Forests, fire histories, and futures of Columbian and Rocky Mountain forests, western Canada

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Abstract: *Throughout the past few decades, shifting perspectives on fire management have led to the recognition that disturbance by fire is critical in maintaining ecological resilience in fire-adapted forests and grasslands. Long-term fire histories provide important information for land and resource managers seeking to understand the controls on wildfire dynamics in western North America. In this paper we summarize fire history research that has recently been undertaken in the Canadian Cordillera. Using proxy records to reconstruct fire activity and vegetation change, these studies shared the overarching goal of identifying factors that control long-term fire regimes. A further aim was to identify how human activity has measurably altered various aspects of fire regimes. Looking to the future, these studies highlight the need to continue integrating information about local fire regimes and historical land-use activities when developing responsible fire and resource management strategies and identifying conservation priorities.*

Introduction

During the Holocene in western Canada, forest compositions, structures, and disturbance regimes have varied in response to biotic and abiotic processes. Paleoecological records of the post-glacial range expansion of conifers have shown that trees typically migrated from southern refugia early in the Holocene as climate and dispersal limitations were overcome (McLeod et al. 1997). Climatic conditions suitable for forest reestablishment likely emerged between 17,000 and 14,000 yr BP (McLeod and MacDonald 1997) and most arboreal species reached their post-glacial extents by ca. 8000 BP (MacDonald 1989; Pisaric et al. 2003). Climatic and dispersal constraints controlled forest compositions at a large scale, and modern species assemblages established by the mid-Holocene, ca. 5000 - 4500 yr BP (Luckman et al. 1986; MacDonald 1989; Beaudoin et al. 1990; Hebda 1995; Gavin et al. 2006; Courtney Mustaphi et al. 2014b). Throughout several millennia, human occupation and land use have co-evolved with the development of western forest systems.

The recent histories of western forests are characterized by the steadily increasing influence of human activities on forest composition, extent, and disturbance regimes. These forests have been particularly influenced by the use of fire by Indigenous peoples (Barrett et al. 1982; MacLaren 2007), European settlement and colonial forestry activities (Troup 1932; Brownstein 2016), and industrial forestry and modern management (Keane et al. 2002; Munteanu et al. 2015). At present, several additional pressures are being exerted on these and forests including global climate change impacts (Flannigan, Krawchuk, et al. 2009; Krawchuk et al. 2009), and an increasing human population and a more complex wildland-urban interface (WUI) (McGee 2007), and differing land and resource management perspectives. Understanding the socio-ecological dynamics of these forests is crucial to developing evidence-based and outcomes-oriented management plans and objectives (Arno et al. 2000; Bergeron et al. 2004) to optimize the natural capital benefits to community economic development (Markey et al. 2005), conservation, and non-pecuniary values.

Fire histories and management in western Canada

Fire protection policies were initiated in Canada in the early 20th century, spurred by a series of severe fire seasons that occurred in the late 1890s and early 1900s (Flannigan, Stocks, et al. 2009). The development of modern firefighting technologies has enabled a significant reduction in the overall extent and severity of wildfires in many parts of western Canada since the European settlement era (Tande 1979; Cochrane 2007; Dinh 2014). While intense suppression efforts were on-going throughout the 1900s, the ecological consequences of those same activities were largely overlooked due the gradual nature of their emergence (Keane et al. 2002). Wildfire is an important ecological process in the western forests of North America. It is crucial for maintaining landscape heterogeneity (Rhemtulla et al. 2002; Chavardès et al. 2016), biogeochemical cycling (McLauchlan et al. 2014), disruption of pests (Axelson et al. 2010), and is important for the success of certain taxa (e.g., Pinus albicaulis; Tomback et al. 2001; Moody 2006). Accordingly, fire suppression in western landscapes has contributed to changes in forest stand composition and structure, transformed wildlife habitat, and has altered nutrient and water cycling (Keane et al. 2002). Further, increasing fuel loads as biomass accumulates in unburned areas (Bowman et al. 2013) and thickening of woody plants in rangelands that are not subject to frequent, low-intensity burning, increase the likelihood of hazardous fires occurring that are difficult to control. The risk of large and severe wildfires is also amplified by the effects of on-going climate change. Longer, and thus more severe fire seasons are expected for the interior and southern Cordillera of western Canada as temperatures continue to rise (Wang et al. 2015). As the fire risk grows, traditional management (suppression) activities are likely to become “ecologically and economically unsustainable” (Bowman et al. 2013).

In the past several decades, the ecological consequences of long-term fire suppression have emerged, and land and resource managers have begun to recognize the integral role of wildfire in maintaining healthy forests and grasslands (MacLaren 2007; Flannigan, Stocks, et al. 2009; Theberge et al. 2015). Attitudes have begun to shift towards more sustainable fire management policies (e.g., prescribed fire, forest thinning, allowing fires to burn unimpeded when possible), and so too has the information used to guide decision making processes. A series of ongoing projects with the primary aim of identifying biotic and abiotic factors that have historically been important drivers of local-regional fire regimes in the Canadian Cordillera. By providing a better understanding of the processes that influence wildfires over various spatial and temporal scales, these studies can provide a scientific basis to inform on-going land and resource management, conservation, and fire control policy throughout the region.

Ongoing research in the Columbia and Rocky Mountain forests

There have been multiple studies published on the postglacial and recent histories of forests in southeastern British Columbia and western Alberta (Table 1; Figure 1). These include lake sediment studies of subfossil plant remains and dendrochronological studies of tree rings to examine how the forests evolved over time and to understand the long-term environmental processes. By analyzing ecological proxies preserved in the sediment deposited on lake bottoms, lake sediment analysis has been used to examine interactions between Holocene climate, infrequent high severity fires, and vegetation changes (Gavin et al. 2006; Hallett et al. 2006; Courtney Mustaphi et al. 2013; Davis et al. 2016; Stretch 2016). Using information gleaned from the tree-ring records of dead and living trees, dendrochronological studies have used fire scars and forest-stand establishment dates to reconstruct spatially explicit fire histories at the centennial scale. These studies have informed us of how stand age structures emerge following fire events, and combining extensive fire scar sampling with stand-ages has permitted analyses of mixed-severity fire regimes (Nesbitt 2010; Greene 2011; Marcoux et al. 2013; Marcoux et al. 2015). The influence of climate on pest and disease cycles remains an important focus and there are emerging paleoenvironmental tools for examining these dynamics over long time periods (Daniels et al. 2011; Morris, Courtney Mustaphi, et al. 2015; Morris, McLauchlan, et al. 2015).

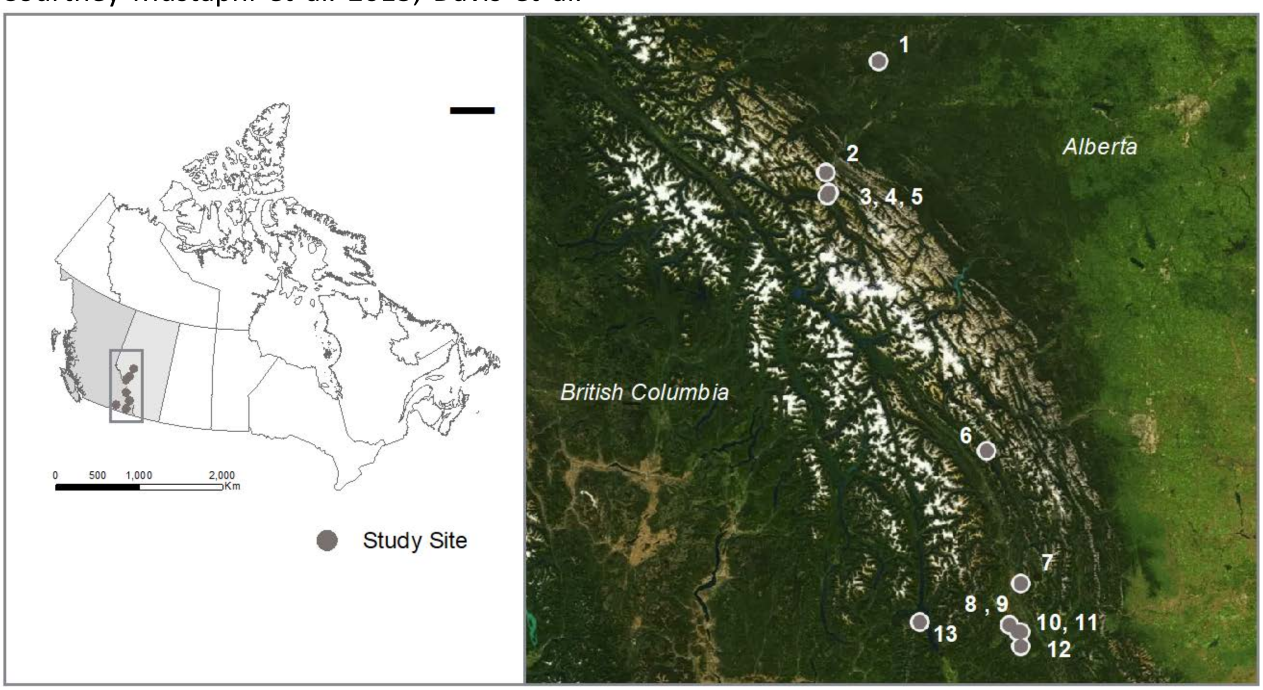

Figure 1 Several fire history studies have recently been completed in the Canadian Cordillera of Alberta and British Columbia, Canada (see Table 1 for corresponding references).

Table 1 Location of fire history studies and primary methods used (**[n]** Corresponds to study sites in Figure 1).

Paleolimnology		
Methods	*Study Area*	*Reference*
Palynology, macroscopic charcoal, sedimentology	Columbia Mountains, southeastern B.C.	Courtney Mustaphi (2013); Courtney Mustaphi and Pisaric (2013); Courtney Mustaphi and Pisaric (2014); Courtney Mustaphi et al. (2015) [13]
Macroscopic charcoal morphologies	Pyatts Lake, Rocky Mountain Trench, southeastern B.C.	Courtney Mustaphi and Pisaric (2014) [8]
Diatoms, biogenic silica, Chl *a*, sedimentology	Jasper National Park, AB; Hinton Wood Products Forest Management Area, Hinton, AB	Gall (2016) [5]
Dendrochronology		
Methods	*Study Area*	*Reference*
Fire scars, tree ages, stand structure	Jasper National Park (north of townsite), AB	Chavardès (2014); Chavardès and Daniels (2015) [2]
Fire scars	Southern Rocky Mountain Trench, southeastern B.C.	Cochrane (2007) [7]
Fire scars, species distributions	Joseph and Gold Creek Watersheds, East Kootenay Mountains, B.C.	Da Silva (2009) [10]
Fire scars	Jasper National Park (townsite), AB	Dinh (2014) [4]
Fire scars, tree ages, geospatial analysis, disturbance classification	Darkwoods, South Selkirk Natural Area, southeastern B.C.	Greene (2011); Greene et al. (2014) [9]
Fire scars, tree ages, stand structure	Kootenay Valley, Kootenay National Park, B.C.	Kubian (2013) [6]
Fire scars, tree ages	Nelson, B.C.	Nesbitt (2010) [12]
Fire scars, tree ages, stand structure, disturbance classification	Joseph and Gold Creek Watersheds, East Kootenay Mountains, B.C.	Marcoux et al. (2013; 2015) [11]
Multiple Proxies		
Methods	*Study Area*	*Reference*
Fire scars, tree ages, macroscopic charcoal, palynology, sedimentology	Jasper National Park (townsite), AB	Davis et al. (*in press*) [3]
Fire scars, tree ages, stand structure, macroscopic charcoal, sedimentology	Hinton Wood Products Forest Management Area, Rocky Mountain foothills, Hinton, AB	Stretch (2016); Stretch et al. (2016) [1]

The information about local-regional fire regimes is notable and has wide ranging implications for the development of policy around wildfire and resource management.

In the montane ecoregion of Jasper National Park, dendrochronological analyses have been used to examine the recent fire histories using stand establishment data and records of fire events preserved in fire scars (Dinh 2014; Chavardès and Daniels 2016; Davis et al. 2016). These fire histories have helped to reveal the extensive influence of humans on the fire regime in Jasper. Chavardès and Daniels (2016) found evidence of a significant decrease in fire activity since the onset of fire suppression era and an overall homogenization of the forest system studied. Dinh (2014) saw a similar decrease in fire activity in the latter half of the 20^{th} century in Jasper, as well as a shift in the seasonality of fire events. They attribute this shift from early season to late season fires to the relocation of Indigenous peoples, who used regularly used fire as a land management tool, from the park in 1910 (MacLaren 2007; Dinh 2014). Many of the impacts of modern fire suppression are now widely documented (e.g., homogenization of forest system, reduction in overall fire activity, loss of grassland extent, change in seasonailty of surface fires; Rhemtulla et al. 2002; Dinh 2014; Chavardès and Daniels 2016; Davis et al. 2016), such that the reintroduction of wildfires to this protected landscape has emerged as an important and on-going conservation issue in Jasper (Parks Canada Agency 2015). Fire management is a challenging process in Jasper and other protected areas in Canada. Disturbance by wildfires is required in order to maintain "ecological integrity", a federally mandated objective of national parks, but this must be balanced with the need to protect human life, infrastructure, and recreational opportunities for visitors (Theberge et al. 2015).

Further south, in southeastern British Columbia, several tree-ring studies have been conducted to investigate various aspects of the local fire regimes. Working in the Joseph and Gold Creek watersheds, Da Silva (2009) found evidence of reduced fire activity and landscape homogenization in their 33 study plots. Taken together, it is suggested that this has set up the conditions for the increased risk of large, high-severity fires occurring at the region's wildland-urban interface. Working in the same watershed areas, Marcoux et al. (2015) used dendrochronological techniques to identify the type of fire regimes characteristic of the surrounding forest. Their research determined that a significant portion of the study area is typified by mixed-severity fire regimes, where fires of differing severities overlap spatially. Until recently, the extent of mixed-severity fire regimes in the Canadian Rocky Mountains has been largely overlooked (Marcoux et al. 2013), a significant oversight given the species diversity and complex forest structures associated with the regime type (Arno et al. 2000). Accurately identifying the variability of a fire regime is a necessary step for developing fire management plans that reflect typical frequency, size and severity of fires in a given area. Finally, in their study area in Rocky Mountain trench near the Purcell Mountains, Cochrane (2007) identified a decline in fire activity in the contemporary suppression era compared to the period of European settlement when fire activity was at its modern peak. Notably, they also found significant variability in fire activity between study plots, suggesting that a single, overarching fire management prescription would be unsuitable for the area.

Long-term records of climate, vegetation composition, and fire history have now been developed for many areas of the western Cordillera using lake sediment analysis (Courtney Mustaphi and Pisaric 2013; Courtney Mustaphi and Pisaric 2014b; Davis et al. 2016; Gall 2016). Focusing on longer time scales than tree-ring analysis, these studies have revealed important interactions between fire activity and local-regional environmental conditions. Working in the Columbia Mountains of southeastern British Columbia, Courtney Mustaphi and Pisaric (2013) developed 5000 yr fire histories for three lakes in the region, and found that local factors such as slope aspect, as well as top-down factors, such as regional climate, were important in determining the frequency of fire events over time. Further, their work has also identified forest biomass to be an important driver of fire activity, such that biomass and fuel accumulation can serve as a triggers of fire activity (Courtney Mustaphi and Pisaric 2014b). Long-term fire histories such as these are rich sources of information for developing fire management strategies that are based on emulating the historical range of variability (HRV) in disturbance regimes (Davis et al. 2016). An HRV approach to fire management involves reintroducing fire in a manner that is reflective of the general fire regime of the area (Keane et al. 2009). Information derived from lake sediment cores about the type and frequency of wildfires can be used as baseline data during conservation efforts in fire-suppressed landscapes.

Combining information from lake sediment records with dendrochronology offers an opportunity to understand factors of the wildfire regime over multiple spatial and temporal scales (Davis et al. 2016; Stretch 2016; Stretch et al. 2016). For example, in the Hinton Wood Products Forest Management Area (FMA) in the foothills region of west-central Alberta, Stretch (2016), combined records of macroscopic charcoal preserved in lake sediment with dendrochronological sampling of the surrounding forest. The results of their research provided evidence of a mixed-severity fire regime in the region. Furthermore, they demonstrated that traditional methods of classifying fire events are biased against the detections of mixed-severity fires (Stretch 2016). This information can now be used to inform management strategies during resource extraction in the forest management area. Listed as being at high to extreme risk of wildfire, the Hinton Wood Products FMA is currently being harvested using silviculture practices that attempt to mimic natural disturbances, such as wildfire (Hinton Wood Products 2010; Stretch 2016).

Conclusions and Future Directions

The need for science for to inform restoration activities is significant in degraded ecosystems worldwide (Suding 2011). Paleoecology, which includes lake sediment and tree-ring analyses, presents an opportunity to determine baselines and ecosystem variability and to inform conservation strategies (Froyd et al. 2008). There remain new opportunities for emerging techniques to further enhance our understanding about historical fire regimes. In particular, opportunities exist to advance methods of analysis to glean new information from both tree-ring and lake sediment proxy data. For example, examining the morphology of charcoal particles preserved in lake sediment offers insights into vegetation structure (open versus closed forests), fire regimes (severity, burned area), or charcoal taphonomy (transport and deposition) to the lake system over time (Courtney Mustaphi et al. 2014a). Further, in recognition of the need to understand ecological processes at multiple spatial and temporal scales, opportunities exist for further integration of lake sediment analyses with tree-ring sampling. Tree-ring analyses offer relatively short-term (hundreds of years) fire histories at a high temporal and spatial resolution, whereas lake sediment analysis provides information about climate, vegetation, and fire over long time periods (thousands of years) at a low resolution. Combining these techniques in a single fire history study helps to overcome the limitations imposed by each proxy type (e.g., Davis et al. 2016; Stretch 2016).

Overall, improvements in the techniques used to collect and analyze proxy data have made a significant amount of information available regarding the recent and long-term history of fire regimes in western Canada. One area of fire history research in particular that deserves further attention is in identifying approaches for integrating the cultural, economic, and societal values of western forests with the type of information derived from tree-ring and lake sediment analyses. The most thorough classifications of the historical fire regime are of little socio-ecological value if the information cannot be translated to management or restoration activities. Fire and land management goals differ significantly depending on the stakeholders involved in the decision making process. For example, the fire history information required by protected area managers is used to help reintroduce fire in a way that reflect the historical range of variability in the fire regime of the area, whereas the aim of resource managers is to continue harvesting activities in a manner that emulates disturbance by fire. Accordingly, the associated costs (economic, ecological, and societal) of prescribed burning or reducing suppression efforts will be viewed differently in protected areas (e.g., national or provincial park) relative to a timber extraction context. Identifying the objectives of management activities from the outset will remain an essential consideration for future fire history studies in the Canadian Cordillera.

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