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# Harvesting in Burned Forests

## Issues and Orientations for Ecosystem-Based Management

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Québec

# Harvesting in Burned Forests

## Issues and Orientations for Ecosystem-Based Management

**Ministère des Ressources naturelles et de la Faune**
Direction de l'environnement et de la protection des forêts

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## Text

### Expert Committee on Harvesting in Burned Forests[1]

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1. When the work for this publication was completed, the committee members were affiliated with the organizations shown on this page. At the present time, however, Antoine Nappi is employed by the Chief Forester's Office (Direction du développement stratégique), Frédéric Bujold by the Ministère des Ressources naturelles et de la Faune (Direction du développement socio-économique, partenariats et éducation) and Jacqueline Peltier by the Ministère des Transports.

# Foreword

The thinking process set out in this document began when the forest protection and development objectives were first implemented (PDOs; Ministère des Ressources naturelles, de la Faune et des Parcs [MRNFP], 2005). As part of the objective of preserving deadwood in managed forests, the Ministère des Ressources naturelles et de la Faune (MRNF) undertook to "[…] set up a committee of experts in the coming months, with the mandate to prepare orientations for special salvage plans that will ensure the maintenance and distribution of a sufficient volume of deadwood for the purposes of biodiversity. These orientations will form an integral part of the salvage plan preparation guide produced by the MRNFP".

The committee, as part of its mandate, carried out an analysis to identify the main issues associated with the harvesting of burnt wood. The analysis also identified a number of other environmental, social and economic issues. In the wake of these observations, and to ensure that these various issues are taken into account, the committee has proposed a number of orientations aimed at achieving an ecosystem-based approach to the management of burned forests.

Basically, the orientations set out in this document are designed to provide a response to the environmental issues associated with the harvesting of burnt wood. Their aim is to mitigate the impacts of harvesting in burned forests on certain key features and functions of burned ecosystems. Although the information presented here is specific to the boreal forest (the spruce-moss and balsam fir-white birch bioclimatic domains), the issues and orientations are general in scope and should be considered for Québec's forest as a whole. Additionally, although the document deals more specifically with harvesting in burned forests, many of the recommendations also apply to the harvesting of wood damaged by other types of natural disturbances (e.g., windfall, insect epidemics).

# Note to Readers

The term “fire severity”, as used in this document, is defined as a qualitative indication of the level to which the soil and vegetation at a given forest site has been damaged by fire. It is dependent on the intensity of the fire and the time for which it burns in a given location. Fire severity is often measured by variables such as depth of burn, crown scorch and burned crown percentage. Various ecosystem functions and components may be damaged to different degrees, depending on fire severity.

# Summary

Fire is a major natural disturbance in the boreal forest. When commercial forests are damaged by fire, special management plans are drawn up to harvest the burnt wood before it loses its market value. The main purpose of harvesting – often referred to as “salvage cutting” or “salvage logging” – is to compensate for financial losses. However, it also raises a number of other environmental, economic and social considerations and issues.

This document sets out the main environmental issues raised by post-fire harvesting, specifically in Québec’s boreal forest. These issues were identified from a summary of the impacts of forest fires and post-fire harvesting, and are based primarily on recent research carried out in Québec. They include the impacts of post-fire harvesting on the maintenance of plant and wildlife habitats, soil productivity and natural regeneration.

Management orientations for an ecosystem-based approach to harvesting in burned forests are also proposed. They should serve as guidelines for the preparation of strategies designed to maintain the ecological integrity of burned forests, not only by ensuring that such forests are properly represented, but also by introducing measures to mitigate the impacts of post-fire harvesting in logged sectors. They should also help to ensure that environmental, economic and social concerns are taken into account during the preparation of special management plans for the harvesting of burnt wood.

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# 1. Harvesting in burned forests in Québec

## 1.1 Harvesting policy

In Québec, harvesting of burnt wood, commonly known as "salvage logging" or "salvage cutting"[1], is governed by section 60 of the Sustainable Forest Development Act[2]. The Act stipulates that: "If substantial damage to timber stands in a forest area is caused by a natural disturbance or human influence […], the Minister may, with the participation of the local integrated land and resource management panel concerned, prepare a special management plan to ensure that the timber is salvaged and that the appropriate silvicultural treatments are applied, and administer the plan for the period and on the conditions specified in it."

The Act provides for a number of mechanisms to foster the harvesting of burnt wood. For example, it stipulates that: "The plan may set out conditions that depart from the forest development standards prescribed by government regulation if the departure is necessary to salvage the timber, and may provide that the allowable cut be exceeded if the Minister considers it necessary so as not to lose timber that may be salvaged." In addition, the Act states that: "A person or body to which the Minister has entrusted or delegated forest development activities on land covered by a special plan must comply with the plan. To the extent specified in it, the plan replaces any development plan that was applicable on that land."

1. In the Regulation respecting standards of forest management for forests in the domain of the State (RSFM), "salvage cutting following a destructive agent means the felling or harvesting of trees in a stand that has deteriorated as a result of a natural disaster, such as an insect infestation, a cryptogamic disease, a forest fire or a windfall, in order to salvage the timber that would otherwise be lost and to prevent the propagation of insects or diseases."
2. This section replaces section 79 of the Forest Act.

Generally speaking, special management plans for harvesting in burned forests must be prepared and applied quickly by regional stakeholders, to prevent timber losses. The need for fast action usually does not leave time for public consultations. In fact, section 61 of the Sustainable Forest Development Act stipulates that: "[…] a special plan is not subject to the public consultation process if the Minister considers that there is an urgent need for its application, particularly if the plan is considered necessary in order to avoid a deterioration or loss of timber". Although regional stakeholders have been given instructions to help them prepare special management plans and obtain financial assistance, there is very little information available to help them incorporate environmental, economic and social considerations into their decisions.

## 1.2 Statistics

The volume of timber obtained from a forest after a natural disturbance depends to a large extent on the scope of the disturbance (frequency, area damaged, severity), the nature of the forest, and the ease with which it can be accessed. Post-disturbance harvesting has been used in many regions to mitigate the economic losses caused by fires, windfall and infestations by insects (especially the spruce budworm). In the last decade, most salvage cutting has taken place in burned forests, mainly during years in which large areas were damaged by fire (Figure 1).

At the present time, it is difficult to obtain a reliable historical profile of burnt wood harvesting rates in Québec. Although some information is available from forestry databases, fire and harvesting data tend not to be integrated, making it difficult to compile harvesting rates. In addition, burned forest harvesting rate calculations can vary significantly, depending on the elements considered (area or volume, all damaged stands or only those with merchantable volumes, etc.). The available information suggests that overall burned forest harvesting rates were fairly low in the 1990s (Nappi, Drapeau and Savard, 2004; Chabot, 2005: unpublished data), but the various incentive measures provided by law (and the higher demand for wood products and increased access to the boreal forest) have probably led to an increase in the last decade. Generally speaking, salvage harvesting is limited mainly by economic considerations (lack of access, low volumes of harvestable wood) and the fact that burnt wood deteriorates quickly.

In years where large areas are damaged by fire, a significant percentage of the timber volumes harvested in certain regions may in fact come from fire-damaged forests. For example, following the fires of 2005, nearly half the total volume of timber harvested in public forests in the Saguenay–Lac-Saint-Jean region came from post-fire harvesting (MRNF, 2008). For Québec as a whole, in fiscal year 2005-2006, the MRNF approved special post-fire harvesting plans for more than 6 million cubic metres of timber (Figure 1), accounting for roughly 20% of the total volume harvested in the province's public forests during that period (MRNF, 2008). Although this may well be a record, it nevertheless shows that post-fire management work may involve large areas of forest. In addition, experience has shown that a significant portion of accessible burned areas can be harvested locally (Purdon et al., 2002; Nappi, Drapeau et Savard, 2004). Post-fire harvesting is therefore likely to alter conditions in the forests quite substantially.

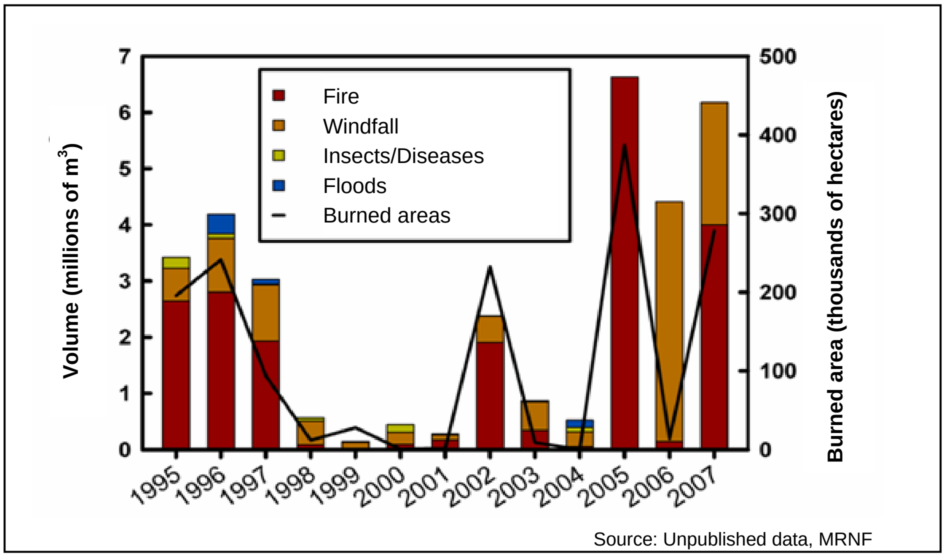


Figure 1. Volumes harvested following four types of natural disturbances, and areas damaged by fire between 1995 and 2007 (harvesting did not necessarily take place in the year of the disturbance)

The harvesting of burnt wood depends mainly on access to the burned areas, the types of stands damaged and the demand for timber. Post-fire harvesting may well continue to be important, or gain in importance, in future years, as it extends into regions where forest fires occur more frequently (Chabot et al., 2009) and as the road network develops and provides better access to burn areas (Nappi, Drapeau and Savard, 2004). In addition, if fire risks are not fully considered when calculating allowable annual cuts, current logging rates will only be sustainable through better control of forest fires – something that has not been possible to date – or by more intense logging of burn areas, a prospect that raises concerns regarding the principles of sustainable forest management (Le Goff et al., 2005; Bergeron et al., 2006).

## 2. The issues

A number of environmental, economic and social issues are associated with the harvesting of burned forests. Currently, the primary concern is to minimize losses of fire-damaged timber while complying with minimal forest management standards. Because forest fires are often perceived as "natural disasters" and therefore as having only negative impacts, and because so little is known about the impacts of post-fire harvesting on ecosystems, there is currently no forest management strategy to govern this type of harvesting and ensure that key processes and features of burned forests are maintained (Beschta et al., 2004; Lindenmayer et al., 2004 and 2008; Noss and Lindenmayer, 2006).

From an environmental standpoint, there is growing evidence to suggest that burned forests play a vital role in maintaining forest biodiversity, and that post-fire harvesting affects the maintenance of ecological integrity (Lindenmayer, Burton and Franklin, 2008). Burned forests form an integral part of the boreal ecosystem, and provide unique conditions that differ from those available in more advanced successional stages and from those created by logging (Lecomte et al., 2006; Chabot et al., 2009). For example, fire destroys some of the organic matter on the ground, allows nutrients to be recycled more quickly, and creates a range of structural elements in the landscape, including an abundant supply of deadwood. These conditions can often be conducive to pioneer vegetation, as well as to certain plant species and numerous invertebrate, mammal and bird species associated with deadwood. Post-fire harvesting alters key fire-created features and conditions, and constitutes a second successive disturbance that can have significant human-induced effects in the short, medium and longer term, in addition to the effects of the fire itself.

From a social and economic standpoint, post-fire harvesting can have considerable impacts on forestry activities. Although fire can maintain or even increase economic activity in a region in the short term, the forestry companies must generally restructure their planning, incurring additional costs in the process. In addition, post-fire harvesting must often be carried out quickly, before the timber declines in value due to the damage inflicted by wood-eating insects and cracking caused by the sudden drop in humidity in burnt trees. Forest managers must therefore prepare their special management plans quickly, meaning that they do not have time to consider economic, environmental and social concerns.

Reflection is therefore needed to identify the issues associated with post-fire harvesting, and take them into consideration in a strategy to guide harvesting activities. This section examines the main issues associated with post-fire harvesting. They were identified from an examination of the impacts of fire and post-fire harvesting on different components of the burned ecosystem (e.g., vegetation, soils and wildlife). Because there has been so little research into the impacts of post-fire harvesting (see the summaries by McIver and Starr, 2000, and by Lindenmayer, Burton and Franklin, 2008), the impacts of the fire itself have been placed in context, to help explain the actual or anticipated effects of post-fire harvesting. This section does not claim to provide an exhaustive review of the subject. It does, however, set out the main issues, using real-life examples taken from Québec's boreal forest. Special attention has been given to environmental issues, but an overview of economic and social considerations is also presented, to provide a basis for a more detailed analysis in the future.

The following issues are derived from current general knowledge of the impacts of fire and post-fire harvesting for forests. However, an analysis of province-wide and regional impacts will also be needed in the future, to define the current situation and identify any issues that should take priority.

## 2.1 Biodiversity

### 2.1.1 Maintenance of burned forests

Fire has been part of natural ecosystem dynamics in the boreal forest for thousands of years. Animal and plant populations have adapted to the effects of fire and to the long-term and short-term changes it engenders. Fires, especially when severe, considerably reduce the available forest cover by killing large numbers of trees and temporarily eliminating shrub vegetation. In addition, by altering habitat structures, they influence growing conditions for plants as well as feeding, travel, breeding and shelter conditions for wildlife (Brown and Smith, 2000; Smith, 2000). As a result, communities are generally restructured, as some species are favoured at the expense of others. The more severe the fire, the more significant and sustainable the changes in habitat structures and organism responses will be (Smith, 2000).

Burned forests are characterized by an abundance of deadwood (a) and by significant gaps in shrub vegetation and tree cover (b). The habitat conditions they provide therefore differ significantly from those in unburned forests and are suitable for a number of plant and wildlife species.

In the boreal forest, species assemblages in habitats such as these often differ from those in unburned, harvested (and unburned) or post-fire harvested forests. The differences have been documented in the case of vegetation (Nguyen-Xuan et al., 2000; Purdon, Brais and Bergeron, 2004) and for several wildlife groups, including beetles (Saint-Germain, Drapeau and Hébert, 2004a; Saint-Germain et al., 2005), spiders (Buddle, Spence and Langor, 2000; Larrivée, Fahrig and Drapeau, 2005), birds (Hutto, 1995; Morissette et al., 2002) and mammals (Crête et al., 1995; Smith, 2000). According to studies that compare the impacts of fire and logging, the differences are especially striking in the first few years following the disturbance, but gradually subside over a thirty-year timeframe (Hobson and Schieck, 1999; Buddle, Spence and Langor, 2000; Simon et al., 2002).

*2.1.1.1 Impacts of fire on vegetation*

One of the ways in which burned forests differ significantly from other forest types lies in the availability of deadwood generated by the fire, especially when severe (Pedlar et al., 2002; Drapeau et al., 2002; Harper et al., 2005). Areas damaged by fire over the years provide a significant quantity of deadwood regionally. Deadwood, both standing and fallen, is a key element in forest ecosystem biodiversity  (Laudenslayer et al., 2002; Crête et al., 2004; Vallauri et al., 2005), regardless of species or level of deterioration. It also contributes to the complexity of stand structures at different stages of forest dynamics.

Post-fire succession depends largely on crown fire and ground fire severity, and on stand and station characteristics. Severe fires trigger succession by burning significant portions of the vegetation and varying portions of organic matter on the ground, reducing or eliminating competition, increasing the potential of hydrogen (pH) and making large concentrations of nutrients available (Brown and Smith, 2000; Neary, Ryan and DeBano, 2005). This triggers major changes in the post-fire composition of vascular and non-vascular plants species (Nguyen-Xuan et al., 2000; Purdon, Brais and Bergeron, 2004). Some species adapt better than others to the effects of fire (Doyon, 2002; Payette, 2002; Chabot et al., 2009). In the boreal forest, the jack pine, black spruce and trembling aspen have adjusted well to the effects of fire and are able to become established in the first few years post-disturbance (St-Pierre, Gagnon and Bellefleur, 1992; Greene et al., 1999). The jack pine and black spruce have serotinous and semi-serotinous cones respectively, which open when exposed to intense heat, whereas the aspen tends to regenerate vegetatively (Gauthier, Bergeron and Simon, 1993; Gauthier, Bergeron and Simon, 1996; Greene et al., 1999). The black spruce is more dependent than the jack pine on the conditions for regenerative success, including the production of viable seeds and the presence of conditions conducive to germination and plant survival.

*2.1.1.2 Impacts of fire on invertebrate wildlife*

The large volume of recently-killed trees and wood debris, reduced canopy, increased soil temperatures and reduced competition that result from forest fires are conducive to several invertebrate species (Ahnlund and Lindhe, 1992; Wikars, 1992 and 1997; Buddle, Spence and Langor, 2000; Saint-Germain, Drapeau and Hébert, 2004a and 2004b; Larrivée, Fahrig and Drapeau, 2005). Some pyrophilous species (species that thrive in post-fire conditions) have sensory mechanisms that they use to detect fires at distances of many kilometres, via the volatile components and infrared waves produced by the fire (Evans, 1966; Schütz et al., 1999; Schmitz, Schmitz and Bleckmann, 2000; Suckling et al., 2001).

Many saproxylic insect species (i.e. deadwood-dependent species) use burned forests to complete their life cycle. They include the whitespotted sawyer *Monochamus scutellatus*, which is present in large numbers in the first few years post-fire.

*Arhopalus foveicollis* uses recent deadwood, but may also be found in burn sites more than 10 years post-fire.

In Québec's boreal forest, Saint-Germain, Drapeau and Hébert (2004a) studied and compared beetle assemblages in recently burned forests (one and two years post-fire) and in unburned control sites. They identified more than 40 species that were found only in the burned stands. Insect communities in the burned forests were composed largely of saproxylic species (i.e. species associated with standing or fallen deadwood and tree fungus) and subcortical predator species (i.e. sub-bark species) (Ahnlund and Lindhe, 1992; Wikars, 1992 and 1997; Saint-Germain, Drapeau and Hébert, 2004a).

The large number of recently dead trees of good nutritional quality (trees that were growing when killed) is particularly conducive to the presence of xylophagous (wood-eating) species (longhorned beetles, bark beetles, wood-boring beetles) that use deadwood to complete their life cycle (Werner, 2002; Saint-Germain, Drapeau amd Hébert, 2004b). Longhorned beetles such as *Monochamus* are known in particular for the galleries they dig in tree trunks and the resulting decline in the commercial value of the wood (Gardiner, 1957; Ross, 1960). However, this particular insect guild also includes lesser known species. In an experiment carried out on black spruce trunks in recently burned forests, Saint-Germain, Drapeau and Hébert (2004b) identified roughly 15 species of wood-eating beetles in the first two years post-fire. Some of the beetles are specific to certain tree species, meaning that the variety of species found post-fire depends partly on stand composition, and is likely to be greater in stands composed of numerous tree species (Gardiner, 1957). Trunk deterioration, fallen trees and a more complex ground structure gradually change the composition of invertebrate species assemblages (Wikars, 1992; Buddle, Spence and Langor, 2000; Boulanger and Sirois, 2007; Nappi et al., 2010). Some wood-eating species such as *Arhopalus foveicollis* may still be present in large numbers more than ten years post-fire (Nappi et al., 2010).

#### *2.1.1.3 Impacts of fire on birds*

A number of studies of birdlife have documented differences in bird assemblages in burned, non-burned and logged forests (post-fire and others) (Hutto, 1995; Hobson and Schieck, 1999; Imbeau, Savard and Gagnon, 1999; Smith, 2000; Morissette et al., 2002). Generally speaking, fire creates conditions that are particularly conducive to insect-eating and seed-eating species, and to several species associated with deadwood (Hutto, 1995; Murphy and Lehnhausen, 1998; Morissette et al., 2002; Hoyt and Hannon, 2002). Fire-killed trees are used by several woodpecker species (e.g., the black-backed woodpecker, three-toed woodpecker and hairy woodpecker) as food substrates due to the large numbers of wood-eating insects they contain (Murphy and Lehnhausen, 1998; Nappi et al., 2003; Nappi, 2009).


Many bird species nest in burned forests: (a) The black-backed woodpecker taking an insect larva to its nest. This is one of the most commonly found species in recently burned forests; (b) The Eastern bluebird. This cavicolous species uses the cavities excavated by the black-backed woodpecker to nest in burned forests; (c) The common nighthawk. This vulnerable species nests on the ground in burned areas.

The cavities dug by woodpeckers are used over the years as nesting sites or shelter by numerous bird species (e.g., Eastern bluebird, tree swallow) and mammal species (Saab, Dudley and Thompson, 2004). Snags in clearings may also be used as perches by insect-eating species that feed in flight (e.g., flycatchers), and by raptors (e.g., Northern hawk owl, red-tailed hawk) that feed in burn areas (Smith, 2000; Hannah and Hoyt, 2004). Some seed-eating species (e.g., dark-eyed junco) also take advantage of the seeds from cones that have opened due to the heat of the fire.

The gradual changes in the forest structure, including fallen and decomposing dead trees and shrub regeneration, cause ongoing changes in species assemblies. Some species are present in large numbers in the first few years post-fire, while others, such as those associated with shrub strata, become more abundant later in the succession (Raphael, Morrison and Yoder-Williams, 1989; Imbeau, Savard and Gagnon, 1999; Smucker, Hutto and Steele, 2005; Schieck and Song, 2006).

#### *2.1.1.4 Impacts of fire on mammals*

The presence of mammals in burned forests depends on the amount of food and cover available. Generally speaking, the presence of small mammals depends on the complexity of ground vegetation, which is influenced by fire severity, the time that has elapsed since the fire, and the amount of wood debris (Crête et al., 1995; Greenberg, 2002; Simon et al., 2002). Although the number and variety of small mammals usually decline immediately after a fire, post-fire plant regeneration, combined with the accumulation of wood debris on the ground (e.g., 10 to 20 years post-fire), will attract species that are highly dependent on forest cover and the food supply from dense vegetation (Krefting and Ahlgren, 1974; Simon et al., 1998; Smith, 2000). Some species, such as the deer mouse and red squirrel, are nevertheless commonly found in recently burned forests because of the availability of post-fire seeds (Sims and Buckner, 1973; Krefting and Ahlgren, 1974; Martell, 1984; Crête et al., 1995; Sullivan, Lautenschlager and Wagner, 1999).

Depending on the size of the small mammal population, a burned forest may also be a good hunting ground for predator mammals and birds. Although the American marten is normally found in habitats with a certain amount of closed canopy, it has also been found to use burned forests as a hunting ground, largely due to the abundance of prey (Koehler and Hornocker, 1977; Paragi et al., 1996). An increase in productivity, and in the availability and nutritional quality of ground vegetation, may also attract some large mammal species (Gasaway and Dubois, 1985; Smith, 2000). In Northern Québec, Crête et al. (1995) found more bears and moose in recently burned forests than in older burn areas or unburned forests. The bears' presence was explained mainly by the abundant supply of small fruits, which make up a large part of the species' diet (Boileau, Crête and Huot, 1994), while the moose were attracted by strong hardwood regeneration (Crête and Jordan, 1981).

*2.1.1.5 Impacts of harvesting in burned forests*

The above summary of fire impacts clearly shows that, contrary to popular belief, fire is not in fact a natural disaster. Instead, it triggers a restructuring of plant and animal species assemblages, as the conditions it creates favour some species at the expense of others. Post-fire harvesting, by altering the new conditions created by the fire, inevitably has an impact on certain species in the short, medium and longer terms. The impacts of harvesting can be grouped into two categories: 1) direct impacts (e.g., movement of machinery, soil compaction); and 2) structural impacts caused by the elimination of vegetation (McIver and Starr, 2000).

Vegetation appears to be influenced by both types of impacts. For example, it has been shown that movement of machinery during harvesting may directly destroy some post-fire vegetation (Purdon et al., 2002; Purdon, Brais and Bergeron, 2004; Fraser, Landhäusser and Lieffers, 2004; Kurulok and Macdonald, 2004). In these cases, the disturbance is limited mainly to logging trails. However, harvesting may also have an indirect impact on the growing conditions of certain species. Purdon, Brais and Bergeron (2004) found that burned forests that had been harvested contained plant species normally associated with more xeric habitats, suggesting that harvesting causes soils to dry out more quickly. These drier conditions have also been identified as a potential cause of poor black spruce regeneration in post-harvest burned areas (Noël, 2001; Greene et al., 2006). The dry conditions may be due, among other things, to a reduction in the ground vegetation and trees (living and standing dead) that normally provide shade and protection from the wind. In addition, burnt trees, although dead, carry significant reserves of seeds and their removal early in the post-fire period may short-circuit the stand regeneration process, especially for black spruce and, to a lesser extent, jack pine. Where this is the case, the stands resulting from regeneration tend to be dominated by trembling aspen, a species that is less sensitive to post-fire harvesting (Greene et al., 2006; Noël, 2001). Although winter harvesting mitigates some of these impacts, it is not without consequence, and has been shown to influence biomass and vegetation composition (Sexton, unpublished, cited in McIver and Starr, 2000).

As far as animal communities are concerned, they are influenced mainly by habitat composition and structure. Harvesting in burned forests generates changes that can be just as important as, if not more important than, those caused by the fire itself. Morissette et al. (2002) provide an interesting example of the combined effects of fire and post-fire harvesting on bird life. They compared unburned forests, burned forests and post-fire harvested forests, and found that harvesting in burned forests caused changes that were just as significant as, if not more significant than, those caused by the fire itself (compared to green forests). Harvesting in burned forests changed the composition of bird species quite significantly, by reducing the number of resident species, insect-eating species and cavity and canopy-nesting species. The group of species found to be least sensitive to post-fire harvesting was composed of general and omnivorous species and ground-nesting or shrub-nesting species.

One of the major impacts of post-fire harvesting is obviously the considerable reduction in the number of large-diameter burnt trees, which are key components in the biodiversity of burned forests and vital to deadwood-dependent species. Wood-eating insects are more likely to colonize large-diameter burnt trees that were in good pre-fire condition (Nappi et al., 2003; Saint-Germain, Drapeau and Hébert, 2004b). This appears to be due to the thickness of the phloem in mature trees, which improves the insects' performance, and also to the thickness of the bark, which prevents the wood from drying out (Saint-Germain, Drapeau and Hébert, 2004b). As a result, these trees are of interest to wildlife, in that they provide food for woodpeckers, which feed on insects at the larva stage (Murphy and Lehnhausen, 1998; Nappi et al., 2003). In a study carried out in Québec's boreal forest, Nappi (2009) showed that recently-dead conifers (spruce, pine and larch) measuring more than 10 cm in diameter were important as sources of food for woodpeckers, whereas conifers and hardwoods measuring more than 20 cm in diameter and in poorer condition (pre-fire snags) were used for nesting. Older burned forests are therefore more important for deadwood-dependent organisms due to the plentiful supply of large-diameter trees, but they are also the most likely to be subjected to post-fire harvesting, and this inevitably has a direct impact on the populations of deadwood-dependent species (Saab and Dudley, 1998; Lecoure et al., 2000). In addition, harvesting also reduces the available volume of fallen deadwood in the longer term, with consequences for the species that use this type of habitat structure. Given the ecological affinities of many species with the different stages of deadwood deterioration, harvesting in burned forests is likely to have consequences not only in the short term, but in the longer term as well.


A nesting tree and food tree typically chosen by the black-backed woodpecker in burned forests. Large-diametre damaged trees are used to dig cavities for nesting, whereas recently-killed softwoods over 10 cm in diametre are chosen for food. Given the importance of diameter for nesting and food, the age of the forest at the time of the fire has a significant impact on the quality of the burned environment.

Recent research has shown that partial cutting in burned stands helps to reduce differences between the conditions generated by fire and those generated by post-fire clearcutting. It also fosters the presence of some deadwood-associated species (Saab and Dudley, 1998; Lecoure et al., 2000; Haggard and Gaines, 2001; Schwab et al., 2006). Partial cutting maintains living and dead trees, both individually and in strips or small patches, throughout a significant percentage of the stand's total area (e.g., 25%, 50%, 75% of the tree canopy). It generates habitat structures and cover for wildlife, and helps to diversify the present and future structure of the stand. Unlike post-fire clearcutting, it allows for the survival of certain deadwood-associated species. The fact of maintaining both deadwood and living wood on the cutting site can have a positive impact on environmental conditions (shade, wind) and soil properties (water retention, nutrients), thereby encouraging regeneration and helping to maintain site productivity (Brais, Paré and Ouimet, 2000; Purdon et al., 2002; Neary, Ryan and DeBano, 2005).

*2.1.1.6 Habitats for species sensitive to forest management*

Many of the species found in burned forests are sensitive to forest management work. This is the case, among others, for deadwood-dependent species, since deadwood is one of the habitat features most affected by forest management (Imbeau, Mönkkönen and Desrochers, 2001). Because fire produces large volumes of deadwood within a given region, burned forests are important as habitats for many of these species. Burned forests also have characteristics that separate them from other types of habitats containing large quantities of deadwood (e.g., old-growth forests, forests disturbed by insect infestations). Nappi and Drapeau (2009) found that black-backed woodpecker productivity (i.e. the number of fledglings) was high in burned forests, due to both the abundant supply of food resources (wood-eating insects) and the low rate of predation on burned sites. Tremblay (2009) found no significant difference in nesting success in burned forests and unburned forests, although he did find more fledglings in burned forests. It would therefore seem that burned forests are one of the best types of habitats for woodpecker nesting, and they can help to increase regional black-backed woodpecker populations (Nappi, 2009; Tremblay, 2009).

Although it is difficult to assess the long-term impacts of burned forest depletion on associated populations, Scandinavia provides an excellent example of the impacts of eliminating burned forests by actively and effectively suppressing forest fires. In the regions in which fires have been suppressed, many deadwood-associated species and several species associated with different post-fire succession stages have declined substantially in recent decades. Many are now on the red list of threatened species (Ahnlund and Lindhe, 1992; Wikars, 1992 and 1997; Angelstam and Mikusinski, 1994; Jonsell, Weslien and Ehnström, 1998). In Québec, more intense harvesting in burned forests, combined with longer fire cycles in some regions (Flannigan et al., 2001; Bergeron et al., 2004), may also cause habitat depletion and declining populations of associated species (Imbeau, Mönkkönen and Desrochers, 2001). However, our lack of knowledge of biodiversity in Québec (e.g., insects) and population trends means that it is virtually impossible to obtain a reliable overview of the current situation regarding sensitive species. It should also be noted that burned forests provide a nesting habitat for the common nighthawk, a designated vulnerable species in Québec (COSEPAC, 2008).

*2.1.1.7 Issue*

**Harvesting in burned forests may deplete a form of habitat that is important to biodiversity.** Burned forests, regardless of age, provide unique habitats within the natural forest mosaic and make a significant contribution to regional biological diversity. They provide conditions that are ideally suited to many plant, invertebrate, bird and mammal species. Recent research has shown that the species assemblages found in this type of habitat differ from those found in unburned forests, harvested forests and harvested burned forests, and that the differences persist for several years post-fire. Recently-burned areas are particularly important to deadwood-dependent species populations; deadwood is a major component of boreal forest biodiversity and one of the most vulnerable to forest management work. Burnt wood harvesting alters these habitats significantly, and creates conditions very different from those naturally created by the fire itself, in the short, medium and longer terms. Although management strategies inspired by natural disturbances have been proposed as a means of maintaining regional ecological integrity, they are unable to recreate all the natural conditions generated by fire. It is therefore essential for the ecological integrity of forest ecosystems that burned forests, along with their key features and functions, should be maintained.

### 2.1.2 Heterogeneity of burned forests

Although there is a common perception that most fires are severe and create fairly similar habitats, researchers have shown, on the contrary, that they can in fact produce a wide variety of conditions (Bergeron et al., 2002; Schmiegelow et al., 2006). This is due, first, to the variable severity of fire, which creates a blend of forests ranging from unburned to severely burned. In addition, fire, especially when covering a large area, is likely to burn stands with different compositions and structures. This combination of variable severity and different stand types generates a range of ecological conditions that have a significant impact on the composition of post-fire plant and animal communities.


There are many different types of burned forests. Fire severity (a) can differ considerably within the burn area, and burned stands (b) can vary in terms of structure and composition. These types of variations have a significant impact on habitat conditions for both plants and wildlife.

#### *2.1.2.1 Types of burned stands*

Fire area, configuration and severity are influenced by weather conditions before and during the fire (rainfall, temperature, wind, season), by the physical limitations of the area (topography, water, soil types) and by stand composition, age and structure (Rowe and Scotter, 1973; Foster, 1983; Bergeron, 1991; Turner et al., 1994; Kushla and Ripple, 1997; Kafka, Gauthier and Bergeron, 2001). These factors interact within a burned landscape to create a mosaic of sectors that are burned to different degrees.

Although fires in the boreal forest are usually regarded as being severe, research has shown that a significant percentage of the zones damaged by fire are composed of unburned or partially burned residual areas (Eberhart et Woodard, 1987; Kafka, Gauthier and Bergeron, 2001; Bergeron et al., 2002; Perron 2003; Nappi et al., 2010). The percentage of residual forest that is unaffected by the fire can vary from very low to nearly 50% of the total burn area[1]. In the case of large residual patches (e.g., more than 1 ha), the areas unaffected by fire normally range from 1% to 15% (Eberhart and Woodard, 1987; Kafka, Gauthier and Bergeron, 2001; Bergeron et al., 2002). Eberhart and Woodard (1987), in a study of 69 fires in Alberta, found that residual forests accounted for slightly under 5% in the case of fires covering more than 2,000 ha. Perron (2003), in a study of 35 fires (35 to 30,000 ha) north of Lac-Saint-Jean, estimated that tall residual forests (50 years of age or older) located within the fire perimeter (isolated fragments) accounted for between 0% and 8% of the burn area. Similar percentages (2% to 10%) were found in an analysis of 42 fires in Northern Ontario (Ontario Ministry of Natural Resources, 1997). The percentage of residual forest increases significantly if “peninsulas” (i.e. residual forests connected to unburned forests around the fire perimeter) are taken into account. In Ontario, residual forests on fire perimeters accounted for between 8% and 40% of the total area (in addition to the 2% to 10% of residual unburned forest patches). Perron (2003) considered both peninsulas and isolated residual fragments, and estimated that tall residual forests accounted for between 7% and 37% of the total area.

Although these patches are important elements of burned landscapes, the fact that fire intensity is variable means that many of the undamaged trees will be grouped together in small patches (under 1 ha), or will be mixed to differing degrees with burnt trees. In Québec, the fire severity classification associated with the MRNF’s fire damage map reflects this variability (see the Appendix). The classification, based on the percentage of trees of different types (green, scorched, charred, standing or fallen), is used to identify sectors where the fire impact is slight to moderate, with varying percentages of green and scorched trees. Using this classification, Kafka, Gauthier and Bergeron (2001), Bergeron et al. (2002) and Chabot et al. (2009) all found that the percentage of unburned residual forest was much higher if partially burned areas (i.e. a combination of green and scorched trees) were taken into account. Bergeron et al. (2002) examined burn patterns from 16 fires that occurred in Québec in 1995 and 1996. In 1995, the fires were generally more severe than in 1996. Their study revealed that slightly burned areas accounted for between 10% and 30% of the total burn area in 1995, and more than 40% in 1996. Another study of 837 fires that occurred in Québec between 1986 and 2007 also confirmed that partially burned areas accounted for an average of nearly 40% of the total burn area (Chabot et al., 2009).

The variations in fire severity reflected by the mix of burnt and green trees in burned stands are also visible among individual fire-damaged trees (Nappi et al., 2003; Saint-Germain, Drapeau and Hébert, 2004b; Nappi et al., 2010). In severely burned areas, individual tree trunks tend to be charred, the needles and small branches are completely destroyed, and in some cases the tree will have fallen. At the other end of the scale, in some of the trees only the bark at the base of the trunk is partially burned, or the needles are scorched by the excessive heat. Some trees that will ultimately die do not lose their burned needles until some weeks after the fire, and take on the appearance of scorched trees. Although the MRNF’s assessment does not identify variations in the severity of trunk damage, it does distinguish between scorched trees and more severely burnt (charred or fallen) trees. Although some of the trees that are only slightly damaged by fire are likely to die over time (Harrington 1993; Nappi et al., 2010), there is insufficient information available to quantify the extent of this process among boreal species.

1. Percentage estimates depend on the methodology and resolution used.

### *2.1.2.2 Impacts of burned stand characteristics on wildlife and vegetation*

Depending on fire severity, post-fire habitat conditions will vary according to the percentage of dead trees, the level of charring, the amount of lost crown, and the amount of burnt organic matter on the forest floor. These variations have a significant impact on post-fire diversity and the abundance and composition of plant and animal species (Buddle, Spence and Langor, 2000; Purdon, Brais and Bergeron, 2004; Saint-Germain, Drapeau and Hébert, 2004b; Smucker, Hutto and Steele, 2005; Larrivée, Fahrig and Drapeau, 2005).

Not only do unburned areas play a role in the short-term and long-term diversity of the forest mosaic, but they also provide shelter and act as corridors for species associated with dense, mature forests (Galipeau, Kneeshaw and Bergeron, 1997; Greene and Johnson, 2000). Unburned trees left standing in burned areas can also help to maintain species that are less tolerant of post-fire conditions (Morissette et al., 2002; Smucker, Hutto and Steele, 2005). In a study carried out in the Western United States, Smucker, Hutto and Steele (2005) found that some bird species responded differently to fire severity. For example, populations of species known to be associated with fire (e.g., hairy woodpecker, Northern flicker, olive-sided flycatcher) only increased significantly in severely burned areas. Similarly, some other species only responded significantly (either positively or negatively) in moderately or slightly burned sites. These results clearly show that each species responds in a different way to the range of conditions produced by variable fire severity. For example, some species may benefit from the more abundant post-fire food resources (seeds, insects) in the burned forest and also use the residual unburned canopy for shelter or nesting. This combination of factors will vary proportionally to fire severity.

Fire response variations have also been observed for vegetation. In a study carried out in Québec, Purdon, Brais and Bergeron (2004) examined the impacts of fire severity on plant communities, based on pre-fire stand composition (hardwood, mixed, softwood). Although plant communities in burn areas were strongly influenced by the composition of the burned stand, the difference decreased proportionally to the increase in fire severity. In a study of the same sites, Greene et al. (2004) showed that increased fire severity had a positive impact on softwood regeneration, especially for jack pine.

Fire severity can also significantly affect the way in which individual trees are used by wildlife. Generally speaking, a very severe fire will create dry conditions less suitable to most wood-eating insects (Ross, 1960; Saint-Germain, Drapeau and Hébert, 2004b). However, these impacts appear to be more marked for spruce and fir than for pine (Gardiner, 1957; Ross, 1960), probably because pine trees have thicker bark. Fire severity, by influencing wood-eating insect population sizes, also affects the quality of the burnt trees as sources of food for woodpeckers (Nappi et al., 2003; Nappi, 2009; Nappi et al., 2010).

### *2.1.2.3 Impacts of harvesting in burned forests*

Post-fire harvesting may reduce or alter the range of conditions that would otherwise have been present. First, salvage cutting can standardize conditions in the salvaged sites, leading to a simplification of plant and animal communities. Purdon, Brais and Bergeron (2004) found that understorey vegetation in forests where timber was harvested post-fire was much less rich, less abundant and less diversified than in unharvested control forests. Although the species composition in forests where post-fire harvesting had taken place was still within the natural range of variation created by fire, it was more standardized than in unharvested burned stands, more typical of severely burned sites, and comprised only a handful of species typically found in drier sites. In a study of bird life by Morissette et al. (2002), the species composition in forests that had been harvested post-fire was more standard and outside the natural range of variation, due to a lack of diversity in the residual vegetation.

Post-fire harvesting is likely to produce residual forests that are not representative of pre-fire forests. Because harvesting is concentrated primarily in mature stands, the residual forest may, for example, be composed mainly of unproductive sites (e.g., peat bogs, bare dry areas) or immature pre-fire forests. Similarly, the fact of harvesting certain severity classes only will affect the extent to which the residual forest is representative. In addition, some types of stands are less likely to be harvested because of their nature (e.g., composition, volume) or because of operational constraints (e.g., uneven relief, no road network) or their position within the burned area.

The MRNF has not yet issued a clear directive concerning the harvesting of living trees in burned areas. Although some special management plans allow for the maintenance of large unburned patches, a significant portion of the residual unburned area will nevertheless be composed of small patches or scattered green trees. Eliminating these biological legacies will inevitably widen the gap between the conditions created by the fire and those created by post-fire harvesting.

*2.1.2.4 Issue*

**Harvesting in burned forests may reduce the range of normal post-fire conditions.** The conditions in burned forests vary considerably in terms of stand composition, age and density, and fire severity. Extensive unburned or partially burned areas increase the diversity of the forest mosaic and can play an important role as shelters or corridors for species that are less tolerant of post-fire conditions, or as sources of wildlife and plant life for recolonization of regenerating areas. In addition, the combination of varying fire severity and different forest types produces a range of ecological conditions that has a significant impact on post-fire animal and plant communities. Post-fire harvesting is likely to adversely affect this natural variation, since it tends to be concentrated in specific types of stands.

### 2.1.3 Distribution of burned and unburned forests

*2.1.3.1 Elements of importance to plant and wildlife communities*

The distribution of burned and unburned forests in a fire-damaged landscape is extremely important for the distribution and abundance of certain plant and wildlife species. First, the location and size of the unburned forests can influence the short-term and long-term presence of certain species. Unburned forests are permanent sources of burn area recolonization by organisms such as lichen and epixylic bryophytes, which have a weak dispersal capacity, as well as species that do not regenerate vegetatively or whose seeds are destroyed by fire, such as the white spruce and balsam fir (Galipeau, Kneeshaw and Bergeron, 1997; Greene and Johnson, 2000). Recolonization by these species is therefore easier when they are located at shorter distances from unburned areas (i.e. less than 200 metres) (Eberhart and Woodard, 1987; Galipeau, Kneeshaw and Bergeron, 1997; Greene and Johnson, 2000; Kafka, Gauthier and Bergeron, 2001). Some animal species only use regenerating areas located close to unburned forests that provide protective cover and good winter habitats. This is the case, among others, for the American marten and the moose (Koehler and Hornocker, 1977; Gasaway and Dubois, 1985; Potvin, Courtois and Bélanger, 1999; Potvin, Bélanger and Lowell, 2000; Courtois et al., 2002). Moose feeding appears to decline beyond 200 metres from the borders of residual forests (LeResche, Bishop and Coady, 1974; Euler, 1981). Accordingly, a high percentage and even distribution of unburned forests can encourage species such as these to use regenerating areas.

Areas in which burned forests and green forests are juxtaposed appear to provide conditions that are suited to a number of species. These areas generally account for a significant percentage of burn areas. In a study of 69 forest fires, Eberhart and Woodard (1987) found that a significant percentage of burn areas were located close to the fire perimeter or to unburned residual areas of more than one hectare (e.g., between 31% and 83% of burn areas located less than 100 metres from unburned forests; between 53% and 100% located less than 200 metres from unburned forests; and between 86% and 100% located less than 500 metres from unburned forests). This juxtaposition of burned and unburned areas is conducive to several bird species that nest in green forests but feed in burned forests (Morissette et al., 2002; Smucker, Hutto and Steele, 2005). In the case of wood-eating insects, peripheral burn areas appear to offer better-quality habitats. In a study carried out in Alaska, Werner (2002) found larger populations of wood-eating species (longhorned beetles, bark beetles, wood-boring beetles) in zones peripheral to fires than in zones within the burn area. The peripheral zones were also used over a longer timeframe, especially by bark beetles (Werner, 2002). They often contained trees that had been less severely burned and were therefore more conducive to the insects' survival (Saint-Germain, Drapeau and Hébert, 2004b). In addition, dead tree recruitment probably took place over a longer period due to the gradual mortality of slightly-damaged trees, providing conditions suitable for saproxylic species over a longer timeframe (Dixon et al., 1984; Nappi et al., 2010).

The distance from green forests also seems, of itself, to limit the colonization of burnt trees by some insect species. For example, Saint-Germain, Drapeau and Hébert (2004c) found that the presence of green forests within a radius of 500 metres had a positive impact on colonization by the whitespotted sawyer (*Monochamus scutellatus*), a situation that can be explained by the nutritional requirements of adult sawyers, which feed on the needles of living trees. Lastly, it has also been shown that black-backed woodpecker productivity may be higher in burned stands located close to unburned areas. This is explained mainly by the more abundant supply of wood-eating insects (Nappi and Drapeau, 2009).

The distribution of burned forests (isolated forests vs. forest clusters) can also affect habitat quality for some species. Large contiguous burn areas may be favourable to species such as woodpeckers, which use deadwood and have large home ranges. For example, the concentration of mature burned forests has a positive influence on the reproductive success of the black-backed woodpecker (Nappi and Drapeau, 2009).

#### *2.1.3.2 Impacts of harvesting in burned forests*

Special management plans for burnt wood rarely contain spatial instructions (e.g., residual forest size, location and concentration). One of the major consequences of this lack of direction is the creation of large areas with few residual forests (unharvested burned or unburned forests), especially following large fires. The fact that residual forests are small and isolated can also affect the quality of plant and wildlife habitats. A landscape composed of small burned forests separated by logging areas is probably less appropriate for woodpeckers, which are sensitive to concentrations of good quality burn habitats (Nappi and Drapeau, 2009).

Because of the lack of directives concerning the distribution of forest work, logging in burned forests may create huge bare areas with no burned or unburned residual forests.

The localization of residual burned and unburned forests is not planned in a way that fosters connectivity between the two types of habitat. Harvesting in burned forests peripheral to green forests eliminates a type of habitat that is important to biodiversity. By maintaining burned forest areas between unburned areas, it may be possible to foster connectivity for species associated with green forests. Despite the more open canopy in burned forests, burnt trees nevertheless provide a type of structure and cover not found on sites that have been harvested, and allow organisms to disperse and travel from green forests.

*2.1.3.3 Issue*

**The distribution of logging sites and burned or unburned residual forests during post-fire harvesting can have an impact on certain types of connectivity that are important to plant and wildlife communities.** First, small, isolated burned and unburned forests in logged areas are likely to provide poorer quality plant and wildlife habitats. Second, the harvesting of burnt trees along the perimeter with unburned forests can significantly deplete a form of habitat that is of interest to many species, namely the transitional zone between burned and unburned forests.

## 2.2 Soil productivity and water quality

### 2.2.1 Impacts of fire on soils and water quality

Generally speaking, fire alters the physical, chemical and biological properties of soils (Neary, Ryan and DeBano, 2005). The extent of this impact depends on a number of factors, including fire intensity at ground level (Brais, Paré and Ouimet, 2000) – for example, where the fire burns a significant percentage of the organic matter, exposing the mineral soil as a result. While some soil components deteriorate at relatively low temperatures (e.g., micro-organisms, roots, seeds, organic matter), others only begin to suffer the same effects at much higher temperatures (e.g., chemical elements such as calcium and potassium).

One of the impacts fire has on the physical properties of soil is to reduce its water infiltration capacity. Soil is composed of a mixture of organic and mineral particles, and has a porosity that allows for water and air to pass through its micropores and macropores (Neary, Ryan and DeBano, 2005). Water infiltration capacity may be further reduced by rain, which disperses the fine particles in the exposed mineral soil, blocking the soil's macropores. Some authors have also found that fire may actually cause soil to repel water (DeBano 2000a and 2000b); water-repellent substances are released when organic matter burns, and gravitate towards the mineral layers, where they become concentrated and form a waterproof layer under the surface of the soil (Neary, Ryan and DeBano, 2005). This phenomenon has been documented for several soil types, including coarse-textured soil, and appears to be especially significant in severe fires.

Changes such as these to the soil structure, combined with the burning of vegetation and a reduction in tree evapotranspiration rates, may increase runoff and erosion, and hence affect water quality (McIver and Starr 2000; Ice, Neary and Adams, 2004; Neary, Ryan and DeBano, 2005). Erosion risks are generally increased not only by fire severity and soil type, but also by hilly relief and heavy post-fire rain. These impacts, which are especially important during the first year post-fire, decline over time, as vegetation grows back and soils are restructured.

In addition to the effects described above, fire causes chemical elements to be released from organic matter. Although fire usually leads to some kind of reduction in the overall reserve of chemical elements, it also makes them available more quickly, in a form that plants are able to assimilate (Neary, Ryan and DeBano, 2005). For example, while overall nitrogen reserves may decline significantly post-fire, the form of nitrogen that can be assimilated by plants (especially $NH_4$-N) actually increases, and is used up quickly by plants, fostering revegetation. A number of chemical elements may accumulate on the surface (e.g., Ca, K, Mg), helping to increase soil pH (Brais, Paré and Ouimet, 2000). Nutritional elements such as these, which enhance soil productivity, may be leached away or lost in surface runoff if they are not immobilized quickly. The leaching effect may be more obvious following severe surface fires. Burning of the humus, which plays an important role in soluble cation exchanges, may exacerbate leaching, especially in coarse soil (Neary, Ryan et DeBano, 2005).

### 2.2.2 Impacts of harvesting in burned forests

The fire impacts described above are general impacts that have been documented in most regions of North America, and on different soil types (Neary, Ryan and DeBano, 2005). In the boreal forest, however, and especially in Québec, there has been very little research to identify the impacts of fire and post-fire harvesting. The information that is available suggests that care is needed when harvesting sites that may be sensitive to the impacts of fire. Post-fire harvesting is an additional disturbance that, in some situations, may enhance the negative impacts of the fire and alter the station's productivity in the long term. This is particularly true when harvesting takes place soon after the fire, when soils are at their most fragile.

The sensitivity of burned soils was identified as a major issue in a recent summary of the impacts of post-fire harvesting (McIver and Starr, 2000). Negative impacts may be direct, such as those caused by the movement of machinery and road construction, which may accentuate soil compaction, erosion and leaching of chemical elements (Marques and Mora, 1998; McIver and Starr, 2000) or indirect, through the removal of dead trees that would otherwise have helped stabilize the soil, enhance the reserve of chemical elements and improve site productivity (Brais, Paré and Ouimet, 2000; Purdon et al., 2002; Neary, Ryan and DeBano, 2005).

In a study of jack pine and black spruce stands on coarse soils in Québec, Brais, Paré and Ouimet (2000) found that the combined impacts of fire and harvesting may significantly deplete the reserves of certain chemical elements (calcium, magnesium, potassium). Because the depletion of these elements is also influenced by fire severity, post-fire harvesting has even more significant repercussions when it takes place in severely burned forests. Another study of the impacts of harvesting following the fire in Val-Paradis (Abitibi) showed that surface concentrations of phosphorus and potassium were weaker in harvested burn sectors than in their unharvested counterparts (Purdon et al., 2002).

#### 2.2.3 Issue

**Harvesting in burned forests may exacerbate the impacts of the fire on soil and alter water quality and stand productivity.** Generally speaking, fire alters the physical, chemical and biological properties of soils, and this may make them more sensitive to leaching and nutrient loss. The extent of these impacts is influenced by a number of factors, including soil type, fire severity, topography and post-fire rain. Harvesting, especially on exposed sites or sites exhibiting any of these factors (e.g., coarse-textured soils, high level of severity and steep slopes), is an additional disturbance that may exacerbate the fire's impacts. Contributing factors include the use of machinery and road construction, both of which can accentuate soil compacting, leaching and erosion, and the removal of dead trees that would otherwise help to stabilize the soil, maintain the supply of nutrients and improve site productivity.

Harvesting in stands exposed to a severe fire at ground level and located on relatively steep slopes, may, if carried out in specific conditions (for example, on coarse soil), exacerbate the fire's impacts on leaching and nutrient loss.

## 2.3 Natural regeneration

#### 2.3.1 Conditions influencing regeneration

Fire can not only cause immediate and significant changes to the conditions of a stand, but it can also have a major impact on the composition, structure and configuration of future stands.

Generally speaking, stand regeneration will be influenced by the type of stand that was burned (structure, age and composition, surface deposits) and by the conditions created by the fire (crown and ground fire severity).

Jack pine, black spruce and trembling aspen all have reproductive strategies that allow them to regenerate on-site after a fire: these include canopy seed banks in the case of the jack pine and black spruce, and vegetative reproduction in the case of the trembling aspen. Stands dominated by these species normally do not change much post-fire (Gagnon, 1989; Greene and Johnson, 1999) and regeneration becomes established quickly, usually in the first three years post-fire (St-Pierre, Gagnon and Bellefleur, 1992; Charron and Greene, 2002; Greene et al., 2004). In the case of species that do not regenerate directly post-fire (larch, white spruce, balsam fir), recolonization of burn sites is dependent on dispersal from the fire perimeter or from unburned patches (Galipeau, Kneeshaw and Bergeron, 1997; Greene et al., 1999; Greene and Johnson, 2000).


Some species, such as the jack pine (a and b), have adapted to fire and regenerate well post-fire. In the case of other species, such as white spruce and balsam fir, recolonization of burn sites will depend on dispersal from the fire perimeter or from unburned forest patches (c).

In the case of jack pine and black spruce, the success of post-fire natural generation will depend to a large extent on the reproductive potential of the trees (as well as on other biophysical conditions of the site, such as surface deposits, topography, drainage, etc.). For both species, reproductive potential is related to the number of cones and seeds produced. For the jack pine, cone production begins at between five and ten years of age, and peaks between 70 and 80 years of age, while for the black spruce, production begins later (between 15 and 30 years of age) and peaks between 100 and 200 years of age (Burns and Honkala, 1990). In both cases (and also for the trembling aspen), regenerative success is positively influenced by basal area, which is itself connected to stand age and density (Greene and Johnson, 1999; Jayen, Leduc and Bergeron, 2006). Accordingly, the age and density (or basal area) of the stand are key factors in assessing the natural regeneration potential.

Crown and ground fire severity will also influence regeneration potential (Jayen, Leduc and Bergeron, 2006). In the case of the jack pine and black spruce, it may affect the opening of the cones and the survival of the seeds. A more intense fire fosters the cone abscission process, especially in the case of the jack pine, which has serotinous cones (as opposed to the semi-serotinous cones of the black spruce). However, a crown fire that is too intense may compromise the viability of the seeds, especially in the case of the black spruce (Greene and Johnson, 1999; Greene et al., 2004). A more intense fire is generally favourable to the regeneration of both species, but this is especially true for the jack pine (Greene et al., 2004).

Fire severity at ground level may also affect regeneration by creating good germination beds, such as bare mineral soil, humus and thin layers of organic matter (Charron and Greene, 2002; Jayen, Leduc and Bergeron, 2006). Thinner germination beds exhibit less variation in terms of their ability to retain humidity, and are therefore conducive to the germination of black spruce and jack pine seeds. Fire can create good germination beds by burning organic matter on the ground. However, its ability to do this will depend on the interaction between the thickness of the pre-fire organic matter, soil humidity and the intensity of the fire at ground level (Greene and Johnson, 1999). Generally speaking, the percentage of favourable germination beds and regeneration success are influenced positively by fire severity at ground level (Greene et al., 2004; Jayen, Leduc and Bergeron, 2006). In a study of two fires in Saskatchewan, good germination beds (mineral soils and organic soils < 3 cm thick) covered between 35% and 51% of the total burn area (Miyanishi and Johnson, 2002). However, when the fire is less severe at ground level (e.g., spring fire, fire perimeter), good germination beds may account for as little as 5% of the total burn area (Greene et al., 2004 and 2005).

It is important to note that crown fire severity is not necessarily correlated with ground fire severity (Greene et al., 2004; Jayen, Leduc and Bergeron, 2006; Neary, Ryan et DeBano, 2005). Ground fire severity may be influenced by conditions that are not conducive to intense burning of organic matter, such as high humidity, the presence of frost or snow on the ground, and the fire's behaviour (Brais, Paré and Ouimet, 2000; Greene et al., 2004 and 2005). Although the fire may be severe at ground level, good germination beds may not be available because of significant accumulations of organic matter. These accumulations may vary, for example according to the time that has elapsed since the last fire, the type of surface deposit, topography (bottom of slope, depression) and the type of stand. They may also vary within the same stand (e.g., smaller accumulations at the base of trees).

### 2.3.2 Impacts of harvesting in burned forests

Because regeneration becomes established quickly post-fire, the machinery used to harvest dead trees may have a direct impact on post-disturbance regeneration (Kurulok and Macdonald, 2004; Fraser, Landhäusser and Lieffers, 2004). In addition, post-fire harvesting may alter conditions that are generally conducive to natural regeneration, by diminishing the quality of germination beds or eliminating seed trees (Noël, 2001; Purdon et al., 2002). For example, harvesting of trees, even dead trees, may enhance insolation at ground level and create drier conditions, thereby altering the quality of germination beds and adversely affecting the conditions required for young plants to survive (Purdon, Brais and Bergeron, 2004).

A study carried out in Abitibi showed that, although post-fire harvesting helped to expose the mineral soil, black spruce regeneration success was affected by the removal of seed trees (Greene et al., 2006). This impact is probably more serious for the black spruce than for the jack pine, since although the cones of both species open quickly post-fire (in less than four years), black spruce seeds are released more slowly. For example, Greene and Johnson (1999) found that 35% of the seeds were still in the cones of fire-killed standing black spruce trees two years post-fire, whereas 97% of jack pine seeds were released during the same period. Recent findings suggest that most jack pine seed dispersal takes place in the first few months post-fire (Greene, 2010, personal communication). In other words, most of the jack pine trees will already have released their seeds when logging takes place. Moreover, although spruce cones may be left on the ground during logging, the seeds will be released more slowly and the capacity for dispersal will be greatly reduced in comparison with standing seed trees (Fleming and Mossa, 1996).

However, in situations where the conditions are not favourable to natural regeneration, for example due to a shortage of seeds or germination beds, post-fire harvesting may be an essential step in restoring production quickly to the fire site.

#### 2.3.3 Issue

**Post-fire harvesting may reduce the natural regeneration potential of certain sites.** Fire creates a range of conditions that may or may not be conducive to natural regeneration. For the jack pine and black spruce, stand regeneration will depend on the presence of seed trees and good germination beds. When the conditions are favourable to natural regeneration, harvesting activities may compromise its success by destroying established regeneration, altering the quality of germination beds and eliminating seed trees. On the other hand, when conditions are not conducive to natural regeneration, sylvicultural work may be able to create more favourable conditions (e.g., the movement of machinery may create good seed beds) and help restore production to burn sites.

## 2.4 Economic considerations

Generally speaking, harvesting takes place soon after a fire, so as to minimize the negative impacts of fire on the value of the wood products. These impacts are the result of galleries dug by wood-eating insects, and cracking of trunks due to the sharp decline in sapwood humidity. A better knowledge of the mechanisms that alter wood quality, such as the factors that influence burnt wood colonization by wood-eating insects (e.g., the whitespotted sawyer), would be useful in setting priorities for harvesting and taking maximum advantage of the period during which the wood may be salvaged (Nappi, Drapeau and Savard, 2004; Chabot, 2005).

Damage to wood by wood-eating insects. The photograph shows the galleries dug by insects in a black spruce trunk ten years post-fire.

A better understanding of the real impacts of this type of damage on the value of wood products would help open up new avenues for burnt wood harvesting. For example, one potential practice already used by some forestry companies is to harvest burn areas several years post-fire for pulp production (or, eventually, for the production of forest biomass). There is also general agreement that product value loss is by no means catastrophic up to two years post-fire (less than 20%), and that the bulk of the problem is related to marketing. Information such as this should help reduce the pressure to harvest quickly, and can be used to develop more flexible approaches to burnt wood harvesting. Among other things, it would open up some interesting methods of maintaining, if not increasing, our ability to reduce losses from forest fires while gaining more flexibility in achieving biodiversity, soil protection and natural regeneration targets.

Post-fire harvesting should also take into account the cost of restoring the site to production, and the resulting productivity losses in certain types of stands. These two aspects (restoration of production and soil productivity), examined earlier as environmental issues, should also be considered from an economic standpoint. By taking the natural regeneration potential into account, it would be possible to optimize sylvicultural investments aimed at restoring production to the site. In addition, the long-term productivity of the more sensitive sites could be maintained by considering the impacts of fire and post-fire harvesting on soils.

Lastly, the management approach used in burned forests may also be considered for forest certification purposes, in which case it is also of major economic importance. For example, the national boreal standard of the Forest Stewardship Council (FSC) identifies the conservation of burned forests as an element to be considered under principle no. 6, concerning environmental impacts: “The applicant avoids salvage harvesting in some proportion of burned habitat, because it provides ecological benefits” (FSC, 2004; Intent 6.3.11).

## 2.5 Social considerations

Because special management plans must be prepared quickly after a fire, there is very little time for public consultation. Past experience has shown that forest users other than the forestry companies, including local communities (Bourassa et al., 2002) and the First Nations, may have concerns regarding the harvesting of burned forests. The Québec population is also more sensitive to environmental issues and Aboriginal concerns. Because of this, it is important to consider the social acceptability of the practices used to harvest burned forests. Although steps are only just beginning to be taken in Québec to raise public awareness of issues arising from the harvesting of burned forests, the topic has been the subject of debate for some years in other countries and in other regions of North America, especially in the Western United States (McIver and Starr, 2000; Beschta et al., 2004; Lindenmayer et al., 2004). Because of this growing concern, the MRNF must be publicly accountable for the value of its special management plans for burned forests, due to the issues involved. This is particularly true in light of the large volumes of wood that are harvested in years where more fires take place, the lack of guidelines to structure the work, and the often striking visual impacts of harvesting in burned forests.

# 3. Management orientations

Based on current knowledge of the impacts of fire and harvesting in burned forests, we propose a number of management orientations in order to ensure that the issues are considered as part of a sustainable forest management process. The proposed orientations should help the MRNF to establish guidelines for the preparation of special management plans in burned forests.

## 3.1 General considerations

### 3.1.1 Ecosystem-based management of burned forests

**Harvesting activities in burned forests should form part of an ecosystem-based approach to the management of Québec's forests.** The aim of ecosystem-based management is to maintain healthy, resilient ecosystems by reducing the differences between natural landscapes and managed landscapes, to ensure that the ecosystem's many functions are maintained in the long term, and to preserve the social and economic benefits derived from them (Gauthier et al., 2008). Under this approach, natural disturbances become points of reference for forest management. Paradoxically, when a disturbance occurs, there are very few guidelines available to ensure that biodiversity and natural processes are maintained within the disturbed ecosystems.

The application of an ecosystem-based approach to the management of burned forests should be considered from two standpoints. First, burned forests provide a unique type of habitat within the natural forest mosaic (forests of different ages, compositions and structures), and make a significant contribution to regional biological diversity. Under this approach, biodiversity can only be maintained in boreal ecosystems by preserving significant tracts of different types of forests, including burned forests. Second, harvesting activities in burn sectors should be carried out in a

way that helps to maintain the diversity of the main biological legacies and existing ecological processes, while minimizing any negative impacts. Accordingly, harvesting work should be based on knowledge of the impacts of fire and post-fire harvesting in the affected forests.

In recent years, several Canadian provinces have prepared orientations and guidelines aimed at preserving fire-damaged forests and their key features (Saint-Germain and Greene, 2009). Generally speaking, they recommend: (1) not intervening after certain fires, in order to preserve burned forests within the region; (2) during forest management work, preserving a certain percentage of commercially valuable burned forests of different shapes and sizes; and (3) prohibiting harvesting in unburned sectors (Ontario Ministry of Natural Resources, 2001 et 2003; Alberta Sustainable Resource Development, 2007; Saskatchewan Ministry of Environment, currently under preparation).

From the standpoint of sustainable forest management, the following three major concerns should be considered when authorizing harvesting activities in burned forests.

1. *Foster the maintenance of biodiversity and natural processes in burned forests*. Post-fire harvesting should leave intact a significant percentage of the habitats and conditions created by the fire, while minimizing the negative impacts on ecosystems (e.g., soils, water, regeneration).
2. *Foster the short-term and long-term economic viability of post-fire harvesting activities.* Post-fire harvesting should be driven not only by short-term profits, but also by the costs and repercussions it may generate for the restoration of production and maintenance of productivity on the sites in question.
3. *Ensure the social acceptability of the practices used.* Given the extent of the burn area in fire-rich years, and given the very short timeframe available for consultation when preparing special management plans, it is important to ensure that the proposed forest management strategies are socially acceptable.

### 3.1.2 A priori management strategies

**Although it is difficult to predict where and when a fire will occur, current knowledge of the impacts of fire and post-fire harvesting can nevertheless be used to develop management strategies for future application when a fire occurs. This would speed up the preparation and implementation of special management plans, and would help to ensure that environmental, economic and social objectives are taken into account.** Special management plans for post-fire harvesting in burned forest areas must usually be prepared and applied quickly by the regional stakeholders concerned, in order to minimize loss of value due to the deterioration of the timber. Because the plans must be prepared so quickly, there is very little time available for public consultation. Currently, regional managers only have instructions regarding the preparation of special management plans and the allocation of financial assistance. There is very little information available to help them include environmental, economic and social considerations in their plans.

Because the MRNF has committed to the ecosystem-based approach, and because of the large areas in which post-fire harvesting will take place in certain years, as well as the issues related to this practice and the likelihood that it will increase in the coming years, a well-planned, joint approach is now needed to minimize any negative impacts and ensure that some of the key features of burned forests can be preserved.

### 3.1.3 A profile of forest fires and post-fire harvesting in burned forests

**It is important to have a detailed description of the fire-damaged forests, in order to identify the applicable issues and the most appropriate management strategy for each fire.** Characteristics such as pre-fire stand composition, topography, type of surface deposit and crown and ground fire severity have a significant impact on the biodiversity, productivity and regeneration of burned forests. This information is vital in ensuring that the issues are properly considered when preparing special management plans.

**Post-fire harvesting data should be available and compiled to obtain harvesting rates (i.e. the percentage of burn area harvested on local, regional and provincial scales) and help identify the most important of the above-mentioned issues.** The data currently available is insufficient to characterize post-fire harvesting projects and to establish accurate harvesting rates for burned forests in Québec. The data generated by the special management plans are often incomplete and cannot be combined with other fire-related data to assess harvesting rates in burned forests. The issues set out in this document were derived from a summary of available knowledge on the impacts of fire and post-fire harvesting, combined with several case studies in harvested burn areas. Therefore, a more complete profile of the impacts of post-fire harvesting on these issues would help not only to determine their importance, but also to identify the management actions required in burned forests.

### 3.1.4 Adaptive management

**The management strategies derived from the chosen issues and orientations should form part of an adaptive management approach.** A considerable amount of information on the impacts of fire and post-fire harvesting has been acquired in Québec over the last few years. Although the issues and orientations presented here are based on what is currently considered to be the latest knowledge, updates will nevertheless be required as research produces new information. Moreover, it is important to ensure that the forest management strategies (guidelines, management standards) adopted are monitored with a view to deciding whether or not they are effective in achieving the goals set (Drapeau et al., 2008). Monitoring will therefore be required to assess this factor, meaning that both monitoring programs and related funding must be included at the planning stage.

### 3.1.5 Terminology

**From the standpoint of sustainable forest management, it is important that the terms used in ministerial documents should reflect current knowledge of forest ecology and the latest vision of forest management. The use of incorrect terminology is one of the reasons why some forest managers are not concerned about the impacts of post-fire harvesting.** Upon reading the summary of this document, it is clear that the use of terms such as “natural disasters” and “timber salvage” is incorrect. For example, section 79 of the Forest Act states that: “Where substantial damage has been caused to timber stands in a forest area intended for forest production by natural disasters such as forest fires, windfalls, infestations of insects or cryptogamic diseases, the Minister shall prepare and administer a special forest management plan […] to ensure the salvage of the timber.” In section 60 of the Sustainable Forest Management Act, the term “natural disasters” in section 79 of the Forest Act is replaced with “natural disturbance”. However, the use of “timber salvage” still remains. The term “timber salvage” has been criticized by a number of authors who argue that it is not the burnt timber itself that is salvaged, but the market value of the burnt timber (Lindenmayer, Burton and Franklin, 2008). Many authors now use other terms such as “post-fire harvesting”, “post-fire logging" or "cutting or harvesting in burned forests" (e.g., McIver and Starr, 2000; Morissette et al., 2002).

## 3.2 Management orientations

### 3.2.1 Management strategy application scales

To address the issues relating to post-fire harvesting, management strategies will be applied on two different scales, namely the major landscape scale, where the goal will be to maintain burned forests, and the fire scale, where the goal will be to consider the various issues when carrying out logging work.

### 3.2.2 Management orientations on a major landscape scale

**On this scale, the principal management orientation is to identify a minimum target for the maintenance of burned forests.** This orientation allows forest managers to address a number of ecological issues on a major landscape scale (e.g., management unit scale), including the conservation of biodiversity associated with burned stands. It also allows them to address economic considerations on a local scale (e.g., more or less harvesting on the fire scale).

**The minimum target for the maintenance of burned forests should be roughly 30% of the burn area from the last five years, calculated for the management unit as a whole.** The amount of burned forest area that is left untouched may vary from one fire to the next, but generally speaking, it is important to ensure that the overall target for the management unit as a whole is met. The reason for taking this approach is to give forestry planners more flexibility, since they must also deal with economic and operational constraints (e.g., access). For example, a fire sector located at some distance from the road network may, if post-fire harvesting is not carried out, contribute more to the 30% target than a sector that is easily accessible and can therefore be harvested to a greater extent. In other words, the amount of burned forest area that is not logged may vary from one fire to another, although a minimum threshold should be set (see section 3.2.3.2).

In setting the 30% target for burn areas in a management unit, forest managers should base their decisions on the scientific literature on population alteration and viability thresholds (Andrën, 1994; Radford, Bennett and Cheers, 2005; Vaillancourt et al., 2009) and on the acceptable alteration thresholds retained in the past by the MRNF (e.g., PDOs for permanent mature and over-mature forests). Over the five-year period used to calculate the 30% threshold, the aim should be to preserve a representative sample of all post-fire conditions over time. This is important, because in the early years post-fire, burned forests exhibit essential habitat characteristics (see section 2.1.1) that do not exist in older burn areas. Lastly, the use of the management unit as the basic target land mass allows the burned forest areas to be distributed evenly throughout the region, and also helps ensure that a similar level of effort is devoted to post-fire harvesting and burn area maintenance in all the management units in a given region.

### 3.2.3 Management orientations on fire scale

**The management orientations proposed in this section should be applied to every fire.** They will ensure that forest management work helps to mitigate repercussions throughout the burn area. In addition, the fact of maintaining a minimum amount of residual forest for each fire allows for proper representation and distribution of burned forests throughout the region. At the same time, given that natural conditions change quickly in the first few years post-fire, it also helps to ensure that the different post-fire succession stages are represented in the region (burn areas of different ages).

*3.2.3.1 Conservation of unburned forests*

**Unburned forests within the fire perimeter should not be harvested post-fire.** Forest areas left untouched by the fire play a significant role as biological legacies. They act as shelters and are used as travel corridors for the dispersal of species less tolerant to or intolerant of post-fire conditions. They are also source habitats for recolonization of burn areas by plant and wildlife species, and will play an important role not only by helping to create an irregular structure in the preserved stands, but also by providing mature trees and deadwood. At the same time, they can help mitigate the combined visual impacts of fire and post-fire logging. Lastly, given that they were not damaged by the fire, they should not be subject to legal provisions concerning the harvesting of burnt wood.

Unburned residual forests left standing after harvesting activities within the burn area.

*3.2.3.2 Conservation of burned forests that are representative of post-fire diversity*

**A significant percentage of burned stands that are representative of post-fire forest conditions should be maintained during logging activities.** Fire creates a variety of ecological conditions through a combination of pre-fire stand composition and structure (e.g., species groups, density, height) and fire severity. These conditions can have different impacts on plants and wildlife. Regional differences in burned forest characteristics can exist and could be revealed by taking into account pre-fire stand characteristics (e.g., species groups, stand structures).

Residual burned and unburned forests left standing during logging activities. Residual forests should be representative of the different types of burned stands present after the fire, and should be of varying shapes and sizes.

On a fire scale, it is important that the minimum percentage of burned forest left standing should be sufficient for the landscape scale target to be achieved. However, depending on the general situation in the management unit, the percentage may be changed for each separate fire (see section 3.2.2), provided it **never falls below a minimum threshold of 15%**. Below this threshold, the environmental alteration is considered to be severe, and the risks of biodiversity loss are significant. The percentage of burned forest left standing could also be adjusted in light of the forest’s natural regeneration capacity. For example, a lower percentage may be acceptable where regeneration is likely to be difficult, and a higher percentage when regeneration is likely to be successful. The percentage of burned forest left standing should include areas where harvesting is not possible due to operational constraints (hilly relief, low volume per hectare, etc.) or regulatory requirements. This would ensure effective salvage while maintaining a minimum percentage of burned forest. Lastly, the percentage of burned forest to be left standing should apply to all types of burned stands (see section 2.1.2).

*3.2.3.3 Configuration and location of residual forests*

**Residual forests should vary in terms of shape and size, and should be located in such a way as to foster connectivity.** Residual forests play a number of roles through their configuration and location. Among other things, they help to maintain the diversity of habitat conditions created by fire, favour heterogeneous forest structures, minimize the impacts of leaching and erosion, foster natural regeneration and mitigate the visual impacts of fire and post-fire logging.

**Residual forests should differ in terms of size and shape.**

- *Large forest blocks*. Large blocks of burned forest are better able to meet the ecological requirements of species that need significant concentrations of dead trees or those with large home ranges. In addition, they offer a wider variety of natural conditions within a single block. Their minimum size could be based on the minimum home ranges of species associated with fire, such as the black-backed woodpecker (e.g., more than 20 ha, Nappi, 2009).

- *Riparian wooded strips.* Given the potential impacts of fire and logging on soil erosion and nutrient leaching, riparian wooded strips can play an important role in maintaining water quality and protecting aquatic environments. Strips containing burned and unburned forests help to maintain a certain level of connectivity within the logged burn area.

- *Operational constraints.* There are a number of operational constraints that may prevent burn areas from being harvested. Forest areas that cannot be harvested, scattered throughout the patchwork of cutting areas, will also help to maintain a certain level of connectivity within the logged burn area.

- *Standing trees with commercial value.* The fact of maintaining a certain amount of canopy, for example by preserving seed trees during partial cuts, may help to encourage natural regeneration, and will also mitigate the negative impacts of logging on abiotic conditions at soil level (e.g., heat and wind), and on the maintenance of certain post-fire species (e.g., understorey vegetation, invertebrates and birds).

- *Standing trees with no commercial value*. Standing trees with no commercial value may nevertheless be of significant value to wildlife. This is the case of trees that were dead or dying before the fire, which are sought-after by some bird species, including woodpeckers, to dig their nesting cavities (Nappi, 2009).

**The residual forest should be spread evenly throughout the burn area, so as to ensure that there are no large sectors without residual forest, and to foster connectivity.** Areas that are sensitive to harvesting (e.g., coarse-textured soils), sites subject to operational constraints (e.g., steep slopes, limited access, high operating costs and special protection status), and riparian wooded strips, should serve as focal points for the creation of other types of residual forests, in order to ensure connectivity. In addition, sectors in which burned and unburned forests are juxtaposed are important as habitats for a number of vertebrate and invertebrate wildlife species. A significant portion of residual burned forest should therefore be located alongside unburned forest areas, in order to ensure connectivity.

Connectivity between burned and unburned forests. Sectors such as these are important as habitats for a number of species.

*3.2.3.4 Protection of soils and water quality*

**Post-fire harvesting activities should be limited or controlled on sites that are sensitive to the movement of machinery, in order to protect soils and water quality.** Post-fire harvesting is a second successive disturbance that may exacerbate some of the fire's negative impacts and alter both soil productivity and water quality. To maintain soil production capacity, it is preferable not to harvest sites that are potentially sensitive, including those located on steep slopes or coarse soil, or where ground fire severity was especially high. Conversely, harvesting should be focused in priority in less sensitive areas, such as those where the ground fire was less severe, or where the organic layer is thicker.

Some forest management practices should be given priority, to minimize the potential negative impacts of post-fire harvesting on sensitive soils. They include:

- Using the sound practice approach (Ministère des Ressources naturelles, 2001) when building road infrastructures;
- Fostering the maintenance of residual forests (grouped, scattered and individual trees) and timber waste on the ground;
- Limiting the movement of machinery;
- Encouraging the use of winter harvesting in order to avoid disturbing the soil.

**Given the potential impacts of fire and post-fire harvesting on soil erosion and nutrient leaching, the provisions concerning wooded strips in the Regulation respecting standards of forest management for forests in the domain of the State (Divisions II and III) should be applied as a minimum, to help protect aquatic ecosystems.** The required width of the wooded strips could be increased in the presence of conditions likely to provoke nutrient leaching and soil erosion (e.g., steep slopes, severe ground fire[1] and coarse-textured soil), and to make up for the lack of residual forests in adjacent logged sites. In addition, in sensitive sectors, the requirement to maintain wooded strips (and the requirements concerning their width) could also be applied to intermittent watercourses, in order to protect the aquatic ecosystem. Because it is difficult in some regions to map permanent watercourses, the measure would also provide a means of protecting permanent watercourses that are not shown on maps.

Maintenance of burned and unburned wooded strips

1. Crown fire severity, as defined by the impact maps, is not automatically correlated with ground fire severity. For example, a fire that occurs early in spring (when the ground is still frozen) may be very severe at crown level but cause only slight damage at ground level. In the absence of more accurate tools, ground-level severity should be estimated on site.

*3.2.3.5 Restoring timber production*

**Restoration of timber production is a costly process, and it is important either to minimize forest management work in sectors with high natural regeneration potential, or apply strategies to preserve that potential. Conversely, forest management, access and production restoration efforts should be focused in sectors where natural regeneration is likely to be deficient, and in burn sectors that did not regenerate well after previous fires.** In the case of recently-burned forests, forest management priorities and treatment choices should be based on the characteristics of the burned stands. Data concerning the nature of the stands (composition, age, etc.), surface deposits and fire severity (crown or ground) can be used to identify sites with good natural regeneration potential and those where harvesting and production restoration activities will be needed (Jayen, Déry and Nappi, 2010).

In the case of the black spruce and jack pine, natural regeneration depends on the presence of seed trees and good germination beds. It is particularly important to maintain black spruce seed trees, since the seed dispersal process is spread over two to three years, and will therefore not be complete if harvesting takes place in the year of or the year following the fire. The presence of seed trees is less critical for the jack pine, since seed dispersal mostly takes place in the first few months post-fire, and not only do the seeds remain viable for several years, but they can also germinate on a broader variety of microsites than the black spruce seeds.

Black spruce regeneration is fostered by leaving seed trees on burn sites.

Sylvicultural interventions should also be adjusted according to whether or not good germination beds are available. Where germination beds are present, the selected treatments should limit soil disturbance (e.g., winter logging). Conversely, where the existing germination beds are not suited to natural regeneration, a certain amount of soil disturbance may actually help to improve them. Good germination beds, such as mineral soils, humus and thin layers of organic matter, depend on the depth of pre-fire organic matter, soil humidity and ground fire severity.

*3.2.3.6 Planning harvest of residual forests*

**Burned and unburned residual forests should be preserved long enough to play their role properly.** Unburned or slightly burned stands should be maintained until closed canopy characteristics have been restored in adjacent regenerating sectors. Management guidelines may resemble those for residual forests in aggregated cut blocks. In addition, a portion of the unburned or slightly burned residual forest could be permanently maintained, in order to help achieve regional closed canopy and old forest targets, provided, of course, they meet the criteria.

It is also important to consider maintaining some areas of burned or mostly burned stands over the longer term, in order to preserve representative elements of all successional stages (post-fire age), since habitat conditions and animal and plant succession vary according to the time that has elapsed since the fire. However, delayed harvesting (e.g., two or five years post-fire) may still be carried out in some of the burned residual forest. An approach such as this would ensure that some features of recently-burned forests are maintained, and would limit harvesting immediately after the fire (i.e. during the period that is most critical for biodiversity, soil fragility and natural regeneration), while still allowing some of the economic benefits of harvesting to be salvaged. It would also help ensure the restoration of poorly regenerated sites. However, very little information is available on the economic and environmental impacts of this practice, and experimental projects would be required to assess their feasibility and effects.

# Appendix Fire severity stand classification, used until 2008[1]

| Severity Class | Description of stand based on the condition of fire-damaged trees[2] |
|---|---|
| V | Green trees |
| V1 | Mix of green trees and scorched trees, with a majority of green trees |
| 1V | Mix of green trees and scorched trees, with a majority of scorched trees |
| 1 | Scorched trees; generally less than 25% of windfall |
| 2 | Charred trees; generally less than 40% of windfall |
| 3 | Charred trees; generally more than 40% of windfall |

(Adapted from Chabot, 2005)

1. The MRNF was in the process of reviewing this classification when this document went to press.
2. green tree: a tree that was not or was only slightly damaged by the fire (possibility of charred bark at the base of the tree); scorched tree: a tree that still has its needles, but the needles have been scorched by the heat; charred tree: a tree where most of the trunk bark has been charred, and whose needles have been destroyed by the fire.

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