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Distribution and frequency of wildfire in California riparian ecosystems

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Abstract

Although wildfire has been recognized as having important ecological impacts on California's riparian environments, understanding of its occurrence is largely anecdotal, based on studies of fire impacts in scattered locations. In this paper we use data for 21 years of wildfires to examine the distribution, seasonality and climatic context of riparian wildfire across the state. We used the Monitoring Trends in Burn Severity and LANDFIRE databases to identify fires that had burned in areas classified as having riparian vegetation, and matched those fires with the Fire and Resource Assessment Program database to determine the date of occurrence of each. From 1990 through 2010, an average of 1197 ha of riparian vegetation burned per year, which extrapolates to a fire return interval of 843 years. The statewide totals are misleading, however, because there is substantial geographic variance in the occurrence of riparian fire. In southern California ecoregions, extrapolated return intervals are as low as 74 years, contrasting with the Basin and Range ecoregions, where return intervals exceed 1000 years. Moreover, there is substantial geographic variation in the season of riparian fire, and in the relationship between fire occurrence and climatic variables. Both the widespread occurrence of riparian fire and its spatial variability are potentially important for management of critical riparian habitat.

1. Introduction

California's riparian environments provide diverse habitat, and account for a disproportionate share of the state's biodiversity (Holstein 1984). The importance of these environments has long been acknowledged in both the scientific literature (e.g. Warner and Hendrix 1984) and in state law (California Riparian Habitat Conservation Act 1991). Moreover, while we focus here on California, we recognize the similar importance of riparian habitat in other primarily Mediterranean climate regions worldwide, and the fact that similar processes occur in those settings (Stella *et al* 2013, Verkaik *et al* 2013). As is the case across ecosystems (Bowman *et al* 2009), riparian environments are potentially influenced by fire. Since about 2000, a growing body of literature has suggested that wildfire may indeed have quite significant impacts on riparian ecosystems (Dwire and Kauffman 2003, Pettit and Naiman 2007a), including within California (Bendix and Cowell 2010a, 2013).

The state of California offers a context in which, overall, wildfire is inescapably important in both natural (Keeley and Safford 2016) and human (Pyne 1982) terms. From 2011 to 2015, for example, an average of 256 239 ha burned annually within the state, with annual damages from those fires averaging almost $630 million (California Department of Forestry and Fire Prevention 2011, 2012, 2013, 2014, 2015). The extensive occurrence of wildfire makes it a ubiquitous ecological factor (Sugihara and Barbour 2006); indeed, as Sugihara and Barbour note, 'It is difficult to overstate the importance of fire in California ecosystems' (2006, p1). But it would also be difficult to overstate the geographic variability in fire regimes across the state. The wide range of climatic conditions, topographic settings, and vegetation types ensures an equally wide range of fire regimes (Keeley and Safford 2016). Consequently, fire rotation intervals vary from more than 500 years in some coniferous forests of the North Coast (Stuart and Stephens 2006) to 20 years or less in oak woodlands of the Tehachapi Mountains

(Mensing 1992). The climatic/meteorological drivers of fire also vary geographically, from the northern part of the state where summer drought is a major contributor (Trouet *et al* 2006), to southwestern California, where the most extreme fire weather and most (economically) damaging fires are engendered by the regional downslope 'Santa Ana' foehn winds, which favor fire by heating and desiccating fuels (Keeley and Fotheringham 2001, Jin *et al* 2014, Jin *et al* 2015).

The riparian zone makes up a very small part of the landscape, and the economic impacts of riparian fire are limited, because expensive structures are rarely built in locations that are inherently flood-prone. Riparian environments are, however, ecologically important because they provide key habitat and migration corridors for a wide range of species, some of them threatened or endangered (Bombay *et al* 2003, Semlitsch and Bode 2003, Hilty and Merenlender 2004). Morever, riparian fire may be key to the spread of upland fire, as it can serve as a wick to carry wildfire across otherwise nonflammable areas (North 2012).

In California, and indeed globally, most of the research on specifically riparian fire has been case-specific—that is, it has focused on the ecological and broader environmental impacts of individual fires, rather than on the frequency with which they occur (e.g. Pettit and Naiman 2007b, Bendix and Cowell 2010b, Stromberg and Rychener 2010). The exceptions to this tendency are a few studies from coniferous forests in western North America where dendroecological evidence has been used to reconstruct histories of riparian fire. It seems logical that riparian settings should burn less frequently than surrounding uplands because of their greater fuel moisture (Pettit and Naiman 2007a), and there is evidence to support this (Everett *et al* 2003). Of note, however, some chronologies have found comparable fire frequency for riparian and upland conifer forests (Olson and Agee 2005, Charron and Johnson 2006, Van de Water and North 2010).

Published riparian fire histories have been limited to the coniferous forests that are particularly amenable to dendrochronological methods, and have been limited in their spatial extent. There are no regional-scale studies available thus far that actually quantify the frequency with which riparian fire occurs. In this paper, we use remotely sensed data to determine the frequency with which riparian environments burn in the state of California. We focus on California because it is a region where wildfire is known to be of great importance, importance that is likely to increase with global climate change (Westerling *et al* 2011). We include the entire state because we recognize the likelihood that riparian fire frequency will vary among ecoregions, and we seek to capture that variation. Specifically, our goals are to determine the frequency with which riparian environments in California burn, to determine the variation in that frequency among ecoregions within the state, to compare the frequency of riparian fire with that of surrounding uplands, to describe the variation in seasonality of fire occurrence among ecoregions, and to explore whether year-to-year variation in riparian fire can be related to basic climatological variables.

2. Methods

2.1. Fire data

We used the Monitoring Trends in Burn Severity (MTBS) database to determine the area of individual fires throughout California. MTBS data are derived from comparison of pre- and post-fire Landsat Thematic Mapper and Enhanced Thematic Mapper Plus images at a 30 m resolution, and provide perimeter and burn severity information for fires greater than 4 km^2 in area (Eidenshink *et al* 2007). This is the most comprehensive dataset of its type (Hao and Larkin 2014), and is a widely used resource for wildfire studies (e.g. Miller *et al* 2012, Parks *et al* 2014). Although smaller fires are excluded by dependence on this dataset, large fires account for most of the area burned (Jin *et al* 2014). We did not distinguish among the MTBS burn severity classes (High, Medium, and Low) because of the challenges in relating distinctions from Landsat data to actual ecological impacts, especially in varying vegetation types (Keeley 2009), and because our purpose was to determine the extent of riparian fire, rather than its gradations.

To determine the starting dates of those fires that had included riparian areas, we identified each within the Fire Perimeter Database developed by California's Fire and Resource Assessment Program (FRAP), which includes the requisite ignition dates (http://frap.fire.ca.gov/projects/fire_data/fire_perimeters_methods.php). In data for years prior to 1990, fire perimeters in the two databases (MTBS and FRAP) did not consistently align, suggesting that there might be some reliability concerns with one or both. We therefore limited our analysis to fires that occurred from 1990 through 2010. The use of MTBS rather than FRAP data to determine the area burned was owing to the different nature of the two datasets. MTBS specifically identifies pixels which have burnt, whereas the FRAP data are based on perimeters alone, and do not account for the fact that there are often substantial unburned patches within those perimeters—patches that are often concentrated in the riparian zone (Kolden *et al* 2012).

2.2. Vegetation

To delineate the bounds of riparian vegetation, we used the existing vegetation type (EVT) data product from the Landscape Fire and Resource Management Planning Tools Project (LANDFIRE; www.landfire.gov), which combines field-referenced databases, biophysical gradients and Landsat imagery in a

Figure 1. USEPA Level III ecoregions for California.

landscape model to describe current vegetation (Rollins 2009, Ryan and Opperman 2013). Like the MTBS data, LANDFIRE data are at a 30 m resolution. We included all pixels for which EVT was classified as of 'riparian' or 'wetland' as being riparian for our analyses. We considered all terrestrial pixels that were not riparian to be 'upland' for comparative purposes.

2.3. Ecoregions

We used US Environmental Protection Agency (USEPA) shapefiles (www.epa.gov/wed/pages/ecoregions/level_iii_iv.htm#Level III) to assign each fire to one of the 13 Level III Ecoregions delineated by the agency for California (figure 1; ecoregion descriptions are at ftp://ftp.epa.gov/wed/ecoregions/ca/CA_poster-front_Dec2010_DRAFT_v7.2.pdf). If a fire perimeter spanned more than one ecoregion, we placed it in the ecoregion in which the centroid of the fire fell.

2.4. Climate data

To examine the influence of climate on riparian fire, we considered annual precipitation, seasonal temperature maxima, drought severity, and (where appropriate) frequency of Santa Ana wind occurrence. We used the spatial datasets of precipitation and temperature developed by the PRISM Climate Group (www.prism.oregonstate.edu/); these data are at a 30 second resolution, and were averaged across each ecoregion. For precipitation, we tested several variables: totals for the water year (October 1 to September 31), totals for winter and spring (Jin *et al* 2014), and totals for the prior one, two and three years. The antecedent precipitation was considered to account for the possibility that high precipitation the year(s) before a given fire season might allow for an increase in fine fuels that would, by the subsequent years, allow in increase in fire occurrence or size

(Keeley 2004, Jin *et al* 2014). For temperature, we focused on the seasonal high temperatures likely to affect fire occurrence and spread, calculating average maximum temperatures for Spring (March–May), Summer (June-August) and Autumn (September-November), again averaged across each ecoregion. Because our concern was to determine the impact of variation in precipitation and temperature, rather than the effect of specific values, we normalized each of these variables, using z-scores for our analyses.

For drought severity, we used annual averages of self-calibrated Palmer Drought Severity Index (PDSI) data (Wells *et al* 2004) from the WestWide Drought Tracker (www.wrcc.dri.edu/wwdt/archive.php?folder=scpdsi). These data are also calculated from PRISM data, but are coarser (2.5 minute grid). Here again we used means for the area of each ecoregion. We quantified Santa Ana wind frequency as the number of days per year with Santa Ana wind conditions or extreme Santa Ana wind conditions, as determined by Abatzoglou *et al* (2013) in their synoptic scale analysis of mean sea level pressure gradient and lower tropospheric temperature advection.

2.5. Data analyses

To determine the frequency of riparian fire, we overlaid the MTBS fire boundaries on the riparian areas as mapped by LANDFIRE, and classified the area of overlap between the two as burned riparian. From this we calculated the riparian area burned each year, the mean riparian area and percent of riparian area burned/year over the 21 years for which we had data, and extrapolated the mean recurrence interval for riparian fire across the state and within each ecoregion. We did the same with upland (i.e. non-riparian) fire, to allow for comparison.

To compare the seasonality of riparian fire among ecoregions, we calculated the percentage of riparian area burnt in each ecoregion in fires starting during each month of the year. To assess the impact of climate on year-to-year variation in riparian fire we regressed z-scores of riparian fire for each ecoregion on all possible combinations of the climatological variables. We report only those regression results for which both the overall model and the parameter estimates were significant ($p < 0.05$). Because no multiple regression equations met these criteria, collinearity was not an issue.

3. Results and discussion

3.1. Frequency of riparian fire and variation among ecoregions

Overall, an average of 1197 ha of California riparian vegetation burned per year. This amounts to 0.12% of the area mapped as riparian vegetation, and extrapolates to an 833 year mean fire interval (MFI). For comparison, 0.32% of the upland area burned each year, for a 318 year MFI. While these totals confirm that fire in the moist riparian zone is more limited than in the uplands, they also show that a substantial area of riparian habitat does burn each year. Perhaps more important, the totals obscure the substantial variance that exists among ecoregions. Figure 2 illustrates that variance, and shows that while riparian fire is almost non-existent in some ecoregions (Central California Valley, Northern and Southern Basin and Range), it is widespread in others, especially in Southern California. Indeed, in the Southern California Mountains ecoregion, 1.35% of riparian habitat burned annually, for a MFI of 74 years—a recurrence interval shorter than that of many of the classic fire-adapted conifer forests of the western US (e.g. Baker and Kipfmueller 2001).

The ecoregions can be roughly grouped by their extent of riparian burning (table 1). The low frequency group is dominated by the interior desert ecoregions (especially Northern and Sonoran Basin and Range), although the Central California Valley and the moister Coast Range and Cascades also fall within this group. These are mostly ecoregions within which large wildfires are rare (recall that this analysis only includes fires for which the overall size including both uplands and riparian exceeded 4 km^2) due to either limited fuels or moist conditions, although their frequency in the deserts may be increasing due to arrival of exotic species as well as ongoing climate change (Brooks and Matchett 2006, Abatzoglou and Kolden 2011). In the Central Valley, the scarcity of large fires is probably more due to intensive agricultural land use. Throughout the low frequency group, the riparian fire that did occur tended to be concentrated in one or two years (indeed often one or two fires) during the period we examined (figure 3).

The intermediate frequency group includes the conifer-dominated Sierra Nevada as well as the oak and pine woodland areas of the Central California Foothills and Coastal Mountains and the Klamath Mountains/California High North Coast Range where the uplands are dominated by mixed conifers and hardwoods. The mean area burned in the Sierra Nevada extrapolates to a MFI of 611 years, which is substantially longer than the fire intervals reported by Van de Water and North (2010). This discrepancy is unsurprising given the different sampling strategies: our analysis includes all of the area categorized as riparian in the LANDFIRE data, whereas their study explicitly sampled sites with numerous fire scarred trees and remnants. The high frequency riparian fires were in the chaparral landscapes of the Southern California Mountains and Southern California/Northern Baja Coast. This is a context in which large wildfires are common. It is also one in which, under extreme fire weather conditions, fuel characteristics offer little impediment to the spread of those fires (Keeley *et al* 2004). It is thus unsurprising that even the

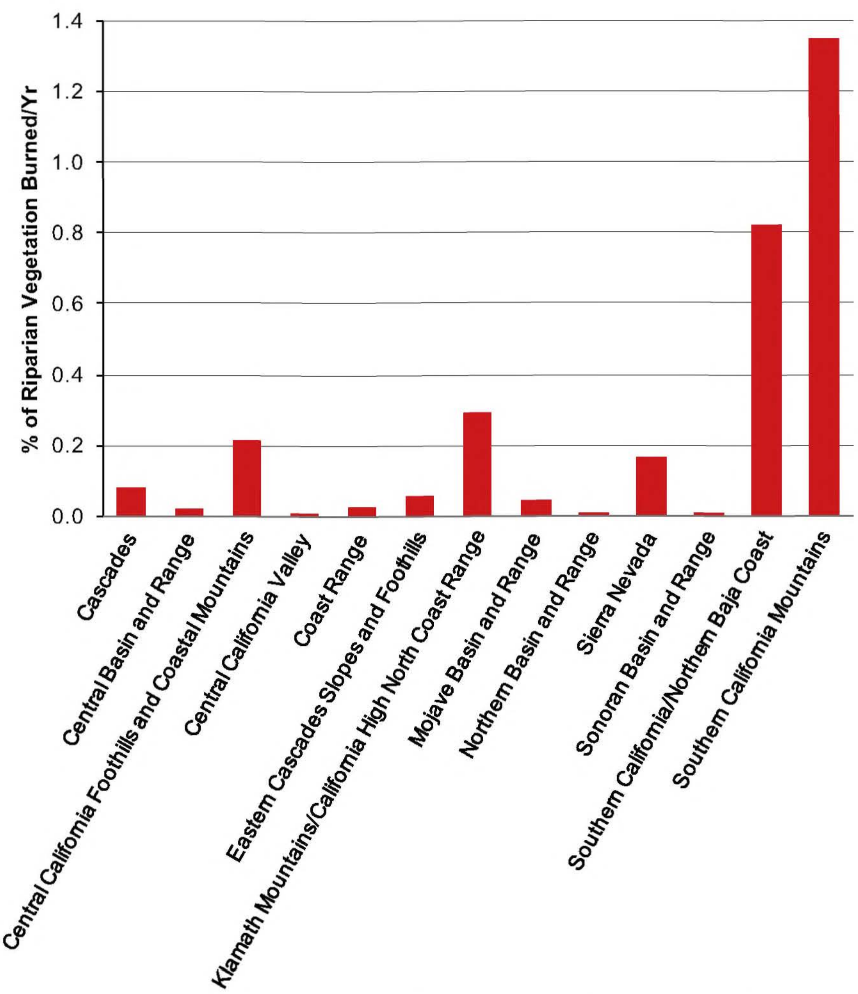

Figure 2. Percent of riparian vegetation burned annually in California ecoregions.

Table 1. Mean (± standard deviation) percent of riparian vegetation burned annually within ecoregions.

Ecoregion	Mean (± SD)
Low frequency (<0.1% yr^{-1})	
Sonoran Basin and Range	0.00 (± 0.00)[a]
Northern Basin and Range	0.01 (± 0.02)
Central California Valley	0.01 (± 0.02)
Central Basin and Range	0.02 (± 0.06)
Coast Range	0.03 (± 0.06)
Mojave Basin and Range	0.04 (± 0.17)
Eastern Cascades Slopes and Foothills	0.06 (± 0.14)
Cascades	0.08 (± 0.23)
Intermediate frequency (0.1%–0.5% yr^{-1})	
Sierra Nevada	0.16 (± 0.18)
Central California Foothills and Coastal Mountains	0.21 (± 0.29)
Klamath Mountains/California High North Coast Range	0.29 (± 0.63)
High frequency (>0.5% yr^{-1})	
Southern California/Northern Baja Coast	0.82 (± 1.68)
Southern California Mountains	1.35 (± 2.12)

[a] Non-zero values for Sonoran Basin and Range are obscured by rounding.

riparian zone would burn (relatively) frequently in such a fire-prone setting. Table 1 and figure 3 also show that the interannual variability in area burned was high, with the standard deviation being more than twice the mean for most ecoregions.

3.2. Comparison of riparian to upland fire frequency

Although it seems reasonable to relate riparian fire frequency to that in the surrounding landscape, the actual relationship between the riparian and upland fire proved to be spatially variable. Table 2 shows that

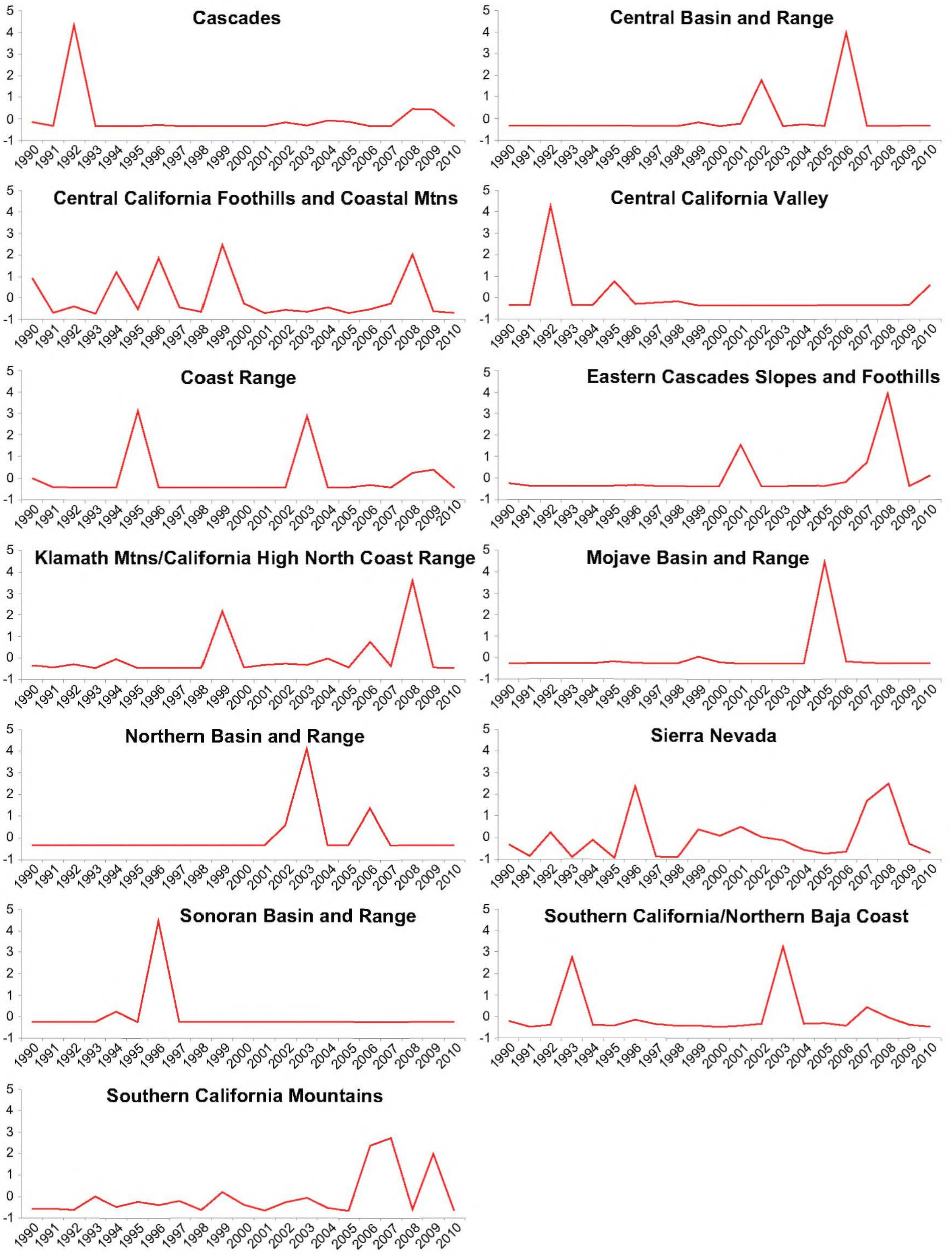

Figure 3. *Z*-scores of riparian area burned annually within each ecoregion.

the ratio of percent riparian area burned to that of the uplands ranges from less than 0.1 in the Sonoran- and Northern- Basin and Range to more than 1.0 in the Mojave Basin and Range. It is notable that these extremes are all in desert ecoregions where fire is rare enough (only 2 in the 21 years for Northern Basin and Range) that the ratios are strongly influenced by individual fires. The same is true of the correlation between riparian and upland annual area burned: the ecoregions where the correlations are non-significant (table 2) are all in the low frequency group (table 1). Where fire is more frequent (the intermediate and high frequency groups), the ratios between riparian and upland area burned are more intermediate (0.40 to 0.89) with the highest ratios, unsurprisingly, in the ecoregions with the most riparian fire. Similarly, the correlations for annual area burned are all above 0.85 for these groups.

3.3. Seasonality of riparian fire occurrence

Figure 4 shows the percent of riparian area burned within each ecoregion by fires starting in each calendar

Table 2. Ratio of percent riparian to percent upland area burned, and correlation between percent riparian and upland area burned annually within California ecoregions[a].

Ecoregion	Ratio	r	Significance
Low frequency ($<0.1\%$ yr^{-1})			
Sonoran Basin and Range	0.00[b]	0.03	0.908
Northern Basin and Range	0.08	0.82	0.000
Central California Valley	0.14	0.14	0.549
Central Basin and Range	0.25	0.70	0.000
Coast Range	0.30	0.55	0.009
Mojave Basin and Range	1.40	0.98	0.000
Eastern Cascades Slopes and Foothills	0.42	0.36	0.104
Cascades	0.44	0.93	0.000
Intermediate frequency (0.1%–0.5% yr^{-1})			
Sierra Nevada	0.40	0.82	0.000
Central California Foothills and Coastal Mountains	0.59	0.93	0.000
Klamath Mountains/California High North Coast Range	0.59	0.96	0.000
High frequency ($>0.5\%$ yr^{-1})			
Southern California/Northern Baja Coast	0.89	0.89	0.000
Southern California Mountains	0.67	0.91	0.000

[a] $n = 21$ (1990–2010)

[b] Non-zero value for Sonoran Basin and Range is obscured by rounding.

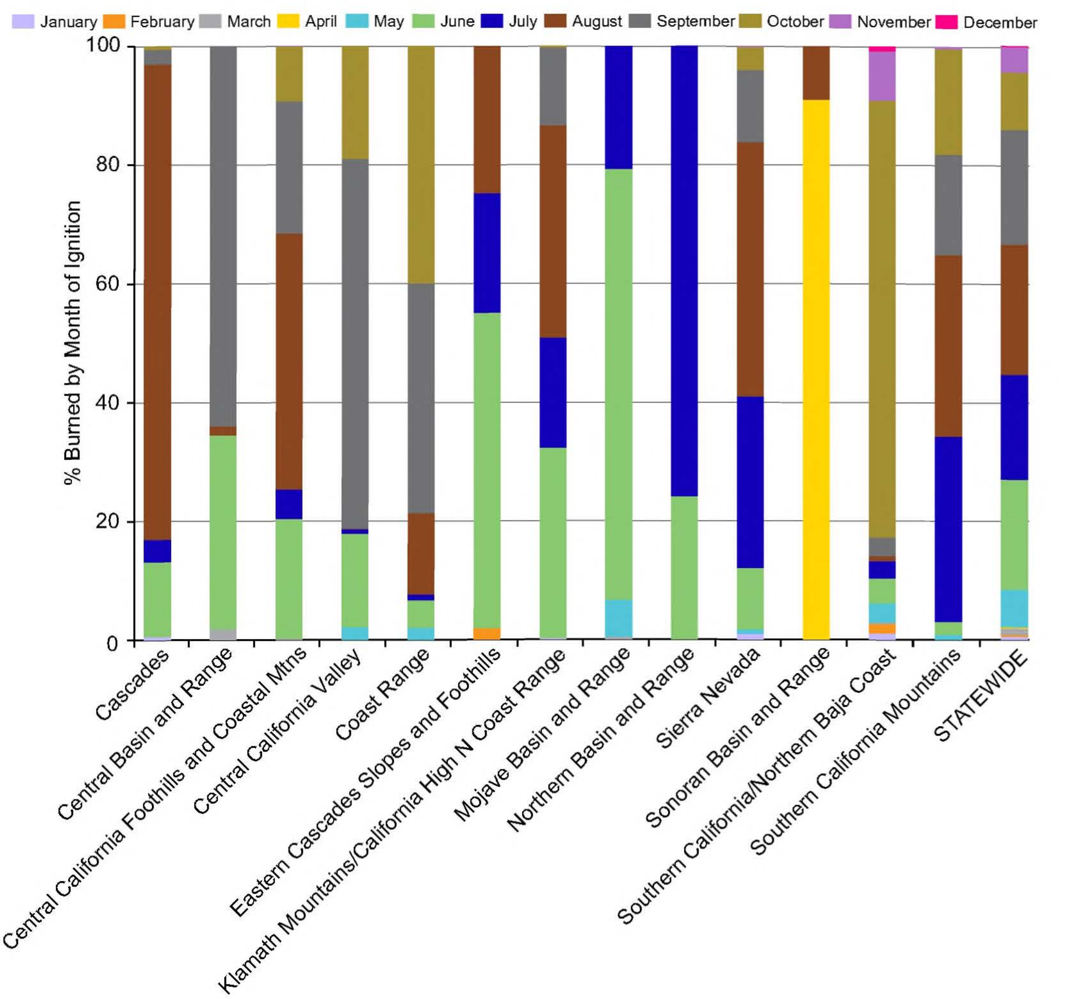

Figure 4. Percent area burned by month of ignition.

Table 3. Summary of regression results relating z-scores of riparian area burned annually to climate variables, by ecoregion[a].

Ecoregion	Climate variable	b	R^2	Significance
Cascades	Spring maximum temperature	0.435	0.19	0.049
Central California Foothills and Coastal Mountains	Previous year precipitation	0.557	0.32	0.009
Coast Range	Spring precipitation	0.475	0.24	0.025
Mojave Basin and Range	Same year precipitation	0.565	0.32	0.008
Sierra Nevada	Summer maximum temperature	0.554	0.31	0.009
Southern California Mountains	Extreme Santa Ana wind	0.164	0.45	0.001

[a] $n = 21$ (1990–2010); Durbin-Watson statistics indicate absence of autocorrelation in the residuals for each of the regression equations.

month. As might be expected given the Mediterranean climate that typifies much of the state, fires starting in June, July, August or September accounted for most of the riparian area burned (77.5%). Fires starting in August burned the largest riparian area (21% overall), reflecting both the drying of fuels and in many instances the diminishment of stream discharge in the latter part of the summer drought period.

The principal exception to this overall pattern was in the Southern California/Northern Baja Coast ecoregion, with 73.6% burned in fires that started in October. This is in keeping with a region where the largest fires generally occur in Santa Ana (foehn wind) conditions (Keeley *et al* 2009). Santa Ana wind conditions are most common in fall and winter, and Santa Ana-driven fires in southern California are most likely to begin in October (Bendix 2015). The Southern California Mountains ecoregion also had a substantial number of October-initiated fires that burned riparian areas, but the greatest area (31.2%) burned in fires starting in July. This is due specifically to the impact of the very large 2007 Zaca Fire, which began in August, and perhaps more generally to the fact that in the more northerly part of the ecoregion autumn foehn winds are less common and have less influence on the fire regime (Keeley 2004). Santa Ana winds do remain important in this ecoregion, however, as discussed below (section 3.4). In the Sonoran Desert, the April 1996 Sheep Fire skewed the area burned into the spring, simply because it was the larger of just two fires in our data that had burned riparian area within the ecoregion.

3.4. Climate influence on riparian fire

Only six of the ecoregions had significant relationships between any climate variable and the annual variation in riparian area burned; regressions for those relationships are summarized in table 3. Several of these are ecoregions in the low frequency group (table 1); in these regions fire was so rare that the years with extensive fire constitute outliers that may substantially affect the regression models, so that the results should be interpreted with caution. In the Cascades, maximum spring temperature explains less than 20% of the variation in riparian area burned, but the contribution is a significant one. This is a region in which Miller *et al* (2009) demonstrated significant impacts of springtime temperature on fire size, which they attributed to the impact on snowmelt (also see Westerling 2016). In their study, Miller *et al* found that in recent decades springtime temperature gave way to fire season (summer) climate variables as being the most influential, so it is interesting that riparian fire still shows the spring influence in our relatively recent data. It is possible that high spring temperatures, by accelerating snowmelt, ensure that the associated discharge peak has dissipated by fire season, so that the moisture difference between the riparian zone and the uplands is diminished.

In the Central California Foothills and Coastal Mountains, precipitation in the previous water year had a significant impact on the riparian area burned. Such a relationship has been noted for upland fire both in this region and elsewhere in California (Keeley 2004), and presumably relates to the positive impact on the growth of herbaceous fine fuels. Indeed, it is less surprising that this variable was correlated in this ecoregion than that it was uncorrelated in all of the others. Same-year spring precipitation explained 24% of the variance for the Coast Range. This is approximately the region (Central Coast) for which Keeley (2004) found a significant contribution by spring precipitation to overall area burned, however in his case it was spring precipitation for the previous year. He attributed the lag to the short time period for herbaceous fuels to dry between same-year spring precipitation and a presumed June peak fire season. However our findings show that most of the riparian area burned in the Coast Range was in fires that ignited later, in August through October (figure 4), apparently allowing for sufficient curing of fine fuels. In the Mojave Basin and Range, however, there is a positive relationship with annual precipitation, suggesting that in this ecoregion there was only sufficient fuel density to carry fire into the riparian zone during relatively wet years.

Summer maximum temperature was a predictor of riparian area burned in the Sierra Nevada, in keeping with studies that have found summer temperature to be a driver of Sierran forest area burned, especially in recent decades (Miller *et al* 2009, Keeley and Syphard 2015). The strongest climate relationship for riparian area burned was in the Southern California Mountains, where the number of extreme Santa Ana wind days explained 45% of the variance. Numerous scholarly studies (e.g. Keeley and Fotheringham 2001, Westerling *et al* 2004), along with common experience among wildland firefighters (multiple sources, personal communication), attest that extreme Santa Ana wind conditions are dramatically capable of allowing fires to spread through fuels that might be resistant under more normal climatic conditions. Presumably this includes burning through the riparian zone, despite its generally mesic contrast with the surrounding chaparral.

The lack of significant climatic drivers for riparian fires in many of these ecoregions, and limited explained variance for those regions in which significant drivers were found, may simply be in keeping with Keeley (2004) finding that little variance of fire in the region is explained by climate regression models. But it is also worth noting that there is logic to riparian environments being less responsive to climate variability than the surrounding uplands. To the extent that drought or high temperatures contribute to drying fuels in the landscape at large, the higher water table near streams should provide some buffer from that impact. By the same token, in dry ecoregions where moist years contribute to the growth of fine herbaceous fuels, that is likely to make less of a difference in the relatively moist riparian zone than in the dryer uplands. This is not to say that climate has no impact on riparian fire, for it demonstrably does in some instances. But it is unsurprising that those impacts would be relatively limited in the riparian context.

4. Conclusions

A variety of field studies have indicated that where riparian vegetation burns the ecological impacts may be substantially different than those of the more commonly studied disturbance by flooding (Pettit and Naiman 2007a, Bendix and Cowell 2010a), but there have been no regional scale studies to indicate whether such impactful fires are commonplace or anomalous. Our results indicate that riparian fire is indeed common enough in California to be ecologically significant. But they also suggest that the frequency (and hence the likely impact) of such fire is geographically contingent. Although caution must be used in extrapolation from just 21 years of data, it appears that riparian vegetation in Southern California is particularly prone to burn, probably because of the severity of the fires that originate in the surrounding chaparral matrix. In the wettest and driest parts of the state, riparian fire is quite infrequent, presumably owing to moist conditions in the former, and sparse fuels in the latter. Several ecoregions are intermediate in the extent of riparian fire, and even within in these, there is clearly spatial variability in its frequency, as demonstrated by the dendrochronological findings of Van de Water and North (2010).

There is, similarly, geographic variation in both the seasonality of riparian fire and its responsiveness to the climatic variables that we tested. This variability makes it particularly difficult to generalize about the changes in riparian fire regime that may result from climate change. Large-scale modelling projections have tended to indicate increasing overall fire frequency across much of California (e.g. Moritz *et al* 2012, Liu *et al* 2013, but note that Parks *et al* 2016 project no change in fire severity for most of California). This seems realistic for riparian fire as well in ecoregions such as the Cascades and Sierra Nevada, where temperature increases are likely to drive increased riparian fire. Miller and Schlegel (2006) had variable results in their projection of future Santa Ana wind occurences, depending on the global climate models used, but concluded that there may be increases in those winds and their associated fire threats. Such an increase implies more riparian fire in the Southern California Mountains, where it is already the most common, and where Bendix and Cowell (2010a, 2013) have concluded that wildfires impose qualitatively and quantitatively different impacts from those of the floods that would otherwise shape the riparian plant community. Elsewhere, the impacts are less certain, as in the Mojave, where Abatzoglou and Kolden (2011) do project increased fire danger and a lengthened fire season, but their projection of decreased winter precipitation may drive the kind of low total precipitation that projects to less riparian fire in our data.

In most of the ecoregions, of course, there were no statistically verifiable climatic drivers for riparian fire, so that any projection would be entirely speculative. This uncertainty notwithstanding, it is apparent that riparian wildfire is a recurring reality in many ecoregions, and similar to wildfire more generally, is likely to change as climate does. Given the importance of riparian habitat in California, and the challenges inherent in fire management within that habitat (Van de Water and North 2011, North 2012), the occurrence, the geographic variability, and the likely future changes in riparian fire will all merit attention from scholars and land managers alike.

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