Post-Wildfire Logging Hinders Regeneration and Increases Fire Risk

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Recent increases in wildfire activity in the United States have intensified controversies surrounding the management of public forests after large fires (*1*). The view that postfire (salvage) logging diminishes fire risk via fuel reduction and that forests will not adequately regenerate without intervention, including logging and planting, is widely held and commonly cited (*2*). An alternate view maintains that postfire logging is detrimental to long-term forest development, wildlife habitat, and other ecosystem functions (*1*). Scientific data directly informing this debate are lacking.

Here we present data from a study of early conifer regeneration and fuel loads after the 2002 Biscuit Fire, Oregon, USA, with and without postfire logging. Because of the fire's size (~200,000 ha), historic reforestation difficulties in the region (*3*), and an ambitious postfire logging proposal, the Biscuit Fire has become a national icon of postfire management issues. We used a spatially nested design of logged and unlogged plots replicated across the fire area and sampled before (2004) and after (2005) logging (*4*).

Natural conifer regeneration on sites that experienced high-severity fire was variable but generally abundant, with a median stocking density of 767 seedlings per hectare, primarily of Douglas fir (*Pseudotsuga menziesii*) (Fig. 1A). Such density exceeds the regional standards for fully stocked sites, suggesting that active reforestation efforts may be unnecessary. Postfire logging subsequently reduced regeneration by 71% to 224 seedlings per hectare (Fig. 1A) due to soil disturbance and physical burial by woody material during logging operations. Thus, if postfire logging is conducted in part to facilitate reforestation, replanting could result in no net gain in early conifer establishment.

Postfire logging significantly increased both fine and coarse downed woody fuel loads (Fig. 1B). This wood was composed of unmerchantable material (e.g., branches), and far exceeded expectations for fuel loads generated by postfire logging (*4*, *5*). In terms of short-term fire risk, a reburn in logged stands would likely exhibit elevated rates of fire spread, fireline intensity, and soil heating impacts (*6*).

Postfire logging alone was notably incongruent with fuel reduction goals. Fuel reduction treatments (prescribed burning or mechanical removal) are frequently intended after postfire logging, including in the Biscuit plan, but resources to complete them are often limited (*7*). Our study underscores that, after logging, the mitigation of short-term fire risk is not possible without subsequent fuel reduction treatments. However, implementing these treatments is also problematic. Mechanical removal is generally precluded by its expense, leaving prescribed burning as the most feasible method. This will result in additional seedling mortality and potentially severe soil impacts caused by long-duration combustion of logging-generated fuel loads. Therefore, the lowest fire risk strategy may be to leave dead trees standing as long as possible (where they are less available to surface flames), allowing for aerial decay and slow, episodic input to surface fuel loads over decades.

Our data show that postfire logging, by removing naturally seeded conifers and increasing surface fuel loads, can be counterproductive to goals of forest regeneration and fuel reduction. In addition, forest regeneration is not necessarily in crisis across all burned forest landscapes.

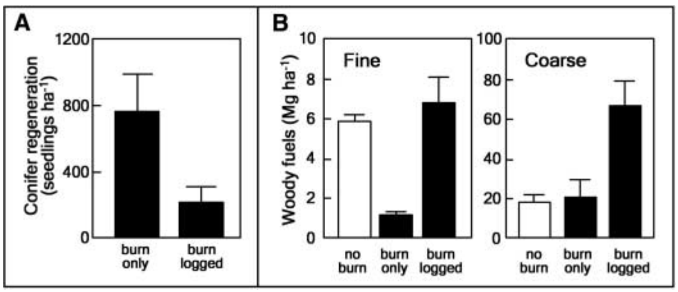

Fig. 1. (**A**) Natural conifer regeneration and (**B**) surface woody fuel loads before and after postfire logging of the Biscuit Fire, Oregon, USA. (A) shows that regeneration was abundant after the fire. Postfire logging significantly reduced seedling densities ($P < 0.01$, Wilcoxon signed rank test) from 767 seedlings per hectare to 224 seedlings per hectare. (B) shows that postfire logging significantly increased downed fine ($P < 0.01$) and coarse ($P < 0.05$) woody fuel loads (Mg ha^{-1}) relative to burn-only fuel loads by Wilcoxon signed rank test. To provide context, fuel data from unburned stands are shown as reference for prefire conditions (fuel loads in burn-logged stands were at or well above prefire levels). Graphs of seedling densities and fine (≤7.62 cm) and coarse (>7.62 cm) surface woody fuels are medians ± SE; sample size $n = 8$ stands for no burn, $n = 9$ for burn-only and burn-logged (*4*).

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Supporting Online Material for

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Abstract

We present data from a study of early conifer regeneration and fuel loads following the 2002 Biscuit Fire, Oregon, USA, with and without postfire logging. Natural conifer regeneration was abundant after high-severity fire. Postfire logging reduced median regeneration density by 71%, significantly increased downed woody fuel loads, and thus short-term fire risk. Postfire logging can be counterproductive to the goals of forest regeneration and fuel reduction.

Materials and Methods

We used a before-after/control-intervention (BACI) design to capitalize on pre- (2004) and post-(2005) treatment data and to account for interannual variation in responses. While the Biscuit Fire area includes a broad range of biophysical conditions, this study focused on stand types relevant to postfire logging: mature mixed-conifer stands that experienced high severity fire (>95% overstory tree mortality). Sampled burn stands were spatially nested within "sites," defined by proximity (500-1000 m) and similar topographic/soil characteristics, and measured before logging. The five sites were separated by $\geq$3 km. Stands were sampled using one-hectare plots that included four systematically-placed 75-m transects for downed wood using the planar intercept method (*S1*); conifer seedlings were concurrently sampled in four 75-m x 1-m belt transects. In each site, logging occurred in some but not all stands; selection was determined largely by land-use designations and socio-political influences rather than ecological boundaries. All stands were re-measured after logging. Unburned mature forest stands with similar stand characteristics and adjacent to the fire area were sampled as a reference only for pre-fire conditions. Nonparametric statistical tools (Wilcoxon signed rank tests, rank sum tests) were used for comparisons. Analyses for effect of logging were carried out using paired tests of pre- and post-treatment data for logged stands only. Time and space effects were assessed by comparing data from unlogged stands through time and against data from logged stands. Logged and unlogged stands were not significantly different prior to treatment ($p>0.10$ by rank sum test), and unlogged stands did not change significantly between years ($p>0.10$ by Wilcoxon signed rank test). Standard errors (SE) for graphical presentation were computed by back-transforming log scale mean SE.

Supporting Text

It has been thought that any pulse of unmerchantable woody materials on the ground resulting from postfire logging would be negligible due to consumption of fine materials in the initial fire (*S2*). However, our measurements show that <10% of woody biomass was consumed in the Biscuit Fire. In addition, a key difference between postfire logging and green tree harvest is that merchantable wood volume is generally lower in fire-killed trees due to burning, desiccation, decay, and lack of "crown sail" to lessen impact during falling. This difference results in comparatively high levels of unmerchantable large woody material left on the ground. Administrative delays in postfire planning can exacerbate decay levels, but in the case of the Biscuit Fire, logging commenced 2 years after fire at which time decay has been found to affect only ~10-15% of merchantable wood volume in this region (*S3*). Thus the difference in merchantability is not solely due to time since fire and is partly intrinsic to any dead-tree harvest.

While our data show postfire logging increased short-term fire risk, it has been suggested that overall removal of woody material by logging reduces longer-term fire risk (*S2*). This hypothesis merits study. An important consideration is that contribution of woody fuel loads to potential fire behavior can be especially important during early stages of forest development, when low-profile vegetation structure renders stands more prone to mortality from fire (*S4*). If postfire logging would achieve longer-term fuels reduction, it would do so in intermediate-aged stands in which susceptibility is lower, while compounding higher risk in young stands.

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The abstract was edited to remove mention of the pending legislation.

Comment on "Post-Wildfire Logging Hinders Regeneration and Increases Fire Risk"

M. Newton,[1] S. Fitzgerald,[2] R. R. Rose,[1] P. W. Adams,[3] S. D. Tesch,[3] J. Sessions,[3]* T. Atzet,[4] R. F. Powers,[5] C. Skinner[5]

Donato *et al*. (Brevia, 20 January 2006, p. 352) concluded that logging after wildfire kills natural regeneration and increases fire risk. We argue that their paper lacks adequate context and supporting information to be clearly interpreted by scientists, resource managers, policy-makers, and the public.

Donato *et al*. (*1*) recently concluded that logging 2 to 3 years after wildfire kills natural regeneration and increases fire risk. The research may make a valuable contribution, but the study lacks adequate context and supporting information to be clearly interpreted. Here, we discuss the paper's methods and conclusions in the context of relevant management objectives and the forestry knowledge base concerning natural regeneration processes, mortality from logging, and fuel accumulations in southwestern Oregon and northwestern California.

Donato *et al*. (*1*) made inferences about natural regeneration processes, mortality from logging, and fuel accumulations without presenting key information regarding (i) agency postfire management directives for reforestation or downed wood levels (*2*), (ii) implications of delays in postfire plan implementation, or (iii) important environmental and disturbance descriptors such as plant associations, fire intensity, seed tree proximity, and weather patterns. Results from their study cannot be readily extrapolated because it was a short-term observational study of site-specific forest operations governed by agency management objectives. Other management plans, operations, or conditions could yield different results (*3*). In the case of the 2002 Biscuit Fire, logging was postponed for 2 years, allowing more seeds to germinate and increasing seedling exposure to injury during logging (*4*).

Donato *et al*. cite a lack of scientific data regarding the management of public forests after large fires. However, it should be noted that conifer reforestation (planted and natural) and vegetation ecology have been widely studied in the region. Studies show variable responses with plant association, competing vegetation, local climate, soils, and other factors (*5*, *6*). Hobbs *et al*. (*5*) provide a synthesis of 13 years of research in southern Oregon and northern California. Fewer studies have examined reforestation after wildfire, especially over longer periods (*4*, *7*–*9*), but damage to natural regeneration after delayed salvage logging was reported more than 50 years ago (*4*, *8*).

Donato *et al*. (*1*) reported that natural conifer regeneration on sites affected by the Biscuit Fire was common, without also describing proximity to recent seed crops, weather, and competing vegetation, and further suggested that planting may be unnecessary to achieve some reforestation goals. Caution is urged when projecting forest development from such early conifer survival results. Competing vegetation can develop rapidly after disturbance in this region and can dramatically affect small conifer seedling survival and growth (*5*–*7*). Agency reforestation objectives were to establish a minimum number of suitable conifer trees in "free to grow" condition (*2*). Given the documented competitiveness of shrubs and hardwoods, as well as the historical variability in natural regeneration success, federal managers specified tree planting after salvage to better ensure the desired density and distribution of conifers (*2*). Artificial reforestation practices are science-based and well tested in southwestern Oregon and northwestern California (*3*, *5*, *7*). Performance of planted seedlings also commonly exceeds that of natural seedlings, which will assist in achieving some objectives (*5*, *7*, *10*).

It is also inappropriate to compare the 1- to 2-year-old seedling density measured in (*1*) with "free to grow" stocking standards prescribed under state regulations (*11*) and federal fire-recovery goals (*2*). Such standards are always defined at an older age or larger size after early seedling mortality stabilizes. Related protocols for conducting stocking surveys are designed to estimate both seedling density and distribution (*12*). The belt transects used by Donato *et al*. (*1*) also differ from systematic plot grids widely used in forestry stocking surveys to determine the "number of well-distributed trees per unit area." Therefore, their reported results cannot be directly compared with regional stocking standards (*2*, *11*, *12*), because there is no indication of spatial distribution.

We also note that the term "logging" used in (*1*) is not adequately descriptive (*13*). Logging prescriptions provide a flexible silvicultural tool with capabilities and impacts that vary by equipment, management objectives, and site-specific conditions (*4*, *5*). Seedling protection was not prescribed in the postfire harvests studied in (*1*) because prompt salvage and subsequent planting were planned (*2*). Logging plans can be designed to limit damage to seedlings when desirable (*4*, *5*). Notably, the seedling damage reported by Donato *et al*. cannot be extrapolated without improved descriptions of the logging or follow-up slash treatments (*5*, *7*, *13*).

Turning to the data presented on fuel loads after the Biscuit Fire, Donato *et al*. reported increased "fire risk" as a consequence of increased downed woody fuels. However, what they actually assessed was fuel quantity in two fuel size classes. Moreover, they did not describe fuel continuity, a major factor contributing to fire behavior, nor did they present approximate differences in projected fire behavior, which can be determined using standard fire models (*14*, *15*). Conclusions suggesting that future fire hazard is less from deteriorating standing trees than from observed postlogging slash are unsupported speculation as presented. Management directives specifically included leaving logging slash for soil protection and wildlife habitat in areas deficient in downed wood as a function of plant association, topographic aspect, and fire intensity (*2*). On some sites, the observed increases in slash after logging may have been an intended result of the prescriptions, but Donato *et al*. provide insufficient information to discern this.

We believe the Donato *et al*. paper (*1*) could have better informed the discussion of this complex topic for all audiences with a more accurate title, use of standard forestry protocols, more complete disclosures of methods and management objectives, and less speculation beyond the presented data. If the authors were constrained by print space limitations, we urge them to use alternative mechanisms to disclose details critical to understanding and interpreting their results.

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Comment on "Post-Wildfire Logging Hinders Regeneration and Increases Fire Risk"

B. N. Baird

Based on limited sampling 2 years after the 2002 Biscuit Fire in Oregon, Donato *et al.* (Brevia, 20 January 2006, p. 352) concluded that postfire logging reduced seedling regeneration by 71%. Analysis of the study methodology and raw data suggest that this estimate is statistically flawed and misleading and says nothing about the impacts of more prompt postfire harvest.

Donato *et al.* (*1*) reported results from small sections of forest studied 2 years after the 200,000-ha 2002 Biscuit Fire in central Oregon. They cited data collected over a 1-year interval comparing conifer seedling survival and woody debris remaining before and after logging and in control sites that were left unharvested. Based on this limited spatial and temporal snapshot, the authors offered a quantitative estimate of the effects of salvage logging that is potentially misleading and statistically unsound. Their conclusions also fail to consider the potential beneficial or adverse effects of harvest conducted much more promptly after fire, a practice that is commonplace on lands throughout the Pacific Northwest.

Donato *et al.* reported that postfire logging reduced seedling regeneration by 71%, but the methods they used to arrive at this figure are questionable. Close inspection of the raw data [see table 1 in (*2*)] reveals that Donato *et al.* arrived at their 71% figure by comparing preharvest values from one plot with postharvest values obtained in a completely different plot. Absent other information about plot selection or characteristics, it is inappropriate to compare pre- and postharvest values from different plots and attribute causation entirely to logging or to suggest that this one comparison is indicative of logging effects in general. The validity of the 71% figure is further vitiated by the broad range of percent changes in seedling survival across both logged and unlogged plots [table 1 in (*2*)]. In five of the seven unlogged sites, substantial seedling loss, as great as 56%, occurred, perhaps due to factors such as heat mortality or grazing. Thus, even when pre- and posttreatment measures are assessed for the same plots, it is misleading to attribute the entirety of seedling reductions observed over a 1-year period to harvest alone, because some mortality would likely have occurred in the absence of harvest.

There are also questions about the appropriateness of the statistical tests employed in this study. Donato *et al.* tested the significance of their results using the Wilcoxon signed rank test. In doing so, they failed to use a multivariate, repeated measures statistical procedure when they have clearly followed a multivariate research design. By using two or more univariate tests, the Donato *et al.* analysis erroneously inflates the error rate. When a more appropriate Between-Within Repeated Measures Analysis of Variance is performed comparing condition (i.e., unlogged versus logged) by time, the results fail to achieve significance

Although there are a number of ways the data presented in (*1*) could be analyzed, Donato *et al.* drew their conclusions based on very small data sets assembled over a short period of time and using methodologies that cannot sustain the sorts of causal statements made by the authors. Assessments about the ecological importance of postfire logging based on such limited sampling and narrow study design should therefore be considered with due caution. Furthermore, results of this study should not be used to make broad inferences about the impacts of other postfire harvest practices on forest health and recovery.

U.S. House of Representatives, 1421 Longworth House Office Building, Washington, DC 20515, USA.

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Response to Comments on "Post-Wildfire Logging Hinders Regeneration and Increases Fire Risk"

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We reported that postfire logging 2 to 3 years after the 2002 Biscuit Fire was associated with significant mortality in natural conifer regeneration and elevated potential fire behavior in the short term as a result of increased surface fuel loads. We underscore the strength of our study design and statistical conclusions, provide additional details of the research setting and scope, and address comments pertinent to forest development and fire ecology.

Although Newton *et al*. (*1*) and Baird (*2*) provide no compelling evidence to refute our findings, we are pleased with the opportunity for dialogue and to expand on our article (*3*). We respond by underscoring the strength of our study design, providing additional details of the research setting and scope, and addressing comments pertinent to forest development and fire ecology.

Study background. We reported that postfire logging (salvage) 2 to 3 years after the 2002 Biscuit Fire was associated with significant mortality in natural conifer regeneration and elevated potential fire behavior in the short term due to increased surface fuel loads (*3*). Our study design has robust inferential power (*4*), and the data strongly support these straightforward conclusions, as verified by independent statistical evaluations (*5*, *6*).

Our scope of inference (*3*) is the salvage of the Biscuit Fire [see (*4*) for study details]. Areas sampled were typical of portions of the Biscuit Fire designated for salvage (*4*). Responses to postfire logging may vary between and within fires, forest types, and technique/timing of logging. Similar patterns of seedling damage/reduction resulting from postfire logging operations have been documented across a range of conditions (*7*–*11*), which may be because postfire logging is often conducted under the presumption of negligible natural regeneration and is therefore not designed to protect it. The logging techniques on which we reported (hand-felling with helicopter yarding >2 years postfire) occur on public lands throughout the western United States.

The hypothesis that prompt postfire logging could have different effects merits study. Currently, there are no data comparing effects of early versus delayed logging operations (*12*) and, to date, the few relevant studies of prompt postfire logging have also reported reductions in seedling densities (*7*, *8*). More field data are needed to elucidate the range of potential effects under different conditions and prescriptions.

Short-term data from well-designed studies, such as (*3*), are important in providing benchmarks for long-term studies and isolating the mechanisms through which management affects forest processes. To date, the few longer term studies of postfire logging (*13*) have been confounded by multiple postfire treatments (e.g., logging, fuel treatment, replanting). A review of postfire management studies (*12*) states, "when treatments involve logging as well as other site preparation measures, it is impossible to distinguish the specific causative factor behind any observed vegetation change." We maintain that research on postdisturbance management effects will be most valuable when each treatment is studied as a distinct variable [e.g., (*3*, *14*)].

Early regeneration. Although various reforestation practices after live tree harvest in southwest Oregon have been well studied (*1*, *15*), natural post-wildfire regeneration remains far less studied in the region. Postfire conditions differ substantially from conditions following live tree harvest in several important ways [e.g., (*16*, *17*)], including seedbed qualities, legacy structure, and stress seed crops. Thus, we caution against extrapolating knowledge from postharvest studies to natural post-wildfire regeneration.

Early regeneration data provide insight into important processes, including seed production, dispersal, germination, and early survival. The relation between short-term effects of postfire logging on these processes (*3*) and long-term recruitment patterns (*1*, *18*, *19*) is key to understanding the legacy of logging effects on stand development. Conifer regeneration following wildfires can be limited during two phases: (i) initial establishment due to seed source deficiency in large burned areas, and (ii) subsequent competition, survival, and release. We reported on the former, not the latter. This is important in light of uncertainties regarding the degree to which this first phase would occur in high-severity portions of the Biscuit Fire (*20*, *21*). We did not draw further conclusions about long-term effects of postfire logging (*3*). Relevant long-term data from replicated experiments do not exist (*12*).

Postfire succession in mixed-evergreen forests of the Klamath-Siskiyou region (which covers much of southwest Oregon and northwest California), is characterized by a period during which broadleaf vegetation forms a substantial overstory component (*19*). Several authors have suggested that, in the presence of shrub competition, early conifer establishment is especially important in attaining eventual conifer dominance (*15*, *20*, *22*). Alternatively, current studies indicate a variable, protracted conifer regeneration period in this region, with peak establishment generally within 5 years of fire and persistence in the presence of broadleaf species (*18*). Under either scenario, establishment of seedlings 2 to 3 years after fire represents an important period of succession in the Klamath-Siskiyou region. Subsequent competition from broadleaf vegetation has been shown to occur with or without postfire logging (*13*) and is therefore a related but separate issue from the results of our study (*3*).

With respect to regional stocking standards (*23*), we followed federal definition M, which states that a suitable tree (capable of meeting forest management objectives) "may qualify as a component of the stand by having survived at least one growing season in the field." The vast majority of seedlings we reported had been present for at least two growing seasons by 2005 (*24*). Regional stocking standards include prescriptions for density and distribution (*1*, *23*). We reported data pertinent to density standards, quantified at the hectare scale using an effective method (*4*) and assessed for variability at the treatment scale (across logging units) rather than within each logging unit. Traditional stocking surveys (*1*) were not our intent. We indicated that the median density we quantified exceeded that found in adequately stocked sites per the Biscuit management plan [since sites must be stocked at a minimum density (*23*)]. This was a benchmark for comparison and not a conclusion regarding stocking per se, which is quantified differently. Because much of the Biscuit salvage was planned in land use allocations for which very low densities and variable spacing were prescribed (*25*), we suggest that stand level density is an important parameter relative to other stocking standards.

Fuel dynamics. Although fuel composition, arrangement, and continuity are all important variables contributing to potential fire behavior, a predominant factor affecting behavior of the flame front is the mass of fine downed wood (*26*, *27*). We reported an increase by a factor of about 5 in fine downed wood as a result of postfire logging (*3*), which suggests that

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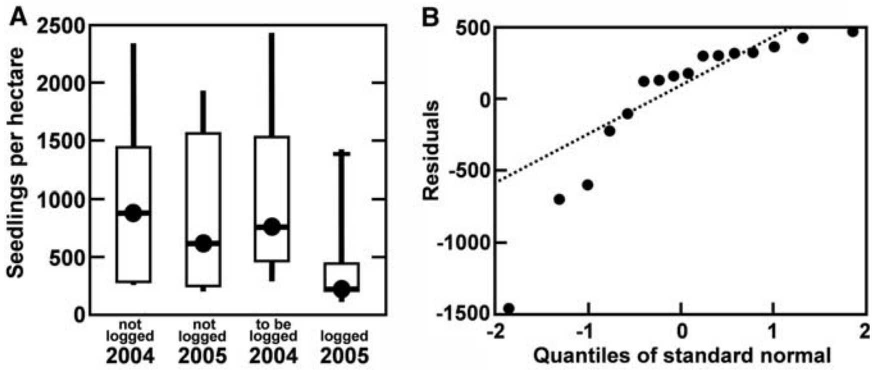

Fig. 1. (**A**) Box-and-whisker plots of Biscuit Fire seedling data (seedlings per hectare) from (*3*) and (**B**) residuals from parametric test [analysis of variance (ANOVA)] on interannual changes in untransformed seedling data, as in (*2*). (A) shows tendency toward positive skewness (typical for ecological count data) for all groups and unequal variance, as well as marked difference between the 2005-logged sample compared with other samples. Dot within box is the median; box edges are the 25th and 75th percentiles; whiskers represent the data range; points beyond 1.5 times the interquartile range from the quartiles are drawn as horizontal lines across the whisker. Shapiro-Wilk normality test (*32*) indicates lack of normality: W = 0.7173, $P = 0.0023$ for 2005-logged plots. (B) shows that parametric ANOVA tests on untransformed data, as in (*2*), are prone to spurious results for the seedling data due to substantial departure from normality (Shapiro-Wilk normality test: W = 0.7226, $P = 0.0026$ for annual change in density between years in logged plots). Analyses after data transformations or nonparametric analyses are highly preferred (*31*).

Table 1. Seedling densities for each of the 16 burn plots before and after logging treatment. The following are test statistics and one-tailed *P* values from multiple analytical methods of testing the hypothesis that the reduction in seedling density in logged plots exceeded interannual variation in unlogged plots. Rank sum test on percentage change in each plot: W = 53, $P = 0.006$; rank sum test on untransformed (raw) changes: W = 60, $P = 0.045$; two-sample *t* test on percentage change in each plot: $t_{14} = 3.15$, $P = 0.004$; two-sample *t* test on changes in $\log_e$-transformed densities: $t_{14} = 2.70$, $P = 0.009$; two-sample *t* test on untransformed (raw) changes: $t_{14} = 1.52$, $P = 0.075$ [to our understanding this is equivalent to the analysis of Baird (*2*); see also Fig. 1B]. One-tailed tests are logically appropriate because, given the time frame of study as well as the timing of logging relative to the interannual and seasonal timing of regeneration, the immediate effect of logging on seedling densities (if different from zero) would be a reduction (*7*–*10*).

	Seedlings per hectare		
Plot	2004	Treatment	2005
1	298	logged	164
2	471	logged	221
3	767	logged	454
4	576	logged	141
5	407	logged	217
6	1534	logged	224
7	2423	logged	349
8	1697	logged	1388
9	1137	logged	646
10	288	unlogged	220
11	622	unlogged	747
12	300	unlogged	260
13	888	unlogged	584
14	1448	unlogged	1566
15	1425	unlogged	626
16	2349	unlogged	1924

salvaged environments are predisposed to fires of greater intensity than unsalvaged sites in the near term. Fire behavior modeling of different salvage/fuel-treatment scenarios, parameterized with field data, will best characterize potential fire behavior in postfire settings. However, standard fire behavior models [e.g., (*26*)] do not include fuel continuity as an independent variable and therefore assume similar connections between fuel loads and fire behavior.

One of the primary purposes of the Biscuit management plan was to reduce the "risk" of high intensity and/or stand replacement fire (*21*); thus, we presented our results relative to this objective (*28*). Prescriptions also called for broad ranges of downed wood levels for soil function and habitat (*21*). Our observation was that downed wood levels following logging were variable relative to prescriptions, often as much a function of inherent, localized felling and handling practices as they were reflective of any specific prescription. Regardless, our research quantified higher postsalvage fuel loads, which are associated with higher potential fire behavior, thus adding empirical field data to what has only been modeled thus far (*29*).

Given the observed pulse of surface fuels after logging and its potential effects on surface fire behavior, our suggestion that leaving woody material (dead trees) standing could result in lower fire hazard is a reasonable hypothesis. Surface fuel loads derived from fire-killed trees are determined by the dynamic balance between inputs (from the canopy) and outputs (decomposition). As such, no scenario produces a larger pool of fine (up to 7.62 cm) and 1000-hour [7.62 to 20.32 cm (*19*)] fuels than a single one-time input from clearfelling shortly after a fire.

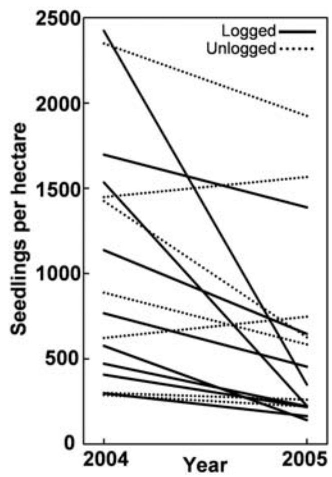

Fig. 2. Changes in seedling densities between 2004 and 2005 for logged and unlogged plots, with logging occurring between measurement periods. Equivocal variation between years can be seen in the unlogged plots (no consistent trend), whereas logged plots all show marked declines.

Long-term interactions between these inputs and live fuel succession are poorly understood, especially for the largest fuel size classes. As we stated in (*3*), hypotheses regarding long-term fire potentials merit study [see (*30*)].

Statistical analysis. All appropriate, conservative methods for analyzing our data yield robust, biologically and statistically significant effects (*3*, *5*, *6*). These methods employ either nonparametric analyses that do not require normality or equal variance, or a common transformation ($\log_e$) to more closely meet assumptions of parametric tests [Fig. 1 and (*31*)]. Parametric tests on untransformed data, as in (*2*), are prone to spurious results due to substantial departure from normality and unequal variance (Fig. 1).

Baird's (*2*) description of our analysis is misleading. Repeated measures are irrelevant because we did not assume independence of 2004 and 2005 measurements within each plot (Table 1). We intended to quantify annual change within plots. In addition, our descriptive estimate of the sample-wide change in logged plots between years was a 71% decline in the sample median, which does not arise from analysis of any particular plot. Rather, the median is a conservative measure of central tendency for the entire sample before and after logging, providing descriptive information at the broader, treatment-wide level.

Because the sample of unlogged plots showed no consistent or statistically significant pattern in changes in seedling density over time (Fig. 2 and Table 1) (*3*, *6*), and new in-seeding as well as mortality was occurring [see (*18*)], the statistically significant change in logged plots was attributed to logging. Analyses that include the variation observed in the unlogged sample also yield findings of significant logging effects that differ only in the point estimate of effect magnitude (Table 1) (*5*, *6*).

Independent statistical evaluations of our data support the conclusions of significant effects of postfire logging on seedling regeneration and fuels (*5*, *6*). As stated in one such review, "Although there can be differences of opinion on methods of analysis, all reasonable methods will lead to congruent conclusions" (*5*).

The study design, results, and conclusions presented in (*3*) are strong, relevant, and straightforward. Newton *et al*. (*1*) and Baird (*2*) present different perspectives, but provide no data or evidence from other studies to contradict our findings and conclusions. A short-format paper such as ours is not intended to review or explore every angle but to present key data that will stimulate discussion and further research. We hope our research findings and comments provide direction for future studies and management.

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24. Such seedlings count toward meeting standards for density/distribution, even before a stand is "accepted" as beyond the juvenile stage [see definition P in (*23*)].
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33. This manuscript benefited from reviews by statisticians L. L. Conquest, A. Gitelman, E. A. Housworth, M. M. P. Huso, P. Murtaugh, and F. L. Ramsey, as well as several colleagues and five anonymous reviewers. This work was supported by the Joint Fire Science Program and DOE grant DE-FG02-04ER63917. The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the opinions or policies of the U.S. Government. Mention of trade names or commercial products does not constitute their endorsement by the U.S. Government.

Supporting Online Material

www.sciencemag.org/cgi/content/full/313/5787/615/DC1
Materials and Methods
References

20 March 2006; accepted 7 July 2006
10.1126/science.1126583

www.sciencemag.org/cgi/content/full/313/5787/615c/DC1

Supporting Online Material for

Response to Comments on "Post-Wildfire Logging Hinders Regeneration and Increases Fire Risk"

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This PDF file includes:

Supporting Online Material

Study Design. We (S1) employed a replicated BACI (Before-After/Control-Intervention) design to assess the immediate impacts of salvage logging on the density of naturally seeded conifers and woody surface fuels. Conifer seedlings and fuels were sampled on 16 one-hectare plots using long, rectangular subplots oriented in systematic directions (determined *a priori*) from a random start, first in 2004 and once again in 2005. During this period, nine of the plots were logged (intervention) while seven were not logged (control). Logged and unlogged burn plots were spatially intermingled across the fire to avoid confounding landscape heterogeneity with treatment effect, and were statistically verified for pre-treatment similarity (*post facto*). Comparison of unlogged plots between years allowed us to control for time effects and attribute changes in logged plots to the effect of logging. Unburned reference plots (n=8) were presented for comparison but did not enter into statistical analyses.

A replicated BACI design offers one of the most statistically robust, inferentially powerful approaches to studying postfire management (see S2). We hope this design is applied more broadly, allowing strong inference to the effects of postfire management.

Study Location. Our study was conducted in areas of the Biscuit Fire selected by the Forest Service for potential salvage logging. Study sites were located in severely burned (overstory mortality >95%) mature to old-growth (>22.5cm DBH) Douglas-fir *(Pseudotsuga menziesii)* type conifer forests (S3). We estimate 80-90% of all salvage logging on the Biscuit Fire occurred within this condition. Study sites, and most Biscuit salvage areas, can be further characterized by: 1) dry Douglas-fir, dry white fir (*Abies concolor*), and dry to moist tanoak (*Lithocarpus densiflorus*) super Plant Association Groups (S4); 2) midslope topographic positions between 500 and 1200 m elevations; 3) generally >20^{o} slope; 4) a full range of aspects; 5) non-ultramafic soils originating from coarse-grained igneous and metamorphic/metasedimentary parent materials (S4); 6) ≤500 m from contiguous live tree seed sources. Logging techniques consisted of hand-felling with helicopter yarding, occurring 2-3 years postfire and comprising a range of harvest intensities from very few to nearly all trees felled at the scale of several hectares. Common broadleaf associates included tanoak, Pacific madrone (*Arbutus menziesii*), canyon live oak (*Quercus chrysolepis*), chinquapin (*Chrysolepis chrysophylla*), greenleaf manzanita (*Arctostaphylos patula*), Oregon myrtlewood (*Umbellularia californica*) and snowbrush (*Ceanothus velutinus*).

Regeneration Sampling Methods. Our research questions addressed hectare-scale conifer seedling density. Because naturally occurring plants typically are not randomly or uniformly distributed in space (S2), we subsampled hectare plots for seedlings using long rectangular subplots (Four 75 m x 1 m subplots) where length exceeded the scale of any sub-hectare aggregation. This technique yields more precise estimates of density than round or square subplots of the same size (S2), and subsamples a large area to maximize accuracy. This method for sampling regeneration has ample precedent in ecological studies (e.g. S5,S6) and is effective in quantifying logging effects on regeneration (S7).

Additional Details. This study represents part of a larger project examining vegetation, fuel profiles, and wildlife responses following wildfire and postfire management in the Klamath-Siskiyou region.

The study area experiences a warm-temperate, summer-dry Mediterranean climate regime (see S8,S9) in which growing season moisture can be limiting to plant growth and survival (S9,S10). Data averaged across four surrounding weather stations (Western Regional Climate Center, wrcc.dri.edu) show the following precipitation patterns for the growing seasons following the Biscuit Fire relative to 30-year averages: 2003 included a wet April and a dry May-September; 2004 (the critical first growing season [S9] for most of the reported seedlings) was dry throughout April-September; and 2005 included a wet April-June and a dry July-September. More extensive, site-specific data are needed to make detailed inferences on the relationship between climatic variability and regeneration in this topographically complex region.

Newton et al. requested information regarding fire intensity of our study areas. Fire intensity is the thermal energy released during combustion, typically reported during the flaming phase of combustion (S11). In our article we reported fire severity, clearly defined as >95% overstory mortality (S1). Because we did not observe passage of the flaming front, we would only be able to report quantitative metrics of fire severity, not intensity.

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Scorched Earth. Controversy remains over a paper that measured harm done by postfire logging

ECOLOGY

Salvage Logging Research Continues To Generate Sparks

A premier forestry department is still smoldering over a controversial paper about salvage logging. The research garnered national headlines in early January when *Science* published a paper online by researchers, including some from Oregon State University (OSU), who concluded that logging after wildfires hinders the regeneration of forests and increases the risk of further fires. The paper made headlines again a few days later when another group of OSU faculty members asked that print publication be delayed until their criticisms were addressed.

That request led to cries of attempted censorship. The group of critics, in turn, charged that the paper was politically motivated. Now, a government agency that helped fund the study has put a hold on the grant, pending an investigation. "I expected a dustup, but nothing of this scale," says Jerry Franklin of the University of Washington, Seattle, who says he reviewed the paper.

Salvage logging is a long-standing forestry practice. If a wildfire kills trees but doesn't completely burn them, logging companies will harvest those logs and plant tree seedlings. Proponents of the practice say it can accelerate forest regrowth and make forests safer for firefighters.

Environmentalists have long criticized the practice, however, charging that logging machinery tears up the soil and that hauling out the dead wood removes valuable habitat for wildlife. But not much research has been published in peer-reviewed journals on the effects of postfire salvage logging. The topic is hot now because two bills pending in Congress would make it easier for companies to do salvage logging in national forests.

Enter the *Science* paper. The research comes from an ongoing study of the 2002 Biscuit Fire, which ravaged 200,000 hectares in southern Oregon. Comparing plots before and after salvage logging finished last year, a team led by plant physiologist Bev Law of OSU Corvallis and Boone Kauffman of the U.S. Forest Service (USFS) found 71% fewer naturally sprouted seedlings in the logged plots. Much of the work was done by first author Dan Donato, a second-year graduate student. Downed branches and twigs left over from the logging increased the amount of flammable material on the forest floor by severalfold, compared to the burned but unlogged plots. The team concluded that salvage logging hinders forest recovery and actually exacerbates fire risk—a finding that contradicts assertions made on behalf of the practice.

What really stirred up controversy, however, was a letter sent to the *Science* editors on 17 January by John Sessions, a forest modeler at OSU. He and eight co-authors from the university and USFS pointed out what they considered to be serious shortcomings in the paper. They say the conclusions are preliminary and that the paper didn't put the findings into context—neglecting to describe soil moisture at the site, for example, and not spelling out that fire risk is more complex than just the amount of dead wood left behind: "We believe that the peer review process failed." The letter was reported by *The Oregonian*, the state's largest newspaper.

Their request to delay publication of the print version of the paper until these concerns were corrected, or to print them alongside the paper, struck some as meddling with peer review. "I was stunned," says OSU's Barbara Bond. The paper appeared in print on schedule (*Science*, 20 January, p. 352). "We have confidence in our peer-review decision," says *Science* Editor-in-Chief Don Kennedy. "I think it's fairly clear [the letter] was an effort to suppress a paper."

The critics deny that and charge in turn that the authors of the *Science* paper are attempting to sway the debate on the bills in Congress. Sessions points out that the online version of the paper referred to the House and Senate bills, and the Bureau of Land Management (BLM) is now investigating whether this crossed the line of using government funds for lobbying.

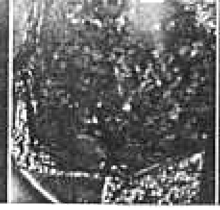
Two other facts make critics suspect politicking. One of the administrators of the grant, former BLM ecologist Tom Sensenig, now with USFS, was not informed of the paper. "It was quite a surprise to have a cooperative agreement turn into a publication that was essentially kept secret," says Sensenig, who says he disagrees with the conclusions. In addition, the paper did not get the normal review from USFS or BLM, which Sessions and Sensenig say would have removed what they perceive as political overtones. Ann Bartuska, USFS's chief of research, agrees, but she doesn't see any major problems with the paper: "It's a good piece of work that's adding to the discussion."

Donato denies any political agenda and says the authors referred to the bills to highlight the timeliness of the research. There was no intention to avoid reviews, Donato says, but he declines to elaborate on that or why Sensenig wasn't included. "It was a misunderstanding," he says. Donato says he and his co-authors will respond to technical criticisms in the peer-reviewed literature. (Sessions and his colleagues plan to submit a technical comment to *Science*.)

Meanwhile, the dean of OSU's college of forestry, Hal Salwasser, has tried to calm the waters. A first attempt backfired when some students and faculty members interpreted a memo as criticizing Donato and his co-authors. On 26 January, Dean Salwasser wrote another department-wide e-mail in which he praised the authors for having a paper accepted at *Science* and reiterated a commitment to academic freedom. "I profoundly regret the negative debate that recent events have generated," he wrote. He has set up a committee on academic freedom within the college.

Sessions isn't backing off. He says he will press the board of AAAS (*Science*'s publisher) to investigate what he sees as shortcomings in peer review. Donato is hoping to be able to concentrate on his research sometime soon. "This has dominated my waking hours," he says. "It's been really crazy."

—ERIK STOKSTAD


Fruits of earliest cultivation?
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Lineage of hobbit tools
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ACADEMIC CONDUCT

University Bids to Salvage Reputation After Flap Over Logging Paper

Five tumultuous months after controversy erupted over industry influence and academic freedom, a leading U.S. academic forestry program is struggling to restore harmony and reestablish its credibility. A faculty report issued last week describes deep divisions within the College of Forestry at Oregon State University (OSU), Corvallis, in the aftermath of a paper by graduate student Dan Donato and colleagues on the ecological effects of salvage logging: the practice of removing timber after a major fire. The college's dean, Hal Salwasser, has agreed to adopt some reforms, but fallout over the paper continues and Salwasser himself may face a no-confidence vote later this month.

Salvage logging is seen by the forest industry as a good way to encourage regrowth and reduce fire risk. But a paper, published online by this journal on 5 January, found that the heavy equipment used to remove dead trees in one southern Oregon forest had killed seedlings and left woody debris that increased fire hazard. The paper attracted national attention when other OSU researchers claimed the work was deeply flawed and asked *Science* to delay its print publication. That request was widely perceived as an attempt at censorship (*Science*, 10 February, p. 761).

Observers say the conflagration has exposed a deep divide between departments with different perspectives on forest management. Last week's report by a faculty committee on academic freedom criticized Salwasser for "significant failures of leadership" that it says worsened those divisions. The committee suggests several ways to improve governance and collegiality, including a faculty code of ethics. But observers see those as first steps on a long road to recovery. "It's a really tough situation," says forest ecologist Jerry Franklin of the University of Washington, Seattle.

Historically, colleges of forestry have been dominated by departments that favor active management to increase harvests and spur regeneration after fires, including salvage logging. That includes OSU's, which derives 12% of its budget from taxes on the logging industry in a state with highly productive forests. During the 1980s and 1990s, however, OSU and other colleges also increased their emphasis on biodiversity conservation.

But that tension isn't confined to academic circles. Responding to the *Science* paper, the U.S. House of Representatives' Committee on Resources held a field hearing in Medford, Oregon, on 24 February on a bill to facilitate salvage logging. Two of the bill's sponsors grilled Donato on his research, subjecting him to what the OSU committee's report labels "intense, sometimes hostile, questioning." Meanwhile, memos critical of the Donato article—"some quite personal in their attacks," according to the report—were anonymously posted around the College of Forestry building.

The dispute intensified in April, after a state senator subpoenaed e-mails from Salwasser's office. Those e-mails depicted the dean collaborating closely with industry to minimize the political fallout of the Donato paper. "It showed all of them working together to squash this *Science* article," says Denise Lach, an OSU sociologist on the academic freedom committee.

Salwasser says his goal was to protect students from the attacks. In other e-mails, however, Salwasser expressed contempt for environmental activists, calling them "goons" and comparing their protests to Mafia extortion. Salwasser says he now regrets those e-mails, which he calls "stupid, unthinking, unkind."

The committee agrees. It concludes that Salwasser's actions have "fostered the divisions within the college" and that the college's leadership council is too narrowly focused on industry interests. To improve the situation, the committee recommends a more diversified governing body, more transparent decision-making, a faculty code of conduct, and a possible reorganization of the college.

Although these suggestions have been greeted favorably, few expect them to resolve the underlying tension within the college. Beverly Law, Donato's adviser, says she worries that a code of conduct doesn't address the problem of bullying by some faculty members. Forest modeler John Sessions, one of the faculty members who lobbied *Science* to delay publication, says he wants access to both the field site and the data that were collected to understand the context of the study and its conclusions. But Law says that's out of the question. "It's my student's thesis, and [Sessions] is infringing on his ability to produce papers," she says, adding that plot locations are often not disclosed until a study is completed. "There has been a history of sabotaged research plots in this region." Replies Sessions, "The only thing that will satisfy me is full disclosure."

That lack of collegiality lies at the heart of the problem, according to the faculty committee. "In many ways, what we're trying to deal with is an interpersonal problem," says Lach. She and others hope that more conversations can help. But as Law notes wistfully, "I still think we have a long ways to go." A no-confidence vote is scheduled for 5 June, although the academic freedom committee has yet to decide who gets to vote.

–ERIK STOKSTAD

Under fire. Dean Hal Salwasser (*inset*) of Oregon State University has been criticized for his leadership during the controversy over research by graduate student Dan Donato, who was called to testify before a congressional hearing.

CREDITS: ROSS HAMILTON/THE OREGONIAN; (INSET) OREGON STATE UNIVERSITY