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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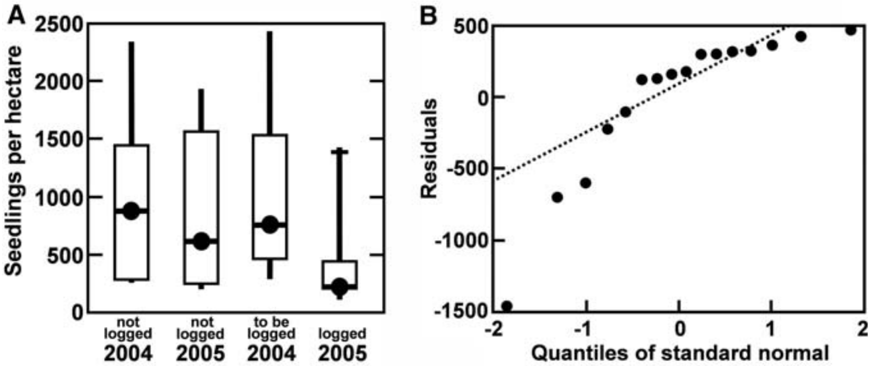

Fig. 1. (**A**) Box-and-whisker plots of Biscuit Fire seedling data (seedlings per hectare) from (*3*) and (**B**) residuals from parametric test [analysis of variance (ANOVA)] on interannual changes in untransformed seedling data, as in (*2*). (A) shows tendency toward positive skewness (typical for 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*).

Plot	Seedlings per hectare 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.

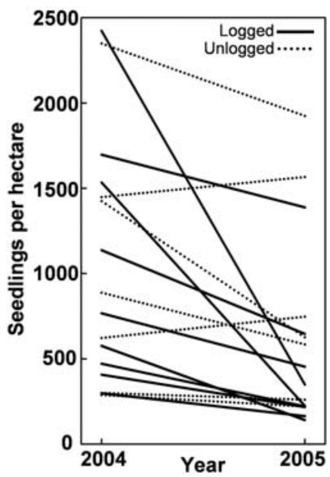

Fig. 2. Changes in seedling densities between 2004 and 2005 for logged and unlogged plots, with logging occurring between measurement periods. Equivocal variation between years can be seen in the unlogged plots (no consistent trend), whereas logged plots all show marked declines.

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.

References and Notes

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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

Science

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Science **313** (5787), 615.
DOI: 10.1126/science.1126583