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# Dry forests in the Southern Interior of British Columbia: Historic disturbances and implications for restoration and management

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ABSTRACT

We critically examine the hypothesis that dry forests in southern British Columbia evolved in the context of a low-severity fire-dominated disturbance regime, that fire suppression has led to ecological conditions which are radically different from the past, and that "restoration" initiatives are required to re-establish former ecological conditions. Four sources of information were used to infer historic disturbance regimes and forest condition and to quantify the nature of disturbance since the early 1900s: (1) patterns of annual and seasonal weather and lightning strikes, (2) topographic variability, (3) records of wildfire, insect attack, and timber harvesting practices, and (4) early systematic forest surveys.

Our analyses consistently indicate that historic natural disturbances were likely diverse and episodic at multiple spatial and temporal scales. High seasonal and annual variability in weather and the number of lightning strikes in complex topography suggest that a widespread low-severity fire regime is very unlikely, with a mixed-severity disturbance regime more consistent with our analyses. Although the nature of disturbance has changed from one largely dominated by fire and insect attack historically to harvesting and insect attack since 1950, the area disturbed annually has not diminished. Several interacting factors including climate, extensive fires coincident with European settlement, harvesting, fire suppression and insect attack have been key drivers in creating the conditions observed today. A complex, mixed-severity disturbance regime creates uncertainty about what represents "natural" forest conditions, or what the target conditions for restoration activities are if the objective is to "restore natural conditions". We conclude that dry forest ecosystems in British Columbia typically experienced mixed-severity disturbance regimes that included fire, bark beetles and defoliators. Trying to "restore" these forests with applications of frequent, low-severity fire is not an ecologically sound objective over large areas. Landscape management should focus on maintaining forest heterogeneity that would have existed historically under a mixed-severity disturbance regime.



## 1. Introduction

Since the early work of Leopold (1924), appropriate management of dry forest ecosystems in North America has been the subject of ongoing debate. Numerous studies from the south and western United States (Weaver, 1943; Cooper, 1960; Covington and Moore, 1994; also see reviews in Allen et al., 2002; Baker et al., 2007) provide evidence supporting the view that prior to settlement by Europeans, ponderosa pine (*Pinus ponderosa* Laws) forests in this area were often composed of stands with a widely-spaced overstory, a vigorous growth of grasses and forbs in the understory, and experienced frequent low-severity fires. Fire suppression or exclusion in this area (which began in the early 1900s but was not effective until the mid-1900s; Allen et al., 2002) is thought to have contributed to several structural changes including increases in the density of trees (Covington and Moore, 1994), shifts in tree species composition (Weaver, 1943), shifts in grassland-forest ecotones (Arno and Gruell, 1983), and an increase in forest fuels and fire severity (Covington, 2000).

At higher elevations and more northern latitudes across the range of ponderosa pine and in mixed stands that include Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), lodgepole pine (*P. contorta* Dougl.) or western larch (*Larix occidentalis* Nutt.), the historic range of natural variability for dry forests is far less certain. Shinneman and Baker (1997), Baker and Ehle (2001), Heyerdahl et al. (2001), Ehle and Baker (2003) and Sherriff and Veblen (2007) document spatially and temporally complex fire regimes in ponderosa pine dominated forest. The occurrence of such mixed- or moderate-severity fire regimes (Agee, 1993, 1998; also termed variable severity fires in Baker et al., 2007) in more productive

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habitats or topographically complex areas creates uncertainty about natural or historic forest conditions. Forests that historically experienced mixed- or high-severity fire regimes are less likely to be in a structural condition that is outside the historic range of natural variability (Baker et al., 2007), and ponderosa pine forests in areas like the Colorado Front Range fall into this category (Sherriff and Veblen, 2007).

In British Columbia, there is little published information on disturbance history in dry forest ecosystems and no work that has evaluated disturbance regimes systematically across these forests in the Southern Interior. Arsenault and Klenner (2005) concluded the evidence of disturbances they examined suggested a mixed-severity fire regime, while Heyerdahl et al. (2007) reported evidence of a frequent, low-severity fire regime in their study in southwestern British Columbia. Despite the lack of information on frequency and severity of historic disturbance in BC's dry forests, calls have been made for widespread and intensive "restoration" efforts to return dry forests to "natural" conditions (Daigle, 1996; Gayton, 1996; Filmon, 2004). The concern over this perceived "unnatural change" has increased over the last decade primarily because of recent large fire events and pest outbreaks in the western United States (Romme et al., 2006), widespread and severe outbreaks of mountain pine beetle and western pine beetle (*Dendroctonus ponderosae* and *D. brevicomis*) in British Columbia (Maclauchlan et al., 2006), and numerous large wildfires in British Columbia in 2003 (Filmon, 2004). Social perceptions of "unnatural" conditions may also be exacerbated by an increasingly populated wildland urban interface area (Dombeck et al., 2004). Debate has centred on whether recent large-scale disturbances result from widespread and abnormal structural changes to dry forest ecosystems or are simply the result of weather conditions. More specifically, are the dry forests in southern British Columbia outside their historic range of natural variability or are wildfire and insect attacks the consequence of a non-equilibrium disturbance regime with high spatial and temporal variability (e.g. Botkin, 1990; Sprugel, 1991; Shinneman and Baker, 1997)?

A clear understanding of disturbance regimes is necessary prior to undertaking restoration treatments (e.g. Schoennagel et al., 2004) because the inappropriate application of treatments may threaten site productivity and diminish the abundance of critical habitat structures (Tiedemann et al., 2000; Feller, 2005). Due to the lack of information on disturbance regimes in the dry forests and grasslands of southern British Columbia, an alternative approach is warranted to establish a technical basis for the management of these ecosystems prior to implementing costly restoration programs. We critically examine the hypothesis that, historically, dry forests in southern British Columbia were shaped largely by a frequent low-severity fire regime. Because direct information on the historic fire regime at multiple, unbiased sites is not available, we examine indirect evidence relating to controls of fire regimes that affect fire size, frequency and severity, and direct information about disturbances and historic forest condition from early surveys and annual reports.

## 2. Study area

The study area is located in southern British Columbia and covers approximately 7.5 million ha, of which 2,550,170 million ha is dry forest and grassland in the Bunchgrass, Ponderosa pine and Interior Douglas-fir biogeoclimatic zones (Fig. 1; Lloyd et al., 1990). These dry grasslands and forests generally occur at low elevations (under 1200 m a.s.l.) and usually have a lower canopy closure than forests at higher elevations that receive more precipitation. Frequent low-severity, "stand-maintaining" fires are thought to have played a key historic role in shaping these ecosystems. In western North America, forests of ponderosa pine or Douglas-fir are widespread from Mexico to southern British Columbia as pure stands or as mixtures with other species such as larch, grand fir (*Abies grandis* (Dougl. Lindl.)) or lodgepole pine. Open grassland and pure stands of ponderosa pine represent a minor component of the study area (393,824 (15.4%) and 254,554 ha (10%) respectively) with Douglas-fir, Douglas-fir and ponderosa pine, or Douglas-fir and lodgepole pine or western larch (primarily in the southern half of our study area) mixtures being the most common (1,901,792 ha).

## 3. Methods

We evaluated two regional ("top-down") controls (Lertzman et al., 1998; Heyerdahl et al., 2001) of fire regimes, weather and lightning, and one local ("bottom-up") control, topography, to assess whether these controls exhibit characteristics likely to create and maintain a frequent, low-severity fire regime in dry forests across our study area (Table 1). Several components of local and regional weather including temperature, precipitation, relative humidity, and extended periods of drought are widely recognized as key factors that affect fire regimes (Flannigan and Harrington, 1988; Bessie and Johnson, 1995; Nash and Johnson, 1996; Flannigan and Wotton, 2001; Hely et al., 2001; Flannigan et al., 2005). Lightning is the primary non-anthropogenic ignition source and both the timing and nature of lightning strikes influence fire regimes (Nash and Johnson, 1996; Latham and Williams, 2001; Wierzchowski et al., 2002). Topography, a local or "bottom-up" control, was examined since numerous studies in western North America indicate that the frequency and severity of fires can be strongly affected by slope, aspect and elevation (Agee, 1993; Larsen, 1997; Taylor and Skinner, 1998; Heyerdahl et al., 2001, 2007).

### *3.1. Patterns of annual and seasonal weather and lightning strikes*

The BC Ministry of Forests and Range (Protection Branch) maintains a system of weather stations and lightning strike sensors throughout the study area to facilitate early detection of wildfires, to develop fire hazard ratings and to predict fire behavior. Forty-nine weather stations were active across the grassland and dry forest areas between 1982 and 2006. We chose a centrally located weather station (Merritt: 50°5′N; 120°45′W) to illustrate the annual and seasonal variability in temperature, relative humidity, fine fuel moisture (FFMC, Fine Fuel Moisture Code; Van Wagner, 1987) and a composite index, the Fire Weather Index (FWI, a measure of frontline fire intensity; Van Wagner, 1987), that incorporates several weather variables and fuel moisture indices. Lightning strike data for 1982–1997 were acquired from the BC Ministry of Forests and Range (Protection Branch) provincial lightning detection network, and for 1998–2006, from the Canadian Lightning Detection Network maintained by Environment Canada.

### *3.2. Topography*

To evaluate topography, we created a digital elevation model (DEM) of the study area from 1:250,000 scale 25 m cells with slope and aspect information. These were then classified into four categories (gentle 0–20% slope, moderate 21–50%, steep 51–100%, very steep > 100%) and two aspect classes (warm = southeast to west [120–270°], cool = west to southeast [271–119°]) that were then derived from the overall DEM using ArcMap spatial analyst functions.

### *3.3. Observations on disturbances and forest conditions*

We reviewed historic documents and more recent forest inventory records for information on the timing, nature and

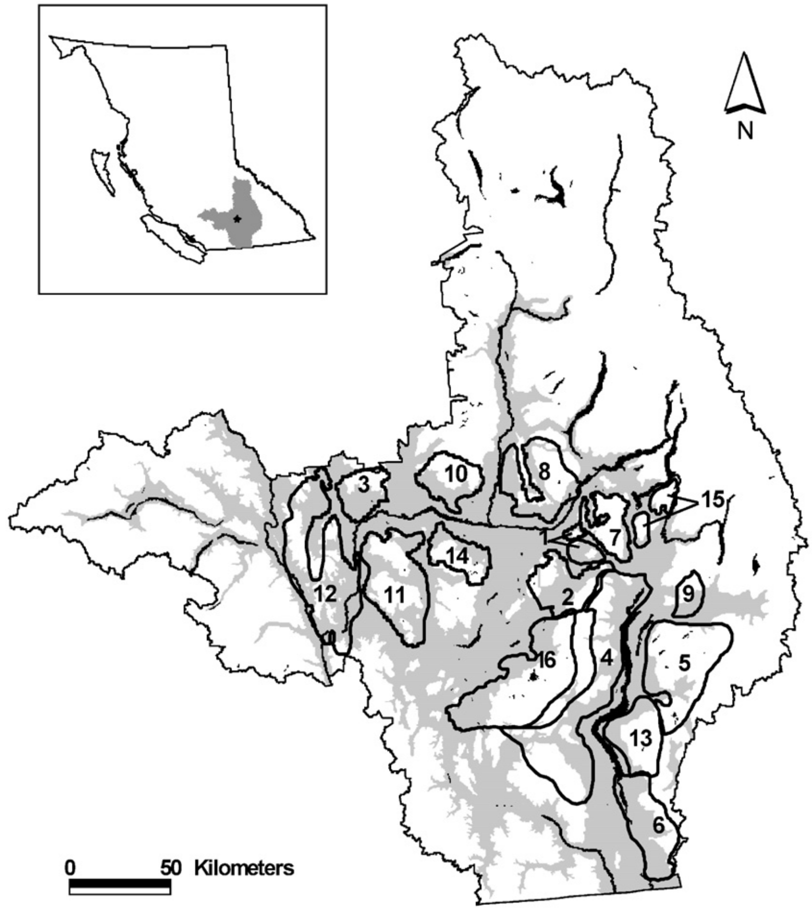


**Fig. 1.** Overview of the study area illustrating boundaries of Provincial Forest survey areas. Star on the inset diagram indicates the location of the city of Kamloops (51°45′N; 120°20′W) and grey shading delineates the extent of dry forest and grasslands. Provincial Forest survey areas: (1) Martin Mt.; (Hodgins, 1932a), (2) Monte Hills (Hodgins, 1932b), (3) Arrowstone (Hodgins, 1932c), (4) Okanagan (Anonymous, 1930), (5) Grizzly Hill (McGee, 1926), (6) Inkaneep (Stevens and Mulholland, 1925), (7) Fly Hill (Hodgins, 1932d), (8) Niskonlith (Andrews, 1932), (9) Aberdeen Mt. (McKee, 1926), (10) Tranquille (Andrews, 1931), (11) Nicola (Hodgins, 1932e), (12) Hat Creek (Hodgins, 1932f), (13) Little White Mt. (Stevens et al., 1925), (14) Long Lake (Hodgins, 1932h), (15) Mt. Ida and Larch Hills (Hodgins, 1932g) and (16) Pennask (Schultz, 1931).

**Table 1**
Ecological features and expected conditions required to support the frequent low-severity fire regime hypothesis in dry forests of southern British Columbia

| Feature | Conditions that would support the frequent, low-severity fire regime hypothesis |
|---|---|
| Weather | A low level of between year variability in temperature and moisture regimes during the snow-free period<br>Periods of extreme droughts are unlikely |
| Lightning | Low to moderate spatial and temporal variability<br>Lightning unlikely when weather conditions would promote catastrophic fires |
| Topography | Flat or gentle topography that allows fires to spread |
| Fires | Low variability in fire frequency (intervals 10–30 years)<br>Low-severity fires predominant |
| Other disturbances | Little evidence of other large-scale natural disturbance |
| Forest structure | Little evidence of dense even-aged stands<br>Open canopy condition predominant, primarily large trees with occasional patches of regeneration that escaped fires |

extent of fire and other disturbances. Historic survey documents were consulted for descriptions and photographs of forest conditions that would help interpret or reconcile statements made in these reports.

### 3.4. Fires

Due to the lack of direct empirical information on fire regimes across the dry forests in our study area, we reviewed Provincial Forest Survey reports (e.g. Hodgins, 1932a) for information on fires in dry forests, with a focus on return intervals during the 10 years preceding the survey, and observations or anecdotal observations of fire regimes in general. For 1919 to present, we assessed the area burned using historical fire records (1950–2006) maintained by the BC Ministry of Forests and Range, Protection Branch, and recent updates to this database (Taylor and Thandi, 2002; see http://cfs.nrcan.gc.ca/subsite/disturbance/sources). This information was supplemented with summaries from BC Forest Service Provincial Annual Reports for 1915–1950.

### 3.5. Insect disturbances and timber harvesting

To place fire in the context of other disturbances and to assess the likely role of these disturbances in creating current conditions, we reviewed historic and recent information on insect attack and harvesting from two sources: (1) Provincial Forest survey reports for descriptions of the extent and nature of insect and harvesting disturbance from 1920 to 1930. Also, BC forest resources reports from 1918 (Whitford and Craig, 1918) and 1937 (Mulholland, 1937) provided information on forest conditions and management outside the Provincial Forest areas. (2) Insect disturbances were mapped and severity evaluated using data from the Canadian Forest Service Forest Insect and Disease Surveys (see http://cfs.nrcan.gc.ca/subsite/disturbance/sources). Harvesting data from 1950–1996 were obtained from forest inventory planning data.

We recognized that these reports and databases may be flawed by imprecise mapping, accidentally omitted records, inconsistencies in data collection or the presentation of results, but they represent the only systematic information that documents the timing and amount of insect attack and harvesting. To minimize errors, we attempted to cross-reference data from different sources to identify duplicate information or omissions.

### 3.6. Historic forest structure

We reviewed reports published between 1914 and 1935 for information on the condition of dry forest habitats at that time, to assess the nature of forest and grassland management prior to 1930, and to gather further information on insect and fire disturbances for the 1900–1930 period when many forests had not been harvested and when the effects of fire suppression on forest conditions were minimal. Most information came from surveys undertaken by the BC Forest Service, Forest Surveys Division, to assess the economic potential of Provincial Forests existing at the time (see Mulholland, 1937, p. 137). The reports were based on systematic timber surveys and hence should represent a more accurate depiction of historic conditions than anecdotal accounts which seldom give insight into the frequency or extent of a particular forest or grassland condition. The reports represent a relatively extensive and dispersed sample across the study area (Fig. 1), however forest and range conditions and management may have been different on areas outside the surveys, especially on private lands or crown lands adjacent to settlements.

We reviewed 16 reports that covered an overall area of 1,589,822 ha, and we focused primarily on the mature "selection" or "uneven" aged forests in the reports (320,328 ha) as these relate directly to dry forests. The methods and measures used during the surveys were somewhat difficult to reconcile with our objective of describing forest structure since only trees that were >11 (28 cm) and 17 (43 cm) in. d.b.h. for Douglas-fir and ponderosa pine, respectively, were tallied. Trees with defects and that were unsuitable for lumber were not included, and trees less than the minimum diameters for timber were inconsistently recorded as "fuelwood" or "cordwood". Each Provincial Forest was divided into "compartments" that represented species–age combinations (from 4 to 40 dry forest compartments in each of the 16 reports examined). To evaluate the relative abundance of different stand conditions, we reviewed the 238 individual compartments (from 120 to 4800 ha each) in the 16 survey reports for which timber information was available and recorded estimates of timber volume (foot board measure, f.b.m.) as a surrogate for stand density. Compartments that did not contain estimates of volume were excluded from the analysis. The dry forest area was classified as <1000, 1000–3000, 3000–5000 and >5000 f.b.m. per acre, and we present photographs from the survey reports to illustrate structural conditions in each category.

To complement the information on forest and range conditions found in the Provincial Forest survey reports, we examined the British Columbia Forest Service (BCFS) Annual Reports for the 1912–1955 period (see BCFS Annual Reports, 1911–1992). Although these reports did not provide quantitative estimates of conditions, they qualitatively summarized the type and general magnitude of key issues relating to forest and range management at that time. Two provincial forest resources reports by Whitford and Craig (1918) and Mulholland (1937) focused on a broader provincial overview than the Provincial Forest survey reports but addressed several issues pertinent to dry forests in the study area.

## 4. Results

### 4.1. Annual and seasonal weather patterns

Temperature and relative humidity showed consistent patterns during the 25-year monitoring period at the Merritt weather station. Average monthly temperatures peak in July and August, while relative humidity in general shows the opposite trend (Fig. 2a and b). High temperatures and low relative humidity are correlated with area burned (Flannigan and Harrington, 1988), likely due to the effects of these variables on the rate at which fuels dry. July and August are also the period when the FFMC can be above 92 for a large proportion of the month (Fig. 2c), but there is considerable variability from year to year. FFMC values need to exceed 87 if lightning strikes are to become ignitions (Nash and Johnson, 1996), and at FFMC values above 92, lightning strikes have approximately a 1% chance of becoming ignitions. In addition to the FFMC values which influence the likelihood of an ignition occurring, the number of consecutive days with less than 1.5 mm precipitation is correlated with area burned (Flannigan and Harrington, 1988). We observed high variability in the pattern of extended droughts at the Merritt weather station from 1982 to 2006 (Fig. 2d), and the two most prolonged periods (1998 and 2003) coincided with large areas burned and intense fires that were largely stand-replacing in nature (Filmon, 2004). High FFMC values are correlated with high FWI values (Fig. 3), but considerable variability exists. For example, at an FFMC value of 92, the FWI ranges from approximately 15 to 110, and this will likely translate into a wide range of fire severity should an ignition occur (Harvey et al., 1986). The weather, fuel moisture (FFMC) and fire intensity (FWI) conditions presented relate to the Merritt weather station. We examined data from three other weather stations (representing locations approximately 100 km to the north, northwest and southeast) and found similar patterns, although not entirely synchronous, suggesting the Merritt station was indicative of conditions in dry forest areas within our study area.

### 4.2. Annual and seasonal lightning strikes

Lightning is the primary non-anthropogenic ignition source of forest fires (Latham and Williams, 2001; Wierzchowski et al., 2002). We examined seasonal and annual patterns of lightning strikes to evaluate the period when strikes are most common and the likely weather and fuel conditions during these periods. From 1982 to 2006, July and August were the peak periods for lightning strikes, but there is high variability among years (Fig. 4a). Positive polarity lightning strikes are more likely to initiate a wildfire (Latham and Williams, 2001) and these follow essentially the same pattern, except the density of positive polarity strikes is approximately 10% of the overall total (Fig. 4b). An examination of the 1950 to 2006 fire history data is consistent with this result, with both the number of fires of lightning origin and the area burned by these fires greatest in July and August (Fig. 4c and d). The greater area burned and higher proportion of fires from anthropogenic ignitions is not representative of all forest types in BC (e.g. high elevation Engelmann spruce forests have far fewer human-caused fires), and likely relates to the accessibility and proximity of dry forest ecosystems to settlements and human activity.

Lightning strikes are common under a wide range of FFMC conditions but it is unlikely that strikes occurring when FFMC

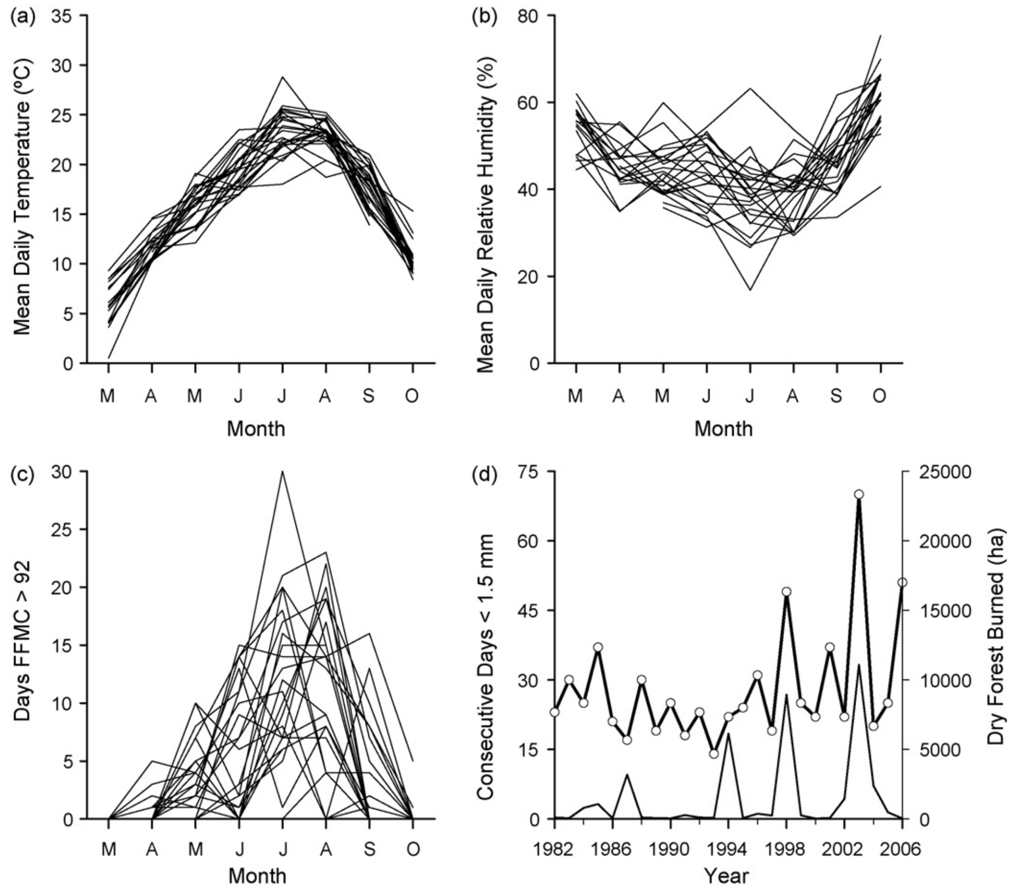


**Fig. 2.** Patterns in (a) temperature, (b) relative humidity and (c) the number of days in a month in which Fine Fuel Moisture Code values are ≥92. Data recorded during 1 March–31 October with mean monthly values presented. Each line represents data for 1 year. (d) Maximum number of consecutive days from 1 May to 31 August with precipitation <1.5 mm (bold line, open circles) and the annual dry forest area burned within 25 km of the Merritt weather station (solid line). All weather data collected at the Merritt weather station from May 1982 to October 2006.

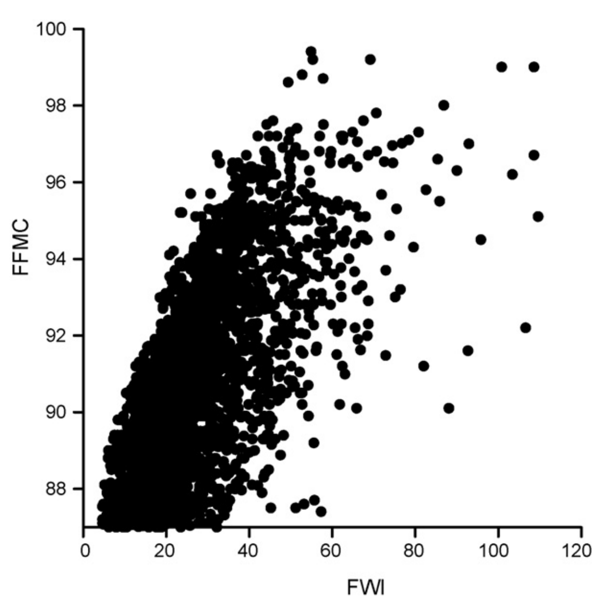


**Fig. 3.** The relationship between the Fine Fuel Moisture Code and Fire Weather Index values at the Merritt weather station from May 1982 to October 2006. Only data for FFMC values ≥87 are presented. Two extreme FWI values (131, 188) were omitted.

values are less than 87 will become ignitions (Nash and Johnson, 1996). Lightning strike density is highly variable at FFMC values >87, and on a subset of days when the FFMC is ≥92 (representing a higher probability of ignition), the corresponding FWI is also highly variable (Fig. 5a and b). FWI values of around 20 represent the transition to very high hazard conditions (Harvey et al., 1986), with FWI conditions above 50 representing conditions when fire intensity and behavior can become extreme and result in large stand-replacing fires. Many factors, including precipitation associated with weather systems that generate lightning activity, affect the likelihood of a strike becoming an ignition. However, given the wide range of fuel and weather conditions associated with lightning activity, we believe lightning ignitions are likely to generate fires of variable severity.

### 4.3. Topography

Topography, a "bottom-up" control of fire regimes, can affect fire severity directly by affecting fire spread rates and fuel conditions directly ahead of the fire (Agee, 1993), influencing the length of the fire season and the moisture content of fuels (Taylor and Skinner, 1998; Heyerdahl et al., 2001), creating barriers in fuel continuity (Larsen, 1997; Heyerdahl et al., 2001) and by affecting vegetation characteristics (Taylor and Skinner, 1998; Odion et al., 2004). About half (48.8%, Table 2) of the dry forests and grassland in the study area are on flat or gentle slopes (0–20%), 36.5% are on moderate (21–50%) and 14.7% are on steep ground (50 to >100%). Large, flat areas are usually associated with valley bottom grasslands that have sparse

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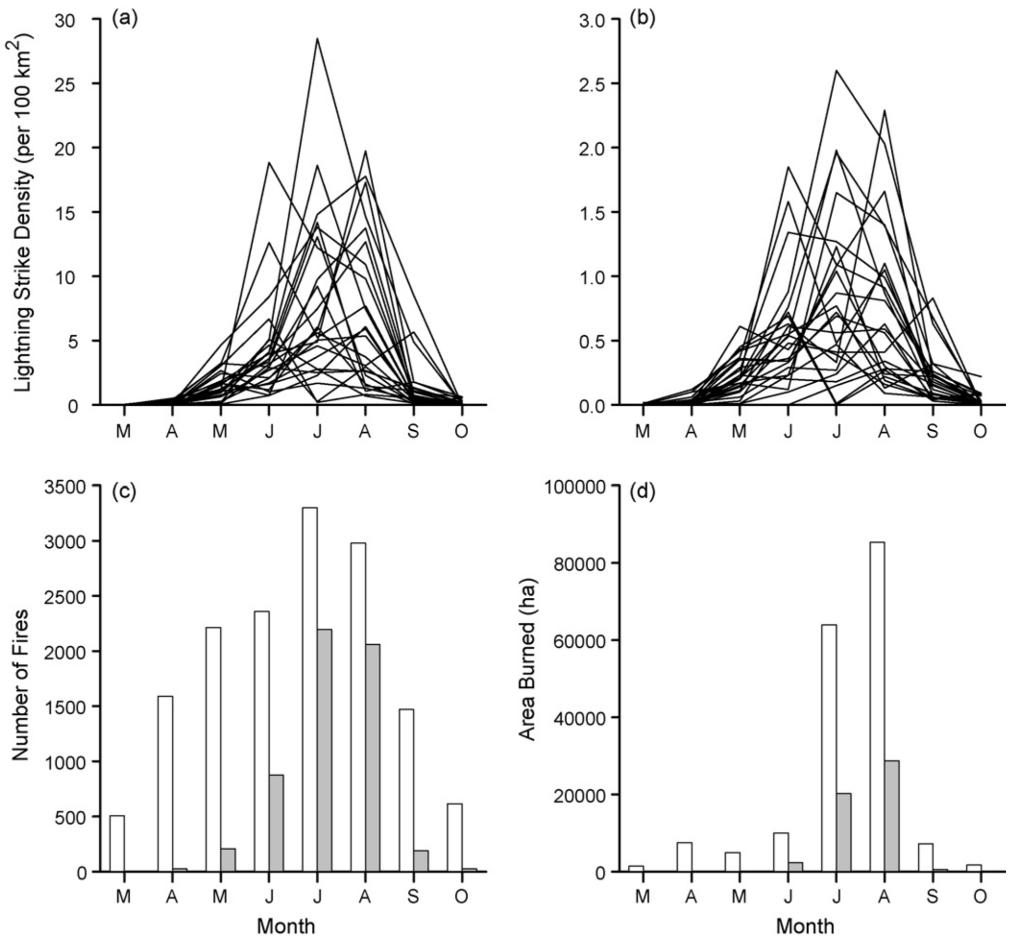


**Fig. 4.** Patterns in (a) the overall density of lightning strikes and (b) the density of positive polarity lightning strikes in dry forest and grasslands in the study area during March to October over a 25-year period from 1982 to 2006. Each line represents data for 1 year. (c) Number of fires and (d) area burned each month by human (open) and lightning origin fires (grey) in dry forests and grasslands in the study area between 1950 and 2006.

tree cover. Approximately, 40% of the dry forests are on "warm", southern exposures that typically are more open and have a less dense understory than "cool" northern exposures. Together, slope and aspect create a complex mosaic of different structural conditions including relatively dense forest, open forest, and riparian vegetation along watercourses and wetlands.

### 4.4. Observations on disturbances and forest conditions: fires

The Provincial Forest surveys reported few fires in ponderosa pine or Douglas-fir forests in the 10 years prior to the survey (Table 3), with most fires in lodgepole pine types. An exception to this pattern was the Inkaneep Forest (Stevens and Mulholland,

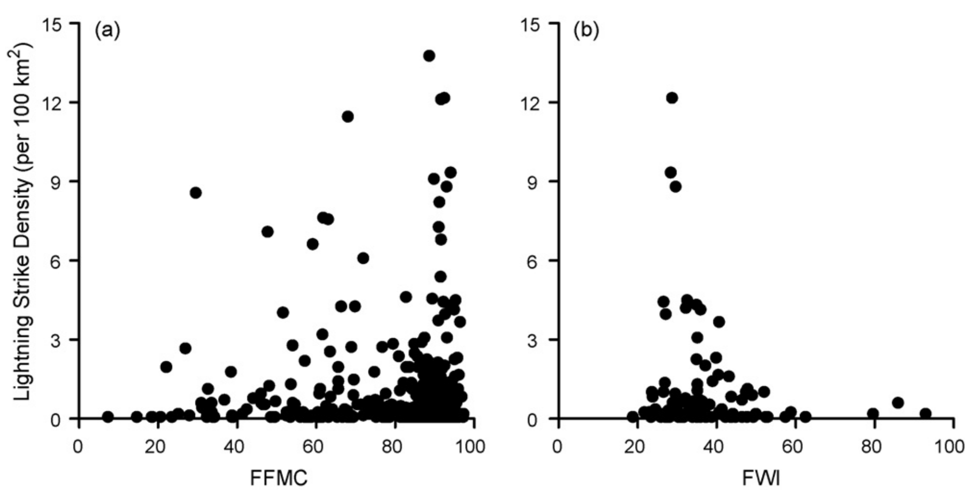


**Fig. 5.** Lightning strike density in dry forest and grassland habitats (169 368 ha out of a potential 196 350 ha) within a 25 km radius area around the Merritt weather station between 1 May 1982 and 31 October 2006 in relation to (a) Fine Fuel Moisture Code (***n*** = 487), and (b) the Fire Weather Index on the subset of days when the FFMC ≥92 (***n*** = 102). Only days with lightning strikes are presented.

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**Table 2**
Area and percent of study area (in parentheses) of dry forest and grassland summarized by slope class and aspect (warm and cool)

| Aspect class | 0–20% Slope ha (% of area) | 20–50% Slope ha (% of area) | 50–100% Slope ha (% of area) | >100% Slope ha (% of area) |
|---|---|---|---|---|
| None (flat) | 108,776 (4.3) | 0 (0) | 0 (0) | 0 (0) |
| Warm (120–270°) | 503,242 (19.7) | 378,260 (14.8) | 152,123 (6.0) | 7,709 (0.3) |
| Cool (271–119°) | 633,424 (24.8) | 552,656 (21.7) | 202,809 (8.0) | 10,706 (0.4) |
| Total | 1,245,441(48.8) | 930,922 (36.5) | 354,933 (14.0) | 18,415 (0.7) |

1925, p. 14) where 18,895 ha were "destroyed" by wildfire in 1925. No data on fire severity are presented other than the observation of large areas "swept by fires and the original Fir, Larch and yellow pine timber destroyed", suggesting these fires were high-severity, stand-replacing events that killed most mature trees in the stand. Where fires were noted in the decade preceding the report, 1920–1930 is repeatedly identified as a period of high fire years and this is consistent with our compilation of the area burned within the study area (Fig. 6). In addition to the early 1920s, almost all Provincial Forest survey reports directly cite episodes of extensive and repeated fires relating to the period of settlement by Europeans (1860–1890). These reports, along with the results presented in Fig. 6, indicate periods of extensive fires associated with prolonged drought as occurred in 2003 are not without historic precedence (BC Forest Service Annual Report; Filmon, 2004).

In addition to the moderate- and high-severity fires that affected mature timber, frequent reference was made to areas that had been previously affected by "low-severity ground fires". These non-stand-replacing fires were inferred from the many large, fire-scarred trees surveyors recorded (Andrews, 1931; Hodgins, 1932e). These fire legacies were noteworthy in the surveys because they diminished timber quality by contributing to pitch seams and general decadence. The spatial extent of these low-severity fires, the site conditions they occurred on (e.g. soil type and moisture regime), their impact on the stand and their frequency are not quantified in the reports so it is difficult to determine the extent of low-severity fires relative to moderate- or high-severity wildfires.

### 4.5. Insect disturbances and timber harvesting

Timber losses stemming from insect attack were widely documented in the Provincial Forest survey reports (Table 3), and relate primarily to bark beetles in mature timber. In the Provincial Forest surveys, 68 of 151 compartment descriptions made note of insect attack, with 24, 27 and 17 compartments described as low, moderate and high severity attack, respectively.

Infestations by the Douglas-fir bark beetle (*D. pseudotsuge*) and Douglas-fir tussock moth, (*Orgyia pseudotsugata*) were the most common insect disturbances documented in the reports in Douglas-fir stands and were also identified by Whitford and Craig (1918) and Mulholland (1937). Douglas-fir bark beetle infestations do not appear to have been perceived as a serious threat to the

**Table 3**
Summary of harvest, insect outbreaks and wildfire from Provincial Forest survey reports (1925–1933) (total area and dry forest area within the survey area (in parenthesis) in hectares)

| Forest # and total area (dry forest area)[a] | Harvest by 1930[b] | | Insect outbreaks[c] | Wildfire |
|---|---|---|---|---|
| | PP | DF | | |
| (#1) 22,804 (7408) | H | L | Extensive BB and TM in DF; BB in PP | Large fires during settlement. Negligible fire during last 10 years |
| (#2) 90,212 (22,553) | M | L | BB killed most mature LP; serious outbreak of TM in DF | No fires in past 5 years. Earlier fires coincident with settlement |
| (#3) 75,595 (15,710) | N | N | BB in mature and immature LP. Some DF damaged by TM | 2835 ha of LP burned in last 11 years |
| (#4) 260,104 (45,562) | H | L | LP not expected to reach maturity due to BB | Large fires during settlement. In last 10 years, 20,250 ha burned (mostly LP) |
| (#5) 153,631 (13,776) | M | L | BB mentioned on LP | Lightning caused 71% of fires over last 3 years |
| (#6) 83,068 (14,616) | L | N | None recorded | 18,895 ha of immature and mature DF, PP, LP and WL burned in 1925 |
| (#7) 65,919 (8608) | L | L | Some DF BB killing 5–50% of stand; TM locally abundant | 6480 ha burned in last 10 years, large areas destroyed by wildfire |
| (#8) 116,550 (21,011) | M | M | None recorded | 6694 ha burned in last 7 years. High levels of burning between 1871 and 1890 |
| (#9) 30,675 (2582) | N | L | None recorded | 1738 ha burned in last 8 years |
| #(10) 76,405 (19,769) | N | N | 75% of mature LP killed by BB | 1154 ha burned in last 7 years. Earlier extensive fires by miners and railway |
| (#11) 151,814 (49,938) | N | N | High BB attack on LP, some BB on PP and DF. TM present in DF | 6318 ha burned in last 7 years (mostly LP) |
| (#12) 198,826 (56,106) | N | N | Sporadic BB on PP and TM on DF | 1863 ha burned in last 11 years (mostly LP). Majority burned in 1925–1926 |
| (#13) 75,272 (4249) | N | N | None recorded | None recorded |
| (#14) 69,339 (24,346) | N | N | Severe LP BB outbreak in last 10 years; some TM | 1498 ha burned in last 7 years (mostly LP) |
| (#15) 26,677 (2272) | N | N | None recorded | 891 ha burned in last 10 years (most in immature stands and in 1925–1926) |
| (#16) 92,932 (8822) | N | N | 11,417 ha of LP attacked by BB; some BB in DF | 2252 ha burned in last 11 years (mostly LP) |

[a] Refer to Fig. 1 for reference key to areas covered by historic surveys and sources.

[b] H, M, L and N refer to High, Moderate, Low and Negligible in relation to the calculated sustainable yield (SY) in 1930. H exceeds SY, M = approximately 50% of SY, L = approximately 25% of SY, N = very minor use.

[c] PP = Ponderosa pine, LP = lodgepole pine, DF = Douglas-fir, WL = western larch, BB = bark beetle, TM = tussock moth.

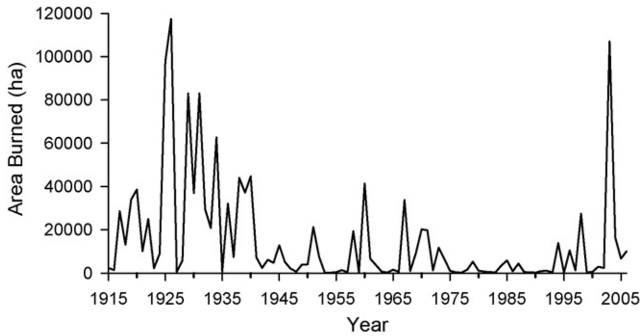


**Fig. 6.** Area burned in the overall study area (all forest types) between 1915 and 2006.

timber resource due to the lower level of within stand mortality and the relatively extensive but scattered nature of the infestations. The western pine beetle and the mountain pine beetle were important pests that attacked ponderosa pine, the tree most valued for timber at the time. Whitford and Craig (1918, p. 221) noted the extensive nature of bark beetle attacks and losses of mature timber on productive forest lands, indicating that attacks by bark beetles "have killed an immense quantity of timber". The extent and percent mortality were not quantified, but the southern half of the dry forest habitats in our study area (Okanagan Lake, Princeton, Merritt) was identified as having "large areas upon which the pine has been already almost entirely killed off by the beetles, and others upon which 50% or more of the pine is now dead or freshly infested this season". Mulholland (1937, p. 62) also comments on the effects of bark beetles in stands of ponderosa pine, noting that bark beetles "have destroyed most of the yellow pine [ponderosa] occurring in pure stands in the Province". How accurate these reports are is difficult to determine, but extensive attacks by the mountain pine beetle in lodgepole pine stands, a forest type with relatively low commercial value at the time, were also noted, suggesting that insect attacks leading to losses of current or future timber were noted and consistently reported.

Harvesting of low elevation ponderosa pine forests began concurrent with European settlement around 1860. By the early 1900s, harvesting of ponderosa pine was so extensive that sustainability of harvest levels was a widespread concern (BC Forest Service Annual Report, 1923, p. 9). Whitford and Craig (1918, p. 65) reported that heavy harvesting had already occurred in ponderosa pine forests in most of the interior, noting "greater inroads on this type than any other". By 1950, little ponderosa pine remained and Douglas-fir became the primary species harvested in dry forest areas (BC Forest Service Annual Reports, 1912–1950). Some Provincial Forests that contained a significant proportion of ponderosa pine and dry Douglas-fir forest had experienced little or no commercial harvesting prior to publication of the reports, while others had been affected by harvesting. Of the 13 Provincial Forest areas with pure stands of ponderosa pine, 6 areas reported negligible harvest of ponderosa pine and the remainder reported low (2), moderate (3) and high (2) use. In Douglas-fir dominated stands, 8 documented no use, 7 low and 1 reported moderate utilization (Table 3). Over the next 30 years, harvesting removed large trees greater than 43 cm d.b.h. for ponderosa pine and greater than 28 cm for Douglas-fir, leaving small stems and openings.

The overall perspective that these reports present indicates extensive and intensive utilization of ponderosa pine forests beginning shortly after settlement by Europeans in the mid-1800s and continuing until approximately 1950 when supply was exhausted. Douglas-fir represented a less desirable resource largely because of wood characteristics, hence extensive and intensive harvesting of this forest type began somewhat later (e.g. 1920) than for ponderosa pine and continued into the 1980s (Fig. 7). Since harvesting focused primarily on the removal of the largest stems in the stand, the structural condition of dry forests was heavily modified by harvest.

When viewed comprehensively, it is clear that dry forests in the Southern Interior of BC have been affected on an ongoing basis by a wide range of disturbances including wildfire, insect attack and, more recently, harvesting, that began at the time of European settlement (1860). To protect the timber resource, increased fire suppression effort, a more extensive system of roads and aerial fire suppression technology implemented in the 1970s kept the area of dry forest affected by fire below 1% per decade (Fig. 7). Not shown in Fig. 7 is the current outbreak of mountain pine beetle and western pine beetle that has affected large areas of ponderosa pine dominated stands in the study area since 1999. In 2006, over 40,000 ha of ponderosa pine in the northern half of the study area experienced within stand mortality greater than 11% and, of this, at least half the area had mortality levels greater than 50% in that 1 year alone (Maclauchlan et al., 2006). Although the area affected by fire may have diminished since 1950, the overall area affected by disturbance has not declined. Harvesting, especially during the 1960–1990 period, and insect attack have affected extensive areas of dry forests.

### 4.6. Historic forest conditions

The 16 Provincial Forest Survey reports provide information on structural conditions in dry forest and grasslands prior to extensive management (Fig. 1 and Table 3). Prior to these surveys, Whitford and Craig (1918, p. 65) noted that forests dominated by ponderosa pine were characterized primarily by grass in the understory and that the area "as a whole is fairly open". Douglas-fir and ponderosa pine mixtures, and relatively pure stands of Douglas-fir that were more common than pure stands of ponderosa pine, are described in all the reports as "uneven aged" or "open, park-like" (e.g. Hodgins, 1932a, p. 7). However, it was difficult to reconcile this generic description with photographs in the survey reports that depicted diverse structural conditions. Using the 238 individual compartment descriptions (representing 315,232 ha) with information on f.b.m. per acre, we found that 27.4% of the area was <1000 f.b.m. per acre, 32.2% was 1000–3000, 27.1% was 3000–5000 and 13.4%

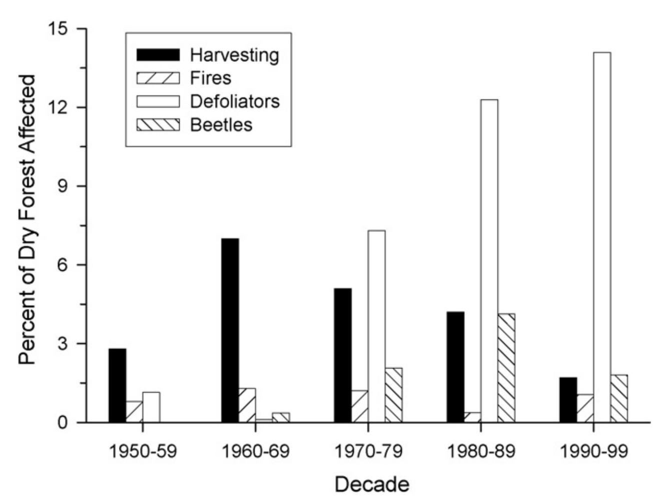


**Fig. 7.** The percent of dry forest area (2 156 346 ha) each decade affected by harvesting, fire, insect defoliators (Douglas-fir tussock moth western spruce budworm) and bark beetles (mountain pine beetle, Douglas-fir beetle) in the study area between 1950 and 1999. Insect disturbances with associated mortality of <10% are not included in these estimates. Harvesting records for the 1990s are not complete for the entire study area beyond 1996.


**Fig. 8.** Examples of forest conditions in relation to timber yield estimates from Provincial Forest surveys. (a) 1000 f.b.m., (b) 2500 f.b.m., (c) 4000 f.b.m. and (d) 6500 f.b.m. per ha. Original figure captions: (a) Hodgins, 1932e, p. 10; "Uneven-aged fir—yellow pine [Ponderosa pine] type. Portion of Compartment 5, averaging 1000 f.b.m. and 4 cords per acre. Note the open grazing." (b) Hodgins, 1932c, p. 9; "Illustrative of the fir—yellow pine type. Portion of Compartment 4 averaging 2500 f.b.m. per acre (80% yellow pine) and 2 cords per acre (75% fir). Note the open Grazing", (c) Hodgins, 1932f, p. 9 "Illustrative of the better stands of yellow pine-fir. Average volume 4000 f.b.m. per acre, Oregon Jack Creek. Bark beetles have infested the yellow pine on this area. Note the open grazing." (d) Hodgins, 1932d, p. 7; "Illustrative of fir stands growing on better sites".

was >5000 (Fig. 8). These results clearly indicate that the dry forest areas in the Provincial Forests were structurally diverse and the term "open, park-like condition" likely reflects a description relative to the often very dense forest types encountered in the surveys.

## 5. Discussion

Our analysis of weather patterns, lightning strikes, topography, historic fire, insect attack and harvesting, and historic forest structure questions the likelihood of a region-wide, low-severity fire regime in dry forests. High variability in seasonal and annual weather patterns and lightning strikes that occur across a wide range of fuel moisture and fire hazard conditions suggests that fire intensity will likely vary in space and time, especially when placed in the context of complex topography found in our study area.

High temperatures, low relative humidity and extended periods of drought (Flannigan and Harrington, 1988; Flannigan and Wotton, 2001) are correlated with area burned, and extreme weather conditions are often associated with very large fires across a wide range of forest conditions and types (Harvey et al., 1986; Flannigan and Harrington, 1988; Bessie and Johnson, 1995; Larsen, 1997; Filmon, 2004). Although fuel accumulation arising from reduced fire frequency has been identified as a leading cause of high-severity fires in some areas (Covington, 2000), other studies do not support this perspective (Odion et al., 2004). Extended droughts in our study often coincided with large fire years, and this is consistent with the increased likelihood of lightning strikes becoming ignitions as fuel moisture decreases (Nash and Johnson, 1996). It does not appear that seasonal or annual patterns in the weather, fuel moisture or lightning strike patterns we examined are likely to singly or in concert provide a mechanism that promotes frequent low-severity fires across extensive areas.

In British Columbia lightning is the primary non-human cause of fire, often causing ignitions in areas of poor access where suppression efforts may be slow to respond (Wierzchowski et al., 2002). A peak in lightning activity is common in July and August, the period when temperature and drought indices are typically highest. In years of periodic drought combined with lightning or human-caused ignitions, extensive and severe wildfires will likely occur (Harvey et al., 1986; Filmon, 2004).

Topography in our study area also does not appear to be conducive to extensive low-severity (ground) fires. Steep or upper slopes and south aspects are more likely to experience high-severity fires than north aspects and lower slopes (Taylor and Skinner, 1998), and warm aspects (south and southwest) are likely to have more frequent fires (Heyerdahl et al., 2001, 2007). Increased solar radiation on south aspects facilitates the drying of fuels, and a longer snow free period extends the season over which fires are likely to occur. We believe the complex topography in our study area would prevent the spread of low-severity fires across extensive areas, and would promote some moderate- and high-severity fires.

The few direct observations of fire severity in our study area also found a mix of fire regimes. In a 300 ha portion of the Stein Valley (western part of our study area), Heyerdahl et al. (2007) found evidence of a low-severity fire regime with a return frequency of 14–24 years, with differences in fire frequency and season related to aspect and vegetation composition. They used the presence of fire-scarred trees to identify low-severity fires and noted fires in their study were most common in July and August, indicating that low-severity fires are not necessarily inconsistent with mid-summer fires. However, they suggested some of the stand structures they observed (plots with only young trees) may indicate moderate- or high-severity fires also occurred in their area, and Wong (1999), working in the same valley, documented these conditions. Lightning is not the only source of ignitions, and First Nations likely contributed to fires in the Stein Valley because of the cultural significance of the area to the Nlaka'pamux First Nation (Heyerdahl et al., 2007). Also, there is considerable evidence to suggest that fire was routinely used by First Nations peoples to create desired vegetation conditions (Turner, 1991; Agee, 1993; Krech, 1999). There is no consensus on the effects of First Nations burning on historic fire regimes, as the extent was likely strongly affected by the culture of the group, weather, and topography. We believe the complex incised topography in much of our study area would likely have frustrated attempts to apply low-severity fire over extensive areas.

Our observation of variable weather patterns, lightning activity and topography does not provide support for a mechanism that would promote frequent, low-severity fires across the regional scale that our study addresses, and suggests a mixed-severity fire regime is more likely. This perspective is consistent with a number of recent studies from the western United States and British Columbia (Shinneman and Baker, 1997; Arsenault and Klenner, 2005; Daniels, 2005; Hessburg et al., 2005; Baker et al., 2007; Sherriff and Veblen, 2007) that indicate mixed-severity fire regimes are common in some regions. Mixed-severity fire regimes encompass a broad range of fire severity (Agee, 1998; Baker et al., 2007) which are likely to be non-equilibrium (Botkin, 1990; Sprugel, 1991) and spatially and temporally dynamic if fire controls exhibit high variability.

Fire is an obvious disturbance that affects forest composition and density, and we present evidence that bark beetles and defoliators also played a strong role in determining historic and present forest structure in our study area. Mountain pine beetle, western pine beetle and Douglas-fir beetle (*Dendroctonus pseudotsugae*) are common forest insects that attack ponderosa pine and Douglas-fir across much of the range of these forest types (Weaver, 1943; Romme et al., 2006). As they have in the past (Table 3), recent outbreaks of mountain pine and western pine beetle in our study area are profoundly changing forest structure in ponderosa pine stands, with large areas affected by high-severity attacks of greater than 50% mortality annually within stands (Maclauchlan et al., 2006). Pine- and Douglas-fir beetles kill the larger stems in a stand and mortality from these agents works largely in opposition to the "from below" thinning effect of low-severity fire. Severe attacks of defoliators (Hadley and Veblen, 1993) such as Douglas-fir tussock moth and western spruce budworm (*Choristoneura occidentalis*) also change forest structure by thinning stands, creating gaps or favoring non-host species. The extensive and severe attacks by bark beetles in ponderosa pine stands (Whitford and Craig, 1918, p. 221; Mulholland, 1937, p. 62), and by bark beetles and defoliators in Douglas-fir forests in our study area (Fig. 7), suggests that disturbance studies should focus on a broader suite of agents. In addition to bark beetles and defoliators, harvesting has played a key role in affecting forest structure in dry forest habitats in our study area over the last century. The harvest of large diameter overstory trees in ponderosa pine and Douglas-fir forests (e.g. >43 and 28 cm d.b.h., respectively) was standard practice in logging operations (e.g. Hodgins, 1932a,b) and likely increased the density of small diameter stems in the stand while reducing the density of large overstory trees. Canopy gaps would likely promote dense regeneration (Kaufmann et al., 2000) that either resists fire during periods of high relative humidity or is vulnerable to stand-replacing fires during hot, dry periods.

In an assessment of historic forest conditions in the Black Hills of South Dakota, Shinneman and Baker (1997) found evidence of episodic stand-replacing disturbances, and demonstrated the value of systematic surveys to infer historic conditions and disturbance regimes. Our review of Provincial Forest surveys in BC led to a similar conclusion: forest conditions prior to extensive management were likely diverse, and that high-severity fires and insect attack occurred episodically and played a strong role in shaping forest conditions. Although these reports consistently referred to dry forests as "open and park-like", a closer examination of photographs and survey results revealed greater complexity than was inferred from the term.

Initiatives to modify existing forest structure and pattern in dry forests are well established in some regions (e.g. Friederici, 2003) and are based largely on the perspective that frequent, low-severity fires are the key process that will restore productivity and desired structural characteristics (Weaver, 1943; Covington, 2000; Allen et al., 2002). In BC, extensive fires during the initial period of settlement by Europeans were followed by a long period (1860–1970) of largely unregulated harvesting and extensive insect attack. These disturbances likely have had long-term implications for forest structure (Hadley and Veblen, 1993; Smith and Arno, 1999; Kaufmann et al., 2000). Although mechanical thinning followed by frequent low-severity prescribed fire (Covington et al., 1997; Allen et al., 2002) is the most common approach to restoring ecological integrity in dry forests, we believe a more comprehensive and site specific understanding of forest disturbances and historic conditions should be developed prior to the widespread application of this approach in BC. Fire has and continues to be an important disturbance that shapes forest structure and pattern. It is, however, only part of a historic suite of disturbances ranging from single tree windthrow events to large stand-replacing wildfires. Timber harvesting is a relatively recent disturbance that has and continues to affect a large proportion of the dry forests in southern British Columbia. The structural consequences of historic and recent harvesting, along with insects and fire, need to be considered when assessing the need for restoration, and when developing a coordinated approach to implementing silvicultural (Agee and Skinner, 2005) and prescribed fire treatments to achieve desired conditions.

## 6. Management implications

Our analyses indicate that a mixed-severity disturbance regime (including fire, insects and other disturbances) likely maintained diverse stand and landscape conditions in our study area. Hence, choosing a reference condition for "ecological restoration" is problematic as conditions likely changed in space and time. Future management in dry forest ecosystems in British Columbia should include the development of a better understanding of the spatial and temporal variability of historic disturbances, and the historic role of low-, moderate- and high-severity fires and other disturbances at the regional level versus specific locations. Forest managers should: (1) focus on clearly defining desired stand conditions and the mosaic of habitats necessary to maintain multiple values across landscapes (e.g. Fischer et al., 2006), (2) identify the commodity, social and ecological objectives that will be met or compromised with these conditions, (3) identify the most effective interventions for achieving these objectives, and (4) implement a program to monitor, assess and revise activities to ensure objectives are met.

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