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Supplementary material

Spatially varying constraints of human-caused fire occurrence in British Columbia, Canada

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Data compilation for statistical analysis

Response variable

Our response variable for the GLMs was a count metric of the number of human-caused ignitions per 100km^2 over the 24-year study period. Wildfire incident location data for BC were obtained from the MFLNRO BC Wildfire Service fire database (BC Wildfire Service 2013). The data represent spatially-explicit wildfire ignition points determined with multiple verification methods, including fire lookout stations and aerial surveys. Fires in this dataset exclude prescribed burns. We summed the number of human-caused ignition points for each 100km^2 sampling grid using the Geospatial Modelling Environment (GME) tools (Beyer 2012). We included all fires as opposed to only large fires as each ignition point represents the fire initiation process that has the potential to become large and problematic.

Explanatory variables – human influence

Linear features: paved and unpaved roads, trails.

We assembled road data from the BC Digital Road Atlas (Table 1), which is an up-to-date catalogue of roads that is maintained by GeoBC (GeoBC 2013a). Roads were differentiated between paved and unpaved roads to account for potential differences human behaviour associated with each type. For example, recreational activities and timber harvesting sites are often solely accessible via unpaved forest roads. Paved roads were defined as active roads with a surface type of "paved", while unpaved roads were defined as active roads with a road surface type of "loose" or "rough". Active roads were considered active as of 2013, however, the actual roads and road data might have changed through the time period of the study. We also included trail density, which was quantified from the Recreation Line dataset provided by BC MFLNRO (Recreation Sites and Trails BC 2013). The dataset is a linear spatial layer of recreation trails first created in 2008; we used a dataset updated to 2013.

The wildland-urban interface

The WUI is the area where we expect the highest human-environment interaction to occur and thus spatial variation in the WUI to have the greatest effect on human-caused ignitions. We adapted the Radeloff *et al.* (2005) method to BC using the 2011 Census of Canada digital cartographic files (Statistics Canada 2012) and the 2011 Canada 250m Land Cover Time Series data (Government of Canada, Natural Resources Canada 2012). Radeloff *et al.* (2005) outlined a method to map the WUI in the United States (US) according to US Federal Register definitions using publicly available geographic census data combined with land cover datasets. The US Federal Register makes a distinction between two types of WUI: i.e. intermix and interface; however, for this study, we made no distinction and simply classified areas as WUI or non-WUI. In BC, there is no publicly-available mapping or specific definition of the WUI, there is a current effort by the Wildfire Management Branch to classify the WUI in the province by structure density, the results of which may be ready in the near future.

Following guidelines in Radeloff *et al.* (2005), census dissemination blocks were classified as WUI if they had a housing density of ≥ 6.17 units/km^2 within $\geq 50\%$ wildland vegetation or had $< 50\%$ of wildland vegetation, but within 2.4 km of area that is heavily vegetated, or $> 75\%$ wildland vegetation. Wildland vegetation was defined as forests, shrublands, grasslands, and wetlands of all types and densities. We excluded lichen-dominated areas, agriculture, barren land, urban built-up, and snow/ice. Proportion of WUI was calculated for each of the study cells. The WUI product is accurate to 2011, and we made the assumption that the relationship between fire and the urban fringe of housing development from 1990-2013 is generally preserved by these data at a resolution of 10km.

Land use

Recreational, logging, and rangeland activities can have a profound impact on fire frequency by affecting fine fuels for fire ignition and also because these activities are a proxy for human activity that might lead to human-caused ignition. The BC Baseline Thematic Mapping Present Land Use Spatial Layer (BC BTM) is a frequently updated land use dataset compiled from multiple analytic techniques on Landsat 5 image mosaics and is accurate to 250m (GeoBC 2013b). The data set uses a combination of analytic techniques to determine specific land use polygons, such as recently harvested forests and areas designated for recreational activities. From the BC BTM, we calculated the proportion of timber harvesting (defined as "recently-"or "selectively-logged areas"), recreation areas (defined as "recreational activities"; e.g. Bear Creek Provincial Park) and rangelands (defined as "rangelands") in each cell. We used a dataset updated to 2013.

Explanatory variables – biophysical

Vegetation type

Vegetation type can affect ignitability and the initial rate of fire spread that ultimately leads to a detectable fire (Whelan 1995; Krawchuk *et al.* 2006). We developed five vegetation metrics (Table 1) based on the Natural Resources Canada's 2011 250m Land Cover Time Series data (Government of Canada, Natural Resources Canada 2012) to characterise variability in different fuel types. The dataset contains temporally-consistent land cover classes for 2011 derived from MODIS 250m spatial imagery (Pouliot *et al.* 2014). Natural Resources Canada updates the data annually to reflect any land cover change that is detected within the year, though the clear majority of land cover classes stay the same. We chose the 2011 dataset because it was the same year used to map the WUI. The dataset classifies 25 land cover types including various densities of conifer forests, grasslands and urban areas, amongst other types. The grasslands classification, however, is restricted to the Canadian Prairies and was excluded from our analyses. To simplify analysis, all densities of each forest type were grouped into one category, specifically coniferous, mixedwood and deciduous forests. The other land cover classification types included were shrublands, and wetlands, as these represented wildland vegetation that is potentially influential to the fire ignition process.

Climate

Climatic conditions, specifically variations in precipitation and temperature during the fire season, are essential for creating dry fuels and are strongly associated with ignitability and area burned (Littell *et al.* 2009; Meyn *et al.* 2012). Climatic variables were developed by using the ClimateBC/WNA computer module (Hamann *et al.* 2013) that utilises historical data from weather stations and interpolates annual, seasonal and monthly climatic variables for BC given input data (Spittlehouse 2006). We selected the seasonal variable "mean summer temperature" (June – August) and "mean summer precipitation" over the period 1990-2013. Though, this seasonal variable misses key fire periods like the May "spring dip" in the Boreal, and fire-prone grasses in March-April, it characterises the bulk of wildfire activity in large ecologically diverse province.

Topography

We quantified three topographic variables by using a BC digital elevation model (BC DEM) from the Base Mapping and Geomatics Services Branch of the BC Ministry of Sustainable Resource Management (Base Mapping and Geomatics Services Branch [now GeoBC] 2002). For each 10km spatial unit, we calculated mean elevation, slope, and a transformed metric of aspect called southwestness, which measures how southwest-facing a slope is and is calculated as: cos(aspect – 225). Differences in elevation lead to differences in temperature, precipitation and fuel structure. Variation in slope can be a determinant of ignitability and the rates of fire spread increases on steeper slopes as fires preheat fuels on higher elevations (Bennett *et al.* 2010; Faivre *et al.* 2014). In the northern hemisphere, southwest-facing slopes receive more solar insolation and so are generally the warmest and driest slopes and have been linked with increased ignitability (Syphard *et al.* 2008, 2012). We understand that there is a potential loss in topographic variation calculating means at this scale and are open to alternative measures of topography in future analyses.

Supplementary references

BC Wildfire Service (2013) Fire Incident Locations – Historical. Ministry of Forests, Lands and Natural Resources Operations. Victoria, BC. Available at http://catalogue.data.gov.bc.ca/dataset/fire-incident-locations-historical.

Bennett M, Fitzgerald S, Parker B, Main M, Perleberg A, Schnepf C, Mahoney R (2010) Reducing Fire Risk on Your Forest Property. A Pacific Northwest Extension Publication PNW 618.

Beyer HL (2012) Geospatial Modelling Environment. Version 0.7.2.1. (software). Available at http://www.spatialecology.com/gme.

Faivre N, Jin Y, Goulden ML, Randerson JT (2014) Controls on the spatial pattern of wildfire ignitions in Southern California. *International Journal of Wildland Fire* **23**: 799–811.

GeoBC [formerly Base Mapping and Geomatics Services Branch] (2002) Gridded Digital Elevation Model Product Specifications. Edition: 2.0. Published: December, 2002. Victoria, BC.

GeoBC (2013*a*) Digital Road Atlas (DRA) - Demographic Partially-Attributed Roads. Ministry of Forests, Lands and Natural Resource Operations. Published 27 February 2013. Available at http://catalogue.data.gov.bc.ca/dataset/digital-road-atlas-dra-demographic-partially-attributed-roads.

GeoBC (2013*b*) Baseline Thematic Mapping Present Land Use Version 1 Spatial Layer. Version 1. Ministry of Forests, Lands and Natural Resource Operations. Originally published 09 March 2011. Available at http://catalogue.data.gov.bc.ca/dataset/baseline-thematic-mapping-present-land-use-version-1-spatial-layer.

Government of Canada, Natural Resources Canada/Earth Sciences Sector/Canada Centre for Remote Sensing (2012) Canada 250m Land Cover Time Series 2000-2011. Ottawa, Ontario, Canada.

Hamann A, Wang T, Spittlehouse DL, Murdock TQ (2013) A comprehensive, high-resolution database of historical and projected climate surfaces for western North America. *Bulletin of the American Meteorological Society* **94**: 1307–1309.

Littell J S, McKenzie D, Peterson DL, Westerling AL (2009) Climate and wildfire area burned in western U.S. ecoprovinces, 1916-2003. *Ecological Applications* **19**: 1003–1021.

Meyn A, Schmidtlein S, Taylor SW, Girardin MP, Thonicke K, Cramer W (2012) Precipitation-driven decrease in wildfires in British Columbia. *Regional Environmental Change* **13**: 165–177.

Pouliot D, Latifovic R, Zabcic N, Guindon L, Olthof I (2014) Development and assessment of a 250m spatial resolution MODIS annual land cover time series (2000-2011) for the forest region of Canada derived from change-based updating. *Remote Sensing of Environment* **140**: 731–743.

Radeloff V C, Hammer RB, Stewart S, Fried JS, Holcomb SS, McKeefry JF (2005) The wildland-urban interface in the United States. *Ecological Applications* **15**: 799–805.

Recreation Sites and Trails BC (2013) Recreation Line. Ministry of Forests, Lands and Natural Resource Operations. Originally published: 09 March 2011. Available at http://catalogue.data.gov.bc.ca/dataset/recreation-line.

Spittlehouse D (2006) ClimateBC : Your Access to Interpolated Climate Data for BC. Streamline: *Watershed Management Bulletin* **9**: 16–22.

Statistics Canada (2012) Census of Canada. Cartographic Boundary Files, 2011. v1.0. 24 January 2012. hdl:11272/CT0T7

Syphard AD, Keeley JE, Bar Massada A, Brennan TJ, Radeloff VC (2012) Housing arrangement and location determine the likelihood of housing loss due to wildfire. *PloS one* **7**: e33954.

Syphard AD, Radeloff VC, Keuler NS, Taylor RS, Hawbaker TJ, Stewart SI, Clayton MK (2008) Predicting spatial patterns of fire on a southern California landscape. *International Journal of Wildland Fire* **17**: 602.

Generalised linear model results

Table S1. Final model results of human ignitions modelled by human and biophysical variables in the Boreal Black White Spruce (BWBS) BEC Zone of British Columbia

BWBS	(n = 1718)								
Variable	**Estimate**	**s.e.**	***z* value**	***p***	**ΔAIC**	**VIF**	**β rank**	**ΔAIC rank**	**Final rank**
WUI	1.94	0.19	10.47	<0.001	42.2	1.04	1	2	1.5
Logging	0.79	0.10	8.05	<0.001	51.5	1.21	3	1	2
Unpaved	0.77	0.11	6.79	<0.001	40.6	3.53	4	3	3.5
Paved	1.24	0.31	3.93	<0.001	12.3	4.13	2	6	4
Slope	0.58	0.15	3.93	<0.001	13.2	2.52	5	5	5
Rec. Areas	0.41	0.12	3.55	<0.001	17.3	1.21	6	4	5
Summer PPT	–0.33	0.16	–2.10	<0.05	2.9	1.32	7	7	7
Summer Temp	0.29	0.14	2.16	<0.05	2.8	3.24	8	8	8
Conifer	–0.19	0.08	–2.29	<0.05	2.7	3.74	9	9	9
Deciduous	0.09	0.04	2.19	<0.05	2.4	3.53	10	10	10
Mixedwood	–0.09	0.04	–2.00	<0.05	1.6	1.89	11	11	11
AIC	3173.5								
D-squared	0.50								

Table S2. Final model results of human ignitions modelled by human and biophysical variables in the Coastal Western Hemlock (CWH) BEC Zone of British Columbia

CWH	(*n* = 1174)								
Variable	**Estimate**	**s.e.**	***z* value**	***p***	**ΔAIC**	**VIF**	**β rank**	**ΔAIC rank**	**Final rank**
Summer Temp	1.22	0.13	9.50	<0.001	84.3	3.55	1	2	1.5
Summer PPT	–0.71	0.06	–12.17	<0.001	154.2	1.29	2	1	1.5
Mixedwoods	0.55	0.09	5.91	<0.001	30.8	1.29	3	3	3
Conifer	0.51	0.10	5.24	<0.001	20.4	2.69	4	5	4.5
Elevation	0.48	0.09	5.34	<0.001	24.8	2.09	5	4	4.5
Wetlands	0.42	0.12	3.62	<0.01	11.3	1.35	6	6	6
Deciduous	0.23	0.07	3.33	<0.001	8.2	2.31	7	7	7
Rec. Areas	0.08	0.03	2.68	<0.01	6.3	1.11	10	8	9
SW	0.13	0.06	2.20	<0.05	3.1	1.30	9	9	9
Unpaved	0.20	0.08	2.40	<0.05	2.9	2.33	8	10	9
WUI	0.06	0.03	2.19	<0.05	2.1	2.68	11	11	11
AIC	3297.1								
D-squared	0.62								

Table S3. Final model results of human ignitions modelled by human and biophysical variables in the Interior Cedar-Hemlock (ICH) BEC Zone of British Columbia

ICH	(n = 652)								
Variable	**Estimate**	**s.e.**	***z* value**	***p***	**ΔAIC**	**VIF**	**β rank**	**ΔAIC rank**	**Final rank**
Summer Temp	1.12	0.09	12.45	<0.001	145.50	1.67	2	1	1.5
Mixedwoods	–1.17	0.28	–4.16	<0.001	16.20	1.13	1	3	2
WUI	0.31	0.05	6.69	<0.001	31.10	1.26	3	2	2.5
Logging	0.17	0.04	4.01	<0.001	11.40	1.15	4	4	4
SW	–0.14	0.04	–3.44	<0.001	9.50	1.27	5	5	5
Trail	–0.12	0.05	–2.34	<0.05	3.80	1.24	6	6	6
AIC	2369.8								
D-squared	0.39								

Table S4. Final model results of human ignitions modelled by human and biophysical variables in the Ponderosa Pine – Bunchgrass – Interior Douglas-fir (PPBGIDF) BEC Zone of British Columbia

PPBGIDF	(n = 544)								
Variable	**Estimate**	**s.e.**	***z* value**	***p***	**ΔAIC**	**VIF**	**β rank**	**ΔAIC rank**	**Final rank**
Conifer	0.42	0.07	5.75	<0.001	32.6	3.06	3	3	3
Summer Temp	0.55	0.10	5.39	<0.001	26.5	4.32	2	4	3
Summer PPT	–0.77	0.15	–5.07	<0.001	25.2	1.16	1	5	3
Shrub	0.38	0.05	8.41	<0.001	79.9	2.35	5	1	3
WUI	0.14	0.02	6.69	<0.001	43.9	1.63	6	2	4
Elevation	–0.40	0.16	–2.47	<0.05	4.4	4.75	4	6	5
AIC	3594.9								
D-squared	0.42								

Table S5. **Final model results of human ignitions modelled by human and biophysical variables in the Sub-Boreal Pine-Spruce (SBPS) BEC Zone of British Columbia**

SBPS	(n = 241)								
Variable	**Estimate**	**s.e.**	***z* value**	***p***	**ΔAIC**	**VIF**	**β rank**	**ΔAIC rank**	**Final rank**
WUI	4.90	1.10	4.43	<0.001	36.49	1.03	1	1	1
Summer PPT	–1.44	0.28	–5.10	<0.001	29.57	1.53	2	2	2
Deciduous	1.11	0.27	4.13	<0.001	15.80	1.14	3	3	3
Unpaved	0.29	0.10	2.81	<0.01	5.62	1.47	4	4	4
SW	0.19	0.10	1.96	<0.05	1.40	1.15	5	5	5
AIC	943.75								
D-squared	0.39								

Table S6. **Final model results of human ignitions modelled by human and biophysical variables in the Sub-Boreal Spruce (SBS) BEC Zone of British Columbia**

SBS	(n = 1099)								
Variable	**Estimate**	**s.e.**	***z* value**	***p***	**ΔAIC**	**VIF**	**β rank**	**ΔAIC rank**	**Final rank**
Paved	1.06	0.13	8.09	<0.001	59.9	1.87	1	1	1
Deciduous	0.44	0.06	7.64	<0.001	54.7	4.19	6	2	4
Shrub	0.51	0.08	6.12	<0.001	33.5	5.12	4	4	4
Conifer	0.62	0.15	4.09	<0.001	14.2	8.43	3	7	5
SW	0.32	0.04	7.27	<0.001	47.9	3.82	7	3	5
Rangelands	0.93	0.31	2.98	<0.01	6.7	1.05	2	9	5.5
Summer Temp	0.48	0.12	3.82	<0.001	13.7	1.87	5	8	6.5
WUI	0.23	0.04	5.32	<0.001	17.1	1.28	8	5	6.5
Rec. Area	0.13	0.03	4.54	<0.001	14.5	1.02	9	6	7.5
AIC	3950.3								
D-squared	0.39								