CPAWS
CANADIAN PARKS AND WILDERNESS SOCIETY
SOUTHERN ALBERTA CHAPTER

Does Logging Stop Fire?

An Examination of Forest Fire Risk in Relation to Clearcut Logging on the Southern Eastern Slopes of Alberta

CPAWS Southern Alberta, 2020

1 Fire and Logging in the Southern Eastern Slopes of Alberta

Logging practices in which most or all of the trees in specified areas of older forests are cut down (i.e., clearcut logging) are often justified on the grounds that removing these mature trees reduces the potential of catastrophic fire that may be threatening forest production and human developments. However, this assumption is rarely backed up with peer-reviewed literature and cannot be applied uniformly across all forests or landscapes. Weather, climate, forest type, natural fire regime, and past forest management all influence the effectiveness of fire management (Hesseln, 2018; Lindenmayer et al., 2009).

1.1 Natural Fires in the Southern Eastern Slopes of Alberta

Fire is an important natural disturbance in most of Canada's forests, and has been integral in maintaining the biodiversity of these ecosystems since the last ice age (Hirsch et al., 2001). Wildfires are important for sustaining ecosystem services such as stimulating vegetation regeneration, promoting diversity of vegetation types, and creating habitat for many species that would not exist without fire (Moritz et al., 2014). Severe fire is not necessarily ecologically catastrophic, but rather a natural mechanism of renewal and diversity (Schoennagel et al., 2016).

However, despite the ecological importance of wildfires, their impacts can be devastating for human societal values and communities, single-species conservation, or resource management (Hirsch et al., 2001). Thus, it is important to understand the factors that affect fire on Alberta's landscape, specifically the Southern Eastern Slopes, and to critically assess the commonly used assertion that clearcut logging reduces fire risk in this landscape.

Alberta's boreal forest,foothills, and montane forests of the Southern Eastern Slopes are historically fire disturbance-dominated systems. As such, logging is commonly referred to as emulating fire on this landscape, and reducing the subsequent risk of wildfire. However, logging does not emulate fire as a disturbance (Cyr et al., 2009; Lindenmayer et al., 2009; Long, 2009; Nitschke, 2005). The impacts of logging on water, wildlife, vegetation, and landscape structure differ from the influence of fire on these systems (Brassard & Chen, 2008; Buddle et al., 2006; Cumming, 2001; Cyr et al., 2009; Drapeau et al., 2000; Durall et al., 2006; Hart & Chen, 2008; Long, 2009; Narayanaraj & Wimberly, 2012; Nitschke, 2005; Schieck & Song, 2006). For a full discussion of the difference between fire and logging, see the other paper in this series titled, *Does Logging Emulate Fire?*

The purpose of this paper is to discuss the assertion that is commonly used as justification for logging: that clearcuts mitigate the risk of wildland fire. For the forests of the Southern Eastern Slopes of Alberta, this justification is unsupported by science, as reviewed and discussed below.

1.2 Logging as a Fire Management Strategy in the Southern Eastern Slopes of Alberta

In this summary paper, literature was examined from similar coniferous-dominated forests to that of Southern Alberta to determine the effectiveness of logging in controlling wildfire risk. Does logging decrease fire frequency, extent, and/or severity while maintaining natural forest age patterns and ecosystems on the landscape? It is standard practice in research to make generalizations across similar ecosystems from research conducted in specific locations.

In general, logging can influence wildfire frequency, extent, and/or severity under certain conditions. Logging does not, however, decrease the risk of subsequent wildfire, and, as Krawchuk & Cumming (2009) show, logging can actually **increase** wildfire risk. Depending on the forest type and climate in the area, the relative importance of weather and fuel on wildfire behaviour may differ. In boreal pine-spruce-fir systems, fire initiation, spread, and intensity are determined more by weather and forest type than by other factors, such as forest age or structure (Bessie & Johnson, 1995; James et al., 2011; Johnson et al., 2001). Additionally, slope and aspect are primary determinants of wildfire initiation and spread. Although logging can sometimes influence wildfire, there are other factors that are substantially more important, as discussed below.

2 Factors Affecting Wildfire Risk in the Southern Eastern Slopes of Alberta

We examined a number of factors outlined in the fire ecology literature in relation to their likelihood to affect forest fire frequency, extent, and severity. Table 1 summarizes these factors and the applicability of each factor to the Southern Eastern Slopes. Further details are provided in the sections below.

Table 1: Summary of factors potentially affecting wildfire frequency, extent, and severity on the Southern Eastern Slopes of Alberta

Factor	Influence of Factor on Fire Risk	Effect of Logging on the Factor
Weather	Likely the greatest effect on wildfire in the Southern Eastern Slopes. Hot, dry, windy conditions increase fire ignition and spread (Bessie & Johnson, 1995). Climate change has emerged as an important driver of increased forest fire activity (Flannigan et al., 2009), as the climate shifts toward higher than average spring and summer temperatures and drier than average summers in this region (IPCC, 2014), causing	Logging does not have a direct impact on weather. However, clearcut areas are hotter and drier than adjacent older forests (Aussenac, 2000). As a consequence, they likely accentuate the effects of weather on fire. Forest thinning has a similar unintended effect in that ground fuels get hot and dry

	increased drying of forest fuels (Abatzoglou & Williams, 2016).	from exposure to sun, instead of the generally cool, mossy surface of un-thinned stands.
Forest type	Coniferous forests are more likely than deciduous forests to have more frequent and higher intensity fires (Cumming, 2001; Krawchuk et al., 2006). Forests on the Southern Eastern Slopes are largely coniferous-dominated (Downing & Pettapiece, 2006).	Clearcut logging could influence the current or historical forest type, depending on the species that are planted or come up following the disturbance.
Forest fuels (amount and size of woody debris)	Fine to medium fuels play an important role in the rate and intensity of fire spread (Bessie & Johnson, 1995). The amount of fine fuels in a coniferous forest becomes relatively stable after the forest reaches approximately 20 years of age (Johnson et al., 2001).	Clearcut logging increases fine and medium fuel debris on the ground, potentially increasing wildfire risk (Krawchuk & Cumming, 2009).
Forest age (successional stage)	Young (early succession) forests are typically denser, which can affect wildfire spread and severity (Bigler et al., 2005; Krawchuk & Cumming, 2009). In the Southern Eastern Slopes, both old and young forests are coniferous-dominated, contain fine fuels and support crown fires.	Regrowth of dense stands of pine or spruce saplings after logging can create more available fine fuels. Young, dense forests after regeneration of logged areas may increase area burned and risk of fire (Lindenmayer et al., 2009; Song, 2002). One way in which logging may be found to lower the risk of fire following harvest, is if stands are replanted at a lower density. However, this is not often the case.
Changes to microclimate	In some forests, the opening of forest clearings and edge habitat can change the microclimate (Lindenmayer et al., 2009). While this effect is important in moist forests, it is likely not a large factor in fire risk in the forests of the Southern Eastern Slopes. However, there is little peer-reviewed research investigating this effect in this locale.	Removal of trees through clearcutting creates new, significantly large openings in the forest canopy. This exposes understory vegetation and debris to increased drying, subsequently increasing the risk of fire (Lindenmayer et al., 2009).

Roads	Road networks increase the number of human-caused ignition points and therefore the number of human-caused wildfires (Narayanaraj & Wimberly, 2012). It is unclear whether the overall effect of roads increases the number of large, high intensity fires or mitigates large fires through faster fire response.	Logging increases the density of roads on a landscape (Lamb et al., 2018), thereby increasing the access and the number of potential ignition points.

2.1 Weather

Weather conditions are the most important factor in assessing fire risk. Bessie and Johnson (1995) found that in subalpine forests, which make up approximately 50 percent of the forests of the Southern Eastern Slopes of Alberta (Downing & Pettapiece, 2006), weather has a greater influence on fire than does fuel or forest composition. Under extreme fire conditions (high-heat, low-moisture, and wind), crown fires will initiate from all surface fires in subalpine forests, regardless of variation in fuels (Bessie & Johnson, 1995).

The majority of area burned in Canada can be attributed to few large fires (Hirsch et al., 2004). For example, in the Southern Canadian Rockies (Southern Eastern Slopes), extreme fire conditions account for 99 percent of area burned in subalpine forests (Bessie & Johnson, 1995), and total area burned is only expected to increase as fire weather becomes more extreme due to climate change (Erni et al., 2018; Schoennagel et al., 2016). Given the coniferous dominance and relatively low diversity of forest types in the montane and subalpine forest eco-regions of the Southern Eastern Slopes (Downing & Pettapiece, 2006), it is likely that weather is a more important factor in determining fire risk in this landscape than forest type or age (Bessie & Johnson, 1995; Moritz et al., 2018).

Climate change has emerged as an important driver of increased forest fire activity as the climate shifts toward higher than average spring and summer temperatures, and drier than average summers in the Southern Eastern Slopes region (Abatzoglou & Williams, 2016; Harvey, 2016; Prichard & Kennedy, 2014). Abatzoglou and Williams (2016) state that human-caused climate change has lengthened the annual fire season (i.e., the window of time each year with weather that is conducive to wildland fires) in North America, and suggest that based on the effects of human-caused climate change, the total area in the western United States that has burned in the last three decades is double what would have burned due to natural climate drivers alone . Given the similar geographic region and forest types, similar trends likely exist in southern Alberta. Increases of 74-118 percent in wildfire season length, fire severity, and area burned in Canadian forests have been projected by the end of the century (Flannigan et al., 2005, 2009). It is particularly important under a changing climate to understand and incorporate climate change modelling, disturbance scenarios, and landscape changes into forest management planning.

2.2 Forest Type

In addition to weather, forest type is one of the most important factors in determining fire rate of spread and severity (Cumming, 2001; James et al., 2011). Coniferous forests, regardless of age, are more likely to have more frequent and higher intensity fires than deciduous-dominated forests (Cumming, 2001; Krawchuk et al., 2006), due in large part to difference in foliage characteristics, sap, and debris. The forests of the Southern Eastern Slopes are mainly coniferous-dominated montane or subalpine forests (Downing & Pettapiece, 2006). In addition to weather, forest type largely influences the spread of wildfire, as it is the main indicator of forest fuels; both availability and moisture of forest fuels influence the spread of fire.

2.3 Forest Fuels

Forest fuels, which are largely affected by forest type, are another important factor influencing wildfire. Fires in boreal and subalpine forests easily increase in intensity to become crown fires because of the trees' low crown height, dead lower branches, distribution of needle-bearing branches from ground to canopy, and low moisture of needles compared with deciduous leaves (Johnson et al., 2001). While older forests do have a higher amount of large fuels that influence the intensity of crown fires, fine, dead, and cured fuels actually play a larger role in the spread rate of fires on the front line (Bessie & Johnson, 1995; Cumming, 2001; James et al., 2011; Long, 2009). While total biomass increases with forest age and trees grow larger, the spread of wildfire is primarily influenced by the burning of fine-to-medium sized fuels which are mostly stable after the forest has reached approximately 20 years old (Johnson et al., 2001).

While debris can accumulate in a forest in a number of ways (Brassard & Chen, 2008), forest harvesting increases the amount of fine fuel debris on the ground such as tops, limbs, and un-merchantable stems and logs left on a clearcut site (Krawchuk & Cumming, 2009). While leaving logging debris and slash on site is important for soil stability and providing wildlife habitat (Baxter, 2002), it can increase fire hazard in the short term by increasing highly flammable fine fuels (Krawchuk & Cumming, 2009). Due to the unpredictable winds on the Southern Eastern Slopes, burning of slash piles is not a realistic option and may increase fire risk in this region (Baxter, 2002). Where harvesting is considered appropriate to meet ecological values, slash and resulting fire risk must be carefully managed to provide for soil and wildlife needs while reducing fire risk.

Additionally, recent cutblocks and burns can often have a heavy grass fuel-loading, and while grassfire intensity is fairly low, it can remain a hazard because the spread potential is quite high when the grass is fully dried (Krawchuk & Cumming, 2009). For example, in Canadian mixedwood boreal forests, fire following lightning strikes is more likely to occur in harvested areas because of increased fine fuels resulting from logging slash debris and grass fuel types, and this effect can remain for 10-30 years following logging (Krawchuk & Cumming, 2009; Lindenmayer et al., 2009).

In contrast, past wildfires can tamper the spread of fire across the landscape, due to the fact that previously burned areas have a lack of available surface fuels for fire spread (Bigler et al., 2005; Parks et al., 2015; Prichard & Kennedy, 2014). However, the effect of previously burned areas on reducing subsequent fire spread decreases over time. This effect does not hold under extreme fire-conducive weather (Parks et al., 2015). Available forest fuels to burn are important for wildfire ignition and spread.

2.4 Forest Age

Older forests are often pointed to by foresters as a higher fire risk, however there is little substantiating evidence for this in coniferous-dominated forests. Forest age does appear to affect fire risk in mixedwood forests, as succession shifts young deciduous-dominated forests to more spruce-dominated forests as the stand ages (Krawchuk et al., 2006). However, this increase in fire risk appears to be a factor of forest composition and fuel type, rather than age of the stand itself (Bigler et al., 2005; Krawchuk & Cumming, 2009). In coniferous-dominated forests, such as those in the Southern Eastern Slopes, this same pattern of succession is not as prominent, as both young and old forests are dominated by dense, coniferous trees. Hirsch et al. (2004) indicate that young, dense stands of pine and spruce are at high risk of burning on extreme weather days, whereas mature pine forests support crown fires only on the most extreme fire days.

A number of studies have found that in these dense coniferous conditions, logging could actually increase fire size and overall area burned on the landscape through conversion of more of the landscape to young, dense, highly flammable forest types (Hirsch et al., 2004; James et al., 2011; Krawchuk & Cumming, 2009). In fact, James et al. (2011) found that in a similar forest type, in the Quebec boreal region, the total area burned on the landscape increased with an increase in Annual Allowable Cut (AAC; total volume of timber harvested). Tree densities and dense crown spacing can also affect fire risk, particularly under extreme fire weather (Bigler et al., 2005). Thus, the regrowth of dense stands of pine or spruce saplings after logging can create more available fuel than if the forest was not clearcut (Lindenmayer et al., 2009; Song, 2002). However, Bigler et al. (2005) found that in extreme fire weather, both sapling/pole stands and old stands had a high probability of burning at high fire severity, likely due to dense stocking, continuity of fuel (small branches, needles, etc.) from ground to canopy, and the spatial configuration of trees.

While fire and subsequent coniferous regrowth are natural processes, regeneration after clearcut logging differs from regeneration after fire, and may further increase fire risk, mainly due to differences in tree density, deciduous regrowth, and increase in available surface fuels such as tops, branches, and broken boles left on the ground immediately after harvest (Bowd et al., 2018; Johnson et al., 2001; Leverkus et al., 2018; Thompson et al., 2007). Thompson et al. (2007) found that following salvage logging (harvesting of trees after a fire), young conifer plantations burned at higher severity than naturally regenerated stands of comparable age and fire history. While it is possible that older forests influence fire risk, the evidence suggests that it is more likely younger, more densely planted stands that create an elevated fire risk following logging disturbances (Bigler et al., 2005; Krawchuk & Cumming, 2009).

2.5 Changes in Microclimate

In some forests, the opening of forest clearings and edge habitat can change microclimate conditions. Particularly these changes are seen in sunlight penetration, temperature levels, wind speed, and humidity

(Krawchuk & Cumming, 2009; Lindenmayer et al., 2009; Narayanaraj & Wimberly, 2012). These changes can increase forest and fuel drying, possibly increasing the subsequent risk of ignition (Lindenmayer et al., 2009). While this effect is important in moist forests (Lindenmayer et al., 2009), it is likely not a large factor for fire risk in the Southern Eastern Slopes due to the already relatively dry conditions. However, there is little peer-reviewed evidence available in the literature to further discuss the effects of wildfire on microclimates in the Southern Eastern slopes.

2.6 Roads

Road networks required for logging operations increase the number of ignition points and therefore the number of human-caused wildfires, regardless of the other factors discussed above (Lindenmayer et al., 2009; Mcgarigal et al., 2001; Narayanaraj & Wimberly, 2012). While we acknowledge that forest roads can be used as firebreaks and access for fire suppression activities, it is also noted that increasing road access also increases the frequency of human-caused fires (Narayanaraj & Wimberly, 2012). This increased risk comes from a number of factors including the release of burning carbon from vehicle exhaust pipes, improperly extinguished cigarette butts, and recreational activities such as increased off-highway vehicle (OHV) activity and failure to properly extinguish campfires (Narayanaraj & Wimberly, 2012).

3 So what do we do?

The evidence suggests that clearcut logging in southern Alberta is an ineffective tool for decreasing fire risk across the landscape (Hirsch et al., 2004; James et al., 2011; Krawchuk & Cumming, 2009; Lindenmayer et al., 2009; Prichard & Kennedy, 2014; Schoennagel et al., 2006). In fact, Hirsch et al. (2004) propose that logging strategies focused on maximizing timber production could increase the risk of fire on the landscape over time. Thus, other management options may be required. To move toward more natural forest structures and protection against large wildfires on the Southern Eastern Slopes, we must move away from timber-driven clearcut logging and toward forest management that effectively protects ecosystem values and minimizes wildfire risk where needed. Forest management techniques such as prescribed burning and land use planning are further discussed below.

3.1 Forest Management and Prescribed Burns

Prolonged fire suppression activities in the dry low-elevation montane and upper foothills forests may have actually altered natural fire regimes. As such, it may be necessary to implement a new, proactive approach to fire management to emulate natural age structures and reduce fire risk in surrounding communities (Cumming, 2001; Hirsch et al., 2004; Rogeau et al., 2016).

However, it should be noted that not all forests are in need of restoration of the natural fire regime (Schoennagel et al., 2016). Moister and cooler high-elevation forests, such as subalpine forests, naturally support fires of mostly high severity. In these systems, forest densities have changed little from their pre-suppression era condition (Schoennagel et al., 2016). While the fire cycle is lengthening in the subalpine, the current fire regime appears to be within the expected range of historical variation, so immediate management or restoration actions are not required (Rogeau et al., 2016).

On such a large area as the Southern Eastern Slopes, particularly in changing climatic conditions, we will not be able to manage fire on the entire landscape or to alter the trend of increasing acreage burned (Schoennagel et al., 2016). Most firefighting risks and costs are directly related to protecting communities from active wildfires (Rasker, 2015; Schoennagel et al., 2016). It is therefore important to focus our fire mitigation efforts around communities to reduce losses of homes and infrastructure and better protect people living in or near forested areas while allowing natural disturbance processes in wild areas.

Where management may be needed to restore natural fire regimes, carefully prescribed tree removals, such as thinning and reintroducing fire where it is ecologically desirable, can be the first step in recreating a modern (although somewhat crude) approximation of past fire regimes where appropriate, while also reducing the likelihood of high-severity wildfires in proximity to communities (Hirsch et al., 2004; Lindenmayer et al., 2009). Commercial thinning alone, which targets larger commercial trees to help offset operational costs, typically generates more surface-fuel residues (Moritz et al., 2014). Natural or prescribed fire, alone or in combination with forest thinning, can help prevent more extreme fires in the future as these fires consume debris and live fuel, often limiting the places where new fires can burn for several years after the fire (although this is less effective under extreme fire weather conditions) (Parks et al., 2015; Prichard & Kennedy, 2014).

Converting highly flammable coniferous stands to less flammable deciduous or mixedwood stands can also reduce potential fire spread. While on a landscape scale this is not desirable, as it would change the habitat conditions for many coniferous-dependant species, among other issues. This approach may be particularly applicable to wildland-urban interface areas where there is a need to decrease the threat of wildfire to people and infrastructure (Hirsch et al., 2004).

3.2 Land Use and Site Planning

A key mechanism to protect loss of property during wildfires is land use planning which minimizes residential expansion into forested areas, as well as encouraging the use of residential fire prevention mitigations such as clearing of trees near existing homes (Calkin et al., 2014; Rasker, 2015; Schoennagel et al., 2016). Comprehensive municipal or provincial plans which give governments the authority, incentives and responsibility to reject, redirect, and redesign subdivision and home site proposals based on fire risk would decrease risks and costs associated with fire fighting (Rasker, 2015). Additionally, strengthening programs, such as Alberta's FireSmart program, would encourage homeowners to select fire-resistant building and landscaping materials, and encourage routine yard maintenance near their homes to decrease fire risk (Schoennagel et al., 2016). Without these land use and site planning measures, communities will continue to be at risk of wildfires.

4 Conclusions

The most important factors influencing fire on the Southern Eastern Slopes are weather, forest type, density, and fuel (irrespective of forest age). These factors are largely independent of logging, and in some situations, clearcut logging may in fact increase fire risk on the landscape (Lindenmayer et al., 2009). Additionally, it is difficult to predict where a fire will ignite in the backcountry. Therefore, the common assertion that clearcut logging stops, or reduces, fire on the landscape does not hold on a landscape scale.

Coexistence with wildfire including land use planning and mitigations on private land and homes should allow ecologically appropriate fire regimes to operate on landscapes with relatively low risks to people, property and resources, while also allowing us to enjoy ecosystem services enhanced by fire (Moritz et al., 2014). The objective of forest management and restoration should be to eventually restore or maintain the natural structure to achieve a natural fire regime or a close emulation with prescribed fire (Allen et al., 2002), including considerations of climate change, while also maintaining and restoring the biodiversity, headwaters, and species at risk values of the system that have been impacted by the cumulative effects of previous management. We cannot achieve this through timber-driven logging practices such as clearcut logging. A new model is needed, for our forests and our communities.

5 Literature Cited

Abatzoglou, J. T., & Williams, A. P. (2016). Impact of anthropogenic climate change on wildfire across western US forests. *PNAS*, *113*(42), 11770–11775. https://doi.org/10.1073/pnas.1607171113

Allen, C. D., Savage, M., Falk, D. A., Suckling, K. F., Swetnam, T. W., Schulke, T., Stacey, P. B., Morgan, P., Hoffman, M., & Klingel, J. T. (2002). Ecological restoration of Southwestern ponderosa pine ecosystems : A broad perspective . Ecol Appl. *Ecological Applications*, *12*(5), 1418–1433. https://doi.org/10.2307/3099981

Aussenac, G. (2000). Interactions between forest stands and microclimate: Ecophysiological aspects and consequences for silviculture. *Annals of Forest Science*, *57*(3), 287–301. https://doi.org/10.1051/forest:2000119

Baxter, G. (2002). Management of harvesting debris along the eastern slopes of Alberta ' s Rocky Mountains. *Foret Engineering Research Institute of Canada*, 1–12.

Bessie, W. C., & Johnson, E. A. (1995). The relative importance of fuels and weather on fire behavior in subalpine forests in the southern Canadian Rockies. *Ecology*, *76*(3), 747–762.

Bigler, C., Kulakowski, D., & Veblen, T. T. (2005). Multiple Disturbance Interactions and Drought Influence Fire Severity in Rocky Mountain Subalpine Forests. *Ecology*, *86*, 3018–3029.

Bowd, E. J., Lindenmayer, D. B., Banks, S. C., & Blair, D. P. (2018). Logging and fire regimes alter plant communities. *Ecological Applications*, *28*(3), 826–841. https://doi.org/10.1002/eap.1693

Brassard, B. W., & Chen, H. Y. H. (2008). Effects of forest type and disturbance on diversity of coarse woody debris in boreal forest. *Ecosystems*, *11*(7), 1078–1090. https://doi.org/10.1007/s10021-008-9180-x

Buddle, C. M., Langor, D. W., Pohl, G. R., & Spence, J. R. (2006). Arthropod responses to harvesting and wildfire: Implications for emulation of natural disturbance in forest management. *Biological Conservation*, *128*(3), 346–357. https://doi.org/10.1016/j.biocon.2005.10.002

Calkin, D. E., Cohen, J. D., Finney, M. A., & Thompson, M. P. (2014). How risk management can prevent future wildfire disasters in the wildland-urban interface. *Proceedings of the National Academy of Sciences*, *111*(2), 746–751. https://doi.org/10.1073/pnas.1315088111

Cumming, S. G. (2001). Forest Type and Wildfire in the Alberta Boreal Mixedwood: What Do Fires Burn? *2Ecological Applications*, *11*(1), 97–110.

Cyr, D., Gauthier, S., Bergeron, Y., & Carcaillet, C. (2009). Forest management is driving the eastern North American boreal forest outside its natural range of variability. *Frontiers in Ecology and the Environment*, *7*(10), 519–524. https://doi.org/10.1890/080088

Downing, D. J., & Pettapiece, W. W. (2006). Natural Regions and Subregions of Alberta. In *Government of Alberta, Alberta, Canada.* https://doi.org/Pub. No. T/852

Drapeau, P., Leduc, A., Giroux, J., Savard, J. L., & Vickery, W. L. (2000). *Landscape-Scale Disturbances and Changes in Bird Communities of Boreal Mixed-Wood Forests Bergeron and William L . Vickery Published by : Wiley on behalf of the Ecological Society of America Stable URL : http://www.jstor.org/stable/2657210 JSTOR is a not-*. *70*(3), 423–444. https://doi.org/Doi 10.1021/Ct3004645

Durall, D. M., Gamiet, S., Simard, S. W., Kudrna, L., & Sakakibara, S. M. (2006). Effects of clearcut logging and tree species composition on the diversity and community composition of epigeous fruit bodies formed by ectomycorrhizal fungi. *Canadian Journal of Botany*, *84*, 966–980. https://doi.org/10.1139/B06-045

Erni, S., Arseneault, D., & Parisien, M. A. (2018). Stand Age Influence on Potential Wildfire Ignition and Spread in the Boreal Forest of Northeastern Canada. *Ecosystems*, *21*(7), 1471–1486. https://doi.org/10.1007/s10021-018-0235-3

Flannigan, M. D., Logan, K. A., Amiro, B. D., Skinner, W. R., & Stocks, B. J. (2005). Future area burned in Canada. *Climatic Change*, *72*, 1–16. https://doi.org/10.1007/s10584-005-5935-y

Flannigan, M. D., Stocks, B., Turetsky, M., & Wotton, M. (2009). Impacts of climate change on fire activity and fire management in the circumboreal forest. *Global Change Biology*, *15*(3), 549–560. https://doi.org/10.1111/j.1365-2486.2008.01660.x

Hart, S. A., & Chen, H. Y. H. (2008). Fire, logging, and overstory affect understory abundance, diversity, and composition in boreal forest. *Ecological Monographs*, *78*(1), 123–140. https://doi.org/10.1890/06-2140.1

Harvey, B. J. (2016). Human-caused climate change is now a key driver of forest fire activity in the western United States. *Proceedings of the National Academy of Sciences*, *113*(42), 11649–11650. https://doi.org/10.1073/pnas.1612926113

Hesseln, H. (2018). Wildland Fire Prevention: a Review. *Current Forestry Reports*, *4*, 178–190. https://doi.org/10.1007/s40725-018-0083-6

Hirsch, K., Kafka, V., & Todd, B. (2004). Using forest management techniques to alter forest fuels and reduce wildfire size : an explanatory analysis. *Canadian Forest Service Information*, 175–184. http://www.cfs.nrcan.gc.ca/pubwarehouse/pdfs/25113.pdf

Hirsch, K., Kafka, V., Tymstra, C., McAlpine, R., Hawkes, B., Stegehuis, H., Quintilio, S., Gauthier, S., & Peck, K. (2001). Fire-smart forest management: A pragmatic approach to sustainable forest management in fire-dominated ecosystems. *Forestry Chronicle*, *77*(2), 357–363. https://doi.org/10.5558/tfc77357-2

Holsinger, L., Parks, S. A., & Miller, C. (2016). Weather , fuels , and topography impede wildland fire spread in western US landscapes. *Forest Ecology and Management*, *380*, 59–69. https://doi.org/10.1016/j.foreco.2016.08.035

IPCC. (2014). *Climate Change 2014: Synthesis Report*. https://doi.org/10.1046/j.1365-2559.2002.1340a.x

James, P. M. A., Fortin, M. J., Sturtevant, B. R., Fall, A., & Kneeshaw, D. (2011). Modelling Spatial Interactions Among Fire, Spruce Budworm, and Logging in the Boreal Forest. *Ecosystems*, *14*(1), 60–75. https://doi.org/10.1007/s10021-010-9395-5

Johnson, E. A., Miyanishi, K., & Bridge, S. R. J. (2001). Wildfire Regime in the Boreal Forest and the Idea of Suppression and Fuel Buildup. *Conservation Biology*, *16*(6), 1177–1178. https://doi.org/10.1046/j.1523-1739.2002.16502.x

Krawchuk, M. A., & Cumming, S. G. (2009). Disturbance history affects lightning fire initiation in the mixedwood boreal forest: Observations and simulations. *Forest Ecology and Management*, *257*(7), 1613–1622. https://doi.org/10.1016/j.foreco.2009.01.019

Krawchuk, M. A., Cumming, S. G., Flannigan, M. D., & Wein, R. W. (2006). Biotic and Abiotic Regulation of Lightning Fire Initiation in the Mixedwood Boreal Forest. *Ecology*, *87*(2), 458–468. https://doi.org/10.1890/05-1021

Lamb, C. T., Mowat, G., Reid, A., Smit, L., Proctor, M., McLellan, B. N., Nielsen, S. E., & Boutin, S. (2018). Effects of habitat quality and access management on the density of a recovering grizzly bear population. *Journal of Applied Ecology*, *55*, 1406–1417. https://doi.org/10.1111/1365-2664.13056

Leverkus, A. B., Lindenmayer, D. B., Thorn, S., & Gustafsson, L. (2018). Salvage logging in the world’s forests: Interactions between natural disturbance and logging need recognition. *Global Ecology and Biogeography*, *27*(10), 1140–1154. https://doi.org/10.1111/geb.12772

Lindenmayer, D. B., Hunter, M. L., Burton, P. J., & Gibbons, P. (2009). Effects of logging on fire regimes in moist forests. *Conservation Letters*, *2*(6), 271–277. https://doi.org/10.1111/j.1755-263X.2009.00080.x

Long, J. N. (2009). Emulating natural disturbance regimes as a basis for forest management: A North American view. *Forest Ecology and Management*, *257*(9), 1868–1873. https://doi.org/10.1016/j.foreco.2008.12.019

Mcgarigal, K., Romme, W. H., Crist, M., & Roworth, E. (2001). Cumulative effects of roads and logging on landscape structure in the San Juan Mountains, Colorado (USA). *Landscape Ecology*, *16*(4), 327–349. https://doi.org/10.1023/A:1011185409347

Moritz, M. A., Batllori, E., Bradstock, R. A., Gill, A. M., Handmer, J., Hessburg, P. F., Leonard, J., McCaffrey, S., Odion, D. C., Schoennagel, T., & Syphard, A. D. (2014). Learning to coexist with wildfire. *Nature*, *515*(7525), 58–66. https://doi.org/10.1038/nature13946

Moritz, M. A., Topik, C., Allen, C. D., Hessburg, P. F., Morgan, P., Odion, D. C., Veblen, T. T., & McCullough, I. M. (2018). *A Statement of Common Ground Regarding the Role of Wildfire in Forested Landscapes of the Western United States*. www.wildland-fires.smugmug.com

Narayanaraj, G., & Wimberly, M. C. (2012). Influences of forest roads on the spatial patterns of human- and lightning-caused wildfire ignitions. *Applied Geography*, *32*(2), 878–888. https://doi.org/10.1016/j.apgeog.2011.09.004

Nitschke, C. R. (2005). Does forest harvesting emulate fire disturbance? A comparison of effects on selected attributes in coniferous-dominated headwater systems. *Forest Ecology and Management*, *214*, 305–319. https://doi.org/10.1016/j.foreco.2005.04.015

Parks, S. A., Holsinger, L. M., Miller, C., & Nelson, C. R. (2015). Wildland fire as a self-regulating mechanism: The role of previous burns and weather in limiting fire progression. *Ecological Applications*, *25*(6), 1478–1492. https://doi.org/10.1890/14-1430.1

Prichard, S. J., & Kennedy, M. C. (2014). Fuel treatments and landform modify landscape patterns of burn severity in an extreme fire event. *Ecological Applications*, *24*(3), 571–590. https://doi.org/10.1890/13-0343.1

Rasker, R. (2015). Resolving the Increasing Risk from Wildfires in the American West. *The Solutions Journal*, 55–62.

Rogeau, M.-P., Flannigan, M. D., Hawkes, B. C., Parisien, M.-A., & Arthur, R. (2016). Spatial and temporal variations of fire regimes in the Canadian Rocky Mountains and Foothills of southern Alberta. *International Journal of Wildland Fire*, *25*(11), 1117. https://doi.org/10.1071/wf15120

Schieck, J., & Song, S. J. (2006). Changes in bird communities throughout succession following fire and harvest in boreal forests of western North America: literature review and meta-analyses. *Canadian Journal of Forest Research*, *36*(5), 1299–1318. https://doi.org/10.1139/x06-017

Schoennagel, T., Morgan, P., Balch, J. K., Dennison, P., Hrvaey, B., Hutto, R., Krawchuk, M., Moritz, M. A., Rasker, R., & Whitlock, C. (2016). Insights from wildfire science: A resource for fire policy discussions. *Biological Sciences Faculty Publications*, *423*, 9. https://doi.org/10.13140/RG.2.1.2811.4966

Schoennagel, T., Veblen, T. T., & Romme, W. H. (2006). The Interaction of Fire, Fuels, and Climate across Rocky Mountain Forests. *BioScience*, *54*(7), 661. https://doi.org/10.1641/0006-3568(2004)054[0661:tioffa]2.0.co;2

Song. (2002). *Ecological Basis for Stand Management: A summary and synthesis of ecological responses to wildfire and harvesting in boreal forests* (S. J. Song (ed.)). Alberta Research Council Inc.

Thompson, J. R., Spies, T. A., & Ganio, L. M. (2007). Reburn severity in managed and unmanaged vegetation in a large wildfire. *Proceedings of the National Academy of Sciences*, *104*(25), 10743–10748. https://doi.org/10.1073/pnas.0700229104

CPAWS

CANADIAN PARKS AND WILDERNESS SOCIETY

SOUTHERN ALBERTA CHAPTER

Become a Steward for Alberta's Forests:

https://cpaws-southernalberta.org/forest-stewards/