A Brief Overview of Fire Suppression and Fuel Mitigation

Charmaine Liu
University of British Columbia – FRST 497
April 22, 2014

Abstract

This essay reviews how fire is an integral component of the ecosystem, and how fire suppression has affected the forested landscape as a result of altering natural fire regimes. This essay will expand on current fuel mitigation treatments used in the United States by reviewing the effectiveness of mechanical harvesting, prescribed burns, and the combination treatment of mechanical harvesting and prescribed burns discussed in the National Fire and Fire Surrogate Study. Current fuel mitigation treatments will be reviewed with regards to climate change in British Columbia, a massive forested landscape that has experienced decades of fire suppression, and how climate change affects fuel mitigation treatments, with the hope to encourage further discussion, research, and ongoing programs that implement fuel management techniques with regards to climate change.

Keywords: fire suppression, fire exclusion, fuel mitigation, fuel reduction, National Fire and Fire Surrogate Study, British Columbia

Table of Contents

Appendix A: Brief Summary of the Short-term Findings of the National FFS Study

Introduction

Fire is an important function in many ecosystems globally, as it existed even before humans evolved as part of the world. Fire is a naturally-occurring disturbance where most ecosystem components mainly rely on the process to help keep the ecosystem relatively stable to maintain forest health as it dominantly drives spatial heterogeneity and can increase complexity in many ecosystem components through influencing successional trajectories. It contributes to important habitat for wildlife as it creates gaps in the canopy to allow for accelerate growth of surviving trees and the establishment of understory regeneration (Schwilk et al., 2009). Subsequently, it is not fire that has adapted to humans in a global and timely context, but rather, it is human beings that have adapted to and manipulated fire processes such that it has become a tool for utilization– we have colonized it, controlled it, cultivated it, built it, and even technologized it to the point where pyrotechnics exist today (Pyne, 2001). And yet, there is the current trend where overwhelming fuel loads can be found on various landscapes today due to absence of fire mostly as a result of anthropogenic causes, otherwise known as fire suppression. Therefore, we have changed some historic, natural fire regimes so that stand-replacing fires may be expected to increase in the near future with increasing fuel loads and a warming climate.

There are three, main types of fire regimes classified according to fire effects on the ecosystem – low-severity, high-severity, and mixed-severity fire regimes. In low-severity fire regimes, frequent fires result in small to large areas burned and heterogeneous, low-density forests. Because of variable fire size in this regime, fuel mass is a vital attribute in this fire regime. Because the intervals between frequent fires are short, high-severity fires rarely occur in this regime due to the lack of fuel buildup and a net loss in coarse woody debris (Nesbitt, 2010). Thus, low-severity fire regimes are typically limited by fuels. In high-severity fire regimes, less frequent, yet high-impact crown fires are to be expected that would also result in small or large areas burned. Often, it is the larger fires that have the greatest impact on the landscape and remain to be legacies of this fire regime. Because high-severity fire regimes are mostly composed of high impact-crown fires, the end result is usually near to total stand mortality with the initiation of even-aged cohorts composed of fire-intolerant species, particularly thin-barked trees (Nesbitt, 2010). High-impact crown fires are a result of not just availability of fuel mass, but also fuel moisture determined by relative humidity and daily temperatures. Thus, high-severity fire regimes are typically limited by weather conditions. In mixed-severity fire regimes, fuels and weather are complex in nature and thus this particular regime varies in space and time. The end result, usually, is uneven-aged stands scattered amongst even-aged stands at a local scale due to the patchiness found within and among fires. Because of multiple cohorts and patchiness, mixed-fire regimes include a combination of low, moderate, and high-severity fires across the local, regional and landscape level. (Nesbitt, 2010; Schoennagel, Veblen, & Romme, 2004).

Fire regimes can also change from anthropogenic, land use changes (Schwilk et al., 2009; Pyne, 2001), particularly in the low- and mixed-severity fire regimes. Such land use management changes include fire suppression, timber harvesting, and livestock grazing that, in general, have lead to increased stand density, higher proportion of saplings and sub-canopy trees, altered community compositions that favour fire-intolerant and shade-tolerant species, fewer and smaller canopy gaps, surface fuel accumulation, and altered habitats for the wildlife and plant community (Schwilk et al., 2009). These land use changes have altered the natural fire regimes by increasing the buildup of surface fuels that alter forests in such a way that they are more susceptible to stand-replacing crown fires, or in other words, the land use changes have altered the particular patterns of fires (Pyne, 2001). As a result in altered patterns of fires, the resulting ecological effects have a large impact on the ecosystem as the effects may not be similar to historical levels (Schwilk et al., 2009).

In response to altered fire regimes, one potential strategy to rehabilitate forests back to their familiar, historical fire levels is through fuel reductions. In this essay, I will discuss whether fuel mitigation, or fuel reductions, will reduce fire intensity and severity in the future, especially with ongoing climate change. Because of climate change, it is important to consider whether fuel mitigation actions are worth the effort if large, stand-replacing fire events continue to occur, even in fuel treated areas. This essay critically reviews the National Fire and Fire Surrogate Study (FFS) that took place in the United States (Schwilk et al., 2009), as well as multiple studies in the dry forests of British Columbia (BC) to further review how fire suppression has affected fire regimes.

Background

What happens when fire suppression occurs?

With fire suppression, fire behaviour, intensity and severity may increase due to a substantial increase in fuel loads. Forest structure changes with more growing stock on the land base, increasing competition among biotic individuals within the stand and changing not only horizontal and vertical components of forest structure, but vegetation composition as well. As a consequence of the absence of fire in forests, what has historically maintained the outbreaks of pathogens and forest insect outbreaks at a natural and regular interval has now intensified the their eruptions, including observed increases in the prominent mountain pine beetle (*Dendroctonus ponderosae*) infestation and dwarf mistletoe (*Arceuthobium*) infection (Association of BC Forest Professionals [ABCFP], 2005). Fire suppression has also resulted in an ingrowth of dry forests and encroachment of grasslands, and largely impact forest structure and function such as successional pathways, habitat availability, and species composition (ABCFP, 2005) because of changes in microclimate, stand structure, fuel continuity, and frequency of ignition starts (Da Silva, 2010). Because of decades of fire suppression, the buildup in fuels over time can lead to stand-replacing fires.

In the past, the breaking up of the continuity of fuels depended on natural wildfires in order to reduce susceptibility of stand-replacing fires (Schwilk et al., 2009). Anthropogenic fire suppression has altered the natural fire disturbance regime through increasing tree density and thus stand density, and increased aerial and surface fuels and homogenization of such fuels. These landscape changes have allowed for unexpected wildfires to pass through long distances at high intensity levels and resulting in extensive environmental degradation (Gray & Blackwell, 2008) – essentially, the natural fire disturbance regime has altered the landscape's historical fire frequency, intensity, and severity. Fire suppression also leads to an extreme fire hazard by leaving large carbon sinks through the accumulated fuels in vegetation (Mitchell, Harmon, & Connell, 2009) through carbon sequestration in forest biomass, dead organic matter, and soils. Consequently, if a large fire were to occur, these forest carbon sinks can turn into forest carbon sources with large areas burned (Natural Resources Canada, 2014), and "megafires" may occur as a result of masses of understory biomass and over-accumulation of surface fuels through organized fire suppression (Williams, 2013). In addition, fire suppression not only exacerbates fire frequency, intensity, and severity in most places, but also their associated actions emit greenhouse gases through the use of fossil fuels when utilizing equipment and machinery such as aircrafts, trucks, and pumps when achieving fire suppression objectives (Daigle & Dymond, 2010).

Altered fire regimes may also result indirect forms of fire exclusion, such as land use changes including logging and livestock grazing, which can exacerbate fire suppression (Da Silva, 2009). Historically-logged sites may exacerbate fire suppression as it caused changes in plant growth and composition, including increased total stand density and slash left on site, as well as increased homogenous forest structure and smaller, fire intolerant tree species resulting from their study (Naficy, Sala, Keeling, Graham, & DeLuca, 2010). Livestock grazing can reduce understory vegetation, especially grasses, which may promote or aid fire event frequencies (Brooks, 2008). As such, because fuels are mostly made up of vegetation, such land use changes or conversions as a result of logging or livestock grazing can change the fuel bed on different temporal scales. This change can also result in the rapid change of fire regimes and change fire intensity, frequency, severity, extent, pattern, and seasonality (Brooks, 2008), especially in dry forests where active fire suppression may take place and lead to the forest fuel accumulation and encroachment on grasslands (Wildfire Management Branch, 2013).

Analytical Assessment

How to mitigate fuel accumulation

Because of increased stand density, change in vegetation communities, increase in fuel accumulation, and change in habitat compositions, among many other alterations in the forest, there is a need to better understand fuel management and its role in contributing to ecosystem health (Schwilk et al., 2009). Historically, the health of forests and its ecological processes have been dependent on the natural wildfires to aid in maintaining stand density and reduce fuel accumulations in order to make forests less vulnerable to stand-replacing crown fires (Schwilk et al., 2009). The National Fire and Fire Surrogate (FFS) study assessed the costs and ecological effects of fuel reduction experiments in seasonally dry forests, including a control, mechanical-only, prescribed-burn only, and mechanical and burn treatments at 12 locations in eastern and western United States (US) (Schwilk et al., 2009). As such, three methods may be used to perform fuel reduction treatments and help build a stronger, resilient forest. Mechanical-only treatments, or thinning, are used to help reduce tree density in order to improve individual tree health while also reducing risk of severe fire events through the removal of ladder fuels (Parker & Bennett, 2005). This method may be preferred over prescribed burning if a land manger's objective were to maintain air quality while obtaining possible benefits from commercially-viable individuals, as well as offsetting carbon emissions that may result from prescribed burning (Oliver, 2009). Second, prescribed burning is also used mainly for the objective of building a fire-resilient stand structure while also aiming to reduce surface fuels in the forest. Third, a combination of both methods may be used to aid in the reduction of forest fuels. Thinning would be performed first to help reduce stand density, followed by prescribed burning to remove surface fuels and residuals. As a result, this combined method would result in the reduction of both stand density and fuel accumulation.

According to Schwilk et al., (2009), implementation of each method is different depending on the site that calls for fuel mitigation. In their study *The National Fire & Fire Surrogate Study: Effects of Fuel Reduction Methods on Forest Vegetation Structure and Fuels*, in which the main goal is to reduce fuels to a point in order to support surface fires instead of crown fires, Schwilk et al. (2009) suggest that if a head fire were to occur, fuels must be reduced such that at least 80% of the basal area of dominant and codominant trees would survive the disturbance. This 80th percentile standard postulates that there would be some form of residual stand following fuel mitigation activities in some forests (McIver, Weatherspoon, & Edminster, 2001). Chiefly, fuel mitigation techniques are used not to reduce fuels to a point where fire events should not occur due to lack of fuels, but rather leave a sufficient amount of fuels to re-introduce surface fires into the ecosystem to promote and maintain healthy strand structure (McIver et al., 2012).

Is fuel mitigation effective?

In the National FFS report, Schwilk et al. (2009) found that, on a short-term basis when results were assessed one year application of the fuel mitigation techniques, generally, mechanical treatments were most effective at the overstory level due to the reduction in overstory tree density and basal area. Schwilk et al. (2009) concluded that if this technique were to be used, the objectives to be considered for such treatment would include reducing stand density to a more historical structure, as well as creating a more resilient forest structure in terms of other disturbances such as bark beetle attacks. However, mechanical treatments should not ecologically serve as fire surrogates for fuel reduction treatments. This is due to past fire suppresion, and how it has allowed trees to grow such that if a fire event were to occur, they would be less susceptible to death (Schwilk et al, 2009; McIver et al., 2012).

For their prescribed fire treatments, Schwilk et al. (2009) found that such treatments were most effective at reducing surface fuels, although most of the prescribed burns had also resulted in additional snags and killed seedlings in addition to elevating height to live crown ratio. These effects did not account for delayed mortality such that after the occurrence of fire events, there may also be the possibility of an increase in beetle attacks – events that are common in coniferous forests. In addition, the reduction in surface fuels were also only found to be temporary due to the foreseeable future of increased fuel loading from creation of additional snags. Even though this contribution would add to surface fuel loading, Schwilk et al. (2009) concluded that prescribed fire treatments should be used if the objective was to affect fuel factors such as total surface loads and height to live crown ratio.

The mechanical and burn combination treatments were found to most desirable in terms of the impact left on ecological conditions as they had not only reduced surface fuels, but also decreased stand density and increased plant species richness (Schwilk et al., 2009). On the other hand, the combination treatment had typically resulted in the increased frequency of alien species invasion. The initial reaction of native plants in the understory under all prescribed treatments were generally positive due to more exposure of light and mineral soil on the ground that gave way to further colonization of native and alien plant species. The combination treatment was also most effective in creating fire-resilient structures due to fewer ladder fuels and lower rates of accumulation, particularly in the western sites where the FFS study took place. Therefore, Schwilk et al. (2009) concluded that the mechanical and burn treatments should be used if the objective was to build a more fire-resilient forest structure as it resulted in the reduction of surface fuels and fuel accumulation rates more rapidly than if the mitigation was to only burn for the site, with the additional monitoring and mitigation or adaptive strategies because of the increase in herbaceous alien species invasion.

The major difference between the western and eastern sites were in the woody fuel mass, with more impact on the western sites through burning treatments as they had less understory biomass and proportionally more woody surface fuels than the eastern sites (Schwilk et al., 2009). As such, prescribed burning was more influential and effective on the western sites than mechanical treatments in terms of the reduction in surface fuels (Schwilk et al., 2009), where mechanical treatments had either increased or had little change on surface fuels. However, this reduction was only temporary, and also led to an increase in snags that will eventually fall to the ground and increase surface fuel loading in the future (Schwilk et al., 2009). The combination of mechanical treatment and prescribed burns were most effective in the rapid building a resilient stand structure to wildfire in the western sites as the treatments resulted in less ladder fuels and lower fuel accumulation rates (Schwilk et al., 2009). When comparing between the western and eastern sites, site management of eastern sites were more centred on altering tree species composition than on historical composition and structure. As such, mechanical treatments were more successful than burning in the reduction of hardwood tree density and basal area and in the increase in quadratic mean diameter (Schwilk et al., 2009). Although burning did reduce surface fuels at the eastern sites, the reduction was not as successful as the western sites since some understory biomass was much more abundant and would fall to the forest floor quicker, adding to surface fuel loads (Schwilk et al., 2009). The combination treatment of mechanical and prescribed burn treatments, however, also resulted in a more rapid building of a resilient strand structure to wildfire (Schwilk et al., 2009).

Nonetheless, because all these observed findings were short-term, such effects described in their articles may not be concrete as they are deficient to provide adequate information for long-term trajectories and trends in the ecosystem (McIver et al., 2012). In addition, since the study was conducted shortly after the experiment, the effects observed may diminish overtime, which would result in an increase in fire risk as components of the forest structure may yield to decomposition processes, especially in prescribed burn sites (McIver et al., 2012). McIver et al. (2012) also state that due to strong, site-specific ecological effects resulting from each treatment, adaptive management is best used when implementing fuel mitigation strategies at the local scale. Furthermore, although most of the treatments had generally reduced fuels on site and thus projected fire risk as a consequence of changing forest structure, none of the treatments had sufficiently had the effect of reverting it back to their historic structure (Mciver et al., 2012).

Through this FFS review, the western sites in the US are most relevant to British Columbia (BC), Canada, as each western site is dominated by conifer species, primarily ponderosa pine (*Pinus ponderos*a P. & C. Lawson) and Douglas-fir (*Pseudotsuga menziesii* (Mirbel) Franco) (McIver et al., 2012). In BC, the dominant vegetation cover are coniferous forests, with western hemlock, western redcedar, and Douglas-fir dominating the coastal forests and ponderosa pine, Douglas-fir, and lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.) dominating much of the interior regions in BC (Meidinger, 1991). There are also many dry forest ecosystems that have also experienced intense fire suppression in BC, and these ecosystems are also greatly at risk in terms of the altering of fire regimes should fire suppression continue (Arsenault & Klenner, 2003).

What does this mean for British Columbia?

In BC, where approximately 60%, or 55 million hectares, of the landscape is forested (Ministry of Forests, Mines and Lands, 2010), mixed-severity regimes are much more common as they are limited spatially in mountain landscapes. This launches variability to fire intensity, severity, and behaviour, and as a result the mixed-severity fire regime includes a combination of low, moderate, and high-severity fires across the local, regional, and landscape level (Nesbitt, 2001; Schoennagel et al., 2004). In addition, BC has had successful fire suppression for the past four decades, with a success rate of 92% for fires less than four hectares in size (Wildfire Management Branch, 2012). As such, time since the last-known fire disturbance has been increasing and furthers the aging of forests with successful fire suppression (Association of BC Forest Professionals [ABCFP], 2005).

With a major component of BC being composed of lodgepole pine stands, it is important to consider fuel mitigation techniques since the species is associated with stand-replacing crown fires and surface fires. Lodgepole pine is a fire-dependent species, where not only do their cones need fire or an analogous heat source to flex their scales and release seeds, but fire events help maintain healthy lodgepole pine stands of all ages. Thus, as a result of fire suppression, lodgepole pine stands may result in a very dense cohort and experience self-thinning due to strong competition. With the occurrence of self-thinning, surface and ladder fuels may build up due to the falling of dead trees or snags. Fire suppression would then increase fire hazard and fuels, and decrease fire resilience in the system as the buildup of ladder fuels would allow the event of crown fires to spread from tree to tree – a dangerous threat, especially in a very dry ecosystem where many of such ecosystems can be found in the interior of British Columbia. In response, Da Silva (2009) states that dominating lodgepole pine stands should have fuel mitigations that consist of natural fire breaks at the edge of natural fire zones or at the wildland-urban interface as lodgepole pine stands are mostly subject to high-severity crown fires, in addition to crown thinning and removal of fuel logs with active stand maintenance every ten years.

British Columbia has also experienced an immense, ecological change that involves forests and grasslands that are dominated by medium to short fire return intervals, most notably in the southern and central interior regions (Association of BC Forest Professions [ABCFP], 2005). With past and persistent fire suppression in these relatively dry ecosystems, there has been an observed trend in forest health problems due to increased competition for moisture and nutrients, changes in species composition, overall aging of the forest, and reduction in grassland areas (2005). Currently, most of the”dry-belt” grasslands of BC are in the Bunchgrass(BG), Ponderosa Pine (PP), and Interior Douglas-fir (IDF) biogeoclimatic (BEC) zones that occur at lower elevations in the interior of BC (Arsenault & Klenner, 2003). Historically, these ecosystems were maintained by frequent, low-severity fires that resulted in widely spaced large trees and low crown cover density, with sparse seedlings and woody shrubs – in other words, these ecosystems experience stand-maintaining fires (Arsenault & Klenner, 2003). As such, with fire suppression, these ecosystems alter forest structure by increasing stand density and fuel accumulation that may lead to the treat of stand-replacing fires.

In the Rocky Mountains of British Columbia, which can be found in the East Kootenay region, Switzer (2011) devised an experiment to determine which fuel management strategy would result in the highest fuel consumption, lowest fire temperatures, and the least negative, ecological impacts to the forest floor and soil by examining forest floor depth and volume, moisture, carbon and nitrogen concentrations, plant root simulator probes, and soil pH. Fuel management strategies used in their experiment included thinning to reduce stand density and fuel load, fuel placement strategies such as scattered slash, slash piles, and cut-and-left, and prescribed fire that also resulted in reduced fuel loads. The results of his experiment found a strong correlation between pre-fire moisture content and forest floor consumption, such that the more moisture present in a particular site, the less consumption seen of the forest floor in that site. The experiment also resulted in considerably higher nutrient availability in burned sites than in the control sites. There was also no recovery one year after the treatment in the forest floor and mineral soil bacteria after their populations had decreased significantly, as well as the fungus arbuscular mycorrhiza, along with other fungi. Switzer (2011) concluded that the largest negative impacts to the forest floor were due to low moisture content and consumption of deep litter in the forest floor. These results may be common in the subalpine forests of the Rocky Mountains since the region experiences infrequent large fires as a result of low surface fuel levels and high ladder and aerial fuel levels that are slightly different from historic stands (Schoennagel et al., 2004). Therefore, it is important to consider the role of climate as its variability may be the main driver in subalpine forests with respect to fire events and their associated frequencies, intensities, and severities (Schoennagel et al., 2004). However, Switzer did not measure plant species richness, particularly those of native and alien backgrounds, and thus this should be studied more carefully as this indicator can play a huge role in biodiversity and can add further ecosystem resiliency in ecosystem restoration projects. However, there is the case that fire may be best avoided in stands that are monopolized by fire-intolerant species, and that fire suppression may be used after thinning and mechanical removal of fuels in low-resilient stands that are fire-intolerant (Nitschke & Innes, 2008).

Therefore, it may be important to address fuel mitigation with regard to climate change. Daigle and Dymond (2010) stress the importance of understanding the relationships between fire management and carbon emissions and storage. Carbon dioxide is emitted as a result of fire events and decomposition in forests. However, there are many benefits to using prescribed burns with the reduction of fuels and creating complex and diverse ecosystems. There is a current trend observable in British Columbia with longer fire seasons that come with probable increases in fire behaviour and weather severity, as well as an increase in the possibility of ignitions (Daigle & Dymond, 2010), especially in the dry ecosystems such as interior British Columbia. These carbon emissions emitted that are sourced from fire-prone forests could hasten global warming and contribute to climate change, especially with increasing size and severity of wildfires. Although coastal systems have yet to see the increased risk of stand-replacing fires due to different ecosystem processes, it is possible that climate change will result in more coastal fire events, especially in rainshadow regions (2010), or dry areas of a mountainside.

In Nitschke and Innes' (2008) article concerning landscape vulnerability and how to manage forests while integrating a "climate-smart" framework into forest management, the overall results from their study area, which encompasses five forested ecosystems, including the Ponderosa pine (PP), Montane Spruce (MS), Interior Cedar-Hemlock (ICH), ESSF and IDF BEC zones, suggest that at every 50 years or less, 93% of their 145,000 hectare study area is forecasted to be at risk from longer and more severe fire seasons. In addition to the 93% predicted-statistic, 51.5% of the landscape is to be at risk from future mountain pine beetle epidemics, 39% will be at high risk to climate change, of which 77% is to have at least one tree species at risk, as well as an anticipated increase in drought systems that will further risk and accentuate fire intensity, severity, and behaviour (Nitschke & Innes, 2008). These results were derived by using programs such as ArcGIS to do analyses of each risk variable, Prometheus to project fire spread and growth depending on fuel type, topography, and weather, Canadian Forest Service Mountain Pine Beetle Risk Rating System, Tree and Climate Assessment Model to measure tree species vulnerability and their basic regeneration regions, habitat suitability models, the Canadian Forest Fire Danger Rating System, the Canadian Forest Fire Behaviour Prediction (FPB) System for the assessment in fire season severity, length, and behaviour, and the Global Climate Change system and weather station data (Nitschke & Innes, 2008).

With their assessments in the study, Nitschke and Innes (2008) stress the importance of timing of subsequent management actions, and that timing of such actions will depend on climatic conditions. For example, fire season length was expected to increase by 27% in spring, however, length is to remain relatively unchanged in the summer and fall seasons, and implies that fuel-reduction strategies such as prescribed burns could occur in the fall instead of the spring (2008). Timing of budburst for tree species will also need to be considered when implementing fuel mitigation treatments. For example, those with early budburst dates will result in forest managers to apply fuel mitigation treatments such as mechanical harvesting or burning in smaller time windows such as early spring or late fall (2008). In addition, if planting of pure lodgepole pine stands across the bulk of the landscape continues to occur due to their fast regeneration, this course of action will further assist the rate of increase in frequency and severity of fire events, as well as future mountain pine beetle epidemics.

As such, there are three “climate-smart” techniques to reduce vulnerability of ecosystems to climate change (Nitschke & Innes, 2008). The first is pre-commercial thinning, which will be mainly utilized for the reduction in stand density to optimise growth of remaining trees (Nitschke & Innes, 2008). Commercial thinning is another technique used to lower competition and accelerate growth of residual trees. This technique would allow for reductions in stress that may be found in the systems. Consequently, with an expected increase in drought systems for the foreseeable future, commercial thinning would reduce water stress and can aid in reducing tree mortality that may be affected by other factors such as bark beetle attacks (Nitschke & Innes, 2008). The third technique involves fuel reduction actions to reduce fuel loads in both the surface and the canopy to reduce the potential for crown fires (Nitschke & Innes, 2008). These techniques will be key to achieve the objective of not only reduction surface fuel loads, but also maintain ecosystem resilience as it benefits biodiversity and other forest resources in response to climate change (Nitschke & Innes, 2008).

British Columbia is also composed of many mixed-severity fire regimes, particularly dry forests located near mountainous regions. Climate change in certain areas may not be the superceding factor that can overrule fuel mitigation efforts – for example, in their study located in the East Kootenay, Daniels and Gedalof (2012) discussed that fires burned in the area occurred more frequently than expected during the warm years of the Pacific Decadal Oscillation (PDO). However, Da Silva (2009) disputes the fact that such climatic conditions caused by changes in ocean temperatures, including the El Nino Souther Oscillation (ENSO) and the Atlantic Multidecadal Oscillation (AMO) do not significantly affect drought and fire. Therefore, although it is important to not only continue to support fuel mitigation programs and fire restoration through techniques such as thinning and prescribed burns in the many low- and mid-elevation forests (Daniels & Gedalof, 2012), it is also important to continue the ongoing research and conversation in regards t PDOs, ENSOs, and AMOs, and how they may affect fuel mitigation treatments at a local and regional scale.

Overall ecosystem health must also be considered alongside with fuel management. According to Commission of Public Lands for the State of Washington Peter Goldmark, there is a forecast of increasing tree mortality spanning 900,000 hectares spanning over Washington, and this is also forecasted to happen in British Columbia (Gray, 2012). With a big landscape that is predicted to have a declining forest health trend, it is important to reiterate ecosystem restoration, sustainability and resiliency techniques with an accelerating rate of climate change. Gray (2012) focuses on reducing stresses to the system by reducing stand density to lessen severe self-thinning operations, and consequently lessening competition for moisture, nutrients, and sunlight and allow for more growing space. Gray (2012) proposes that in order for to secure forest resiliency and ecosystem sustainability for future generations, the bioenergy sector is a segment to look into as the material needed from forests has a raw resource value. With the intense fire suppression British Columbia has experienced over the past couple decades, considerable volumes of biomass on the landscape are currently not being accessed, and will remain to be a considerable hazard because of the electricity market and its limitations while the provincial government and the industry sector attempt to identify all available sources of low-cost feedstock in the current system (Gray, 2012). As such, it may be important to target market factors such as the electricity market and other forms of energy markets to sustainably manage and build resiliency in the forest ecosystem in order to mitigate fuels across the landscape (Gray, 2012).

Conclusion

Fire remains to be an integral function in our ecosystem as it provides ecological components to the forest structure that contributes to building ecosystem resilience. Fire suppression has resulted in the buildup of surface and ladder fuels, and thus not only are high costs at high stake were a stand-replacing fire event to occur, but it would also alter the natural fire regime. Although there are several fuel mitigation treatments to reduce fire risk and fuel load such as mechanical harvesting, prescribed burn, or a combination of mechanical harvesting and prescribed burn, all treatments should be subject to local sites in order for to reduce fire intensity, severity, and behaviour. In addressing climate change and whether it greatly affects fuel mitigation treatments, climatic conditions need to be continually researched for further dialogue on whether they are significant forces driving drought systems and fire events, especially if large fires continue to occur across a fuel-treated landscape.

Literature Cited

Arsenault, A., & Klenner, W. (2003). *Fire regime in dry-belt forests of British Columbia: Perspectives on historic disturbances and implications for management*. Available from http://www.trench-er.com/public/library/files/arsenault-klenner.pdf

Association of BC Forest Professionals. (2005). *Forest fires in British Columbia: How policies and practices lead to increased risk*. Retrieved from http://www.abcfp.ca/publications_forms/publications/documents/PositionPaper_Fire%20Management(July%202005).pdf

Brooks, M.L. (2008). Chapter 3: Plant invasions and fire regimes. Gen. Tech. Rep. RMRS-GTR-42. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 14p. Retrieved from http://www.fs.fed.us/rm/pubs/rmrs_gtr042_6_033_046.pdf

Da Silva, E. (2010). *Wildfire history and its relationship with top-down and bottom-up controls in the Joseph and Gold Creek watersheds, Kootenay mountains, British Columbia.* (Order No. MR64609, University of Guelph (Canada)). *ProQuest Dissertations and Theses*, 139. Retrieved from http://search.proquest.com/docview/745592540

Daigle, P. W., & Dymond, C. C. (2010). *The carbon conundrum – Fire and fuel management in fire-prone forests*. Available from http://trench-er.com/public/library/files/carbon-climate-change-wildfire-restoration.pdf

Daniels, L. D. (2004). *Climate and fire: A case study of the Cariboo forest, BC*. Available from http://www.trench-er.com/public/library/files/climate-fire-cariboo.pdf

Daniels, L. D., & Gedalof, Z. (2012). Mixed-severity fire regimes in the dry forests of British Columbia: Historical reconstructions using tree-ring evidence [Report to Ecosystem Restoration, Ministry of Forests, Lands and Natural Resource Operations, Victoria, BC]. March 2012. 21p.

Evans, A. M., Everett, R. G., Stephens, S. L., Youtz, J. A. (2011). *Comprehensive fuels treatment practices guide for mixed conifer forests: California, central and southern Rockies, and the southwest*. Retrieved from http://www.firescience.gov/projects/09-2-01-7/project/09-2-01-7_final_report.pdf

Gedalof, Z. (2012). Fire and biodiversity in British Columbia. In Klinkenberg, Brian. (Editor) 2013. Biodiversity of British Columbia [www.biodiversity.bc.ca]. Lab for Advanced Spatial Analysis, Department of Geography, University of British Columbia, Vancouver. Retrieved from http://www.geog.ubc.ca/biodiversity/FireandBiodiversityinBritishColumbia.html

Gray, R. W. (2012). *Tree trouble in BC: Forest health dictates that we make more of the biomass available*. Available from http://trench-er.com/public/library/files/Canadian-Biomass-Tree-Trouble-BC-GRAY.pdf

McIver, J., Erickson, K., & Youngblood, A. (2012). Principle short-term findings of the national Fire and Fire Surrogate study. Gen. Tech. Rep. PNW-GTR-890. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 210p. Retrieved from http://www.fs.fed.us/pnw/pubs/pnw_gtr860.pdf

McIver, J., Weatherspoon, P. & Edminster, C. (2001). Alternative restoration treatments in the western United States. Pages 104-109 In: Ponderosa pine ecosystems restoration and conservation: Steps toward stewardship, April 25-27, 2000, Flagstaff, AZ. Proceedings RMRS-P-22. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. Retrieved from http://www.frames.gov/documents/ffs/ffs008_mciver_general.pdf

Meidinger, D. (1991). Terrestrial vegetation of British Columbia. In Klinkenberg, Brian. (Editor) 2013. E-Flora BC: Electronic Atlas of the Flora of British Columbia [eflora.bc.ca]. Lab for Advanced Spatial Analysis, Department of Geography, University of British Columbia, Vancouver. Retrieved from http://www.geog.ubc.ca/biodiversity/eflora/Terrestrial Vegetation.html

Ministry of Forests, Mines and Land. (2010). The State of British Columbia's Forests, Third Edition. Forest Practices and Investment Branch, Victoria, B.C. Retrieved from http://www.for.gov.bc.ca/hfp/sof/2010/SOF_2010_Web.pdf

Mitchell, S. R., Harmon, M. E., & O'Connell, K. E. B. (2009). Forest reduction alters fire severity and long-term carbon storage in three Pacific Northwest ecosystems. *Ecological Applications, 19*, 643 – 655. http://dx.doi.org/10.1890/08-0501.1

Natural Resources Canada. (2014). *Forest carbon*. Retrieved from http://www.nrcan.gc.ca/forests/climate-change/13085

Nitschke, C. R.,& Innes, J. L. (2008). Integrating climate change into forest management in south-central British Columbia: An assessment of landscape vulnerability and development of a climate-smart framework. *Forest Ecology and Management, 256*(3), 313-327. http://dx.doi.org/10.1016/j.foreco.2008.04.026

Oliver, M. (2009). Bioenergy from trees: Using cost-effective thinning to reduce forest fire hazards. *Science Findings, 117*, 1-5. Retrieved from http://www.fs.fed.us/pnw/sciencef/scifi117.pdf

Parker, B., & Bennett, M. (2005). *Reducing hazardous fuels on woodland properties: Thinning*. Retrieved from http://oregonforests.org/sites/default/files/Haz_Fuels_Thinning_LF.pdf

Schoennagel, T., Veblen, T. T., & Romme, W. H. (2004). The interaction of fire, fuels, and climate across Rocky Mountain forests. *Bioscience*, *54*(7), 661-676. http://scholarsarchive.library.oregonstate.edu/xmlui/bitstream/handle/1957/17533/The%20interaction%20of%20fire%20fuels%20and%20climate.pdf?sequence=1

Schwilk, D. W., Keeley, J. E., Knapp, E. E., McIver, J., Bailey, J. D., Fettig, C. J., . . . Youngblood, A. (2009). The national Fire and Fire Surrogate study: Effects of fuel reduction methods on forest vegetation structure and fuels. *Ecological Applications, 19*(2), 285-304. Retrieved from http://www.jstor.org/stable/27645971

Switzer, J. M. (2011). *Thinning and prescribed fire for ecosystem restoration in Rocky Mountain forests of BC: Changes in physical, chemical and biological properties of forest floors and soil*. Available from http://trench-er.com/public/library/files/treatment-effects-soil-photos.pdf

Taylor, S. W., Pike, R. G., & Alexander, M. E. (1996). *Field guide to the Canadian forest Fire Behavior Prediction (FPB) system*. Retrieved from http://www.for.gov.bc.ca/hfd/pubs/docs/Frh/Frh012.pdf

Wildfire Management Branch. (2014). *Prescribed fire*. Retrieved from http://bcwildfire.ca/prevention/PrescribedFire/

Wildfire Management Branch. (2012). *Wildfire Management Branch: Strategic plan 2012 – 2017*. Retrieved from http://bcwildfire.ca/Strategic_Planning/docs/Wildfire%20Management%20Strategic%20Plan%202012_17.pdf

Youngblood, A., Metlen, K. L., Knapp, E. E., Outcalt, K. W., Stephens, S. L., Waldrop, T. A., & Yaussy, D. (2005). Implementation of the fire and fire surrogate study – A national research effort to evaluate the consequences of fuel reduction treatments. In: Peterson, C. E. & Maguire, D. A., eds. Balancing values: Innovative experiments for sustainable forestry: Proceedings of a conference. Gen. Tech. Rep. PNW – 635. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 315-321. Retrieved from http://www.fs.fed.us/ne/newtown_square/publications/other_publishers/OCR/ne_2005_youngblood001.pdf

Appendix A: Brief Summary of the Short-term Findings of the National FFS Study

ND = Not Described

Location		Forest Type	Treatment(s)	Effectiveness		
				Reduced Fire Risk	Reduced Fuel Mass	Fire Resiliency
Western United States	central California	Ponderosa pine, white fir	Mechanical (2002)	✓	✓	✓
			Burn (2002)	✓	✓	✓
			Mechanical + Burn	✓	✓	✓✓✓
	northeastern Oregon	Ponderosa pine, Douglas-fir	Mechanical (1998)	✓	✓	✘
			Burn (2000)	✓	✓✓✓	✓
			Mechanical + Burn	✓	✓✓	ND
	western Montana	Ponderosa pine, Douglas-fir	Mechanical (2002)	✓	✘	✓
			Burn (2002)	✓	✓	✓
			Mechanical + Burn	ND	✓	✓✓
	southern California*	Ponderosa pine, sugar pine, white fir	Burn (2002, 2003)	✓	✓	✓
	northern California	Ponderosa pine	Mechanical (2001)	✓	✓	✓
			Burn (2001)	✓	✓	✓
			Mechanical + Burn	✓	✓	✓✓

	northern Arizona	Ponderosa pine	Mechanical (2003)	✓	✘	ND
			Burn (2003)	✓	✓	ND
			Mechanical + Burn	✓	ND	ND
	northeastern Washington	Ponderosa pine, Douglas-fir, grand fir	Mechanical (2001)	✘	✓	✓
			Burn (2004)	✘	✘	ND
			Mechanical + Burn	✓✓	✓	✓
Eastern United States	southern Ohio	Mixed oaks	Mechanical (2001)	ND	✓	ND
			Burn (2001)	✓	✘	✘
			Mechanical + Burn	✓	✓	ND
	southwest North Carolina	Hickory, oaks, shortleaf pine	Mechanical (2001-2002)	✓	✓	✓
			Burn (2003, 2006)	✓✓	✓	✓
			Mechanical + Burn	✓✓✓	✓	✓✓
	south central Alabama	Longleaf pine	Mechanical (2002)	✓	✓	✓
			Burn (2002)	✓	✓	✓
			Mechanical + Burn	✓	✓	✓
	northwestern South	Loblolly pine, shortleaf pine	Mechanical (2000-2001)	✓	✘	✓

	Carolina		Burn (2001, 2004)	✓✓	✓	✓✓
			Mechanical + Burn (2002, 2005)	✓✓	✓	✓
	southern coastal Florida	Longleaf and slash pine	Mechanical (2002)	ND	✓	ND
			Burn (2000, 2001)	ND	ND	✓✓
			Mechanical + Burn	ND	ND	ND