An Integrated Model of Two Fire Regimes

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Introduction

Casual observers of chaparral in southern California (SCA) quickly learn two key facts about fires: they may be started in a variety of weather conditions—windy or calm, dry or humid—and the most spectacular modern burns occur during Santa Ana winds. Serious researchers who seek to understand ecosystems and guide land managers must ask whether this has always been true. Readers should be surprised that Keeley and Fotheringham (2001 [this issue]) answer yes. First, the chaparral ecosystem has certainly not been static: it has experienced major changes in fire management as southern California's population has increased. Second, observations of the chaparral in nearby Baja California (BCA) immediately reveal a very different dynamic that surely deserves serious consideration as a model for SCA, one that precedes the establishment of modern suppression practices and dense population. The chaparral of BCA is characterized by smaller stands and a propensity for low-intensity fires in relatively calm, humid weather. The sharp transition between the two regimes cannot be explained by natural gradients in flora or weather; it follows the international border, an artificial line drawn by human beings. Vegetation maps show that California ecosystems extend 200 km into BCA (Minnich & Franco-Vizcaino 1998).

Climatic gradients including temperature and mean annual precipitation cross the border at right angles, and prevailing winds are everywhere westerly. Open-range cattle grazing is practiced in BCA, but chaparral is unpalatable to livestock (Minnich & Bahre 1995). Without distinctive suppression systems, changes in fire regime should be expressed in a continuum along environmental gradients, not the discontinuity seen along the border. The primary difference is that BCA has not experienced the same protectionist management policies as SCA, and the divergence in chaparral fire ecology may provide insight into the nature of historical vegetation change in SCA. The seminal question is how fires shaped ecosystems without management interference. Suppression is unprecedented in ecological history.

Keeley and Fotheringham are obviously aware of the need to balance the BCA and SCA models in any plausible account of chaparral history. Yet their analysis focuses on a 1983 account of the cross-border contrast and ignores a substantial body of more recent publications, including a 52-year transborder fire history (1920–1971; Minnich & Chou 1997), a study of transborder postfire chronosequences (Minnich & Bahre 1995), and studies of presuppression fire regimes in SCA (Minnich 1987, 1988). To evaluate their case for dismissing the BCA model, I must review the key findings they ignore. These findings concern the following sequence of topics: (1) the nonrandom turnover of fire patches, (2) the overabundance of natural ignitions compared with fuel production; (3) the dominance of landscape burning by relatively few fires (most fire starts fail), and (4) the random phasing of fires with normal weather in the absence of fire control. This is not just an intellectual exercise: these are serious implications for fire management.

Both the original and subsequent studies (Minnich 1983; Minnich & Chou 1997) show that, in the absence of suppression, the chaparral of BCA is a diverse, fine-grained patch mosaic. With fire suppression in SCA, the chaparral comprises unbroken carpets of mature vegetation interspersed with a few extensively denuded watersheds (Fig. 1). There are ample data to suggest differences in fire management, including the number of fires of >15 ha (BCA, 2000 events; SCA 350 events), maximum fire size (BCA, 3,000 ha; SCA 59,000 ha), and differences in fire weather (BCA, onshore flows; SCA, offshore flows). The only similarity is that fire-return intervals are 50–70 years in both countries. Our integrated model explains the disparate fire outcomes that have existed in the two countries since the 1920s, Keeley and Fotheringham do not.

An important aspect in developing fire-disturbance theory is choosing an incontrovertible starting point that leads in directions productive for research. The model by Minnich and Chou (1997) is based on the fact that

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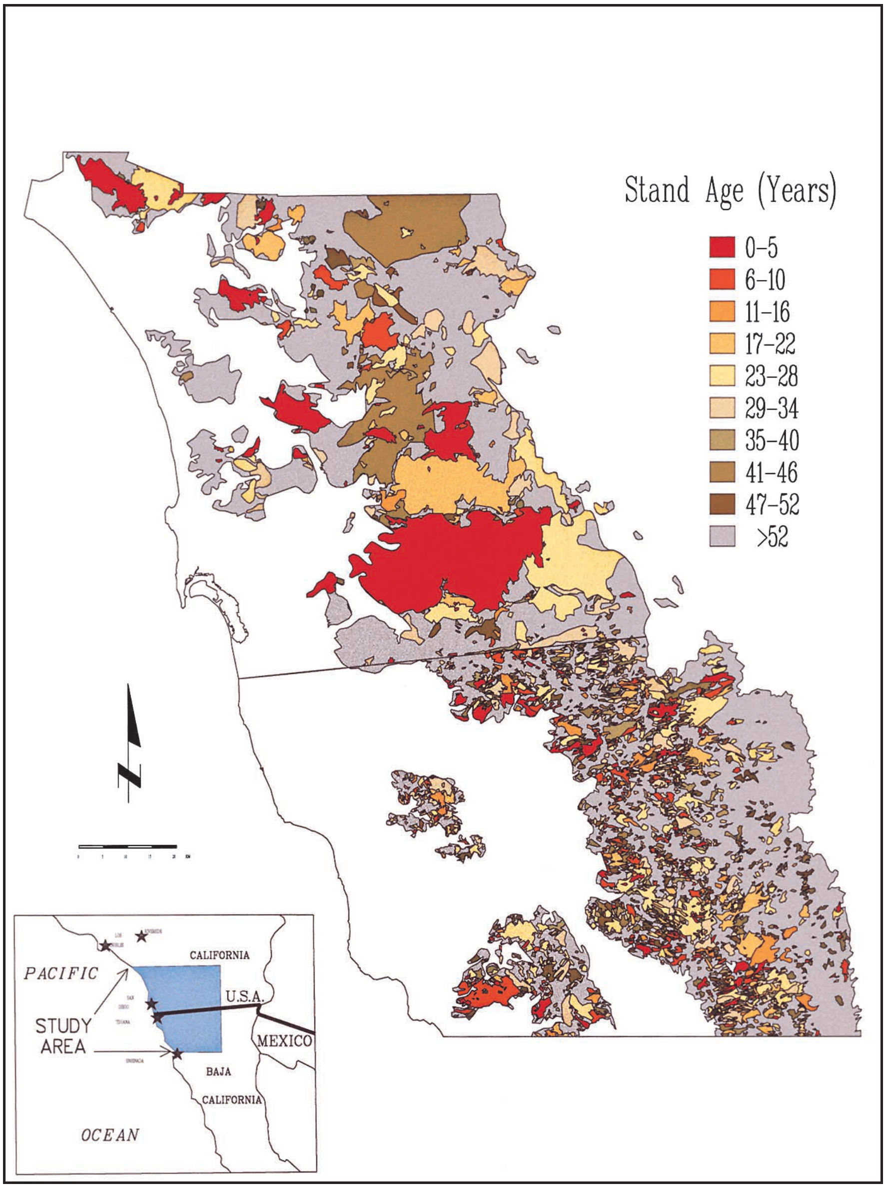

Figure 1. Chaparral patch mosaic (time since fire) in 1971 (after Minnich & Chou 1997).

fire requires fuel; this reveals that the cause of fire is fuel-energy accumulation in vegetation (chemical energy accumulates when carbon dioxide is fixed in carbohydrate). Fire occurrence in chaparral is time dependent as a result of cumulative fuel build-up. How stored energy in chaparral is released reflects the interactions of factors such as vegetation growth and structure, weather, ignitions, and terrain. The 52-year study affirmed the original findings and leads to a model in which fire occurrence is constrained in space and time by the rate of fuel accumulation and by previous fire history. Chaparral fire hazard gradually increases with time since the last fire, causing the probability of fire to vary from stand to stand. Fires preferentially burn old stands; younger stands constrain the progress of burns. The similarity of fire-return intervals in SCA and BCA argues that the chaparral productivity (i.e., fuel supply) dictates landscape-scale rates of burning, with a negative feedback between fire frequency and fire size.

Ignitions

Keeley and Fotheringham offer a puzzling argument that natural ignitions are rare. In fact, there is an overabundance of ignitions. Electromagnetically recorded lightning-strike densities from summer thunderstorms average 0.5 to 3.0/km^2/year (Minnich et al. 1993) in chaparral, and flames may persist for weeks or months in trees and logs (Minnich 1987). The potential for ignition saturation in ecological time scales is evident if one considers three factors: (1) lightning flux (strikes/area/time); (2) time required for patch elements to reach flammability; and (3) the size of patches. To illustrate, 1-km patches in BCA are struck once a year and 50 times over a 50-year cycle. In SCA, 10-km patches are struck 500 times over the same period. Clearly, most fire starts fail to establish landscape fires in both SCA and BCA because the vegetation is not mature enough to support flame lines. This is the primary reason why most fires are small and why relatively few account for most landscape-scale burning (Clar et al. 1994; Minnich & Chou 1997; Malamud et al. 1998). The size-frequency distribution of fires predicts two outcomes: (1) most suppressed fire starts would quickly die out on their own, and (2) the maintenance of large patches in SCA is unstable over long time scales in the absence of efficient suppression of fire starts.

Keeley and Fotheringham's ignition hypothesis does not account for transborder differences in fire regime. If fire occurrence were strictly a function of ignition rates and weather, then frequency-distribution curves of fire size should be similar in both countries. Because there are more fires in BCA, comparable frequency-distribution curves should translate into shorter fire intervals in BCA than SCA.

Weather

Fires occur in different weather patterns in SCA and BCA (Minnich & Chou 1997). On an area-weighted basis, most burning in SCA coincides with offshore Santa Ana winds (relative humidity, 10–20%; winds, 20–50 miles per hour). Fires in BCA occur with onshore sea breezes and slope winds (relative humidity, 20–40%; winds, 5–20 miles per hour). Perimeters typically elongate in the direction of wind: north-south in SCA and west-east in BCA (Fig. 1). Landsat data also document the disparate seasonality of burning (summer in BCA, fall in SCA; Minnich 1983).

Keeley & Fotheringham take the view that Santa Ana winds do not occur in BCA, but the SCA/BCA region is much smaller (200 km) than the area of influence of winds arising from hemispheric atmospheric flows scaling in thousands of kilometers. (In a sense, Santa Anas do stop at the border; the Mexicans call them *nortes.*) In our model, fires can burn under a broad range of weather conditions if they start at random. One can visualize "climate" as some normal statistical distribution, with a high frequency of normal days bounded by rare moist and dry days. In SCA/BCA, most days consist of sea breezes and mountain upslope winds, especially in summer. Santa Ana winds are restricted to a few days in fall. Although the rates of fire spread (and potential fire size) increase as weather becomes drier, the seminal question is how much "slow burning" occurs in normal weather without suppression. In BCA, fires typically establish by chance in normal weather because sea-breeze and slope-wind circulations dominate the fire season. Few establish in Santa Ana winds because these conditions are rare. The size of these fires is constrained by patches produced by summer burns. In SCA the efficient elimination of countless small fires is a selective process that nonrandomly encourages "escaped," very large burns to coincide with severe weather (fire starts are easily extinguished in "normal" weather), resulting in high average spread rates and flame-line intensities. The corresponding denudation of younger stands increases fire size and mosaic homogenization.

History of Fire Suppression

Keeley et al. (1999) propose an argument that, because (1) the size of fires in SCA have remained unchanged since records began in 1910 and (2) suppression became effective with technological advancements in 1950, fires have always been large, even before suppression. This argument rests on an unsubstantiated ad hoc assumption that suppression effectiveness is coupled with technology. The reality is that suppression of very large fires was never effective, and suppression of small fires succeeds with relatively primitive means. Since 1950, SCA fires have been larger than those in BCA, where fires are not fought. Moreover, the discontinuity in patch density and size along the international border had already developed by the 1920s (Minnich & Chou 1997; their Fig. 4A). The most expensive aspect of suppression—encircling large fires—is futile because the energy release of flame lines exceeds the energy of suppression by orders of magnitude. Suppression is effective only during low energy states, and the extinguishing of small fires starts can be done at little cost and with little technology. This process began in earnest by 1900 (Minnich 1987). Tree-ring studies show a fall-off in fire scarring by 1900 (e.g., Swetnam 1993). Unfortunately, what we know of presuppression patch structure is limited to fragmentary historical accounts from the 1800s but these writings do describe fine-grained patch structure in many areas of SCA (Minnich 1987, 1988). Newspaper accounts frequently described mountain smoke columns in summer, although some fires persisted for months into autumn.

In support of their model, Keeley and Fotheringham cite studies of fossil charcoal in annual sediment layers (varves) from the Santa Barbara basin (Mensing et al. 1999). They found uniform intervals of carbon deposition for the period 1425–1985, with average intervals of 25 years. Calibration of the charcoal record with twentieth-century fire history in surrounding watersheds shows that charcoal lenses correlated with fires of >20,000 ha. But the dominance of large fires in the calibration period could be an artifact of suppression. The record of prehistoric fires may be filtered by charcoal transport. The charcoal residence time in watersheds may span several years because charcoal moves with major runoff events (i.e., charcoal in the Santa Barbara Basin may be an outcome of a runoff cycle, not the fire cycle). Hence, fires could be single events spanning >20,000 ha or simultaneous multiple smaller events aggregating to similar spatial extent over multiple years. The constant carbon flux supports our time-dependent fire-regime model, although fire intervals are shorter, perhaps because chaparral is more productive near Santa Barbara than in our study areas. Intervals may also be underestimated unless charcoal lenses reflect the complete burning history of surrounding watersheds, especially if small fires are underrepresented.

Mensing et al. (1999) also argue that most fires result from Santa Ana winds, but this interpretation is based on the dominant weather condition in the calibration period, which is Santa Ana winds. Sediment core data are not weather-event recorders, however, but a signal that filters a large array of climatic events. The difference between SCA and BCA fire regimes calls into question whether the deduction of varved charcoal records from twentieth-century records of fire may yield a spurious interpretation of presuppression fire regimes: the findings may reflect suppression history more than an intrinsic outcome of the presuppression fire history.

Fire Management and Conservation Biology

The beginnings of fire suppression were a response to threats to land use and watersheds. Thus, suppression is fundamentally "reactive" and cannot be reconciled with fire as a natural process. The focus on universal suppression of all fires fails to address regional vegetation management. The concept that surrounding burns can prevent the destruction of infrastructure is illogical because suppression forces cannot control large fires.

Examination of the fire history SCA and BCA leads to several fundamental conclusions vital to fire management. Most important, fire poses a cyclical threat in space and time. The removal of fuels by fire precludes a recurrence for decades. Based on preexisting patch structure, a fuel-management strategy that maintains a patch mosaic can be accomplished through the use of planned broadcast burns of moderate size. There are other advantages to such a strategy. Landscape burning can be accomplished in normal weather, and the fragmentation of denuded lands helps to attenuate post-fire sediment yields in watersheds. Fine-grained patch mosaics sustain biodiversity because they enhance local variability in vegetation successions. The reduction of fire intensity will serve to reverse the degradation of adjoining ecosystems such as mixed-conifer and big-cone-Douglas-fir (*Pseudotsuga macrocarpa*) forests due to excessive stand-replacement fires (Minnich 1999). (Mixed-conifer forests are stable without suppression in BCA; Minnich et al. 2000). The assertion of Keeley and Fotheringham that fires will cause expansion of exotic annual grasslands into chaparral is unsupported by time-series databases. Minnich and Bahre (1995), utilizing post-fire chronosequences on the SCA and BCA side of the international boundary, found little exotic cover and that chaparral species are flexible to fire size and return intervals.

Although wildland fires present the greatest threat to communities at the urban-wildland interface, the most intractable problem has been the growth of dispersed, small landholdings within wildlands, whose presence complicate broadscale regional fire management. The paradox of the Californias is that the spectacular divergence in chaparral patch dynamics between SCA and BCA gives the appearance that humans have actually changed the fire regime. What really happened was that suppression encouraged large conflagrations merely by snuffing out little fires; fire-return intervals have not changed. Keeley and Fotheringham's management model maintains the status quo, a continuation of the parade of catastrophic fires in which land managers are least able to protect property and resources. Humans are still powerless to control landscape fires, even with 1950 technology.

In the final assessment, my model for chaparral wildfires encompasses all fire events, whereas Keeley and Fotheringham explain only the fires forming under rare Santa Ana winds. We both agree that Santa Ana winds are a natural part of the ecosystem, and it is possible that extremely severe weather conditions will burn any vegetation. From a pragmatic perspective, we agree that houses built in chaparral are destined for destruction. We disagree over the effect of summer fires, which I say is substantive and which they do not address. Their assertion that fire patterns in SCA and BCA are explained by weather changes along the U.S.–Mexico border is not substantiated by the climatological literature. My assertion is that there is a strong difference in fire suppression between the two regions. My model, which predicts a patch mosaic as the most likely condition, can be empirically tested by the relaxation of fire suppression in summer months. Their model, that large fires are natural and that BCA fires are induced by humans, remains untestable because the data on human ignition rates are Mexico is unsubstantiated. From a management perspective, my model provides a mechanism that may reduce catastrophic fires. Their method offers no management alternatives.

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