# Does Clearcut Logging Emulate Fire?

## Examining the Key Differences Between Fire and Clearcut Logging in the Southern Eastern Slopes of Alberta

CPAWS Southern Alberta, 2020

# 1 Introduction

The idea that logging, particularly clearcut logging (where most, or all, of the trees in a specified area of older forests are cut down) replicates or replaces fire is a commonly heard justification for forest harvesting. However, this simplification does not reflect the real differences between natural fire and timber-driven logging. While forest management would do well to imitate natural patterns as closely as possible, logging alone does not replace natural disturbances such as wildfire. Forest management may include timber removal to meet certain objectives, such as to reduce the risk of wildfire to human structures, in key drinking source water areas, or important habitats. In such cases, the prescriptions for forest state should be clearly based on risk-management outcomes, rather than being timber-driven.

The forests of Alberta's Southern Eastern Slopes are an important area for source water for all of southern Alberta. As such, they need to be properly managed to maintain the integrity of these ecosystems for generations to come. The Eastern Slopes are also iconic landscapes, rich with biodiversity. Forest management must be done in such a way as to maintain natural levels of biodiversity and natural ecosystem processes on the landscape. The purpose of this paper is to discuss the key differences between natural disturbance by fire and clearcut logging on the landscape and to argue that the common justification behind large scale logging operations, that they emulate natural disturbance patterns, is not true.

# 2 Key Differences Between Fire and Logging

Logging and wildfire differ greatly on both a local and a larger landscape scale. The differences can be largely attributed to the removal of trees and the location of disturbances. Logging tends to target older, more accessible tree stands, while wildfire is relatively indiscriminate in location and occurs randomly on the landscape (Cumming, 2001). This section will discuss key differences between these disturbances in more detail. Figure 1 illustrates this discussion, along with some main landscape-level differences.

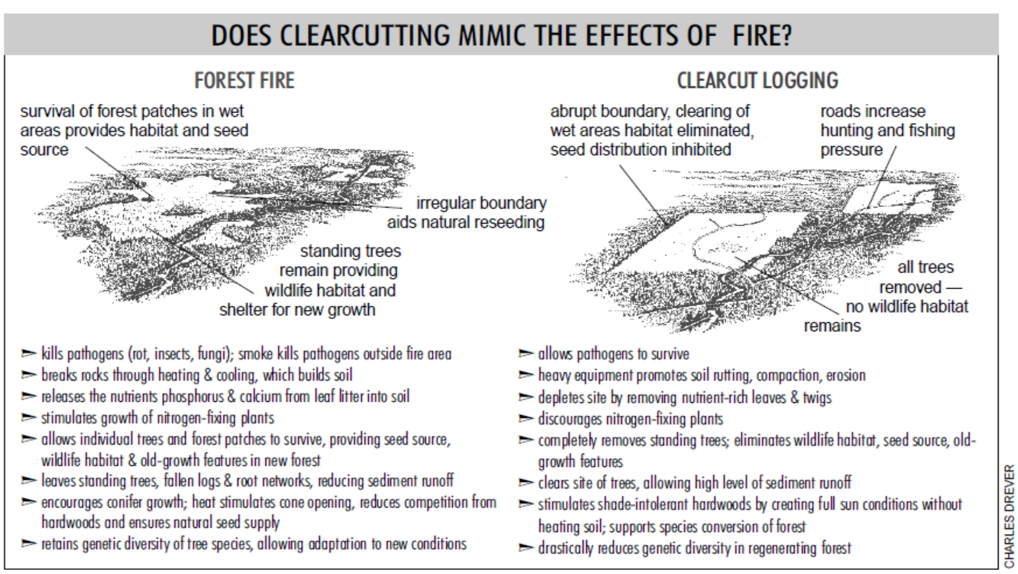


*Figure 1: Main differences between forest fire and clearcut logging (CPAWS Wildlands League).*

There are four key differences between wildland fire and clearcut logging that will be discussed in this paper:

1. Vegetation structure (both at a local and landscape scale), diversity, and age.
2. Diversity and composition of wildlife and insects.
3. The hydrological system (water temperature, chemistry, streamflow, and sediment).
4. Soil characteristics such as composition, soil organisms, and nutrients.

## 2.1 Vegetation: Structure, Diversity, and Age

Natural forest stands have a diverse structure and composition that is derived from multiple disturbance sources such as small or low intensity fires, windfall, or insects (Boucher et al., 2017; Økland et al., 2003). This results in a complex forest structure with more diverse tree and understory species, ages, and physical structure, including dead, standing, and fallen trees (Carleton & Maclellan, 1994). Logging, however, simplifies the structure and composition of the stand by targeting only specific species and age classes that are easily accessible by machinery. Stands are selected based on these features of the trees, and almost all are removed. Additionally, there is a focus on regeneration of commercial species following the disturbance. Consequently, the forest composition following logging is relatively homogeneous in spacing, density, species, and age, with low retention of coarse woody debris (Bergeron & Harvey, 1997; Brassard & Chen, 2008; Long, 2009; Weyenberg et al., 2004).

In addition to vegetation structure, the forest floor structure also differs drastically between logging and fire (Pedlar et al., 2002). Following natural disturbance by wildfire, the forest floor is covered in both coarse and fine woody debris of different sizes and species, creating a very diverse structure of microsite conditions, while logging has been found to show lower levels of coarse woody debris following disturbance (Brassard & Chen, 2008). While there are regulations for forestry companies to leave coarse woody debris on site (Government of Alberta, 2016), typically only deciduous species of low economic value or coniferous trees that are too small for commercial use are left. Because these broadleaf deciduous species decay more rapidly than conifers, much of the coarse woody debris left on site decays within approximately seven years, leaving little structure on the ground (Brassard & Chen, 2008). The effects of these differences in forest floor debris are evident for approximately 30 years post-harvest (Brassard & Chen, 2008), and can have important impacts on wildlife, microclimate, and water filtration capabilities, among others.

Additionally, vegetation differs greatly between post-harvest and post-fire sites. Diversity in both species type and stand age is greatly affected**.** Because fire is largely driven by weather, it can occur anywhere on the landscape, regardless of forest age or stand type (Bessie & Johnson, 1995; Johnson et al., 2001). This results in a large diversity in stand ages, as fire can re-burn areas of young forest, or burn older forests (Bessie & Johnson, 1995; Boucher et al., 2017). Logging, on the other hand, regardless of silvicultural method, specifically targets older stands as these trees are more marketable (Cyr et al., 2009). This, coupled with a harvest-return interval that is shorter and much less variable than the natural fire-return interval, leads to an overall homogeneity in age and species type (Carleton & Maclellan, 1994; Cyr et al., 2009). These differences in post-disturbance vegetation result in landscape-level changes to forest structure. Research has shown that post-clearcut sites generally have smaller patches of vegetation with less spatial variation than post-wildfire disturbance sites (Boucher et al., 2017; Mcrae et al., 2001; Schroeder & Perera, 2002).

In sum, because logging and fire differ in the nature of affected stands pre-disturbance, and the vegetation and structure post-disturbance, clearcut logging cannot emulate fire. Important consequences of these differences for wildlife and insects is discussed in the next section.

## 2.2 Wildlife and Insects: Composition and Diversity

The structure, composition, and diversity of animal communities also differ between sites that have been logged vs. burned. Some differences can largely be attributed to disturbance-specific differences in material left on site, such as standing live and dead trees, snags, and woody debris on the ground (Cyr et al., 2009; Drapeau et al., 2009; Haeussler & Bergeron, 2004; Nguyen-Xuan et al., 2000; Payer & Harrison, 2003; Pedlar et al., 2002).

The different post-disturbance sites from fire and logging create vastly different habitat types that favour different types of species. Wildlife communities such as birds, arthropods, and mammals in early-successional habitats originating from human disturbances such as clearcuts are different from those in forest openings that result from natural disturbances such as fire (Bond et al., 2012; Drapeau et al., 2000; Hutto, 1995; Imbeau et al., 1999; Linder & Ostlund, 1998; Moses & Boutin, 2001). For example, in post-fire sites, large diameter trees and snags (a standing, dead or dying tree, often missing a top or most of the smaller branches) provide habitat for cavity-nesting birds, mammals, and large raptors; fallen trees and debris provide habitat for small mammals. Neither is commonly available in post-harvest clearcut sites (Bond et al., 2012; Hobson & Schieck, 1999; Moses & Boutin, 2001; Raphael et al., 1987; Raphael & White, 1984). In fact, two thirds of all wildlife species use snags or other woody debris that is present at post-fire sites at some point in their life cycles (Bond et al., 2012). Additionally, litter-dwelling arthropod assemblages from young clearcut stands differ from those in post-fire sites, and these effects have been found to stay for up to 30 years following the disturbance (Buddle et al., 2006; Hammond et al., 2017).

Some forest species are specifically adapted for post-fire sites. For example, species whose habitat needs only exist after severe fire include fire morel mushrooms, Bicknell's geraniums, jewel beetles, and black-backed woodpeckers (Bond et al., 2012; Hoyt & Hannon, 2002; Rees & Juday, 2002; Schieck & Song, 2006; Schoennagel et al., 2016; Song, 2002). For species like these, logging cannot substitute fire in the creation of their habitat. The black-backed woodpecker, for example, is a species that has been widely studied. Numerous studies have documented adverse effects on the black-backed woodpecker as a result of modern forestry practices, as this species is almost entirely dependent on fire (Hanson & North, 2007; Hoyt & Hannon, 2002; Hutto, 1995; Imbeau et al., 1999).

Mammals may be a different story, however. Depending on the severity of the fire, there may be no difference in mammalian species over the short- or long-term (Fisher & Wilkinson, 2005). Additionally, the presence of roads following logging activities dissects the remaining wildlife habitat into smaller patches. The habitat fragmentation associated with linear disturbances such as logging roads can have significant impacts on mammal species on a post-fire landscape, such as increased mortalities, reduced habitat quality and availability, and segregation of the population (Edenius & Elmberg, 1996; Lamb et al., 2018; Mcgarigal et al., 2001).

Following a disturbance, wildlife species occurrences are complex and affected by many variables, such as habitat availability, food, competitors, microclimate, and others. As such, it is difficult to generalize across all species. However, some are well-documented, and do vary greatly between disturbance-types, especially those species who directly rely on forest fires to create desirable habitats.

## 2.3 Water: Temperature, Chemistry, Streamflow, and Sedimentation

Fire and logging generally have different impacts on freshwater aquatic systems, the first of which to be discussed is stream temperature. In natural systems, extreme fires can cause higher stream temperatures because they remove large parts of the canopy cover and increase sun exposure to the stream (Nitschke, 2005). This in turn creates stream temperatures that are higher than natural. Clearcut logging has a similar effect on stream temperatures, although to a lesser extent (Mellina et al., 2002). While both of these disturbances increase stream temperatures, a study in a headwaters system found no statistical difference in the response between wildfire and clearcuts on maximum temperature and diurnal flux (Nitschke, 2005). Increased stream temperatures have important implications on the health of the stream and the aquatic biota living in it (Minshall et al., 1997). These effects are especially important for native trout species in Alberta that require fast-flowing, cold-water streams to survive (Nelson & Paetz, 1992; Selong et al., 2001; Sloat & Shepard, 2005). Even slight changes in stream temperatures can have important implications on egg incubation, susceptibility to disease, and movement patterns and timing for these kinds of sensitive species (Macdonald et al., 2003). For example, Alberta native westslope cutthroat trout (*Oncorhynchus clarkii lewisi*) have an upper lethal temperature of only 19.6°C (Bear et al., 2007), which has the potential to be reached following any kind of disturbance. Although both disturbance types can cause increased stream temperatures, the short- and long-term effects may vary depending on a multitude of factors, such as the streambed composition, stream depth, discharge, input, and amount of riparian shade that is removed (Mellina et al., 2002). Stream temperature changes have important implications for the biota living within them; as such, the differential effects of post-harvest and post-fire sites on nearby stream temperatures need further understanding and research.

Streamflow is also differentially affected by clearcut logging and wildfire. Following fire on the landscape, streams experience an increased flow in the early season due to an increased volume of water, and a decreased flow volume in the later season over the long-term (Nitschke, 2005; Silins et al., 2009). Similarly, logging has the potential to affect downstream flooding and streamflow changes through increased peak flows and decreased summer low-flows to below base flow (Nitschke, 2005; Swanson & Hillman, 1977). Hicks et al. (1991) found that clearcut logging increased summer stream flows by 159% for eight years, which was then followed by a 25% decrease in low-flows, which after 18 years had still not returned to pre-harvest levels. Additionally, it has been found that even moderate levels of harvest have the potential to influence the frequency, magnitude, and duration of streamflow (Green & Alila, 2012). These changes in flow, both as a result of logging and fire, can have important implications on flooding and drought, as well as water temperature, volume, dissolved oxygen, and available habitat (Green & Alila, 2012; Hicks et al., 1991; Nitschke, 2005); all of which have the potential to influence sensitive aquatic species, such as native trout.

Both logging and fire increase sediment loads in streams following the disturbance (Nitschke, 2005). However, the impacts of both differ. Post-fire sites can result in larger sediment loads for severe fires. Severe fire often disturbs much larger land areas, consequently exposing more soil to the risk of erosion (Nitschke, 2005; H. G. Smith et al., 2011). Clearcut logging also greatly increases sediment loading, although to somewhat of a lesser extent than fire, and over a longer time period (Carignan et al., 2000; Mcrae et al., 2001; Nitschke, 2005; Silins et al., 2009). The recovery times of sediment loading following both disturbance types varies between the two. Following wildfire, the system experiences a large increase in sediment that recovers quicker than that of clearcuts (Nitschke, 2005). Due to the presence of logging roads, there is a continuous source of sediment created that takes a longer time to recover. Although both disturbances increase sedimentation in the streams, these important differences suggest that logging does not emulate natural disturbance by fire in this regard.

Logging and wildfire affect the water chemistry of headwater systems in different ways and this divergence could have potentially substantial consequences on biodiversity in aquatic systems. Wildfire can especially influence nutrients such as nitrogen and phosphorus in the water supply. This can have impacts on potential contamination of surface water as well as impacts on stream biota (Martin et al., 2000). While wildfire can cause increases in several nutrients such as phosphorous and nitrogen, harvesting can increase other compounds such as dissolved organic carbon and different forms of nitrogen (Nitschke, 2005). The ratio of nutrients is also different from wildfire, particularly related to an increase in the phosphorous to nitrogen ratio, and in the residence time of phosphorus, which can influence algal growth (Martin et al., 2000; Nitschke, 2005).

Differences in water temperature, stream flow, sedimentation, and chemistry between wildfire and logging are complex and need to be managed carefully to meet ecosystem objectives. Although some impacts on the water system are similar between the two disturbance types, logging does not emulate natural disturbance by wildfire in terms of impacts on the aquatic system, both in the short- and long-term. For additional information on the impacts of forest harvest on the hydrological system, see the other paper in this series, *The Effects of Forest Harvest on Hydrology.*

## 2.4 Under the Forest Floor: Soil Composition, Organisms, and Nutrients

The influence of both fire and logging on soil factors varies between the two types of disturbances, but also by fire severity. The impact that fire has on soil, for example, depends largely on the severity of the fire (Certini, 2005; Neary et al., 1999). Depending on the fire severity, the soil is impacted in different ways. For low-to-moderate severity fires, the impacts on soil properties are generally beneficial. In general, following a lower severity fire, the soil sees an increase in pH as well as an increased influx of nutrients. This is mainly due to the water-soluble components of ash creating more available forms of soil nutrients that would otherwise take years to become available with natural decomposition rates (Debano, 1990; González-Pérez et al., 2004). However, when fire becomes higher intensity or more severe, these beneficial soil processes mostly disappear. Intense fires have several negative effects on soil; for example, the almost complete removal of organic matter has implications for both soil erosion as well as subsequent soil creation processes, or “pedogenesis”. Additionally, with the extremely high temperatures associated with severe fires, the soil structure becomes deteriorated and experiences a loss in nutrients, invertebrate, and bacterial communities (Certini, 2005; Debano, 1990; González-Pérez et al., 2004; N. R. Smith et al., 2008). Additionally, following all fire intensities, the bare soil left can seal off due to the effect of raindrops. Raindrops can reduce the particle size and cause a crust to form on top of the soil, consequently reducing the infiltration capabilities and increasing the amount of surface runoff in the area (Certini, 2005; Neary et al., 1999).

The effects of logging on soil do not seem to be well-studied in the literature. However, it appears that most impacts from logging on the soil are as a result of either the addition of organic matter or the compaction caused by heavy machinery (Froehlich, 1979; Startsev & McNabb, 2000). Forest harvest practices generally leave an abundance of undecomposed organic matter on the soil that has implications for changes in soil nutrients, compared to unlogged sites (Bock & Van Rees, 2002); thus the organic matter left on site following logging versus fire is very different. Additionally, the use of heavy equipment and machinery can cause rutting and soil compaction, creating an increase in surface runoff and gullying (Froehlich, 1979; N. R. Smith et al., 2008; Startsev & McNabb, 2000). Although the relative impacts on soil composition, nutrients, and organisms are not well-defined nor compared between the two disturbance types, it can be postulated that logging does not emulate fire in all regards relative to soil properties.

Soil organisms such as mycelium (fungi) experience different changes with fire and clearcut logging. There are two main factors that affect the mycelium community: a shift in the type or amount of inoculum (the material used to start the fungi culture), or a change in the soil environment (Jones et al., 2003). Following clearcut logging, these types of changes to the soil environment can cause changes in soil fungal species diversity, which will inevitably affect both soil organisms, and above-ground plant species (Jones et al., 2003). Additionally, there is always a concern following logging that new fungi will be introduced on the roots of planted seedlings (Jones et al., 2003). Wildfire is an important process for regenerating soil fungi organisms, as higher intensity fires will initiate new colonization and succession in these species (Dahlberg et al., 2001). Additionally, some species, such as nitrogen-fixing bacteria, have been known to increase following a fire (González-Pérez et al., 2004). Logging, on the other hand, has been found to reduce the activity of soil organisms approximately 2-3 years post-harvest (Hagerman et al., 1999).

Clearcut logging does not emulate wildfire in terms of soil processes. Soil composition, compaction rates, nutrients, and organisms following wildfire are not the same as those following forest harvest.

# 3 Conclusions

As discussed throughout this paper, clearcut logging does not emulate fire in any substantial manner. There are key differences that exist between the two disturbances in terms of vegetation, wildlife, soil, and water. Therefore, the commonly used rationale behind clearcut logging, especially in sensitive areas such as Alberta’s southern eastern slopes, is untrue. We need better forest management that accounts for these differences in forest disturbance in such a way that the natural ecosystem is prioritized above all else.

Forest management practices need to acknowledge that clearcut logging does not emulate fire on the landscape, and that harvested landscapes are unnatural and not the same as those that have experienced fire disturbances in the past. The southern eastern slopes of Alberta need to see a move toward more holistic, ecosystem-based management of our forests. The sooner the timber industry acknowledges that logging does not emulate wildfire, the sooner we can move forward with responsible forest management practices that prioritize healthy, functioning landscapes and ecosystems.

# 4 Literature Cited


Bear, E. A., Mcmahon, T. E., & Zale, A. V. (2007). Comparative Thermal Requirements of Westslope Cutthroat Trout and Rainbow Trout: Implications for Species Interactions and Development of Thermal Protection Standards. *Transactions of the American Fisheries Society*, *136*, 1113–1121. https://doi.org/10.1577/T06-072.1

Bergeron, Y., & Harvey, B. (1997). Basing silviculture on natural ecosystem dynamics: an approach applied to the southern boreal mixedwood forest of Quebec. *Forest Ecology and Management*, *92*, 235–242.

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.

Bock, M. D., & Van Rees, K. C. (2002). Forest harvesting impacts on soil properties and vegetation communities in the Northwest Territories. *Canadian Journal of Forest Research*, *32*(4), 713–724. https://doi.org/10.1139/x02-014

Bond, M. L., Siegel, R. B., Hutto, R. L., & Shunk, S. A. (2012). A new forest fire paradigm: the need for high-severity fires. *The Wildlife Professional*, *6*, 46–49.

Boucher, Y., Perrault-Hébert, M., Fournier, R., Drapeau, P., & Auger, I. (2017). Cumulative patterns of logging and fire (1940–2009): consequences on the structure of the eastern Canadian boreal forest. *Landscape Ecology*, *32*(2), 361–375. https://doi.org/10.1007/s10980-016-0448-9

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

Carignan, R., D'Arcy, P., & Lamontagne, S. (2000). Comparative impacts of fire and forest harvesting on water quality in Boreal Shield lakes. *Canadian Journal of Fisheries and Aquatic Sciences*, *57*(S2), 105–117. https://doi.org/10.1139/cjfas-57-S2-105

Carleton, T. J., & Maclellan, P. (1994). Woody vegetation responses to fire versus clear-cutting logging: a comparative survey in the central Canadian Boreal forest. *Ecoscience*, *1*(2), 141–152. https://doi.org/10.1080/11956860.1994.11682238

Certini, G. (2005). Effects of fire on properties of forest soils: a review. *Oecologia*, *143*, 1–10. https://doi.org/10.1007/s00442-004-1788-8

CPAWS Wildlands League. (n.d.). *Forests, Fires and Logging: Setting the Record Straight (Forest Ecology Series, Fact Sheet #2)*. Retrieved March 27, 2019, from http://wildlandsleague.org/attachments/Forests,Fires, Logging.pdf

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

Dahlberg, A., Schimmel, J., Taylor, A. F. S., & Johannesson, H. (2001). Post-fire legacy of ectomycorrhizal fungal communities in the Swedish boreal forest in relation to fire severity and logging intensity. *Biological Conservation*, *100*, 151–161. www.elsevier.com/locate/biocon

Debano, L. F. (1990). *The Effect of Fire on Soil Properties*. http://www.ncrcd.org/files/3014/0857/3352/THE_EFFECT_OF_FIRE_ON_SOIL_PROPERTIES.pdf

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

Drapeau, P., Nappi, A., Imbeau, L., & Saint-Germain, M. (2009). Standing deadwood for keystone bird species in the eastern boreal forest: Managing for snag dynamics. *Forestry Chronicle*, *85*(2), 227–234. https://doi.org/10.5558/tfc85227-2

Edenius, L., & Elmberg, J. (1996). Landscape level effects of modern forestry on bird communities in North Swedish boreal forests. *Landscape Ecology*, *11*(6), 325–338. https://doi.org/10.1007/BF02447520

Fisher, J. T., & Wilkinson, L. (2005). The response of mammals to forest fire & timber harvest in the N-A boreal forest. *Mammal Review*, *35*(1), 51–81.

Froehlich, H. A. (1979). Soil compaction from logging equipment: Effects on growth of young ponderosa pine. In *Journal of Soil and Water Conservation* (Vol. 34, Issue 6). https://andrewsforest.oregonstate.edu/sites/default/files/lter/pubs/pdf/pub570.pdf

González-Pérez, J. A., González-Vila, F. J., Almendros, G., & Knicker, H. (2004). The effect of fire on soil organic matter-a review. *Environment International*, *30*, 855–870. https://doi.org/10.1016/j.envint.2004.02.003

Government of Alberta. (2016). *Alberta Timber Harvest Planning and Operating Ground Rules Framework for Renewal*. https://open.alberta.ca/publications/alberta-timber-harvest-planning-and-operating-ground-rules-framework-for-renewal-2016#detailed

Green, K. C., & Alila, Y. (2012). A paradigm shift in understanding and quantifying the effects of forest harvesting on floods in snow environments. *Water Resources Research*, *48*(10), 1–21. https://doi.org/10.1002/2013WR013613

Haeussler, S., & Bergeron, Y. (2004). Range of variability in boreal aspen plant communities after wildfire and clear-cutting. *Canadian Journal of Forest Research*, *34*(2), 274–288. https://doi.org/10.1139/x03-274

Hagerman, S. M., Jones, M. D., Bradfield, G. E., Gillespie, M., & Durall, D. M. (1999). Effects of clear-cut logging on the diversity and persistence of ectomycorrhizae at a subalpine forest. *Canadian Journal of Forest Research*, *29*, 124–134. https://doi.org/10.1139/cjfr-29-1-124

Hammond, H. E. J., Langor, D. W., & Spence, J. R. (2017). Changes in saproxylic beetle (Insecta: Coleoptera) assemblages following wildfire and harvest in boreal Populus forests. *Forest Ecology and Management*, *401*, 319–329. https://doi.org/10.1016/j.foreco.2017.07.013

Hanson, A. C. T., & North, M. P. (2007). News in brief: North America: United States: ConocoPhillips and Peabody Energy... *Petroleum Economist*, *74*(9), 777–782. https://doi.org/10.1525/cond.2008.8611

Hicks, B. J., Beschta, R. L., & Harr, R. D. (1991). LONG-TERM CHANGES IN STREAMFLOW FOLLOWING LOGGING IN WESTERN OREGON AND ASSOCIATED FISHERIES IMPLICATIONS. *Water Resources Bulletin, American Water Resources Association*, *27*(2). https://journals-scholarsportal-info.proxy.library.brocku.ca/pdf/1093474x/v27i0002/217_lcisflwoaafi.xml

Hobson, K. A., & Schieck, J. (1999). Changes in bird communities in boreal mixedwood forest: Harvest and wildfire effects over 30 years. *Ecological Applications*, *9*(3), 849–863. https://doi.org/10.1890/1051-0761(1999)009[0849:CIBCIB]2.0.CO;2

Hoyt, J. S., & Hannon, S. J. (2002). Habitat associations of black-backed and three-toed woodpeckers in the boreal forest of Alberta. *Canadian Journal of Forest Research*, *32*(10), 1881–1888. https://doi.org/10.1139/x02-109

Hutto, R. L. (1995). Composition of Bird Communities Following Stand-Replacing Fires in Northern Rocky Mountain (U.S.A.) Conifer Forests. *Conservation Biology*, *9*(5), 1041–1058.

Imbeau, L., Savard, J.-P. L., & Gagnon, R. (1999). Comparing bird assemblages in successional black spruce stands originating from fire and logging. *Canadian Journal of Zoology*, *77*(12), 1850–1860. https://doi.org/10.1139/cjz-77-12-1850

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

Jones, M. D., Durall, D. M., & Cairney, J. W. G. (2003). Ectomycorrhizal fungal communities in young forest stands regenerating after clearcut logging. *New Phytologist*, *157*(3), 399–422. https://doi.org/10.1046/j.1469-8137.2003.00698.x

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

Linder, P., & Ostlund, L. (1998). Structural changes in three mid-boreal Swedish forest landscapes, 1885-1996. *Biological Conservation*, *85*, 9–19.

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

Macdonald, J. S., Macisaac, E. A., & Herunter, H. E. (2003). The effect of variable-retention riparian buffer zones on water temperatures in small headwater streams in sub-boreal forest ecosystems of British Columbia. *Canadian Journal of Forest Research*, *33*, 1371–1382. https://doi.org/10.1139/X03-015

Martin, C. W., Hornbeck, J. W., Likens, G. E., & Buso, D. C. (2000). Impacts of intensive harvesting on hydrology and nutrient dynamics of northern hardwood forests. *Can. J. Fish. Aquat. Sci.*, *57*(2), 19–

29. https://doi.org/10.1139/cjfas-57-S2-19

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

Mcrae, D. J., Duchesne, L. C., Freedman, B., & Lynham, T. J. (2001). Comparisons between wildfire and forest harvesting and their implications in forest management. *Environmental Reviews*, *9*, 223–260. https://doi.org/10.1139/er-9-4-223

Mellina, E., Moore, D. R., Hinch, S. G., Stevenson Macdonald, J., & Pearson, G. (2002). Stream temperature responses to clearcut logging in British Columbia: the moderating influences of groundwater and headwater lakes. *Canadian Journal of Fisheries and Aquatic Sciences*, *59*, 1886–1900. https://doi.org/10.1139/F02-158

Minshall, G. W., Robinson, C. T., & Lawrence, D. E. (1997). Postfire responses of lotic ecosystems in Yellowstone National Park, U.S.A. *Canadian Journal of Fisheries and Aquatic Sciences*, *54*, 2509–2525. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.623.8953&rep=rep1&type=pdf

Moses, R. A., & Boutin, S. (2001). The influence of clear-cut logging and residual leave material on small mammal populations in aspen-dominated boreal mixedwoods. *Canadian Journal of Forest Research*, *31*(3), 483–495. https://doi.org/10.1139/cjfr-31-3-483

Neary, D. G., Klopatek, C. C., Debano, L. F., & Ffolliott, P. F. (1999). Fire effects on belowground sustainability: a review and synthesis. *Forest Ecology and Management1*, *122*, 51–71. https://www.sierraforestlegacy.org/Resources/Conservation/FireForestEcology/FireScienceResearch/FireEcology/FireEcology-Neary99.pdf

Nelson, J. S., & Paetz, M. J. (1992). *The Fishes of Alberta*. University of Alberta Press.

Nguyen-Xuan, T., Bergeron, Y., Simard, D., Fyles, J. W., & Paré, D. (2000). The importance of forest floor disturbance in the early regeneration patterns of the boreal forest of western and central Quebec: a wildfire versus logging comparison. *Canadian Journal of Forest Research*, *30*, 1353–1364. https://doi.org/10.1109/WiSEE.2016.7877313

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

Økland, T., Rydgren, K., Økland, R. H., Storaunet, K. O., & Rolstad, J. (2003). Variation in environmental conditions, understorey species number, abundance and composition among natural and managed Picea abies forest stands. *Forest Ecology and Management*, *177*(1–3), 17–37. https://doi.org/10.1016/S0378-1127(02)00331-6

Payer, D. C., & Harrison, D. J. (2003). Influence of Landscape Pattern on Habitat Use by American Marten in An Industrial Forest. *Forest Ecology and Management*, *179*, 145–156.

Pedlar, J. H., Pearce, J. L., Venier, L. A., & McKenney, D. W. (2002). Coarse woody debris in relation to disturbance and forest type in boreal Canada. *Forest Ecology and Management*, *158*(1–3), 189–194. https://doi.org/10.1016/S0378-1127(00)00711-8

Raphael, M. G., Morrison, M. L., & Yoder-Williams, M. P. (1987). Breeding Bird Populations during Twenty-Five Years of Postfire Succession in the Sierra Nevadag. *The Condor*, *89*(3), 614–626.

Raphael, M. G., & White, M. (1984). Use of Snags by Cavity-Nesting Birds in the Sierra Nevada. *Wildlife Monographs*, *86*.

Rees, D. C., & Juday, G. P. (2002). Plant species diversity on logged versus burned sites in central Alaska. *Forest Ecology and Management*, *155*(1–3), 291–302. https://doi.org/10.1016/S0378-1127(01)00566-7

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

Schroeder, D., & Perera, A. H. (2002). A comparison of large-scale spatial vegetation patterns following clearcuts and fires in Ontario's boreal forests. *Forest Ecology and Management*, *159*(3), 217–230. https://doi.org/10.1016/S0378-1127(01)00434-0

Selong, J. H., Mcmahon, T. E., Zale, A. V, & Barrows, F. T. (2001). Effect of Temperature on Growth and Survival of Bull Trout, with Application of an Improved Method for Determining Thermal Tolerance in Fishes. *Transactions of the American Fisheries Society*, *130*, 1026–1037. http://www.montana.edu/mcmahon/documents/Selong et al  2001.pdf

Silins, U., Stone, M., Emelko, M. B., & Bladon, K. D. (2009). Sediment production following severe wildfire and post-fire salvage logging in the Rocky Mountain headwaters of the Oldman River Basin, Alberta. *Catena*, *79*(3), 189–197. https://doi.org/10.1016/j.catena.2009.04.001

Sloat, M. R., & Shepard, B. (2005). Influence of Stream Temperature on the Spatial Distribution of Westslope Cutthroat Trout Growth Potential within the Madison River Basin, Montana. *North American Journal of Fisheries Management*, *25*, 225–237. https://doi.org/10.1577/M03-165.1

Smith, H. G., Sheridan, G. J., Lane, P. N. J., Nyman, P., & Haydon, S. (2011). Wildfire effects on water quality in forest catchments: A review with implications for water supply. *Journal of Hydrology*, *396*(1–2), 170–192. https://doi.org/10.1016/j.jhydrol.2010.10.043

Smith, N. R., Kishchuk, B. E., & Mohn, W. W. (2008). Effects of Wildfire and Harvest Disturbances on Forest Soil Bacterial Communities. *APPLIED AND ENVIRONMENTAL MICROBIOLOGY*, *74*(1), 216–224. https://doi.org/10.1128/AEM.01355-07

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.

Startsev, A. D., & McNabb, D. H. (2000). Effects of skidding on forest soil infiltration in west-central Alberta. *Canadian Journal of Soil Science*. www.nrcresearchpress.com

Swanson, R. H., & Hillman, G. R. (1977). Predicted increased water yield after clear-cutting in west-central Alberta. In *Northern Forest Research Centre, Canadian Forest Service, Department of the Environment*. http://cfs.nrcan.gc.ca/pubwarehouse/pdfs/12115.pdf

Weyenberg, S. A., Frelich, L. E., & Reich, P. B. (2004). Logging Versus Fire: How Does Disturbance Type Influence the Adbundance of Pinus strobus Regeneration? *Silva Fennica*, *38*(2), 179–194.