Wildfire Threat to Residential Structures in Western Montana

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1 Assessment overview

1.1 Purpose of the assessment
This assessment evaluates wildfire threat to residential structures in western Montana. It entails a comprehensive analysis of fire simulation outputs and structure locations that emphasizes the fire effects, fire exposure, potential loss, and exposure-source for residential structures. The assessment incorporates two types of residential structure exposure: direct and indirect. Direct-exposure structures may be directly exposed to ignition from a wildfire. Indirect-exposure structures may be ignited secondarily, such as through spotting or house-to-house spread. In our analysis, we evaluate both types of exposure to assess overall threat to residential structures.

1.2 Assessment area
The assessment area is a 17.2 million ha polygon covering western Montana (Figure 1). To obtain the necessary fire behavior datasets for our analysis, we extracted subsets of the fire modeling results used in the Northern Region Risk Assessment (NoRRA), an assessment of wildfire hazard and risk for the USFS Northern Region (Scott et al. in prep). To produce valid threat results for the assessment area we extracted the NoRRA subsets within an expanded 21.4 million ha fire modeling area, which includes a 20-km buffer beyond the assessment area (Figure 1). This buffer allowed simulated wildfires to originate well outside of the assessment area and spread into it if fuel and weather conditions were conducive to such fire growth. Neither the assessment area nor the fire modeling area extend north of the US-Canadian border.
1.3 Risk concepts and framework

This analysis examines the potential for loss of residential structures due to wildfire. A quantitative framework for assessing wildfire risk to highly valued resources and assets (HVRAs) was first proposed by Finney (2005). That framework measures wildfire risk as the expected net value change (eNVC) to an HVR due to wildfire. The fundamental components of the wildfire risk framework are wildfire likelihood and intensity, HVRA exposure to wildfire, and HVRA response to fire given its susceptibility (Finney 2005; Miller and Ager 2012; Scott 2006; Scott et al. 2013). Estimating HVRA response to wildfire—called effects analysis—is a crucial step for assessing wildfire risk and prioritizing mitigation efforts (Fairbrother and Turnley 2005). Analyzing the susceptibility of HVRAs to varying levels of fire intensity relies on a combination of fire effects modeling and expert judgment. The three primary data requirements to assess eNVC to an HVRA include: (1) geospatial representations of wildfire likelihood and intensity, (2) a geospatially characterized HVRA, and (3) a response function (RF) that describes the susceptibility of the HVRA over a range of fire intensity levels (FILs). Although several measures of fire intensity are available, FILs are typically expressed in terms of flame length.

Calculating eNVC for a discrete element of an HVRA—a pixel, point or polygon—is a two-step process. First, the conditional NVC, or cNVC, is calculated as the sum-product of FLP, and RF, over a range of flame length classes.
\[ c_{NVC} = \sum_i (FLP_i \times RF_i \times N) \]

where \( c_{NVC} \) is the conditional response of the HVRA to wildfire, given that one occurs, \( FLP_i \) is the conditional probability of observing flame-length class \( i \), and \( RF_i \) is the response function value for flame-length class \( i \), and \( N \) is the number of structures represented by the pixel, point or polygon. In this analysis, our single HVRA is residential structures, and \( c_{NVC} \) values are the conditional response (potential loss) of residential structures to wildfire given that a wildfire occurs.

In the second step, \( e_{NVC} \) is the product of \( c_{NVC} \) and burn probability (BP)

\[ e_{NVC} = c_{NVC} \times BP \]

where \( e_{NVC} \) is the expected value of the HVRA to wildfire; in this analysis, \( e_{NVC} \) is a measure of expected loss of value to residential structures by wildfire.

### 1.4 Perimeter-based analyses

Planning and assessment efforts are increasingly using the set of simulated fire perimeters, in addition to the pixel-based fire behavior results, to capture variation in the size, shape, and location of simulated fires (Thompson et al. 2015a; Kuhlmann et al. 2015). We utilize this approach in our exposure-source analysis (Section 3.3). Exposure and risk assessment methods that use simulated fire perimeters involve overlaying the simulated fire perimeters with spatial data representing the HVRA in point, line, polygon, or raster data. The spatial data representing the HVRA can be simply the location of the HVRA, without consideration for its susceptibility, or it can be \( c_{NVC} \) as calculated above. Direct calculation of individual fire-level effects at any given pixel based on intensity is not possible due to limitations of existing simulation systems; hence reliance on aggregate \( FLP \) and \( c_{NVC} \) values (Thompson et al. 2015b).

The results of perimeter-HVRA overlays can be used to summarize information about potential fire impacts in a variety of ways. Scott et al. (2012b) quantified the conditional distribution of the amount of HVRA burned in a single wildfire event, focusing on municipal watersheds. The same information can be used to produce an exceedance probability curve that relates the magnitude of an effect to its likelihood of occurring (Thompson et al. 2015b).

Perimeter-based analyses can further associate the effects of simulated fires with their ignition locations to explore spatial patterns in the transmission of wildfire risk across landscapes. For instance, by identifying the locations of all ignitions associated with simulated fires that ultimately reached an identified critical wildlife habitat polygon, Thompson et al. (2013b) delineated a biophysical fireshed as the area within which a wildfire could ignite and impact the habitat. Related applications have examined the potential for ignitions to reach delineated residential communities or to impact human populations. After tying simulated wildfire impacts to communities and human populations back to their ignition locations, areas of high risk-source potential can be identified (Ager et al. 2014; Haas et al. 2014; Scott et al. 2012a).
2 Data preparation

2.1 Fire modeling

As mentioned in Section 1.2, we extracted the FSim large-fire simulator (Finney and others 2011) results from NoRRA to estimate annual burn probability (BP) and conditional flame-length probability (FLP) across the assessment area. FSim is a comprehensive wildfire occurrence, growth, and suppression simulation system that integrates models of fire weather, occurrence, growth (Finney 1998, 2002), and containment to simulate wildfire ignition and growth for thousands of fire seasons. FSim BP is the annual probability of burning; it is estimated by dividing the number of simulated fires that burned each pixel by the total number of simulated fire seasons. FLP is the conditional probability of wildfire burning in the $i$th flame-length category, given that a wildfire occurs at all (Table 1). At a given pixel, FLP values across the range of all flame-length categories necessarily sum to one. FSim results have been used for spatial risk analyses in a number of contexts ranging from national- to forest-level assessments (Calkin et al. 2010, Scott et al. 2012a, 2012b; Thompson et al. 2011, 2013a, 2013c).

<table>
<thead>
<tr>
<th>Fire Intensity Level (Flame-length class)</th>
<th>Flame-length range (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FIL1</td>
<td>0-2</td>
</tr>
<tr>
<td>FIL2</td>
<td>2-4</td>
</tr>
<tr>
<td>FIL3</td>
<td>4-6</td>
</tr>
<tr>
<td>FIL4</td>
<td>6-8</td>
</tr>
<tr>
<td>FIL5</td>
<td>8-12</td>
</tr>
<tr>
<td>FIL6</td>
<td>12+</td>
</tr>
</tbody>
</table>

FSim’s stochastic simulation approach can be computationally intensive and therefore, time constraining on large landscapes. A challenge, therefore, is to determine a resolution sufficiently fine to retain detail in fuel and terrain features, yet produce calibrated results in a reasonable timeframe. Moreover, HVRA are typically mapped at the same resolution as the final BP and FLPs produced by FSim. To enable greater resolution on HVRA mapping, we chose to downscale the 180-m NoRRA FSim results to a 30-m resolution, consistent with both the native fuel data and many HVRA datasets.

We accomplished the downscaling in a multi-step process that also involved smoothing the 180-m values from the direct-exposure pixels to the indirect-exposure pixels. In this multi-step process, we first defined a raster mask for identifying direct- and indirect-exposure pixels. Direct-exposure pixels were defined as all burnable pixels—where fire has a direct effect on a structure. Indirect-exposure pixels—where effects on a structure would result from ember ignition or structure-to-structure spread—were defined as all non-burnable pixels within 150 m of a burnable pixel.

For the BP grid, we first resampled the original 180-m BP grid to a 30-m BP grid ($BP_{30}$) using the nearest-neighbor method. We then smoothed $BP_{30}$ using the Focal Statistics tool in ESRI’s ArcGIS, which calculated the mean within a moving window (11-pixel radius) to create a smoothed 30-m BP grid. We used this moving-window size to ensure we were sampling from at least two 180-m cells. This smoothing procedure results in nonzero BP values where the $BP_{30}$ value was zero (which indicates either a nonburnable pixel or a burnable pixel that did not burn in any simulation iteration).

We then created a final BP grid ($BP_{final}$) by setting all pixels for which $BP_{30}$ was 0 to this smoothed-$BP_{30}$ value, and setting all other pixels to the unsmoothed $BP_{30}$ value (Figure 2). This approach retains the
original BP values from FSim where burnable 30-m pixels aligned with the original 180-m results, and used the smoothed grid to both backfill holes left by the resample and spread burn probability into the indirect exposure area.

We applied this same methodology to downscale and augment the FLP grids generated with FSim.

Figure 2. Final 30-m burn probability (BP) values, incorporating downscaled NoRRA BP\(_{30}\) values for direct-exposure pixels and the smoothed BP\(_{30}\) values for indirect-exposure pixels.

FSim also generates polygons, in ESRI Shapefile format, representing the final perimeter of each simulated wildfire. An attribute table specifying certain characteristics of each simulated wildfire—its start location and date, duration, final size, and other characteristics—is included with the shapefile. This data was further refined in the NoRRA process to generate ESRI feature classes of fire ignition location points and fire perimeter polygons. To extract the ignitions and perimeters for this assessment, we selected all NoRRA perimeters that intersected the assessment area, extracted those, and then extracted the corresponding ignitions for the extracted perimeters. Further manipulation and analysis of these datasets is discussed in Section 3. For additional information on the generation of the NoRRA datasets, see the NoRRA report (Scott et al. in prep).
2.2 Structure location

We used the Montana Structures/Addresses Framework dataset for representing residential structure locations. This dataset is a statewide spatial database of structure and address points in the state of Montana that is routinely updated. We used the 6/29/2017 version, extracting the structures with residential codes (Table 2) within the assessment area. This selection resulted in 342,386 structures (Figure 3). To be conservative, we also included any structure listed as a K-12 school.

Table 2. Residential structure types and exposure classifications.

<table>
<thead>
<tr>
<th>Type Code</th>
<th>Description</th>
<th>Unexposed</th>
<th>Direct Exposure</th>
<th>Indirect Exposure</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Generic or unknown structure</td>
<td>28,022</td>
<td>114,472</td>
<td>91,307</td>
<td>233,801</td>
</tr>
<tr>
<td>100</td>
<td>Residential and general (generic)</td>
<td>6,890</td>
<td>16,722</td>
<td>20,413</td>
<td>44,025</td>
</tr>
<tr>
<td>101</td>
<td>Dwelling, single-family</td>
<td>4,180</td>
<td>6,088</td>
<td>16,778</td>
<td>27,046</td>
</tr>
<tr>
<td>102</td>
<td>Dwelling, multi-family</td>
<td>1,253</td>
<td>8,751</td>
<td>10,298</td>
<td>20,302</td>
</tr>
<tr>
<td>106</td>
<td>Cabin / guest house</td>
<td>1,390</td>
<td>5,983</td>
<td>4,699</td>
<td>12,072</td>
</tr>
<tr>
<td>107</td>
<td>Mobile home</td>
<td>1</td>
<td>3,510</td>
<td>130</td>
<td>3,641</td>
</tr>
<tr>
<td>203</td>
<td>Nursing home / long term care</td>
<td>96</td>
<td>342</td>
<td>706</td>
<td>1,144</td>
</tr>
<tr>
<td>601</td>
<td>School (K-12)</td>
<td>47</td>
<td>65</td>
<td>243</td>
<td>355</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>41,878</td>
<td>155,933</td>
<td>144,574</td>
<td>342,386</td>
</tr>
</tbody>
</table>

Although the native format of the structures dataset is a point feature class, some of the required analyses could only operate on rasters. In order to perform those raster analyses, we converted the structure-point data to a 30-m raster that represented a count of the number of residential structures in each 30-m cell.
2.3 Response functions

A response function describes susceptibility of the HVRA as the percent net value change (\(NVC\)) of the HVRA should it experience a fire of a given intensity (Calkin et al. 2010; Scott et al. 2013). Response functions can accommodate both positive and negative value change. A response function value of -100 indicates the greatest possible loss of value, whereas +100 would indicate the greatest possible increase in value, or benefit. This paper focuses on wildfire threat to residential structures, which do not benefit from wildfire of any intensity.

Rather than apply a single response function to all structures, as is typical when using a more generalized characterization of residentially developed areas, we designed two response functions based on whether the structure was exposed to direct ignition (any structure located over a burnable fuel model in the NoRRA fuelscape) or indirect ignition (spotting or house-to-house spread). The response functions are displayed in Table 3.
Table 3. Response functions for damage to residential structures as a function of fire intensity (flame length) and structure exposure type.

<table>
<thead>
<tr>
<th>Structure Exposure Type</th>
<th>Fire Intensity Level (flame-length class)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FIL1 0-2ft</td>
</tr>
<tr>
<td>Direct</td>
<td>-10</td>
</tr>
<tr>
<td>Indirect</td>
<td>0</td>
</tr>
</tbody>
</table>

The response function values in Table 3 can be taken to represent the equivalent chance of complete loss of the structure. Residential structures typically suffer complete loss of value if they suffer any loss at all (Cohen and Butler 1998), so it may be more convenient to think of the RF values as the chance of the residential structure burning. For example, a response function value of -80 means the equivalent of 80 percent chance of 100% loss. Such a result could also come about from a 100 percent chance of 80% loss of value, or any number of other combinations. We made the calculations of $cNVC$ by sampling the six final $FLP_i$ rasters where the residential structures are located. That information, along with the structure exposure type for the pixel, enables calculation of $cNVC$ for each pixel. Because the response function value represents the equivalent chance of 100% loss, $cNVC$ has the same interpretation; it is simply the weighted mean of the response function values, with $FLP_i$ providing the weighting factors.

3 Analysis methods and results

3.1 Wildfire hazard-in-context

Wildfire hazard is the combination of probability and intensity. Typically, probability is measured as the annual probability that fire will burn a given location. Intensity is typically measured as the conditional intensity of a wildfire, in some biophysically relevant units such as flame length or fireline intensity. But, as seen in the response functions above (Table 3), a fire’s effect is not necessarily directly proportional to its intensity. In this analysis, we specifically look at hazard in the context of residential structures by utilizing the response functions in addition to the probability and intensity. In other words, we apply the response functions to all relevant parts of the landscape (areas subject to either direct- or indirect-exposure) regardless of whether a structure is present there. That is, we generate rasters of $cNVC$ and $eNVC$ to assess the conditional risk to a structure (if one were present). We do this by applying the equations outlined earlier in Section 1.3.

This provides us with the conditional hazard: if a given pixel were to experience a wildfire, and if it contained one or more residential structures, this would be the effect on a residential structure (Figure 4). We ensured the appropriate response function (direct vs indirect) was used for each pixel.
The cNVC map in Figure 4 does not include the likelihood of a wildfire burning, which is an important component of wildfire hazard. To fully capture wildfire hazard we calculated $eNVC$ as the product of $cNVC$ and $BP_{final}$. The result is shown in Figure 5 below.
Figure 5. Expected wildfire hazard, in the context of residential structures. This figure plots the conditional “expected loss” of a residential structure if one were present. This map is generated by multiplying the conditional hazard-in-context (Figure 4) by the likelihood that fire will visit each pixel (Figure 2). Strongly negative values occur where the combination of fire likelihood and fire intensity are both high. Areas of dark red on this map indicate hazardous locations to build a residential structure; yellow areas are less hazardous.
3.2 Effects analysis

We used the final BP and FLP rasters (Section 2.1) along with the response functions (Table 3, Section 2.3) to calculate \( cNVC \) and \( eNVC \) for the assessment area, using the equations in Section 1.3. Note that because the only HVRA contributing to \( NVC \) calculations was residential structures, \( NVC \) values were only non-zero in pixels that contained residential structures.

Figure 6 displays the \( cNVC \) for each residential structure as a variable size point depending on the magnitude of the \( cNVC \) value for that structure. Conditional \( NVC \) varied widely across the assessment area (Figure 6) due to variability in fire intensity. The burn probability is not included in this \( cNVC \) result; burn probability is only a factor in \( eNVC \) (Figure 7).

![Figure 6. Conditional net value change \( (cNVC) \) for each residential structure, where point size for a structure is determined by the magnitude of \( cNVC \).](image-url)
Figure 7. Expected net value change (eNVC).
3.3 Exposure-source analysis

Although simulated fires started throughout the assessment area, it is apparent that the majority of wildfires exposing structures originated relatively near those structures. To quantify that observation, we divided the assessment area into zones based on the distance from any structure (Figure 8), and then evaluated simulated ignitions within those zones to summarize the propensity of the different zones to produce fires that expose residential structures.

To create the zones, we buffered the structures the desired distances shown below in Table 4. We calculated the percent area for each zone that was directly exposed, indirectly exposed, and unexposed to wildfire (Table 4). The zone closest to the structures notably contained the lowest percentage of directly-exposed area.

Figure 8. Source-distance zones, indicative of the nearest distance from any point on the landscape to a residential structure.
Table 4. Percent area by exposure type for each source-distance zone.

<table>
<thead>
<tr>
<th>Distance from structure to zone (km)</th>
<th>Source-distance zone area (ha)</th>
<th>Percent area directly exposed</th>
<th>Percent area indirectly exposed</th>
<th>Percent area unexposed</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1</td>
<td>4,073,078</td>
<td>84%</td>
<td>13%</td>
<td>3%</td>
</tr>
<tr>
<td>1-2</td>
<td>3,387,315</td>
<td>92%</td>
<td>6%</td>
<td>2%</td>
</tr>
<tr>
<td>2-3</td>
<td>2,509,180</td>
<td>95%</td>
<td>4%</td>
<td>1%</td>
</tr>
<tr>
<td>3-5</td>
<td>3,245,880</td>
<td>95%</td>
<td>4%</td>
<td>1%</td>
</tr>
<tr>
<td>5-7</td>
<td>1,957,043</td>
<td>93%</td>
<td>6%</td>
<td>1%</td>
</tr>
<tr>
<td>7-10</td>
<td>1,812,019</td>
<td>90%</td>
<td>9%</td>
<td>1%</td>
</tr>
<tr>
<td>10-15</td>
<td>1,755,240</td>
<td>88%</td>
<td>11%</td>
<td>2%</td>
</tr>
<tr>
<td>15-20</td>
<td>1,282,487</td>
<td>88%</td>
<td>10%</td>
<td>2%</td>
</tr>
<tr>
<td>20+</td>
<td>1,337,802</td>
<td>94%</td>
<td>6%</td>
<td>1%</td>
</tr>
<tr>
<td>TOTAL</td>
<td>21,360,044</td>
<td>91%</td>
<td>8%</td>
<td>2%</td>
</tr>
</tbody>
</table>

To obtain information about ignitions within a zone, we utilized the perimeter summary approach (Section 1.4). We first calculated the number of structures exposed to each simulated wildfire by tallying the number of structures located within each fire perimeter. Second, we associated each tally with the respective simulated fire ignition location. Finally, we summarized the ignition data within each zone (Table 5).

Although fires can reach at least one residential structure from almost anywhere within the assessment area, the data summary confirms that fires starting relatively close to the structures are far more likely to expose structures than fires originating more remotely (Table 5). Moreover, because structures tend to be clumped together, those fires originating near structures account for most of the overall exposure. For example, roughly two-thirds of the overall exposure is accounted for by fires starting within 1 km of any structure; 99 percent of the total structures exposed to wildfire annually are by ignitions within seven km of a structure.

Within the assessment area, the proportion of ignitions that reached at least one structure was greatest near the structures (83.5 percent within the first 1-km zone) and declined to less than 10 percent in the 5-7 km zone. For all zones greater than seven km from any structure, the fraction of large-fire ignitions that reached any structure was 3.5 percent or less. All ignitions capable of reaching a structure originated within 20 km of a structure. The total expected number of structures exposed annually is 616.

To illustrate the propensity for fires to damage structures, we normalized the annual exposure to structures to a unit area (1,000,000 ha), by distance zone. This normalization is required because the area varies among the distance zones (Table 5).
Table 5. Summary of exposed residential structures based on distance from a structure. Distance zone width increases beyond 7 km because of the relatively small number of fires that reach a structure from beyond that distance.

<table>
<thead>
<tr>
<th>Distance from structure to ignition (km)</th>
<th>Fraction of large fires reaching at least one structure (%)</th>
<th>Expected annual structures exposed</th>
<th>Normalized expected annual structures (per 1 million ha)</th>
<th>Proportion exposed (%)</th>
<th>Cumulative proportion exposed (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1</td>
<td>83.5</td>
<td>408</td>
<td>100.2</td>
<td>58.07</td>
<td>58.1</td>
</tr>
<tr>
<td>1-2</td>
<td>47.7</td>
<td>91.3</td>
<td>27.0</td>
<td>15.63</td>
<td>73.7</td>
</tr>
<tr>
<td>2-3</td>
<td>29.5</td>
<td>53.3</td>
<td>21.2</td>
<td>12.31</td>
<td>86.0</td>
</tr>
<tr>
<td>3-5</td>
<td>16.4</td>
<td>42.0</td>
<td>12.9</td>
<td>7.50</td>
<td>93.5</td>
</tr>
<tr>
<td>5-7</td>
<td>7.72</td>
<td>13.6</td>
<td>6.9</td>
<td>4.03</td>
<td>97.5</td>
</tr>
<tr>
<td>7-10</td>
<td>3.50</td>
<td>6.00</td>
<td>3.3</td>
<td>1.92</td>
<td>99.5</td>
</tr>
<tr>
<td>10-15</td>
<td>1.20</td>
<td>1.32</td>
<td>0.8</td>
<td>0.44</td>
<td>99.9</td>
</tr>
<tr>
<td>15-20</td>
<td>0.25</td>
<td>0.22</td>
<td>0.2</td>
<td>0.10</td>
<td>100.0</td>
</tr>
<tr>
<td>20+</td>
<td>0.00</td>
<td>0.00</td>
<td>0.0</td>
<td>0.00</td>
<td>100.0</td>
</tr>
<tr>
<td>TOTAL</td>
<td>616</td>
<td>172.5</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 9 below is an exposure-source map, highlighting the fraction of large fires that exposed at least one residential structure. It is an example of the outcome of exposure analysis in this study and the likelihood of ignitions nearest structures to cause damage. Generally, the propensity for a wildfire to expose structures is greatest very near the structures and decreases significantly further out.
Figure 9. The fraction of simulated large fires reaching at least one structure, summarized by source-distance zone. Color intensity is directly proportional to the fire fraction magnitude. In this map, all land within a given distance zone across the Assessment Area is assigned the same fraction, with no further accounting for spatial variability across the area.
4 Summary

The results presented in this report are suitable for a number of finer-scale applications related to wildfire threat to residential structures. For example, the results presented in Figure 6 and Figure 7 can be summarized for a variety of administrative units, including: fire protection districts, counties, adjacent National Forest land. Such summaries will produce information on the number or residences and their cumulative threat across western Montana, producing a quantitative ranking of communities “at risk” of wildfire.

This assessment of wildfire threat to individual residential structures could benefit from at least two improvements. First, the current generic response functions could be improved by calibrating them against known structure loss rates. Second, a susceptibility rating for individual structures, based on structure characteristics known to influence the loss rate of structures exposed to wildfire, could be used to generate structure-specific response functions. This would be necessary to incorporate the influence of defensible-space into the assessment of communities at risk.

The simple fireshed analysis presented in Figure 9 can be overlaid with land ownership to identify the land ownerships on which the most residential exposure occurs. It must be kept in mind, however, that being a source of threat to structures, especially distant ones, is not necessarily mitigable on that land ownership.

The maps in Figure 5 carries a lot of information about guiding where future residential development would be exposed to the greatest (and least) wildfire hazard, if it were to occur today. This map incorporates the likelihood of a fire burning (BP), the intensity of a wildfire if it were to occur, and the generic susceptibility of a structure to those intensities.

5 References


Gilbertson-Day, J.; Scott, J. H.; Vogler, Kevin C.; Brough, April. 2017 Northern Region Wildfire Risk Assessment: methods and results. Final report to the Northern Region. September 2017.


