FireSmart®-ForestWise: Managing Wildlife and Wildfire Risk in the Wildland/Urban Interface—a Canadian Case Study

Alan Westhaver[1], Richard D. Revel[2], and Brad C. Hawkes[3]

Abstract*—Reducing the risk of losses from wildfires that threaten homes and communities is a growing priority in Canada. To reduce risk, "FireSmart®" standards have been adopted nationwide for managing forest fuel. However, these standards largely disregard interests of wildlife and conservation of wildlife habitat – thus raising concerns among residents and other stakeholders. To be acceptable, fuel treatments in wildland/urban interface areas of Jasper National Park, Alberta, required that potential environmental impacts and the requirements of wildlife also be carefully considered. A research project conducted in conjunction with the Foothills Model Forest used literature and experimental manipulations to develop ecologically based approaches for treating fuel in ways that optimize conditions for wildlife, within constraints of current standards. The research was conducted during a 30-month prototype project on more than 250 ha of forest surrounding the community of Jasper, Alberta. The study concluded fuel treatments for the purpose of reducing wildfire risk can be compatible with wildlife habitat conservation and ecosystem restoration goals. This paper describes the interface challenges faced by park managers, explains the adaptive management approach used to develop practicable solutions, and describes resulting species-specific mitigations, guidelines, and best practices that satisfy community wildfire protection standards and ecosystem management objectives, concurrently.*

Introduction

Canada is experiencing an increase in interface fires. The vulnerability of people, property, and forests has reached alarming levels during recent fire seasons and helped trigger the Canadian Wildland Fire Strategy (Canadian Intergovernmental Secretariat 2005). Bothwell (2006) documented more than 900 cases of structure loss to interface fire since 1980, and in the past 10 years more than 250 communities and 700,000 Canadians have been threatened directly by wildfires (Natural Resources Canada 2005). In British Columbia, recent fire seasons showed a large upward trend related to the interface when compared to the 10-year average (Fuglem 2004). In 2003, more than 100 of 2,517 wildfires in British Columbia struck interface areas, and 15 were major incidents that caused evacuation of 50,000 people and destroyed 334 homes or businesses.

Several factors combine to underpin the need for more effective community wildfire protection, particularly in Western Canada: (1) increasingly dense country residential development (Duke and others 2003), (2) growing risk of human-caused ignitions, (3) warmer climate resulting in increased frequency, size, and severity of wildfires (Flannigan and others 1998; Flannigan and others 2003), and (4) rising socio-economic costs of fire control (Filmon 2004).

In: Butler, Bret W.; Cook, Wayne, comps. 2007. The fire environment—innovations, management, and policy; conference proceedings. 26-30 March 2007; Destin, FL. Proceedings RMRS-P-46CD. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 662 p. CD-ROM.

[1] Vegetation/Fire Specialist, Parks Canada, Jasper National Park, Alberta, Canada. alan.westhaver@pc.gc.ca

[2] Faculty of Environmental Design, University of Calgary, Alberta, Canada.

[3] Natural Resources Canada, Canadian Forest Service, Victoria, British Columbia, Canada.

Western Canadian wildland fire managers and researchers have observed disturbing changes in the structure and density of forests formerly subject to frequent disturbance by fire, an upsurge in wildfire intensity at these locations, and a corresponding increase in the difficulty of wildfire control (Quintilio 2005). For example, dense forest annually encroaches on ~30 km^2 of open forest and grassland in the Rocky Mountain Trench of British Columbia (Kootenay National Park 2002). Remote sensing and ground plots revealed significant stand and vegetation changes in Jasper National Park (Rhemtulla 1999; Mitchell 2005). Following the catastrophic 2003 fire season in British Columbia, a Provincial Review (Filmon 2004) concluded past fire suppression has contributed directly to fuel buildup in forests and that this buildup will result in more significant and severe wildfires, including more interface fires, unless action is taken. In Canada, many of the fire-adapted forests most severely impacted are at drier, low elevation areas most attractive to recreational and residential development (Duke 2001). Fuel buildup may be a lesser problem in the boreal forest where stand-replacing fires prevail.

These trends mirror the experience in the United States, where decades of fire exclusion policies have resulted in high accumulations of combustible fuels relative to conditions prior to 1900 (Mutch 1994; Graham and others 2004; United States Department of Agriculture 2005). Covington and Moore (1994) described how once frequent low-intensity surface fires served to clean the forest floor of fine fuels and remove regenerating conifers. From a fire perspective, reduced fire activity results in increased fuel loads, increased fuel continuity, and enhanced probability of crown fire (Daigle 1996; Scott and Reinhardt 2001; Graham and others 2004).

Improvements to fire management such as training, response, and enhancing structural resistance to fire are important, but fuel reduction remains as a leading method to decrease the incidence and severity of interface fires (Partners in Protection 2003). The principles of wildfire behaviour form the basis for fuel modification standards. Byram's equation for fireline intensity (Byram 1959) and more recent analysis by Countryman (1974) and Graham and others (2004) reveal that fuel is the only variable humans can manipulate to reduce the energy released by fire, whereas there is no control over weather or topography. Studies of wildfire behavior and severity in treated and untreated fuels by Martinson and Omi (2003) lend further support for fuel reduction approaches. Specifically, the ignition, development, and spread of wildfire are affected by characteristics of the fuel complex (Canadian Forest Service 1968). These include the total fuel load, fuel size and arrangement, the moisture and chemical content of fuels, and the "canopy base height" and bulk density of fuels (Scott and Reinhardt 2001; Cruz and others 2002). Interface residents and fire prevention agencies manipulate these fuel properties to reduce risk. When they do so, they are also affecting key aspects of wildlife habitat.

Fuel Management Standards in Canada

Current Canadian standards for interface fuel management were developed by the nonprofit organization "Partners in Protection™" and first published in the manual *FireSmart®: Protecting Your Community from Wildfire*, in 1999.

The FireSmart manual sets out preventive standards for management of forest fuels by individual homeowners, or agencies working at larger scales to protect communities. The purpose of these standards is to limit wildfire intensity, ease fire suppression efforts, and prevent structural ignitions (Partners in Protection 2003). Canadian FireSmart standards are based on the National Fire Protection Association code, *NFPA 1144 Standard for Protection of Life and Property from Wildfire* (NFPA 2002). The standards employ the four basic strategies of fuel removal, reduction, isolation, or conversion to alter fuel bed properties to reduce the potential for fire initiation and propagation of crown fire.

These standards require that more fuel be removed as the distance to a home or structure decreases. Based on this, the concept of three concentric "interface Priority Zones" was adopted by Partners in Protection (2003). These zones and the treatments that are found in them served as one basis for this study (fig. 1).

Overall, Canadian fire protection agencies are meeting with limited success in convincing individuals or communities at the interface to voluntarily modify or manipulate forest structure on and around private property. The Auditor General for British Columbia (British Columbia 2001) noted that only 3 percent of communities in the province had undertaken significant levels of risk mitigation, and that little was being done in 55 percent of communities where wildfire risk levels were rated moderate to high. Only 11 percent of communities had undertaken fuel reduction programs of any significance. Independent reviews following large interface fires in Alberta (DeSorcy 2001) and British Columbia (Filmon 2004) both concluded the lack of prefire preparation is a factor, and there is a great need to accelerate

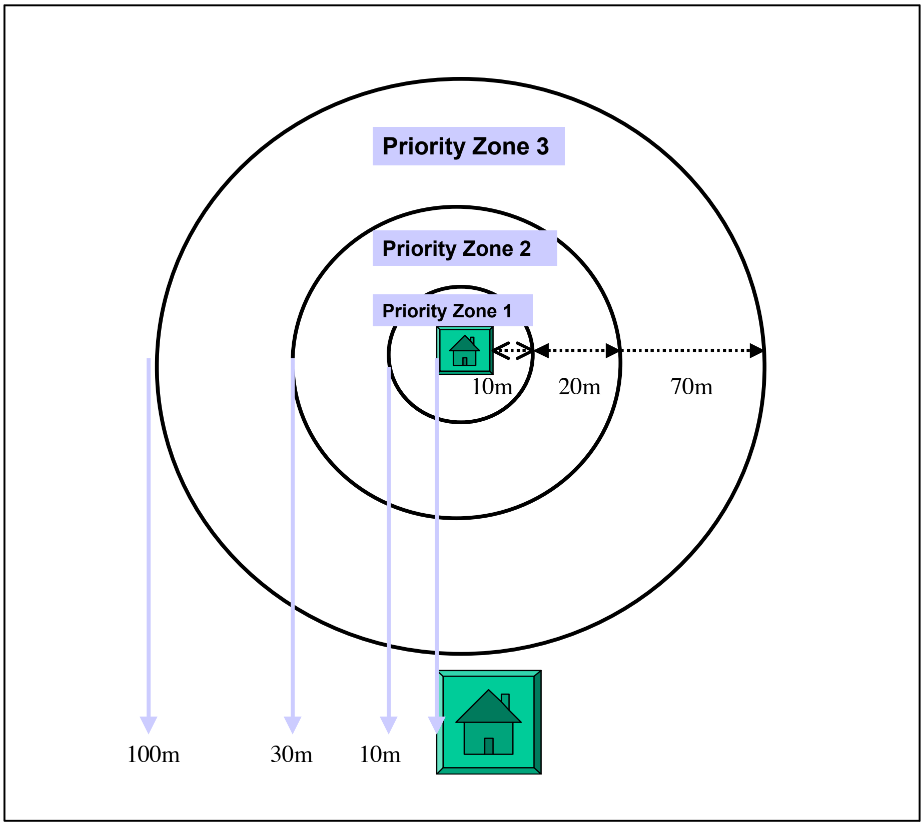


Figure 1—FireSmart fuel management Priority Zones within the wildland/urban interface (Partners in Protection 2003).

fuel management programs, which can ameliorate this danger. Since these surveys, both provinces have instituted improved hazard assessment and fuel management programs; however, the reluctance of residents and communities to treat fuel more aggressively frustrates many wildland and municipal fire managers.

Several reasons for this lack of action have been documented (Boura 1996; Winter and others 2004; McCaffrey 2004b; Mc Gee and others 2005; Brenkert and others 2005): resident perceptions that wildfire risk is lower than it actually is; lack of knowledge about risk reduction measures; willingness by residents to accept the risk of wildfire losses; constraints on the ability, funds, or time to implement solutions; skepticism about the effectiveness of risk reduction measures; lack of trust in public agencies responsible for fuel management; and conflicts between risk reduction measures and other resource values held by residents such as wildlife, conservation, or aesthetics.

Evidence is building that recurrent conflicts between existing standards for risk/fuel reduction and other resource values such as wildlife conservation may deter interface residents or communities from taking preventive actions. In Australia, fire hazard reduction practices reduced environmental qualities and caused bitter social divisions within local communities (Boura 1996). In Arizona local citizens opposed forest thinning “because they moved here for the forest,” making it clear that not everyone was comfortable with the concept of cutting trees or openly protested such actions as being destructive (Winter and others 2004). Graham (2003) listed privacy, wildlife viewing, recreation, aesthetics, and ideas of naturalness as key landscape values that influenced the acceptability of fuel management activities. For many Jasper residents and property owners, it seemed difficult to reconcile FireSmart fuel treatments with the personal importance they placed on aesthetic values, wildlife viewing opportunities, and the “natural” environment they live in. Citizens were also concerned about secondary environmental impacts, such as soil erosion or stream pollution, which may result from mechanized fuel treatment (Westhaver 2003). Consequently, it is easy for conflict to arise between fire managers who advocate manipulation of vegetation, and conservationists who view these actions as destructive (Brown 2002).

Such controversies suggest deficiencies in current approaches to community and residential wildfire protection. Further evidence for deficiencies is found in careful review of current FireSmart standards, which reveals a preoccupation with physical characteristics of the fuel complex and disregard for other resource values such as wildlife, wildlife habitat, biodiversity, cultural, and aesthetic qualities. Likewise, few procedures for limiting the secondary environmental impacts associated with major fuel manipulation projects are included. Interestingly, FireSmart authors recognized these shortcomings but could find little information to address these issues (Partners in Protection 2003).

Conversely, fuel initiatives have the best chance of being implemented if managers provide effective responses to the questions, objections, and concerns of residents (Winter and others 2002; McCaffrey 2004a). A better understanding of how fuel reduction treatments affect forest resources is required to minimize and resolve conflicts and to more effectively manage wildlife habitat (Kotliar and others 2002). The hesitancy of interface residents to implement FireSmart measures, due to conflicts with other resource values or needs such as wildlife, conservation, and aesthetics, was a primary motivation for this research.

Study Problem and Purpose

Based on the foregoing description, it is clear that conflicts between fuel modification to reduce wildfire risk and conservation of other resource values must be reconciled if objectives for protecting wildland/urban interface communities from wildfire are to be achieved. An urgent need for increased community wildfire protection, deep concerns of local citizens for wildlife and environmental protection, and Parks Canada's mandate for ecological integrity provided an opportunity to integrate innovation and research into a prototype program of fuel treatment in the wildland/urban interface at Jasper, Alberta. This situation also makes the town of Jasper an ideal site for gauging public support for modified fuel treatments.

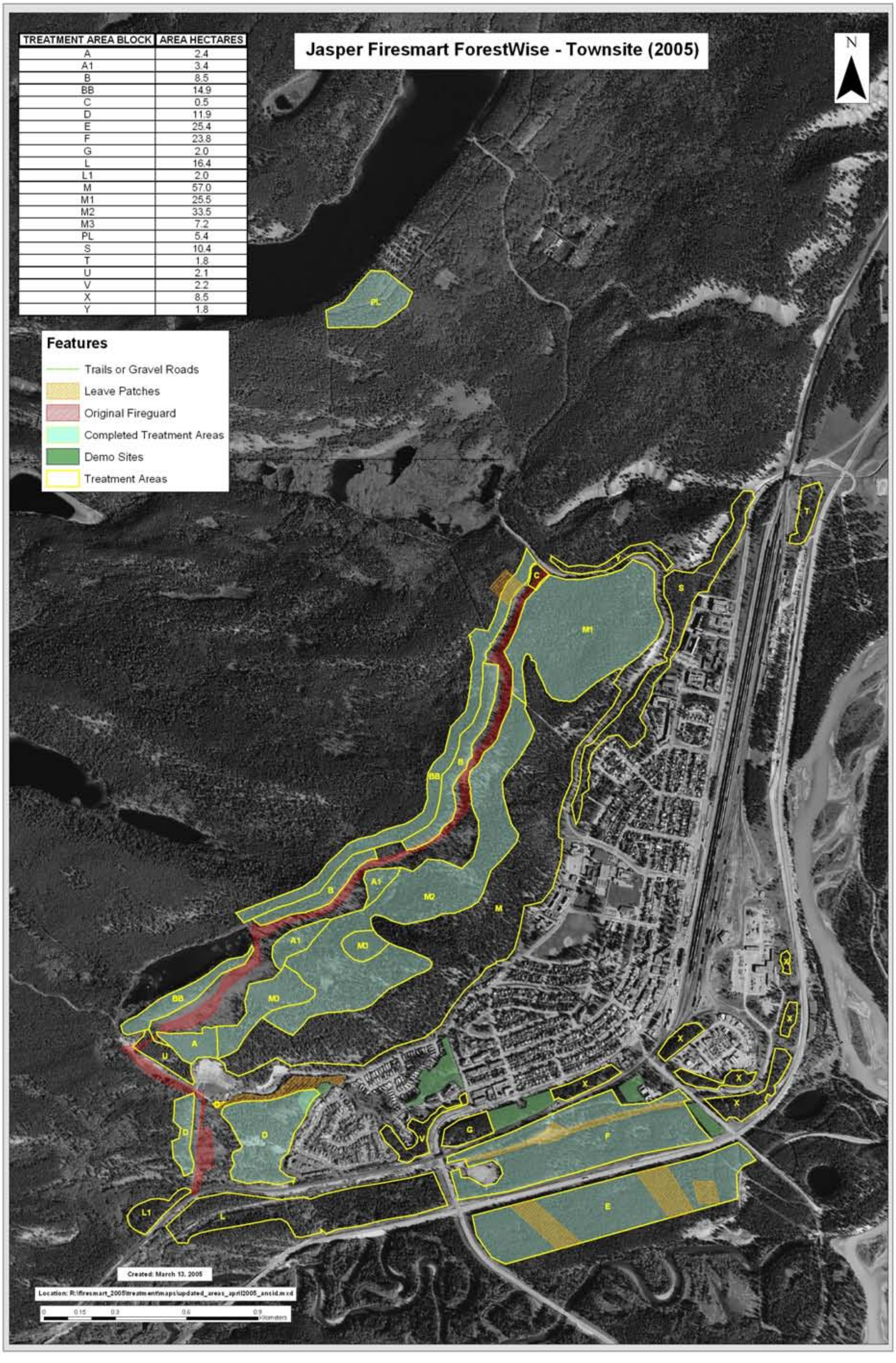
The primary purpose of this research was to develop, implement, and recommend practicable, ecologically based approaches for managing vegetation at the wildland/urban interface in ways that optimize conditions for wildlife, within constraints of current fuel treatment standards. A secondary purpose, not discussed in this paper, was to establish a methodology for monitoring the long-term effects of fuel management on wildlife habitat and use (Westhaver 2006).

Study Area

The 250+ ha study area is within a heavily forested area of Jasper National Park, Alberta, at the confluence of three large glacial valleys. These fuel treatment areas are arrayed around the town of Jasper (fig. 2) and the recreation cottage subdivision at Lake Edith. Research was conducted under the joint auspices of Parks Canada, the Foothills Model Forest, and University of Calgary.

The area lies in the valley-bottom "Montane" ecoregion (Holland and Coen 1982) at an elevation of about 1100 m. This area is among the most productive and biologically diverse ecosystems in Jasper National Park (Holroyd and Van Tighem 1983). A wide range of forest types comprise much of the park's critical ungulate winter range, and other specialized wildlife habitats.

Coniferous forests of the study area are mostly composed of mature lodgepole pine (*Pinus contorta* Dougl. *ex* Loud.), with less area of Douglas-fir (*Pseudotsuga menziessi* (Mirb) Franco) forest and mixed conifer forest. White spruce (*Picea glauca* (Moench) Voss) and Douglas-fir are typically late-succession species with white spruce dominating conifer regeneration in mesic and hygric sites, and lodgepole pine and Douglas-fir regeneration in xeric sites. Plant species and communities in this ecoregion are adapted to frequent, low-intensity surface fire or mixed-intensity fire (Tande 1979; Achuff 1996; Andison 2000). Low intensity (stand maintaining) surface fires predominated in grasslands and open canopy Douglas-fir and lodgepole pine stands. High intensity (stand replacing) crown fires prevailed in moister, continuous pine stands on the valley sides and some valley bottom areas (Tande 1979). Due to the absence of fire for much of the past century, formerly open, savannah-like Douglas-fir forest and lodgepole pine forest in the study area have changed significantly. They are now characterized by a scattering of dominant widely spaced, large diameter Douglas-fir veterans (200 to 300 years old) that are ingrown with a dense multilayered canopy of shorter, smaller-diameter lodgepole pine and Douglas-fir.



TREATMENT AREA BLOCK	AREA HECTARES
A	2.4
A1	3.4
B	8.5
BB	14.9
C	0.5
D	11.9
E	25.4
F	23.8
G	2.0
L	16.4
L1	2.0
M	57.0
M1	25.5
M2	33.5
M3	7.2
PL	5.4
S	10.4
T	1.8
U	2.1
V	2.2
X	8.5
Y	1.8

Figure 2—Wildland/urban interface operating areas surrounding the town of Jasper.

Prior to Euro-American arrival, aboriginal peoples influenced these Montane ecosystems and the vegetation found here for more than 10,000 years (Heitzmann 2001; White 2001). Although aboriginal peoples appear to have ignited the majority of Montane fires, lightning ignitions also played a role in establishing ecosystem patterns, processes, and the plant composition now being managed (Wierzchowski and others 2002). Since settlement by nonnatives, anthropological use of fire has dramatically declined in this area (White 2001).

Impacts of the recent "fire-free" period on vegetation are significant. Over the past 65 years the amount of Montane forest older than 100 years has nearly quadrupled from 21 to 78 percent (Andison 2000). Between 1915 and 1995, the proportion of the Montane occupied by grasslands and open forest habitats decreased by more than 50 percent, with similar decreases in the number of these patches/100 ha (Rhemtulla 1999; Mitchell 2005). Hammond (2003) stated that much of the current structure of Montane forest is an artifact of recent fire management practices, rather than reflective of natural processes and the historical range of variation. Subsequently, Parks Canada concluded that, due to fire control, the current fire regime and forest conditions are outside the historical ranges of variation, that fire must be actively restored, and that risks to developed areas must be ameliorated (Parks Canada 2000).

For Parks Canada, it is also important to avoid wildlife/human conflicts (Ralf and Bradford 1998); maintain grizzly bear habitat effectiveness (Parks Canada 2000); provide connectivity and corridors so that wildlife, particularly carnivores, are able to move freely through the landscape (Mercer and Purves 2000); and provide adequate protection for species listed under the Canadian Species at Risk Act.

The interface is also the portion of Jasper National Park that receives the majority of human development and use. Jasper, a community of about 5,000 residents and 500 businesses, is the service centre for park visitors and administration, and a division point for Canadian National Rail. Up to 20,000 visitors can be accommodated nightly and more than 2 million visitors use the park each year (Parks Canada 2000). Wildfire risk (La Morte and Associates 1996) in the town area is substantial and has been recognized for many years (Carnell and Anderson 1974; Haney and Anderson 1978; Fenton 1986; FireLine Consulting 1997; Mortimer 1998, 1999; Blackwell and Mortimer 2004). Risk arises from a combination of high probability of fire ignition from frequent lightning, industrial, transportation, and other human-caused sources and extreme consequences that would result, given the expectation of a fast-moving high intensity wildfire.

Starting in 1999, solutions to reduce wildfire risk were methodically implemented. Initial efforts focused on infrastructure improvements, structural modifications, and better emergency preparedness (Jasper Interface Steering Team 2002). By 2001, efforts shifted to fuel reduction, by landowners and Parks Canada. At the same time, residents and park managers became increasingly aware that fuel manipulations could adversely affect wildlife and wildlife habitat, and deficiencies in FireSmart standards grew more apparent. Without more appropriate fuel measures to address resource and social concerns, it seemed unlikely that sufficient public or management support for fuel reduction programs would be obtained. It also seemed obvious that improvements to standard fuel treatments could, and should, be made. This study addresses these deficiencies.

Methods

This study employed a combination of literature review, experimentation learning through adaptive management (Walters and Holling 1990), and deductive analysis to develop innovative fuel treatments that better accommodate wildlife while managing interface vegetation to reduce wildfire risk. Improved fuel treatments were applied by labor crews and specialized industry contractors, then evaluated and refined by Parks Canada in a 250-ha prototype fuel management project at Jasper, Alberta. The work took place over three winters between 2003 and 2005. This approach was adopted as the best means of achieving the goals of this study and overall risk reduction objectives at Jasper, given the constraints of time, and the near absence of reproducible scientific studies specific to fuel treatments in the wildland/urban interface. Figure 3 summarizes the overall sequence of analytical steps employed to achieve the study purpose.

The key principles of wildland fire behavior (Van Wagner 1977; Forestry Canada Fire Danger Group 1992; Scott and Reinhardt 2001; Cruz and others 2002; Graham and others 2004) and home ignition (Cohen 2000a,b;

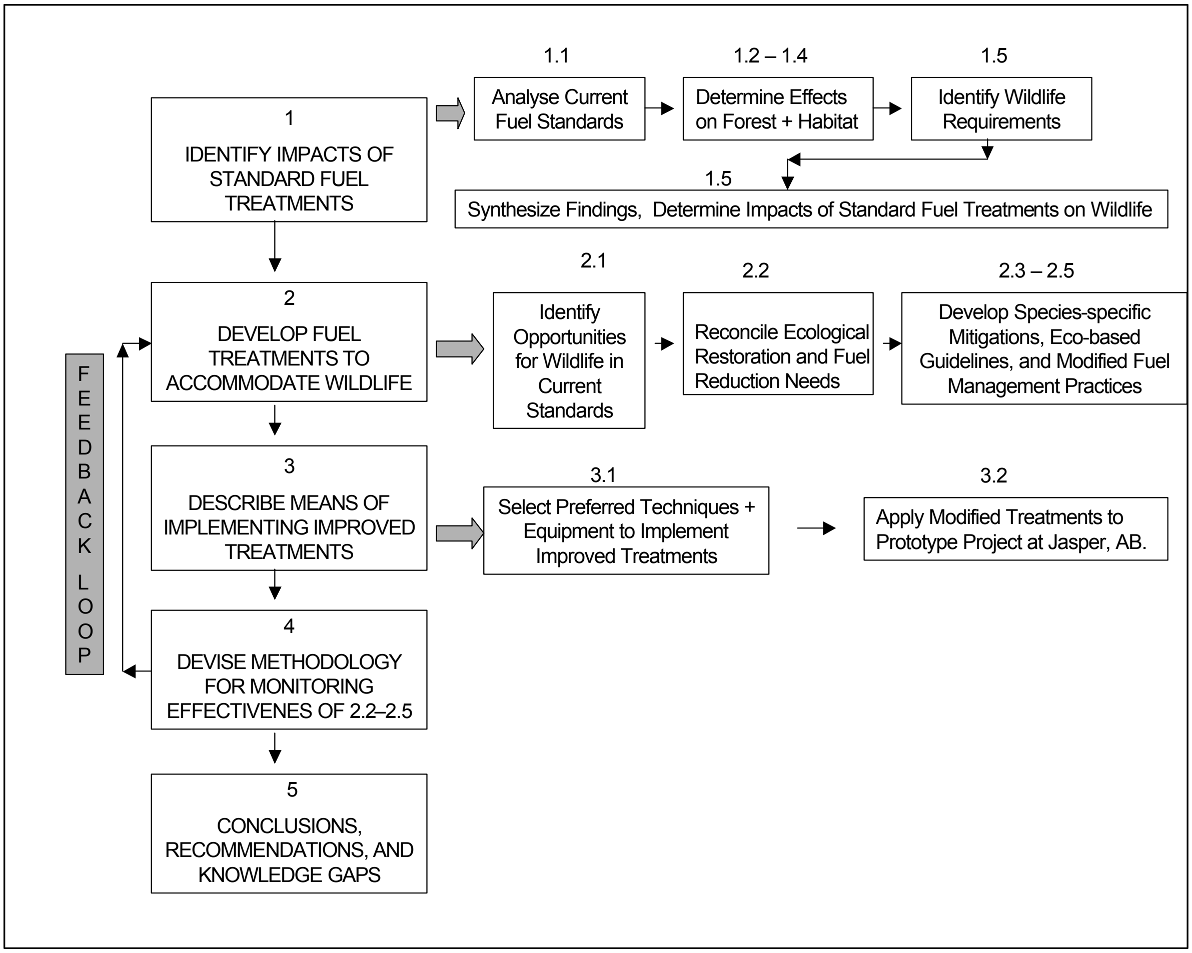


Figure 3—Schematic of research methods.

Cohen and Stratton 2003) were reviewed at the onset of the study. This was done to avoid violating the intent or efficacy of existing fuel treatment standards when proposing more environmentally sensitive methods. FireSmart standards were dissected and reorganized in relation to six horizontal fuel bed layers as described by Sandberg and others (2001) to facilitate a logical review of the ecological effects of fuel treatments and practical presentation of improved methods (table 1). For biological reasons, Sandberg's ground fuel stratum (2001) was sub-divided into fine and coarse woody fuels, and the tree canopy sub-divided into overstory and understory, thus creating eight layers in this study.

Extensive literature reviews were conducted to identify potential impacts of fuel treatments on abiotic forest components such as insolation, temperature, wind flow, effective precipitation, relative humidity, soil moisture, and soil nutrient status. Literature was also surveyed about the habitat roles of each fuel bed stratum to help predict the direct and/or indirect effects of fuel treatments on each of these. Existing literature was reviewed to determine how fuel management treatments alter important habitat features. We chose habitat trees, forest edge, coarse woody debris, and wildlife corridors as important habitat attributes, and grasslands, aspen forest, and wetland/riparian areas as being significant habitat types. Next, we identified the potential impacts of fuel treatments on 41 species of wildlife common to the interface. Selected species included four cavity excavators, eight songbirds, six raptors, 12 small mammals, one bat, six carnivores, three ungulates, and one amphibian.

Table 1—Fuel bed layers (from Sandberg and others 2001) used to assess wildlife habitat impacts and develop mitigation techniques.

Fuel bed strata	Characteristics
1. Ground fuel stratum	Duff or organic soil horizons, roots, and buried wood. Generally, ground fuels are consumed by long duration smoldering fire, after passage of the flame front characteristic of surface and crown fires.
2. Moss-lichen-litter stratum	"Fine" fuels consisting of bryoids and loose undecayed needles and leaves. These fuels burn during flaming and glowing combustion phases of surface fires.
3. Woody fuel stratum	Fine (<0.76 cm), medium (0.76 to 7.5 cm), and coarse (>7.5 cm) woody material on, or in contact with, the ground; may be sound or rotting, and arranged individually (stumps), loosely, or in piles.
4. Low vegetation stratum	Grasses and herbs. Cured fine fuels burn quickly contributing to surface fire intensity, but not to fire residence time.
5. Shrub stratum	Dwarf shrubs, tall shrubs, and coniferous regeneration. Burn vigorously in surface fires to increase fire intensity depending on fuel moisture content. These fuels serve as connecting "fuel ladders" and transmit surface fire into the canopy.
6. Tree canopy stratum	Crown or "aerial" fuels consisting of live and dead trees (needles and branches <0.76 cm) and arboreal lichens. Continuous, high density, canopies lead to crown fire and ember spotting.

Current fuel reduction standards were examined, by fuel bed layer and interface Priority Zone, to discern prospects for incorporating measures that could improve wildlife and habitat quality, or at least reduce adverse impacts, without reducing effectiveness of fuel treatments. Literature pertaining to forest health, natural disturbance, and ecological restoration was then surveyed to establish possible linkages with vegetation manipulation for fire protection purposes.

Once potential mitigations for protection of wildlife and habitat were identified, these were incorporated into prototype fuel treatments and presented in the form of "prescriptions." Unique prescriptions were developed for each forest type in the study area. To aid in assessing the practicability of the prototype fuel treatments they were first applied at several 0.5 to 1.5 ha "demonstration sites." Initially, Parks personnel worked with resident volunteers during neighborhood "work-bees" to implement fuel treatments. Later, between April 2003 and October 2005 these treatments were refined and applied on much larger areas around the town of Jasper, by specialized timber firms under contract to Parks Canada.

Results

Detailed information about FireSmart fuel standards, literature reviews, and step-wise analyses of impacts of fuel treatments on abiotic forest components and biological attributes of fuel beds, and the impacts of fuel treatments on 41 species of birds, mammals, and amphibians common to wildland/urban interface areas are found in Westhaver (2006), which also provides the results of an analysis to identify opportunities for accommodating wildlife and habitat attributes in each forest/fuel bed stratum (within the constraints of current fuel treatment standards). See Westhaver also for details of other results of the prototype project not discussed in this paper, including a methodology for long-term monitoring of wildlife and habitat responses to fuel treatments, and assessment of mechanized techniques for implementing large-scale fuel treatments.

We investigated the potential for achieving ecological restoration concurrent with measures for community wildfire protection. That approach is advocated by several authors (Arno and Wakimoto 1987; Covington and Moore 1994; Fule and others 2001; Brown 2002; Omi and Joyce 2003) but was, to our knowledge, untested in Canada. We found strong similarities between the solutions required to resolve ecological problems in fire-dependent forests such as forest in-growth, forest encroachment, and replacement of deciduous species by conifers, and fire protection issues caused by hazardous fuel accumulations. We judged that, by selectively thinning the forest canopy to restore stand structure and composition to within their historic ranges of variability, the net effect is also to reduce wildfire risk. We also concluded that by using information about historical forest density and structure as a guide to thinning intensity, wildfire risk can be reduced (in some areas) to levels below what could be expected by applying FireSmart standards alone. These overlapping objectives did not extend to even-aged lodgepole pine forests initiated by stand-replacing fires. In these stands, prescribed thinning standards result in habitat conditions that depart from historic norms, but may still benefit wildlife. For example, marten may find more meadow vole prey within thinned stands, but the density of red squirrels in the interface zone is likely to be less than found during pretreatment levels.

Numerous opportunities for maintaining or enhancing wildlife conditions within constraints of current fuel treatments were identified after examining FireSmart standards. Due to stricter needs for fuel removal close to structures, opportunities increased with increasing distance from structures. Five strategies were identified for managing the forest canopy to benefit wildlife: (1) variations of single-tree thinning, (2) cluster thinning, (3) selective preservation of habitat trees, (4) stand type conversion, and (5) selection for prevention of posttreatment windthrow. The opportunity analysis was carried out through other fuel bed/forest layers and yielded many more wildlife prospects in treated fuels (Westhaver 2003).

Species-Specific Mitigations for Wildlife and Habitat Conservation

A key result of this study was to synthesize information about the life/habitat needs of wildlife common to the interface and identify mitigations to minimize the impact or obtain wildlife benefits within the context of current fuel treatments. A sampling of that content from Westhaver (2006) is provided in table 2. This synthesis resulted in a variety of species-specific conservation measures to minimize adverse impacts to wildlife or, alternatively, optimize wildlife benefits from fuel management treatments. Overall, we suggest that protection of habitat trees, coarse woody debris, and structural diversity within stands are the most significant mitigation factors. Species-specific mitigations were refined during three operating seasons of the Jasper prototype fuel management project to ensure their practicability. The full set of wildlife habitat requirements and mitigations are summarized in seven tables, grouped by species with similar habits and life requirements, and are presented in Westhaver (2006).

Ecosystem Based Fuel Management Guidelines – by Priority Zone and Fuel Bed Strata

For each interface Priority Zone and within each of the eight fuel bed strata, we developed and field-tested ecosystem based fuel treatment guidelines for benefits to wildlife or reducing potential adverse impacts of fuel management activities. Once again, these guidelines respect the overriding principle that FireSmart standards for reducing fire intensity be followed.

In Priority Zone 1, these guidelines provided for preserving or planting deciduous trees to provide important seasonal habitat, measures to allow selective retention of existing snags and creating additional snags by topping mature conifers, suggestions for preserving "feature" trees while reducing ignition potential, managing native shrubs to optimize forage, shade, and cover for wildlife, cultivating fire-resistant ground covers, and preserving isolated logs.

Even more extensive opportunities for accommodating wildlife are possible in Priority Zones 2 and 3. Guidelines were provided that recommend retention of all deciduous trees and offer a series of principles to preserve long-term wildlife benefits when deciding which conifers to retain or remove from mixedwood or pure conifer stands. Guidelines to identify and preferentially retain long-lived tree species and individuals with windfirm traits are presented. Trees with twin, multiple, and broken tops or fire scars should be retained since these deformities, and associated decay, make these trees highly suitable for wildlife nesting, roosting, and feeding sites. Exceeding the single-tree spacing standards is recommended to create forest gaps or open

Table 2—Example habitat requirements and mitigations to minimize impacts of fuel management or obtain benefits for interface wildlife.

Species	Habitat Requirements	Mitigations to Minimize Impact or Obtain Benefits
Pileated Woodpecker	Widespread but relatively uncommon year round resident of most Canadian forests; has a large territory; needs minimum 33 cm Diameter at Breast Height (DBH) snags or live trees with decay for excavating nests and roosts; ants and insects in trees and logs are main year round food; uses live hollow or decaying trees for drumming; attracted to sheltered clumps of dead trees and downed logs.	Retain a mix of forest ages and types in the region; retain 12-15 snags and 12-15 living trees with decay (legacy trees) per ha of all diameters, species and sizes with bias towards large diameter (>33 cm DBH) trees; broken-top trees most important; use cluster thinning technique to retain cover adjacent habitat trees; retain trees infested with ants/insects; retain up to 50 logs/ha on ground (long and large is best) and extra snags for forage and future downed logs; keep tall stumps of all sizes; survey areas for active use by woodpeckers first.
Black-capped Chickadee	Common year-round resident Canada-wide; feed by gleaning insects and insect eggs from bark, twigs, boles, and foliage of trees and shrubs from ground to crowns; seeds, berries augment diet; can excavate nests in rotted wood; use existing cavities/hollow trees; stubs are important nest sites; select nest trees <or= 10 cm. DBH, often in open areas; roost in cavities/dense conifers out of wind.	Retain or create a variety of dead or dying trees of different diameters and species for nesting and foraging; preserve broken-topped trees, even short stubs; thinning will encourage seed sources from native flowering plants and berry production; augment these with planted landscapes around home and/or bird feeders; preserve shelter around habitat trees and small clusters of conifers for roosting out of the wind and rain.
Red-backed Vole	Common in boreal and mountain forest across Canada; closely linked with moist, mossy, mature conifer forest; downed woody material very important for cover; feeds heavily on fungi (mushrooms) associated with decaying wood; also eats seeds, insects, berries; use squirrel middens; key prey items.	Leave abundant coarse woody debris, large logs, small brush piles, and decaying matter to foster fungus foods and provide shelter and moisture; use cluster thinning and protect shrubby understory to preserve pockets of dense forest and shaded sites; limit thinning in moist forest areas where possible; protect squirrel middens.
Weasel	Coarse woody debris provides access to under-snow environments and cover for potential prey species; most common in regenerating forest and grassy areas suited to prey species, residual trees.	Leave abundant coarse woody debris, large logs, and small brush piles where possible to foster abundant prey and provide cover. Leave protruding debris to provide access routes and under snow travel routes; use cluster thinning and protect shrubby understory to preserve pockets of dense forest and shaded sites; protect squirrel middens.
White-tailed Deer	Found across Canada in grassland, parkland and boreal mixedwood; spring/summer diet mostly flowering plants, grasses; browse on deciduous trees and shrubs in winter; mostly inhabit forest edges to feed in open and seek cover in forest/shrubs; small conifer thickets are winter refuge.	Interface areas can provide forest edge favorable to white-tailed deer; encourage and preserve deciduous shrubs and aspen during thinning; open canopy will increase summer forage availability; preserve thickets of coniferous saplings in deciduous/mixedwood forest for cover (remove mature conifers that overtop regeneration to reduce fire spread).

forest habitats that provide habitat diversity while further decreasing fuel continuity, which significantly reduces fire spread rates while increasing ease of fire control. All habitat trees with nests and cavities should be preserved. Wildlife use can be increased by pairing habitat trees with living trees, or by preserving clusters of habitat trees. A minimum of 12 to 15 snags per hectare should be retained for optimal wildlife conditions. In the forest understory, rather than removing all coniferous regeneration, overtopping mature trees can be removed in some cases to provide increased wildlife cover and security while also allowing for long-term tree replacement and seral succession. At least 25 to 350 linear metres of logs should be left on the ground, with preferential protection for older, larger, and more decayed individuals.

"Best Practices": Guidelines for Modified Fuel Management

This study also developed a series of general guidelines for modified fuel practices more sensitive to ecological considerations in the wildland/urban interface. These are not specific to wildlife species or interface priority zone.

Burning of woody debris in many smaller piles is recommended in preference to disposal methods such as chipping and spreading. This encourages nutrient cycling and hastens establishment of native plant cover. Restricting mechanized fuel operations to winter when organic layers are frozen and covered with insulation snow will minimize soil disturbance and disruption of low habitat structure. Curtailing the season and hours of mechanical operations allows wildlife migrations and diurnal movements. We found that key habitats such as forest edge could be enhanced by enlarging and making existing forest openings more irregular in shape, and that knowledge of wildlife habits and local animal movements can be used to preserve existing wildlife corridors or ensure adequate hiding/security cover for animals as they move between foraging sites. We recommend minimal vegetation disturbance around groundwater discharge areas, temporary pools, and moist depressions but compensating for this with adjacent areas of more stringent fuel reduction.

We also produced guidelines for adapting thinning from below methods to Douglas-fire and open lodgepole pine forest types and regimes of frequent fire. These guide tree retention decisions in terms of age, diameter, species, and spacing and utilize large veteran trees as "anchor" points to start the process. Conversely, decision rules were developed to adapt thinning from above methods for use in denser, even-aged lodgepole pine stands to encourage stand/habitat diversity and succession of shade tolerant species. Guidelines for minimizing posttreatment windthrow include selective retention of trees with both lateral and tap root systems, greater height and width of live crown, and low slenderness index along with liberal use of cluster thinning. Detailed guidelines for all types of wildlife trees are provided (Westhaver 2006).

Altogether, the foregoing species-specific mitigations, Priority Zone and fuel bed layer guidelines, and general best practices form a set of ecologically based criteria for modifying current fuel management practices in ways that benefit wildlife, but do not compromise risk-reduction objectives of FireSmart standards.

Discussion

Developing the above guidelines and mitigations by adaptive management approaches, during an operational fuel management project, proved to be an effective method for testing and refining practicable solutions. This approach allowed for continuous exchange between researchers and the manual crews, specialized forestry harvesting contactors, and equipment operators responsible for implementing them. That feedback resulted in many practical improvements. Also, adopting a collaborative approach involving operators and crews improved communications regarding wildlife conservation objectives, and led to a shared interest in achieving positive results. As an example, enthusiastic equipment operators offered up many abilities and mitigative actions that heavy equipment is capable of performing, but fuel managers were unaware.

Our assessment of potential ecological effects of standard fuel treatments revealed that manipulating fuel load, arrangement, and size distribution also resulted in substantial alterations to important wildlife habitat qualities. Specifically, we noted that fuel modification directly or indirectly affected most aspects of forest structure, forest composition, and forest function, and that these effects can lead to a wide range of adverse impacts upon wildlife and wildlife habitat. As a corollary, we also concluded that knowledge of these effects was useful to guide fuel manipulation programs in a more informed way, thus allowing adverse impacts to be avoided and potential wildlife benefits to be realized. We judged that the correlation between fuel bed strata and ecological or habitat layers was strong, and this analogy was useful for organizing, understanding, and presenting the effects of fuel manipulation, as well as developing more holistic fuel treatments.

Existing literature provided sound information about life requirements for wildlife. However, we found that most literature concerning wildlife response to forest disturbance was related to major events such as clearcut logging or wildfire, but there are few studies, and few experimental data, to verify the response of wildlife to fuel treatments that leave significant canopy cover, a less severe form of disturbance. Our forecasts of potential impacts of fuel treatments were hampered by this knowledge gap. Future wildlife studies in fuel treatments would be beneficial; in aid of this, pretreatment sampling of small mammal and ungulate activity was conducted in permanent 90 x 90 m grids (Westhaver 2006).

The ability to provide benefits for habitat and wildlife varies between vegetation and fuel types. For example, it is desirable to preserve an ongoing supply of snags of all structural forms (Bull and others 1997), in a variety of topographic positions, and with a range of adjacent cover (Brittingham and De Long 1998). However, we found that the ability to do so was significantly limited in even-aged lodgepole pine stands, whereas opportunities to meet these objectives were plentiful in mixed conifer and Douglas-fir forest types. Forest edge can be increased or decreased during fuel treatments by varying the pattern and degree of canopy thinning, creating or augmenting forest openings, and aligning treatments with topographic or soil type boundaries. However, the utility of artificially created openings and edges is poorly known.

Study Limitations and Knowledge Gaps

This and other attempts to develop ecologically based fuel treatments will continue to be hampered until more field studies to scientifically assess the effects of fuel treatments and the responses of habitat and wildlife are conducted. In aid of this, a fixed plot sampling methodology for monitoring long-term changes in vegetation conditions and wildlife use was developed and put into place prior to fuel manipulations at Jasper (Westhaver 2006). Followup studies are strongly recommended in this prototype area, and other locations, to help fill current knowledge gaps. Aside from limitations that result in applying literature from other forest disturbances that are similar, but not identical to fuel treatments, are limitations that may result from conclusions drawn from studies conducted in similar but different ecosystems.

Given that this study was partly motivated by perceived conflicts between fuel treatments and other values held by interface residents, it is advisable that sociological research be initiated to determine if the improved treatments described by this study are, in fact, more acceptable to these people. We also suggest that, due to the great importance of coarse woody debris for wildlife, studies be directed at better determining threshold levels of debris that can be retained for wildlife purposes without compromising fire protection objectives.

Through this research, we are hopeful that wildland and municipal fire managers will augment the dominant viewpoint of "vegetation as fuel" with a more holistic perspective of vegetation as the basis for wildlife populations and other social or ecological values held by interface residents. In this way concerns of interface residents can be addressed, and a significant barrier to fire prevention actions removed.

Acknowledgments

The authors thank Parks Canada and the Foothills Model Forest for encouraging this research, a component of a large-scale operational undertaking called the *FireSmart – ForestWise Communities Project* in Jasper, Alberta. Our sincere gratitude goes to many local stakeholders who provided encouragement, provoked ideas, and shared in the passion of this project. We are indebted to Brian Wallace, Kevin Van Tighem, and Ron Hooper of Jasper National Park, and to Don Podlubny of the Foothills Model Forest. Our particular thanks go to the gifted field supervisors and members of field crews from the Metis Nation of Alberta, to the exceptional people from the forest industry, and especially to FireSmart Technicians Clayton Syfchuck, Mike Suitor, and Lorraine Wilkinson. Drs. Cormack Gates, Darren Bender, Bill Ross, Michael Mc Mordie, and Pauline Fisk of the University of Calgary provided invaluable support and feedback during this research. Above all, the lead author wishes to express his great appreciation to Lisa, Heather, Robin, and Theresa Westhaver for their loving support and patience throughout this adventure.

References

Achuff, P.L. 1996. Fire in the Rocky Mountain National Parks. Unpublished Parks Canada Paper presented at the National Prescribed Fire Workshop, La Maurice National Park. 19 p.

Andison, D.W. 2000. Landscape level fire activity on foothills and mountain landscapes of Alberta. Bandaloop Landscape-Ecosystem Services. Foothills Model Forest. Ecology Research Series, Report No. 2.

Arno, S.F.; Wakimoto, R.H. 1987. Fire ecology of vegetation common to wildland homesites. In: Fischer, W.C. and S.F. Arno, compilers. 1987. Protecting People and Homes From Wildfire in the Interior West. Proceedings. Gen. Tech. Rep. 251. Ogden, UT: U.S. Department of Agriculture, Forest Service. Intermountain Research Station. 213 p.

Blackwell, B.A.; Mortimer, D. 2004. Jasper National Park municipal wildfire protection strategy. Final Report. Prepared by B.A. Blackwell and Associates and FireLine Consulting and Instruction Ltd. for Jasper National Park. Internal report.

Bothwell, P. 2006. Unpublished data. Fire Research Officer, Canadian Forest Service, Northern Forestry Centre, Edmonton, Alberta.

Boura, J. 1996. Fire and biodiversity: the effects and effectiveness of fire management. Biodiversity Series, Paper No. 8. 9p. http://www.environment.gov. au/life/general_info/biodiver_8/paper22.html, accessed May, 2005.

Brenkert, H.; Champ, P.; Flores, N. 2005. Mitigation of wildfire risk by homeowners. Res. Note RMRS-RN-25. Fort Collins, CO. U.S. Department of Agriculture, Forest Service. Rocky Mountain Research Station. 9 p.

British Columbia. Office of the Auditor General. 2001. Managing interface fire risks. Report; 2001/2002:1. 111 p.

Brittingham, M.C.; De Long, C.A. 1998. Management practices for enhancing wildlife habitat. Pennsylvania State University. College of Agricultural Sciences, Cooperative Extension. 10 p.

Brown, R. 2002. Thinning, fire, and forest restoration: a science-based approach for National Forests in the Interior Northwest. Washington, DC: Defenders of Wildlife. 40 p.

Bull, E.L.; Parks, C.G.; Torgersen, T.R. 1997 Trees and logs important to wildlife in the interior Columbia River Basin. Gen. Tech. Rep. PNW-GTR-391. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 55 p.

Byram, G.M. 1959. Combustion of forest fuels. Chapter 1: 61 – 89. In: Davis, K.P. (ed.). Forest fire control and use, 2nd edition. New York: McGraw-Hill.

Canadian Intergovernmental Conference Secretariat. 2005. Backgrounder: Canadian Wildland Fire Strategy Declaration, Canadian Council of Forest Ministers. 3 p. Ref: 830-858/005. http://www.scics.gc.ca/cinfo05/830858005_e.html Accessed January, 2006.

Canadian Forest Service. 1968. Canadian forest fire danger rating system, fire behavior prediction system (FBP) component.

Carnell, D.; Anderson, G. 1974. Proposal for the development of a fire protection zone around Jasper town site. Jasper Warden Service. Unpublished.

Cohen, J.D. 2000a. Examination of the home destruction in Los Alamos associated with the Cerro Grande fire. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Cohen, J.D. 2000b. Preventing disaster: home ignitability in the wildland/urban interface. Journal of Forestry 98(3): 15-21.

Cohen, J.D.; Stratton, R. 2003. Home destruction within the Hayman fire perimeter. In: Graham, R.T. (tech ed). 2003. Hayman Fire case study. Gen. Tech. Rep. RMRS-GTR-114. Ogden, UT:. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 396 p.

Countryman, C.M. 1974. Can Southern California conflagrations be stopped? Gen. Tech. Report. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station.

Covington, W.W.; Moore, M.M. 1994. Post-settlement changes in natural fire regimes and forest structure: ecological restoration of old-growth ponderosa pine forest. In: Sampson, R. Neil: Adams, D.L., (eds.) Assessing forest ecosystem health in the inland West. New York: The Haworth Press Inc.: 153–181.

Cruz, M.G.; Alexander, M.E.; Wakimoto, R.H. 2002. Predicting crown fire behavior to support forest fire management decision-making. In: Forest fire research and wildland fire safety. Rotterdam, Netherlands: Millpress.

Daigle, P. 1996. Fire in the dry interior forests of British Columbia. Ministry of Forests Research Program. Extension Note #8. Victoria, BC, Canada: British Columbia Ministry of Forests. 6 p.

DeSorcy, G.J. 2001. Chisholm fire review committee: Final report. Commissioned by Alberta Sustainable Resource Development. 50 p.

Duke, D.L. 2001. Wildlife use corridors in the Central Canadian Rockies: multivariate use of habitat characteristics and trends in corridor use. M.Sc. Thesis. Edmonton, Alberta, Canada: University of Alberta. Department of Biological Sciences.

Duke, D.L.; Quinn, M.; Butts, B.; Lee-Ndugga, T.; Wilkie, K. 2003. Spatial analysis of rural residential expansion in Southwestern Alberta. Calgary, Alberta, Canada: University of Calgary, Miistakis Institute for the Rockies. 49 p.

Fenton, G. 1986. Pyramid bench fire protection plan. Jasper Warden Service. Unpublished. Park. Internal Report. 300 p.

Filmon, G. 2004. Firestorm 2003, provincial review. Report to the Provincial Government of British Columbia. Gary Filmon, Chair. 100 p.

FireLine Consulting and Instruction. 1997. Inter-park hazard evaluation project: Prairie and Mountain Parks. Report to Parks Canada – Western Fire Management Centre.

Flannigan, M.; Stocks, B.; Wotton, M. 2003. Climate change and boreal fire activity: fact sheet 9. Sault Ste. Marie, Ontario, Canada: Natural Resources Canada, Canadian Forest Service, Great Lakes Forestry Centre. http://www.nofc.forestry.ca/climate/en/factsheets/factsheet9_e.html

Flannigan, M.; Wotton, M.; Carcaillet, C.; Richard, P.; Campbell, I.; Bergeron, Y. 1998. Fire weather: past, present and future. In: Proceedings of the 3rd International Conference of Forest Fire Research and the 14th Conference Fire and Forest Meteorology. Vol. 1: 113-128.

Forestry Canada Fire Danger Group. 1992. Development and structure of the Canadian forest fire behavior prediction system. Information Report ST-X-3. 63 p.

Fuglem, P. 2004. Personal communication. Victoria, British Columbia, Canada: Director, British Columbia Ministry of Forests, Protection Program.

Fule, P.Z.; McHugh, C.; Heinlein, T.A.; Covington, W.W. 2001. Potential fire behavior is reduced following forest restoration treatments. In: Ponderosa pine ecosystems restoration and conservation: steps toward stewardship. Compiled by R.K. Vance, C.B. Edminster, W.W. Covington and J.A. Blake. Proceedings RMRS-P-22. Fort Collins, CO: U.S. Department of Agriculture, Forest Service. Rocky Mountain Research Station.

Graham. R.T. (tech ed). 2003. Hayman Fire case study. Gen. Tech. Rep.. RMRS-GTR-114. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Stations. 396 p.

Graham, R.T.; McCaffrey, S.; Jain, T.B. (tech ed). 2004. Science basis for changing forest structure to modify wildfire behavior and severity. Gen. Tech. Rep. RMRS-GTR-120. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 43 p.

Hammond, H. 2003. Technical review of FireSmart – ForestWise Methods Jasper National Park. Unpublished Parks Canada report by Silva Ecosystem Consultants Ltd. Slocan Park, British Columbia. 33 p. and follow-up letter report to Parks Canada, Jasper. January, 2006.

Haney, B.; Anderson, G. 1978. Proposal for reduction of forest fire fuel hazards bordering Jasper townsite. Jasper Warden Service. Unpublished report.

Heitzmann, R.J. 2001. In: Collection of Papers from the 33rd Meeting of the Canadian Archeological Assoc. Edited by Jean-Luc Pilon. Ontario Archeological Society.

Holland, W.D.; Coen, G.M. (gen ed). 1982. Ecological (Biophysical) Land Classification of Banff and Jasper National Parks. Volume II: Soil and Vegetation Resources. Publication No. SS-82-44. Alberta Institute of Pedology.

Holroyd, G.L.; Van Tighem, K.J. 1983. Ecological (Biophysical) Land Classification of Banff and Jasper National Parks. Volume III, Parts A and B: The wildlife inventory. Edmonton, Alberta, Canada: Canadian Wildlife Service. 667 p.

Jasper Interface Steering Team. 2002. Unpublished meeting minutes of the resident's wildland/urban interface advisory group. Monthly meetings. Jasper, Alberta.

Kootenay National Park. 2002. Environmental assessment for the Redstreak ecological restoration in Kootenay National Park. Resource Conservation file report. 36 p.

Kotliar, N.B.; Hejl, S.J; Hutto, R.L.; Saab, V.A.; Melcher, C.P.; McFadzen, M.E. 2002. Effects of fire and post-fire salvage logging on avian communities in conifer-dominated forests of the Western United States. Studies in Avian Biology 25:49 – 64.

La Morte and Associates. 1996. Risk assessment of fir management alternatives: Mountain Parks, Parks Canada. Final report. Victoria, British Columbia. 65 p.

Martinson, E.J.; Omi, P.N. 2003. Performance of fuel treatments subjected to wildfires. In: Omi, P. N. and L.A. Joyce, tech ed. 2003. Fire, fuel treatments, and ecological restoration: conference proceedings. Proceedings RMRS-P-29. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 475 p.

McCaffrey, S. 2004a. Fighting fire with education: What is the best way to reach out to homeowners? Journal of Forestry. July/August 2004: 12-19.

McCaffrey, S. 2004b. What factors are most important in shaping the views of residential-wildland intermix homeowners about wild hazard and fuels management? In: 2nd symposium on fire economics, planning and policy: a global view. Cordoba, Spain, April 19 – 22, 2004.

McGee, T.; McFarlane, B.; Varghese, J. 2005. An exploration of wildfire risk reduction within communities directly affected by the Lost Creek fire in 2003. Foothills Model Forest Final Report. 19 p.

Mercer, G.; Purves, H. 2000. An initial assessment of wildlife movement corridors in the Three Valley Confluence of Jasper National Park. Warden Service Report. Unpublished. November, 2000. 32 p.

Mitchell, M.P. 2005. Montane landscape heterogeneity and vegetation change in Jasper National Park (1949-1997). M.Sc. thesis. Prince George, British Columbia, Canada: University of Northern British Columbia. 132 p.

Mortimer, D. 1998. Town of Jasper interface protection project, Jasper National Park. Fireline Consulting and Instruction. Report prepared for Parks Canada. 65 p.

Mortimer, D. 1999. Lake Edith cottage development facility protection project, Jasper National Park. FireLine Consulting and Instruction. Report prepared for Parks Canada. 65 p.

Mutch, R.W. 1994. Fighting fire with prescribed fire: a return to ecosystem health. Journal of Forestry. 92(11): 31-33.

National Fire Protection Association. 2002. NFPA 1144 – Standard for protection of life and property from wildfire, 2002 edition. NFPA. Batterymarch Park, MA. 19 p.

Natural Resources Canada. 2005. Canadian Forest Service – Viewpoint: a new wildland fire strategy for Canada. 3 p. http://www.nrcan.gc.ca/cfs-scf/national/what-quoi/viewpoint/index_e.php?ArticleId=221. Accessed January, 2005.

Parks Canada. 2000. Jasper National Park of Canada management plan. Catalogue Number R64-105/28-2000E. Ottawa, Canada: Minister of Public Works and Public Services Canada. Department of Canadian Heritage. 78 p.

Partners in Protection. 2003. FireSmart: Protecting your community from wildfire. Second Edition. Edmonton, Alberta, Canada: Capital Color Press Ltd.

Quintilio, D. 2005. Presentation to the Jasper Interface Steering Team, March 14, 2005, Jasper, Alberta.

Ralf, R.; Bradford, W. 1998. Bear/human conflict management plan, Jasper National Park. Internal Report, Warden Service. 65 p.

Rhemtulla, J.M. 1999 Eighty years of change: the Montane vegetation of Jasper National Park. M.Sc. Thesis. Alberta, Canada: University of Alberta.

Sandberg, D.V.; Ottmar, R.D.; Cushon, G.H. 2001. Characterizing fuels in the 21st century. International Journal of Wildland Fire 10: 381-387.

Scott, J.H.; Reinhardt, E.D. 2001. Assessing crown fire potential by linking models of surface and crown fire behavior. Res. Paper RMRS-RP-29. Fort Collins, CO. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 59 p.

Tande, G.F. 1979. Forest fire history around Jasper townsite, Jasper National Park, Alberta. M.Sc. Thesis. Alberta, Canada: University of Alberta. 169 p.

U.S. Department of Agriculture, Forest Service. 2005. A strategic assessment of forest biomass and fuel reduction treatments in Western States. Gen. Tech. Rep. RMRS-GTR-149. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 17 p.

Van Wagner, C.E. 1977. Conditions for the start and spread of crown fire. Canadian Journal of Forest Research. 7: 23-24.

Walters, C.; Holling, C.S. 1990. Large-scale management experiments and learning by doing. Ecology 71: 2060-2068.

Westhaver, A.L. 2003. Environmental Screening Report. *FireSmart – ForestWise* community protection and forest restoration project; Foothills Model Forest, Jasper National Park. Park Registry File J03–004. Jasper National Park. April, 2003. 81 p.

Westhaver, A.L. 2006. FireSmart – ForestWise: Managing wildlife and wildfire risk in the wildland/urban interface. M.Sc. thesis. Alberta, Canada: University of Calgary, Faculty of Graduate Studies, Resources and Environment Program. 224 p.

White, C.A. 2001. Aspen, elk, and fire in the Canadian Rocky Mountains. Ph. D Thesis. Faculty of Graduate Studies. Department of Forestry. University of British Columbia.

Wierzchowski, J.; Heathcott, M.; Flannigan, M.D. 2002. Lightning and lightning fire, Central Cordillera, Canada. International Journal of Wildland Fire. 11, 41-51.

Winter, G.; Vogt, C.; Friedy, J.S. 2002. Fuel treatments at the wildland/urban interface: common concerns in diverse regions. Journal of Forestry. January/February 2002: 15-21.

Winter, G.; Vogt, C.A.; McCaffrey, S. 2004. Examining social trust in fuels management strategies. Journal of Forestry. September 2004: 8-15.