Differences in land ownership, fire management objectives and source data matter: a reply to Hanson and Odion (2014)

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Abstract. We respond to Hanson and Odion (2014), who claim in this journal (vol. 23, no. 1, pp. 1–8) that their reanalysis of fire severity patterns in and around the Sierra Nevada refutes earlier work showing increases in fire severity in certain forest types over the last 3 decades. Hanson and Odion base their reanalysis on a highly inaccurate, very coarse-scale, and geographically misregistered vegetation map. Also, in contrast to the previous work, which was restricted to wildfires on Forest Service lands in forest types differentiated by their fire regimes, Hanson and Odion combine all types of fires on lands of all jurisdictions and stratify by very broad, unorthodox vegetation types that conjoin very different fire regimes. As such, their work does not constitute a test of the previous work. We present analyses that demonstrate sources of error associated with Hanson and Odion’s data and the analyses they perform, and explore how that error might confound their results. Fundamental and compounded problems in Hanson and Odion (2014) cast strong doubt on their conclusions.

Introduction

Hanson and Odion (2014; hereafter ‘H&O’) claim to have refuted two earlier studies (Miller et al. 2009a; Miller and Safford 2012) that showed statistically significant increases in fire severity in certain forest types on Forest Service (FS)-managed lands in the Sierra Nevada Forest Plan Amendment (SNFPA) area. However, there are myriad methodological issues with H&O that introduce compounding errors into both their results and interpretations (Table 1). As background for our analyses, we use the Introduction to draw attention to three of the most serious methodological problems in H&O’s study: (1) choice of study area, (2) choice of vegetation data, and (3) statistical analyses performed.

Study area

H&O do not reanalyse the fire severity data of Miller and colleagues, but rather analyse a different dataset from an expanded study area that includes more fires and different jurisdictions. The expanded study area (referred to as the ‘SNEP’ area, from the Sierra Nevada Ecosystem Project (CWWR 1996)), includes private lands and National Park Service (NPS) lands, in addition to FS lands. By including these different ownerships, the authors combine areas supporting very different fire and forest management practices. Furthermore, by using all fires mapped by the Monitoring Trends in Burn Severity (MTBS) project, they include prescribed fires.

Most fires on NPS lands in the SNEP area are managed very differently than on most FS lands. The National Parks for many decades have allowed lightning-ignited fires to burn under specified conditions to meet resource-management objectives. Although some National Forests allow ‘resource benefit’ fires in more remote, higher-elevation areas, the Parks have a longer history of wildland fire use on much more of their landbase (van Wagtendonk 2007). As a result, the proportion of high severity in wildland fires has been lower in the Parks relative to the National Forests (Miller et al. 2012).

Private lands pose yet another challenge for analysing fire severity in California. These lands are typically salvage-harvested within a month or two of fire containment (Zhang et al. 2008), which creates a dilemma because the MTBS data are derived from post-fire satellite images acquired the year after the fire (so-called ‘extended assessments’; Eidenshink et al. 2007). Such data are severely compromised when trees have been harvested between fire containment and the post-fire image. If the proportion of area burned on private lands
<table>
<thead>
<tr>
<th>Category</th>
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</tr>
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<tbody>
<tr>
<td>Vegetation data</td>
<td>H&amp;O claim that periodic remapping in post-1984 vegetation layers used by Miller and colleagues systematically ‘excludes’ more conifer forest affected by high-severity fire over time, introducing an inherent positive trend</td>
<td>Neither vegetation map used by Miller and colleagues is systematically remapped to seral vegetation types after disturbance. Post-1990s versions of CALVEG are potential/current vegetation hybrids because potentially productive forest lands are retained and mapped as forest types. Landfire BpS is a true potential vegetation map.</td>
<td>H&amp;O criticisms of Miller and colleagues studies are unfounded.</td>
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<td>CALVEG77 used by H&amp;O is extremely coarse-scale, and geographically misregistered by &gt;1 km in places</td>
<td>CALVEG77 was created using photo interpretation methods, i.e. hand-drawing polygons on hardcopy prints of satellite images ~1977 before the advent of computer-based registration or vegetation algorithms.</td>
<td>Owing to extremely coarse scale and misregistration, these data do not actually depict prefire forested conditions as claimed by H&amp;O as there are many inclusions of non-forest vegetation in polygons labelled as forested types. Severity data stratified by CALVEG77 often did not represent fire effects in forests.</td>
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<td>Severity data</td>
<td>H&amp;O include prescribed fires</td>
<td>Prescribed fires are conducted under conditions that normally result solely in low to moderate severity effects.</td>
<td>Years with a large amount of area burned in prescribed fires (i.e. 2006 and 2007) can lead to an underestimation of high-severity wildfire.</td>
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<td>H&amp;O include fires on private lands</td>
<td>Private lands are almost invariably salvage-logged within months of high-severity fire, invalidating MTBS 1-year-post-fire severity assessments.</td>
<td>Use of extended assessments for areas that were salvaged-logged in the first year leads to an overestimation of high-severity wildfire.</td>
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<td>H&amp;O include National Park Service fires in their analysis</td>
<td>In general, FS and NPS fires are managed very differently. FS fires are almost entirely suppressed, whereas a large proportion of fires on NPS lands in the Sierra Nevada are managed rather than suppressed. Decades of managed fire have reduced fuels in many NPS landscapes, leading to no recent increase in fire severity.</td>
<td>Including NPS fires in an analysis of severity on FS lands could dilute the evidence of high-severity wildfire on FS lands.</td>
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<td>Interpretation of high-severity effects</td>
<td>H&amp;O claim that their high-severity data relate to ~70% BA mortality. However, nowhere do H&amp;O present methods or results that actually demonstrate that relationship. Rather, Miller et al. (2009b) demonstrate that RdNBR 641 for extended assessments equates to ~95% change in canopy cover, a CBI value of 2.25, or ~89% change in basal area.</td>
<td>RdNBR thresholds defining high-severity categories are similar between H&amp;O and Miller and colleagues and therefore do not affect comparison of trends. However, H&amp;O underestimate the actual effects that are produced by high-severity fire.</td>
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<td>Analysis methods</td>
<td>H&amp;O vegetation groupings</td>
<td>Unorthodox forest type groups created by H&amp;O combine different fire regimes. Historically, fire regimes of more mesic, higher-elevation forest types are inclined to longer return intervals and higher severities than middle-elevation forests.</td>
<td>Combining middle-elevation forests with high-elevation forests confuses severity trends and interpretations of ecological effects.</td>
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(Continued)
was greater in the early portion of the time series, then any trend of increasing severity or area burned at high severity on FS lands could have been masked by combining private and FS lands in the same trend analysis. In a recent study of fire severity in the Sierra Nevada, Mallek et al. (2013) included private portions of some fires that also burned FS lands using fire severity data estimated primarily from immediate post-fire images so as to avoid salvage logging ‘pollution’ of the data. Using Bayesian regression techniques, they found there was a >99 and 96% probability of an increasing trend in proportion of area burned at high severity in dry and moist mixed-conifer forests, respectively, and 82–99% probability of increasing area burned at high severity in all conifer forests.

Vegetation data
H&O claim that the vegetation data used by Miller et al. (2009a) and Miller and Safford (2012) lead to an underestimation of high-severity fire early in the time series. H&O base this claim on significant negative coefficients from a Mann–Kendall comparison of their fire severity data stratified by forest type as delineated by ‘prefire’ vegetation data (hereafter ‘CALVEG77’), versus vegetation data used by Miller et al. (2009a) and Miller and Safford (2012), who used a more recent version of CALVEG and Landfire Biophysical Settings (BpS) respectively. Because there was a negative association between their data stratified by CALVEG77 and the other two vegetation datasets, H&O proclaim that the more recent versions of CALVEG and Landfire BpS underrepresent the high-severity area mapped as conifer forest in the early dataset. This claim, however, is confounded by both the effects of salvage-harvesting on remotely sensed fire severity estimates and the inaccuracy in H&O’s base vegetation map (CALVEG77).

H&O provide no details concerning CALVEG77 or its provenance, other than to report partial results of an unorthodox accuracy assessment. However, as H&O’s basic premise is that CALVEG77 is a more accurate representation of prefire forest conditions than vegetation maps used by Miller and colleagues, readers should be provided with sufficient information to determine if that is indeed the case. CALVEG77 polygons were hand-delineated on hard-copy prints of 1977–79 Landsat Multi-spectral Scanner (MSS) images (Matyas and Parker 1980). The metadata indicate a scale of 1:250 000, but CALVEG77 did not utilise the full resolution of the MSS 69-m pixels. Instead, polygons were drawn with a 160–640-ha minimum mapping unit, resulting in an actual scale coarser than 1:1 270 000 (Goodchild et al. 1991; Goodchild 1993); the average size of vegetation polygons in the CALVEG77 map is over 15 000 ha (Keeler-Wolf 2007). In addition, the source Landsat data used to delineate polygons in CALVEG77 were misregistered by over 1 km in some locations (see Fig. S1 available as Supplementary Material to this paper). Presumably, H&O did not correct the misregistration of CALVEG77 polygons as they did not specifically indicate they did so. An independent accuracy analysis of CALVEG77 using forest inventory and analysis (FIA) data from the 1980s found that statewide commission and omission errors for the seven CALVEG forest types analysed by H&O averaged a very poor 72 and 66% respectively (Goodchild et al. 1991); shrub and herbaceous plots were mapped 2.8 times more often as conifer than as shrub or herb by CALVEG77. Goodchild et al. indicated that the poor accuracy was a result of the coarse scale and mislabelling of polygons. This notwithstanding, using FIA data postdating the CALVEG77 map by several decades, H&O report 85–88% ‘accuracy’ for their conifer polygons, which suggests that they only carried out an evaluation of producer’s accuracy (i.e. 1 – omission error). It is well known that omission errors are reduced by homogenising the analysis area (e.g. by using very-coarse-scale data or aggregating classes, as H&O did by reducing the CALVEG types to three forest classes), but commission errors inevitably increase (Smith et al. 2002). Reporting only omission errors and ignoring errors of commission is incomplete and potentially misleading. For example, using FIA data from the 1980s (in Goodchild et al. 1991), we found a commission error of 63% (user’s accuracy = 37%) for H&O’s ‘western lower montane’ group.

Note that, in contrast to CALVEG77, the more modern CALVEG product used by Miller et al. (2009a), which is based on a merging between the 30-m Landsat images and higher-resolution images (such as India Remote Sensing (IRS) satellite or Satellite Pour l’Observation de la Terre (SPOT)), is much more accurate: for the 2009-vintage CALVEG, the overall commission error for the study area was ~26% (37% when weighted by the number of FIA plots in the different map tiles), the omission error was ~25% (39% weighted) (confusion

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**Table 1. (Continued)**

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<tr>
<td>H&amp;O combine data layers of very different scale</td>
<td>H&amp;O vegetation basemap at &gt;1:1 270 000 scale overlaid with severity data at 1:100 000 scale, with conclusions based on the resolution of the finer-scale layer. Miller and colleagues’ studies match scales of vegetation and severity data.</td>
<td>This violates one of the cardinal rules of cartographic analysis: the resolution of results is only as strong as the resolution of the coarsest-scale data in the analysis. Miller and colleagues’ studies match vegetation and severity data at 1:100 000. H&amp;O’s finding of no temporal autocorrelation does not mean trends do not exist.</td>
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H&O used rank correlation to test for temporal trends in severity | M-K rank correlation test has a high probability of making a Type II error and therefore very little predictive power to detect trends across short time series. |  |  |
matrices from 2009 and earlier found at: http://www.fs.fed.us/r5/rs/ projects/AAbu/, verified 1 January 2014). The scale of these maps is also 100 000 or finer, which matches the published scale of the fire severity data.

In addition, H&O incorrectly claim that the more recent CALVEG data used by Miller et al. (2009a) and Landfire BpS data used by Miller and Safford (2012) represent post-fire conditions in the early years of the time series. With regard to Miller et al. (2009a), the mapping methodology used to produce CALVEG since the early 1990s does not strictly follow an existing vegetation mapping methodology. The CALVEG maps are used by the FS to comply with the National Forest Management Act of 1976, which requires the FS to track all potential productive forest lands. As a consequence, any areas capable of producing productive forests are retained in the map. When stand-replacing events occur in productive forested areas, tree density is set to zero and size to non-stocked, but the primary vegetation type is not changed from a forest type. Miller and Safford (2012) used Landfire BpS, which is a potential vegetation map and therefore does not reflect any particular post-fire condition (Rollins 2009).

Statistical analysis

H&O assert that there are no trends in percentage of area burned at high severity or annual area burned at high severity because they did not find a statistically significant correlation between year and severity using the Mann–Kendall rank correlation test. However, rank correlation has very low statistical power in small datasets, increasing chances of making a Type II error (Yue et al. 2002), and correlations in general are mainly statistical methods for monitoring natural resources emphasise that failing to reject the null hypothesis when using Mann–Kendall does not constitute proof that a trend does not exist. Instead, it is usually a statement that the available data are not sufficient to discern a trend (Helsel and Hirsch 2002; Dickson et al. 2005). Yue et al. (2002) found the power of the Mann–Kendall test increases with increasing sample size. Power was lowest for normally and log-normally distributed data, which are typical distributions for percentage and area of high-severity fire.

The potential bias introduced by using inaccurate vegetation maps and the inferior statistical methods employed are not the only problems with the H&O analysis. There are additional potential sources of error (see Table 1), which interact and ultimately make discrete identification of a single central problem impossible. As a result, we see no value in performing a re-analysis of their data. Rather, we devote our analysis to investigating the possibility that H&O biased their analyses by including prescribed fires, and fires that occurred on private lands mapped with extended assessments or with immediate post-fire satellite images (so-called ‘initial assessments’; http://www.fs.fed.us/postfirevegetationcondition/index.shtml). Therefore, unlike the MTBS database, our database includes assessments for some fires derived from post-fire images that do not reflect effects from salvage logging. Our database also contains many 80–400-ha wildfires that MTBS or RAVG did not map. For this manuscript, we use our fire severity data for fires that occurred on FS and private lands within the SNPE area 1984–2010. As in the Miller and colleagues studies, we used data calibrated to the Composite Burn Index, where the high-severity category is equivalent to ~95% change in canopy cover (Key and Benson 2006; Miller et al. 2009b). We also used perimeters mapped by MTBS for all fires (wildfires and prescribed fires) that occurred in the SNPE area between 1984 and 2010. We corrected two fires that MTBS mapped in the wrong years (1985 Bierceburg and 1999 Lake), and we reattributed three fires as fire-use fires (commonly known as Wildland Fire Use (WFU), where naturally ignited fires are allowed to burn under management rather than being immediately suppressed) that MTBS had mis-identified as prescribed fires (1987 Campbell, 2006 Frog and 2010 Sheep).

Ownership data

We stratified severity data by ownership with FS ownership data for fires that occurred within National Forest boundaries. For areas outside National Forests, we used data from the California Department of Forestry and Fire Protection and Resource Assessment Program (http://frap.fire.ca.gov/index.php).

Analyses

Severity in initial and extended assessments

To determine whether extended assessments overestimate severity on private lands, we ran four paired t-tests. We compared percentage high severity on private lands v. FS lands (one t-test using extended and the other initial assessments), and initial v. extended assessments on private lands or FS alone. We only included fires that occurred on both private and public
lands. We did not analyse fires that had less than 10 ha on either jurisdiction to minimise errors due to misalignment of the ownership and/or severity data. Percentage data were arcsine-square root-transformed to meet normality assumptions (all Kolmogorov–Smirnov tests $P > 0.06$).

**Area burned by fire type and ownership**

We stratified the perimeters of fires mapped by MTBS (www.mtbs.gov, accessed 23 October 2013) by year, ownership (FS, NPS, private), fire type (prescribed, wildfire, WFU), and forest type as mapped with CALVEG77. Dividing the period roughly in half (1984–1997 and 1998–2010), we performed two-sample $t$-tests to determine whether more area was burned in wildfires and WFU fires in the second half of the study period. Area data were first square root-transformed to meet normality assumptions (all Kolmogorov–Smirnov tests $P > 0.15$).

**Results**

**Severity on private lands**

The proportion of high-severity fire in extended assessments was significantly higher on private lands than FS lands, but not in initial assessments (Table 2). On private lands, severity in initial assessments was significantly lower than extended assessments. There was no difference between assessments on FS lands.

**Area burned by ownership and fire type**

FS, private and NPS lands accounted for the largest amount of area burned in wildfires, WFU fires and prescribed fires (Table 3). Although prescribed fires account for a small portion of the area burned, there were 2 years late in the time series (2005 and 2006) when the area burned in prescribed fires was substantial (41 and 34% respectively; Fig. 1). Area burned in wildfires and WFU fires on private and NPS lands was relatively constant over the 1984–2010 period, but average annual area burned increased on USFS lands, although not significantly at $z = 0.05$ (Fig. 2). Dividing the 1984–2010 period in half, the area burned on USFS lands in the second half of the period is significantly higher ($P = 0.045$, Table 4). The area burned on private and NPS lands was unchanged between periods. When the three jurisdictions were combined, the difference in total area burned between the first and second halves of the period was not significant.

**Discussion**

Our results demonstrate some of the possible sources of error associated with H&O’s analyses (plus see Table 1). At least two other issues worth discussing could either have contributed to H&O not identifying trends or confuse the interpretation of the actual effects described by the high-severity data.
First, H&O combine forest types into three unorthodox regional groupings that conjoin very different presettlement fire regime characteristics. One example is the combination of mixed conifer–fir with red fir in their ‘western mid-upper montane’ group. The boundary between high-elevation mixed conifer and red fir is a very important ecotone in the Sierra Nevada, as it coincides with the approximate elevation of freezing in mid-winter storms and the elevation of the deepest winter snowpack. Multiple authors have brought attention to major ecological changes that accompany the transition from mixed conifer to red fir, and these include fire regime (Kilgore 1971; Barbour et al. 2002, 2007; Sugihara et al. 2006; Safford and Van de Water 2013). Mixed conifer–fir supported

Table 4. Comparison of mean area burned in wildfires and wildland fire use (WFU) fires during the first and second halves of 1984–2010 by ownership

<table>
<thead>
<tr>
<th>Owner</th>
<th>Mean area burned per year 1984–97 (ha)</th>
<th>Mean area burned per year 1998–2010 (ha)</th>
<th>Two-sample t-test P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>USFS</td>
<td>10004</td>
<td>18016</td>
<td>0.045</td>
</tr>
<tr>
<td>Private</td>
<td>4337</td>
<td>4246</td>
<td>0.406</td>
</tr>
<tr>
<td>NPS</td>
<td>3096</td>
<td>3014</td>
<td>0.310</td>
</tr>
<tr>
<td>Total</td>
<td>18093</td>
<td>26069</td>
<td>0.109</td>
</tr>
</tbody>
</table>

First, H&O combine forest types into three unorthodox regional groupings that conjoin very different presettlement fire regime characteristics. One example is the combination of mixed conifer–fir with red fir in their ‘western mid-upper montane’ group. The boundary between high-elevation mixed conifer and red fir is a very important ecotone in the Sierra Nevada, as it coincides with the approximate elevation of freezing in mid-winter storms and the elevation of the deepest winter snowpack. Multiple authors have brought attention to major ecological changes that accompany the transition from mixed conifer to red fir, and these include fire regime (Kilgore 1971; Barbour et al. 2002, 2007; Sugihara et al. 2006; Safford and Van de Water 2013). Mixed conifer–fir supported
dependent and independent variables, and then use the
presettlement fire return intervals (FRIs) that were much more
similar to mixed conifer–pine than to red fir (mean FRIs
of 11, 16, and 40 years for mixed conifer–pine, mixed conifer–
red fir have missed fewer fires and have less departed from
Euroamerican conditions, whereas higher-elevation forests like
mixed-conifer forests are burning at much higher severities today than under pre-
Euroamerican conditions, whereas higher-elevation forests like
red fir have missed fewer fires and have less departed from
presettlement conditions (Mallek et al. 2013; Safford and Van
Water 2013). A further example of ill-advised vegetation
grouping is H&O’s ‘eastern montane’ group, which is a com-
posite of different forest types and fire regimes, with presettle-
mortality and field-collected percentage basal area (BA) change values for plots in
Sierra Nevada and Klamath region of California (Miller et al. 2009a).

<table>
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<tr>
<th>Threshold variable and value</th>
<th>RdNBR</th>
<th>% BA mortality</th>
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<tr>
<td>% BA mortality ≥ 70%</td>
<td>791</td>
<td>97 70 100</td>
</tr>
<tr>
<td>% BA mortality ≥ 75%</td>
<td>802</td>
<td>98 75 100</td>
</tr>
<tr>
<td>RdNBR ≥ 574^</td>
<td>849</td>
<td>86 0 00</td>
</tr>
<tr>
<td>RdNBR ≥ 641</td>
<td>886</td>
<td>89 0 00</td>
</tr>
<tr>
<td>RdNBR ≥ 800</td>
<td>972</td>
<td>94 0 00</td>
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^A An RdNBR value of 574 is the regression value for BA mortality of ≥75%
(Miller et al. 2009b).

H&O overestimate the amount of area burned at high
severity on private lands by using MTBS extended assessments
(Table 2). As the percentage of area burned on private lands in
comparison with FS lands is greater at the beginning of the
time period (Fig. 2), it is likely that H&O overestimate severity
early in the time series. Compounding the likely overestimation
early in the time series, H&O also likely underestimate severity
late in the time series by including prescribed fires (Fig. 1).
Merely combining private and NPS lands with FS lands could
mask a significant trend (e.g. Table 4). Coupled with the use of
statistical techniques with low predictive power, their highly
inaccurate and very coarse-scale vegetation data, and aggregat-
ing vegetation types into groupings that include highly disparate
historical fire regimes contribute to considerable uncertainty in
the conclusions they draw. Given the high number of error
sources (Table 1), it is impossible to say which issue contributed
most to the inability of H&O to identify any trends.

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