GEOG 6160 - Spatial Modeling

Project Experiment Report: Eagle Mountain Fire-Evacuation Model

Erik Neemann

3 May 2018

## Experiment Description

For the class group project, we designed a model that simulates wildfire ignition and spread in the vicinity of Eagle Mountain, Utah and subsequent evacuation using a simplified road network. To test this model and learn how changes in parameters impact the simulation outcome, I ran a suite of experiments using the NetLogo BehaviorSpace tool.

Datasets used within the model include a Fire Threat raster from Utah's Department of Natural Resources (DNR), which is used to determine where the initial fire starts. Vegetation data from the DNR is used to set the vegetation density, which affects the probability that patches neighboring a currently burning patch catch fire. A digital elevation model from DNR is also used to modify the probability of fire spread. Finally, a road network from the city of Eagle Mountain was simplified and used as the road network for vehicles evacuating neighborhoods.

The model has adjustable parameters for the probability of fire ignition in each cardinal direction (e.g. "ignitionS"), the probability of fire extinction ("extinction") at each time step, and the probability that exiting cars will correctly follow their evacuation route when they approach an intersection ("q"). To experiment with the model, I designed two primary experiments, one representing a fire in southwesterly winds and one representing a fire in northwesterly winds. These two scenarios represent the most likely directions for strong winds during a wildfire event. This is particularly true for the southwesterly scenario, which typically occurs in a dry environment ahead of approaching low pressure systems. These experiments are run over a variety of settings for "extinction" and "q", with each permutation run for 25 iterations. The table below describes the model setup; brackets indicate a range of values in the following manner: [low-value step high-value].

| Parameter | Southwest Wind Scenario (600 runs) | Northwest Wind Scenario (600 runs) |
|---|---|---|
| "ignitionN" | 0.9 | 0.1 |
| ignitionE" | 0.9 | 0.9 |
| "ignitionS" | 0.1 | 0.9 |
| "ignitionW" | 0.1 | 0.1 |
| "extinction" | [0 0.1 0.5] | [0 0.1 0.5] |
| "q" | [0.7 0.1 1] | [0.7 0.1 1] |

The model, as initially designed (817 x 459 patches, 5m spacing), was too large and caused memory crashes when using the BehaviorSpace tool. For this reason, the patch size was doubled in order to shrink the model domain to a workable size (409 x 230 patches, 10m spacing). Further, the model would ideally be run with additional wind directions and for more iterations for each parameter combination. However, the 1200 model runs (6*4*25 for each scenario) described above took over 13 hours of wall clock computing time (on 8 cores), preventing more runs/combinations to be completed in time for this report.

**Results**

The outcomes from the two model scenarios showed several similar results, but also indicated a few subtle differences. An example screenshot of a typical model run in mid-simulation is shown in Figure 1. Based on the combination of parameters used in the experiment, the most frequent model result burned less than 2.5% of the landscape (34% of simulations) and finished with 0 burned cars (45.3%; Figure 2). In fact, in 25.2% of simulations, the fire did not cross the neighborhood buffer and no evacuation was initiated. As expected, the percentage of the landscape and the number of cars burned decreased as the fire extinction rate increased (Figure 3). Both of these statistics were maximized when the fire extinction rate was zero. Interestingly, the southwesterly wind scenario (2.87) resulted in an average of 1 more car being burned per simulation than the northwesterly wind scenario (1.82). Figure 3 also indicates a higher median number of cars burned in the southwesterly scenario for each extinction value below 0.4.

Of the simulations resulting in evacuation, there was a weak relationship between the number of cars burned and “q” (Figure 4), but it is not likely significant. This subtle trend indicates that fewer cars burn at higher “q” due to more efficient evacuation, while more cares burn at lower “q” due to more wrong turns and a longer evacuation process. This is also reflected in the duration of the simulation, where wrong turns (lower “q”) lead to slower evacuation and a longer median simulation (Figure 4).

Finally, Figure 5 shows plots (only for simulations with evacuation) of average percentage of landscape burned, cars burned, and simulation duration as a function of both extinction and “q”. For both wind scenarios, the maximum percentage of the landscape burned occurs when “q” is minimized and the extinction rate is zero. This is expected as low “q” values prolong the simulation and the fires never actually burn out when the extinction rate is zero. The southwesterly scenario also has a greater maximum percentage burned. This is likely because the fire is designed to start near the western and southern edges of the model domain, leaving more land downwind of the fire origin when there is a southerly component to the wind. A northerly wind component tends to push fires starting near the southern border out of the model domain. Intuitively, the maximum number of cars burned occurs at the minimums of extinction rate and “q.” This combination leads to more burned cars due to widespread fires and the slow evacuation from cars making wrong turns at intersections, as discussed previously. For the simulation length, there appears to a “sweet spot” of maximum duration where low, but non-zero extinction rates lead to a slow burning fire and low “q” values result in slower evacuations. Duration quickly drops off at higher extinction rates (0.4+) where the fires burn out quickly. The northwesterly wind scenario also had a higher maximum average simulation length than the southwesterly scenario, though it's not entire clear why. Perhaps the low extinction rates allow fires starting on the southern periphery of the domain to burn back northward against the wind, resulting in slow-but-steady progression and long simulations when "q" is low.

**Discussion and Conclusions**

It should be noted that both the vehicles and spreading fire move at approximately 23 mph in the current model setup. While this is a decent approximation for evacuating vehicles, it is likely several times faster than wildfire would spread in the real world. In a more realistic model, the fire would only spread every 5-10 time steps, to balance to scale of its spread relative to car movement. However, the rapid fire spread was maintained in this simulation, partly to shorten model runs, and partly to provide more interesting results.

Also, in several of the model runs (~6%) the initial fire started on a patch along the border of the domain that didn't contain vegetation (set as NaN; see black horizontal bars in Fig. 1). When this occurred, it resulted in 0% landscape burn and no fire spread because the initial patch had nothing to burn. In some cases, the evacuation still occurred when the single border patch was inside the neighborhood buffer, resulting in all cars evacuating safely. However, because this scenario is not valid, all occurrences of it were removed from the results and not included in the statistical calculations or analysis.

While this model simulation is far from realistic, it does represent some of the basic processes in the real world. These include fire spread due to properties of vegetation, wind, and elevation, and first draft vehicle evacuation logic. Recommended future work on the model would include better scaling of fire/vehicle speeds, more robust traffic logic, and evacuations by specific neighborhood. Though relatively simple, the current model is still capable of reproducing some realistic results. This includes larger, longer-burning fires when the extinction probability is low or zero. It also demonstrates that vehicles taking wrong turns while evacuating the neighborhood will take longer to exit and, therefore, be more likely to be burned in the fire. Finally, it indicates that Eagle Mountain may be at greater risk from a fire in southwesterly winds, which is likely to burn a larger area and endanger more vehicles, than a fire in northwesterly winds.

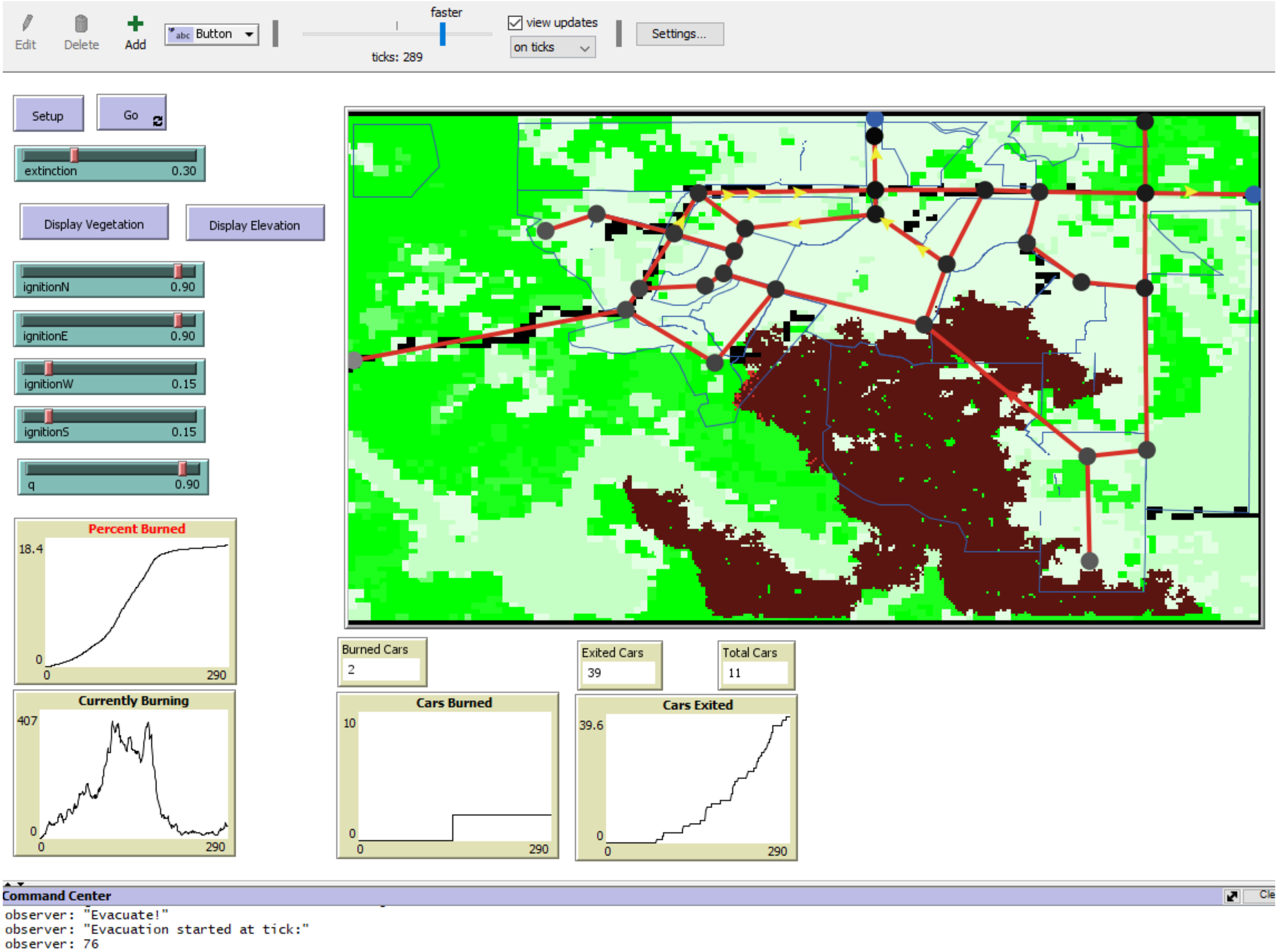


**Figure 1**: Example screenshot of the model in mid-simulation, at time step 289

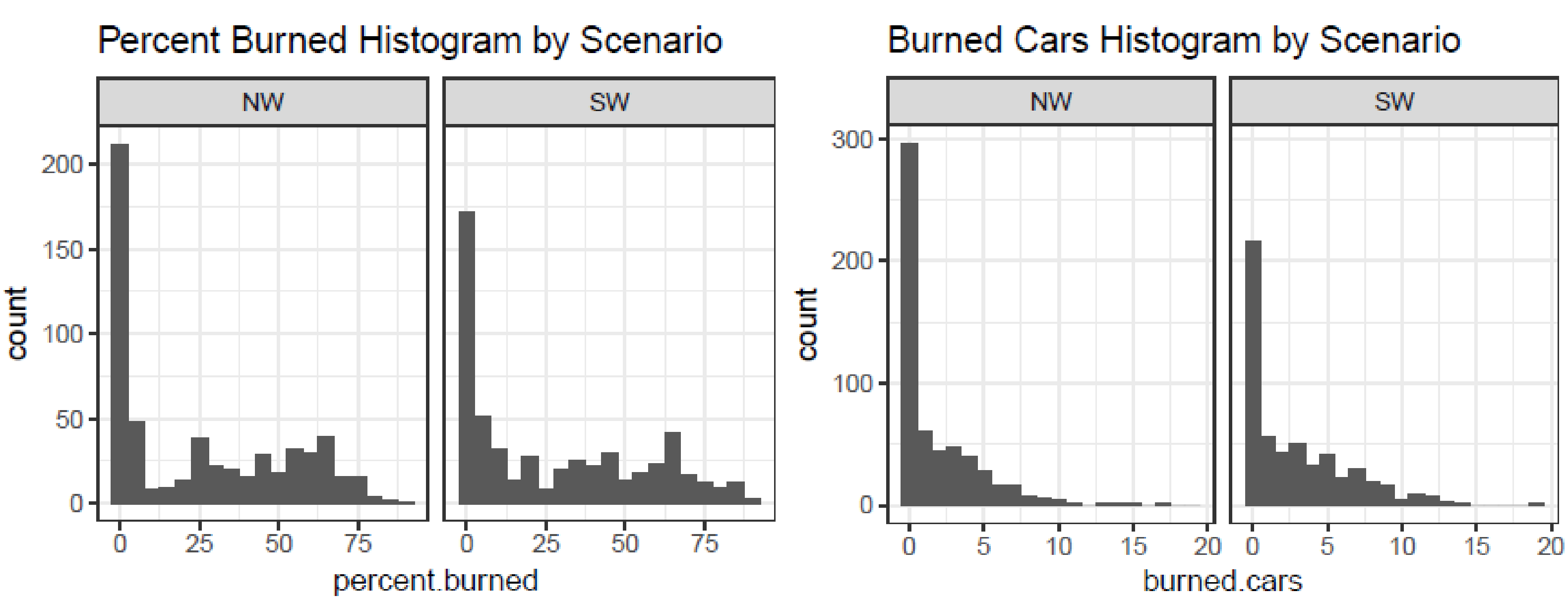


**Figure 2**: Histograms of percent landscape burned and number of cars burned for the Southwest and Northwest wind scenarios

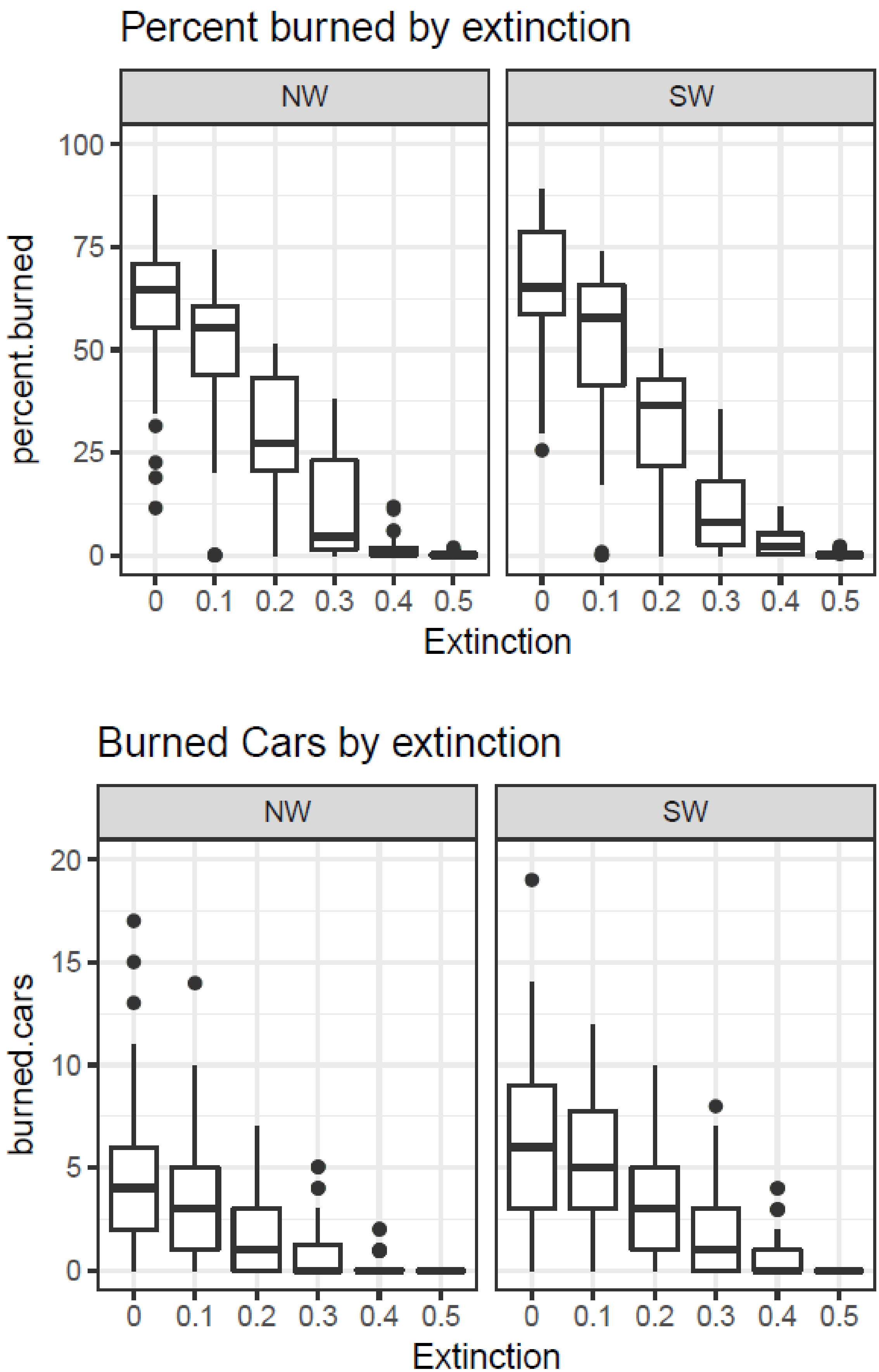


**Figure 3**: Box plots of percentage landscape burned (top) and number of cars burned (bottom) as a function of extinction, by scenario

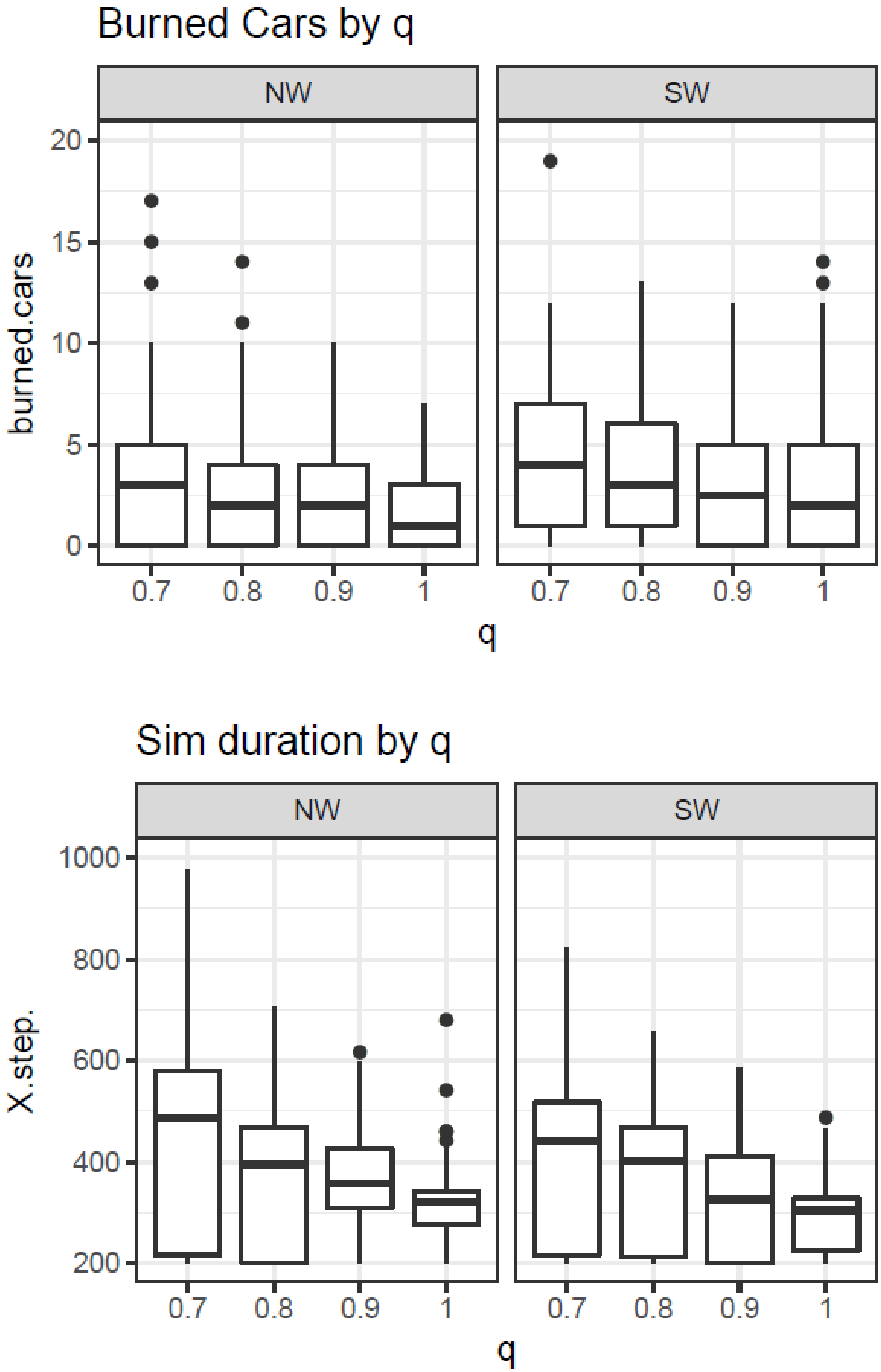


**Figure 4**: Only simulations with evacuation: Box plots of the number of cars burned (top) and duration of simulation (bottom) as a function of "q", by scenario

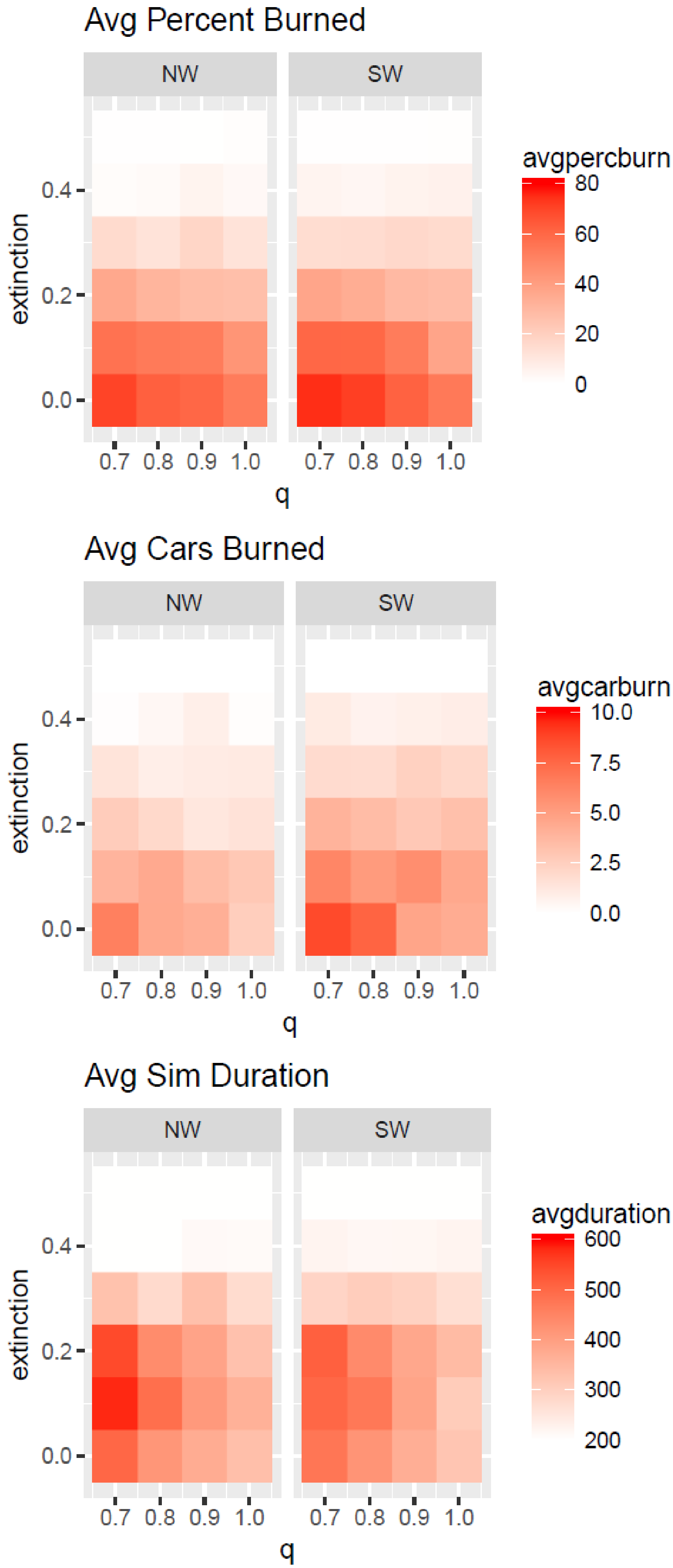


**Figure 5**: Only simulations with evacuation: Average percent landscape burned (top), number of cars burned (middle), and simulation duration (bottom) as a function of extinction and "q"