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BAER Soil Burn Severity Maps Do Not Measure Fire Effects to Vegetation: A Comment on Odion and Hanson (2006)

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Abstract

We comment on a recent *Ecosystem* paper by Odion and Hanson (Ecosystems 9:1177–1189, 2006), in which the authors claim that high severity fire is rare in the Sierra Nevada under current conditions. Odion and Hanson's results are predicated on BAER soil burn severity maps, which are based primarily on fire effects to soil, not vegetation. Odion and Hanson, and we fear others as well, are misinformed as to the nature of the BAER severity mapping process, and proper applications of BAER soil burn severity maps. By comparing the BAER soil burn severity maps to a true vegetation burn severity measure (RdNBR) calibrated by field data, we show that the area in the high soil burn severity class for the three fires analyzed by Odion and Hanson is substantially less than the area of stand-replacing fire, and that BAER maps—especially hand-derived maps such as those from two of the three fires—also greatly underestimate the heterogeneity in vegetation burn severity on burned landscapes. We also show that, contrary to Odion and Hanson's claims, Fire Return Interval Departure (FRID) is strongly correlated with fire severity in conifer stands within the perimeter of the McNally Fire.

Key words: BAER mapping; BARC maps; fire return interval; fire severity; Manter Fire; McNally Fire; mixed conifer forests; RdNBR; Sierra Nevada; Spatial heterogeneity; Storrie Fire.

Introduction

Ecosystems recently published a paper (9:1177–1189) entitled ''Fire severity in conifer forests of the Sierra Nevada, California'' by Odion and Hanson, in which the authors purport to demonstrate that high severity fire in the Sierra Nevada is uncommon under current conditions. To support this assertion, they use soil burn severity maps generated by the Forest Service's Burned Area Emergency Response (BAER) program for three large wildfires, which occurred between 2000 and 2002. Odion and Hanson's use of BAER soil burn severity maps to gauge effects of fire on overstory vegetation constitutes a significant misapplication of these products, and it leads necessarily to invalid conclusions regarding fire effects and fire behavior

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among other things. We feel that a response to Odion and Hanson (2006) is necessary to forestall further misapplication of these products.

The BAER Process

Burned Area Emergency Response is a rapid assessment process undertaken by the federal land management agencies in the event of fires exceeding defined thresholds for size, severity, and/ or soil resource damage. The primary objectives of the BAER program are to (USFS 1995):

(1) determine if fire-caused changes in soil hydrologic function have resulted in an emergency that threatens life, health, property, or critical cultural and natural resources due to flooding, erosion, and debris flows;
(2) prescribe and implement emergency stabilization treatments to minimize these threats.As part of the BAER process, a soil burn severity map is generated which serves as the template for recommended emergency actions to stabilize soil, protect structures, and the like. Under current practice, on sufficiently large fires this map begins as an interim digital product generated from satellite imagery by the USGS-EROS Data Center or the USDA-Forest Service Remote Sensing Applications Center (RSAC). Specialists at RSAC or EROS derive a ''BARC'' (Burned Area Reflectance Classification) map by comparing the reflectance difference in certain wavelengths between a pre- and a post-fire image; the BARC map is used by the BAER team to help identify locations requiring field visits and is then modified based on those field visits into a final BAER soil burn severity map (see Bobbe and others 2001). Note that satellite imagery has only been used in burn severity mapping by the Forest Service since 2002, and until 2004 only a single post-fire image was used; between 1996 and 2002, the preliminary map was produced via post-fire infrared imagery by the BAER team in the field, and prior to 1996 the map was drawn by hand directly onto paper topographic maps. The BAER process is heavily ''soils-centric'', and most modifications to the preliminary map (currently BARC) are made based on data collected in the field on soil heating, hydrophobicity, litter and duff status, soil aggregate structure, and other largely pedological factors (USFS 1995; Bobbe and others 2001; Hardwick and others 2002; Parsons 2003). BAER modifications to the BARC map are most often reclassifications of areas classified by BARC as ''high severity'' into ''moderate'' or ''low'' severity classes, as high mortality areas without complete canopy combustion often show only moderate effects on soil structure and cover. The final fire severity map generated by the BAER process is properly termed a ''soil burn severity'' map, and is intended to identify areas where post-fire soil conditions present potential for accelerated post-fire erosion or flooding. As Parsons (2003) put it:

> ''The most important purpose of a soil burn severity map in a BAER assessment is to identify areas of impaired soil function. The soil burn severity map is the key element in determining if threats exist. It is not a map of vegetation mortality, or timber mortality, nor does it represent a composite of fire effects to all resources. It is not a temporal geospatial representation of ecological condition, nor does it reflect a historical range in variability for the fire regimes over a landscape.''

On p. 1178 of their paper, Odion and Hanson (2006) state that ''BAER fire severity data…are used to map the effects of the fire on overstory vegetation canopy''. This statement demonstrates a clear unfamiliarity with the nature and proper application of BAER soil burn severity mapping. In this response, we reproduce many of Odion and Hanson's (2006) analyses, using a true vegetation burn severity measure to compare with their BAER soil burn severity data. We show that their improper use of soil burn severity data results in a series of mistaken conclusions regarding the nature of fire and its impacts on vegetation in the Sierra Nevada.

Background

BARC Maps

Although remotely sensed BARC maps have now largely replaced single-image classifications and hand-drawn maps generated through aerial reconnaissance or photo interpretation, the purpose of these maps remains the same: they are produced to support BAER soil burn severity mapping, and they are modified by the BAER team based on soil conditions on the ground. BARC maps are based on the ''Normalized Burn Ratio'' (NBR), which is a measure derived using reflectance from Bands 4 and 7 in the Landsat TM 30-m satellite data (Key and Benson 2005). NBR is sensitive primarily to living chlorophyll and the water content of soils and vegetation, but is also driven by a moderate sensitivity to lignin, hydrous minerals, ash and char (Elvidge 1990; Kokaly and others 2007). Where pre-fire images are available, the post-fire NBR measure can be subtracted from the pre-fire measure to give ''delta'' NBR (dNBR); in recent years this has become the most widely used remotely sensed measure of fire severity (Key and Benson 2005). After image classification is complete, the dNBR data are thresholded into four categories of severity (unburned, low, moderate, high), and the resultant BARC map is provided to the BAER team in a format which allows easy alteration. The final BAER soil burn severity map is thus a modification of the BARC map (or some other preliminary map drawn from the air), based on soils maps and field-measured soils effects of the fire.

Issues with BARC Mapping

Although BAER severity maps represent effects of fire on soil resources, the preliminary BARC map is strongly influenced by the pre- and post-fire state of the vegetation canopy. It is therefore tempting to use unmodified BARC maps as approximations of vegetation burn severity maps, but this practice is best avoided. One of the features of the dNBR measure is that its magnitude is strongly correlated with pre-fire chlorophyll, that is, areas that show the greatest absolute difference between pre- and post-fire vegetation will receive the highest severity values (Key and Benson 2005). In practice, this means dNBR is correlated with pre-fire biomass or cover. For example, a forest stand with 40% pre-fire cover that has experienced stand-replacing fire will receive a lower dNBR value than a stand with 70% cover that also experienced stand-replacing fire (Miller and Thode 2007). Because of this, the two stands are likely to be assigned different severity values during severity thresholding: the stand with 40% pre-fire cover might be assigned a moderate severity rating, whereas the stand with 70% cover is likely to be categorized as high severity. In short, dNBR partially decouples tree mortality from severity. The severity bias of dNBR is actually a positive asset where one is interested in potential heating effects to soil (that is, in BAER mapping), as less biomass burned theoretically equals less heat output. However, where one is interested in quantifying the amount of stand-replacing fire and vegetation mortality on a landscape, this measurement bias becomes problematic. In practice, this issue is of minor significance in fairly homogeneous forests, but presents increasing problems as canopy heterogeneity increases (and Sierra Nevada forests are famously heterogeneous).

There are at least three other significant issues with BARC severity maps: (1) The emergency nature of the BAER process dictates that the BARC product be based on the best immediately available post-fire image, which often results in suboptimal mapping due to smoke, weather or other reflectance signature issues, and which means that longer-term effects of fire on tree mortality are missed. (2) Because dNBR is an absolute index, the thresholds between mapped severity classes (which are subjectively assigned by a GIS analyst) often vary from fire to fire. This makes temporal or spatial comparisons of fire severity (between fires, for example) difficult. (3) BARC maps are not calibrated by quantitative field data. The original field assessments of maps produced by the BARC process gave accuracy values of around 60% (Bobbe and others 2001), but there continues to be no programmatic collection of field data to base BARC maps on.

RdNBR: a Better Measure of Vegetation Burn Severity

In our opinion, a better way of remotely sensing fire effects on vegetation is to use a relative index, derived by dividing the dNBR by the pre-fire image (Miller and Thode 2007). Because this index is relative—we call it ''RdNBR''—all patches of stand-replacing fire are assigned a high severity classification, no matter the pre-fire cover. Additionally, RdNBR is on approximately the same scale for all fires, allowing temporal and spatial comparisons across events. Unlike the dNBR-based BARC maps, the RdNBR maps we are generating in California are calibrated using field data collected in Sierra Nevada fires—for example, our current database includes 245 plots sampled within the McNally Fire area (Thode 2005; Miller and Thode 2007). Based on the field data, which follow the Composite Burn Index (CBI) protocol (which measures fire effects on vegetation with some input from soils effects; Key and Benson 2005) and also include data on tree size and mortality, we are able to generate standardized RdNBR maps which can be presented in units of the CBI, percent of basal area mortality, and percent of canopy mortality. Over the course of the last year, RdNBR has become the standard for vegetation burn severity mapping on National Forest System lands in California, and we use RdNBR products extensively in this contribution.

Fire Return Interval Departure

In 1996–1997, Sequoia-Kings Canyon (SEKI) National Parks developed a process to map current departures from historic fire return intervals as part of an ''ecological need'' assessment (Caprio and others 2002). The method simply subtracts time-since-last-fire from the presumed historic (presettlement) mean fire return interval, and divides the difference by the historic mean; the output is called Fire Return Interval Departure, or FRID (Keifer and others 2000; Caprio and others 2002). The FRID measure was intended to highlight those areas where fire had long been absent as an ecological process, that is, it was not intended as a direct surrogate for fuel loading, although a positive correlation with fuels—and hence, predicted fire severity under average weather conditions—would be expected in many vegetation types, especially those characterized historically by high frequency-low severity fire regimes (Agee 1993). FRID maps have become a key part of ecosystem management in SEKI. In 1999–2000, based on the success of mapping in SEKI, the Ecology Program of the US-Forest Service Pacific Southwest Region borrowed the NPS method to map FRID for the three forests of the Southern Sierra Province (Stanislaus, Sierra and Sequoia National Forests). FRID was further categorized into a measure called ''condition class'', based on the magnitude of departure from the presumed historic mean (see Odion and Hanson 2006 for details). Although Odion and Hanson (2006) suggest that the FRID metric is closely related to the national interagency Fire Regime Condition Class (FRCC) measure (Hann and Strohm 2003; FRCC 2005), the two measures were developed for different reasons, at different times, by different people, and they gauge different aspects of fire regime departure.

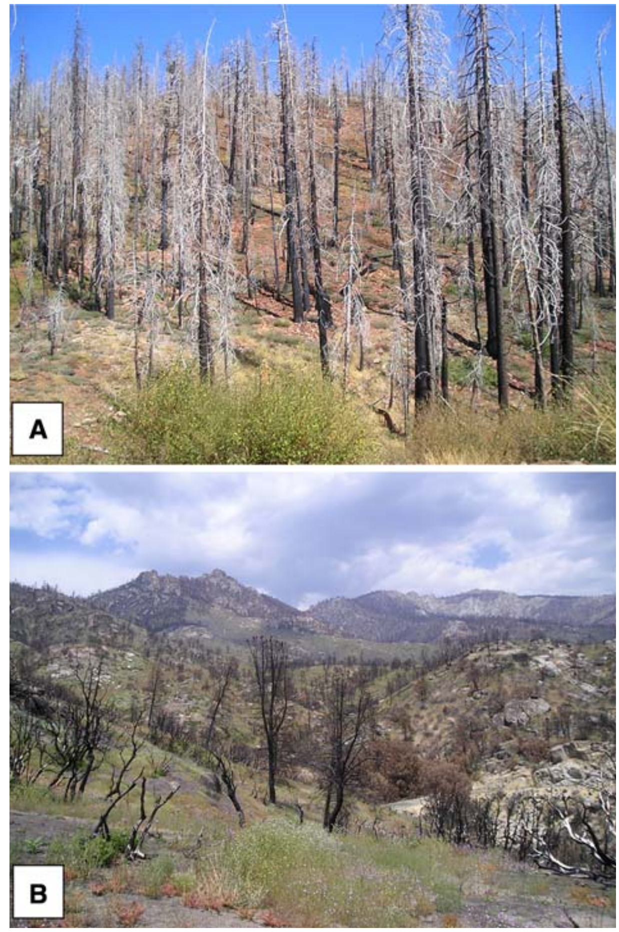

Figure 1. Fire areas classified as ''moderate'' severity by BAER soil burn severity mapping (the maps used by Odion and Hanson) on two of the fires analyzed by Odion and Hanson. **A** Storrie Fire, five years after fire; tree mortality in this area was 100%. **B** McNally Fire, one year after fire; tree mortality in this area was nearly 100%. Safford photos.

Analyses and Discussion

Severity Mapping: Area, Polygon Sizes, and Patchiness

In forest- and shrub-dominated ecosystems, BAER soil burn severity maps and vegetation burn severity maps (whether based on aerial photos or remotely sensed imagery) are usually broadly correlated at the low end of the fire severity spectrum, but this relationship deteriorates as severity increases, and it is common for the soil burn severity-vegetation burn severity correlation to be very poor in areas of high severity. This is because BAER teams often ''downgrade'' areas of high- and sometimes moderate-severity on the BARC or aerial photo maps based on mapped soil characteristics (for example, clay-content, which impedes heat transference to depth) or on the teams' site-specific assessments of a number of primarily soil-based factors (Figure 1). The reverse is also possible, for example, reclassification of moderate severity to high severity, but less likely.

A comparison of the image-derived preliminary burn severity map for the McNally Fire (which was pre-BARC and did not use a pre-fire image; Odion and Hanson's statement [p. 1180] that a pre-fire image was used is incorrect), and the final BAER map of soil burn severity shows how the percent concordance between the two maps strongly deteriorates from low to high severity (Table 1). As can be seen in the totals for the two products, the ''proto-BARC'' map identified 96,235 pixels of high severity fire, but the BAER team ''downgraded'' over 63,000 (96,235 − 32,939) of those pixels based on previous soil mapping and BAER team

Table 1. Matrix Comparing Pixels Identified as Low, Moderate and High Severity in the Preliminary ''proto-BARC'' Map Versus the Final BAER Soil Burn Severity Map for the McNally Fire

	proto-BARC				
Severity class	Low	Moderate	High	Total	User's accuracy
BAER					
Low	296,634	33,740	2,671	333,045	89.1
Moderate	21,125	199,923	60,635	281,683	71
High	5,309	18,344	32,929	56,582	58.2
Total	323,068	252,007	96,235	671,310	
Producer's Accuracy	91.8	79.3	34.2		
Overall Kappa	0.643				

No vegetation types are excluded in this table. The User's Accuracy value is based on the BAER map categories, the Producer's Accuracy is based on the proto-BARC categories. Kappa values run from 0 to 1, with 0 representing complete independence of the two maps, and 1 representing complete concordance. Proto-BARC map concordance with the final BAER soil burn severity map ranged from a high of 89% in the low severity class, to a low of 58% in the high severity class.

field soil observations. Of the 56,582 pixels mapped as high soil burn severity by the BAER team, about 60% of these were retained from the preliminary proto-BARC map, about 40% were ''upgraded'' from areas mapped as moderate and low severity (Table 1). From the standpoint of the proto-BARC map-user (the BAER team), there was about 58% ''accuracy'' (that is, compared to the final BAER product) in the preliminary proto-BARC product in the high severity class, compared to 71% in the moderate severity class, and 89% in the low severity class.

BAER team changes to the preliminary proto-BARC severity map for the central (and most severely burned) portion of the McNally Fire can be seen in graphic form in Figure 2. Scene A represents the RdNBR map, using 90% canopy mortality for the moderate/high severity class boundary to match Odion and Hanson (who claim, incorrectly, that the BAER map used 90% canopy mortality as the boundary; see below). Scenes B and C in Figure 2 represent the proto-BARC and BAER soil burn severity maps, respectively. The McNally Fire BAER team used the proto-BARC map in Scene B as their base map for soil burn severity mapping. Scene C, the BAER soil burn severity map, is the product used by Odion and Hanson.

The final McNally Fire BAER soil burn severity map also made major modifications to the geometry and size-distributions of severity patches in the preliminary proto-BARC map (Figure 2; Table 2). This was due partly to standard procedure in BAER mapping, which dictates a minimum mapping unit for soil burn severity maps (40 acres for most projects; the McNally Fire used a 10 acre MMU), and up to 40% inclusion of high severity patches in moderate severity polygons (USFS 1995). Table 2 gives numbers and mean sizes of high severity patches as mapped for all three fires analyzed by Odion and Hanson (2006) by each of the mapping methods (RdNBR, proto-BARC, BAER). On the McNally Fire, BAER mapping reduced the number of high severity polygons by 84% (149 vs. 949) from the proto-BARC map, which resulted in a quadrupling of mean polygon size; there is a 92% difference in polygon number between the BAER and RdNBR maps (Table 2; Figure 2). On the Storrie Fire, RdNBR maps 399 separate polygons of high severity, whereas the BAER map recognized 49, an 88% drop (and which also resulted in an almost fourfold increase in mean polygon size). On the Manter Fire, RdNBR picked up 1,080 patches of high severity fire, but the BAER team mapped only seven; in this case, the difference in mean polygon size is phenomenal (Table 2; see also Figure 4).

Figure 3 shows the total area of high, moderate, and low severity fire mapped for conifer types in BAER soil burn severity mapping for each of the three fires (data from Odion and Hanson 2006). Compare these values with the values obtained from the RdNBR vegetation burn severity mapping: when calculated based on actual fire effects on the vegetation canopy (that is, by RdNBR), fire severity distributions in the three fires are very different than claimed by Odion and Hanson, whether our preferred severity-class boundaries are used (25%/75%), or theirs (10/80–10/90) (Figure 3; note that we have conservatively used 85% mortality as the moderate/high severity boundary for the Storrie and Manter Fires so as to emphasize the soil bias of the BAER maps). The soil severity-based measure, because it is not vegetation-based, greatly underestimates the percent of landscape subjected to stand-replacing fire, and generally overestimates

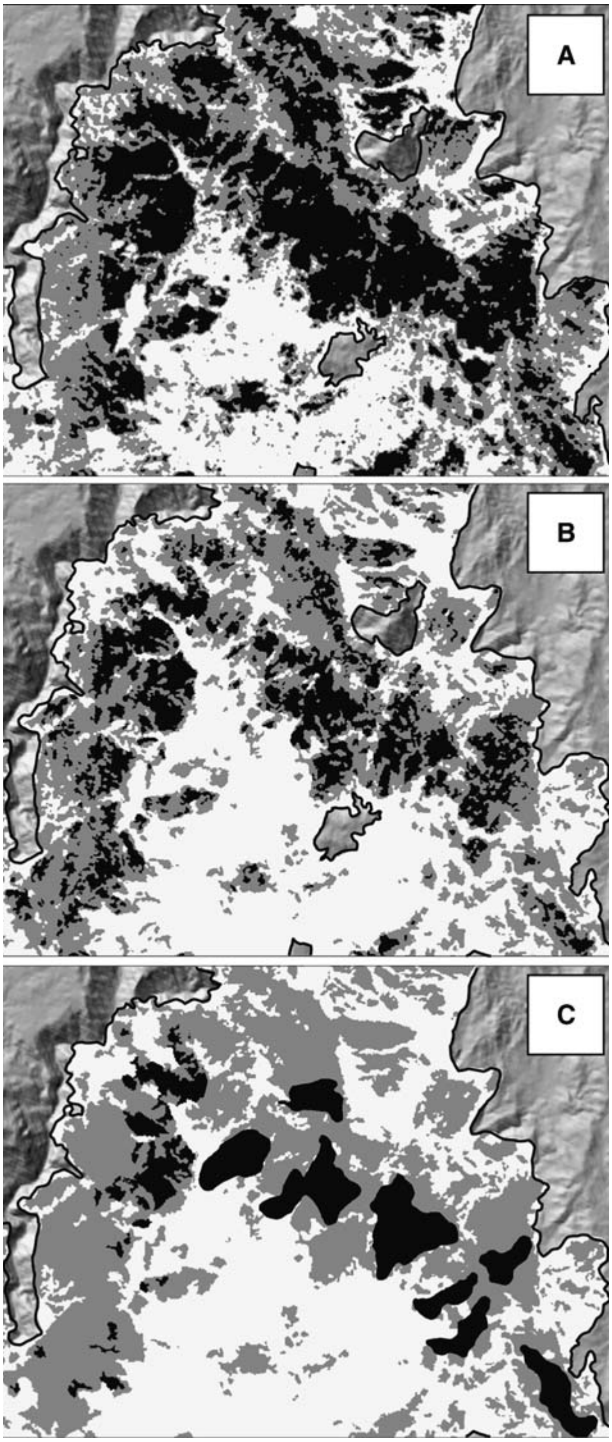

Figure 2. Three versions of burn severity in the central—and most severely burned—portion of the McNally Fire. *Black* high severity, *gray* moderate severity, *white* low severity and unburned. Scene **A** is the RdNBR map, using 90% canopy mortality to match Odion and Hanson. Scene **B** is the preliminary ''proto-BARC'' map which was delivered to the BAER team on the fire. Scene **C** is the final BAER soil burn severity map, generated by modifying the BARC map to match fire effects on soil measured by the BAER team in the field. Scene C is the map used by Odion and Hanson. Each figure measures approximately 15 km top-to-bottom and 18 km across.

the percent subjected to moderate and low levels of fire effects to vegetation. For the Storrie and McNally Fires, the RdNBR vegetation severity measures both found at least twice as many acres had suffered high severity fire than the soil severity measure used by Odion and Hanson; the differences on the Manter Fire ranged from 19 to 36% (Figure 3). The differences in estimates of low and moderate severity fire between vegetation severity and soil severity measures were also similar on the Storrie and McNally Fires. Compared to the RdNBR measure using 25% mortality as the low/moderate boundary, BAER mapping for these two fires ''overidentified'' moderate severity fire by about 1/2 (44 and 57%, respectively), and low severity fire by about 1/4 (19 and 29%); again, these differences are due to the different purposes of the two maps. The number of acres in the moderate severity classes is not very different between the BAER soil burn severity map and the RdNBR vegetation severity measure using 10% as the low/moderate boundary (Figure 3).

Perhaps the best summary of our argument is provided by two simple maps. In Figure 4, we compare the BAER soil burn severity map with the RdNBR vegetation burn severity measure for the Manter Fire (Figure 4; see also Table 2). The Manter Fire BAER map—which was completed before the advent of the BARC process—was hand-drawn with the aid of aerial reconnaissance and infrared imagery (Figure 4B). We generated the RdNBR map (Figure 4A) based on LANDSAT images taken before and 1-y after fire and calibrated by CBI field plots. There is little need for commentary here: it is simply impossible to use BAER soil burn severity maps to come to robust and valid conclusions about the area and patchiness of stand-replacing fire in the Sierra Nevada.

Definitions of Severity Classes

In their paper, Odion and Hanson consider only conifer-dominated vegetation types. On p. 1180, Odion and Hanson incorrectly state that specific quantitative values of tree canopy scorch were used by the BAER teams to identify areas of different fire severities on the three analyzed fires. For example, according to them, on the McNally Fire:

Table 2. Total Number of Polygons and Mean Polygon Size of ''High Severity'' Patches as Mapped in the McNally, Manter and Storrie Fires by RdNBR (Vegetation Burn Severity; Imagery Based, Using Pre- and Post-fire Images and Calibrated by Field Data), ''Proto-BARC'' (McNally Fire Only; Based on a post-fire Image Only with No Field Validation), and BAER (Soil Burn Severity; Modification of a Preliminary Imagery- or Photo-derived Map Based on Field Observation of Soil Condition)

	McNally			Manter		Storrie	
	RdNBR	proto-BARC	BAER	RdNBR	BAER	RdNBR	BAER
Number of polygons	1,792	949	149	1,080	7	399	49
Mean polygon size (ha)	11.3	9.1	34.2	14.5	1722.5	17.6	66.7

Odion and Hanson (2006) base their paper on the BAER soil burn severity maps.

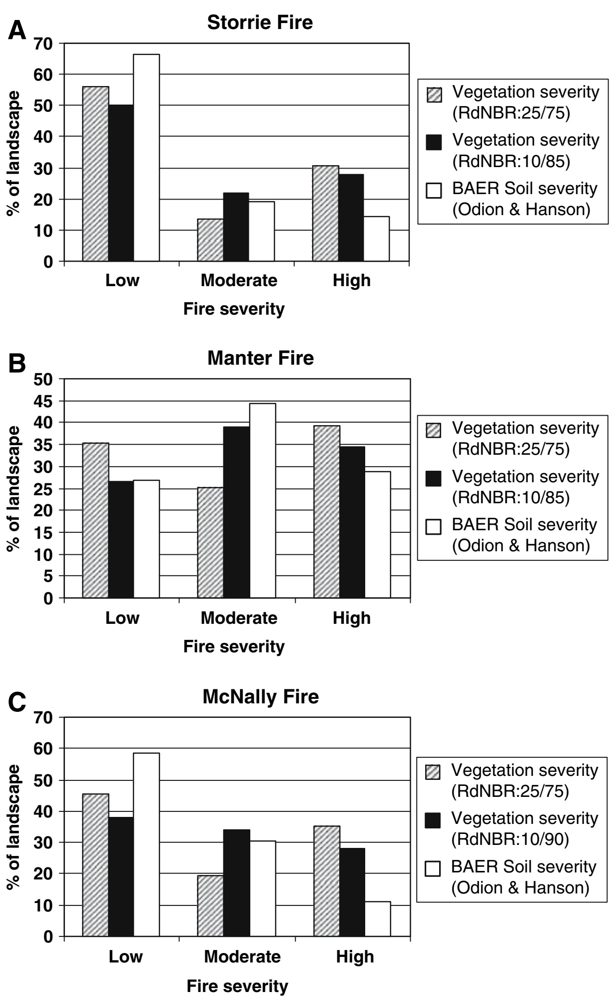

Figure 3. Percent fire area mapped as low, moderate and high severity, for the Storrie, Manter, and McNally Fires. The vegetation-based severity results (RdNBR) are produced twice, using two sets of severity-class cutoffs. The first number is the boundary between low and moderate severity (10 or 25% canopy mortality), the second is the moderate-high severity boundary (75, 85 or 90%).

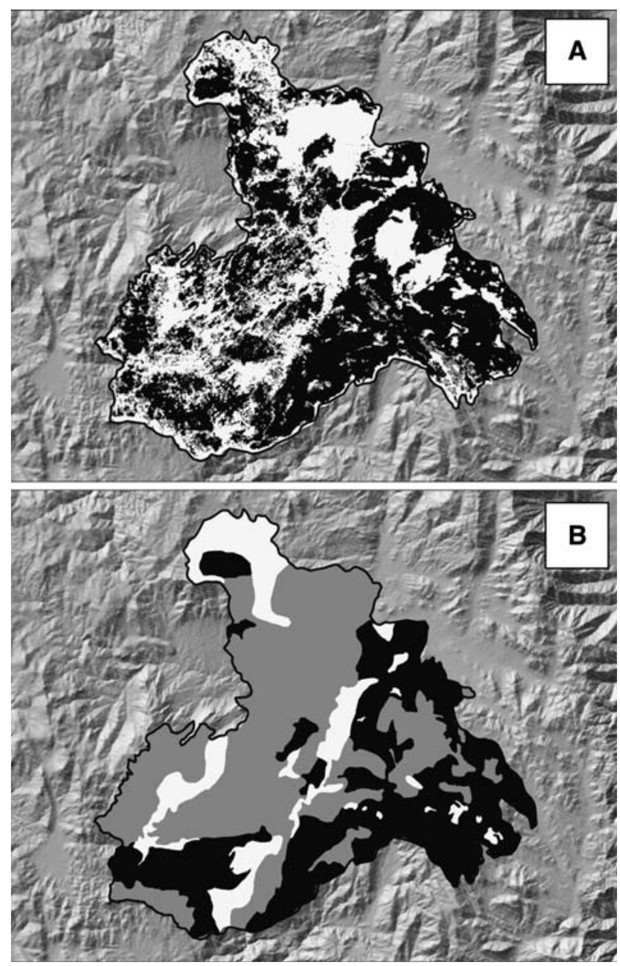

Figure 4. Manter Fire: RdNBR vegetation burn severity map (scene **A**), versus the final BAER soil burn severity map (scene **B**). *Black* high severity, *gray* moderate severity, *white* low severity and unburned. Odion and Hanson base their conclusions regarding area and patchiness of stand-replacing fire on the soil burn severity map (scene **B**). Each figure measures approximately 27 km top-to-bottom and 35 km across.

"*Low severity* included areas where fire-caused crown scorch…affected less than 40% of overstory canopy foliage. The unburned and low-severity classes killed primarily conifer seedlings and saplings. *Moderate severity* included areas where fire scorched 40–89% of the forest canopy. …This level of severity was lethal to most conifer seedlings, saplings, and many small trees, but most overstory trees survived. *High severity* included areas where 90% or more of the canopy was scorched or affected by varying levels of incineration… High-severity fire generally resulted in complete understory mortality. Overstory mortality ranged from complete to mixed depending on degree of canopy scorch and consumption…(and) forest composition…"

These "guidelines" are constructs of the authors however, and bear little resemblance to the actual guidelines used in the McNally BAER effort. The McNally Fire BAER soil burn severity guidance is overwhelmingly based on soil characteristics, and includes only the following information on conifer effects (Parsons 2002; Parsons and Orlemann 2002):

Low severity: …large trees are mostly not killed. …Tree mortality may occur but it is slight. …*Moderate severity*: …brown needles or leaves remain on trees. …trees may exhibit 40–90% mortality…. *High severity*: …Complete consumption of tree crowns has occurred, few to no needles or leaves remain on trees, mortality can be assumed to be close to 100%.

The Manter Fire BAER soil burn severity guidelines were also almost exclusively based on soil characteristics, such as depth, color, and character of ash; amount of litter consumed; loss of soil structure; development of water repellency; and soil crusting. Vegetation-based characteristics included size and amount of live fuel consumed, and condition of plant root crowns, but there was no quantitative reliance on measures of canopy scorch (James and others 2000). Odion and Hanson also refer to the Forest Service Handbook 2509.13 (USFS 1995), which contains general procedural guidelines for BAER project work. Chapter 20 covers the burned area survey process; below is the entirety of quantitative guidance involving vegetation provided in FSH 2509.13.23.32 ("Fire intensity"[sic]):

…2. *Size and amount of live fuels consumed.* When fuels greater than 3/4 in. in diameter and more than 80% of the plant canopy have been consumed, these indicate a high-fire intensity. Low-intensity fire can burn fuels up to 1/4 in. and usually less than 40% of the brush canopy. Moderate intensity is between these two extremes
…4. *Plant root crowns.* Root crowns of sprouting brush and grasses consumed or heavily damaged by the fire indicate a high-intensity burn.

Note that these are general guidelines, not standards. The other severity indicators listed in FSH 2509.13 are: (1) depth and color of ashes; (3) litter consumption; and (5) soil crusting.

There are two primary reasons for the great discrepancies between Odion and Hanson's results and our results. First and foremost is the fundamental issue that Odion and Hanson have based their results and the extrapolations made from those results on soil burn severity mapping and not vegetation burn severity mapping; their fundamental misapplication of BAER soil burn severity mapping is the principal theme of our contribution. A second reason for discrepancy is that Odion and Hanson subjectively select a relatively narrow band of canopy mortality values for their "high severity" class: Odion and Hanson cite 80% canopy mortality as defining high severity for the Storrie and Manter Fires, and 90% for McNally (although it is important to stress that these values are theirs and not those actually used by the BAER mapping efforts on those fires). We prefer 75% mortality, for a number of reasons: (1) this was the fire-modeling standard adopted for lethal fire in the Sierra Nevada Forest Plan Amendment (USFS 2004), which guides land management on the National Forests of the Sierra Nevada; (2) this is the standard used by the national Interagency Fire Regime Condition Class program (FRCC 2005); and (3) 75% mortality is intermediate between 70 and 80%, which are probably the two most commonly used high severity cutoffs in the literature and in management practice (see Morrison and Swanson 1990; Agee 1993; Cissel and others 1999; Hann and Strohm 2003; USFS 2004).

Lack of standardization in BAER severity definitions

The recent advent of the BARC process (see Background) has begun to introduce a degree of consistency to BAER mapping, but the fact remains that there is no national or even regional standard for BAER soil burn severity mapping: the Forest Service Handbook (USFS 1995) provides only very broad guidelines, and severity classification is left up to the discretion of the BAER team in question. In an assessment of BAER severity mapping, Bobbe and others (2001, pp. 8–9) noted that

> ''One factor in which BAER teams differed was the role of needle cast in assessing the degree of burn severity. … Other BAER team members only consider soil hydrophobicity measurements to assess burn severity and do not consider needle cast potential. … (Some) BAER teams also considered … slope or proximity to a resource at risk in assessing the degree of burn severity. … The subjectivity of the interpretation methods of individual BAER teams makes it difficult to attain a consistent burn severity map from incident to incident…''

This incident-by-incident subjectivity makes comparison of BAER soil burn severity maps between fires an extremely difficult proposition, especially where the comparison is made across a span of years in which the technology of mapping is changing radically. Odion and Hanson's (2006) conclusions about area and patchiness of stand-replacing fire in the Manter, McNally, and Storrie Fires are based on their assumptions that: (1) a more-or-less common standard of fire severity definition was used by the three BAER teams, (2) that standard was based primarily on tree-canopy effects, and (3) the polygon maps generated in the three BAER efforts were of comparable resolution and accuracy. All three of these assumptions are incorrect.

Fire Return Interval Departure (FRID) Mapping

As noted in the Background section, Odion and Hanson err in equating the Sequoia National Forest's FRID measure with the national FRCC metric; these are wholly separate measures which would only be expected to correlate closely in high frequency-low severity fire regimes (which are, admittedly, common in the southern Sierra Nevada). Even in these cases, the FRID measure would be expected to correlate with severity primarily where fire behavior was driven more by fuels than by weather conditions. Large fires in the Sierra Nevada and other Southwestern ecosystems are primarily driven by extreme weather (Agee 1993; Taylor and Beaty 2005; Swetnam and Betancourt 1998; van Wagtendonk and Fites 2006), and the McNally Fire was further evidence of this tendency.

In their paper, Odion and Hanson (2006) compare the Sequoia National Forest's FRID GIS coverage against the McNally Fire BAER soil burn severity map, to determine whether FRID is a predictor of fire severity. To see if ''fire spread rate'' had any effect on the correlation of FRID with burn severity, Odion and Hanson use area burned per day as a surrogate and block their analysis by hectares burned per day. We are skeptical that area burned per day is a reasonable surrogate for fire-spread rate. First of all, larger fires have a larger perimeter and thus fires have a tendency to burn more area as they grow, simply as a function of geometry. Second, there are multiple factors that drive fire behavior, and simply using hectares burned per day does not integrate all of these factors, rather it confounds them. As a fire grows, its perimeter lengthens, and different fronts of the fire may be burning dozens of kilometers apart, in different compass directions, in different topography and vegetation, at different elevations (which affects temperature, oxygen supply, fuel moisture, and so on). Also, there is often a negative relationship between fire age and area burned per day in big fires, because such fires become large only after escaping containment, which they do by making huge early runs during periods of extreme fire weather. A proper analysis of the correlation between FRID and fire effects would take all of these variables and more (wind speed and direction, measures of fire weather, and so on) into account, but the *first* step would be to examine the simple univariate relationship between FRID and fire severity. Odion and Hanson do not show the results of such an analysis, but we reproduce it in Figure 5A. Even though Odion and Hanson's data are drawn from a soil burn severity map, which—as we have made clear—strongly dilutes the nature of the fire's effects on vegetation, a clear severity versus FRID pattern still develops. The area of low severity (plus no) fire decreases from 67% of FRID condition class I, to 62% of condition class II and 48% of class III; the proportion of moderate plus high severity fire follows a reversed trend, 33–52%, with high severity fire contributing about 14% of the acreage in classes II and III.

In Figure 5B we repeat the analysis, this time replacing the BAER soil burn severity data with true vegetation burn severity data. In this case, the area of low severity or no fire in FRID condition class I is about 69%, decreasing to 50% in condition class II and 35% in class III. High severity fire contributes only 14% of the area in forests within

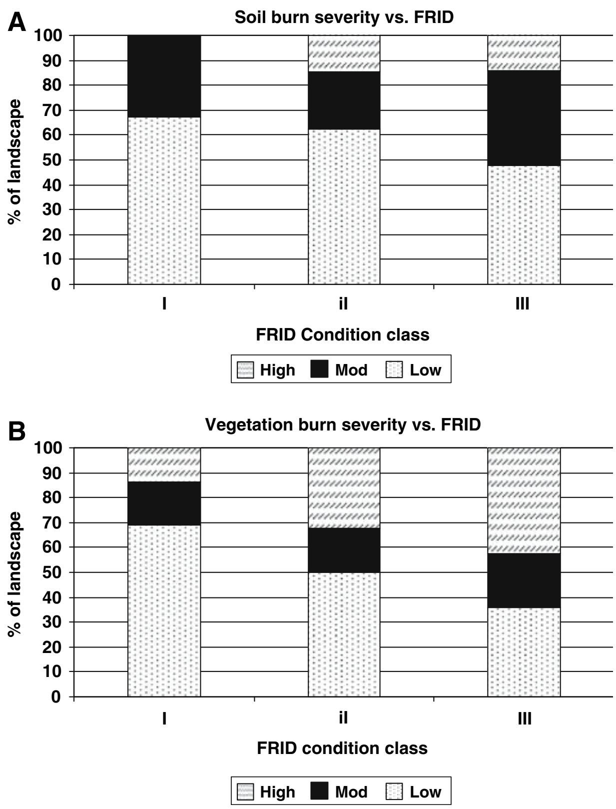

Figure 5. Burn severity versus condition class within the McNally Fire perimeter, as determined from the Sequoia National Forest FRID map; only conifer vegetation is included. **A** BAER soil burn severity, the measure used by Odion and Hanson; **B** vegetation burn severity, using the RdNBR measure. Condition class is a categorization of the FRID statistic: *I* low departure, *II* medium departure, *III* high departure; see the Introduction or Odion and Hanson (2006) for details. To follow standard practice, the low severity class includes both low severity and unburned; high severity includes both high and ''extreme'' burn severity (Odion and Hanson 2006).

FRID condition class I, 32% in class II and 42% in class III; moderate severity fire occurred on 16–17% of the area in FRID condition classes I and II and about 21% in class III (Figure 5B). These results correspond closely to theoretical expectations (Agee 1993; Bond and van Wilgen 1996; Caprio and others 2002): contrary to Odion and Hanson's claims, burn patterns in the McNally Fire are closely correlated with the FRID Condition Class measure, the intrinsic complexity of fire behavior notwithstanding.

Summary

We do not disagree with all of Odion and Hanson's (2006) conclusions. In particular, we agree with the authors' qualitative statements that natural fires are important ecosystem processes with critical links to landscape heterogeneity and biotic diversity. That said, we find serious fault with most of the quantitative analyses carried out by Odion and Hanson (2006). To summarize our main points:

1. *BAER soil burn severity maps represent fire effects to soil, not to vegetation.* BAER maps are correlated with some fire effects to vegetation, but the strength of this correlation decreases as vegetation mortality increases.
2. *BAER maps cannot be credibly used to estimate the severity of fire effects on vegetation.* Because of their soils focus, BAER maps often greatly understate the extent of stand-replacing fire on the landscape. By inappropriately using BAER soil burn severity maps in their analyses, Odion and Hanson (2006) underestimate the area of stand-replacing fire by 19% to more than 50%, depending on the fire in question.
3. *BAER maps cannot be credibly used to assess patchiness of fire effects to vegetation.* As noted above, BAER maps do not map fire effects to vegetation. BAER polygon delineation practices use large minimum mapping units (usually 40 acres) and include much lumping of severity inclusions. This is especially a problem with older, hand-drawn maps such as the Manter and Storrie Fires.
4. *BAER soil burn severity maps are derived principally using soil-based factors*, and there is no national or regional standard for incorporation of vegetation effects in this process. BAER soil burn severity mapping is not based on a standardized, quantitative scale of fire effects to the vegetation canopy, and comparisons between different fire events in different years are difficult, if not impossible to make. The recently developed BARC process should result in greater comparability between future BAER products.
5. Contrary to Odion and Hanson's assertions, *the Sequoia National Forest FRID map showed strong correlations to the severity of fire within the McNally Fire perimeter*, especially when a true measure of vegetation burn severity (RdNBR) was used.

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