EVALUATION OF WILDFIRE RISK ACROSS THE PROVINCE OF BRITISH COLMBIA: A SIMPLIFIED MODEL

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Abstract

Through a simplified model, which assigns different weights to different factors, four factors are considered to produce a map evaluating the wildfire risks across B.C. in the summer months. The factors considered include temperature (0.3), precipitation (0.3), vegetation and natural disturbance type (0.3), as well as fire hall coverage (0.1). Using the climate data from August 2016, wildfire risk is classified into five different categories: low risk, moderately low risk, moderately high risk, high risk, and extreme risk. This present wildfire risk analysis aims to infer a general pattern of B.C.'s wildfire risk in the summer months and suggest future wildfire prevention resource allocation through analyzing the dataset of August 2016. Basic GIS techniques and tools used include interpolation, Euclidean distance, as well as overlay analysis. The resulting map reproduced general trends consistent with official fire danger maps, with slight differences in Central B.C. and along the Northern Coast. It is concluded that the majority of extreme risk and high risk areas concentrates in the Okanagan region, around Metro Vancouver, as well as southern Vancouver Island, where almost half of B.C.'s population reside. Therefore, the fire prevention resources should concentrate in the areas named above.

Project Description

Wildfire risk classification and analysis has become a topic that has been extensively studied, especially in recent years, due to the increasingly warming climate and frequent extreme weather events. According to Natural Resources Canada, "climate change during the 21st century is expected to result in more frequent fires in many boreal forests, with severe environmental and economic consequences (2017)." While the Canadian Wildland Fire Information System (CWFIS) has a structured Fire Behavior Prediction (FBP) system that rates wildfire risks considering fuels, weather, topology, and foliar moisture content, and analyzes the results in terms of rate of speed, head fire intensity, and other categories, the exact breakdown of analysis procedures is not available to the public. In addition, most of these maps present the data at a national scale. This present study, then, aims to focus solely on wildfire risk in the province of British Columbia in August 2016, uses open source data, and mimics the FBP system through a simplified model, to produce a B.C. wildfire risk classification map with five categories. Factors considered in this simplified model include maximum temperature and total precipitation of Aug 2016 across B.C., primary natural disturbance types by ecosystems, as well as distance to the closest fire halls. The produced map is then used to compare with historical fire perimeters dated in August between 2000 and 2015, with the goal of discovering patterns and making suggestions on future allocations of fire management resources at a provincial level.

All of the data used in the analysis are available for download from the provincial data catalogue, Environment Canada, and ArcGIS online. Specifically, B.C. census subdivisions are merged to a provincial outline of B.C.; monthly climate summaries are the base of temperature and precipitation interpolations; biogeoclimatic ecosystem classification define primary natural disturbances; B.C. first responders are used to generate distance from the closest fire halls; historical fire perimeters serve as a comparison to our final map in the search of patterns and future suggestions on fire prevention resource allocation.

Methodology of Analysis

To sketch the methodology of the analysis, a rough description would be to create a classified raster layer for each of the four factors (maximum temperature, total precipitation, distance to closest fire halls, and types of natural disturbances), overlay each layer according to assigned weight to produce the final wildfire risk map. Any subsequent analyses derive from the above process. We now move on to a more detailed description of the steps conducted to achieve the result.

Before we begin the analysis, a projection needs to be established as common ground. Albers Equal Area Conic, the B.C. Environment standard projection, is chosen for the reason that it minimizes distortion in area, as its name may suggest, and that the present study visualizes the classified fire risk in terms of area. It is also determined that the final output raster layers would have a cell size of 500 to show enough detail, and that the risk ratings would be classified using equal intervals for simplicity. For the final map, each factor would take a weight of 0.3, except for proximity to fire halls, which is set at 0.1, since it belongs to the category of fire suppression, which is a secondary factor to risk compared to fire initiation. The next step is to obtain a provincial outline of B.C., as a definition of the study area. From ArcGIS online, the B.C. census division polygon layer includes all of B.C. and is in the desired projection. It is then merged using the editor tool to serve as the provincial outline.

Now that the basis is laid out, the B.C. climate summary table is used to match B.C. weather stations to interpolate both the temperature and precipitation layers. The B.C. weather station layer from Data B.C. includes both active and inactive weather stations as of August 2016. Therefore, it is necessary to keep only weather stations that has a recorded summary for August 2016. Joining the weather station point layer's attribute table and the climate summary table allows us to achieve such goals. As a result, we have 185 records of maximum temperature after removing all null values. Similarly, we obtained 192 records of total precipitation across the province. Maximum temperature is selected over average temperature, because it is a better indicator for the risk of starting a fire. On the other hand, total precipitation is the only record about precipitation that fits the study. Since the original data come in as strings, it is important to convert them to integers in order to classify these values mathematically. To interpolate, inverse distance weighted (IDW) is chosen over Kriging due to the presence of outliers (remotely located weather stations in Northern B.C.) and the fact that Kriging is not robust against outliers. Setting the provincial outline as the processing extent, clipping by the provincial outline, and classify using equal intervals into five categories, we arrive at the maximum temperature and total precipitation output raster layers.

According to Erin Hall, "similar ecosystems tend to exhibit similar fire regimes" and therefore can be used to classify risk (2010). According to her classification considering mainly vegetation and ecosystems, five categories of natural disturbances can be ranked in terms of wildfire risks. Ranking them from lowest to highest risk, the categories are: alpine tundra and subalpine parkland, ecosystems with rare stand-initiating events, ecosystems with infrequent stand-initiating events, ecosystems with frequent stand-initiating events, and ecosystems with frequent stand-maintaining events. Using the biogeoclimatic polygon layer, which features the natural disturbance types (NDT) mentioned above, the polygons are merged by NDT and assigned risk levels. Converting the merged polygon layer to a raster layer by risk, clipping by the provincial outline, we arrive at the final natural disturbance layer. Moving onto distance to fire hall, the Euclidean distance tool is utilized using a point layer of fire halls filtered from the B.C first responders layer. Here, the Euclidean distance, instead of drive time, is used for simplicity and the lack of a provincial road network layer. After classifying, again using equal interval, into five categories, we arrive at the final distance to fire hall raster layer.

Having all four raster layers representing four factors ready, the weighted sum tool helps to produce the final map using the ratio specified above. For further discussion and analysis, a provincial river layer, historical fire perimeters from August between 2000 and 2015, as well as major cities are also included.

Discussion and Results

The results of the analysis (see Appendix B) show that a relatively low land area of the province of B.C. was at the extreme risk of fire in the summer of 2016. Approximately 10.8% of the province, or 101,809 square kilometers is considered to be in a state of extreme fire risk during August 2016. Conversely, our analysis shows that approximately 15.3% of British Columbia was at low risk of wildfire in the summer of 2016. The majority of the province, approximately 74% of its land area, fell in between these two extremes: 11.2% was considered to be at moderately low risk, 35.5% was considered to be at moderate risk, and 28.3% was considered to be at high risk of wildfire. These figures depend on, as mentioned in the previous sections, the risk classification method that is based on consideration of maximum temperature, total precipitation of the month, and risk of each ecosystem type to fire-oriented natural disturbance, with each of the factors weighted equally at 0.3. Proximity to municipal fire halls was weighted most lightly, at 10% of the total contribution to risk. The low weighting of proximity to fire halls is justified by the fact that it concerns fire suppression rather than initiation. In addition, municipal fire stations typically play a more minor role in wildfire suppression than air and land based efforts by the specialized B.C. Wildfire Service, trained wildfire responders from other provinces, and the Canadian Armed Forces (Govt of B.C.). British Columbia's effective wildfire response depends on pre-existing knowledge of geographic locations of high wildfire risk, and statistics regarding population and property density in these regions. Following a discussion on the interpretation and explanation of our analysis, we place our result in the social context in terms of municipalities and populations in areas of varying wildfire risks. Finally, suggestions for efficient resource and fire response personnel will be considered.

Looking at the temperature and precipitation layers individually (see Appendix C and D), the southern area of Vancouver Island is classified as having high risk. However, in the resulting map, the risk of wildfire in this region is lowered, due to the prevalence of coastal hemlock and other vegetation types of lower fire risk (see Appendix E), along with the high concentration of fire halls. Graham Island, which is located north of Vancouver Island, similarly has a dry climate in the summer. However, its overall wildfire risk is the relatively low temperature and natural disturbance that are unlikely to cause fire surrounding the area result in its overall lower risk of fire. Shifting the focus back to the final map, it is easily identified the presence of rough circles clustered, representing a decrease in wildfire risk comparing to its surrounding areas, located at northwest corner of the province, and areas north of Prince George. They coincide with the circles centred around fire halls (see Appendix F). Overlaying the historical fire perimeter layer, which contains locations of fires that took place each August between 2000 and 2015, we observe that most fires took place in the southeastern region of the province (see Appendix G). While the exact locations of historical fires may not fall into the exact areas of highest wildfire risk through our model, the general pattern agrees between the two graphs.

Based on our analysis, the largest identifiable region of extreme wildfire risk occurs in the central to southern interior of the province (widely known as the Okanagan), coinciding with a fairly high population density. Major cities and towns in this region of extreme wildfire risk include: Kelowna, Kamloops, Vernon, Salmon Arm, Penticton, Princeton, Summerland, among others. There is an additional region of extreme fire risk within the Lower Fraser Valley (between Metro Vancouver and the Okanagan region), including the cities of Langley, Maple Ridge, Chilliwack, and Pitt Meadows. On Vancouver Island, there are two primary regions of high wildfire risk, which include Port Alberni, and municipalities surrounding Lake Cowichan. In the Cariboo District (North of the Okanagan Valley), the municipalities of Quesnel and Williams Lake, as well as Clearwater and 100 Mile House are at extreme risk of wildfire. Within the Rocky Mountains of British Columbia, municipalities including Cranbook, Invermere, and Radium are at extreme risk of fire. Generally, Northern B.C. is at a much lower risk of wildfire, and by visual comparison between the final classified risk map and the interpolation of temperatures within the province, we can conclude that the lower risk of wildfire stems largely from the lower temperatures North of Kamloops. The lowest risk of forest fire occurs along the Sunshine Coast and along the Northern coastline, and by visual comparison with temperature and precipitation interpolated maps, we can safely conclude that this low risk primarily occurs due to lower, less volatile temperatures mediated by oceanic proximity along the coast.

When evaluating fire risk across the province and attempting to determine the best allocation of Wildfire Service equipment and personnel, it is constructive to consider municipalities and regions with high population and developed structures, as preservation of life and property is a key responsibility of the B.C. Wildfire Service. By assessing the geographic distribution of population density, resource management will be better equipped to make informed decisions regarding high priority areas. For this component of the analysis, the population statistics referred to were collected in 2010. These figures are likely outdated and do not accurately reflect the current population statistics of the province, but were used due to data availability issues. We may assume that although total population of the province changed through the past decade, overall geographic distribution may be similar, however this represents a possible source of error.

A large proportion of the population of British Columbia lies in the Southern one-third of the province, largely due to the high population of metropolitan Vancouver. For instance, 41.8% of British Columbia's total population resides in 19 municipalities around the City of Vancouver (City of Vancouver to Mission City). The majority of these municipalities are considered to be at high risk of fire during August of 2016, and consequently, a large proportion of the population of British Columbia is likely to be considered at high risk of fire according to our analysis. Ultimately, we concluded that 69 cities and municipalities across the province are at high risk of fire, notably including Prince George, Vancouver, Richmond, North Vancouver, Surrey, Delta, White Rock, Whistler, Nanaimo, West Vancouver, Mission City, Port Coquitlam, Burnaby, and the province's capital, Victoria. Cumulatively, 56.5% of the province's population lives in a region of high wildfire risk. An additional 15.8% of the population live in a region of extreme wildfire risk including residents of Kelowna and Kamloops, and others listed above. Overall, 0.9% of the population lived in a region of moderate fire risk, 0.2% of the population lived in a region of moderately low fire risk, and 1% of the population lived in a region of low or very low fire risk. An additional percentage of the population lives in a non-metropolitan region of the province where population statistics were not available.

Visual inspection of our final map and an official map depicting fire danger assessment produced by Natural Resources Canada on August 21, 2016, shows that despite several key differences, our produced map correctly portrays key trends and the majority of extreme fire risk locations (see Appendix H). In the Okanagan, our map correctly identified the municipalities of Kamloops, Kelowna, Princeton, Penticton, Salmon Arm and municipalities surrounding Shushwap Lake as being in extreme wildfire danger. In the B.C. Rocky Mountains, our map correctly identified the area surrounding Windermere, Cranbook, and Radium Hot Springs being in the most extreme fire danger. On Vancouver Island, our map correctly identified the areas surrounding Port Alberni and the Cowichan Bay as being areas of extreme fire risk. Our map also correctly identified the generally declining risk of wildfire in the Northern half of the province, particularly north of the centre of the province in the vicinity of Williston and McLeod Lake. Our map also correctly identified a region of increasing fire risk in the Northeastern corner of the province around Fort Nelson, however our map may have underestimated the severity of risk in this region and did not pinpoint the specific area of risk around Fort Nelson. Areas where our map overestimated the risk of wildfire included the centre of the province, west of Quesnel. Our map also overestimated risk in the central North of the province close to the border with Yukon Territory. Along the central coast of the province, from Whistler to Pemberton Icefields, our map underestimated the risk of wildfire. By visual inspection of our individual data layers, it is probable that our map underestimated temperature in these regions. In the centre of the province near Williston Lake, our map likely underestimated precipitation. This may have resulted from inaccuracies in the interpolation process, particularly in the Northern half of the province where weather stations were sparse.

The implications for the produced map are clear, as it is evident that areas with high or extreme wildfire risk coincide with those having high population densities in the province of British Columbia. Consequently, the B.C. Wildfire Service and First Responders across the province should aim to maximize coverage of areas of high risk and high population density to avoid loss of life and property. An area of particular focus for the B.C. Wildfire Service and First Responders is municipalities surrounding the Metro Vancouver area, due to the high population density and their relatively high risk, to warrant concern for the population. By inspecting our map layer of first responder fire hall locations, it is clear that the Vancouver area is indeed significantly prioritized. Additionally, density of fire halls throughout the Okanagan region is high, suggesting that the placement of these fire halls according to risk of wildfire has been astutely considered across this region of the province. The density of fire halls is particularly high surrounding the Shushwap Lake and Kelowna, one of the highest risk regions in the province. This density primarily correlates with major cities (population density), but also is significantly higher than average in less population dense regions of the Okanagan. Although fire hall density does seem to be correlated with wildfire risk, it is highly probable that the B.C. Wildfire Service plays a more major role than municipal fire services when responding to Widfires across the province. The accessibility of remote wildfire regions by aircraft and specialized vehicles is an area for further research.

Error and Uncertainty

Being a simplified model as it is, errors and uncertainties may come from different aspects of the analysis. Namely, the difference between area of the provincial outline and actual area of B.C., reduced accuracy of interpolation due to sparsely located weather stations, redundancy of weather and precipitation factors in natural disturbance type classification, the difference between Euclidean distance versus actual drive distance from closest fire halls, arbitrary factor weights, missing factors such as humidity and wind speed, can all contribute to the overall errors and uncertainties in the final map.

Combining census divisions within B.C. gives us a provincial outline of 948,436km^2 in area. Comparing this number to the official area of 944,735km^2, the outline used in the study is off by 0.4%, due to what is likely to be rounding errors. Therefore, the calculation of areas derived from this base needs to be viewed with skepticism.

The next possible source of uncertainty comes from the interpolation step of the analysis. Looking at the point layer of all active weather stations as of August 2016, there is a major decrease of weather stations from Southern and coastal B.C. to the Northern area of the province. From one perspective, the number of stations decrease from south to north, which may result in reduced accuracy of interpolation. On the other hand, the density of weather stations follows a similar pattern, which contributes to the same source of uncertainty. In addition, null values for weather and precipitation is present as well. Although IDW is used as the method of interpolation, which is robust against outliers, the potential presence of error and uncertainty on the two interpolated layers cannot be overlooked. It is worth mentioning again that the use of total precipitation for the precipitation interpolation layer is not ideal, which may take away the accuracy of the result as well.

Although Erin Hall's analysis focused on fire risk classified by vegetation and ecosystems, weather and climate are taken into consideration as well. Therefore, there is a slight redundancy of the temperature and precipitation factors in our analysis. The arbitrary 3:3:3:1 ratio for the four factors may then result in a stronger weight on temperature and precipitation. The exact ratio considering Erin Hall's inclusion on temperature and precipitation, is difficult to calculate, and is beyond the scope of this simplified model.

In the realization that most wildfires are suppressed by means of helicopters and that the fire halls points are indeed municipal fire halls, the idea of distance from closest fire halls does not make strong logical sense. However, without such measure, the effectiveness of wildfire suppression would be extremely difficult to model. Therefore, we include it in our analysis while aware of the fact that this may not be an accurate representation. In addition, in the lack of a road network layer, the use of straight line distance is merely a general representation of the actual accessibility of these fire halls. It is also worth noting that this factor belongs to fire suppression, rather than fire initiation, which is a point already made in the previous sections.

Other miscellaneous source of errors and uncertainties include the arbitrary weights assigned to each factor and missing factors such as humidity and wind speed. However, the fact that this model is only a simplified model for wildfire risk analysis accepts the presence of such errors and uncertainties.

Further Research

Based on the errors and uncertainties mentioned in the previous section, a set of improvements and recommendations can be applied to serve as directions for further research. A few of the major suggestions include using a network analysis to calculate drive time rather than direct distance and studying the correlation between temperature and wildfire risk, and between precipitation and wildfire risk, respectively, to improve the classification method to replace equal intervals.

For the same reason mentioned in the previous section, the use of Euclidean distance is only a general representation of the distance from closest fire facilities. The purpose of such factor is to model the availability of fire facilities across B.C.. To improve this representation, a provincial road network layer can be introduced, and a network analysis can be included in the study to better model the availability of fire facilities. Furthermore, one can also consider traffic as an additional factor. Of course, though, all of this is based on the not-so-accurate model measuring fire facility availability using municipal fire hall locations. A different model to represent such factor would significantly increase the accuracy of studies on this topic.

In the present study, all of the raster classifications are conducted using equal intervals for simplicity purposes. To look at this classification method more closely, it is not difficult to realize that the relationship between temperature, precipitation, and wildfire risk is not strictly linear. Therefore, further studies can use statistical models to find the correlation between temperature, precipitation, and wildfire risks. Furthermore, it could be helpful to look at the interaction between temperature and precipitation on wildfire risk to see what combination of the two factors result in greater risk of wildfire and therefore better classify wildfire risk in terms of these two factors.

To summarize, this simplified model aims to mimic the process of the Fire Behavior Prediction system, and therefore includes certain flaws. However, as a general reference and guideline, it highlights the area of higher wildfire risks. As a suggestion, further research and studies can dig into areas that are classified as having high wildfire risks to further zoom in on the topic and provide more detailed findings.

References

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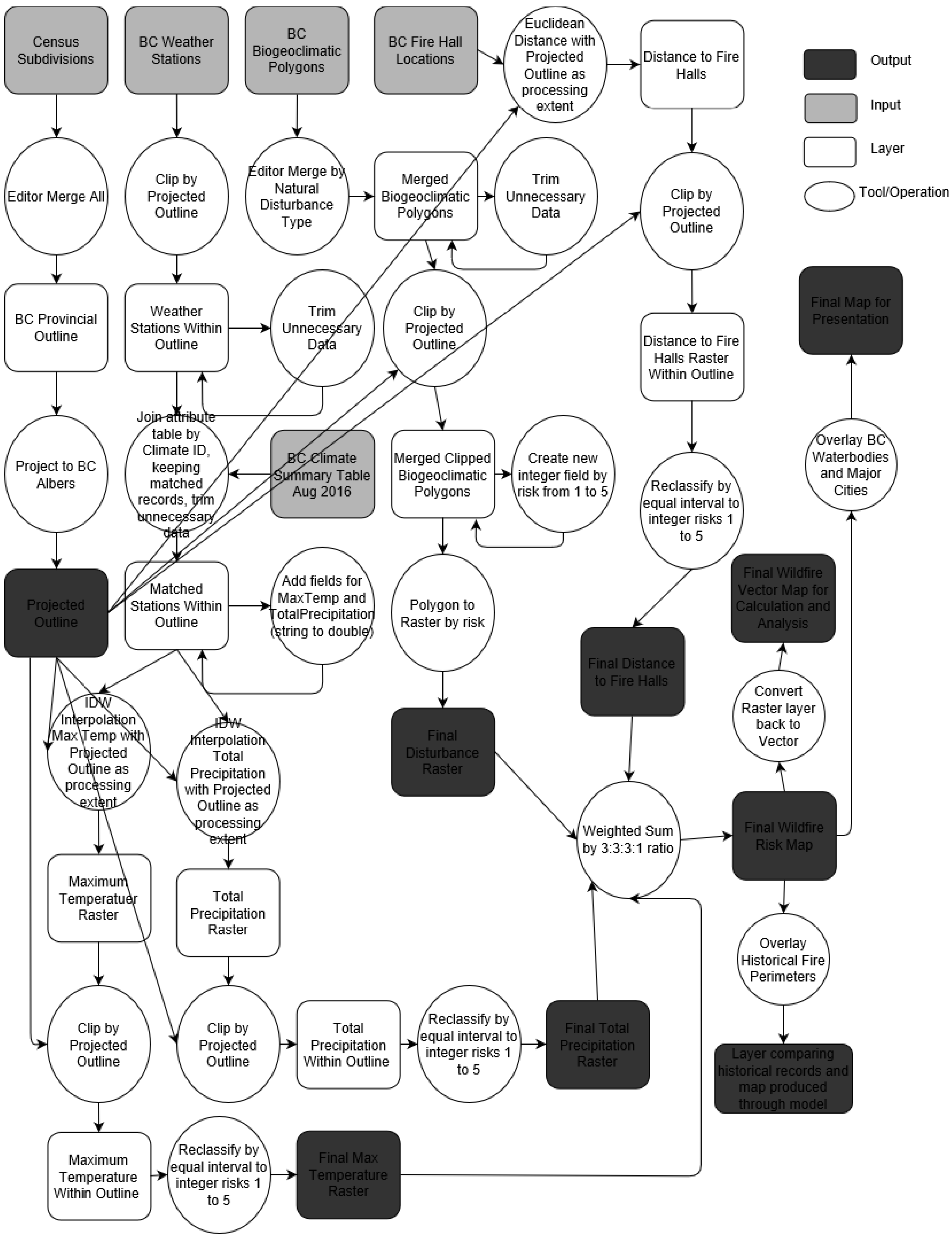
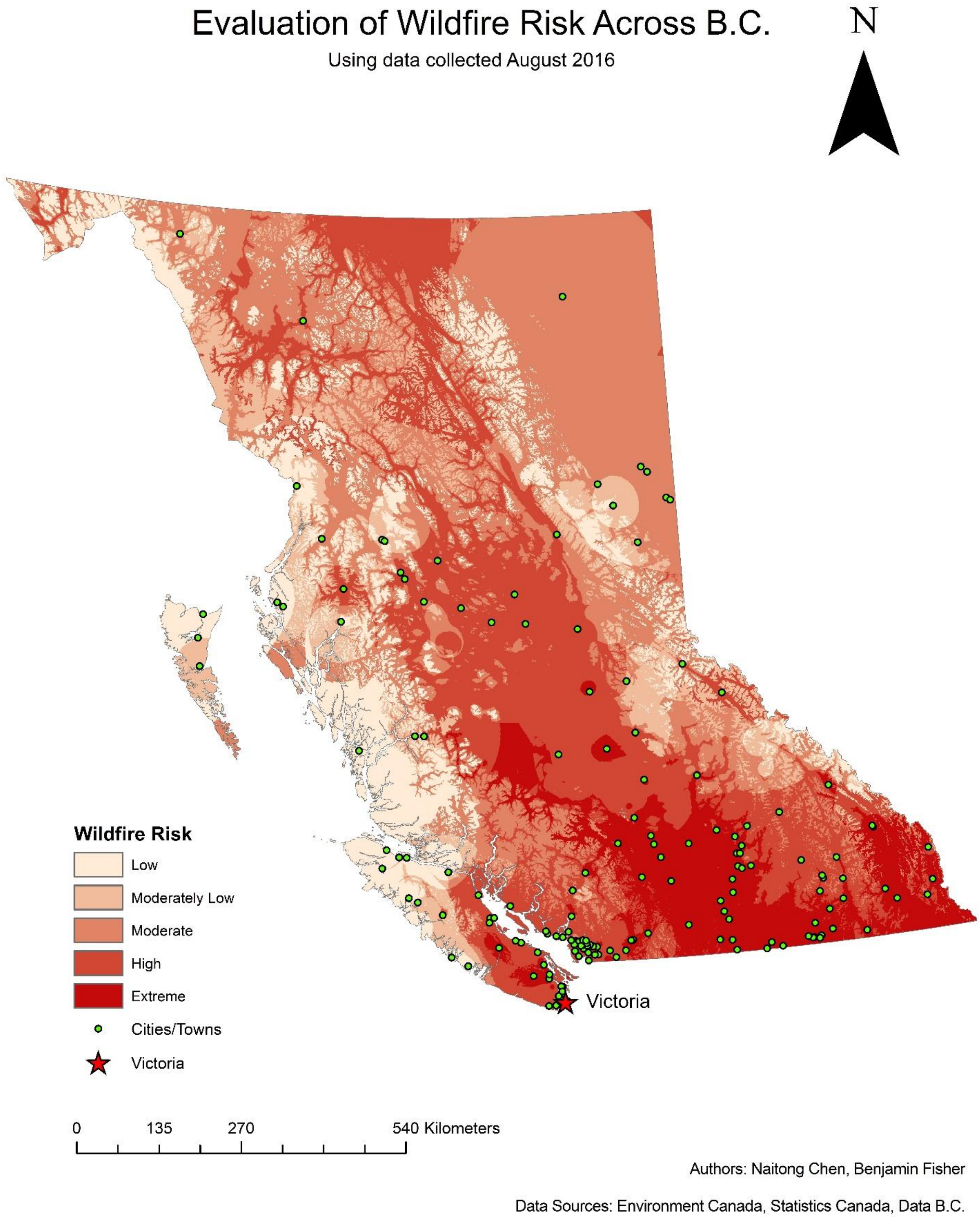
Appendix A

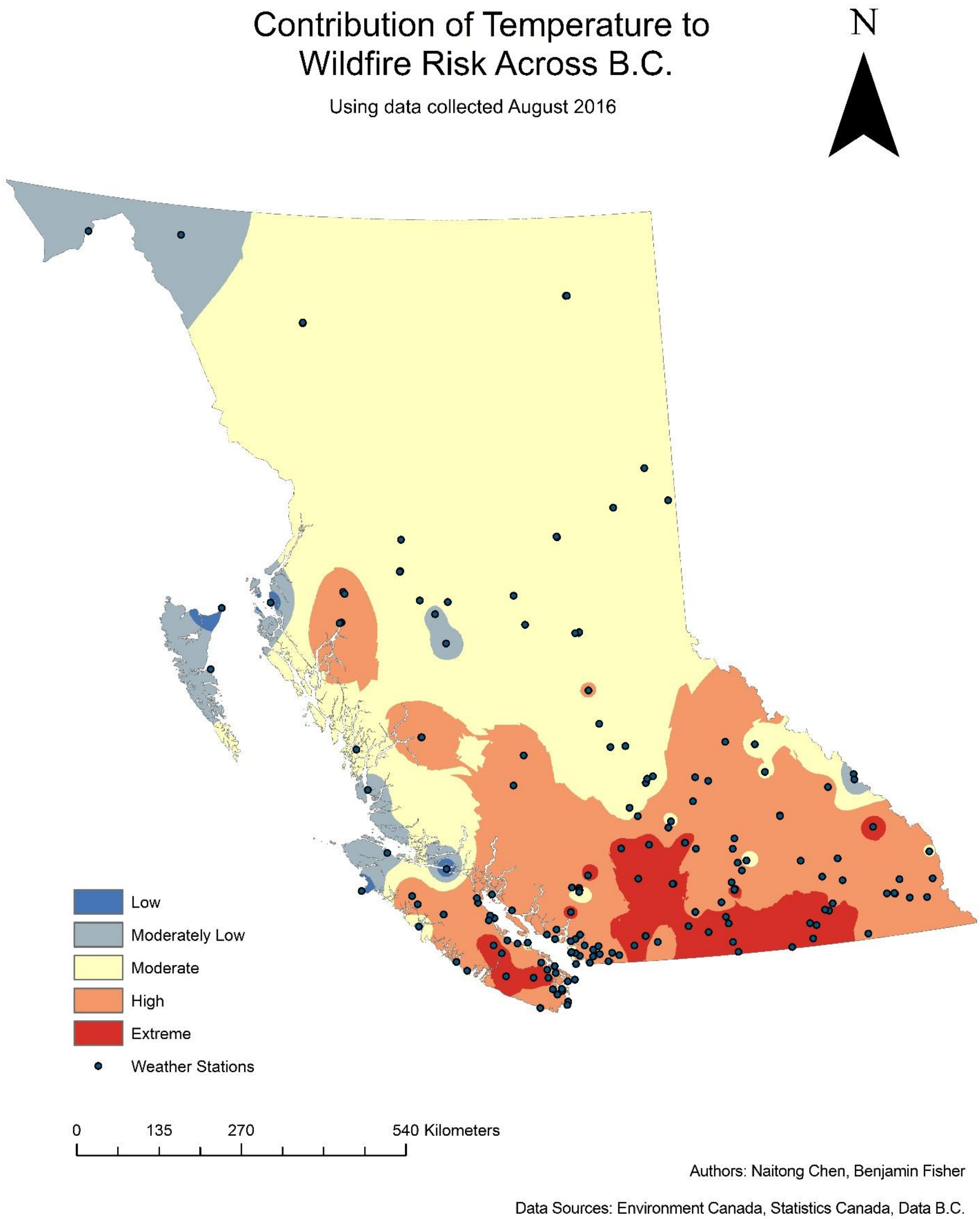


Census Subdivisions
BC Weather Stations
BC Biogeoclimatic Polygons
BC Fire Hall Locations
Euclidean Distance with Projected Outline as processing extent
Distance to Fire Halls
Output
Input
Layer
Tool/Operation
Editor Merge All
Clip by Projected Outline
Editor Merge by Natural Disturbance Type
Merged Biogeoclimatic Polygons
Trim Unnecessary Data
Clip by Projected Outline
BC Provincial Outline
Weather Stations Within Outline
Trim Unnecessary Data
Clip by Projected Outline
Distance to Fire Halls Raster Within Outline
Final Map for Presentation
Project to BC Albers
Join attribute table by Climate ID, keeping matched records, trim unnecessary data
BC Climate Summary Table Aug 2016
Merged Clipped Biogeoclimatic Polygons
Create new integer field by risk from 1 to 5
Reclassify by equal interval to integer risks 1 to 5
Overlay BC Waterbodies and Major Cities
Projected Outline
Matched Stations Within Outline
Add fields for MaxTemp and TotalPrecipitation (string to double)
Polygon to Raster by risk
Final Distance to Fire Halls
Final Wildfire Vector Map for Calculation and Analysis
IDW Interpolation Max Temp with Projected Outline as processing extent
IDW Interpolation Total Precipitation with Projected Outline as processing extent
Final Disturbance Raster
Convert Raster layer back to Vector
Weighted Sum by 3:3:3:1 ratio
Final Wildfire Risk Map
Maximum Temperatuer Raster
Total Precipitation Raster
Overlay Historical Fire Perimeters
Clip by Projected Outline
Clip by Projected Outline
Total Precipitation Within Outline
Reclassify by equal interval to integer risks 1 to 5
Final Total Precipitation Raster
Layer comparing historical records and map produced through model
Maximum Temperature Within Outline
Reclassify by equal interval to integer risks 1 to 5
Final Max Temperature Raster

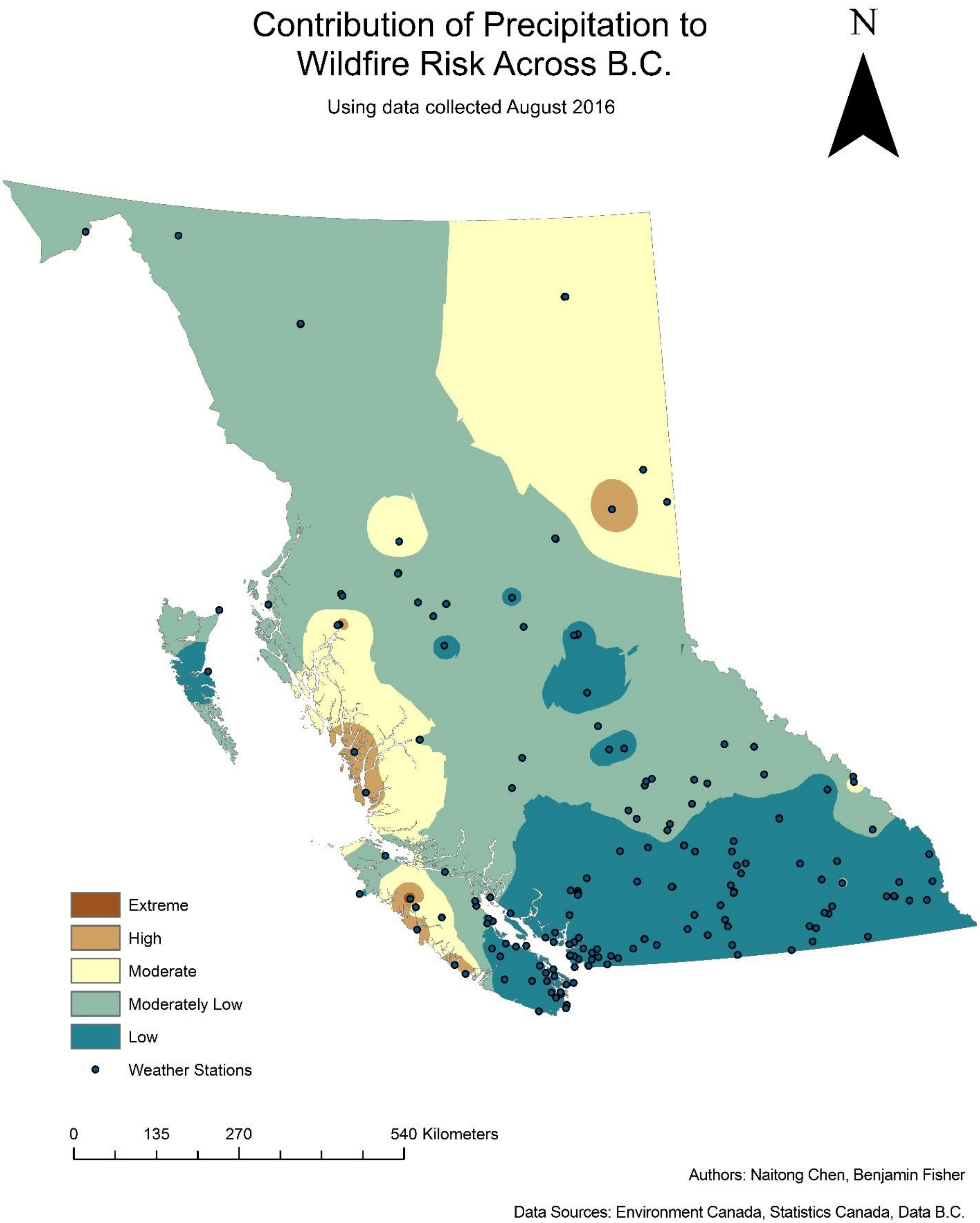
Appendix B


Evaluation of Wildfire Risk Across B.C.
Using data collected August 2016
N
Victoria
Wildfire Risk
Low
Moderately Low
Moderate
High
Extreme
Cities/Towns
Victoria
0
135
270
540 Kilometers
Authors: Naitong Chen, Benjamin Fisher
Data Sources: Environment Canada, Statistics Canada, Data B.C.

Appendix C

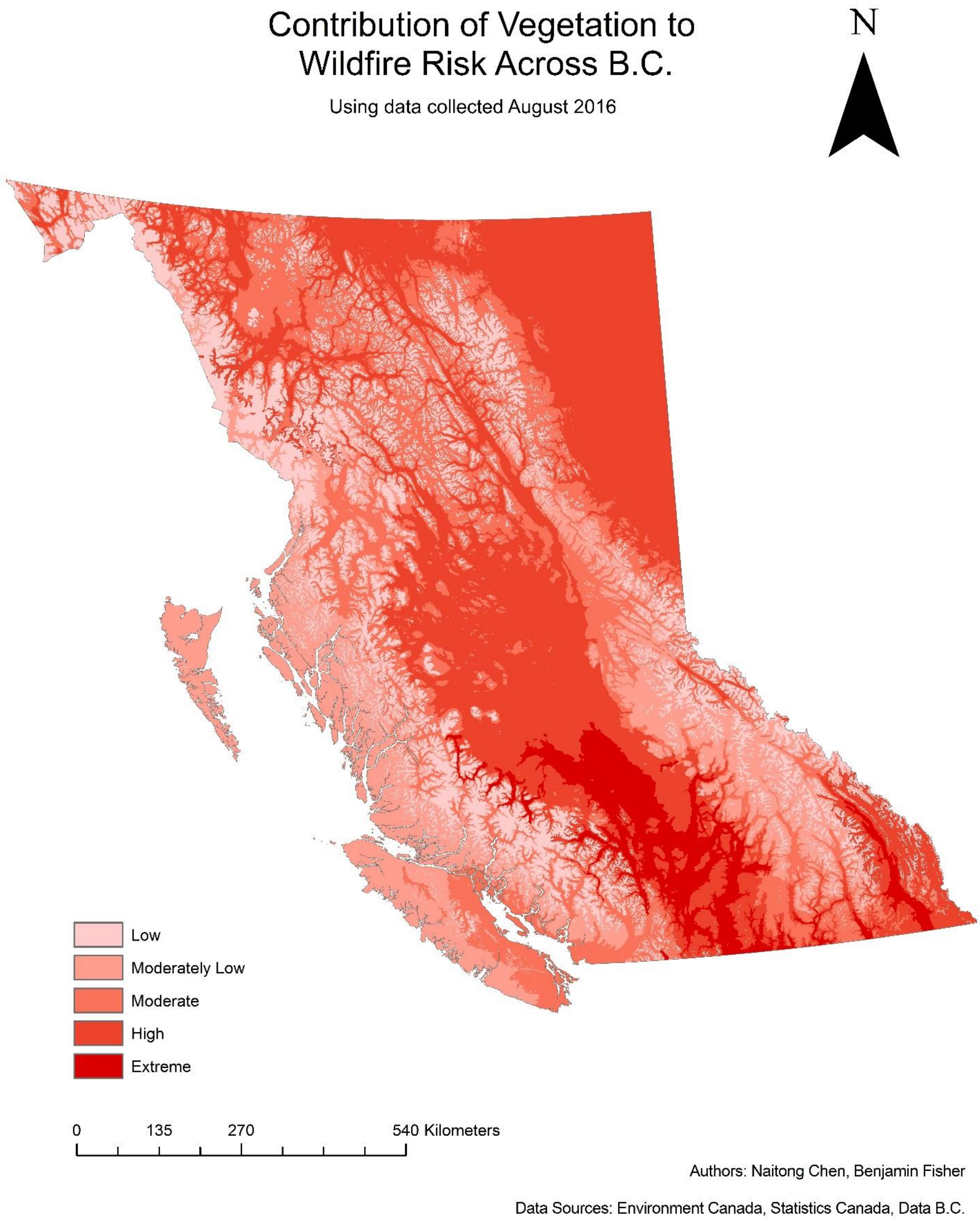

Contribution of Temperature to
Wildfire Risk Across B.C.
Using data collected August 2016
N
Low
Moderately Low
Moderate
High
Extreme
Weather Stations
0
135
270
540 Kilometers
Authors: Naitong Chen, Benjamin Fisher
Data Sources: Environment Canada, Statistics Canada, Data B.C.

Appendix D

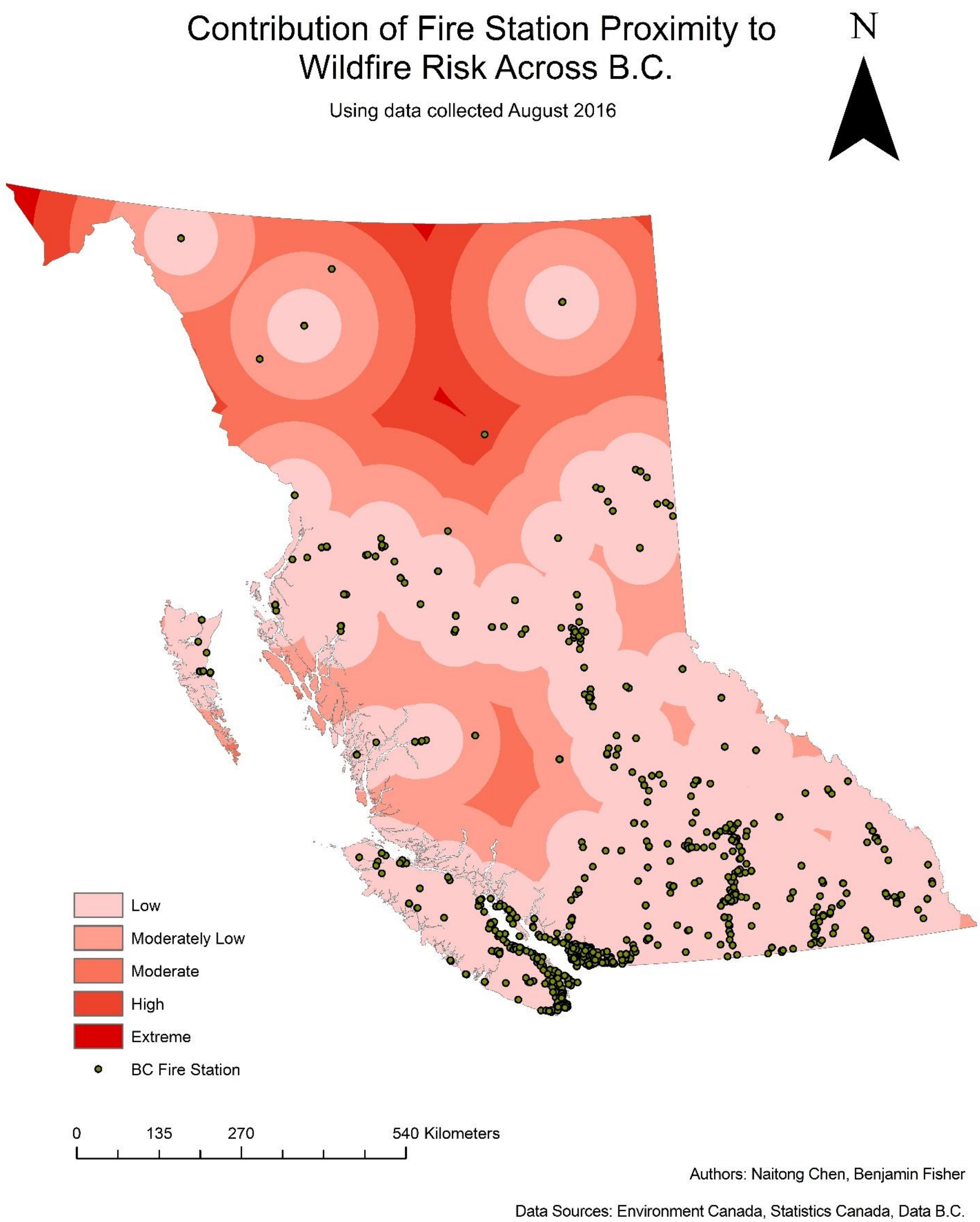


Contribution of Precipitation to Wildfire Risk Across B.C.
Using data collected August 2016
N
Extreme
High
Moderate
Moderately Low
Low
Weather Stations
0
135
270
540 Kilometers
Authors: Naitong Chen, Benjamin Fisher
Data Sources: Environment Canada, Statistics Canada, Data B.C.

Appendix E

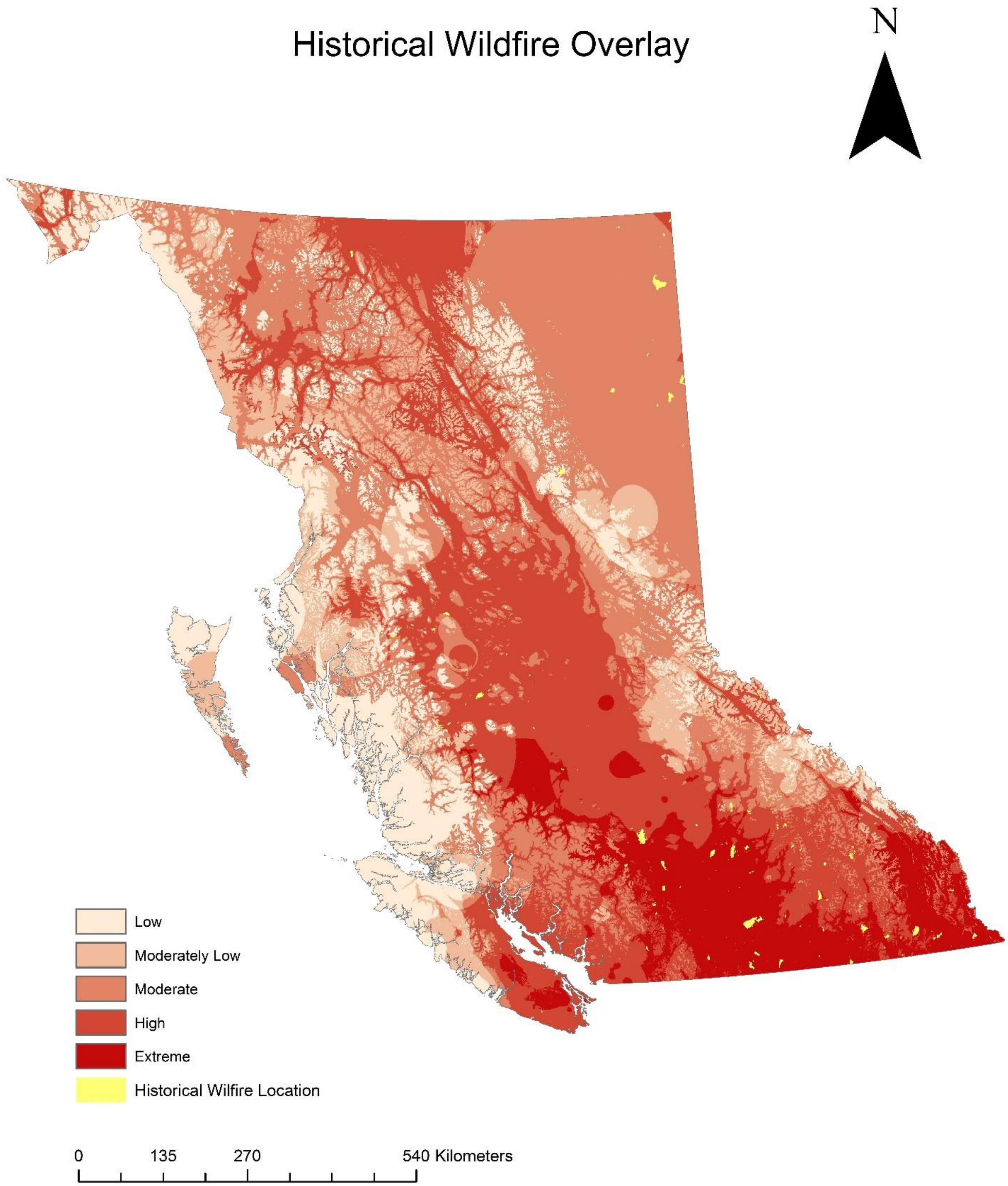

Contribution of Vegetation to
Wildfire Risk Across B.C.
Using data collected August 2016
N
Low
Moderately Low
Moderate
High
Extreme
0
135
270
540 Kilometers
Authors: Naitong Chen, Benjamin Fisher
Data Sources: Environment Canada, Statistics Canada, Data B.C.

Appendix F


Contribution of Fire Station Proximity to Wildfire Risk Across B.C.
Using data collected August 2016
N
Low
Moderately Low
Moderate
High
Extreme
BC Fire Station
0
135
270
540 Kilometers
Authors: Naitong Chen, Benjamin Fisher
Data Sources: Environment Canada, Statistics Canada, Data B.C.

Appendix G

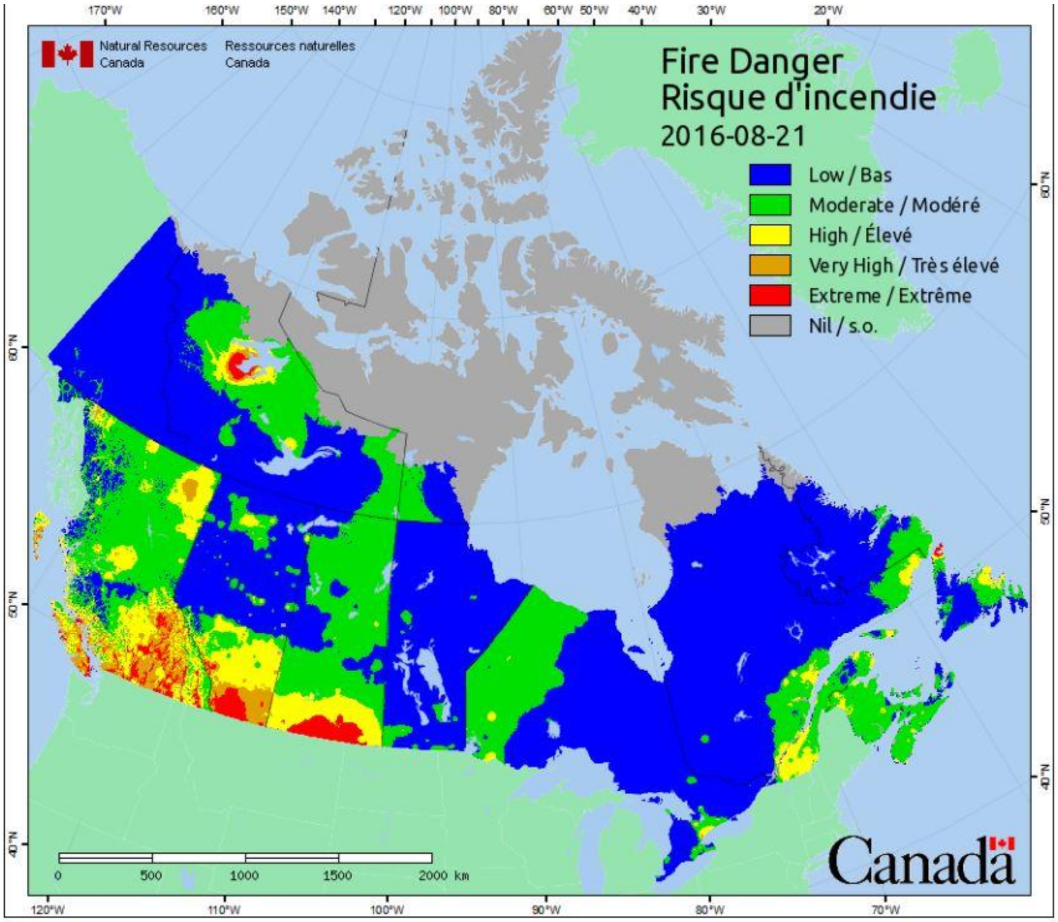
Historical Wildfire Overlay



Authors: Naitong Chen, Benjamin Fisher

Data Sources: Environment Canada, Statistics Canada, Data B.C.

Appendix H



official fire danger map produced by Natural Resources Canada, July 21, 2016. Retrieved from: http://cwfis.cfs.nrcan.gc.ca/maps/fw?type=fdr&year=2016&month=8&day=21. An interactive map was also used for the analysis below, available at: http://cwfis.cfs.nrcan.gc.ca/interactive-map.