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The Impact of Salvage-logging after Wildfire in the Boreal Forest: Lessons from the Abitibi

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Introduction

Although its role in the boreal forest has undergone an important re-evaluation over recent years, wildfire still raises important issues for forest managers and the public. When the forest is aflame, decisions have to be made quickly concerning where and how to intervene and, in some cases, whether or not to intervene. Nonetheless, because forests do burn and will continue to do so, it is important to assess the effects of different forest management options after wildfire.

Recent modifications to Quebec's forest legislation and regulations have provided incentives to increase salvage-logging (essentially clearcutting of burned forest) on public lands in forests that have been recently burned or severely affected by insect outbreaks. Specifically, Article 79 of the Quebec Forest Act (L.R.Q., c. F-4.1) states that land tenure holders must comply with special management plans, created at the provincial government's discretion, to salvage forest after a natural disturbance. As a result of this legal framework, the amount of salvage-logging after forest fire has increased, from $3m^3$ per burned hectare harvested in 1991 to $10m^3$ per burned hectare in 1996. While this increase in salvage-logging may be unavoidable for economic reasons, there is a crucial need to provide science-based guidelines concerning management of recently burned forests.

Due to the short history of this activity, however, basic research on salvage-logging is only now forthcoming. Over the past few years, the NSERC-UQAM-UQÀT Industrial Chair in Sustainable Forest Management (SFM Chair) has been able to conduct several post-fire ecological studies in the boreal forest of the Abitibi region of Quebec. This work began with a fire that occurred near Senneterre in 1995 and continued with a second fire in 1997 near the village of Val-Paradis. This latter fire burned to within 6 km of the village, and covered an area of 12,540 ha (Bordeleau, 1998), 64% of which was salvage-logged. The proximity of Val-Paradis to the fire drew particular attention to social issues of post-fire management.

Most of the SFM Chair's studies have focused on comparing effects of fire alone and when followed by salvage-logging. The reasoning for this is straightforward: forests have evolved ecological mechanisms of resilience which allow them to re-establish after natural disturbances such as fire. Over the millennia, these cycles of disturbance and recovery have evolved into the boreal forest we know today, defining its productivity and biodiversity (Rowe and Scotter, 1973; Messier and Kneeshaw, 1999). The serotinous cones of jack pine,

The mosaic of the Val-Paradis forest fire from vast burnt areas (background) to patches (foreground).
Photo courtesy of Tembec.

Salvage-logged landscape, Val-Paradis.
Photo by Mark Purdon.

which only open under extreme heat, are probably the most well known example of an adaptation to fire. Other examples of adaptations include the rapid regrowth of understorey vegetation following fire that prevents nutrient leaching, the important wildlife habitat created by standing dead trees (snags) and the slow release of nutrients back into the soil upon their decomposition. Because tree harvesting and the additional physical site disturbance it induces have the potential to significantly affect ecological processes after fire, a better understanding of these processes is essential to ensuring that forests are managed sustainably.

As important as these stand-level effects are, however, we now appreciate fire to be important in the determination of patterns across the forest landscape (Bergeron *et al.*, 2002). The natural mosaic of stands of varying compositions and ages found across a regional landscape is largely a result of variations in disturbance parameters such as fire size, frequency and severity (Bergeron *et al.*, 2002), as well as the underlying influence of soil characteristics. Among the questions that need to be addressed is: Does salvage-logging following fire constitute a disturbance of similar order to the natural variability of fire alone?

In this note we summarize findings from research conducted by the SFM Chair in the Abitibi region, results which have bearing on several criteria and indicators for sustainable forest management. We have also included relevant information from the scientific literature. In an attempt to address some socio-economic aspects of salvage logging, we also summarize a number of concerns raised by citizens of Val-Paradis during a one-day workshop held in March 2001. Finally, we offer some avenues of solution toward the development of integrated, multiple-value salvage logging strategies.

Recently burned forests and biodiversity: The case of the Black-backed woodpecker

Though the trees are ravaged, burned forests are still a preferred habitat for numerous species associated with snags. They provide foraging habitats and sites for nests, dens and burrows. Because of the cyclic nature of fire in the boreal forest, different insect and animal species have come to be associated with different stages of forest development including burned sites after fire (Drapeau *et al.*, 2002).

As demonstrated in the case of the Val-Paradis fire, there is an important relationship between species presence and the suitability of snags as habitat.

Wood-boring beetles (Cerambycidae, Buprestidae et Scolytidae) are known to colonize standing dead trees immediately after stand-replacement fires. Some insect species are specialized to feed on fire-killed trees and detect fires with infrared sensors (Hutto, 1995). Female wood-boring beetles in particular are attracted to the moist, inner wood layer as habitat suitable for laying their eggs. Because of the damage it causes to timber, the white-spotted sawyer *(Monochamus scutellatus)* is probably the best known wood-boring species in our forest ecosystems. It is important to note that not all standing dead trees provide this habitat. The more decayed a snag is, the less hospitable it is for certain insect larvae. During the decaying process, the sloughing of bark exposes the inner wood area to desiccation, effectively limiting the habitat suitable for larvae.

The Whitespotted sawyer *(Monochamus scutellatus)*, a wood-boring beetle. Photo by Antoine Nappi.

Male Black-backed woodpecker *(Picoides arcticus)*. Photo by Antoine Nappi.

High concentrations of wood-boring and bark beetles that colonize recently burned forests are followed by an invasion of insect predators such as birds, particularly bark-probing birds. The Black-backed woodpecker *(Picoides arcticus)* is undoubtedly one of the best examples of an opportunistic bird species that capitalizes on the highly concentrated food resource that results from the invasion of woodborers in early post-fire stands (Hutto, 1995; Drapeau *et al.*, 2002). But the Black-backed woodpecker has only a brief window of opportunity, which is why it has been found in high concentrations during the first years following fire. After a few years, as the snags further decay, the woodpeckers must move on as wood-boring beetle larvae mature and disperse.

What have we learned about the Black-backed woodpecker in the Abitibi region? First, as has been observed throughout its range, this species is highly restricted to major disturbances such as fires that produce massive tree kills (Nappi 2000, Drapeau *et al.*, 2002). Hence, this species was highly concentrated in early post-fire forests in Abitibi and far less common in the other forest cover types. Second, within recently burned forests, Black-backed woodpeckers selected the largest available snags. The density of wood-boring beetles was also positively related to snag diameter. Our results also showed that snags that were preferred by woodpeckers were moderately degraded and contained more wood-boring beetles *(Monochamus spp.)* than did lightly or severely degraded trees (Nappi *et al.*, submitted). All these snags were of commercial size (>10 cm DBH) and thus could potentially be salvage-logged. It would thus be necessary to leave more and larger snags standing in salvage-logged burns to provide suitable habitat for bird species such as the Black-backed woodpecker.

Natural Regeneration: The impact on seedlings

Natural regeneration, the establishment of seedlings and vegetative suckers after fire, is important in determining the future characteristics of stands, what tree species and how many will occupy a site. Historically, the establishment and survival of seedlings has been understood in terms of shade tolerance/intolerance, life history traits of the species involved, their preference for various seedbeds, and the quantity and quality of seed banks. In the absence of fire, industry can often rely, at least partially, on advance regeneration (regeneration present in the understorey at the time of harvest) by using careful logging (CPRS in Quebec) techniques. However, in the case of salvage logging of burned forests, advance regeneration is usually destroyed by the fire. Conventional reforestation can cost up to $2,000 per ha and it is important to know if conditions created by salvage logging necessitate the same order of investment.

Some species, such as aspen, jack pine and black spruce, are better adapted to fire disturbance than others such as balsam fir and white spruce. In order to understand the relationships between stand composition and regeneration after fire, a study was undertaken by Noël (2000) in the Val-Paradis fire.

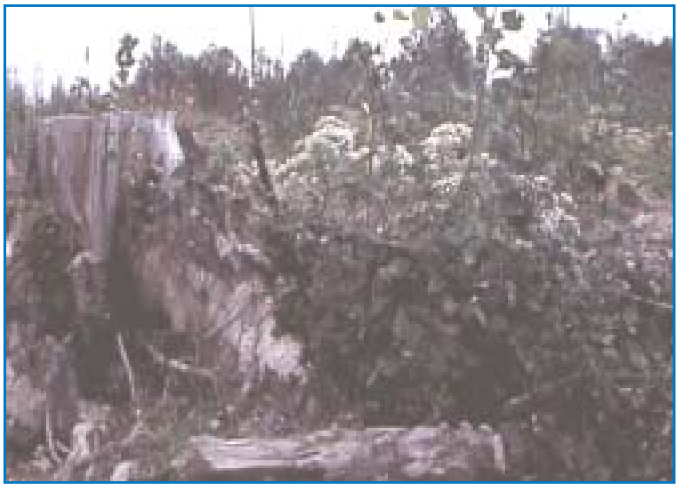
Fire is known to initiate forest regeneration by, for example, opening serotinous cones and exposing mineral soil favourable for establishment of coniferous seedlings. Results from Val-Paradis show that wildfire favoured jack pine and aspen regeneration, two species that establish quickly the first year after fire. The serotinous cones of mature jack pine are opened by fire and the mineral soil exposed by the combustion of organic soil layers tended to favour germination of their seeds. Root suckers from aspen trees killed by fire rapidly take advantage of conditions after fire. Black spruce regeneration was delayed in the first year after of the Val-Paradis fire, but was well established by the second year. Black spruce trees do not disperse all of their seeds immediately after fire but maintain nearly 50% of their seeds for subsequent years. This delay may be attributable to the fact that black spruce is shade-tolerant and thus capable of growing underneath a closed canopy, as well as in direct sunlight, unlike shade-intolerant aspen and jack pine.

How do these different reproductive adaptations affect the outcome of salvage logging? Aspen, primarily regenerated from root suckers, was found to be unaffected by salvage-logging in the Val-Paradis fire. Jack pine, a species that disseminates most of its seeds the year of a fire, suffered only a brief delay. Black spruce, on the other hand, exhibited reduced stocking and density after salvage-logging. Why this difference between jack pine and black spruce when both originate by seed following fire? Part of the explanation comes from the more gradual dispersal of black spruce seedlings mentioned above which was interrupted by the harvesting of seed trees. Differences are also due to the availability of suitable germination beds and the capacity of these two species to use them. Again, here we discuss the effects of fire first in order to compare them with salvage-logging.

After the Val-Paradis fire, the most abundant type of germination bed was duffacharred, fibrous organic materials. This is not, however, the best substrate for seedling establishment. Though less abundant, germination was highest on exposed mineral soil, pioneer mosses (i.e. *Polytrichum spp.*), and sphagnum mosses, the latter being used almost exclusively by black spruce. These scarce, yet highly utilized seedbeds appear to be very important for establishment and survival of jack pine and black spruce.

While more mineral soil was exposed following salvage-logging, this did not lead to increases in its occupation as a seedbed, suggesting that disturbance caused by harvesting may reduce the quality of these germination beds. Our results suggest that some deficiencies exist in seed bed condition, probably related to soil humidity and temperature. Furthermore, because virtually all standing merchantable stems, that would otherwise buffer environmental conditions, are salvaged, this logging could also reduce the extent of moist sphagnum moss carpets. Desiccation is recognized as one of the main causes of seedling mortality (Duchesnes and Sirois, 1995). These effects bear directly on black spruce regeneration. As more sphagnum beds remain after fire alone, the continuous dispersal of black spruce seeds is better accommodated for following this disturbance.

Thus, after salvage-logging, the suitability of both black spruce germination beds and seed sources declines. Strictly from a regeneration viewpoint, delaying salvage operations by one year would very likely improve seedling establishment. As an alternative strategy, leave strips of cone-bearing black spruce snags could provide a seed source for about three years on site while possibly also providing environmental and site conditions favourable to germination and seedling establishment. In the event that these retention strategies are insufficient to assure adequate forest regeneration and tree-planting is required after salvage-logging, favouring black spruce on sites where it is mixed with jack pine would compensate for spruce's generally lower regeneration success.



Suckering of trembling aspen. Photo by Josée Noël.

Counting seedlings in an unlogged black spruce stand. In the background is a salvage-logged area.
Photo by Josée Noël.

Understorey Vegetation

The understorey contains a plant community that usually goes unrecorded in traditional forest inventories. Common plants include: asters *(Aster spp.)* and violets *(Viola spp.)*, shrubby species such as alder *(Alnus spp.)* and let's not forget the lowly mosses and liverworts. During the course of the study conducted in the Val-Paradis fire on the understorey's response to fire and salvage-logging, over 140 species were identified (Purdon *et al.* submitted). Most people know that a fire affects understorey vegetation. For instance, blueberry pickers may have noticed that the first year after fire berries are scarce, only to be overwhelmed by their abundance the following year. What can explain such phenomena?

Most plant species are only able to exist under a limited range of conditions defined by factors such as the amount of sunlight, soil fertility, soil moisture and competition from other plants. After a fire, these ecological conditions are radically changed. Equally important however is fire's direct impact on the plant community and the response of understorey vegetation to the degree of fire severity. Because differences exist in plant reproductive strategies, different groups of plants are favoured over others in the event of fire disturbance. For example, plants that store their seeds or reproductive tissues deep in the organic soil (ex. Bristly Sarsaparilla *(Aralia hispida)* will have an advantage over other species after a moderate fire that burns most, but not all of the organic layer Flinn and Wein, 1977). But when a severe fire burns down to the mineral soil these seeds will also be consumed. In this situation, the exposed mineral soil favours species that invade the site with light, wind-dispersed seeds such as fireweed *(Epilobium angustifolium)*.

This raises some important questions. How does understorey vegetation react to the variability of fire severity at the landscape scale? Moreover, is the response the same in different types of forest? For example, does the understorey in black spruce-feathermoss sites react similarly to that of aspen or mixedwood stands?

The study conducted in the Abitibi has shown that after a light burn, differences in understorey composition between different cover types were maintained. However, after a more severe fire, associations are not so well defined. After the generally severe, stand-replacing fire at Val-Paradis, in stands where more than 75% of the trees were killed, we found that plant community differences between coniferous and deciduous stands were reduced. Much of this is due to the burning of Sphagnum moss, a species dominant in black spruce stands. When sphagnum is removed, understorey species common to mixed boreal stands, are able to establish Bunchberry *(Cornus canadensis)*, Yellow Clintonia *(Clintonia borealis)*, and Gooseberry *(Ribes spp.)*.

How did salvage-logging affect this variability that naturally exists in the understorey after fire? We found that salvage logging generally reduced the diversity of understorey communities, resulting in a gradual homogenization of the understorey across the forest landscape. Following salvage-logging, stands are not necessarily invaded by non-indigenous, invader species; rather, they simply exhibit a lower plant species diversity. Perhaps more important, however, is the effect that salvage-logging had in significantly reducing the amount of understorey vegetation.

We believe that this is probably due partly to site physical disturbance caused by harvesting machinery. The stands at Val-Paradis were harvested in late summer, and the vegetation occupying the site at the time of harvest was directly physically damaged by these operations. But direct effects are generally localized to "careful logging" trails that occupy only about a quarter of cutover area. This suggests another, more indirect impact. An interesting feature of the salvage-logged stands is that they favoured species common to dry habitats such as Bristly Sarsaparilla, the grass *Oryzopsis* *canadensis*, and Houghton's sedge *(Carex Houghtonii)*. Such results suggest that salvage-logging provoked a more rapid drying of the soil. We can only hypothesize on the reasons for this. Reduced vegetation resulting from physical disturbance, provides less shade, and may result in more rapid evaporation from the soil. Another possible explanation is that the removal of both live and dead standing trees eliminated their effect in moderating environmental conditions by casting shade and functioning as a windbreak. More research is necessary to validate these hypotheses.

To summarize this section, natural post-fire plant diversity in the understorey was reduced by salvage-logging. Species that survived in pockets of lightly burned stands tended to lose their habitat as conditions after salvage-logging approached those of more severely burned stands. Evidence suggests then that salvage-logging in the Val-Paradis fire has led to a simplification of understorey community across the forest landscape.

Coniferous stand after severe burn showing understorey regrowth. Photo by Mark Purdon.

Nearby coniferous stand after salvage-logging. Photo by Mark Purdon.

Nutrient retention and reserves

In a mature boreal stand, nutrients stored in the tissues of plants and plant litter are slowly liberated through decomposition and recycled, contributing to soil nutrient availability with little losses from the system. We can think of fire as speeding up this process. Ash is essentially a highly concentrated form of nutrients that existed before in the form of litter, plants and trees. While nutrients in ash are much more soluble and susceptible to loss by leaching, the forest ecosystem has evolved "mechanisms" to minimize nutrient losses after fire.

The previous section on the understorey provided a good introduction to some of these mechanisms. Understorey plants absorb nutrients from the soil which are then locked away in their tissues (stems, leaves and roots), to return gradually to the soil. But plant uptake is not the only mechanism for retaining these liberated nutrients. Snags and downed branches also contribute to immobilize nutrients (Harmon *et al.*, 1986). Soil organisms are able to decompose coarse woody debris (CWD) a source of carbon, resulting in a transfer of nutrients from debris to the soil. But these are generalizations; the "behaviour" of different elements varies and this variation is important.

Perhaps more important to nutrient retention in the forest is the distribution of nutrients within reserves, areas where nutrients accumulate and are held within the ecosystem. Examples of nutrient reserves are tree trunks and soil organic matter. To a certain extent, the degree to which these reserves are consumed during a fire will determine the extent of nutrient losses. Thus when considering the impact of fire and salvage-logging on boreal stands we need to consider both these factors: 1) mechanisms of nutrient retention and 2) nutrient reserves.

In the Val-Paradis study (Purdon *et al.* submitted) we compared severely burned stands (>75% tree mortality) with salvage-logged sites, for major forest overstorey compositions. We found that salvage-logging affected a number of mechanisms involved in nutrient retention, and demonstrated that potassium was the element most at risk of losses through leaching. Understorey vegetation was less effective in taking up nutrients and forest floor concentrations of phosphorous and potassium decreased. Such results suggest that these two elements are leached out of the system at a greater rate after salvage-logging than after fire alone. The retention of potassium in the system is dependant on plants and soil, both of which are significantly reduced after salvage-logging.

With respect to nutrient reserves, even after fire there are still important amounts of nutrients left in the soil and standing snags. However, the quantity of nutrients left will depend on the overall severity of the fire and the extent to which these reserves are depleted. For instance, the nutrient rich, organic forest floor was not consumed to a great extent by the Val-Paradis spring fire, even in areas described as severely burned. Nutrient losses in Val-Paradis were much lower than those caused by the summer fire of 1995 near Senneterre (Brais *et al.* 2000), where, in the severely burned sites, the forest floor was almost completely burned.

Furthermore, there are important differences in nutrient reserves between different stand compositions. At the Val-Paradis fire we found that snags play a greater role as a nutrient reserve in deciduous stands. In contrast, soils are more important as a nutrient reserve in coniferous stands. As well, snags are a relatively important reserve of potassium and, at least for deciduous and mixed stands, of phosphorous. Thus, by removing nutrients held within snags, salvage-logging induces reductions of these two nutrients, particularly in deciduous-mixed stands.

The limited capacity of potassium to be immobilized and reductions in its reserves suggest that, from a nutrient stand-point, the greatest impact of salvage-logging of boreal stands probably occurs on budgets of this element. The importance of potassium reductions needs further research in order to understand whether such reductions will affect future growth.

Val-Paradis : Lessons in «Thinking Global, Acting Local »

As is the case for most accessible forests that are ravaged by fire, the QMNR exercised government policy in requiring the forest companies to implement an emergency management plan to salvage most of the mature forest burned in the Val-Paradis fire. This policy requires companies to modify existing plans, depending on the size of the areas involved, and to quickly shift logging operations to the burned sector. For operators, salvage logging is a dirty job and for forest companies it not only disrupts management planning but usually involves higher logging and transformation costs.

But let's not forget the people for the trees. The salvage operations in Val-Paradis raised a number of questions concerning the socio-economic aspects of sustainable forest management. The sense of urgency with which emergency management plans for salvage logging are developed and generally implemented appears to leave little time for public participation in the planning process. In effect, public participation, while a government priority in "normal" management planning, is reduced to information sessions in which residents most closely affected by logging and transport activities, have very little influence on the emergency plan. To be excluded from the process was clearly a source of frustration for many residents of Val-Paradis and, in retrospect, it is clear that many of their concerns could have been accommodated without significantly affecting logging operations and costs.

For example, at the workshop held in Val-Paradis in March 2001, citizens expressed particular concern for the status of wildlife and some "special areas" and would have appreciated a fuel wood reserve in the area situated closest to the village. Wood is the primary winter heating fuel for Val-Paradis and other forest-based communities in northern Canada. Though a small area was set aside as a conservation area upon the request of local residents and some woodlots designated, there still appeared to be some dissatisfaction with the logging operations four years after the event. Other such communities may benefit from creating contingency plans to identify forest areas of important social value in the case of fire. The people of Val-Paradis hope that their experience may contribute to this end.

Conclusion

If the natural variability created by forest fires and other natural disturbances is intended to provide a reference for a more ecological approach to forest management, then the studies conducted by the Industrial Chair in Sustainable Forest Management have important implications for salvage-logging. A common thread running through all of these studies was the importance of snags. Even dead trees have an important ecological role in the forest. They provide nesting and foraging habitat for wildlife and a seed source for regenerating tree species such as black spruce for several years after fire. They may provide favourable microclimate conditions for establishment and growth of seedlings and understorey vegetation, and constitute nutrient reserves, especially for stands with an important deciduous component.

Maintaining these conditions at least over a portion of burned landscapes to be salvage logged - will depend on identifying thresholds that maintain the positive ecological roles of snags and residual stands; that is, determining what amount of retention is required. This will have to involve science-based information on size of unsalvaged burned areas, their spatial arrangement and the quality of standing dead trees within these areas that should be left in salvaged-logged burned forests. Strategies of salvage logging will have to include maintenance of biodiversity in order to meet both economic and conservation biology objectives. The determination of the rate of invasion of snags by wood-boring beetles and their preferences for different tree species is a key element to developing innovative salvage logging strategies. If we could distinguish stands that need to be salvaged quickly and those for which intervention is less urgent, different salvage options, with concerns for non-wood resources, could be better developed.

Finally, it should be noted that some of the tools necessary for developing more comprehensive salvage management plans exist already. For example, surface deposit maps and eco-forest maps may be analysed very rapidly to locate areas dominated by poor, shallow or coarse-textured soils where nutrient depletion caused by salvage logging would be most critical. As well, we know that cut-to-length or other harvesting systems that use on-site delimbing would favour both natural regeneration of black spruce and jack pine and retention of nutrients on site.

Sustainable forest management is not only concerned with healthy, intact forests but also with forests slated for salvage operations. Given our current understanding, if salvage logging plans are to integrate values other than the economic value of wood, variable retention strategies should be implemented without delay. These should incorporate large and small irregularly-shaped blocks, strip retention, residual clumps and isolated stems and include a variety of stem sizes and species. Protection of portions of burned areas containing standing dead timber, of importance to biodiversity maintenance, forest regeneration and site nutrient potential, will have to be part of any multiple-value salvage management planning framework.

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The mission of the **NSERC-UQAT-UQÀM Industrial Chair in Sustainable Forest Management** is to assure the development and quality of research activities, training and technology transfer necessary in order to elaborate and apply strategies and practices for sustainable forest management. In collaboration with its regional partners, it fixes priorities for research and participates in concerted action in order to respond to regional and national problems in forestry.

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