Report #4:

Climate Change and Area Burned:
Projections for the West Kootenays

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1.0 Introduction

Climate change is projected to bring increased temperatures and changes in seasonal precipitation to the West Kootenays over the coming decades (Murdock et al. 2007, Utzig 2011a). This will directly change ecosystems and species distributions as conditions become unsuitable for some species currently present, and more suitable for other species not able to survive here today. Species distributions are also moderated by other factors such as soil characteristics and disturbance regimes. One of the more important disturbance factors is fire, whose frequency, extent and intensity is in turn also affected by climate. Previous studies have indicated that projected changes in climate over the coming decades could have a profound impact on future area burned in Canada (Flannigan et al. 2005, Meyn et al. 2010), in the Western US (Littell et al. 2009, Littell et al. 2010) and globally (Pechony and Shindell 2010). Other studies have also indicated an increase in the frequency of fires (e.g., Wotton et al. 2010). This report summarizes an analysis of potential impacts of climate change in the West Kootenays on the mean annual area burned into the coming decades.

2.0 Methods

To investigate how the occurrence of fires may change with various climate change projections, we employed regression analysis to identify climatic variables that were predictors of area burned in the past, and then used climate change projections of those variables to estimate future changes in area burned. The West Kootenay study area was stratified into three subregions based on regional climatic characteristics, and each stratum was analyzed separately (see Fig. 1). The stratification criteria were areas of consistent elevational sequences of Biogeoclimatic units. The North subregion (6,130 km^2), which is wetter and cooler, is dominated by ICHwk and ICHvk at lower elevations and ESSFwc4 and ESSFvc at upper elevations. The Mid subregion (10,200 km^2) is dominated by ICHmw2 and ICHdw at lower elevations and ESSFwc4 and ESSFwm at upper elevations. The South subregion (9,950 km^2), which is drier and warmer, is dominated by ICHdw, ICHdm and ICHxw at lower elevations and ESSFdc1, ESSFwc2, ESSFwc6 and ESSFdm at upper elevations.

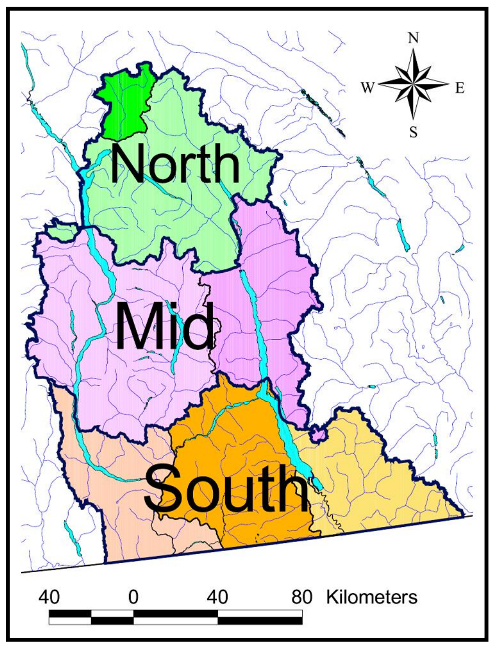

Figure 1. Study area and subregions.

A digital database of fires from 1919-2008 for the West Kootenay study area was used as a data source for past fires (Taylor and Thandi 2003). The database was prepared by researchers from the Canadian Forest Service, Pacific Forest Centre and the BC Forest

Service Research Branch, and includes all fires >20 ha in size that were recorded in administrative fire records, forest inventories and identified from remote sensing data. Because of the extreme annual variations in area burned (0 to 90,000 ha), the values for burned areas were log-transformed for the analyses.

A single location was selected to represent the climate for each of the subregions: Castlegar for the South, Kaslo for the Mid and Trout Lake for the North. Because of incomplete Environment Canada climate data for some locations, and to ensure consistency between the three subregions and future projections, climate variables for past years, as well as future projections were extracted from the monthly ClimateWNA data (Wang et al. 2006) for each location, rather than utilizing the raw climate station data. Due to the use of monthly data, it was not possible to utilize the Canadian Forest Fire Danger Rating System that requires daily data for calculation of Fire Weather Codes and Indices.

Future climate projections were derived from four Global Climate Model (GCM)/ emission scenario combinations. Three of the GCM/ scenario combinations are those recommended by Murdock and Spittlehouse (2011) to represent a range of possible futures for BC. The fourth is an intermediate scenario that was utilized in a companion study of climate envelope shifts for the study area. For further information on the GCM scenarios see Report #3 (Utzig 2011a), and on bioclimate envelope shifts see Report #5 (Utzig 2011b).

A review of literature on the relationship between fire and climate in British Columbia and the Pacific Northwest identified a number of potential climatic variables for the analysis (e.g., Littell et al. 2009, Littell et al. 2010, Heyerdahl et al. 2008, Heyerdahl et al. 2009) These included variables such as mean monthly maximum spring and summer temperatures, previous winter snowfall, moisture deficit[1], spring and summer monthly precipitation, and previous summer precipitation. A multiple regression analysis was performed where these predictors were used to estimate annual area burned for each of the subregions. All of the potential predictors were tested individually and in combination, until the most supported model was created for each subregion. Each model was further evaluated for fit, and then run for projected future values of the predictors to estimate future area burned. Additional details on the analysis methods are available upon request.

3.0 Results

3.1 Historic Patterns: Climate and Area Burned

The area burned in each of the subregions was highly variable from year-to-year, including many years with no fires being recorded, and a few years with extensive burned areas (see Fig. 2).

As expected, over the past ninety years the average annual percentage of area burned was most in the South and least in the North, with the Mid subregion intermediate. The annual percentage of area burned in the early portion of the 20th century was much greater than the long term average, while the annual percentage for latter part of the century was much less than the long term average (see Figs. 2 and 3). These results are consistent with other regional studies for the US Rocky Mountains (e.g., Morgan et al. 2008, Littell et al. 2009, Westerling et al. 2006).

Climate has also changed over this period – and regression analysis of climatic factors with area burned explains a major portion of the decreasing trend, although fire suppression efforts[2] and changes in ignition sources also have likely contributed to the changes. The early decades had higher maximum spring and summer temperatures and

[1] The ClimateWNA database calculates moisture deficit by determining the difference between monthly evaporation and precipitation, and summing the values for months where T=> 0C and evaporation exceeds precipitation.
[2] Some studies from Ontario have shown that fire suppression, especially effective initial attack strategies, have contributed to reduced area burned during the mid to late 20th century (e.g., Podur and Martel 2007, Cumming 2005), while other authors suggest that the evidence is inconclusive (Bridge et al. 2005). Some studies from the Western US point out that near the end of the century, area burned is increasing despite more sophisticated suppression efforts (Morgan et al. 2008).

distinctly less spring and summer precipitation, while the latter decades are cooler and wetter (see Figs. 4 and 5). The data appears to indicate a threshold was crossed in the late 1930s or early 1940s, with area burned severely reduced in the ensuing decades. Temperature decreases during the latter half of the 20th century appear to be ending and parallel precipitation increases are leveling off, coinciding with a slight increase in area burned in the last time period. Other studies assessing area burned in the US and Canada have also noted increasing area burned after the 1980s (e.g., Morgan et al. 2008, Littell et al. 2009), and some have associated this increase in Canada with global climate change (Gillett et al. 2004).

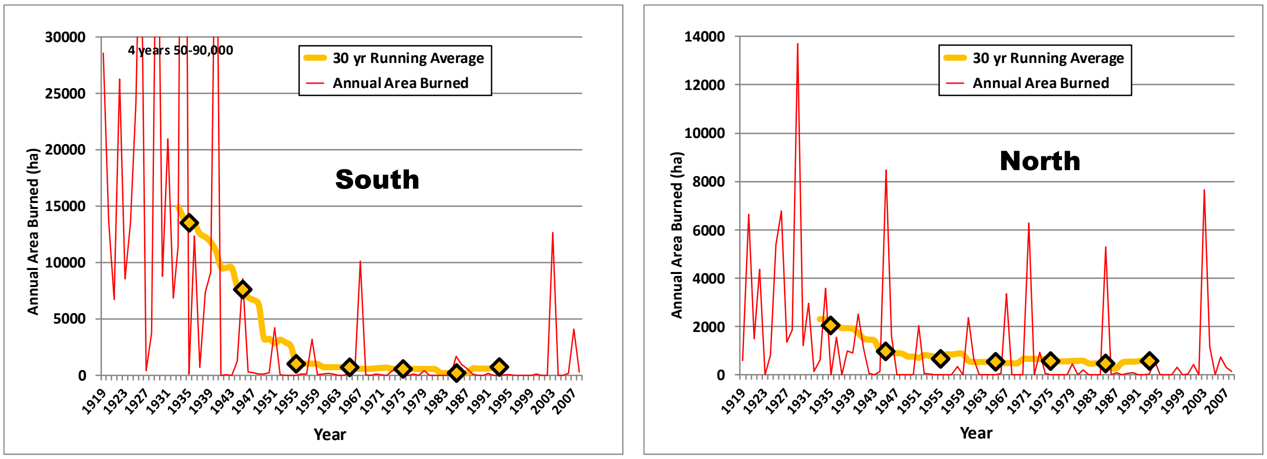

Figure 2. Examples of annual variability for the South and North subregions, and 30 year means utilized in the subsequent graphs (note difference in scale between South and North).

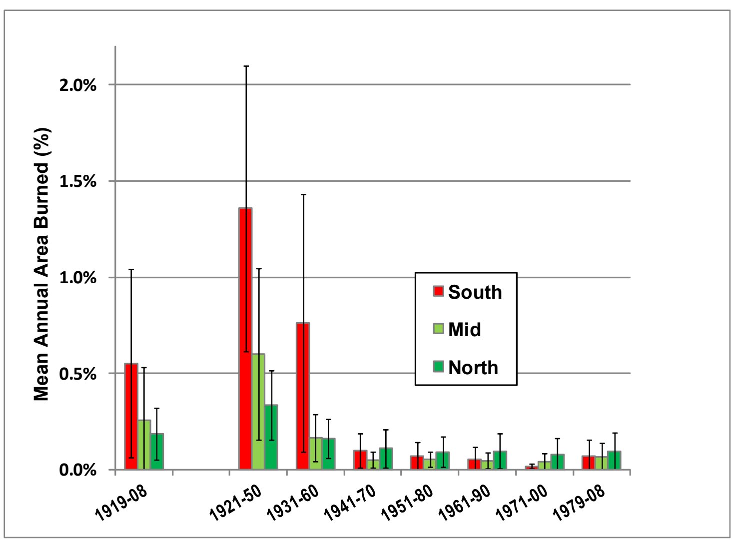

Figure 3. Average annual area burned in each subregion for 1919-2008 and individual 30-year periods.

Regression analysis identified slightly differing predictor variables for each of the subregions. One variable was significant in all areas - mean monthly maximum temperature for the hottest month (July or August). In the South subregion increases in the hottest mean maximum temperature (July or August) and the climatic moisture deficit were correlated with area burned, while increases in precipitation in June and the month preceding or immediately following the hottest month were inversely correlated with area burned. In the Mid subregion increases in the mean monthly maximum temperatures for June and the hottest month (July or August) were correlated with area burned, while July and August precipitation were inversely correlated with area burned. In the North subregion increases in the mean maximum temperature of March, April and May, and the mean maximum temperature of July and August were correlated with area burned, while increases in June precipitation were inversely correlated with area burned. Based on r^2 values, all of the models explained about half of the variation in the data, ranging from 47% in the North subregion, to 53% in Mid, and 60% in the South.

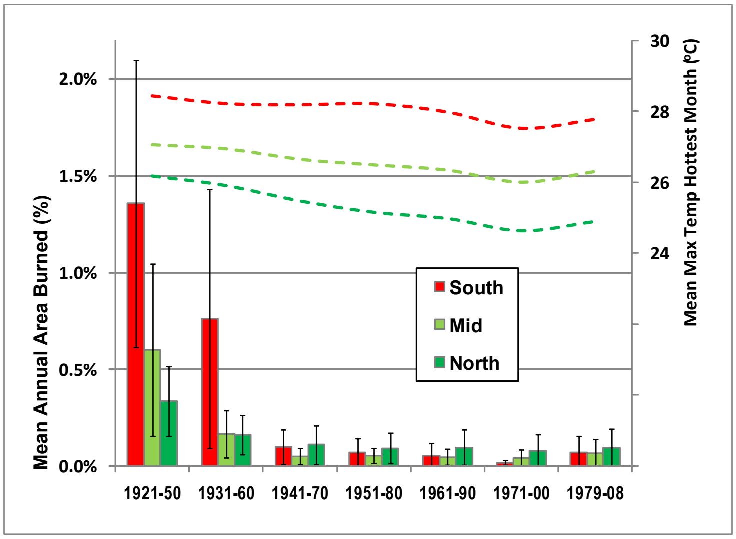

Figure 4. Average annual area burned (bars, 95% CIs) and mean maximum monthly temperature (dashed lines) for the hottest month for 30-year periods in the past century.

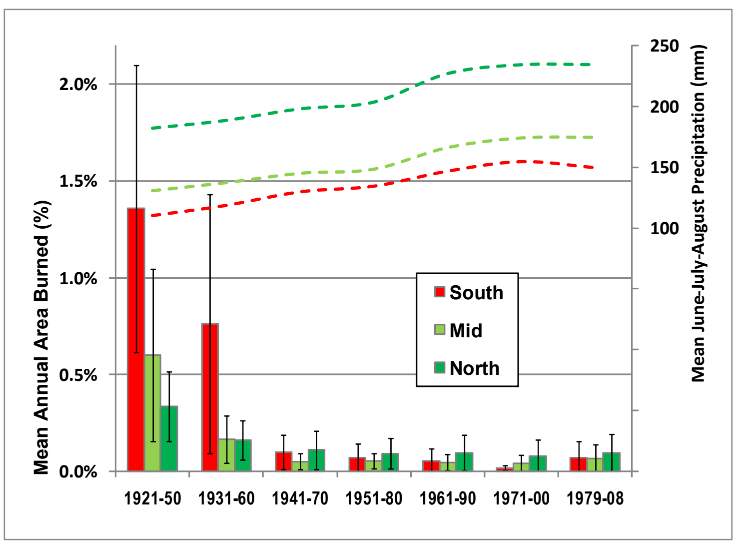

Figure 5. Average annual area burned (bars with 95% CIs) and mean precipitation for June, July and August (dashed lines) for 30-year periods in the past century.

3.2 Predicting the Future: Climate Projections and Potential Area Burned

The primary predictor variables for each subregion were used to estimate the range of area burned into the future, based on scenarios of future climate. The results of the regression models for all three subregions are presented in a series of graphs with logarithmic scales (see Figs. 6, 7 and 8). The graphs show 30-year means of annual area burned for the period 1921-2008, and projections of mean annual area burned for three future time periods[3] for four GCM/ emission scenario combinations. The graphs include 95% Confidence Intervals (CI) for each of the values. The wide and skewed CIs of the historic data reflect the high year-to-year variability in annual area burned, and the high frequency of years with no area burned. The CIs in the projected data reflect the uncertainty in the regression model, but they do not include the uncertainty in the GCMs or the emission scenarios, nor the uncertainty in the assumption that future year-to-year variability will be similar to past variability, and possible changes in the relationship between climate and area burned. The projected mean area burned as a percentage of total area for the 2020s and 2050s is shown in Figure 9.

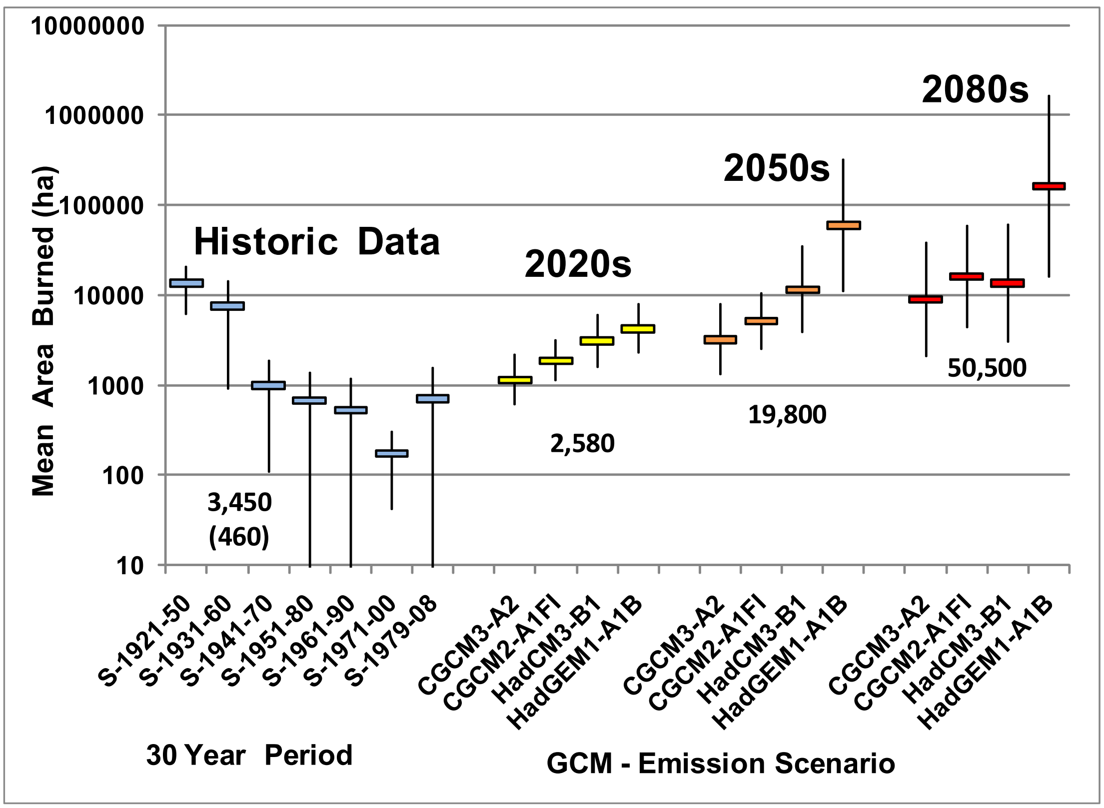

Figure 6. South subregion historic 30 year means (blue boxes) and regression projections (yellow, orange and red boxes) of area burned (with 95% confidence intervals). Values below the historic whisker plots are a mean of the 1921-2008 values, and in parentheses the mean of 1951-2000. Values below the projection plots are means of the GCM/ emission scenarios for each time period. CIs for the projections do not include uncertainty from the GCMs. Note log scale on graph.

[3] 2020s refers to the period 2011 – 2040; 2050s to the period 2041 – 2070; 2080s to the period 2071-2100.

The regression models for all three subregions project steadily increasing area burned in all three subregions for all GCM/ scenario combinations, although there is substantial uncertainty regarding the magnitude of the increases (see discussion below). Comparing the 1961-90 means with the projections for all GCM combinations for the 2050s demonstrates potential changes that range from almost negligible, to increases in excess of 10,000 times for all three subregions, depending on the GCM combination. However, when the means of the four GCM combinations are considered for each subregion, the South shows increases of ***at minimum*** 4 times, the Mid ***at minimum*** 3 times and the North ***at minimum*** 5 times for the 2050s. The ***mean*** projected increases for all GCM combinations for the 2050s are 15 times for the South, 30 times for Mid and almost 300 times for the North from 1961-90 levels.

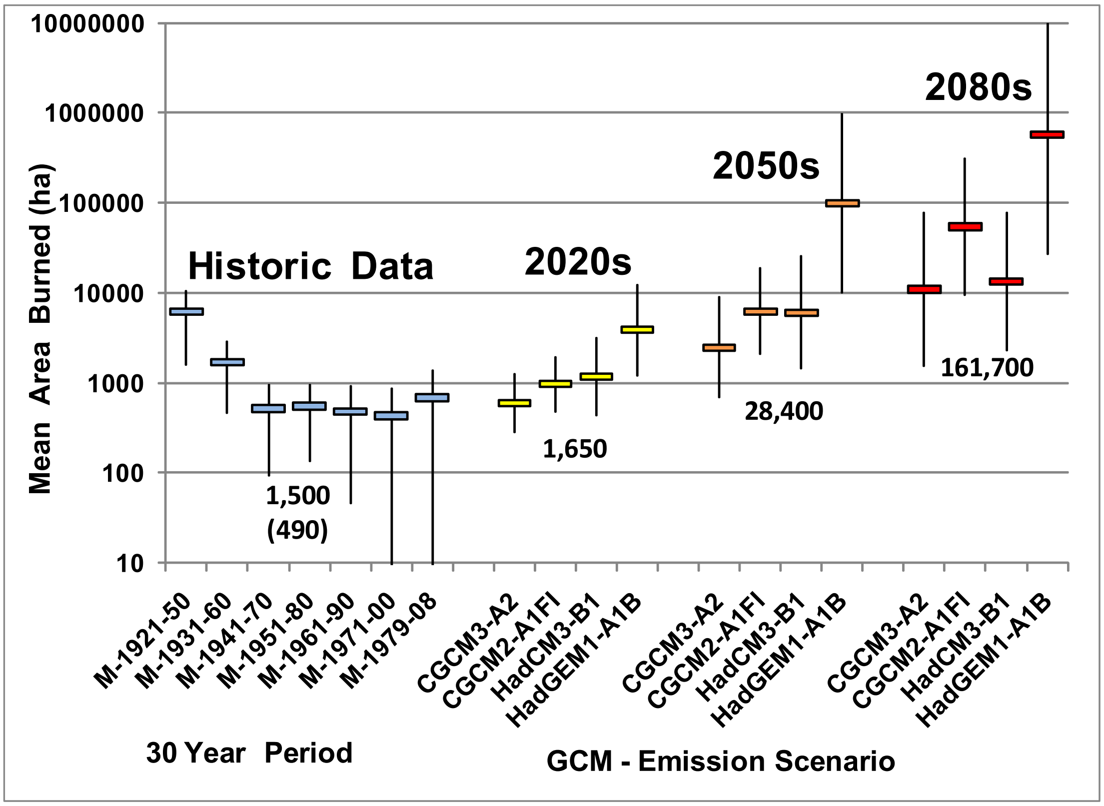

Figure 7. Mid subregion historic 30 year means (blue boxes) and regression projections (yellow, orange and red boxes) of area burned (with 95% confidence intervals). Values below the historic whisker plots are a mean of the 1921-2008 values, and in parentheses the mean of 1951-2000. Values below the projection plots are means of the GCM/ emission scenarios for each time period. CIs for the projections do not include uncertainty from the GCMs. Note log scale on graph.

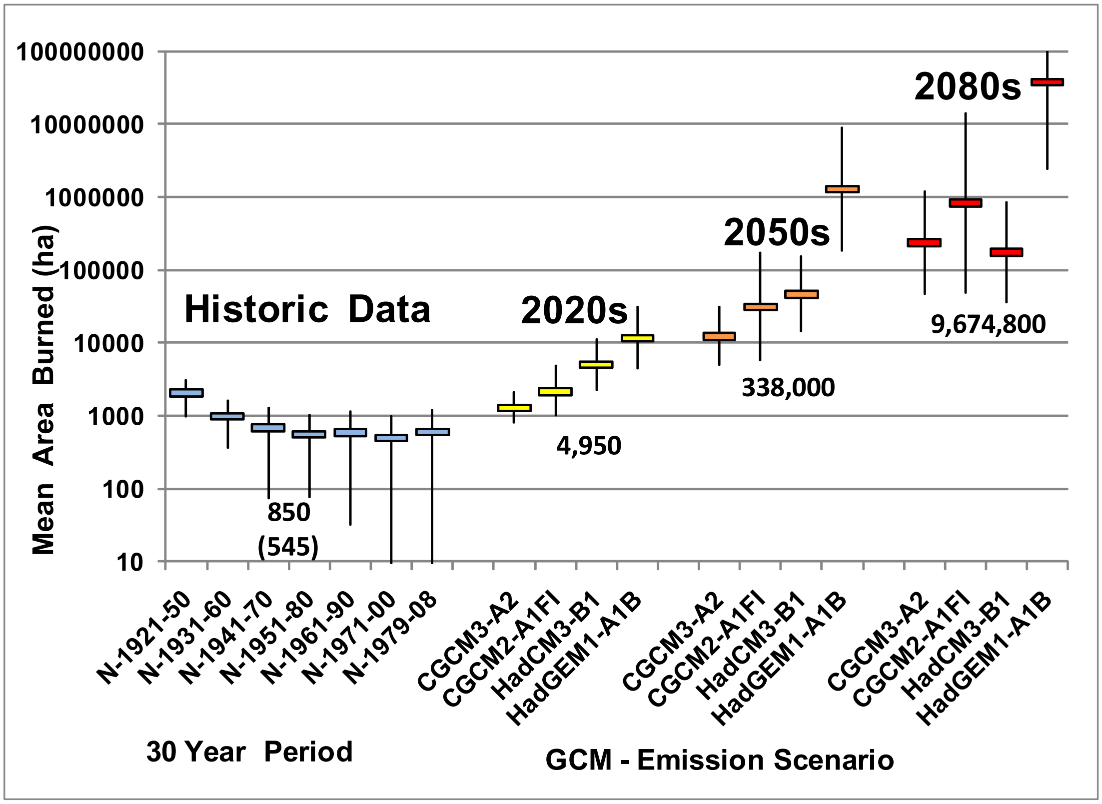

Figure 8. North subregion historic 30 year means (blue boxes) and regression projections (yellow, orange and red boxes) of area burned (with 95% confidence intervals). Values below the historic whisker plots are a mean of the 1921-2008 values, and in parentheses the mean of 1951-2000. Values below the projection plots are means of the GCM/ emission scenarios for each time period. CIs for the projections do not include uncertainty from the GCMs. Note log scale on graph.

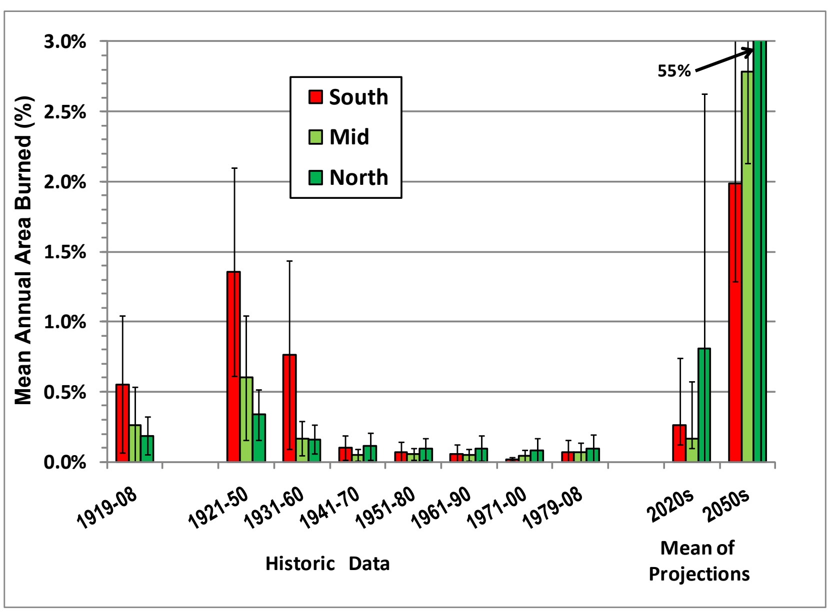

Figure 9. Mean area burned projections as a percentage of total area in comparison to area burned in historic 30-year periods (2020's = 2011-2040 and 2050s = 2041-2070).

4.0 Discussion and Conclusions

4.1 Fire and Climate

Unsurprisingly, for the West Kootenay study area, annual weather variables are correlated with annual area burned. Slightly different climatic factors were found to be significant in the three subregions of the study area, but with maximum temperature in the hottest month to be significant in all regions. As climate shifts into the future, area burned is predicted to increase for all three subregions of the study area – with the greatest increases in the North – the mean projected increase (across all models) shows an increase of almost 300 times for the North, 30 times for the Mid and 15 times for the South subregions of the West Kootenays by the 2050s

The level of explained variability (47-60%) by the regression models is typical for this type of analysis (e.g., Flannigan et al. 2005, Littell et al. 2009, Westerling et al. 2006, Gillett et al. 2004), and is good given that it is well known that available fuel, ignition sources, fire season length, wind patterns and the effectiveness of fire suppression are all additional factors that affect annual area burned (Flannigan et al. 2005). The West Kootenays is a diverse area – ranging from rolling topography and dry open forests in the lower elevations of the South, to steep sided valleys and wet interior cedar hemlock 'rainforest' in the North. This starting point clearly influences how changes in climate will affect future fire - with relatively little fire in the North historically, but with a high potential for drying and warming to increase this level. The increased importance of spring climatic variables in the North likely is a reflection of the increased importance of spring snowmelt and its potential affect on the fire season in that high snowfall subregion. Early snowmelt can facilitate fires by increasing the length of the fire season and increasing fuel drying that leads to the build up of maximum drought codes. Whereas in the South and Mid areas, summer high temperatures and drought seem to be the main factors. The projected changes in climatic variables correlated with area burned in the North appear to be changing at a faster rate than those in the South, leading to a steeper increase in estimated area burned. Available fuel will likely become a limiting factor before the some of the area burned projections will be achieved, especially in the North subregion.

The influence of climatic cycles (e.g., Pacific Decadal Oscillation – PDO and El Nino Southern Oscillation - ENSO) are additional factors that could be considered in the analysis (Meyn et al 2010). Additional analyses that could further explore future annual climate variability, and the potential interactions with the climate cycles would likely improve on reliability of the future projections.

4.2 Additional Sources of Variability

There are various sources of unquantified uncertainty associated with the estimates of future area burned. The annual variability in area burned, where a few years account for a large proportion of area burned and many years have no area burned complicates the analysis. Where the GCM projected predictor variables extend beyond the historic values utilized to build the regression model (see Fig. 9), there is also the potential for that there may be future changes in the relationship between climate and area burned that are not accounted for in the model.

Some variables such as mean maximum temperature, may begin to exceed historic ranges by the 2020s. In the South subregion, based on other analysis (see Utzig 2011b), there is a projected shift from closed forests to grasslands for some areas by the 2050s, which will alter the relationship between climate and fire variables such as area burned and fire intensity due to a shift in fuel type. This difference has been demonstrated in a number of studies, where historic area burned regressions have differing predictor variables in grassland[4] areas than in forested areas (e.g., Littell et al. 2010).

4 Grassland fire regressions often include climate variables that are related to moisture availability in the previous year's growing season, which are related to the level of fuel present in the spring of the current fire season.

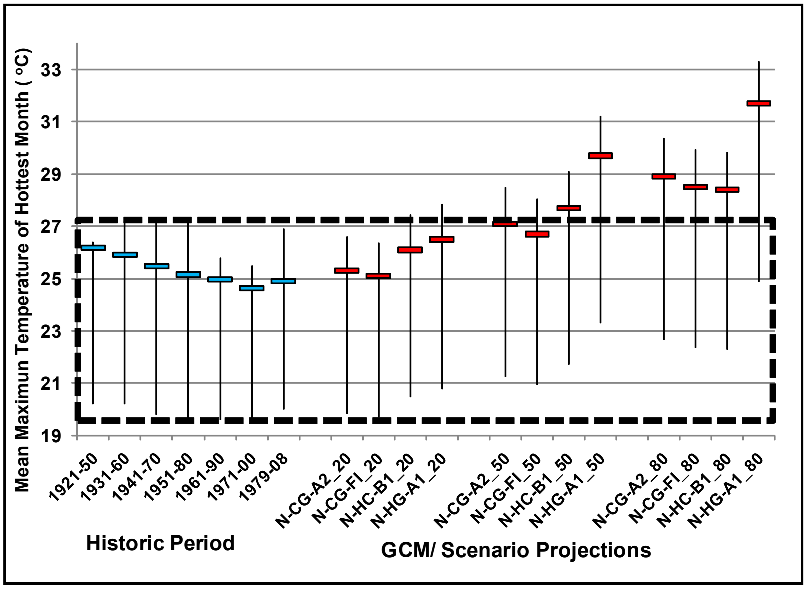

Figure 9. A comparison between historic and projected mean maximum monthly temperatures for the hottest month. The area outlined in the dashed line illustrates the range of historic data. The whiskers on the historic data are the minimums and maximums during each 30 year period. The whiskers on the projected data are based on applying the mean historic distribution of minimums and maximums to the projected future means.

The differences between the various GCMs and emission scenarios are also evident from the graphs. The Canadian GCMs (CGCM) tend to predict warmer and wetter future climates, and hence more modest increases in area burned. The Hadley C (HadC) tends to be cooler and drier, and therefore is projecting intermediate increases in area burned. The Hadley GEM model (HadGEM) tends to be a warmer and drier model, and therefore is projecting the largest increases in area burned. The A1FI emission scenario is consistent with a continued emphasis on fossil fuel consumption, such as we are pursuing today, and therefore it tends to show larger increases in temperatures in the 2080s, and hence larger increases in burned area, while the other scenarios assume significant shifts to non-carbon based energy by 2050.

Although the fire database included information on ignition sources, due to limited resources for this assessment these were not included in the analysis. Some studies (e.g., Price and Rind 1994) have indicated that lightning ignition sources may increase with climate change, and this may also be another avenue for further research.

5.0 Implications

Increasing extent of fires, of the magnitude projected here for all three subregions, will have significant ecological and social implications. In the South and Mid subregions the relatively lower level of increase - compared with the North - is somewhat counter-intuitive. Figures 6 and 7 show that in both 2020s and 2050s, the area potentially influenced by fire is significantly higher than has occurred over the last 50 years, but within the ballpark of what occurred at the beginning of the century. The archive photographs from the southern West Kootenays for this period show extensive areas of the West Arm, Nelson and other areas almost completely burnt, resulting in today's forest cover being dominated by stands of 80 – 120 years in age (e.g., see Fig. 10).

The results from the fire analyses for the South subregion are theoretically consistent with climate envelope shift projections that include substantial area of drier fire resistant forest types, including grassland climate envelopes for the lowest elevations of the South. This would indicate a potential disturbance regime shift in the longer term from infrequent high intensity stand-replacing fires to frequent low intensity fires more associated with grasslands and open forests. The tree species present would likely shift from mixed stands to those limited to fire adapted species. A shift of this magnitude is unlikely to be smooth and gradual, but more likely to be punctuated by a series of high intensity fire years where fuel loadings associated with the previous climate and fire regime are reduced to levels more consistent with higher frequency, lower intensity fires (for example see the episodic nature of the historic record in Fig. 2).

Figure 10. The slopes of Elephant Mountain across from Nelson early in the 20th century (photo courtesy of Touchstones Nelson Museum Archives, Nelson, BC).

For the North subregion, the projected increase in area burned is well above the historic range seen this century, with massive potential increases in area burned into the 2050s and 2080s. The shift to a much more frequent fire regime would have significant ecological consequences, as the existing high value old growth cedar/ hemlock forests are comprised of tree species that are not adapted to frequent fire regimes. The degree of change for this system is therefore predicted to be large, and involves a regime shift, as the stand level gap disturbance processes maintaining these current wet ecosystems shift to a more fire dominated system.

In general, the projections of increased area burned are consistent with ecosystem climate envelope shift projections, that show much of the study area changing from climate envelopes associated with forest types typical of infrequent stand replacement fire regimes (NDTs 1 and 2), to envelopes associated with drier fire resistant forest types typical of areas with frequent stand-replacing fire regimes (NDT 3). In the South subregion, this also includes grassland climate envelopes, indicating a potential disturbance regime shift from infrequent high intensity stand-replacing fires to frequent low intensity fires more associated with grasslands and open forests (NDT 4). In the North subregion a there is a potential regime shift at the lower elevations from a system with very low frequency moderate to high intensity fires and gap dynamics, to a NDT3 system dominated by frequent high intensity fires. As is the case today, it is assumed that higher precipitation and lower temperatures at upper elevations will result in lower fire frequencies and area burned at the upper elevations than at lower elevations, especially in the Mid and North subregions.

There are many implications associated with the results found here – increased risk of fire for the whole region will affect all values currently available from our forests – timber, water supplies, biodiversity and rural living to name a few. The implications for fire management are especially concerning. Recent modeling in Ontario (Podur and Wotton 2010) has similarly projected an eightfold increase in area burned by the end of the 21st century for that area – in part due to increased fire frequency potentially overwhelming fire suppression resources. There will be significant implications for forest management in general, including silvicultural systems, retention levels and selection of species to plant. These issues, and others, will be explored further as the West Kootenay Resilience Project continues.

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