Appendix 4: Burn Severity Spatial Analyses

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Background

Stand-replacing fire, which refers to conditions where most of the forest overstory is killed by fire, is an important outcome of individual fires and fire regimes overall. The shape and size of stand-replacing patches is of particular importance when forecasting, and managing for, postfire forest succession. Tree mortality is often contiguously clustered into patches of stand-replacing fire, which can be mapped based on algorithms comparing pre- and postfire satellite imagery. This process has been well-studied and generally relies on calculating the differenced normalized burn ratio (dNBR) or a relativized version thereof (RdNBR) from LANDSAT imagery, identifying thresholds of (R)dNBR associated with particular levels of basal area mortality or canopy cover loss based on field plot calibrations, and classifying the resultant (R)dNBR raster layers into several fire severity classes (Miller and Thode 2007). The dNBR tends to correlate better with fire intensity because it is highly sensitive to prefire biomass, whereas the relativized measure (accomplished by dividing dNBR by the prefire image) generates more reliable measures of fire severity that do not vary because of prefire biomass (Safford et al. 2008). Severity class thresholds may vary depending on region, timing of postfire image acquisition, or vegetation type. Robust thresholds for low, moderate, and high severity have been developed for use in conifer-dominated vegetation in California. The high-severity category, reflecting stand-replacing fire, is especially accurately demarcated (Lydersen et al. 2016, Miller et al. 2009). The (R)dNBR reflects the change in green vegetation; so for species such as oaks and shrubs that may resprout after fire, it does not directly capture mortality. Imagery collected 1 year postfire (so-called extended assessments), rather than immediately postfire, may better reflect mortality, both for shrubs and oaks, which tend to resprout quickly if they are not completely dead, and conifers, which may green-up or continue to die from fire injuries for months to years postfire (Lydersen et al. 2016). However, in mixed stands, the resprouting of broadleaf trees and shrubs can reduce the severity signal captured by extended assessments relative to initial assessments. As a result, the extended assessments are best used in forest strongly dominated by nonsprouting conifers. Because stand-replacing fire connotes

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such ecological significance, it is most appropriate to use RdNBR thresholds for the highest severity class that capture near-complete tree mortality, e.g. >90 or 95 percent. Using such thresholds means that the vast majority of area classified as high severity that is away from patch edges will have nearly 100 percent mortality (Miller and Quayle 2015).

Not all areas within mapped high-severity patches are ecologically equivalent, and there are a number of methods available to account for the ecological differences within these patches, depending on the spatial attributes of patches such as the distance from the patch edge. The PatchMorph tool can be used to delineate “ecologically meaningful” patches of high severity (Collins and Stephens 2010), and thereby help to identify areas that may be desirable targets for postfire management actions. Collins et al. (2017) developed the stand-replacing decay coefficient (SDC) to describe the continuous relationship between high-severity patch area and distance from edge, allowing comparisons of the spatial patterns of high-severity fire among different fires (Stevens et al. 2017). We describe applications of PatchMorph and SDC in greater detail below.

**PatchMorph Tool**

When defining patches from an underlying raster of landscape classes, one of the simplest ways to define a patch is to include adjacent pixels of the same class. However, the size, shape, and number of patches will strongly depend on the underlying scale. It is preferable to define patches based on ecologically relevant measures of size and dimension. The PatchMorph tool was developed for ArcMap to define patches based on ecologically meaningful inputs (Girvetz and Greco 2007). This tool has not been updated for recent versions of ArcMap; however, we obtained a Python script to run the tool using the original concept (Kramer 2019). There are two main tool settings that affect the size and shape of the resulting patches: the minimum patch width or spur, and the maximum width of gaps within the patch. A minimum patch area and a smoothing window tolerance that adjusts the patch perimeter relative to pixel boundaries can also be specified.

As an example, we used the PatchMorph tool to delineate high-severity patches for the Rough Fire, which burned in 2015 primarily on the Giant Sequoia National Monument. Our high-severity patches were based on classified values of the RdNBR calculated with imagery collected 1 year postfire. The high-severity class corresponded to pixels with RdNBR ≥641, which would be expected to have >95 percent basal area mortality in areas dominated by conifer forest and is the standard threshold used for the highest severity class in conifer-dominated vegetation in California (Lydersen et al. 2016, Miller and Thode 2007). Based on a simple summary of pixel values, 20 percent of the Rough Fire burned at high severity (fig. A4.1A). To define high-severity patches, we used spur and gap settings of 90 m (295 ft), a minimum
Figure A4.1—Different considerations for characterizing spatial patterns of high-severity fire for the 2015 Rough Fire. Based on the simple classification (thresholds from Miller and Thode 2007) 20 percent of the fire area is high severity (A). Using the PatchMorph tool to delineate contiguous patches of high severity, 15 percent of the area was included in patches (B). This percentage was further reduced when only conifer vegetation (C) was considered in the delineation of high-severity patches, resulting in 7 percent of the fire area (D). Considering conifer-dominated areas in high-severity patches that were >120 m from live conifers, this percentage was reduced to 3 percent (E).

patch area of 5000 m$^2$ (1.24 ac) and a smoothing tolerance of 90 percent within a 2-pixel window. For this example, we had no reason to restrict the minimum patch size and used 5000 m$^2$ because it is lower than the smallest area that would be possible within the specified spur distance, so that the spur and gap settings alone would determine the spatial configuration of patches. The smoothing tolerance setting was chosen to create a patch perimeter entirely within high-severity pixels (i.e., no slivers of other pixels along the inside of patch edges). Smaller spur settings
resulted in patches that were more interconnected, as well as the creation of a greater number of smaller patches. Smaller gap settings also increased the interconnectivity of patches and allowed for larger patches with a lower shape complexity. Based on these parameters, high-severity patches identified by PatchMorph within the Rough Fire accounted for 15 percent of the total area burned (fig. A4-1B). The difference between this proportion and that from the simple summary is mainly due to smaller, more isolated areas of high-severity area not meeting the patch delineation criteria.

Considering additional factors when analyzing patch configuration, such as pre-fire vegetation type, can help to distinguish between different kinds of fire effects. Vegetation type is a particularly relevant consideration when there are strong differences in regeneration responses following high-severity fire across types. To illustrate how this might be done, we performed a second patch delineation that included high-severity patches within conifer vegetation only, based on the California Wildlife Habitat Relationships attribute in the Forest Service Pacific Southwest Region 2000–2014 Existing Vegetation spatial dataset (see app. 2). While conifer forest was most prevalent at higher elevations within the Rough Fire footprint, other vegetation types such as shrub and oak woodland were common at lower elevations. Forty-two percent of the area burned was in conifer forest (fig. A4.1C). Using the same settings for the PatchMorph algorithm on a raster that included both fire severity and vegetation type to delineate patches resulted in 7 percent of the fire area in patches of prefire conifer forest that burned at high severity (fig. A4.1D).

In addition to simply defining patches, this approach can be used to gain insight into processes such as expected vegetation recovery within patches. Regeneration of conifer species is typically reliant on wind-dispersed seeds and is therefore limited by distance to the nearest mature trees. This is a concern for large patches with greater interior, or core, area. For this example, we assessed patch interior area >120 m (>393.7 ft) from remaining conifer forest. This is a common dispersal distance threshold in conifer forests (Collins et al., 2017) and is twice the expected dispersal distance used by Welch et al. (2016), which found a steep decrease in regeneration with distance to nearest seed tree. These regeneration-limited areas accounted for 3 percent of the Rough Fire area (fig. A4.1E).

Stand-Replacing Decay Coefficient (SDC)

Because seed dispersal from patch edges contributes strongly to regeneration success (Shive 2017), and is a continuous function (e.g., dispersal does not necessarily change abruptly at a particular distance such as 120 m [393.7 ft]), it can be useful to describe stand-replacing area as a continuous function of distance inward from patch edge. The SDC was developed to characterize this relationship, using
a single free parameter (Collins et al. 2017). The SDC is particularly useful as a single number that can be used to compare fires with different sizes and shapes of stand-replacing patches, without specifying a specific dispersal threshold. However, in the context of postfire restoration, SDC can help identify regeneration-limited, high-severity patches that could be targeted for management activities such as reforestation.

A geospatial vector layer of high-severity area can be processed using a series of internal buffers, where at each internal buffer distance (ranging from 0 to the maximum distance from edge), the proportion of the total high-severity area that is greater than the given distance inward from the edge is calculated. The relationship between those two variables is described as,

\[
P \sim \frac{1}{10^{SDC \cdot Dist}}
\]

Where \( P \) = the proportion of total high-severity area
\( Dist \) = the internal buffer distance, and
\( SDC \) = the free parameter estimated through nonlinear least-squares estimation.

Smaller values of SDC indicate larger and more regularly shaped high-severity patches. See Collins et al. (2017) for more information on SDC calculation.

To illustrate the potential application of SDC, we use the Rough Fire example described above and compare it to the King Fire, which burned in 2014 primarily on the Eldorado National Forest and had one of the largest patches of stand-replacing fire observed on modern record. Again, this approach relies on classifying high-severity areas using a high percent-mortality threshold (Miller and Quayle 2015). In this example, we use the standard RdNBR threshold of 641. Because SDC was designed to compare fires that burned predominantly in forest, our examples here have not filtered out nonforest area to make comparisons more consistent. We filtered any “holes” of lower severity that were less than nine pixels (<0.81 ha [2 ac]) and contained entirely within high-severity patches, by incorporating them into the high-severity patch. These holes are analogous to “gaps” in PatchMorph. Larger holes were left intact and used in the buffer operation. In each case, we buffered inward to 1000 m (3,281 ft). This operation can be done most efficiently in the R software package using code available at http://dx.doi.org/10.5281/zenodo.1002242 (Stevens et al. 2017).

The Rough Fire burned approximately 60 000 ha (148,000 ac), with approximately 11 600 ha (28,660 ac) burning at high severity. The King Fire burned approximately 40 000 ha (99,000 ac), with approximately 18 500 ha (45,700 ac) burning at high severity. The fires had notably different SDC values (fig. A4.2). The Rough Fire had an SDC of 0.0049 (\( \ln[SDC] = -5.319 \)), which was more extreme (patches larger and more regularly shaped) than 81 percent of all fires that burned
Figure A4.2—Example of stand-replacing decay coefficient (SDC) calculation and application. Fire perimeters for Rough (A) and King (B) fires are shown in gray; high-severity area is red and dark blue, respectively. The continuous relationship between proportion of total stand-replacing area and interior buffer distance is shown in panel (C), calculated using 10-m (33 ft) buffer distances. The teal-colored dots in (C) represents a 120-m (394 ft) internal buffer for each fire, also shown spatially by the teal color in (A, B). The natural log of SDC is shown for the Rough (red line) and King (blue line) fires, relative to 477 fires that burned in California interior conifer forests between 1984 and 2015 (See Stevens et al. 2017 for more details).
through primarily conifer forest in California since 1984 (fig. A4.2D). The King Fire had an extremely small SDC of 0.0013 (ln[SDC] = -6.645), which was more extreme than all other fires since 1984 (fig. A4.2D). The King Fire is unique among all modern forest fires in California, with more than 25 percent of its high-severity area at least 0.5 km (0.31 mi) from a live-forest edge, by far the lowest SDC of any fire in the past 33 years. This example shows how the SDC metric is particularly useful for comparing across fires.

References


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