

Can Forest Management Mitigate the risk of High Severity Fire and still Promote Biodiversity in the Klamath Mountains?

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Abstract

The Klamath Mountains mixed evergreen forest is adapted to frequent, low to moderate severity fires. Today, the Karuk Tribe, US Forest Service, and local community organizations have formed the Western Klamath Restoration Partnership to restore this fire regime, altered by a century of fire suppression. One of the main tasks of the WKRP is to address concerns about the impacts to biodiversity of both high severity fire on one hand, and the exclusion of fire on the other. First, I investigate how communities of plants, birds, lichens and insects differ between long-unburnt stands, low severity burns and high severity burns. Next I evaluate the response of diversity to two management options that can reduce canopy cover to within its historical range: multiple burns (wildland fire use) and thinning and burning. Based on 110 plots across the WKRP project area, low severity burns and unburnt areas did not differ in species composition. Plant, bird and insect diversity (alpha, beta and gamma) were as high or higher in high severity burns as in low severity/unburnt stands. Lichens were negatively impacted by high severity fire, beginning to recover only after 16 years. Multiple burns and thinned/burnt stands were the highest in diversity, because they provided habitat for both species preferring high severity burns and those preferring low severity/unburnt stands. This suggests that management, whether passive (allowing fires to burn and overlap) or active (thinning and burning) can help maintain biodiversity in this fire-dependent landscape.

Top findings (so far)

- No detectable difference in community composition between long-unburnt stands and low severity burns. This suggests that in fire-suppressed stands, fires that lead to < 25% canopy reduction do not cause a strong biodiversity response.
- Plant and bird diversity in high severity burns is as high or higher than in low severity/unburnt plots (alpha, beta and gamma diversity); almost all measures of diversity are highest in multiple burns and/or prescribed burnt plots.
 - **Alpha:** High severity burns have higher plant species richness than low severity/unburnt stands, but bird species richness is similar and lichen species richness lower. Several taxa of insect pollinators and herbivores are significantly more abundant in high severity plots than low severity/unburnt plots.
 - **Beta:** High severity burns are more heterogeneous than low severity/unburnt plots.
 - **Gamma:** The total species pool is lowest in low severity/unburnt stands (except for lichens).
 - **Multiple burns and prescribed burns** have the highest bird diversity (alpha, beta and gamma), and similar to higher plant diversity.
- A majority of species with a strong preference for either high severity burns or low severity/unburnt stands also favor multiple burn and prescribed burnt plots, suggesting that such stands can provide suitable habitat for both cohorts of species.

Ongoing questions

- Need to look at spatial autocorrelation (Odion 2010 suggest 2 km needed).
- Is there a better way to look at time-since-fire? I mostly ignored it here because of the high variability.
- What environmental factors mediate species response to different severities/treatments (shrub or tree cover, open space for herbaceous species, snags, tree density/size)? I have much data on stand architecture that I left out.
- Characterize species responses by guilds/functional groups (eg. different fire-related life histories for plants, foraging guilds for birds/insects, plant floristic origins)? Are species that prefer high canopy cover more likely to be generalists, or is it the opposite?

Introduction

After a century of fire suppression, concerns are mounting over the effect of changing fire regimes on biodiversity in Western North American forests adapted to frequent, low to moderate severity fires (Hessburg et al. 2005, Haugo et al. 2019). These changes result in two contrasting impacts: increasing extent of high severity fire on one hand, and the exclusion of fire on the other. The former threatens species and ecosystem services associated with mature forests (Miller et al. 2018, Miller and Safford 2019), while the latter threatens early seral habitats and open forests (Knapp et al. 2013, Swanson et al. 2014, Odion et al. 2014). Despite a broad consensus that the exclusion of fire has been detrimental to biodiversity, disagreement remains over how to balance the ecological need to allow more fire in fire-dependent ecosystems and the need to mitigate the risk of high severity fires to old growth-associated species, communities, and ecosystem services.

Managers may turn to two approaches to achieve this balance and move away from total fire suppression. The active approach is to thin and burn stands to enhance populations of species negatively impacted by fire exclusion and minimize the likelihood of high severity fires in places where there is a concern over the vulnerability of resources and rural communities (Wayman and North 2007, Webster and Halpern 2010, Abella and Springer 2015, Kalies and Yocom Kent 2016). However, thinning and burning has been criticized on the grounds that reducing the extent of high severity fire could reduce the availability of ecologically-important early seral habitats, while at the same time disturbing mature forest habitats and threatening associated species (Odion et al. 2014, Baker 2015). The second approach is to let fires burn when appropriate; this passive approach could lead to more frequent fires, thus reducing fuel loading and canopy homogeneity (North et al. 2012). Understanding the impacts of both active and passive forms of management is important to build a consensus over how to meet both fire management and biodiversity targets.

Such consensus is particularly needed in the context of collaborative landscape management agreements that are becoming increasingly common, particularly on national forests. In the Klamath Mountains of northern California, the Karuk Tribe, United States Forest Service and community and environmental organizations have formed the Western Klamath Restoration Partnership (WKRPP) in order to restore the historically low to mixed severity fire regime that prevailed prior to the disruption of Indigenous fire management (Fry and Stephens 2006, Crawford et al. 2015, Taylor et al. 2016). Extensive planning discussions have taken place to identify zones of agreement among all partners, such as limiting damage to communities from high severity fires and enhancing biodiversity (including both late-seral species and fire-dependent, early-seral species) (Harling and Tripp 2014). But can management achieve both of these objectives, or are there necessarily trade-offs?

Studies from related forest types such as inland dry forests suggest that treatments that reduce canopy cover promote biodiversity (Bartuszevige and Kennedy 2009), but such results are inconsistent (Willms et al. 2017) and their applicability to mixed-severity forests is questionable (Hessburg et al. 2016). In this study, I surveyed biodiversity (birds, plants, lichens and insects) in long-unburnt stands and low severity and high severity single burns. I identified species associated with high severity burns and long unburnt stands as early- and late-seral species respectively. I also surveyed thinned and burnt stands and multiple

burns with intermediate canopy cover representative of forest restoration goals aimed at minimizing the risk of high severity burns. To determine whether this type of management is also compatible with biodiversity conservation objectives, I then ask: do areas with intermediate canopies (actively or passively managed) provide habitat for early-seral species, late-seral species, both or neither?

Methods

Study area

Located in the Klamath-Siskiyou mountains of northern California, the WKRP is a 1.2 million-acre collaborative landscape restoration effort between the Karuk Tribe, US Forest Service and local NGOs (Harling and Tripp 2014). The area’s main vegetation class is mixed evergreen forest (Steel et al. 2015). The prevalence of hardwoods and Douglas-fir (*Pseudotsuga menziesii*) distinguish the Klamath-Siskiyou mixed evergreen forests from those of the Cascade Mountains and Sierra Nevada (Whittaker 1961, Barbour and Billings 2000). These forests were historically managed by the Karuk tribe using frequent (~12.5 year interval), low-intensity prescribed burning (Taylor and Skinner 1998, 2003). One of the main goals of the WKRP is to restore the fire regimes within the Karuk tribe’s aboriginal territory in a way that promotes the resilience of these ecosystems to high severity fire and climate change (Harling and Tripp 2014).

Data collection

I conducted surveys at 110 sites varying in time-since-fire and burn severity (48 sites surveyed in 2018 and 62 in 2019). Most sites were in mixed evergreen forest, with some in transition areas into dry or moist mixed conifer (classification based on FRID data, Safford and Van de Water (2014)). The median historic fire return interval in these forest is 13 years (Van de Water and Safford 2011). Sites sampled were lower elevation (mean 759m, range 241-1500m). They were placed in low severity and high severity burns, defined respectively as <25% canopy mortality and >75% canopy mortality (Miller et al. 2009), in long-unburnt stands (>40 years since last fire), in sites affected by multiple burns, and sites that were thinned and burnt. At all burnt sites, time-since-fire varied from 2 to 32 years. Multiple burns and thinned and burnt sites were placed in areas with intermediate canopy cover (30-65% cover). While it is possible for both to still have high canopy cover (or little canopy), I was only interested in “treatments” (active or passive) that reduce canopy cover significantly. Such canopy reduction corresponds to the level recommended for understory restoration (Abella and Springer 2015) and for mitigating the risk of crown fires (Moghaddas et al. 2010). As a result of this approach, the habitats studied follow a gradient of canopy cover (Figure 1). Burn severity was evaluated a priori based on the relative difference normalized burn ratio (Miller and Thode 2007) and verified in situ by visually estimating the magnitude of canopy cover reduction. Since the habitats differ mostly by the severity of fire’s impact, I will henceforth refer to different “severity categories” for simplicity, even though this is an imperfect description of multiple burn and thinned and burnt sites.

Several tests were used to ensure that the differences observed between site categories were not the product of a climatic or topographic pattern rather than fire history. To test for climate differences, I compared the climatic water deficit (CWD, the difference between potential and actual evapotranspiration). Using the Basin Characterization Model 30-year average for 1981-2010 (Flint et al. 2013), I found no difference between the severity categories (ANOVA, $F = 1.41$, $p = 0.237$). Heat load, which accounts for the effect of slope, aspect and latitude on insolation and temperature (McCune and Keon 2002), was not different among categories except that it was slightly lower for high severity sites (although this might seem counterintuitive, it is explained by the fact that high severity sites were steeper on average, and heat load decreases with slope gradient on north-facing aspects). However, due to the limited availability of prescribed burn areas, I had to make some concessions in study design. While there were numerous sites available for the other severity categories, the only prescribed burn sites that met my criteria for minimum size, canopy reduction, and absence of other disturbance factors were located in two project areas. These were higher in elevation on average than the other severity categories (mean = 1101m, 95% CL = 965-1237m) and more clustered

(average distance among sites <10km compared to 28-36km for the other severity categories). While these factors limit the generalizability of the patterns observed at these sites, this is a common challenge for studies of prescribed fires. Therefore I still include the prescribed burn sites in the study in the hope that my findings can be used in designing more robust future investigations.

At each site, I recorded aspect, slope and elevation. For all sites, I surveyed plants, epiphytic lichens, and birds. Flying insects were sampled in high and low severity sites and unburnt sites only for logistical reasons. Presence of all plants and lichen species was determined in an 11.3m-radius plot following the Common Stand Exam protocol (Service 2008). Plants were identified using the Jepson manual () and lichens were identified using Mccune (). I conducted two 10-minute bird point counts on separate, non-consecutive days (). Lastly, for high severity, low severity and unburnt sites, I set up a custom-built flight-intercept trap for flying insects that were left out for two days (Russo et al. 2011).

Analysis

I conducted a PERMANOVA analysis to test the significance of dissimilarity between the different severity categories (McArdle and Anderson 2001) using the `adonis2()` function from the `vegan` package in R (Oksanen et al. 2007), with 999 permutations. Then I conducted PERMANOVA pairwise comparisons between each severity category. To minimize the risk of making a type-1 error from carrying out multiple pairwise tests on a single data set, I adjusted the p-values using the Bonferroni correction method (Rice 1989).

Next, I analyzed patterns of alpha, beta and gamma diversity for plants, birds, and lichens. Alpha diversity is equivalent to species richness per plot. I calculated beta diversity, or the amount of variation in species composition and richness between sites within each severity category, using R package `vegetarian` v1.2 (Charney and Record, 2009). I used the Jaccard index (Jost 2007) to represent the extent to which species are shared in each pair of samples. I compared results between treatments using standard errors from bootstrapping given by the package `vegetarian`.

To compare the species pool (gamma diversity) between severity categories, I generated sample-based rarefaction curves (Colwell et al. 2012) using package `iNEXT` v. 2.0.20 (Chao et al. 2014, Hsieh et al. 2016). Estimates were interpolated from site-based incidence data to account for unequal sample sizes (Colwell et al. 2012) and then extrapolated to $2\times$ the size of the smallest sample (Chao et al. 2014). I compared results between treatments using 95% confidence intervals from bootstrapping.

Insects were not sampled in the multiple burns and thinned and burnt sites, but I include them nevertheless to compare species communities in the unburnt, low severity and high severity burns. Comparisons of alpha, beta and gamma diversity were not as meaningful for insects, because of the small number of taxa (orders or suborders). Instead, I used an indicator species analysis using the function `multipatt()` in the package `indicspecies` v1.7.8 (De Cáceres and Legendre 2009) to determine which taxa showed a preference for high severity or low severity and unburnt stands (the latter were pooled because the PERMANOVA suggested their community composition did not differ).

Lastly, I wanted to determine if the multiple burns and thinned and burnt stands tended to contain species affiliated with high severity burns and/or those associated with low severity and unburnt stands. Four hypotheses were envisioned: 1) Species associated with high severity burns are associated with the actively or passively managed stands; 2) Species associated with unburnt stands and low severity burns are associated with the actively or passively managed stands; 3) Both of these species cohorts are found in the actively or passively managed stands, presumably because they are intermediate in environmental characteristics such as canopy cover; 4) Neither cohort is found in the actively or passively managed stands, presumably because the intermediate canopy cover creates inhospitable conditions for both and favors a completely different species assemblage. To determine which of these four hypothesis was correct, I identified species that prefer high severity burns and species that prefer unburnt stands and low severity burns by using a simple criterion: if a species was found twice as frequently in one habitat than the other, I considered that it exhibited a preference for that habitat. Only species that occurred in more than five sites (18% of the total number of sites) were included. For each cohort (those found twice as frequently in the high severity burns and those found twice as frequently in the low severity burns and unburnt stands), I then determined if it was also

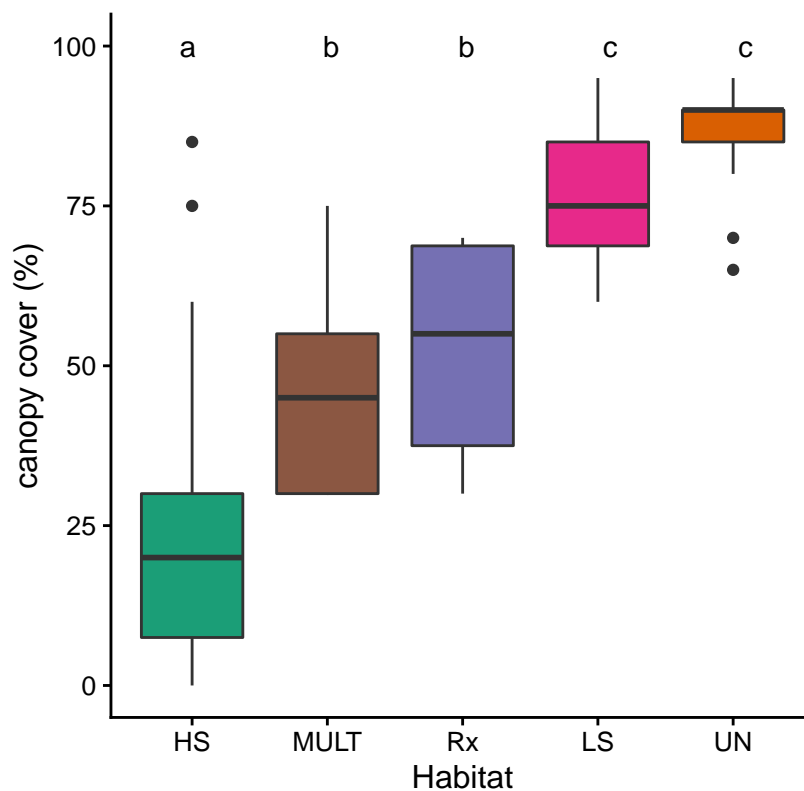
found twice as frequently in the multiple burns and/or thinned and burnt stands. To determine which of the four hypotheses above was correct, I evaluated the frequency with which species preferring high severity burns or low severity burns and unburnt stands also favored the multiple burns and/or thinned and burnt stands.

were species more likely to be found in high severity burns, low severity burns and unburnt stands, both, or neither

compared the occurrence of species with a strong preference for either HS or UN/LS habitats in the MULT and Rx habitats, to see if these habitats can be suitable for such species.

Results

Fig.1: Canopy cover in each severity category



Comparing community composition by habitat

Effect of fire history on species composition

First, I take a look at which habitats have similar or different species composition, using a PERMANOVA. For all taxa, there is an effect of habitat ($p < 0.001$; main PERMANOVA not shown).

Pairwise habitat comparisons

Using pairwise PERMANOVAs to compare the habitats, there is no detectable difference between plant, bird or lichen communities of LS and UN habitat (Table 1) (plants: $p = 0.11$; birds: $p = 0.07$ lichens: $p =$

Table 1: Table 1: Pairwise PERMANOVA results

Pair	plants		birds		lichens	
	F_model	p_adj	F_model	p_adj	F_model	p_adj
HS vs LS	7.32	0.01	6.45	0.01	16.34	0.01
HS vs MULT	3.20	0.01	1.72	0.84	25.11	0.01
HS vs Rx	7.43	0.01	8.11	0.01	18.11	0.01
HS vs UN	9.95	0.01	12.06	0.01	16.46	0.01
LS vs MULT	5.99	0.01	4.52	0.01	3.41	0.01
LS vs Rx	6.85	0.01	6.53	0.01	6.63	0.01
LS vs UN	2.00	0.11	2.68	0.07	1.04	1.00
MULT vs Rx	4.15	0.01	5.90	0.01	6.41	0.01
MULT vs UN	6.98	0.01	8.79	0.01	3.72	0.01
UN vs RX	5.68	0.01	8.73	0.01	7.48	0.01

1.00). For this reason, from here on I will lump unburnt stands and low severity burns together as UN/LS.

In addition, bird communities of HS and MULT are not detectably different ($p = 0.01$). For lichens, the only habitat that stands out is the HS habitat ($p < 0.02$), although it is not statistically different from the MULT habitat ($p = 1$).

Alpha, Beta, Gamma diversity patterns

Next I investigated the patterns of alpha, beta, and gamma diversity for birds and plants (lichens are not included; briefly, lichen species richness is highest in UN/LS, lowest in HS, and intermediate in the multiple and prescribed burns). The analysis here is based on presence/absence data, and does not account for relative abundance.

Alpha diversity

Bird and plant species richness are highest in the prescribed and multiple burns, lower in the UN/LS and HS burns. Plant species richness is significantly higher in the HS burns than in the UN/LS stands.

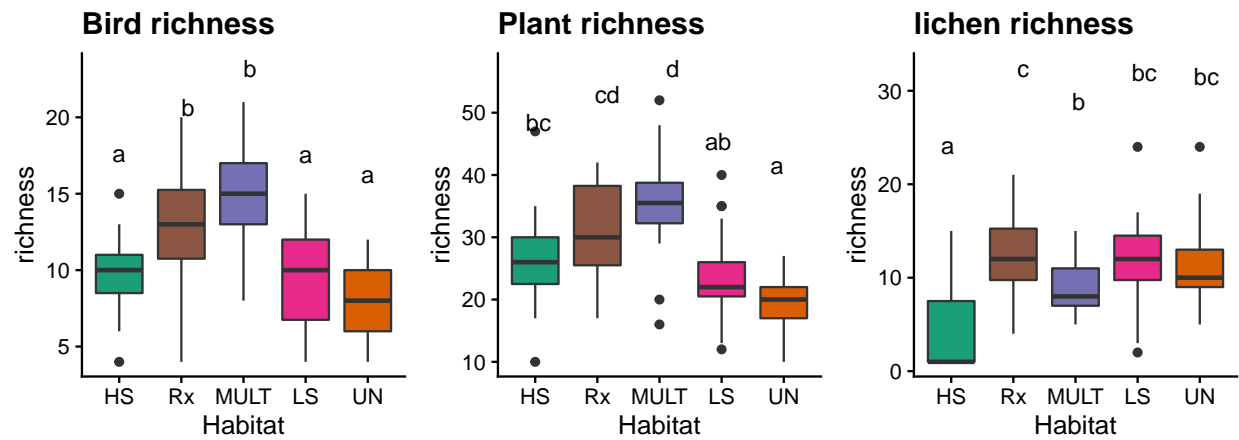


Fig.2: Bird, plant and lichen species richness

Beta Diversity

Beta diversity is highest in the prescribed and multiple burns; it is significantly higher in the HS burns than in the UN/LS stands.

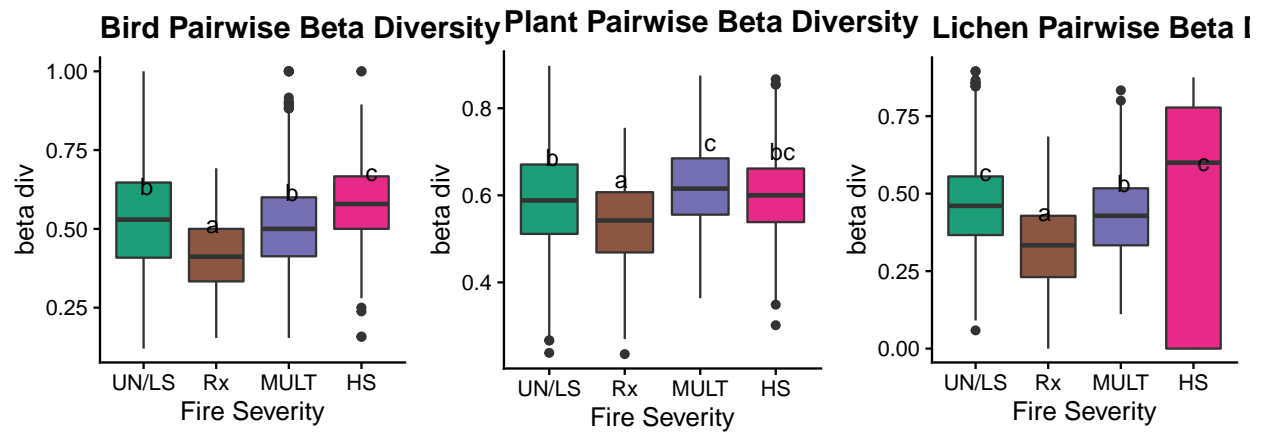


Fig.3: Plant and bird beta diversity

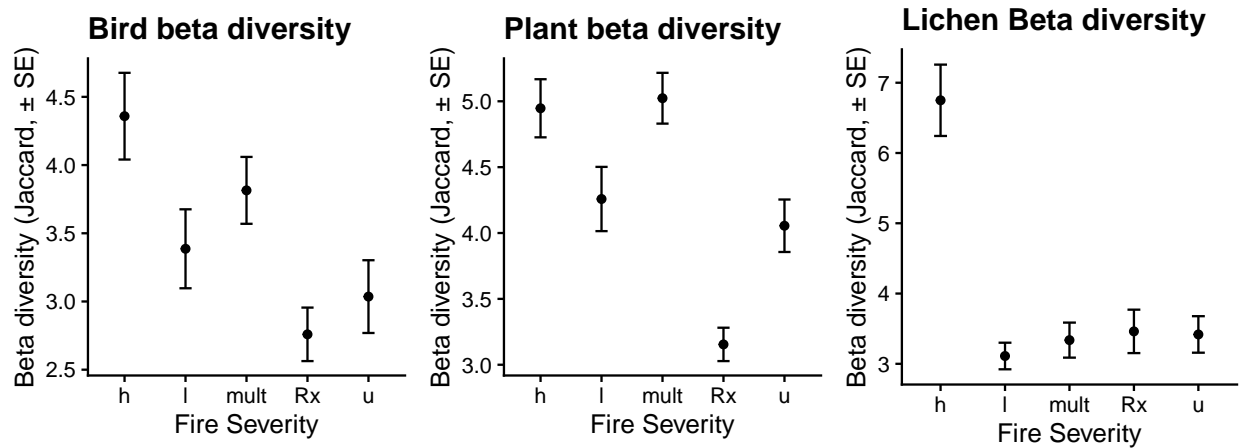
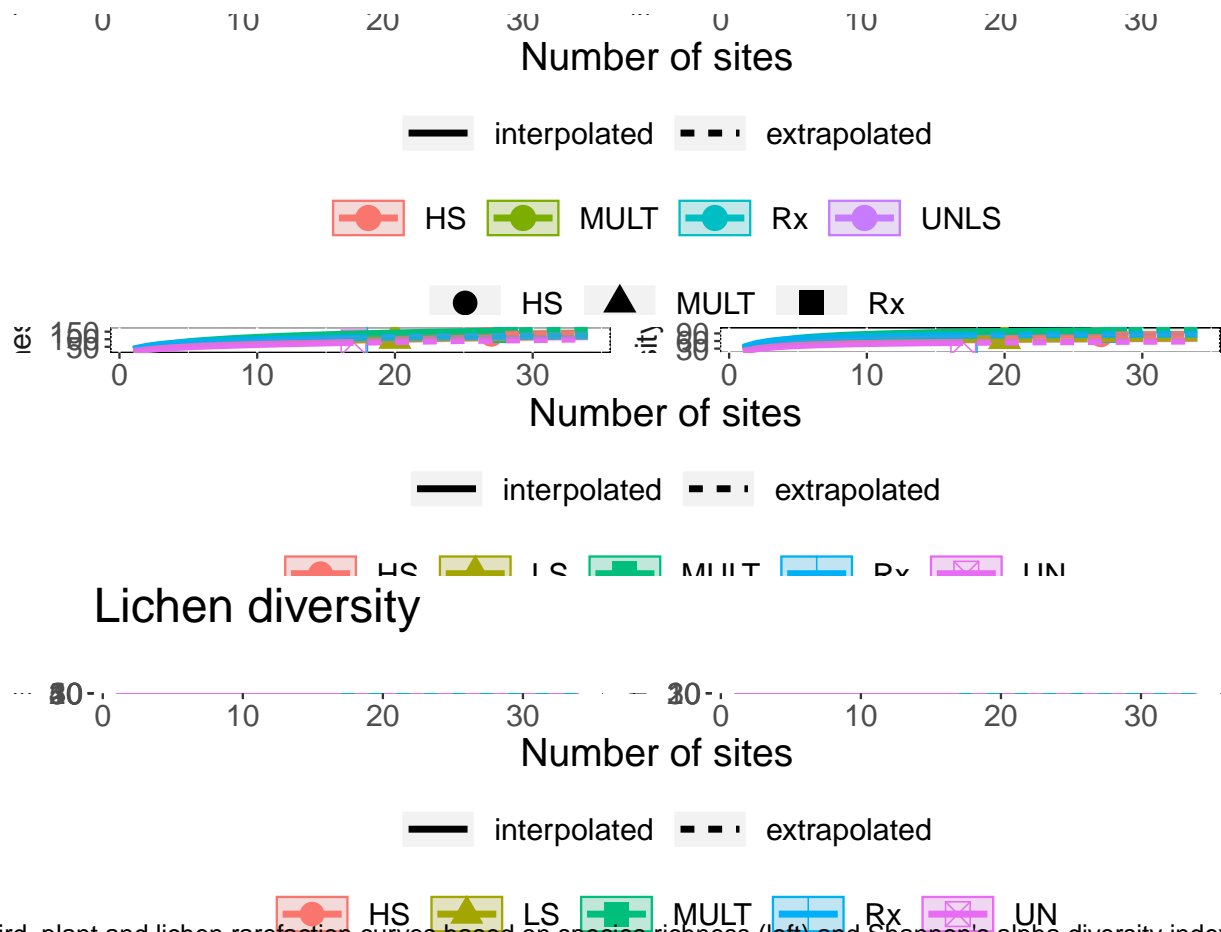


Fig.3B: Bird, plant and lichen beta diversity (Jaccard)

Gamma diversity and rarefaction curves

I had a different number of samples in each habitat, so instead of presenting simple gamma diversity numbers which would be misleading, I am showing species accumulation curves. The pool of species appears largest in the multiple burns, lowest in the UN/LS stands, and intermediate in the HS burns. For birds, the species pool in the prescribed burn sites is also high, but for plants it levels out faster and is intermediate between the HS and UN/LS sites (however I want to caution against over-interpreting the Rx burn sites, because I had fewer plots and they were more geographically clustered).



Bird, plant and lichen rarefaction curves based on species richness (left) and Shannon's alpha diversity index

Insect Indicator Species Analysis

Insect data was analyzed to the order or suborder level (and only for HS, LS and UN habitats). Six taxa were indicator species for the HS habitats. These are mainly pollinators (Aculeata (bees/stinging wasps), Brachyceran flies, Coleoptera), and herbivores (Homoptera, Heteroptera, Orthoptera), which probably reflects the higher abundance of flowers and broadleaf shrubs/trees in HS burns.

```
##
## Multilevel pattern analysis
## -----
##
## Association function: IndVal.g
## Significance level (alpha): 0.1
##
## Total number of species: 13
## Selected number of species: 7
## Number of species associated to 1 group: 7
##
## List of species associated to each combination:
##
## Group h #sps. 7
##          stat p.value
## Homoptera 0.909 0.01 **
```

```
## Coleoptera 0.872 0.01 **
## Aculeata 0.860 0.01 **
## Brachycera 0.819 0.04 *
## Parasitica 0.755 0.09 .
## Orthoptera 0.674 0.04 *
## Heteroptera 0.642 0.02 *
## ---
## Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

## data frame with 0 columns and 0 rows
```

Species community composition

Looking at the frequency of occurrence of all plant, bird, and lichen species detected at least 5 times (144 species), I identified species with a strong preference for HS sites or for UN/LS sites. Species were associated with each of these two cohorts if they were found at least twice as frequently in one habitat than in the other. For example, *Achillea millefolium* (Yarrow) was found in 19% of HS plots and 3% of UN/LS plots; therefore this species was classified as preferring HS stands. Then I determined if these species also favored MULT and/or Rx sites using the same rule. In this case, *Achillea millefolium* is found in 29% of MULT plots and 28% of Rx plots; because this is also more than twice the UN/LS frequency (3%), I concluded this species also favors MULT and Rx sites.

I identified 61 species (birds, plants and lichens combined) that seem to favor HS, and 45 species that favor UN/LS. What I find is that most species that have a preference for UN/LS or HS are **also** found abundantly in MULT and/or Rx sites: 34 species (76%) preferring UN/LS also favor MULT, while 31 (69%) also favor Rx. Conversely, 49 species (80%) that prefer HS also favor MULT, and 41 (67%) also favor Rx.

Figure 5 breaks down the proportion of plants and birds that prefer HS or UN/LS that also favor MULT and Rx sites.

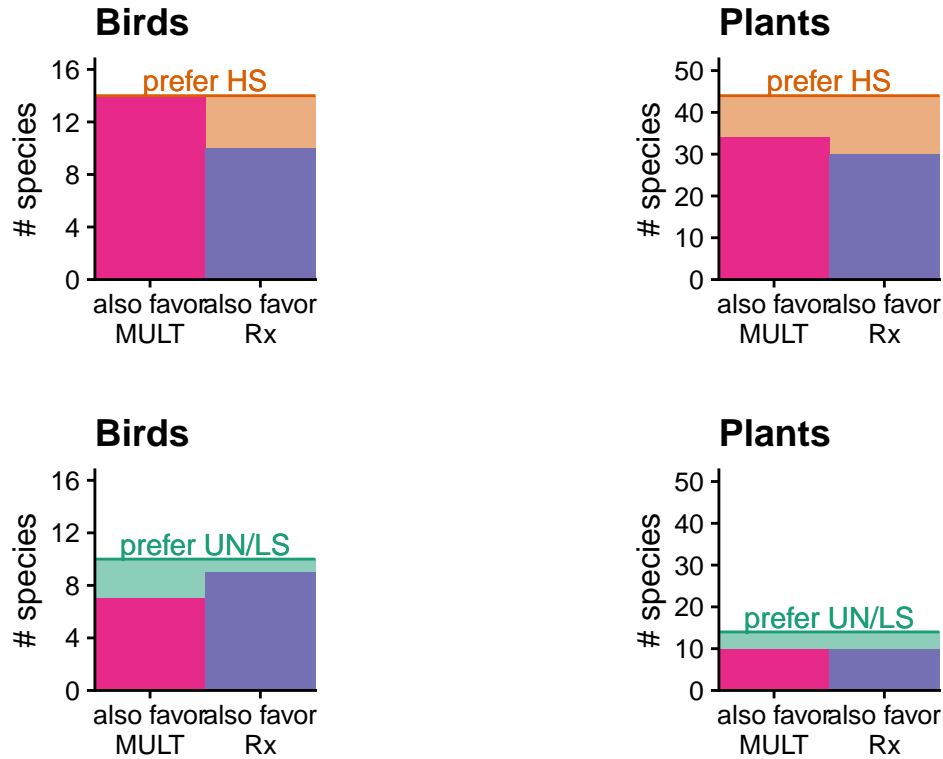


Fig. 5: Most species that prefer HS or UNLS also favor MULT and Rx

Discussion

Fire suppressed stands have lower biodiversity (alpha, beta, gamma diversity) than high severity burn stands, and low severity burns do not appear to change this pattern. While high severity burns are important for biodiversity when compared with unburnt/low severity stands, species that are associated with either of these habitats also favor multiple burns and prescribed burns. As a result, such stands are more diverse than either high severity burns or (especially) unburnt/low severity burn stands. This suggests that both active (thinning/burning) and passive (wildland fire use) management can achieve biodiversity conservation goals while also achieving fuels reduction and forest/community resilience objectives.

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