Background

- The ability to predict the spread of wildland fires is paramount in protecting life, property, and natural resources.
- Current operational models predict overall fire behavior well for dead fuel beds but not as well for live bushes or trees with high moisture.
- Therefore, a semi-empirical model was developed as an attempt to bridge the scale gap between full simulations and empirical correlations.
- Ignition and flame characteristics of fuel segments (3 – 6 cm lengths) burned in a laboratory flat-flame burner system were used in a semi-empirical multi-element fire spread simulator for chamise (Adenocostomata fasiculatum) and Utah juniper (Juniperus osteosperma) shrubs.
- The objective is to develop modeling technology for describing fire initiation and propagation in vegetation with low canopy bulk density:
  - Measure fire behavior of fuel elements (leaves, stems, segments)
  - Represent shrub geometry using Lindenmayer systems
  - Model fire propagation semi-empirically
- Compare model based on fuel elements to shrub scale burns

Flame propagation measurements

- Fuel samples are heated above a flat-flame burner producing 10 mol% O2 and 1000°C post-flame gases.
- Mass, flame and temperature are recorded
- Fuel properties (size, moisture, mass) are correlated to flame and mass loss results
- Flame correlations trace flame profile.

Wind tunnel experiments

- Experiments were performed at the PSW Research Station to measure shrub-scale fire propagation.
- The effects of wind speed, fuel arrangement and moisture content on fire spread were investigated for chamise (see Figure 3, Table 1).

Flame propagation modeling

- Fuel segments with representative distributions of physical properties are given locations in the shrub according to L-systems models.
- Each fuel segment is assigned a flame profile (Figure 2) which is correlated to its unique properties.
- A set of fuel elements is ignited to initiate propagation.
- Ignited fuel elements produce a flame volume which overlaps unreacted elements which then heat to ignition, and so on.
- Flames overlapping other flames are scaled according to a flame coalescence model.
- The model determines a flame height, spread rate, burn path, flame angle, and amount consumed.

Utah juniper results

- Fuel structure was well-represented by L-systems approach (Figure 5).
- According to the measurements in the field, a correlation was developed to predict total Utah juniper bush dry weight (W_dry) by crown diameter (D_crown), which was also embedded in the bush model.
- Different parametric runs were performed to study the effects of bush size, bush shape, fuel density, and wind.

Table 2. Selected parametric runs. (X_s is fraction burned)

<table>
<thead>
<tr>
<th>Run</th>
<th>Diameter (cm)</th>
<th>Height (cm)</th>
<th>segment number</th>
<th>D_0 (leaves/m²)</th>
<th>MC (%)</th>
<th>U (m/s)</th>
<th>X_s</th>
<th>t_{burn} (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>170</td>
<td>244</td>
<td>27.268</td>
<td>4,924</td>
<td>0</td>
<td>90</td>
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</tr>
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<td>244</td>
<td>27.268</td>
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<td>579</td>
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<tr>
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<td>605</td>
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</table>

- When MC decreased, fraction burned increased as expected.
- At high wind speeds, the predicted flame propagation was diminished. This trend is being examined and will be improved.

Chamise results

- Fuel structure simulation using L-systems (Figure 6).
- Burn time increased then slightly decreased with increased wind speed.
- Burn time decreased slightly with loading because fuels were closer together, creating larger flames resulting in faster fire spread.
- Wind increased fire spread rate and fraction burned, as did increased loading. Higher moisture content resulted in less burned, as expected.
- Flame height above the top of the shrub demonstrated a similar response to wind, loading and MC as did fraction burned. This illustrates the correlation between larger flames and more fuel consumption.
- A simulation of wind tunnel experiment 1 (Table 1) was attempted. While most of the shrub actually burned, the simulation only predicted marginal burning.
- The discrepancy between wind tunnel experiments and model predictions will be investigated and resolved. The remainder of the experiments will then be simulated.

Conclusion

- The burning bush model shows the ability to capture basic flame spread behavior at low wind speeds in sparse arrays of fuel.
- Comparisons with experiments show the need for improvement, but will guide further development.
- The placement of fuels has a critical impact on fire propagation and will be improved for chamise in future work.
- Future work will improve the accuracy and applicability of the model, ultimately resulting in a fast model for fires in sparse, live vegetation.