TRADE-OFFS OF REDUCING CHAPARRAL FIRE HAZARD

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ABSTRACT

Fire risk reduction is not always mutually beneficial for people and nature especially in areas with natural stand replacing fire systems. Sometimes there is an inverse relationship, as fire risk decreases the rate of fundamental shifts in plants composition increase. For example, non-native plants invade after all fuel reduction treatments, but only persists in areas with the greatest reduction in fire risk. Therefore, land managers face an acute dilemma between protecting people or nature. Fuel reduction treatments, such as prescribed fire and mastication, are widely applied to reduce fire risk. These treatments help protect homes and communities from fire yet facilitate the invasion of non-native species in the short-term. In the long-term, the ecological trajectory and fire risk of these treatments is poorly understood. We address these research gaps with a 13 year study evaluating how fire risk, non-native species invasion, and preferred deer browse change through time in California's northern chaparral. About ten years post treatment the fuel reduction treatments (fire/ mastication) and their season (fall/winter/spring) have unique influences on plant communities and fuel loads. In contrast to fire, mastication reduces more shrub cover for longer, while it also increases the amount of non-native plants, non-native annual grasses, and preferred deer browse. The treatments' season also influences the outcome, but to a lesser magnitude. Fall fire and mastication treatments have lower shrub cover for longer, and more non-native plants, non-native annual grasses, and preferred deer browse than spring or winter treatments. Based on our findings we conclude that all fire hazard reduction treatments have trade-offs which must thoroughly considered before implementation.

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Cover photo by Danny Fry.

The trade-offs of reducing chaparral fire hazard

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Abstract

Fire risk reduction is not always mutually beneficial for people and nature especially in areas with natural stand replacing fire systems. Sometimes there is an inverse relationship, as fire risk decreases the rate of fundamental shifts in plants composition increase. For example, non-native plants invade after all fuel reduction treatments, but only persists in areas with the greatest reduction in fire risk. Therefore, land managers face an acute dilemma between protecting people or nature. Fuel reduction treatments, such as prescribed fire and mastication, are widely applied to reduce fire risk. These treatments help protect homes and communities from fire yet facilitate the invasion of non-native species in the short-term. In the long-term, the ecological trajectory and fire risk of these treatments is poorly understood. We address these research gaps with a 13 year study evaluating how fire risk, non-native species invasion, and preferred deer browse change through time in California's northern chaparral. About ten years post treatment the fuel reduction treatments (fire/ mastication) and their season (fall/winter/spring) have unique influences on plant communities and fuel loads. In contrast to fire, mastication reduces more shrub cover for longer, while it also increases the amount of non-native plants, non-native annual grasses, and preferred deer browse. The treatment's season also influences the outcome, but to a lesser magnitude. Fall fire and mastication treatments have lower shrub cover for longer, and more non-native plants, non-native annual grasses, and preferred deer browse than spring or winter treatments. Based on our findings we conclude that all fire hazard reduction treatments have trade-offs which must thoroughly considered before implementation.

Key words: California, chaparral, fuel reduction treatments, prescribed fire, mastication, long-term study

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Background

Many people live in the Wildland Urban Interface near highly flammable natural areas which has contributed to a large loss of human life and structures during wildfires (Stephens, Adams et al. 2009). Therefore wildland fire risk reduction is a priority for California's Wildland Urban Interface due to the great wildfire losses and suppression costs especially since costs are most likely to increase with climate change (Westerling and Bryant 2008, Stephens, Adams et al. 2009, Batllori, Parisien et al. 2013). Risk is the combination of wildland fire consequences, such as the loss of property and/or life, and/or the likelihood of fire occurrence. Fuel reduction treatments, such as prescribed fire and mastication, are widely applied to reduce fire risk . These treatments help protect people and their communities from fire (Gill and Stephens 2009, Mutch, Rogers et al. 2011), yet can impact wildlife populations by, for example, shifting the composition of plant communities (Briese 1996, Merriam, Keeley et al. 2006, Potts and Stephens 2009). Fuel reduction treatments can also facilitate the invasion of non-native species in the short-term. In the long-term, the ecological trajectory and fire risk of these treatments is poorly understood yet they are widely applied in many ecosystem types.

Chaparral constitutes only 7% of California, it hosts more than one-quarter of its endemic vascular flora and fauna— nearly half of which are only found in chaparral (Keeley and Davis 2007). Like Mediterranean shrublands, it is highly fire resilient and historically burned high-severity stand replacing events typically every 30 to 100 years (Quinn and Keeley 2006). Chaparral communities have been displaced by frequent fires beginning with Native American prescribed burning and extending into the modern period with increased accidental ignitions (Cooper 1922, Keeley 2002, Vale 2002, Keeley and Fotheringham 2003). Today frequent fires convert chaparral from a native shrubland to non-native annual grassland and drastically reduce species diversity (Keeley 2002). Infrequent fires in combination with climate change induced severe drought may also convert chaparral to non-native annual grassland (Langan, Ewers et al. 1997, Pratt, Jacobsen et al. 2013). Fire and mastication, two of the most common fuel reduction treatments, also facilitate non-native plant invasion which together create the greatest concern for chaparral conservation and at the same time increase wildfire risk for people in the wildland urban interface (Brooks, D'Antonio et al. 2004, Keeley, Baer-Keeley et al. 2005). This is due to delayed canopy closure, allowing non-native annual grasses to invade (Keeley, Baer-Keeley et al. 2005).

Prescribed fires in chaparral are also controversial because they commonly occur outside of the historical fire season, e.g. in winter or spring rather than fall, to reduce the rate of fire spread and thus the potential of an escaped fire, air quality restraints are minimized, and personal and equipment are easily available outside of wildfire season. Fire outside of the historical season is of concern because it may lead to shifts in plant communities due to decreases of obligate fire seeders, like *Ceanothus cuneatus* (buckbrush) and other rare herbs (Parker 1987, Parker 1987, Keeley and Fotheringham 2001, Keeley 2002, Potts, Marino et al. 2010). Some attribute the lack

of obligate fire seeders to shortened growing season (Knapp, Estes et al. 2009) soil moisture resulting in steaming seeds to death or heat sensitive imbibed seeds (Le Fer and Parker 2005). In contrast, others conclude that an indirect effect of season, fire intensity driven by seasonal weather and fuel moistures, rather than the season itself is the main driver of post-burn plant community composition changes (Knapp, Estes et al. 2009). Research about the influence of season, however is sparse and contradictory; ex-situ experimentation suggests a mechanism, moist soil kills seeds, for a seasonal influence (Le Fer and Parker 2005) whereas results from a short-term field study do not suggest a seasonal influence (Beyers and Wakeman 2000). Season may also play an important role in competition between natives and non-natives; the timing of treatment may allow non-natives to become established before natives begin to germinate or grow. We will parse-out the effect of season in terms of plant physiology, plant competition, and treatment efficacy. This is the first long-term and large-scale experimental study to examine the seasonal influence of treatment on plant communities especially with distinct treatment type such as fire and mastication.

Broadly we test the hypothesis, are treatment severity and consequences closely linked whereby as severity increases the negative natural consequences increase. We focus on three main questions: (1) *Which fuel reduction treatment best reduces fire risk?* Following prescribed fire and mastication treatments in different seasons, the probability of fire will be assessed by site flammability, or herbaceous cover, especially nonnative annual grass. The probability of catastrophic fire for humans where loss of life or property is likely will be evaluated with estimates shrub height, cover, and biomass. (2) *Which fuel reduction treatment minimizes nonnative species invasion and persistence?* We will evaluate non-native species abundance. (3) *What are other ecological effects of fuel reduction treatments such as wildlife habitat?* We will evaluate shrub cover of buckbrush which is a preferred black-tailed deer forage. To address these research gaps, we evaluate 13 years of ecological and fire risk changes caused by fuel reduction treatments (fire/mastication) with a seasonal affect.

Methods

Study site

The study was conducted in northern California's Coast Range chaparral, approximately 50 km inland from the Pacific Ocean and 175 km north of San Francisco, CA (39°N, 123°W) near Ukiah, California (Figure 1) (Potts and Stephens 2009). Before treatment, the study sites were ecologically similar to chamisal chaparral throughout California (Figure 2) (Barbour 1999). Sites were dominated by *Adenostoma fasciculatum* (chamise) with more than 65% cover, and buckbrush and *Arctostaphylos spp.* (manzanita) were also common. These shrubs formed a nearly continuous canopy ranging from one to two meters high with little to no understory present. Nonnative annual grasses were rare and restricted to shrub gaps or the roadside. Soils are shallow, rocky, and moderately acidic, derived from weathered sandstone and shale. The study sites were 214 to 305m above sea level on steep (25 to 55%), southern- and western-facing

slopes. Nearby vegetation transitioned to mixed oak woodlands on mesic, north-facing slopes and *Pinus attenuata* (knobcone pine) stands on ridge tops and east-facing slopes. The southern plots were also near grasslands which were historic chaparral converted to rangeland (Figure 1). The region has a typical Mediterranean climate with hot, dry summers and cool, wet winters (Figure 3).

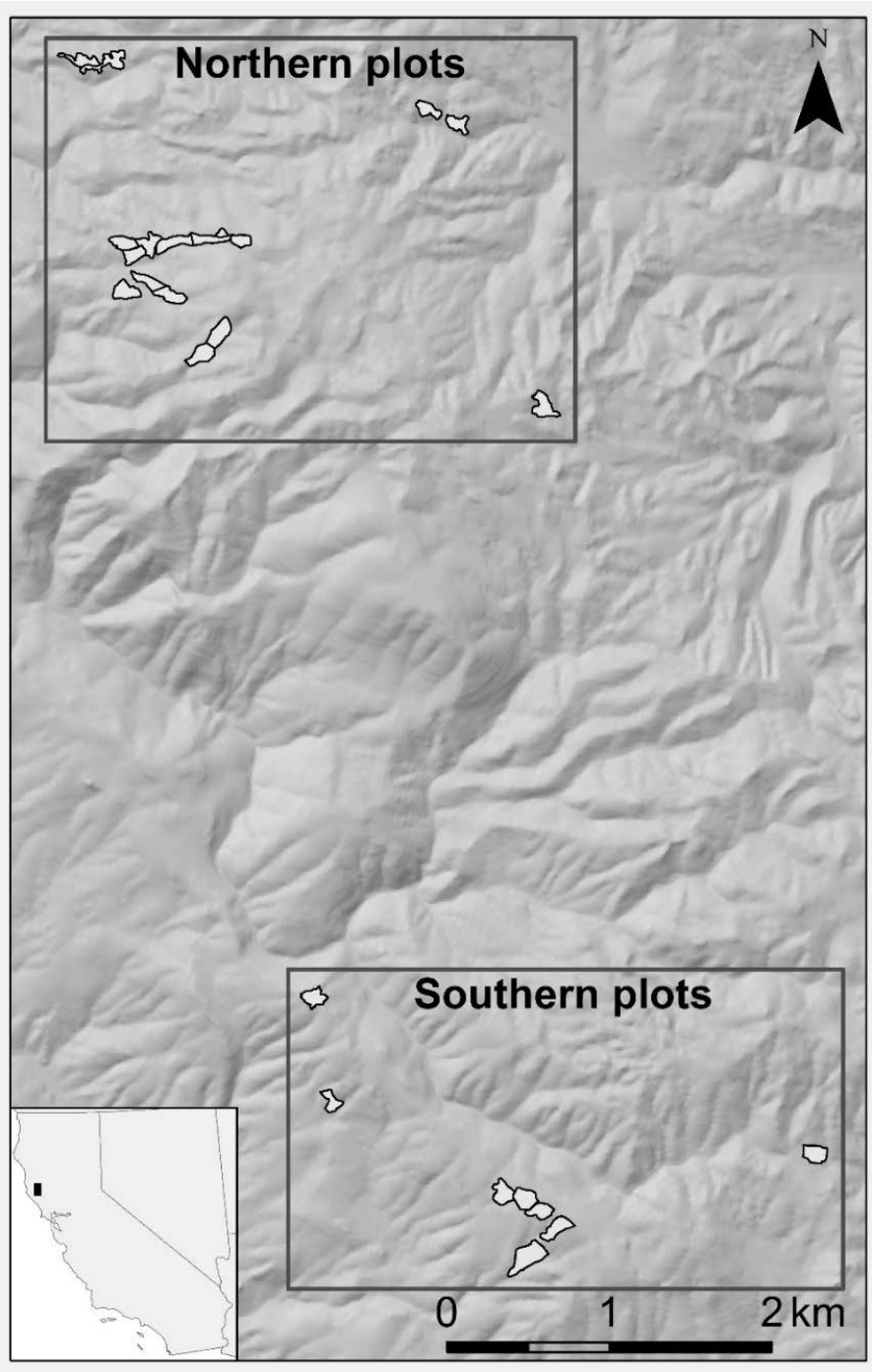

Figure 1. The study was completed ~ 50 miles north of San Francisco near Ukiah, CA. The southern plots are located at the UC Hopland Research & Extension Center. The northern plots are mostly located at BLM's South Cow Mountain OHV Recreation Area. Two other northern plots are located on adjacent private lands.

Figure 2. South to west facing chamisal chaparral at Lost Valley at the BLM's South Cow Mountain Recreation Area. This area had six experimental units adjacent to one another including fire and mastication in spring and winter. Unit boundaries included the two-track road to the top, riparian area to the bottom, and drainages or ridges in between units (Photo credit: D. Fry)

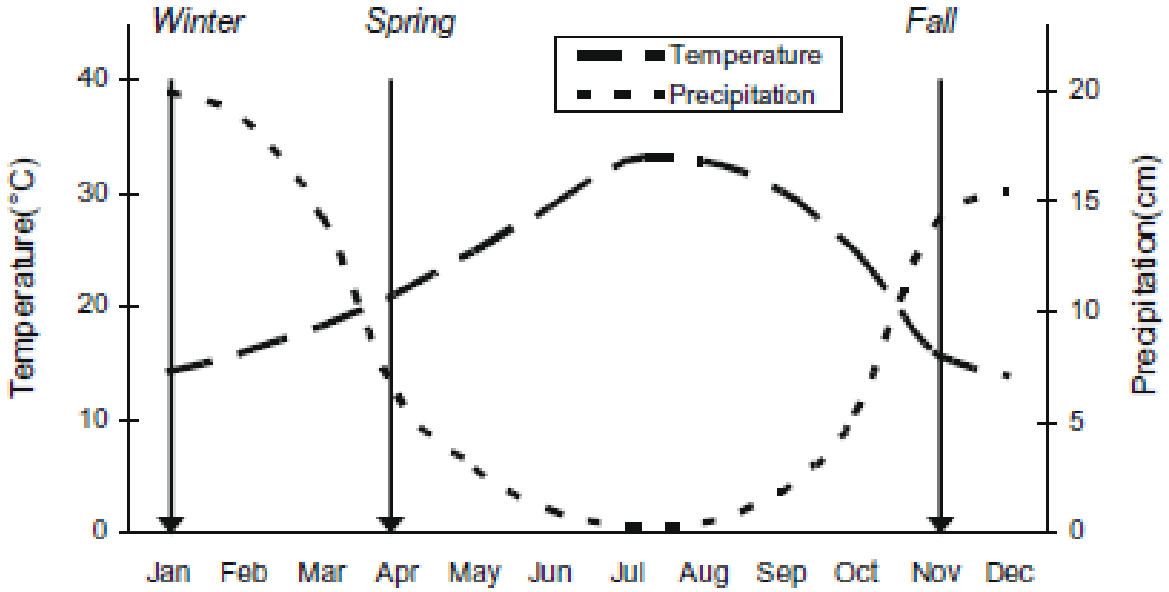

Figure 3. Monthly temperature and precipitation averages for the study area. Arrows indicate the three different seasons of treatment implementation. (From Potts and Stephens 2009)

Study design

The study area was chosen in cooperation with researchers, University of California Hopland Research & Extension Center managers, US Bureau of Land Management South Cow Mountain Recreational Area managers, and a private land owner. Late succession chaparral was chosen for the study where fire and other major disturbances were absent from area for at least 40 years. Experimental units were clustered in the south at University of California Hopland Research & Extension Center and in the north at US Bureau of Land Management South Cow Mountain Recreational Area and an adjacent private land owner (Figure 1). The study area was divided into 24 nearly two hectare experimental units where each of the five fuel reduction treatments and a control were assigned and replicated four times (Table 1, Figure 4).

Table 1. Two field reduction treatments were completed over three seasons Treatments generally occurred during the same time period. Springs mastication treatments were conducted later than spring fire treatments because roads were not dry enough for masticator access. There was no winter mastication treatment because it is not a management option --- masticators damage seasonally wet roads and slopes.

Fuel reduction	Season	Treatment dates
Fire	Fall	November 3-20
	Spring	March 31-3 April
	Winter	January 8-18
Mastication	Fall	November 3-20
	Spring	April 23-June2
Control	No treatment	

Figure 4. Fuel reduction treatments included a prescribed fire, mastication, and a control (left to right). (Photo credit: D. Fry, D. Fry, and K. Wilkin)

Study design was influenced by operational limitations. Mastication was limited to lower grade slopes by equipment maneuverability and safety in steeper terrain. Prescribed fire required fuel breaks and favorable weather conditions to safely conduct burns. All treatments were implemented 2001-2003 (Table 1). These considerations resulted in a non-random distribution of experimental units through both space and time (Figure 5).

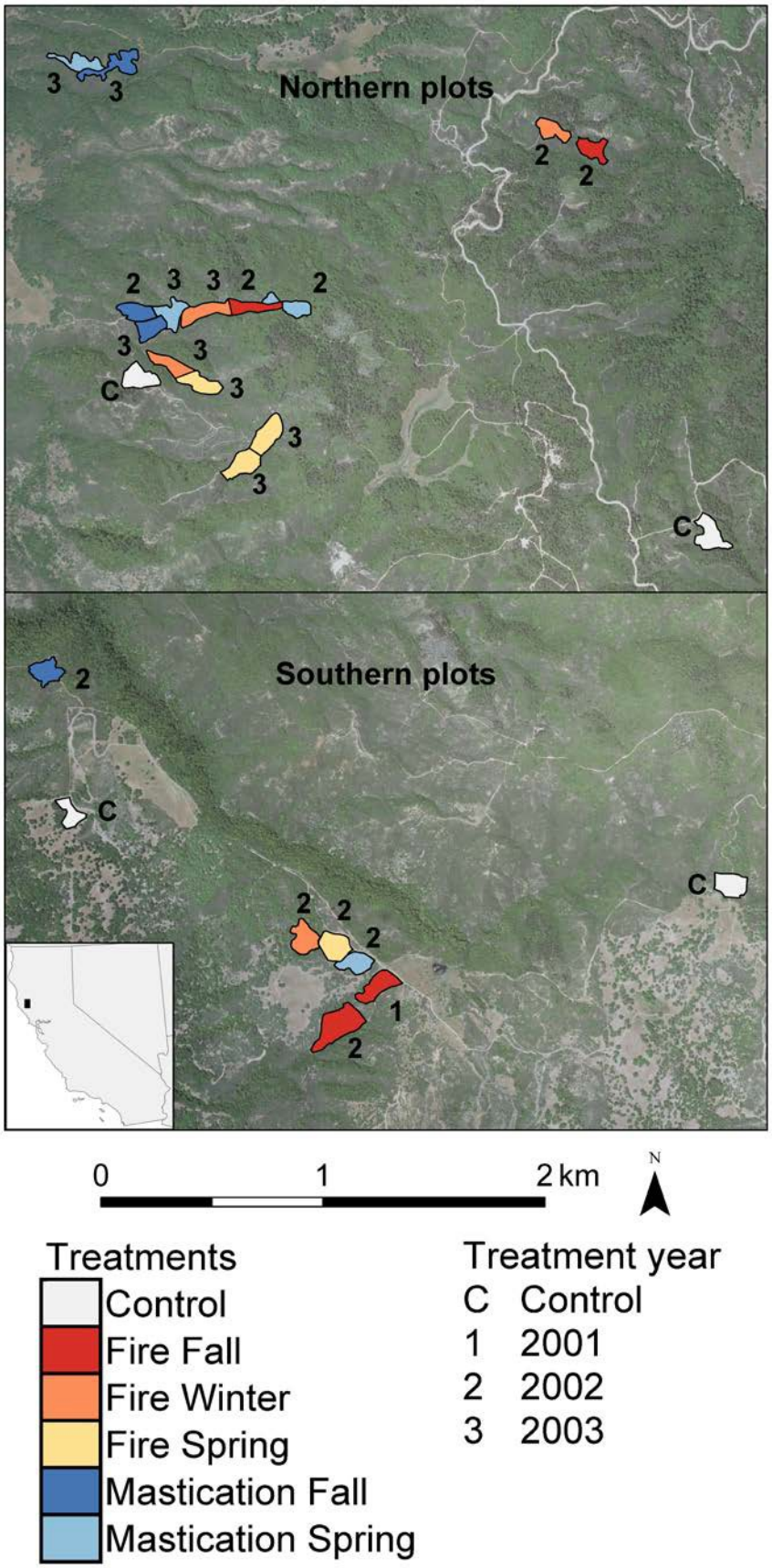

Figure 5. Treatment type, season, and year were distributed across both northern and southern study regions. The treatment for each unit was determined by safety concerns to reduce fire escape risk and heavy machinery instability risk.

Prescribed fires were set to consume as much vegetation as possible, they were ignited with drip torches at the slope's base and produced upslope headfires (Stephens, Weise et al. 2008). Mastication was performed by a track bulldozer with a front mounted rotating toothed drum which shredded aboveground biomass (surface woody debris < 5 cm deep). Particle size ranged from 10 to 40 cm in length by 5 to 10 cm in width. Sub-surface soil and root systems were not disturbed by the masticator. Treatment heterogeneity was minimal in mastication units since the equipment operator performed systematic passes through vegetation. Both fire and mastication reduced vegetation cover reduced by 90 to 100%. (Potts and Stephens 2009) (Figure 6)

Mastication Fire

Figure 6. The fuel reduction treatments, fire and mastication, reduced vegetation cover by 90 to 100%. Mastication redistributed all of the shrub pieces to the ground and there was a discontinuous layer of fuel (top left and bottom left). Fire consumed the fine materials and left larger diameter stems standing (top right and bottom right). (Photo credit: J. Potts and D. Fry)

Sample design

Transects

Woody plant cover and height, and fuels were sampled along 15 meter transects (Figure 7). Prior to treatment, 15 randomly distributed permanent transects were installed and sampled within each experimental unit.

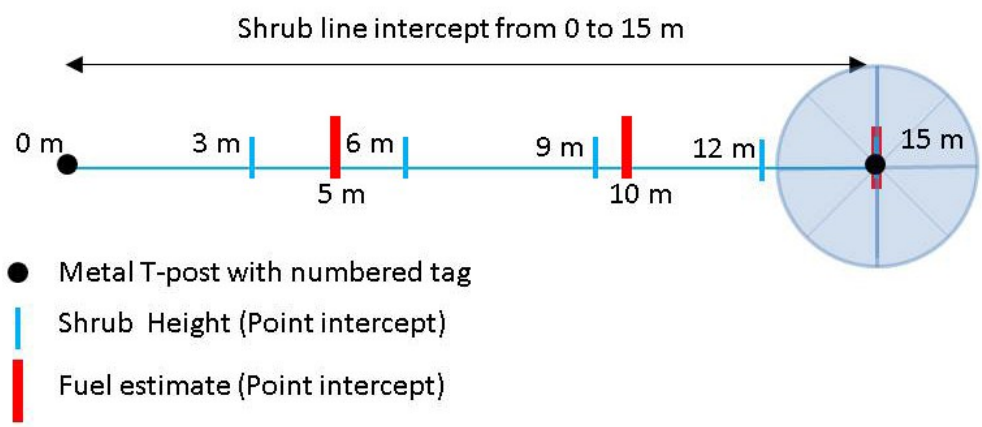

Figure 7. Shrub cover and composition are recorded by continuous line-intercept transect from zero to 15 meters. Shrub height and fuel estimates were recorded at intervals along the transect. Understory plant count and cover are recorded in 1.8 m radius plot which occurred at either the zero of 15m transect endpoint; two of the eight sections were randomly selected before treatment and were monitored.

Plots

Shrub seedling and understory plant count and cover were recorded in 2.5 m^2 vegetation sampling quadrats (Figure 7). Prior to treatment, ten understory plots were randomly established at transect endpoints. Only five of the ten understory plots were resampled in 2012. The other five plots were herbivore exclosures which degraded during the last decade. Degraded exclosures affected plant composition and structure because the wire mesh (1.5 m tall with 1.27 cm squares) was no longer supported by posts and laid irregularly on vegetation.

Data collection

(1) Which fuel reduction treatment best reduces fire risk?

(1a) The probability of fire will be assessed by site flammability or herbaceous cover, especially nonnative annual grass.

Understory non-native annual grass count
Non-native annual grass counts were measured prior to treatment, during the second and third summers after treatment, and in 2012 for burnt and masticated units. Control plots were measured once between 2001 and 2004 and again in 2012.

(1b) The probability of a catastrophic fire for humans will be evaluated with estimates of total fuel biomass and shrub cover.

Shrub cover and height
Woody plant cover and height were measured along transects prior to treatment, during the second and third summers after treatment, and in 2012 for burnt and masticated units (Figure 7). Control plots were measured once between 2001 and 2004 and again in 2012. Shrub and canopy gaps are measured continuously along the line-intercept transect to the nearest centimeter. Shrub height is measured to the nearest centimeter five times at 3 m intervals along each transect (Figure 7).

Fuel biomass
In 2012 alive and dead fuel was estimated following Cowan's (2011) pole-contact method based on three points along each transect (Figure 7) (Cowan 2011). Each branch that contacts the pole was recorded as dead or alive, it is diameter is measured in millimeters, and recorded. If a branch contacted the pole on two or more occasions, each contact point was measured as a separate occurrence and recorded. If dead fuel occurred on the ground that remains from treatment, such as fallen branches in mastication plots, the species and fuel size were measured and recorded.

(2) Which fuel reduction treatment minimizes nonnative species invasion and persistence?

Non-native plant data will be extracted from both the understory plant count and woody plant cover (see Understory plant count and Woody plant cover and height above).

(3) What are other ecological effects of fuel reduction treatment, including deer forage?

Shrub composition
The cover of *Ceanothus cuneatus* will be extracted from woody plant cover (see above).

Analysis

We constructed models to represent our biological hypotheses for the drivers of chaparral succession after treatments. Particularly we wanted to examine how the different treatment and the season they were applied affected the trajectory of the plant community. However, the treatment and its season are difficult to incorporate into a single analysis because fires occurred in fall, winter, and spring, while

mastication only occurred in fall and spring (Table 1, Figure 7). In addition, controls did not receive a treatment so season is not relevant. Therefore, to examine the trajectory of the plant communities following treatment, we asked three interrelated questions about the effect of the treatments on the response variables of interest:

1) Is the effect of the treatments distinct from the control (Equation 1)?
2) Does the season of treatment affect the outcome within each treatment type (Equation 2)?
3) Do the treatments and the season they were applied in (restricted to fall and spring) have distinct outcomes (Equation 3)?

We also included environmental variables that may influence the response variables of interest. We included site harshness (slope and solar radiation index (McCune and Keon 2002)) and precipitation (survey year annual precipitation or precipitation one year post treatment based on growing season (August to July) (UC Hopland Research & Cooperative Extension 2014)) as explanatory variables in the models (Appendix A1, A2). In addition, we modeled the effect of random variability between and within sites (experimental unit and transect), and management type (UC Hopland Research & Extension Center, BLM South Cow Mountain ORV, or private ranch). We used linear and generalized linear mixed effects models to test the significance of response variables between treatments through time (Bates 2014, Bates 2014, Kuznetsova 2014) (Table 2). All analyses we conducted in R3.1.2 (R Development Core Team 2008)

γ ~ **Treatment * Survey Year**
+ **Survey Year Precipitation + Solar Radiation Index + Slope +**
Property Owner + Experimental Unit + Plot

Equation 1. To compare fire and mastication to the control across survey years, the full model includes fire hazard reduction treatments (fire/mastication) and environmental variables. Control includes both control units and pre-treatment measurements. **Fixed effects are bolded.** Random effects are plain text.

γ ~ **Growing Seasons since Treatment * Season**
+ **Survey Year Precipitation + Solar Radiation Index + Slope +**
Property Owner + Experimental Unit + Plot

Equation 2. To compare seasons within a fire hazard reduction treatment (fire or mastication), the full model includes fire hazard reduction treatments (fire/mastication) and environmental variables. No controls or pre-treatment measurements are included. **Fixed effects are bolded.** Random effects are plain text.

γ ~ **Treatment *Season** + **Growing Seasons since Treatment * Season**
+ **Survey Year Precipitation + Solar Radiation Index + Slope +**
Property Owner + Experimental Unit + Plot

Equation 3. To compare fire and mastication across growing seasons, the full model includes fire hazard reduction treatments (fire/mastication) and environmental variables. No controls or pre-treatment measurements are included. **Fixed effects are bolded.** Random effects are plain text.

If any of the seasonal tests, Equations 2 & 3, suggests that season effects the outcome biologically or statistically (p-value < 0.10), then we report the results from the within treatment tests and the between treatment tests restricted to fall and spring. If none of the tests suggests that season effects the outcome (p-value > 0.10), then we drop season as an analysis variable and expand the between treatment test to include all seasons lumped together (fall, winter, and spring).

Table 2. Statistical model types and specifications were tailored for each data set
[1] Non-native annual grass abundance data is both sparse and variable (Appendix B). The control and fire treatments about ten years since treatment generally have no non-native annual grass present. Controls have none while fire treatments have up to 300 individuals. In contrast, mastication treatments have between 100 to 4000 non-native annual grass plants present per plot. Therefore, there is insufficient data for abundance models likely due to the magnitude of the zeros. Even zero-inflated negative binomials do not run. Therefore, we modeled the presence and absence of grasses which is also called an occupancy model.

Response variable	**Model family**	**Data**	**Mixed Effects Model**
Shrub cover	Binomial	Proportion	Generalized Linear
Buckbrush cover	Binomial	Proportion	Generalized Linear
Non-native annual grass	Binomial	Binary[1]	Generalized Linear
Shrub diameter	Normal	Raw	Linear
Shrub height	Normal	Raw	Linear
Non-native species abundance	Normal	Raw	Linear

Results

(1) Which fuel reduction treatment best reduce fire risk?

(1a) The probability of fire

Between fire, masticated, and control units, non-native annual grass occurrence for fire and mastication are significantly greater than the control (Figure 8). Fire sites have more overall non-native annual grass present than the control (p-value= 0.00231, coefficient= 6.60478+/-2.16754). Masticated sites have a marginally significant interaction with time since treatment where they are more likely than burned sites to have non-native annual grasses persist as the number of growing seasons since treatment increases (p-value= 0.06009, coefficient= 0.55391+/-0.29461). Survey year precipitation also increase the probability of non-native annual grass presence (p-value =7.47e-05, coefficient =2.39568+/-0.60484) (Appendix B, Figure B3).

Between fire and masticated units, Masticated sites have a marginally significant interaction between growing season since treatment where they are more likely than burned sites to have non-native annual grasses as the number of growing seasons since treatment increases (p-value= 0.00233, coefficient= 1.18113+/-0.38796) (Figure 9). The season in which the treatment was applied marginally influences non-native annual grass cover as well; fall has greater non-native annual grass occurrence than spring for both mastication and fire treatments (p-value= 0.05771, coefficient=-0.49996+/-0.26343) (Figure 9, 10). Precipitation also has a significant positive non-native annual grass presence (p-value= 0.01659, coefficient= 3.76119+/-1.57005, Appendix B, Figure B3).

Within fire units, season is not significant (Figure 10).

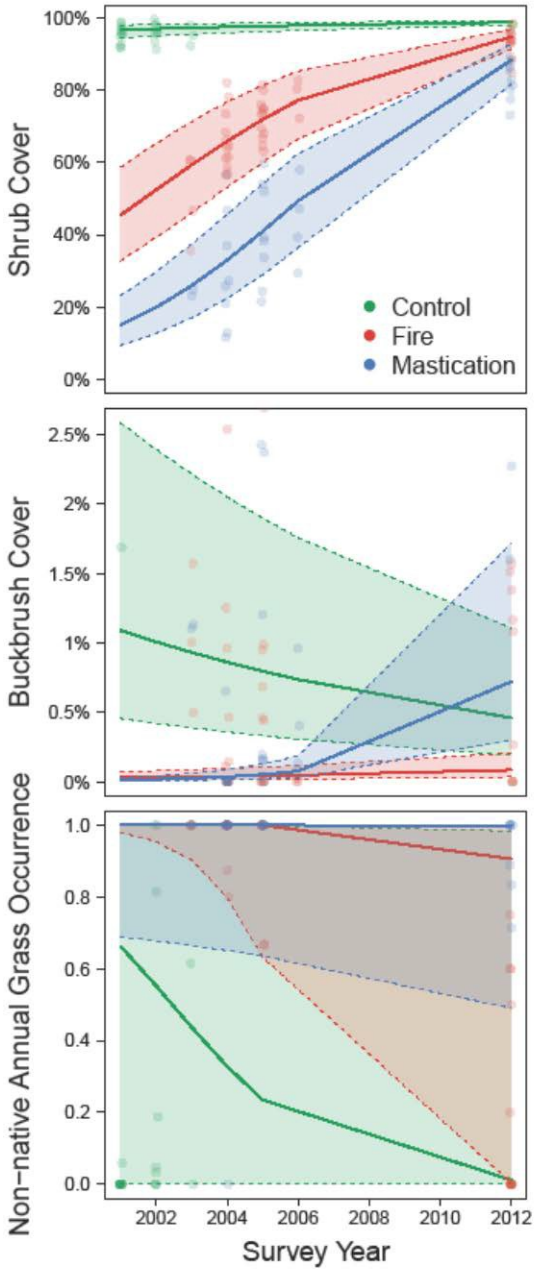

Figure 8. Control, fire, and mastication compared for shrub cover, buckbrush cover, and non-native annual grass occurrence across the 13 year study period.

(Upper figure) Controls have significantly higher shrub cover than fire and mastication across the survey years. The control has persistently high shrub cover across the sampling years while fuel reduction treatments have little shrub after treatment and start to rebound wafter treatment. Fire and mastication rebound and by about ten years after treatment they have 5 and 12% less cover than the control respectively.

(Middle figure) *Ceanothus cuneatus* (buckbrush) cover for fire and mastication are significantly different than the control across survey years. About ten years after treatment, fire units have lower buckbrush cover than control treatments whereas mastication units have greater buckbrush cover than control units. Note, the y-axis for this figure is 0 to 2.5% while the y-axis for other buckbrush figures is 0 to 14%.

(Lower figure) Non-native annual grass occurrence for fire and mastication are significantly or marginally greater than the control. For the control, the confidence interval is quite large because it was only sampled twice and there is high variability between sampling periods.

Curves represent the fit regression coefficients, the shaded area represents 95% confidence intervals, and points represent an experimental unit mean for each survey year.

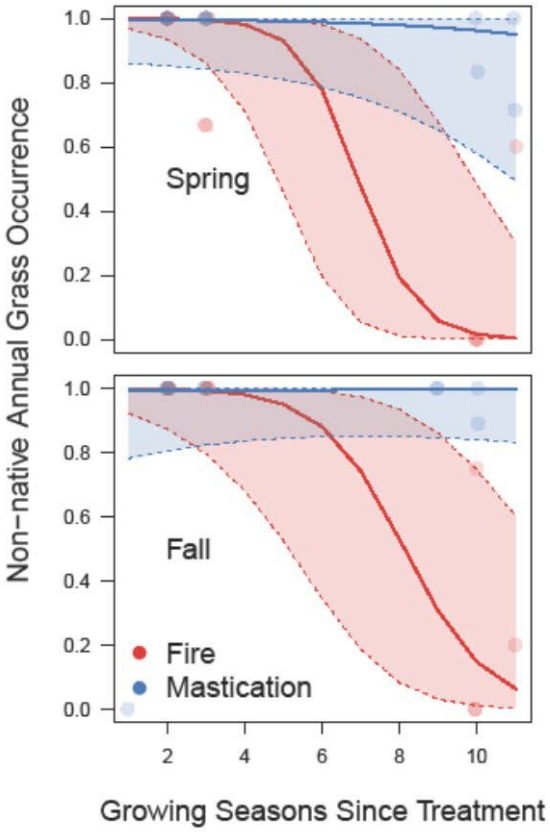

Figure 9. Fire and mastication have distinct amounts of non-native grass through time. Before treatments and until three growing seasons since treatment, fire and mastication have similar occurrence of non-native grasses. After a few growing seasons since treatment, the trends diverge. The presence of non-native grasses persists and is ubiquitous in masticated units while it declines in fire units and becomes nearly absent by around 10 growing seasons since treatment. The treatment effect is much strong than the seasonal effect.

Curves represent the fit regression coefficients, the shaded area represents 95% confidence intervals, and points represent an experimental unit mean for each survey year.

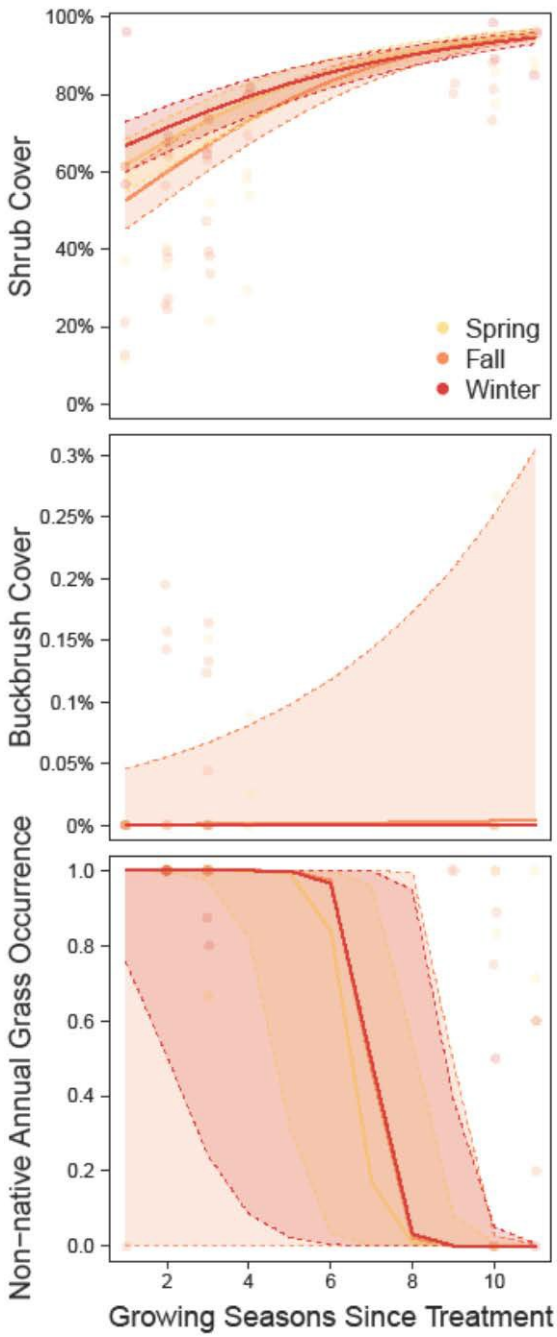

Figure 10. Within the fire treatment, season (fall, winter, and spring) influences the shrub cover and *Ceanothus cuneatus* (buckbrush) cover. Season within fire treatments does not influence non-native grass cover. The seasonal influence of mastication is fully represented within the fall and spring graphics (Figure 3, 4, and 5).

(Upper figure) The fire treatment reduces shrub cover, but is dependent upon the season of treatment from two to six years post treatment (p-value<0.01). Shrub cover is lowest in fall treatment followed by spring and then winter. About ten years after treatment, the seasonal influence is nearly gone and the treatment seasons have similar shrub covers.

(Middle figure) Fall fire promotes *Ceanothus cuneatus* (buckbrush cover) while spring and winter fire do not. Buckbrush is nearly absent from spring and winter fire units and is barely present in fire fall units.

(Lower figure) Within the fire treatment, there are no significant variables including season, growing seasons since treatment, yearly variability, or environmental variability.

Curves represent the fit regression coefficients, the shaded area represents 95% confidence intervals, and points represent an experimental unit mean for each survey year.

(1b) The probability of a catastrophic fire for humans

Woody plant biomass, height, and cover

Shrub biomass

Between fire, masticated, and control units, both fire and mastication treatments have significantly less biomass than control units about 10 years post-treatment in 2012 (fire: 9.9275+/-2.9139, p-value = 0.00239; mastication: =-14.9910+/-2.9551, p-value =6.57e-06). For treatments and control there is significantly more living material than dead (-6.7556+/-3.2133, p-value=0.03613), and both treatments had similar proportions of dead and alive material (p-value > 0.27). Biomass is not related with any environmental variable (p-value > 0.39).

Between fire and masticated units, mastication has significantly less biomass than fire treatments (-5.1073+/-1.8800, p-value= 0.00691). There is no evidence supporting a seasonal influence of treatment on biomass (p-value > 0.12).

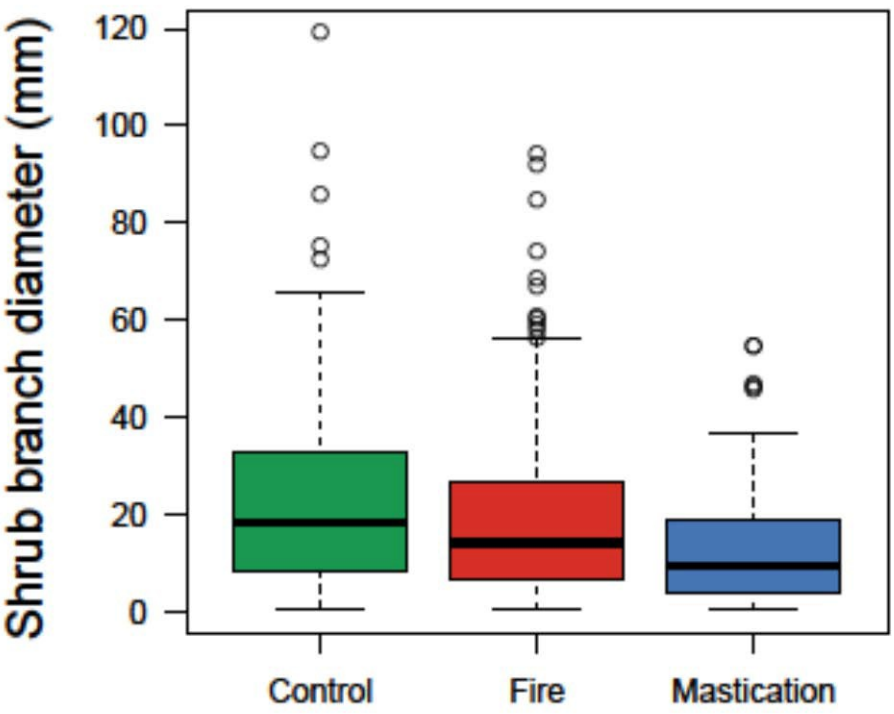

Figure 11. Boxplot of shrub branch diameter for the only significant variable, treatment, nine to eleven years after treatment in 2012.

Boxplots represent shrub branch diameters collected at three points along 10 transects in each unit. Control has more summed shrub diameters than fire and mastication. The bolded line is the median, the colored boxes represent 50% of the data, and each whisker represents 25% of the data. Outliers are depicted as circles and are maximum value if present. When there are no outliers, the whiskers' ends depict minimum and maximum values.

Shrub height

Few significant differences are detected for shrub height as compared to shrub biomass potentially due to survey and surveyor error. Biomass likely has a stronger signal because it is more objective. Shrub height is influenced by treatment, season, growing seasons since treatment, environment, and yearly variability.

Between fire, masticated, and control units, fire and mastication have shorter shrubs than the control (p-value = 0.02855 and p-value = 0.00317, coefficient = -6.58713+/-3.00765 and coefficient = -10.65131+/-3.60894 respectively). Across all treatments and the control, as slope increases, shrub height also increases (p-value = 0.028, coefficient= 2.67913+/-1.21737). As survey year precipitation increases, shrub height increases (p-value = 0.06347, coefficient = 1.77456+/-0.95603).

Between fire and masticated units, mastication and fire treatments are similar to one another (p-value = 0.723801, coefficient=6.4209+/-17.7109). Shrubs grow back from treatments as growing seasons increase (p-value =0.000805, coefficient =3.7023+/-1.1041). Within mastication only treatments analysis, areas treated in the spring had significantly slower recoveries than those treated in the fall (p-value = 0.007775, coefficient = -4.714+/-1.770). However when fire and mastication are analyzed together increasing the sample size, treatments completed in spring only have marginally increased shrub height as the number of growing seasons since treatment increases (p-value = 0.094269, coefficient = -2.0987+/-1.2539). Also, precipitation one year after treatment has a marginal influence on shrub height (p-value=0.062367, coefficient=-37.2978+/-17.8169). (Appendix C)

Within fire treatments, season had no effect.

Shrub cover

Between fire, masticated, and control units, fire and mastication treatments reduce shrub cover and shrubs rebound with greater rates of growth through time than the control (p-value = <2e-16 and p-value = <2e-16, coefficient = 0.183766+/-0.004506 and coefficient = 0.244915+/-0.004494) (Figure 8). Both fire and mastication have persistently lower shrub cover than the control (p-value =2e-16 and p-value = 2e-16, coefficient = -3.752147+/-0.013889 and coefficient = -5.363124+/-0.016039 respectively). Fire and mastication rebound and by about ten years after treatment they have 5 and 12% less cover than the control, respectively. No environmental variables influence shrub cover in this model.

Between fire and masticated units, mastication units have lower shrub cover than fire units (p-value= 4.23e-14, coefficient= -1.495654+/-0.198005) (Figure 12). While mastication rebounds more quickly than fire (p-value < 2e-16, coefficient= 0.044842+/-0.001640), it has consistently less shrub cover. Both fire and mastication completed in spring has lower cover than fall treatments (p-value< 2e-16, coefficient=-0.031277+/-0.001602)

Within fire treatments, shrubs rebound from fire although spring and winter fires recover more slowly than fall fires (p-value=0.0262 and p-value=0.0180, coefficient=0.687819+/-0.309431 coefficient=0.700386+/-0.296081 for spring and winter respectively when compared to fall) (Figure 10). Fall treatments have the greatest shrub cover followed by spring and winter sequentially. As growing

seasons since treatment increase, both spring and winter treatments increase shrub cover more slowly than fall treatments (p-value< 2e-16 and p-value< 2e-16, coefficient = -0.124552+/-0.009265 and coefficient = -0.300300+/-0.009077 respectively).

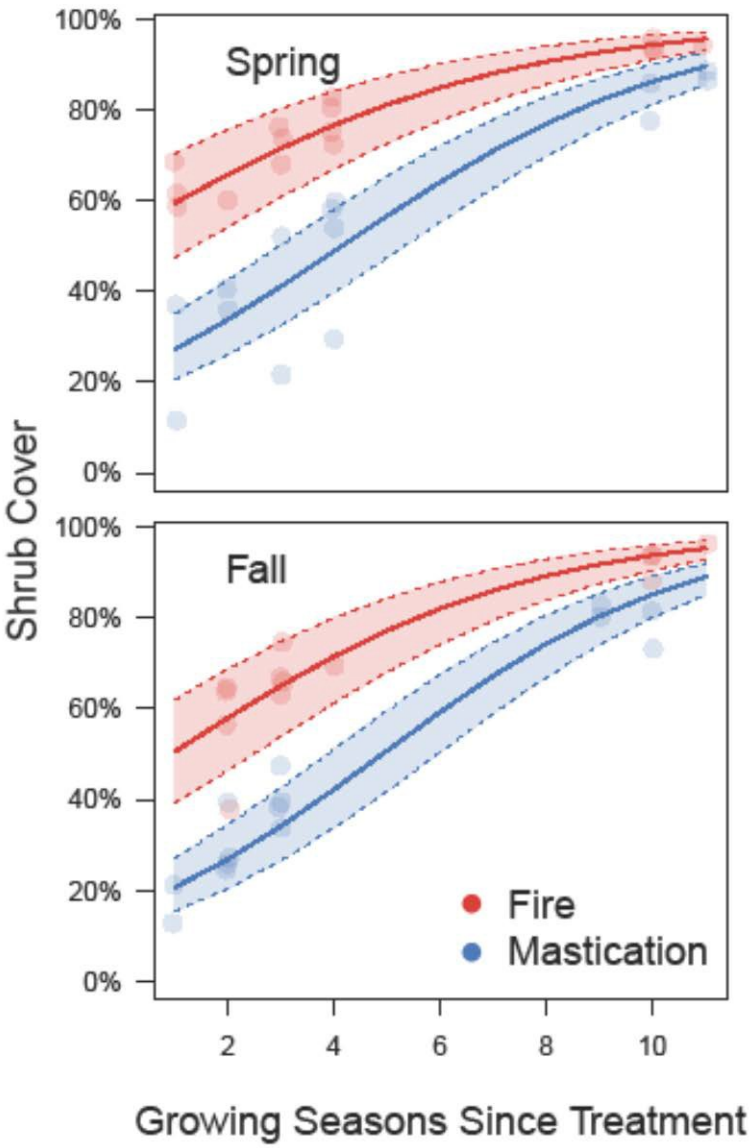

Figure 12. Both the treatment type and season influence shrub cover although the influence of treatment type is three times greater than the influence of season a few years after treatment. Masticated plots have ~30% lower shrub cover than fire treatments through about six years post treatment, but converges to within ~15% of fire by ten years post treatment. The fall treatments have ~10% lower cover than spring treatments. As time progresses, differences between treatments and seasons diminishes.

Curves represent the fit regression coefficients, the shaded area represents 95% confidence intervals, and points represent an experimental unit mean for each survey year.

(2) Which fuel reduction treatment minimizes nonnative species invasion and persistence?

Between fire and masticated units, masticated units have greater abundance of non-native plants in their herbaceous layer than fire (p-value=0.002947, coefficient=634.36+/-184.04) (Figure 13). However, this difference decreases through time (p-value=0.005664, coefficient=-217.48+/-77.92). Spring treatments have a significant interaction with time since treatment where they are more likely to have more non-native plants as the number of growing seasons since treatment increase (p-value=0.000121, coefficient= 236.00+/-60.32). Non-native plants in masticated areas where also more likely to be more harmful chaparral's ecology (Figure 14) (C. E. Bell 2015).

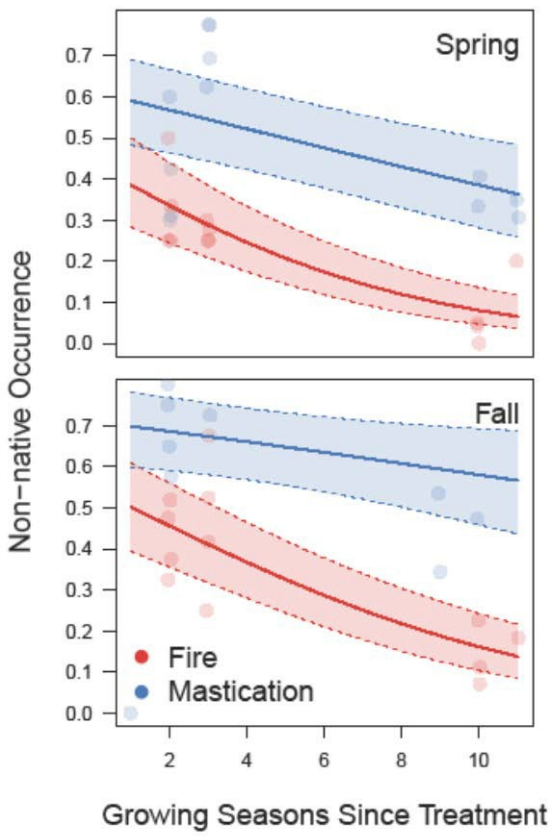

Figure 13. Non-native plants became established after all fuel reduction treatments and persisted for at least a decade. Treatment type and to a lesser extent season influenced the presence of non-native plants. More than a decade after treatment, non-native plants were much more likely to occur in masticated areas rather than fire areas and in fall treatments rather than spring treatments.

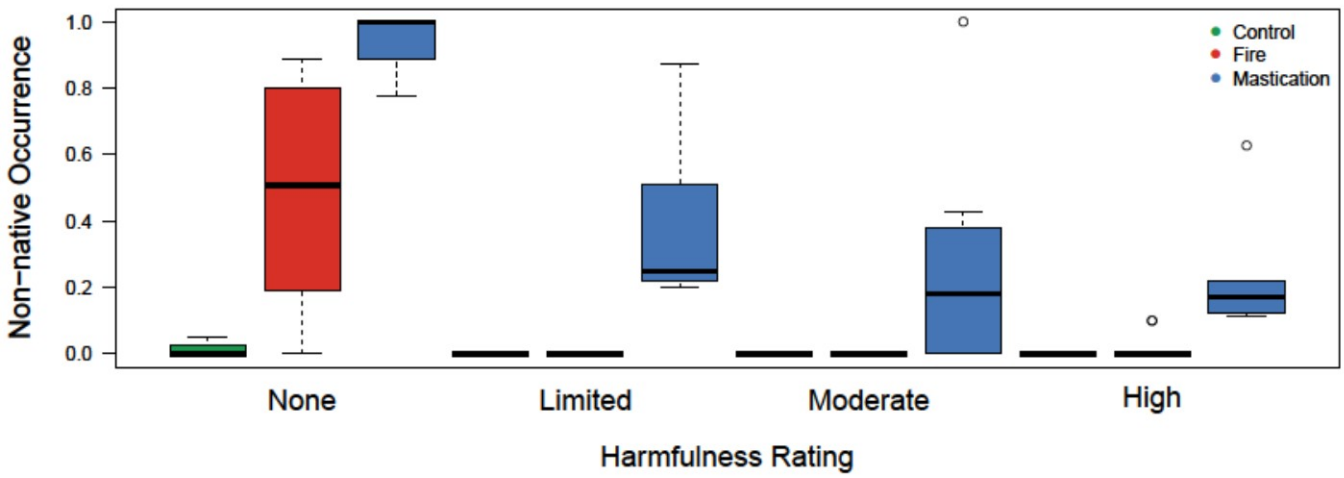

Figure 14. In 2012, masticated areas were more likely to have non-native plants present and these plants had a higher harmfulness rating than fire or control areas. Fire areas were more likely than the control to have non-native plants present, but while these were non-native plants they had no harmfulness rating assigned because they are low impact naturalized plants. Harmfulness rating is from the California Integrated Pest Management and is based on a combination of ecological impact, invasive potential, and current distribution (C. E. Bell 2015).

> "**High**: These species have severe ecological impacts on physical processes, plant and animal communities, and vegetation structure. Their reproductive biology and other attributes are conducive to moderate to high rates of dispersal and establishment. Most are widely distributed ecologically.
> **Moderate**: These species have substantial and apparent—but generally not severe—ecological impacts on physical processes, plant and animal communities, and vegetation structure. Their reproductive biology and other attributes are conducive to moderate to high rates of dispersal, though establishment is generally dependent upon ecological disturbance. Ecological amplitude and distribution may range from limited to widespread.
> **Limited:** These species are invasive but their ecological impacts are minor on a statewide level or there was not enough information to justify a higher score. Their reproductive biology and other attributes result in low to moderate rates of invasiveness. Ecological amplitude and distribution are generally limited, but these species may be locally persistent and problematic.
> **None:** available information indicates that the species does not have significant impacts at the present time." (C. E. Bell 2015).

(3) Other ecological effects of fuel reduction treatment, including wildlife habitat?

Deer forage

Between fire, masticated, and control units, Fire and mastication have significantly less buckbrush cover than the control (p-value<2e-16 and p-value <2e-16, coefficient= -2.81413 and coefficient= -2.47038) (Figure 8). Through time, the cover of buckbrush increases (p-value <2e-16 and p-value <2e-16, coefficient= 0.65365 and coefficient= 1.68945) and about ten years after treatment mastication has more buckbrush than the control.

Between fire and masticated units, mastication has significantly more buckbrush cover than fire (p-value = 6.84e-05, coefficient= 4.71804) (Figure 15). Through time these differences increase (p-value= < 2e-16 coefficient= 0.94994). Season also influences buckbrush cover; fall treatments have more than spring treatments and this differences increase through time (p-value= 0.0202 and p-value= < 2e-16, coefficient= -5.23848 and coefficient= -0.34062). Additionally, the site's slope positively and marginally relates to buckbrush cover (p-value= 0.0554, coefficient = 0.81392). No other environmental or yearly variables influence buckbrush cover.

Within the fire treatment, fall has the most buckbrush present. Both winter and spring have marginally or significantly less than fall respectively (p-value=0.0652 and p-value=0.0164, coefficient=-3.14252+/-1.70439 and coefficient=-4.33852+/-1.80792 respectively) (Figure 10). These differences diminish with time as winter and spring have slower rebound rates (p-value< 2e-16 and p-value< 2e-16, coefficient= -0.54277+/-0.02658 and coefficient=-0.42424+/-0.03199).

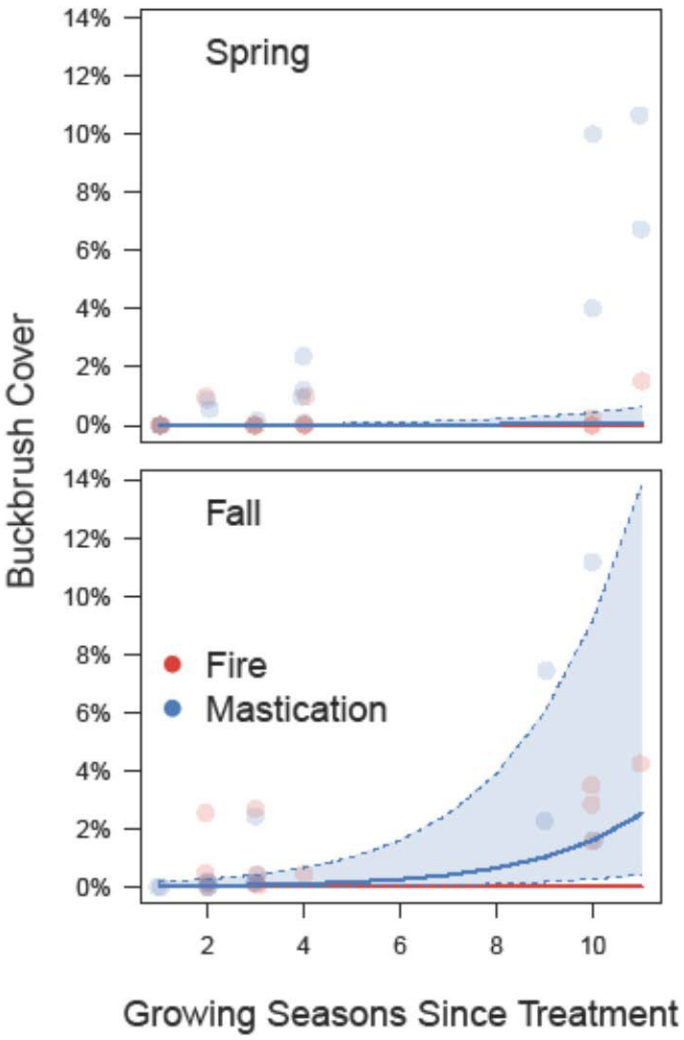

Figure 15. Seasonal effect of treatment type on *Ceanothus cuneatus* (buckbrush) cover was significant.

Both treatment type and season influence *Ceanothus cuneatus* (buckbrush) cover. Fall mastication treatments have buckbrush present about ten years post treatment whereas other treatments (all fire and spring mastication) do not.

Curves represent the fit regression coefficients, the shaded area represents 95% confidence intervals, and points represent an experimental unit mean for each survey year.

Discussion

Our results demonstrate that there are trade-offs for all treatments and their season of application which managers must carefully consider. We discuss two major factors, treatment type and season, that managers should consider when implementing fire hazard reduction.

Treatment type

For shrub cover to return to near pre-treatment levels, burned areas rebounded more quickly than masticated areas. Although, neither treatment reaches a shrub cover similar to the control ten years post treatment, they have 20 to 10% less cover, respectively (Figure 14). Differences in shrub cover between treatments relates to how shrubs and their soil seed bank respond to the treatment. It is likely mastication killed many shrubs by destroying their burls whereas fire only top-killed shrubs. This may allow shrubs to resprout more quickly after a fire than following masticated. Fire also stimulates more seedlings than mastication at two and three years post treatment (Potts, Marino et al. 2010). Fire plots had more than twice as much shrub cover or 25 to 30% greater shrub cover, two years after treatment (Figure 8, 12). However, by about ten years after treatment the differences between treatment diminished and the difference is less than 10% cover. These differences are also present in shrub biomass.

It is likely that the slow shrub recovery creates space where other plants can become established such as non-native annual grasses. Fire units had low non-native annual grass presence, low non-native species richness, and no noxious weeds present despite being placed next to maintained fuel breaks which are known to be weed highways (Merriam, Keeley et al. 2006). In contrast though, mastication units generally were not placed next to fuel breaks, yet they had high non-native grass presence, high non-native plant richness, and the presence of noxious weeds

In masticated units, non-natives in general and non-native annual grasses invade and persist for at least 10 years post treatment which creates a shrub grass matrix (Figure 16). There are direct consequences of increasing non-native annual grasses including increased flammability and even extirpating native plants (Beyers, Wohlgemuth et al. 1998, Keeley 2000, Beyers 2004, Merriam, Keeley et al. 2006). These grasses are much more likely to catch fire than shrubs and grass incursion in chaparral can lead to increased fire frequency (Cione, Padgett et al. 2002, Brooks, D'Antonio et al. 2004). Non-native annual grass invasion and persistence ten years after treatment in chaparral is detrimental to both nature and people in the wildland urban interface (Brooks, D'Antonio et al. 2004). It alters the conservation value of chaparral while at the same time increasing the probability of a wildfire starting. Non-native annual grasses increase fuel continuity between natural areas and homes, “increase rates of fire spread, and lengthen the fire season by curing earlier and persisting later than native species” (Mack and D'Antonio 1998, Keeley 2000, Brooks, D'Antonio et al. 2004, Potts and Stephens 2009). The relationship between non-native annual grass and wildfire risk is not homogenous between years rather it varies with annual precipitation (Appendix B, Figure B3). The wildfire risk decreases during drought years and increases when there is above average rainfall. Beyond increasing flammability, non-native annual grasses also threaten to extirpate native plants. In the short-term, slow shrub recovery rates will result in non-native annual grass colonization and therefore the higher potential for type conversion (Schultz, Launchbaugh

et al. 1955). Chaparral's rich, fire-following annual flora is also out-competed by non-native annual grasses (Keeley, Keeley et al. 1981, Beyers 2004). Overall, persistent non-native annual grasses are a significant consequence of mastication by increasing flammability and excluding native plants.

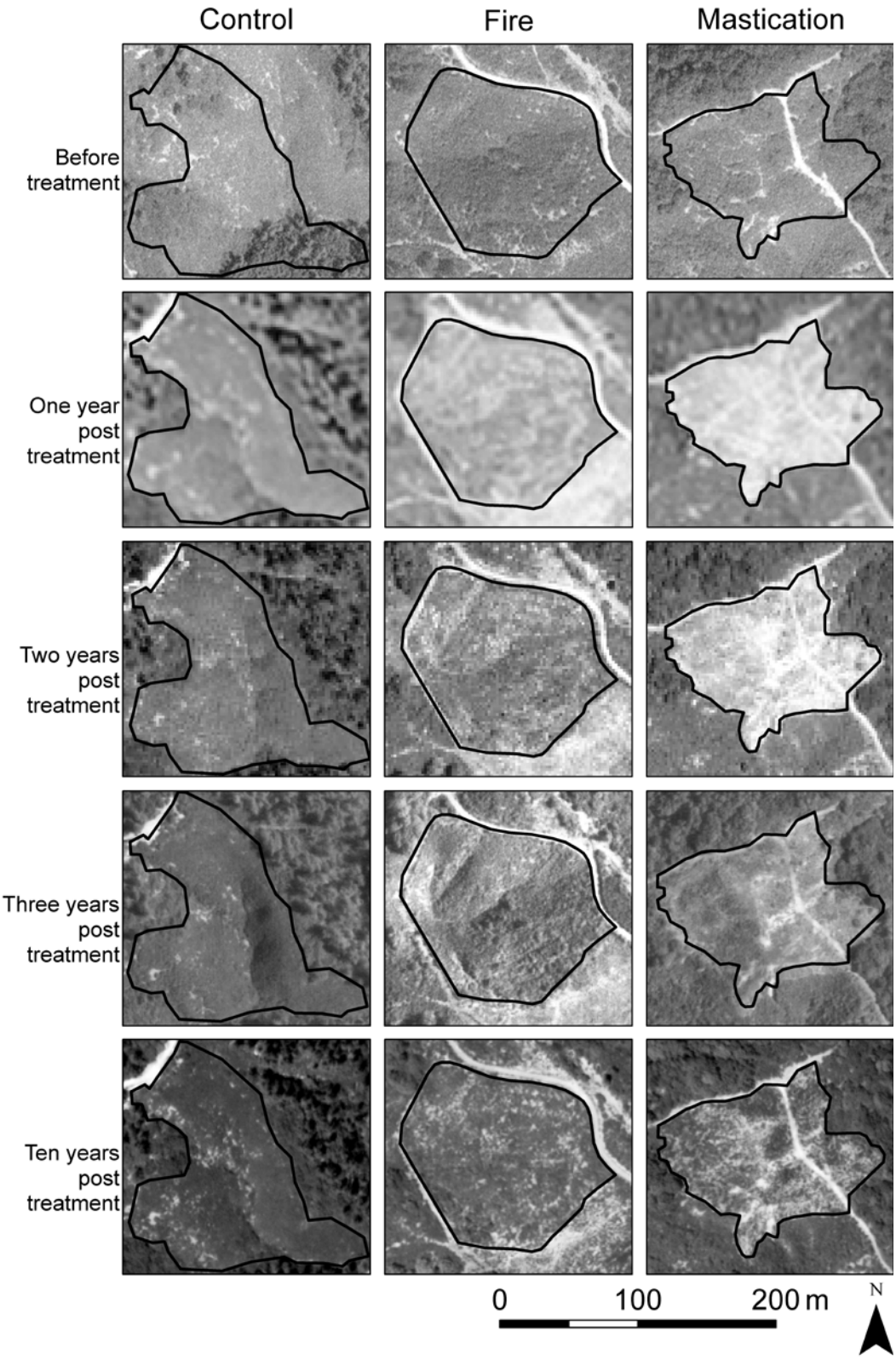

Figure 16. Aerial photos are a chronosequence of shrub cover patterns following treatments in northern California chaparral. Shrub cover is persistent and continuous through time in the control unit. In contrast, shrub cover in the fire and masticated units changes dramatically. Prior to treatments in 1998, there is continuous shrub cover. One year after treatment in 2003, the masticated unit has few shrubs present (as indicated by the lack of coloration) while fire unit had a rapid shrub recovery. Two and three years after treatment, shrubs continue to recover albeit the fire unit recovers more quickly than the masticated unit. A decade after treatment in 2012, controls still have the greatest shrub cover followed by fire units and then masticated units. The fire unit has a nearly continuous shrub canopy whereas the masticated unit has a shrub grass matrix. The 1998 black and white aerial photos are USGS Digital Ortho Quarter Quad. The 2003 to 2012 aerial images are National Agricultural Imagery Products for Mendocino County California.

This space in between shrubs accumulates species some of which are desired by managers such as buckbrush. The differences between fire and mastication treatments while significant is quite small (<2%), but it does change buckbrush from being absent or nearly so to being present. This may be biologically significant given that buckbrush is widespread, but uncommon and important deer forage (Bleich and Holl 1982). Mastication likely promotes buckbrush cover because it also represses resprouters like chamise (Biswell 1961). Changes in buckbrush cover also influence fire risk if buckbrush is abundant. Buckbrush is less flammable than chamise, it creates fuel discontinuities, thus it decreases fire risk (Biswell 1974).

Treatment season

Burning out of seasons is a concern because of unique selection pressures on plant communities due to seasonal differences in plant physiology, plant competition, and treatment efficacy (Knapp, Estes et al. 2009). The seasonal differences for fire are sometimes attributed to soil moisture, steaming seeds or imbibed seeds more susceptible to heat (Le Fer and Parker 2005). However, soil moistures were statistically similar immediately prior to treatment (Potts and Stephens 2009). The other seasonal physiological differences in plants, including bud formation or carbohydrate resources distributed throughout the plant in the spring, leave plants more susceptible because they would have fewer resources for resprouting from fire or mastication. Another attribution for seasonal differences is fire intensity (Knapp, Estes et al. 2009) and there is reason to believe that fire behavior could have been unique between the seasons --- live fuel moistures were statistically greater in the spring than in the fall or winter for our treatments (Potts and Stephens 2009).

Surprising, none of these common hypotheses are supported for total shrub cover, rather fall hazard reduction treatments, including fire and mastication, have the lowest shrub cover in fall treatments while winter and spring treatments have higher shrub cover. This tends to persist across fire and mastication treatments and thus fire intensity alone cannot explain the differences rather fall treatments have lower shrub cover due to plant physiology or competition. These results are also counter intuitive to seedling densities two and three years post treatment --- at two years post treatment fall treatments had the greatest seedling densities present. Perhaps shrubs have greater difficulty resprouting after fall treatments because of harsh environment with low resource storage and availability such as carbohydrate or water (Pratt, Jacobsen et al. 2013)

Buckbrush cover did not follow early trends and expectations either. Despite being an obligate seeder with fire-stimulated seeds (Keeley 1987, Keeley 1991, Potts, Marino et al. 2010, Wilkin, Holland et al. 2013), it had low cover after fire and the highest cover with fall mastication. Again, fire treatments in the fall had greater seedling densities present three years post treatment, they had about two per meter squared which is more than twice as many as all other treatments and seasons. The buckbrush soil seed bank may have continued to be stimulated by heat produced by solar radiation because there were few shrubs to intercept it. Additionally, the seedlings had less competition from aggressive resprouters such as chamise.

Conclusion

Land managers must simultaneously protect human communities from fire and protect natural communities from negative effects of fuel reduction treatments (Wilkin 2015). Three years after treatments, masticated and prescribed fire treatments had unique ecological responses. Masticated units had higher abundance of nonnative species, especially annual grasses, and lower shrub cover than prescribed fire units. As our results demonstrate, responses to common treatment types continue to be for over a decade. Most importantly, both fire and mastication have lasting negative effects on natural communities. (Table 3, Figure 17)

Table 3. There are significant differences between treatments' chaparral succession 10+ years after fuel reduction treatments.

	Focus	**Control**	**Fire**	**Mastication**
Vegetation	Community structure	shrubland	shrubland	shrub grass matrix
	Shrub biomass	high	high	moderate
	Noxious weeds	absent	absent	present
	Non-native plants	absent	Common, but low risk	Dominate and high risk
Deer browse	*Ceanothus cuneatus* (buckbrush)	present	absent	present
Fire risk	(P) of occurrence	less	more	most
	(P) of catastrophe	most	more	less
Erosion	(P) of occurrence	limited	short-term	long-term

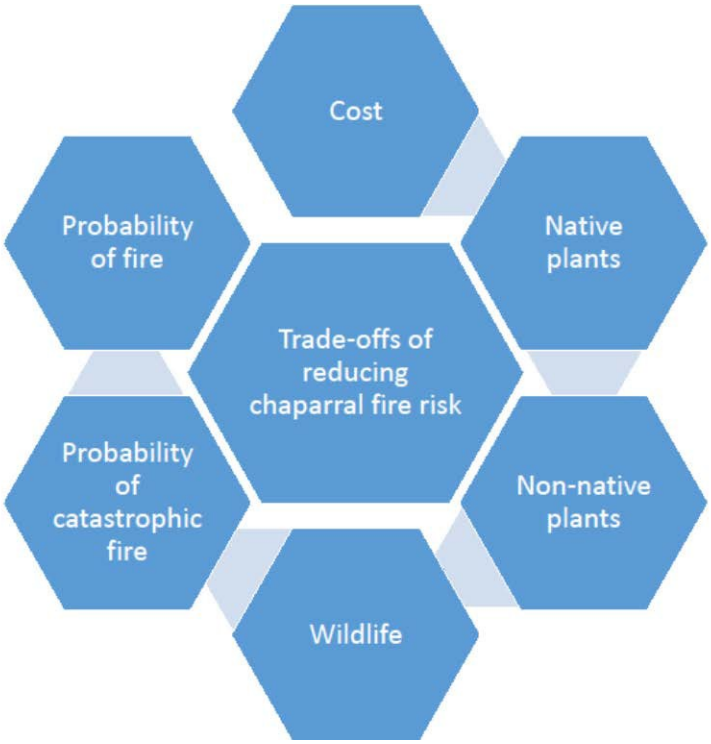

Figure 17. There are strong trade-offs when managing chaparral.

Mastication promotes nonnative species invasion and persistence in chaparral more than a decade after treatment. Our findings support Keeley's (2004) findings where there is literally a "race between rates of shrub recovery" and non-native annual grass colonization (Keeley 2004). Shrubs are excluded by nonnative annual grasses if they don't colonize the site early on (Schultz, Launchbaugh et al. 1955) , and this may depend on climate as well (Pratt, Jacobsen et al. 2013). Despite the significant ecological changes, there is a significant benefit to mastication: treatment longevity greatly diminishes the potential of a catastrophic fire for humans, and reduces cost. However the potential for other catastrophic disturbances, such as a mudslide increase.

Managers must carefully weigh the trade-offs between the desire of their constituents for fire risk reduction (Toman, Stidham et al. 2011) and cost, preserving native systems, increasing flammability, decreasing fire severity, and increasing erosion (Potts and Stephens 2009, Potts, Marino et al. 2010) (Figure 16, Management Implications). Questions remain about chaparral's longer-term succession after fuel reduction treatments, especially repeated treatments. Treatments will need to be maintained to remain effective and reducing fire risk near residential communities. Treatment intervals may vary but regardless they will be shorter now than they were historically. Altering fire regimes by increasing disturbance frequencies will leave ecosystems vulnerable to adverse effects such as vegetation type conversion, species composition changes, and more.

Management implications:

Prescribed fire
- fosters long-term native diversity and community structure
- reduces fire hazard for a shorter period than mastication and requires more frequent treatments
- decreases preferred deer brows

Mastication
- fosters native species in the short-term, but non-native species and a noxious weed invade and persist in the long-term
- reduces fire hazard, but may also increase fire frequency due to highly flammable and abundant annual grasses
- increases preferred deer browse

Season of treatment
- fall treatments slow shrub recovery followed by winter and then spring treatments
- fall treatments promote non-native annual grass occurrence
- fall treatments increase preferred deer browse

Deliverable, Description and Delivery Dates

Deliverable Type	Description	Delivery Dates
Annual progress summaries	Report annual progress to the JFS program	Done
Conference/symposia/workshop	Present results to regional and national fire conferences such as those organized by the Association for Fire Ecology and International Association of Wildland Fire. Lead a regional chaparral summit to learn about how people manage chaparral in Northern California and integrate our findings into their management. Wilkin, K., Quinn-Davidson, L., Frederick, S. Stephens, S. 2015. Chaparral Summit. Northern California Prescribed Fire Council and California Fire Science Consortium. Hopland, CA. In preparation. Wilkin, K. Stephens, S. 2014. The trade-offs of reducing chaparral fire hazard. Large Wildland Fire Conference. Missoula, MT. (Poster Presentation and Student Poster Award recipient) Wilkin, K. Stephens, S. 2014. Trade-offs of reducing chaparral fire hazard. Northern California Prescribed Fire Training Exchange and California Fire Science Consortium. Whiskeytown National Recreation Area, CA.	May 2015 May 2014 May 2013
Invited paper/presentation	Scott Stephens gave a talk on the chaparral project at the UC Hopland Research Symposium.	April 2014
Field demonstration/tour	We lead a field trip (2013), created an auto-tour brochure (2013), will update on-site visitor pull-out displays (2015), and will lead another field trip (2015). Potts, J. Wilkin, K. Newman, E. Stephens, S. 2015. Trade-offs of reducing chaparral fire risk: biodiversity or fire hazard? Northern California Prescribed Fire Council and California Fire Science Consortium. Hopland, CA. Potts, J. Wilkin, K. Newman, E. Stephens, S. 2013. Natural and social trade-offs of reducing chaparral fire risk. Northern California Prescribed Fire Council and California Fire Science Consortium. Hopland, CA.	May 2015 May 2013
Website	This project is part of the California Fire Science Consortium Google Earth database and on the UC Center for Fire Research and Outreach web site (Spring 2013). The web-site will be updated based on peer-reviewed journal results and implications (Spring 2015).	Spring 2015 May 2013
Ph.D. dissertation	Graduate student that works on this project will complete a dissertation. *Complication is this project was funded when UCB did not have tuition and when this changed funds could not be used for student. This is why extension was allowed.	2015*
Refereed publications	Stephens, S.L., Weise, D.R., Fry, D.L., Keiffer, R.J., Dawson, J., Koo, E., Potts, J., and Pagni, P. 2008. Measuring the rate of spread of chaparral prescribed fires in northern California. Fire Ecology 4: 74-86. Wilkin, K. Ponisio, L. Fry, D. Tubbesing, C, Potts, J. Stephens, S. 2015. Trade-offs of reducing chaparral fire risk: biodiversity or fire hazard? Ecology, In review. Wilkin, K. Ponisio, L. Fry, D. Tubbesing, C, Potts, J. Stephens, S. 2015. Chaparral fuel hazard & its ecological impacts. In preparation.	2008 January 2015 May 2015
Final report	Completed	January 2015

Future work needed

- Applied science
  - Questions to ask with this study
    - Understand how composition of native changed through time
    - Explore diversity indices for both shrub and understory data
    - Explore how functional groups responded to treatments such as resprouters versus obligate seeders
    - Explore how chaparral endemic plants respond to treatments
    - Explore how rare plants respond to treatments
    - Remeasure the experiment in another five to ten years to understand longer term trajectory.
    - Potentially retreatment the units and see how they respond with multiple treatments.
  - Additional experiments
    - How do chaparral respond to these treatments compare with goat grazing?
    - How do chaparral respond to these treatments in southern California?
- Outreach
  - Learn how people manage chaparral in northern California
  - Incorporate managers' ideas into a chaparral fire hazard decision tree to aid managers in deciding why, when, where, and how to manage chaparral.
  - Engage managers with results of this study

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Appendix

Appendix A: Review of environmental variables

Slope and solar radiation index are significantly different between treatments and are included in analyses to standardize for these differences.

Appendix A1: Slope and Solar Radiation Index (SRI)

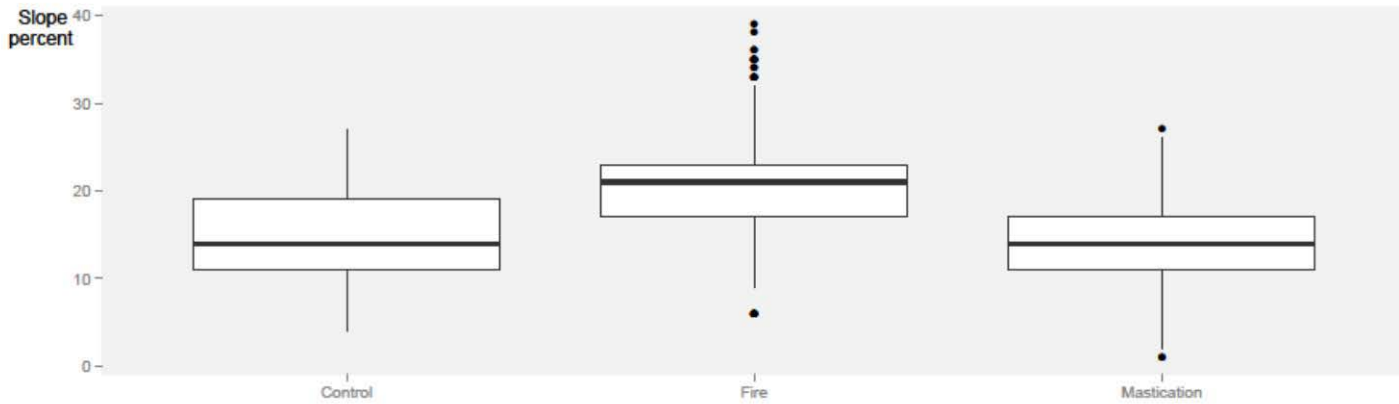

Figure A1. Slopes vary by treatment (p-value = 0) when compared with an ANOVA. While control and mastication units are significantly different (p-value = 0.004068104), their slope differences are quite small (< 2 degrees for the average) and may be biologically similar slopes. In contrast, the fire treatments are generally steeper with an average slope of 20 degrees or more than 5 degrees greater than the control and mastication units. The minimum, quartiles, median, and maximum are represented in the boxplot.

Table A1. Slope values rounded to nearest whole number.

	Control	Mastication	Fire
Minimum	4	1	6
Maximum	27	27	39
Mean	15	13	20
SD	5	5	5

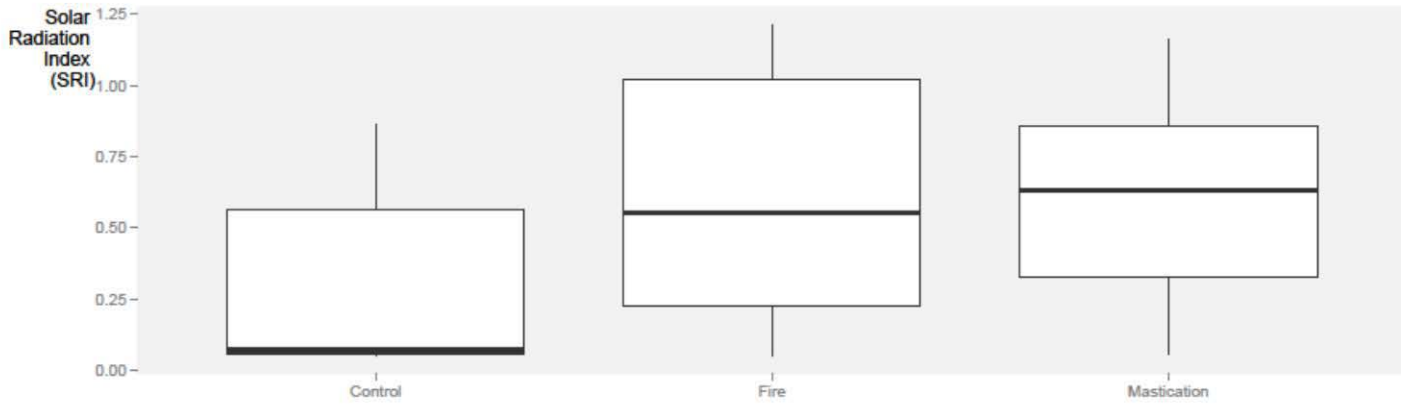

Figure A2. Solar radiation index (SRI) is a synthesized solar radiation variable based on aspect, slope, and latitude (McCune and Keon 2002). The control is distinct from other treatments (p-value = 6.113442e-21). Fire and mastication units are similar (p-value = 0.11). The minimum, quartiles, median, and maximum are represented in the boxplot.

Table A2. Solar radiation index (SRI) rounded to two significant digits.

	Control	**Fire**	**Mastication**
Minimum	0.05	0.05	0.58
Maximum	0.86	1.22	1.16
Mean	0.29	0.61	0.58
Standard deviation	0.28	0.39	0.32

Appendix A2: Precipitation

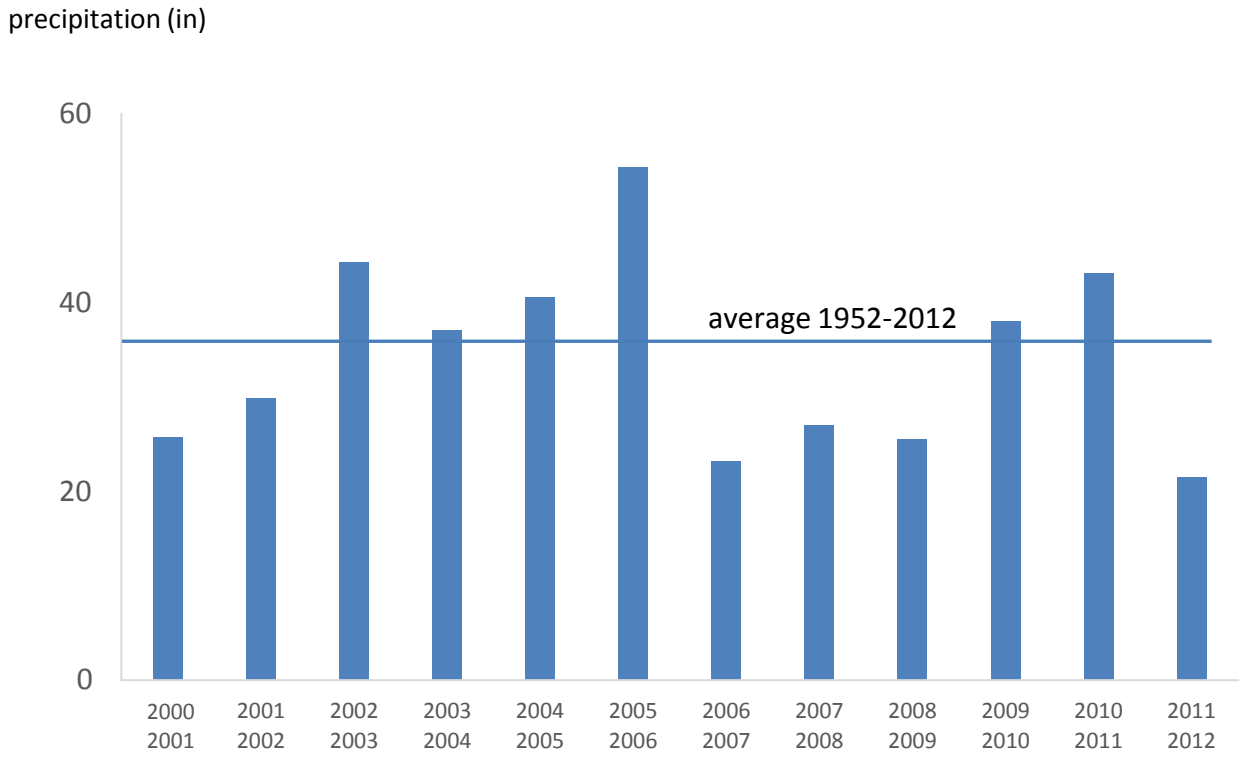

Figure A3. Precipitation (inches) near the study sites at UC Hopland Cooperative Extension Headquarters during the study period. Some of the study years were below average precipitation while others were above average. (UC Hopland Research & Cooperative Extension 2014)

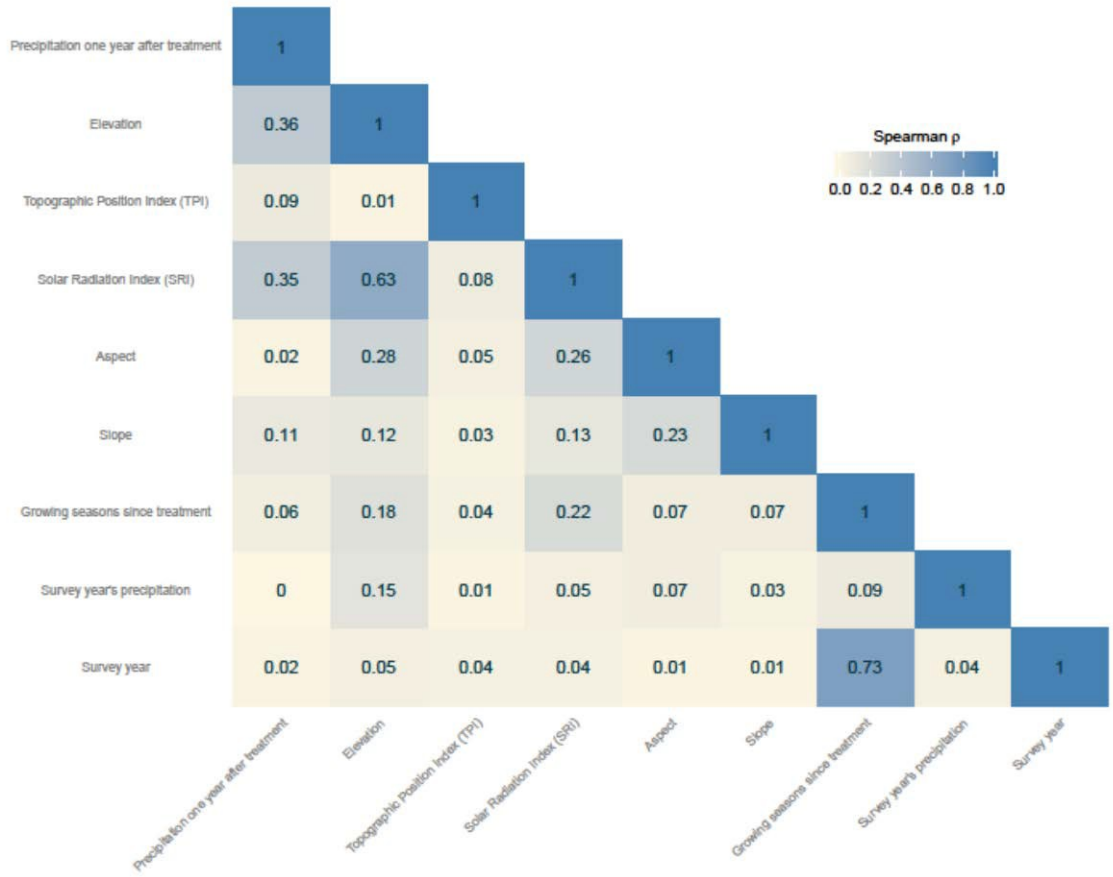

Figure A4. Regression variable are generally not correlated. However, some variables are strongly correlated such as survey year & growing seasons since treatment (0.73), elevation and Solar Radiation Index (SRI) (0.63). Other variables are weakly correlated such as elevation & precipitation one year after treatment (0.36), Solar Radiation Index (SRI) & precipitation one year after treatment (0.35). It would be ideal to include both growing seasons since treatment and survey year in a single model however they are strongly correlated and models do not run.

Spearman's coefficient is a nonparametric test where .00 to .19 is very weak, .20-.39 is weak, .40 to .59 is moderate, .60 to .79 is strong, and .80 to 1.0 is very strong.

Appendix B: Non-native annual grasses

General trends, especially growing seasons since treatment, persists across treatment type. Count of non-native annual grasses changes with growing season. Before treatment, (growing season = 0), the majority of plots didn't have non-native grasses present, or if they were present, then there were very few. After treatment (growing season >0), most plots had non-native grasses present. As growing seasons since treatment increased, abundance of non-native plants diverge based on treatment type. Fire treatments increased non-native grass count until two years after treatment, it persisted at year three, and then it decreased to levels below the second growing season. Mastication treatments increased non-native grass count two years after treatment. The count continued to increase three years after treatment and then it decreased. About ten years about treatment (growing season = 9, 10, or 11), the count of non-native grasses diminishes, but mastication treatments have non-native grasses persisting and sometimes in large numbers.

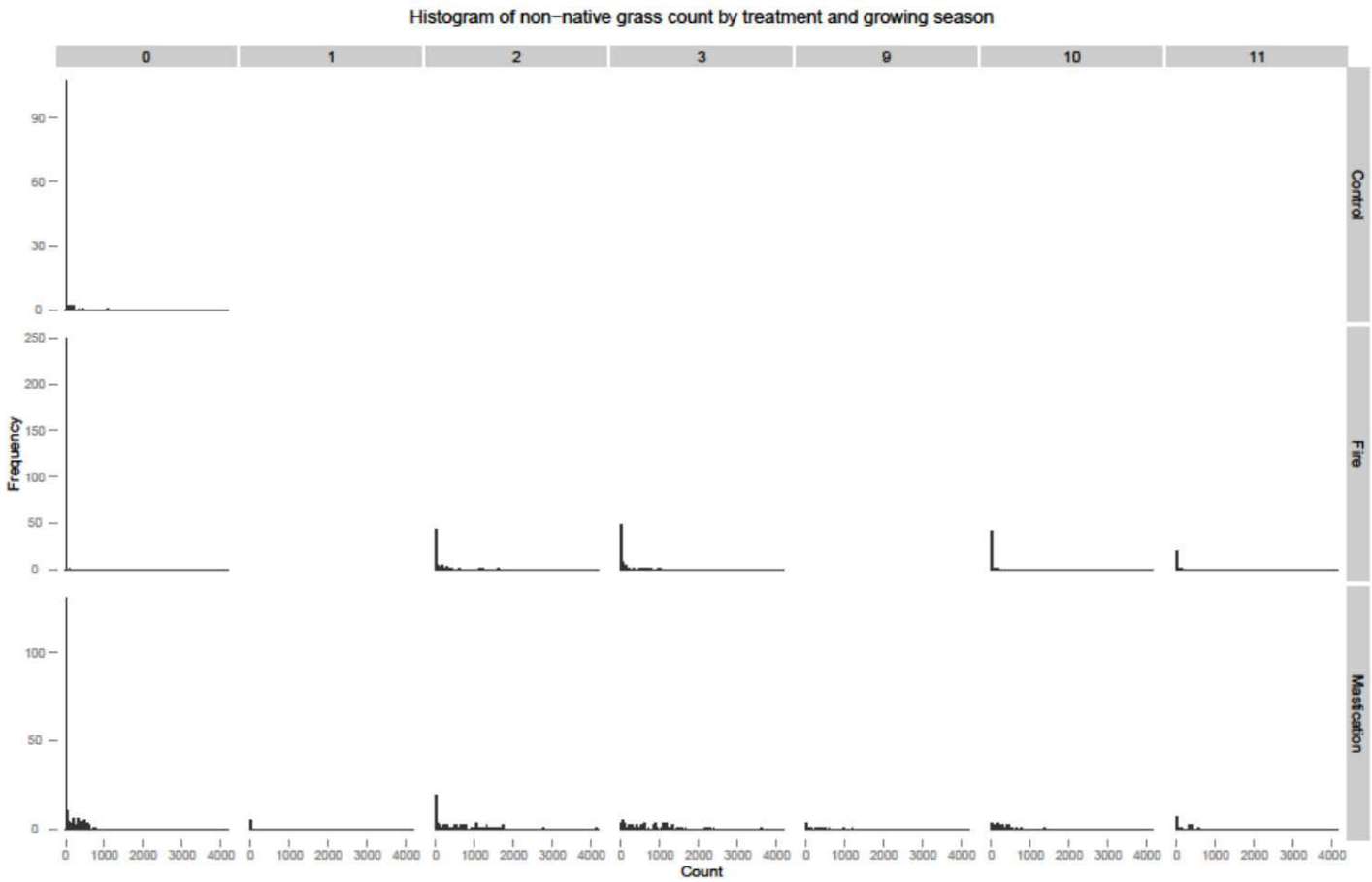

Figure B1. Histogram of non-native annual grasses by treatment and growing seasons since treatment where frequency is the number of plots and count is the number of non-native annual grass plants. Notably, there are many plots without non-native grasses before the treatments and many fire plots without non-native grasses about 10 growing seasons since treatment. The magnitude of plots with no non-native grasses present or very few non-native grasses present is quite high. This sparse data makes it difficult to fit abundance-based statistical models.

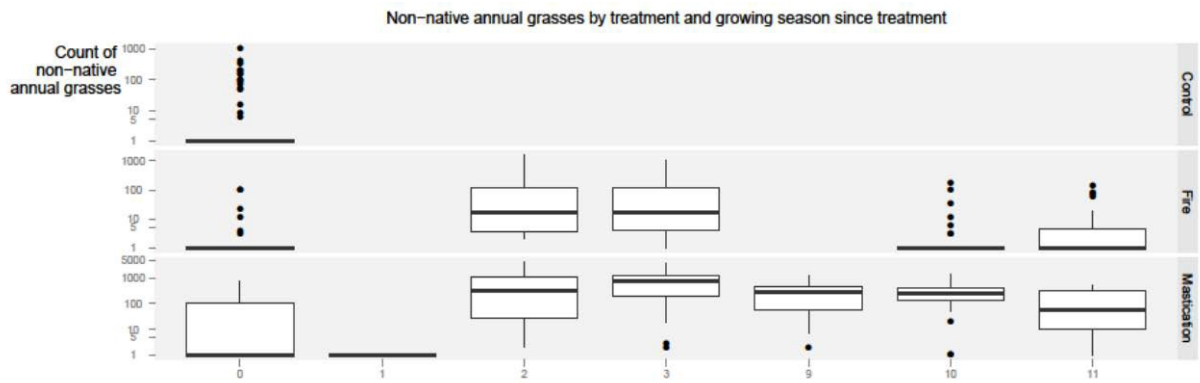

Figure B2. Boxplot of non-native annual grasses by treatment and growing seasons since treatment.

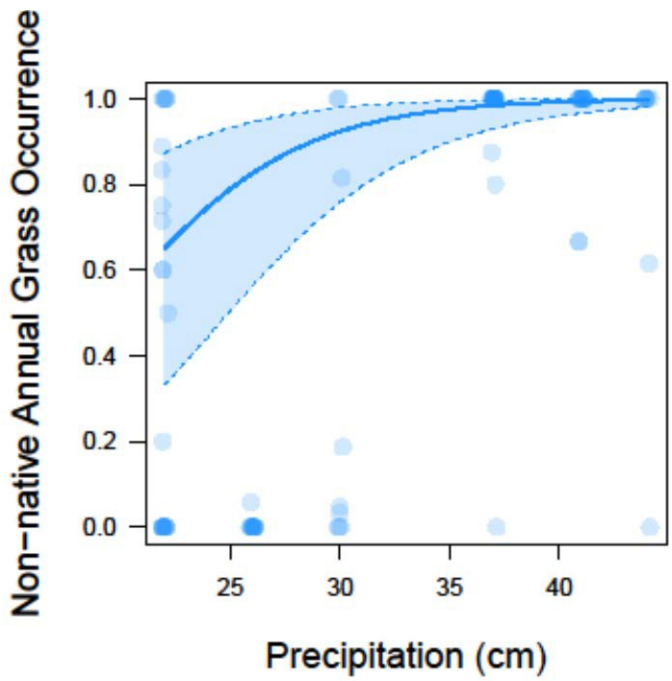

Figure B3. Non-native annual grass occurrence significantly increases with survey year precipitation for fire and mastication treatments (control data not included in this graphic). Precipitation amounts beyond 38 cm are confounded by the number of growing seasons since treatment; these high precipitation years only occurred two to three years post treatment. Precipitation less than 38 cm was dispersed across all growing seasons since treatment. Lines represent Generalized Linear Mixed Effect Model Regression lines, polygons represent 95% confidence intervals, and points represent an experimental unit mean for a survey year.

Appendix C: Shrub height

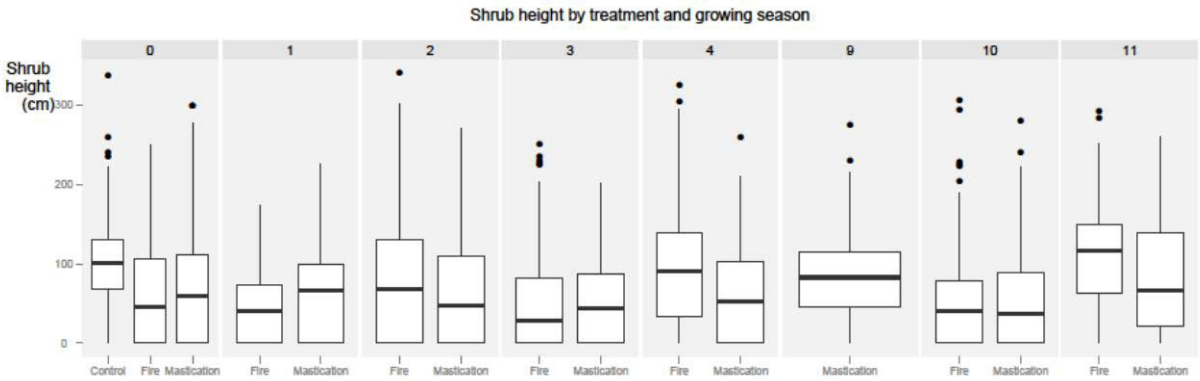

Figure C1. Boxplot of shrub height by treatment and growing seasons since treatment. There are no clear trends within the raw data which may be due to uniform shrub vigor or survey error. Shrub height may be uniform because if an individual is present, it grows vigorously. Shrub height may also be uniform because of poor and unclear survey design where surveyors recorded the maximum shrub height near the sampling points (3, 6, 9, 12 and 15 m along the transect).