RELATING HISTORIC FIRE REGIMES TO 20TH-CENTURY FIRE POTENTIAL MAY AUGMENT ECOLOGICAL JUSTIFICATIONS FOR EXPANDED FUEL TREATMENT PROGRAMS

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ABSTRACT

Federal land management agencies in the U.S. have responded to recent severe wildfire seasons with plans to greatly expand fuel treatment programs. These plans are often accompanied by ecological justifications to assuage environmental objections to fuel treatment activities (e.g., tree removal, smoke production). However, the chain of hypotheses that support ecological justifications for fuel treatments has received scant empirical assessment. With the aid of published repeat photography, we present an objective evaluation of changes in 20th-century wildland fire potential and substantiate the relationship of these changes to historic fire frequency.

Unlabeled photo pairs depicting historic versus recent vegetation conditions at seven diverse locations in the western U.S. were evaluated by 32 wildland fire professionals. Their ratings demonstrated a large and significant increase in perceived crown fire potential (d [the standardized mean difference between ratings for recent and historic conditions] = 0.83, 95% CI = $0.34 \le d \le 1.23$) and a moderate and significant increase in fire severity potential ($d = 0.66$, 95% CI = $0.25 \le d \le 1.04$), but no change in spread rate potential ($d = –0.29$, 95% CI = $–0.79 \le d \le 0.13$). Perceived changes in crown fire potential and potential fire severity are both related to the historic fire regime of forested photo locations ($P = 0.012$ and 0.015, respectively), with the greatest amount of change perceived where fire was historically most frequent. These results support the use of the *historic fire regime–current condition class* concept to justify and prioritize fuel treatments that reduce the potential for crown fires on forested lands.

keywords: fire exclusion, fire hazard, fire regimes, fuel treatments, repeat photography, vegetation change, western U.S.

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INTRODUCTION

The severity of recent wildfire seasons (e.g., 1988, 1994, 1996, 2000, 2002) in the western U.S. support assertions of increased fire potential as a result of more hazardous fuel profiles created by fire exclusion during the 20th century. This chain of hypotheses is often invoked to provide ecological justification for expanded fuel treatment programs on U.S. federal lands (e.g., USDA Forest Service 2000). Fire history studies provide widespread graphic evidence that fire exclusion during the 20th century has dramatically reduced fire frequency in many ecosystems (Swetnam et al. 1999). Since fire is an agent of mortality (Ryan et al. 1988) and a process of accelerated decomposition (Ottmar et al. 1993), reduced fire frequency would be expected to result in greater fire hazard due to increased surface fuel loads, more abundant ladder fuels, and denser canopy fuels (Agee 1996).

Writings (e.g., Cooper 1960) and photographs (e.g., Veblen and Lorenz 1991) from the period of Euro-American settlement anecdotally support suppositions of increased fuel accumulation in some ecosystems since the advent of organized fire suppression in the early 20th century. Gruell et al. (1982) used hazard ratings by a fuels specialist in their repeat photography study to infer a general hazard increase since 1909. We took a similar but broader approach to quantify and differentiate changes in fire potential represented in repeat photographs that have been published for a variety of ecosystems in the western U.S. It is generally presumed that fire exclusion has had the greatest impact on ecosystems that historically experienced a regime of frequent fires (Covington and Moore 1994). We tested the hypothesis that the degree of perceivable difference in fire potential represented in repeat photographs is related to the historic fire frequency at

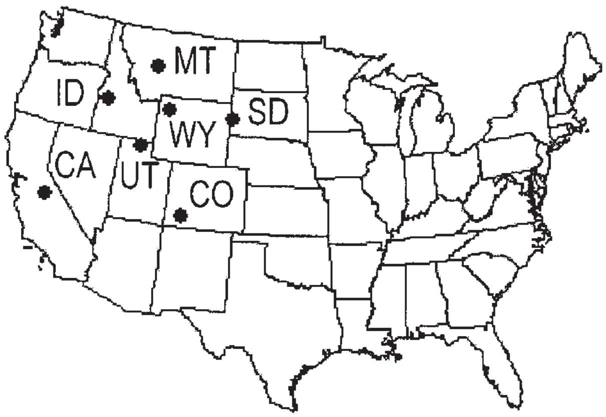

Figure 1. Locations of repeat photography studies used to analyze recent versus historic vegetation conditions in the western U.S. Photos of the sites are from the following sources: California (CA): Kilgore 1970:28–29; Colorado (CO): Baker and Veblen 1990:73; Idaho (ID): USDA Forest Service 1993:124–125; Montana (MT): Gruell 1983:41; South Dakota (SD): Progulske 1974:56–57; Utah (UT): Rogers 1982:60–61; Wyoming (WY): Gruell 1980:16–17.

each photo location. The existence of such a relationship would lend additional support to the use of historic fire regimes and current condition classes (Hann and Bunnell 2001) as guides for fuel treatment activities (USDA Forest Service 2000).

METHODS

Our assessment of changes in fire potential was based on published repeat photography. We identified applicable publications during a literature search for a synthesis of fire history studies (see Martinson and Omi 2003). From each publication identified, we randomly selected one pair of photos that met two criteria: A pre-1900 photo was paired with a post-1970 photo of the exact same location and neither photo contained evidence of the period in which it was taken (e.g., people, buildings, roads, trains). The sources and geographic locations of the seven selected photo pairs are shown in Figure 1.

The selected photo pairs were scanned into a PowerPoint® (Microsoft 2000) presentation comprising 21 slides. Each slide displayed two photo pairs, such that every pairwise comparison between photo pairs was depicted once. The location of each of the four photos on each slide was randomly determined, as was the order of slides in the presentation. The PowerPoint® presentation was shown to 32 fire management practitioners participating in a March 2001 Technical Fire Management fuels course in Seattle, Washington. Participants ranked the four photos on each slide in order of increasing fire potential in terms of spread rate, crowning, and severity (char depth). These fire potential variables were chosen to correspond to the new national fuel characteristics classification system (Sandberg et al. 2001). Participants were given no information regarding the dates and locations of the photos or the purpose of the rankings.

The six ranks by each participant for each photo were summed for each of the fire potential variables. Thus, each of the 14 photos received relative scores from each of the participants that ranged between 6 and 24. We chose this method of evaluation to avoid ties between photos, as well as potential inconsistencies among participants in interpretation of ratings (e.g., high, medium, low). We also sought to avoid overwhelming participants with a large number of photos to compare simultaneously.

We estimated the amount of change in the three fire potential variables at each location as Hedge's standardized mean difference, *d* (Rosenberg et al. 2000):

$$d \approx \frac{\mu_{>1970} - \mu_{<1900}}{\sigma_{pooled}}, \qquad (1)$$

where $\mu_{>1970}$ is the mean relative score from all participants for the recent photo, $\mu_{<1900}$ is the mean relative score for the historic photo and σ_{pooled} is the pooled standard deviation of the relative scores for the photo pair.

Hedges' *d* is a measure of effect size and as a dependent variable is analyzed most appropriately within the context of meta-analysis (Cooper and Hedges 1994). We used the standard meta-analytical software MetaWin (Rosenberg et al. 2000) to relate fire potential effect sizes to an estimate of the historic fire frequency at each photo location. Historic fire frequencies were estimated from fire history studies conducted in relative proximity to each photo location (i.e., within 200 m of elevation, 2° of latitude, and in the same longitudinal region [west of the Cascade–Sierra Nevada mountains, east of the Rocky Mountains, Intermountain]). We identified and selected applicable fire histories from those included in a quantitative synthesis of fire history information (for details see Martinson and Omi 2003).

Historic fire frequencies were standardized from each fire history by calculating the inverse of the average annual point-specific probability of fire in the period 1710–1779. This period was chosen to avoid influences associated with Euro-American settlement and to remain within the temporal extent of most fire

Table 1. Sources of fire history information used to calculate the historic[a] point-specific Mean Fire Interval (MFI)[b] at the location of each repeat photography study[c] used to analyze historic versus recent vegetation conditions in the western U.S.

Location	Pre-settlement MFI (years)	Fire history citations
Colorado	17	Savage and Swetnam 1990:Fig. 1, Wolf and Mast 1998:Fig. 1c
Montana	21	Arno 1976:Fig. 3, McCune 1983:Fig. 2, Weaver 1959:Table 1
California	24	Swetnam et al. 1991:Fig. 1
Utah	35	Young and Evans 1981:Fig. 5
South Dakota	61	Arno 1976:App. B, sites B,C,D,E,F,I; Arno and Gruell 1983:Fig. 6; Brown and Sieg 1996:Fig. 2; Houston 1973:Table 3; Miller and Rose 1999:Fig. 4
Idaho	87	Arno 1976:App. B, sites B,C,I; Arno and Gruell 1983:Fig. 6; Brown and Sieg 1996:Fig. 2; Miller and Rose 1999:Fig. 4
Wyoming	157	Arno 1976:App. B, sites G,H; Murray et al. 1998:Fig. 2; Romme 1982:Fig. 2c; Romme and Despain 1989:Fig. 2

[a] The historic period was standardized to 1710–1779 for all fire history studies.

[b] The MFI at each photo-point location was estimated from a weighted average of the cited studies, where weights were defined by the inverse of the 95% CI about each MFI (Martinson and Omi 2003).

[c] See Figure 1 for photo sources and locations.

histories. Baisan and Swetnam (1997) note grazing influences by Spanish cattle in New Mexico as early as 1779. Few fire history studies based on tree-ring analyses extend back beyond 1700 (Lertzman et al. 1998).

A weight was calculated for each fire history study that was inversely proportional to the variance about its fire frequency estimate. We estimated the historic fire frequency for each photo location as the weighted average of fire frequencies calculated from the proximal fire histories (Table 1).

The significance of historic fire frequency as an explanatory variable was tested nonparametrically by randomization with 5,000 iterations. Nonparametric 95% CIs were generated via bias-corrected bootstrapping (Rosenberg et al. 2000). Such nonparametric resampling techniques produce mixed-effects models. Mixed-effects models incorporate random variation from unknown sources, such as the actual site-specific disturbance histories of the photo locations. We also conducted our analysis with parametric assumptions to allow estimation of the amount of random variance in each model (i.e., variation not explained by the uncertainty in the relative fire potential scores for each photograph, as indicated by their sampling errors). Comparison of the size of the random variance component (σ_θ^2) when the explanatory variable is included in the analysis to its size when the predictor is left out provides a measure of the explanatory power (r_{MA}^2) of a parametric mixed effects meta-analytical model (Cooper and Hedges 1994):

$$r_{\mathrm{MA}}^2 = \frac{\sigma_\theta^2(\mathit{no\ predictor}) - \sigma_\theta^2(\mathit{predictor\ included})}{\sigma_\theta^2(\mathit{no\ predictor})}. \quad (2)$$

RESULTS

Evaluations by 32 fire management practitioners of the fire potential represented in repeat photography of seven diverse western landscapes suggest that crown fire potential and potential fire severity have generally increased significantly (since 95% CIs do not include zero) during the 20th century (d = 0.83 and 0.66, respectively, with 95% CIs of $0.34 \leq d \leq 1.23$ and $0.25 \leq d \leq 1.04$), while fire spread rate potential appears to have decreased, though insignificantly (d = –0.29, 95% CI = $-0.79 \leq d \leq 0.13$).

Perceived crown fire potential has increased at all but one photo location (Utah) and at four locations this increase has been significant (Figure 2). Historic fire frequency was marginally significant as a predictor of the amount of 20th-century change in crown fire potential (P = 0.074, r_{MA}^2 = 0.26). However, the Utah location might be considered an outlier in this analysis (see Discussion) and its exclusion strengthens the relationship between historic fire frequencies and altered crown fire potential (P = 0.012, r_{MA}^2 = 0.94). Though this r_{MA}^2 value is high, note that it is not directly comparable to the traditional coefficient of determination (r^2) produced by an ordinary regression. Unfortunately, interpretation of r^2 for a meta-analytical model is also ambiguous, since it would describe variation in mean effect sizes but ignore the sampling error about

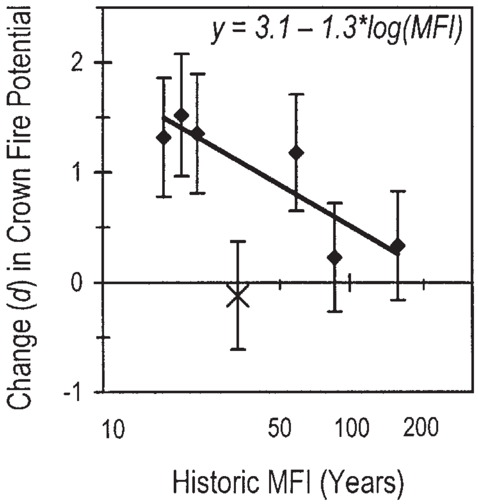

Figure 2. Standardized Mean Differences (*d*) between relative crown fire potential scores for photographs of recent vegetation conditions and those of historic conditions in the western U.S. Error bars represent 95% CIs and indicate a significant change where they do not include zero. The relationship between the amount of perceptible change in crown fire potential and the estimated historic Mean Fire Interval (MFI) of each photo location is significant ($P = 0.012$) when the non-forested Utah site (indicated by "X") is excluded from the analysis. Note the logarithmic scale of the abscissa.

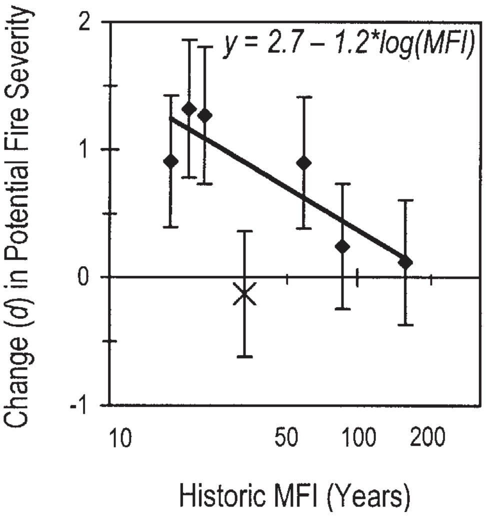

Figure 3. Standardized Mean Differences (*d*) between relative potential fire severity scores for photographs of recent vegetation conditions and those of historic conditions in the western U.S. Error bars represent 95% CIs and indicate a significant change where they do not include zero. The relationship between the amount of perceptible change in potential fire severity and the estimated historic Mean Fire Interval (MFI) of each photo location is significant ($P = 0.015$) when the non-forested Utah site (indicated by "X") is excluded from the analysis. Note the logarithmic scale of the abscissa.

the means. However, for completeness and to avoid appearing overly optimistic, we report the traditional coefficient of determination: $r^2 = 0.79$.

Twentieth-century changes in perceived fire severity potential were similar to changes in crown fire potential (Figure 3). Historic fire frequency was again a marginally significant predictor of the amount of 20th-century change in potential fire severity when the Utah location is included ($P = 0.069$, $r^2_{MA} = 0.33$). The relationship between historic fire frequency and changes in potential fire severity was also substantially improved by the removal of the Utah location ($P = 0.015$, $r^2_{MA} = 0.99$, $r^2 = 0.78$).

In contrast to changes in crown fire and fire severity potentials, spread rate potential was perceived to have decreased during the 20th century at five out of seven locations, and at two of these locations (Montana and South Dakota) the perceived change was significant (Figure 4). The amount of change was insignificant at the two locations where spread rate appears to have increased (Colorado and Utah). The amount and direction of change in spread rate potential was not explained by estimated historic fire frequency ($P = 0.360$, $r^2_{MA} = 0$).

DISCUSSION

Given the complex relationships among landscape disturbances, vegetation change, and future fire behavior, our approach to this assessment was rather simple. Nonetheless, our results provide empirical substantiation of the linkages among historic fire regimes, altered fuel profiles, and current fire potential.

Increases in crown fire potential and potential fire severity were clearly perceptible at most of the locations included in our analysis, though changes in spread potential were less clear. The fuel conditions most likely to be associated with potential crown fire and severity, such as canopy closure, ladder fuels, and large logs, were easier to discern in most of the photos than the fine surface fuels that would be associated with potential fire spread. Even so, the lack of a relationship between historic fire frequency and 20th-century fire spread potential is not too surprising because the effect of fire exclusion on fuels that would contribute most to fire spread is ambiguous. For example, a decrease in fire frequency might be expected to decrease production of fine herbaceous fuels, but to increase the accumulation of litter from a greater number of shade-tolerant trees.

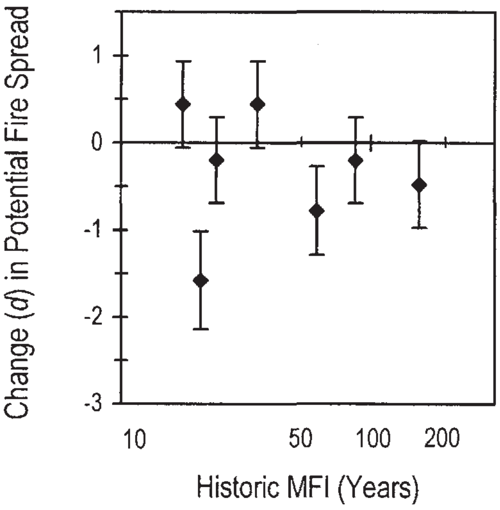

Figure 4. Standardized Mean Differences (*d*) between relative potential fire spread scores for photographs of recent vegetation conditions and those of historic conditions in the western U.S. Error bars represent 95% CIs and indicate a significant change where they do not include zero. The relationship between the amount of perceptible change in potential spread rate and the estimated historic Mean Fire Interval (MFI) of each photo location is not significant (*P* = 0.36). Note the logarithmic scale of the abscissa.

However, the positive relationship between historic fire frequency and the amount of change in both crown fire potential and potential fire severity is evident, and becomes striking when the non-forested Great Basin location is excluded from the analysis. There are several motivations for excluding this site, besides improvement of our statistical relationships.

Ecological justifications for fuel treatment activities presume that fire frequencies have generally decreased in the U.S. as a result of fire exclusion during the 20th century. While this is undoubtedly true in many forested ecosystems, historic fire frequencies in non-forested ecosystems are not nearly as well quantified. The historic fire frequency for the Great Basin sagebrush (*Artemisia tridentata*) site is probably not adequately reflected in the forest fire histories we used for its estimation. Therefore, a possible explanation for the Utah site's lack of fit in our analysis is that its historic fire frequency was overestimated. Historic fire intervals in Great Basin sagebrush are generally presumed to have been in the range of 30 to 70 years (Whisenant 1990), based on Houston's (1973) data for sagebrush in northern Yellowstone National Park. Though our estimate of the Utah site's historic fire frequency is within this range (Table 1), it is on the higher end of the range.

However, it has been argued that many non-forested ecosystems have not experienced reduced fire frequency during the 20th century (Keeley et al. 1999). Current paradigm suggests that Great Basin sagebrush systems are actually under a more frequent fire regime now than in the past due to positive feedbacks promoted by nonnative annual grasses (Young and Evans 1978). Indeed, the Utah location included in our analysis has been converted from sagebrush to cheatgrass (*Bromus tectorum*). It is not surprising, then, that crown fire potential and fire severity potential are lower in the current annual grassland than in the historic shrubland, regardless of what the historic fire frequency may have been.

Thus, the non-forested Utah site does not fit the model now used for ecological justification and prioritization of fuel treatment activities on public lands in the U.S. Morrison et al. (2001) suggest that the new National Fire Plan is misguided in its focus on forested lands for fuel treatment activities. They note that most of the areas burned by wildfires during the last decade have actually been non-forested. Correspondingly, our analysis indicates that while crown fire potential and potential fire severity have decreased at the non-forested Utah location, spread rate potential has increased more there than at any other site. We concur that a fuel treatment prioritization model that gives greater consideration to the unique fire regime situation on non-forested lands is needed.

Nonetheless, vegetation changes at all the other sites included in our analysis strongly support the intuitive assertion that 20th-century increases in wildfire potential are greatest where fire was most frequent prior to Euro-American settlement. Our results support the use of historic fire regimes as guides for fuel treatment prioritization, at least in forested areas. Fuel treatments should be applied where fire regimes have been most altered. Where there is no ecological justification for fuel treatments, they will likely be ineffective and may instead exacerbate problem fires. Alexander et al. (2001), for example, observed greater fire intensity in treated boreal forest of the Canadian Northwest Territories, where fire severity was and remains characteristically high and 20th-century fire exclusion has effected relatively little change in fire frequency (Larsen 1997). However, we have found that fuel treatments reduce wildfire damages in systems where fire was historically frequent and of low severity, such as southwestern ponderosa pine (*Pinus ponderosa*) forests (see Omi et al., *this volume*). We therefore encourage land managers and policy makers to continue their reliance on ecological justifications for guidance on fuel treatment applications.

CONCLUSIONS

This study presents an objective assessment of changes in 20th-century wildland fire potential and empirical substantiation of their relationship to historic fire frequency. Our results support the use of the *historic fire regime–current condition class* concept to justify and prioritize fuel treatments that reduce crown fire potential on forested lands. However, non-forested lands rarely fit into a framework that assigns fuel treatment needs based on increased crown fire potential as a result of decreased fire frequency. A different fuel treatment prioritization model is needed for non-forested lands: one that gives explicit consideration to the problem of increased *fire spread* potential as a result of 20th-century *increases* in fire frequency.

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