered reserve design principles governing optimal form and spatial configuration (e.g., Margules and Pressey 2000).

Once these areas had been identified, we examined the presence of fragmenting elements, including roads and energy supply lines. Areas bisected by primary roads (including highways and paved roads) were eliminated from the list of potential conservation areas. Other ecological issues such as the preservation of rare habitats or ecotypes were also considered; see Bonneau and Kneeshaw (2005) for details.

We submitted our recommendations to the provincial government and were still awaiting final approval by the time the 2008–2013 management plan had to be submitted. We thus decided to include 10 of the areas recommended, as well as 3 large areas and 1 small area suggested by the provincial government. Including the 99 wildlife refuges already protected, the conservation areas included in the management plan span the spatial extent of the FMU and range in size from 68 to over 27 000 ha (Fig. 1c). According to the 2008–2013 management plan, the total area under conservation is thus over 91 000 ha, or about 11% of the FMU. Note that the specific areas protected may change under future management plans due to ongoing negotiations with the provincial government.

Step 2: Select areas for the intensive wood production zone

From those areas not recommended for conservation, we then selected areas for the intensive wood production zone, so named not because it is the only zone in which wood is produced but because, in this zone, wood production is the main objective. We ranked areas based on soil type, aspect, accessibility, proximity of existing roads, and presence of existing plantations. The top 30% were selected as potential areas for wood production (Fig. 1c). After consultations with stakeholders, some of this area was excluded, leaving 20% of the total FMU for this zone. In this zone, a variety of traditional intensive silvicultural treatments will be implemented (vegetation management, thinning and fertilisation) using both naturally regenerated and genetically improved native and exotic tree species. Productivity in this intensive wood production zone would vary between 2.5 and 12 m^3/ha/year.

In the hopes of being able to further minimize the percentage of the FMU in the intensive wood production zone in the future and/or reduce the intensity and amount of timber harvesting across the rest of the management unit, about 3% of the intensive wood production zone has been set aside for fast-growing plantations. One million exotic larch seedlings will be planted per year (*Larix decidua* Mill., *L. decidua* Mill. × *L. kaempferi* [Lamb.] Carrière), with an expected productivity of up to 8 m^3 per hectare per year over 25- to 35-year rotations (Messier *et al.* 2003). Large-scale experiments are also underway to test the ecological, social, and economic feasibility and desirability of mixed plantations (or polycultures: see ***Intensive mixed plantations*** sidebar). To ensure rapid growth, fast-growing plantations have been established on the most productive sites of the FMU.

Step 3: Implement ecosystem management

Once conservation and wood production zones had been identified, the remaining area was designated as the ecosystem management zone (Fig. 1c). This accounted for about 69% of the area of the FMU, making it the largest of the 3 zones.

The ecosystem management zone is designed to address a broad spectrum of social, economic, and environmental values. We chose a natural disturbance-based approach to meet the goals of ecosystem management and thus applied and developed practices to emulate natural forest dynamics (Kohm and Franklin 1997, Seymour and Hunter 1999, Lieffers *et al.* 2003). The management process (outlined in Fig. 2) is being applied to this zone. Although it is not strictly an adaptive management process (*sensu* Holling 1978, Duinker and Trevisan 2003), this process is inspired by the adaptive management process in that it involves constantly monitoring and re-evaluating goals and strategies.

1 – Understanding the "natural" forest

The first step to implementing natural disturbance-based management is to determine the structure and composition of the "natural" forest and the intensity, extent, and periodicity of the main natural disturbances affecting this forest. For lack of any extensive tracts of untouched natural forests for comparison, we examined historical data to establish a portrait of the pre-industrial, and thus presumably natural forest. We used completed (Barrette 2004) and ongoing studies (Alvarez in prep.) to do this, and we designed and continue to design new studies to fill specific knowledge gaps (e.g., Bouchard *et al.* 2007).

There is considerable uncertainty in describing the natural/pre-industrial forest, so this description must be constantly refined. The accuracy of the description in terms of the structure and composition of the reference forest depends

Intensive mixed plantations

Intensive forestry, especially plantation silviculture, need not necessarily be bad for the environment. Indeed, plantation forestry designed to provide multiple ecosystem services can reduce the pressure on natural forests, and even fulfill many of the ecological services provided by natural forests (Paquette and Messier 2009). Mixed plantations, in particular, are more easily accepted by the public in general than monocultures because they are perceived as more "natural." Well-planned polycultures can mimic natural successions and even be used to accelerate the return of a forest ecosystem where succession has been impaired. They may even be more productive than monocultures because they make more optimal use of the resources (Erskine *et al.* 2006, Brooker *et al.* 2008). They also provide many other social and ecological services (Hartley 2002, Kelty 2006), such as decreased vulnerability to insect outbreak and disease, increased bio- and structural diversity, and reduced economic risks. By creating a more complex forest structure, they provide more ecological niches to diverse species and may also avoid the negative impacts of monocultures on soil fertility.

Unfortunately, despite continuing calls from a wide range of advocates for mixed-species plantations, only <0.1% of present industrial plantations are polycultures (Nichols *et al.* 2006). Moreover, mixed-species plantations are often considered by many in the forestry industry to be not operationally or economically viable. In 2007, within the Mauricie TRIAD project, we began establishing operational-scale mixed plantations to test their potential and operational viability. In the first year, we used patches of indigenous white pine and red and white spruce in clearcuts reforested with exotic larch (*Larix decidua*), as well as enrichment following patch scarification for white birch regeneration. Replicated line mixtures and monocultures of exotic larch and white spruce were established in 2008 on a 110-ha clearcut to test their operational feasibility over 2 rotations.

Furthermore, an integrated approach is being used to plan and optimize future plantations. Simulations of species mixtures and spatial or temporal arrangements are being carried out using SORTIE-ND (Paquette *et al.* 2008). Finally, we have also implemented a biodiversity experiment in an intensive plantation forestry setup in the La Tuque region (2007). While very few biodiversity experiments using trees exist in the world (Caspersen et Pacala 2001, Balvanera *et al.* 2006, Scherer-Lorenzen *et al.* 2007), the "Lac-aux-Brochets" experiment is the only one in the mixed-wood boreal forest of north America, and the only one using fast-growing, genetically improved species and hybrids in an intensive setup. The design is that of a formal experiment to test for diversity effects, but the use of fast-growing and nutritionally demanding species of contrasting functional groups, together with advanced mapping techniques at the tree level, should improve our ability to more rapidly detect diversity effects in an otherwise long-term experiment.

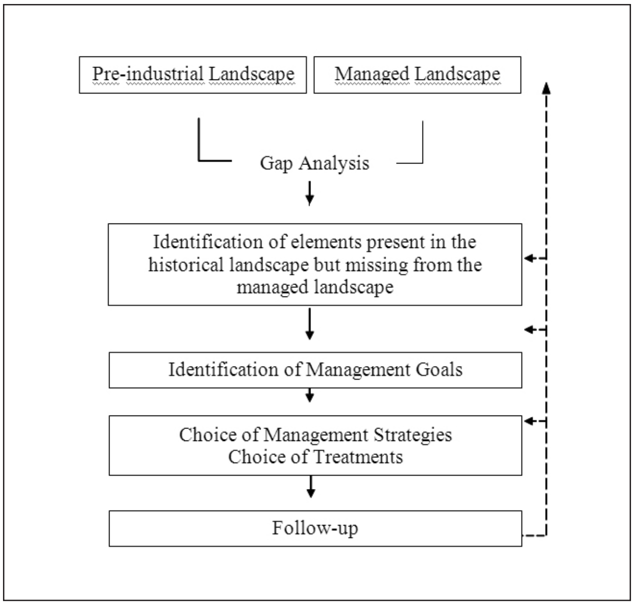

Fig. 2. Schematic representation of the process used to set goals and select management strategies and treatments in the ecosystem management zone and throughout the FMU.

on the existence of forest and ecological inventories carried out before the first wave of industrial harvesting, old aerial photographs, and even the accounts of retired forestry workers. Knowledge of the natural disturbance dynamics comes from published studies not necessarily designed to answer management questions. Furthermore, the use of data from the pre-industrial era assumes that human activity did not substantially affect the structure, composition, or natural disturbance regimes of this forest, an assumption that may not be correct. The implementation process must therefore be flexible, allowing for changes as new ecological knowledge comes to light.

2 – Identifying management goals

Management goals were set for the ecosystem management zone based on an ecological comparison (gap analysis) of the current conditions to those of the pre-industrial forest for the whole FMU. The appropriateness and success of these treatments continues to be monitored so that management will continue to adapt (Fig. 2).

For the TRIAD FMU, initial gap analyses were carried out based on pre-industrial reports and current data on the structure and composition of the forest (Barrette 2004, Alvarez in prep.). These analyses showed us that the current forest is generally lacking old growth and mature stands, conifer-dominated mixed stands, some specific conifer species, and structural and compositional complexity when compared to the pre-industrial forest. Based on these results, and following discussions with researchers and ministry officials, 4 broad management goals were set for the first phase of implementation:

(1) to increase old growth and mature forests and apply and develop silvicultural practices that maintain the stand-level attributes of old-growth forests as much as possible,
(2) to render the structure and composition of the forest more complex at both the stand and landscape levels,
(3) to increase the proportion of conifer-dominated mixed stands,
(4) to increase the proportion of specific conifer species.

3 – Choosing management strategies

Management strategies and treatments were then selected to meet these goals. Although many of the goals are addressed in the ecosystem management zone, the other 2 zones also contribute.

The goal of maintaining old and mature stands will be achieved at least in part by increasing the proportion of protected areas in the FMU. Maintaining these stands was the main goal in establishing the 99 wildlife refuges already protected (20% of the conservation zone), and a main goal of the scientific committee in recommending the other 14 areas (see above). Since timber will not be harvested in them, these conservation areas will ultimately produce and maintain amounts of mature, old, and uneven-aged forests within the range of natural variability. This does not mean that this zone will always be entirely composed of mature and old-growth stands; natural disturbance will be allowed to occur here, so age structures will fluctuate, but they will fluctuate within the range of natural variability. Studies indicate that this "natural variability" generally includes a high percentage of mature and old-growth forest (Gauthier *et al.* 2008b).

The goal of maintaining old and mature stands will also be addressed in the ecosystem management zone, as will the goals of creating and maintaining complexity and the attributes of old-growth forests. In this zone, we are applying harvesting treatments designed to maintain or re-establish the heterogeneous structure of many mature and old-growth stands. Approximately 50% of the ecosystem management zone will be subjected to harvesting using some form of partial cutting, with 50% to 70% of the cover maintained in a heterogeneous structure at all times. More specifically, we are applying a selection cut system for softwood stands, a selection cut with tree-marking in the southern deciduous part of the FMU, and some irregular long-term shelterwood harvesting. Furthermore, on the 50% of the ecosystem management zone managed by clearcutting, we are implementing a variable retention strategy where 3% to 10% (average of 5%) of live trees are left in clumps of 150 m^2 to 600 m^2 (mean of 500 m^2) on the cutovers. These trees will provide some protective cover in the short term, a seed bank and a source of snags and decaying wood in the midterm, and increased structural and compositional complexity in the long term. Due to the effects of windthrow, the smaller clumps may provide more dead and decaying wood than the larger clumps, but both live and dead wood are important to maintain long-term structural and compositional complexity and to provide habitat for forest species.

To further address the goal of creating and maintaining complexity, we are applying and developing specific silvicultural guidelines at the stand level in both the ecosystem management and the wood production zones. These include the following:

- A vast reduction in the amount of thinning and vegetation management carried out in the ecosystem management zone; any such treatments applied will favour the maintenance of as much complexity as possible,

Silviculture for managing complex adaptive systems

The focus of forest management has shifted from improving timber yields to broader issues such as sustaining the full function and dynamics of forested ecosystems, maintaining biodiversity and ecological resilience, and providing for a variety of ecosystem services of value to humanity. These new challenges must be addressed through a new type of silviculture, which we label "Silviculture for managing complex adaptive systems" (Puettmann *et al.* 2008). This silviculture must embrace some of the ecological viewpoints and approaches that are often better suited to deal with ecosystem complexity, variability, unpredictability, and adaptability. It must:

- Consider as wide a variety of ecosystem components and functions as possible (i.e., more than just trees). A silviculture that thinks "beyond the trees" will be better suited to contribute to a wide variety of natural resource management issues.
- Abandon the "command and control" approach to management (Holling and Meffe 1996). Management of forests should accept variability in space and time as an inherent attribute that allows forests to adapt to new internal and external biotic and abiotic conditions.
- Actively maintain and develop within- and among-stand heterogeneity in ecosystem structure, composition, and function to recreate natural variability in forest conditions and processes.
- Allow stands to develop within a wide envelope of possible natural conditions. Foresters must determine silvicultural success at the landscape level rather than at the stand level and allow for multiple development trajectories at the stand level.

Complex forests are better able to adapt to changing abiotic and biotic conditions. This adaptability is especially critical today with the rapid pace of climate change and species invasions. Accepting unpredictability as an inherent feature of forests decreases the emphasis on managing all forests according to a single set of "best" management practices. It therefore requires less vigilance from silviculturists, who can accept a range of developments as long as the whole forest achieves economic, social, and ecological objectives. In many cases, this will result in lower costs, reduced ecological impacts, and higher social acceptance.

- Mixed plantations in the wood production zone,
- A silviculture approach based on complex adaptive systems (Levin 2005, Solé and Bascompte 2006) (See ***Silviculture for managing complex adaptive systems*** sidebar).

Studies are being carried out to compare the level of structural complexity and the diversity and abundance of understory plants, birds and insects of unmanaged stands to that resulting from different types of management. This will help improve our ability to manage for biodiversity and for the appropriate level of structural complexity at the stand scale, addressing issues such as the amount, spatial arrangement, and variation in stand-level retention required to emulate the range of stand structures natural to the forest and to provide habitat for a diversity of forest species.

We are also developing strategies to favour complexity within the natural range of variability at the landscape level. Such complexity will evolve naturally in the conservation areas if they are left to develop under a natural disturbance regime, but management practices in the ecosystem management zone can also favour broad-scale complexity. Through modeling studies, we are examining the issues of cutblock size and distribution, and the effects that varying these 2 factors might have on the structure of the landscape. At present, provincial legislation limits cutblocks sizes to 100 ha in the south and 150 ha in the north, while fires are much more variable in size and large fires (>10 000 ha) have historically been extremely important in structuring the landscape. The current landscape is therefore much more fragmented and less variable than the pre-industrial landscape. Since natural disturbances still occur and are likely to continue to occur in the area, we cannot simply base the spatial configuration (size and spatial arrangement) of cutblocks on the spatial configuration of natural disturbances, but some modification of the current system will undoubtedly allow us to create a landscape structure more similar to that created by natural disturbance.

With these issues in mind, we are using landscape simulation studies calibrated with historical data to examine the level of complexity created by the natural disturbance regime and compare it to that created by various management strategies (e.g., Côté *et al.* in press). Modeling studies will be followed by social studies to examine the social acceptability of the scenarios that best re-create natural landscape structure. This will help us develop management regimes to manage for the appropriate level of complexity at the landscape scale.

As well as allowing natural regeneration in the conservation zone, we are planning to increase the proportion of conifer-dominated mixed stands and of some specific conifer species (red and white pine and red and white spruce) in the ecosystem management and wood production zones to address management goals (3) and (4) above. Partial cuts in the ecosystem management zone should favour the regeneration of conifer over shade-intolerant poplars and white birch. Partial cuts should also produce more decaying wood, which in turn will favour the regeneration of spruce over fir (Greene *et al.* 1999). In addition, in some cases, red and white spruce and white pine will be planted in the skid trails following partial cuts, which should increase the proportion of these particular species. Small numbers of white pine and red spruce are also being planted in clearcuts and in some shelterwood cutovers as an addition to the acquired regeneration. White pine and red and white spruce are also being used as enrichment plantings in areas scarified for the regeneration of white birch. Finally, in the wood production zone, mixed plantations will add to the total proportion of conifer-dominated stands in the FMU.

The actual implementation of ecosystem management will require a change in culture among the professionals working in the field, since the latter have largely been trained to simply harvest those trees of highest timber value. For example, if the variable-retention cutblocks described above are to best emulate the patterns created by fire, residual trees should be selected at random (DeLong and Tanner 1996, Dragotescu 2008).

4 – Follow-up

Follow-up will be crucial to the success of the Mauricie TRIAD project. This follow-up will take the form of ecological and economic studies on the success of the various treatments described above. Examples of such studies include the stand- and landscape-level studies of structural and biological complexity and detailed monitoring of the diversity and abundance of plants, birds, and insects described above. It will be crucial to monitor the state of the forest as it regenerates under the different treatments so as to be able to adapt management strategies appropriately to meet the stated goals, or even adjust the goals to changing conditions.

Regulatory considerations

In Canada, forest management on publicly owned land is largely regulated by the provincial governments. Early on, it became clear that many elements of the current provincial forest regulations would have to be changed if a functional zoning approach were to be adopted in the Mauricie. This is partially why the Quebec provincial government decided to designate the TRIAD project as a special pilot project. Of the many modifications required, the following were the most important:

(1) The regulation regarding the amount of unharvested wood that could be retained in a cutover had to be modified. Under this regulation, managers currently cannot leave more than 3.5 m^3/ha of harvestable wood on a cutover. This corresponds to less than 2% of the total volume found on average. The original objective of this regulation was to minimize timber waste. This objective is inconsistent with the goal of the ecosystem management zone, where we seek to maintain the natural functioning of the ecosystem by emulating the natural disturbance regime. Research indicates that there is often a much greater amount of wood left after a wildfire (see Schmiegelow *et al.* 2006 for a review on the boreal), not to mention after a spruce budworm outbreak (e.g., Cappuccino *et al.* 1998). This residual is important to wildlife species such as woodpeckers. Thus, in keeping with the ecological goals of ecosystem-based management and the natural-disturbance management model, a much more variable amount of dead and live trees must be left on cutovers. According to the current TRIAD plan, up to 10% (3%–10%, mean of 5%) of harvestable wood will be left in some cutovers as part of the variable retention approach.

(2) The regulations are fairly specific as to the way in which the different types of forest should be harvested. The concept of the "best" treatment for a particular forest had to be abandoned because it was not in keeping with the new concept of ecosystem management. The latter aims at restoring the natural complexity of the forest, thus focussing on variability. Silvicultural practices must therefore be much more varied and less prescriptive to manage the forest as a complex adaptive ecosystem rather than a predictable and absolutely controllable system (Puettmann *et al.* 2008).

(3) The details about the distribution of cutblock sizes had to be changed. For example, provincial legislation dictates that a maximum of 10% of cutblocks can be larger than 50 ha in the temperate deciduous forest and 100 ha in the boreal mixedwood forest (*Quebec Regulation respecting the standards of forest management for forests in the domain of the state*). However, research on fire sizes in the area indicates that large fires were very important in the pre-industrial forest, resulting in a size distribution quite different from that specified for cutblocks by the provincial regulations (Alvarez in prep). Thus, in keeping with the natural disturbance model, although the maximum size of cutblocks was still limited to the 100 ha in the northern temperate deciduous forest and 150 ha in the boreal mixedwood set by provincial regulations for social reasons, the distribution of cutblock sizes had to be somewhat altered. Specifically, we proposed a few 500-ha agglomerations of 100- to 150-ha cutblocks, to be harvested over several years. These are short-term recommendations. As discussed above, ongoing modeling and social studies will provide further insight into the most advisable and acceptable distributions of cutblock sizes, both from the social perspective and from the perspective of natural disturbance-based management that seeks to create landscapes structured in a similar way to natural landscapes. Note that, for ecological as well as social reasons, we are not proposing that cutblocks be as large as the largest fires in the area (often >10 000 ha) because we have no indication that these fires will cease to occur and the effect of very large cutblocks would, therefore, be to create a more simplified, coarsely grained landscape than natural.

(4) The spatial arrangement of the mosaic cuts specified in the *Quebec Regulation respecting the standards of forest management for forests in the domain of the state* had to be abandoned. This part of the regulation specifies that for each area cut, an adjacent area of at least equal size must be left uncut until regeneration in the cutblock reaches 3 m in height and 10 years in age. This creates a patchwork forest not at all resembling the natural forest, and therefore inconsistent with the natural disturbance-based management of the ecosystem management zone.

Economic feasibility and social acceptability

Since the main goals of the TRIAD approach applied here include maintaining a viable forest industry and increasing social acceptability, social and economic studies are crucial to the project. Several such studies have been carried out.

Researchers applied the concept of eco-efficiency to examine the economic feasibility of the Mauricie TRIAD project. Eco-efficiency is defined as increasing production or service value while optimizing resource use and reducing environmental impacts (Schmidheiny 1992). It is often applied to factory settings, where managers want to reduce costs and limit their environmental footprint by improving the efficiency of energy or resource use. Improvements in energy use, for example, reduce costs and thus lead to improved profitability. Cost-benefit analysis was used to compare the forest management regime in place in 2003 to 3 possible TRIAD scenarios: (1) 11% conservation, 69% ecosystem management, and 20% more intensive wood production (the scenario being implemented in the Mauricie); (2) 5% conservation, 75% ecosystem management, and 20% more intensive wood production; and (3) 20% conservation, 40% ecosystem management, and 40% more intensive wood production. Ecological benefits and economic return were examined (timber production vs. cost). The focus was placed on the costs of the forestry operations and on timber production by evaluating indicators such as the land area being actively managed, the volume of wood harvested, the development and maintenance of the road network, the silvicultural treatments applied, the costs and returns of the harvesting operations, and the number of jobs created or lost.

All 3 TRIAD scenarios had greater eco-efficiency than the forest management regime in place in 2003, with a calculated savings of around 10% to 15%. Although not harvesting in the conservation zone resulted in some loss in income, it also resulted in some cost savings (i.e., reduced transportation and road maintenance costs). In the wood production zone, road costs were low relative to the volume of wood harvested. In the ecosystem management zone, the application of shelterwood and selection cuts not only increased the non-economic value of the forest for other users, but also reduced the need for expensive vegetation management and thinning, and thus reduced forestry costs in the TRIAD scenarios as compared to the current management scenario.

The TRIAD scenario with the highest proportion of land in the wood production and conservation zones (40% and 20%, respectively) had the highest timber production and the lowest cost. Thus, if as a society we are willing to accept a high proportion of more intensive wood production (40%) to compensate for a high proportion of protected area (20%), there is strong economic support for such a scenario. However, depending on the economic and social value of conservation (e.g., from tourism, recreation, improved quality of life, water quality, air quality, etc.) and the efficiency of the ecosystem management zone in providing wood while preserving biodiversity, other TRIAD scenarios may be more desirable.

Hô and Gélinas (in prep) surveyed residents of La Tuque and vacationers in nearby areas to assess their willingness to pay (AWP), specifically asking subjects how much (if anything) they would be willing to pay in increased income tax, for (1) 8% of the Haut-Saint-Maurice area to be managed as a conservation zone, (2) 50% of the area to be under ecosystem management, and (3) 10% to be more intensively managed for wood production, all assuming no changes in number of jobs.

Although results differed somewhat for the 2 interest groups surveyed, there were some similarities. Both residents and vacationers placed the lowest value on intensive wood production. Residents were willing to pay the most for ecosystem management, with an AWP almost twice that of increased wood production. Vacationers placed the highest value on conservation, with an AWP almost 4 times higher for conservation than for wood production. This implies that both residents and vacationers valued old forest and habitat diversity, although to differing degrees.

The general acceptability of the TRIAD scenario is echoed in the results of a social study carried out by Berninger (2007).

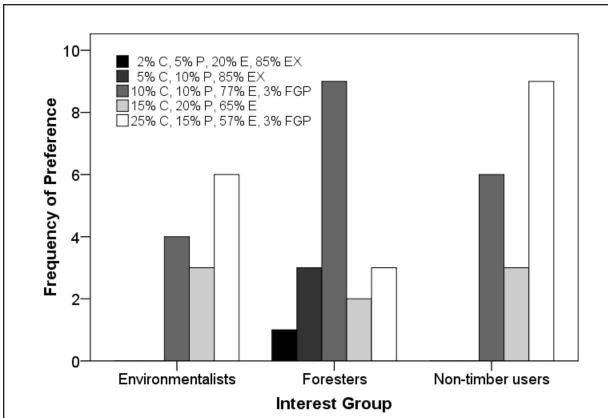

Fig. 3. Preferences of forest users from 3 different interest groups in Quebec forest management unit 042-51 (Mauricie). Subjects were given the choice among 5 different management scenarios with various percentages of land under conservation (C), wood production (P), ecosystem management (E), extensive management (EX), and fast-growing plantations (FGP). N = 13 environmentalists, 18 foresters, and 18 users of the non-timber resources of the forest. Adapted from Berninger (2007).

This study sought to determine attitudes towards the forest management regime in place at the time (2006) and assess the acceptability of TRIAD zoning to 3 interest groups: self-identified environmentalists, professional foresters, and users of the non-timber resources of the forest, including hunters, berry pickers, canoeists and boaters, and campers (Berninger 2007). The majority of those surveyed from all 3 interest groups expressed concern that the forest management regime in place at the time did not provide enough protected areas or enough wood for the future needs of the Mauricie area. Those who identified themselves as environmentalists and non-timber users were also sceptical of the ability of this management regime to maintain forest conditions suitable for uses other than forestry. There was special concern about the suitability of the forest for recreation. When participants were asked to choose between various zoning alternatives, all 3 groups preferred some form of TRIAD zoning (Berninger 2007; Fig. 3), with both more intensive wood production and more conservation than the management regime in place at the time.

The Mauricie TRIAD project has also been presented at various public and scientific meetings in Quebec, Canada, and all over the world in the last 5 years and, in keeping with the results of Berninger (2007) and Hô and Gélinas (in prep), it has received strong support.

Assessing the success of the project thus far

In assessing the success of the project so far, it seems reasonable to refer to the initial project goals set out in 2003. Only time will tell if we are able to meet all of these goals, but we have come a long way.

The primary goals were (1) to reduce the socio-economic impacts associated with the 20% reduction in annual allowable cut announced by the government, (2) to develop a strategy that was more acceptable than the status quo to the various stakeholders within and outside of the region, and (3) to restore as much as possible the ecological integrity of the forest. In terms of the first goal, economic analyses indicate that, if our assumptions are realistic, a TRIAD scenario should be more economically viable than the status quo. In terms of the second goal, the results of Hô and Gélinas (in prep) do indicate a general social acceptability of the TRIAD approach to various local stakeholder groups, and the results of Berninger (2007) indicate a clear preference for the TRIAD over the status quo. In terms of the third goal, ongoing ecological studies and monitoring comparing stand structural complexity and plant, insect, and bird diversity and abundance among uncut stands, traditionally cut stands, and cut stands following natural disturbance will be crucial to assess the effects of TRIAD management on the overall ecological integrity of the forest.

The secondary goals were (1) to develop new silvicultural practices based on ecosystem management for the various forest types in the area, (2) to significantly increase the proportion of land set aside for conservation in the FMU, (3) to develop and implement new intensive forest management practices to complement ecosystem management and conservation strategies, and (4) to accommodate the spatial component of the zoning strategy using new simulation models. To address the first of these goals, we have developed several new practices, including the 4-pass multi-cohort system (see ***Harvesting procedure for partial cutting*** sidebar). We expect this to be an ongoing process, constantly informed and refined based on new information. To increase the area set aside for conservation, the scientific committee has made specific recommendations to the provincial government. If these recommendations are accepted, conservation areas will account for 11% of the area of the FMU, much more than the 2% protected under the status quo. To address the third goal, we are experimenting with several fast-growing hybrids and polycultures, as described in the sidebar entitled ***Intensive mixed plantations.*** To accommodate the spatial component of the zoning strategy, we are developing landscape-level simulation models to allow us to compare the spatial structure of the natural forest to that created by various management strategies, varying the size, shape, and spatial location of cutblocks.

What next?

The TRIAD zoning project is now entering its implementation phase (2008-2013). Much remains to be done and ongoing monitoring and research of the new practices will continue for years to come. The major next step is to implement integrated modeling tools (Sturtevant *et al.* 2007) to evaluate the effects of different silvicultural practices and zoning strategies at various spatial and temporal scales.

Conclusion

Although there is still much work to be done, our experiences with the Mauricie TRIAD project have been largely positive thus far. The TRIAD approach has garnered considerable support from officials and stakeholders, as demonstrated in the social studies outlined above, and in numerous meetings, discussions, and conferences with stakeholders, academics, government officials, industry, environmental interests, etc. Results so far also indicate that the approach has the potential to help us manage Canada's public forests in a more sustainable way. We are addressing many of our initial goals, but it is too early to judge how effective the approach will be in meeting all these goals. Given appropriate monitoring, this should become clear with time. Although we are not following a strict adaptive management process (as defined by Holling 1978, Duinker and Trevisan 2003), we have attempted to build the principle of adaptive management into the project, so that the various goals, strategies, and treatments of the management regime can be adjusted as new challenges appear and new knowledge emerges.

Harvesting procedures for partial cutting (developed and tested by FPInnovations – Feric division)

On the Mauricie TRIAD FMU, a 4-entry selection cut system of partial cuts is being implemented in selected stands with established multi-cohort structures (Fig. 4). For the first entry, a 5-m wide corridor is cut to establish a skidding trail. On each side of this trail, trees are chosen by the feller-buncher operator in a 7-m-wide strip (width determined by the boom reach of the feller-buncher). The tree selection guidelines must be very simple to be reliable. The prescription considers basic silvicultural principles like production objectives, control of removal intensity, tree vigour analysis, etc. In the first trial the cutting rule established for the proposed stands allowed removal of 40% of the total volume. The operator cut the largest tree from every group of 3 trees. Untouched strips 19 m wide (7 m + 5 m + 7 m) were left between harvested strips. In the second entry, the same 3-strip pattern will be applied between the previously treated areas in 20 to 30 years, depending on operational opportunities and stand development (regeneration and vigour) (Fig. 4c). The third and the fourth entries will repeat this process, with consideration for the protection of the developed regeneration. It is reasonable to control the development of a heterogeneous forest using this pattern, offering 4 regeneration opportunities and 2 harvesting possibilities for each rotation. A similar 2-entry shelterwood system is also being applied.

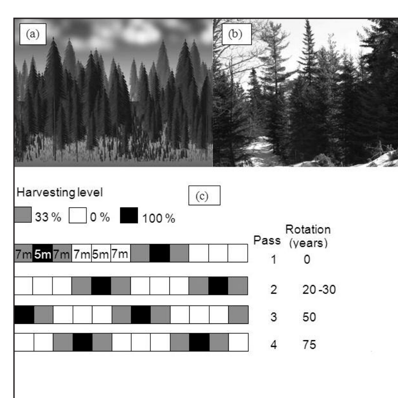

Fig. 4. (a) Hypothetical, (b) actual appearance, and (c) schematic representation of 4-pass multi-cohort partial cuts being implemented in the ecosystem management zone of the Mauricie TRIAD.

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