Fire and Biodiversity in the WKRP

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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 formedthe Western Klamath Restoration Partnership to restore this fire regime, altered by a century of fire sup-pression. Part of the WKRP's mission is to address concerns about the impacts on 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 severityburns. Next I evaluate the response of diversity to two management options that can reduce canopy cover towithin its historical range: multiple burns (wildland fire use) and thinning and burning. Based on 110 plotsacross 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 asin low severity/unburnt stands. Lichens were negatively impacted by high severity fire, beginning to recoveronly after 16 years. Multiple burns and thinned/burnt stands were the highest in diversity, because theyprovided habitat for both species preferring high severity burns and those preferring low severity/unburntstands. 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 pol-linators and herbivores are significantly more abundant in high severity plots than low sever-ity/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

- 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)?

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 concerns are focused on two aspects: increasing high severity fire on one hand, and the exclusion of fire on the other. The former threatens species associated with high canopy cover and mature forests , while the latter threatens species associated with early seral habitats and open forests (Swanson et al. 2014, Odion et al. 2014). While there is a broad concensus that the exclusion of fire has been detrimental to biodiversity, there is disagreement over the relative importance of these two aspects driving change in forest structure.

Further disagreement exists over forest management practices that managers are increasingly using in an effort to address the consequences of changing fire regimes, and to minimize the vulnerability of rural communities to high severity fire. For example, thinning and burning has been criticized on the grounds that it might reduce the availability of ecologically-important early seral habitats, while also disturbing mature forest habitats . Meanwhile, fires are increasingly overlapping, either due to the inability to suppress them, or because of efforts to manage wildfires rather than systematically suppressing them. Understanding the impact of both active and passive forms of management is important if we are to build a consensus over how to meet both fire management and biodiversity targets.

Such concensus is particularly needed in the context of collaborative management agreements that are becoming more an more common. For example, 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 (WKRP) 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 discussions and planning has taken place to identify zones of agreement among all the partners, such as limiting damage to communities from high severity fires, and protecting and enhancing both late-seral associated species and fire-dependent species (Harling and Tripp 2014).

Methods

Study area

Located in the Klamath-Siskiyou mountains of northern California, the Western Klamath Restoration Partnership (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, to promote the resilience of these ecosystems (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. Sites 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. After decades of fire suppression in the Klamath Mountains, forests tend to develop closed canopies and fires tend to burn at either high or low severity. Based on personal observation and a cursory GIS analysis, a reduction in canopy cover of 25-75% is uncommon in the lower elevations of the Klamath Mountains (usually <10% of the burnt area), and such sites were not targeted for sampling. On the other hand, both multiple burn sites and thinned and burnt sites were intermediate in canopy cover (30-65% cover). Burn severity was evaluated a priori using satellite imagery, 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/burnt sites.

At this point it is important to note that plots in multiple and thin/burn sites were not randomly distributed. Instead I used a form of stratified random sampling, targeting stands where the canopy had been reduced to 30-75%, which I am assuming to be closer to the historic range of variation pre-fire-suppression. My findings are therefore meant to investigate biodiversity responses in treatments that achieve this level of canopy reduction; multiple high severity burns removing all canopy cover or prescribed burns that do not reduce the canopy cover signitficantly are intentionally not included in this study. As a result of this sampling approach, the habitats studied follow a gradient of canopy cover (Figure 1).

At each site, I recorded aspect, slope and elevation. Because time-since-fire alone may not always accurately predict vegetation development, I may use these measurements to weight fire ages depending on the productivity of the site (McCune and Keon 2002). I also took standard forest architecture measurements (modal height, diameter-at-breast-height, and cover for each species, number and DBH of snags). Tree cover and stand architecture was recorded in 50m plots.

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. The abundance of all plant 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 percent cover was estimated for each species. Lichens were identified using Mccune (), and abundance was recorded using an ordinal scale (1: rare, 1-3 thalli; 2: uncommon, 4-10 thalli, 3: common >10 thalli but found on less than half the boles or branches; 4: abundant, >10 thalli and found on more than half the boles or branches). 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 (left out for 2 days) (Russo et al. 2011). Plant and lichen specimens were preserved and submitted to the UC Davis herbarium.

Analysis

Differences between communities

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, we 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.

Insect data was analyzed separately using an indicator species analysis, because I did not sample insects in the MULT and Rx sites.

Lastly, I 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 habitat
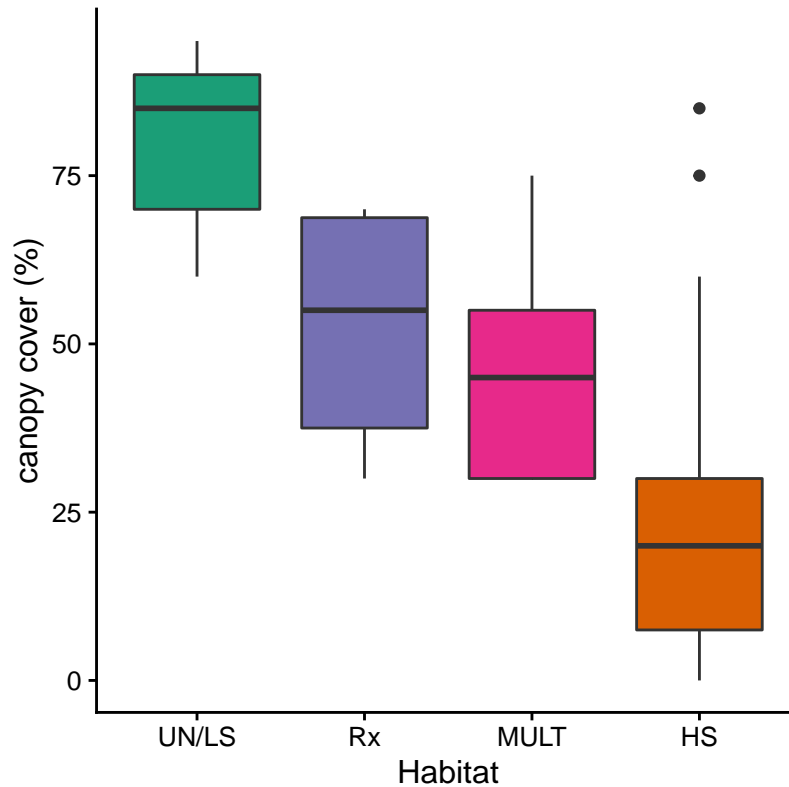
Comparing community composition by habitat

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 = 0.26; birds: p = 0.12 lichens: p = 1). 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).

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	7.321	0.01	6.446	0.01	12.848	0.01
HS vs MULT	3.200	0.01	1.721	0.58	1.161	1.00
HS vs Rx	7.432	0.01	8.106	0.01	14.852	0.01
HS vs UN	9.946	0.01	12.057	0.01	8.085	0.02
LS vs MULT	5.986	0.01	4.520	0.01	6.908	0.06
LS vs Rx	6.849	0.01	6.528	0.01	4.205	0.03
LS vs UN	1.996	0.26	2.678	0.12	1.031	1.00
MULT vs Rx	4.152	0.01	5.902	0.01	8.106	0.03
MULT vs UN	6.984	0.01	8.791	0.01	3.871	0.35
UN vs RX	5.680	0.01	8.732	0.01	4.117	0.08

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.
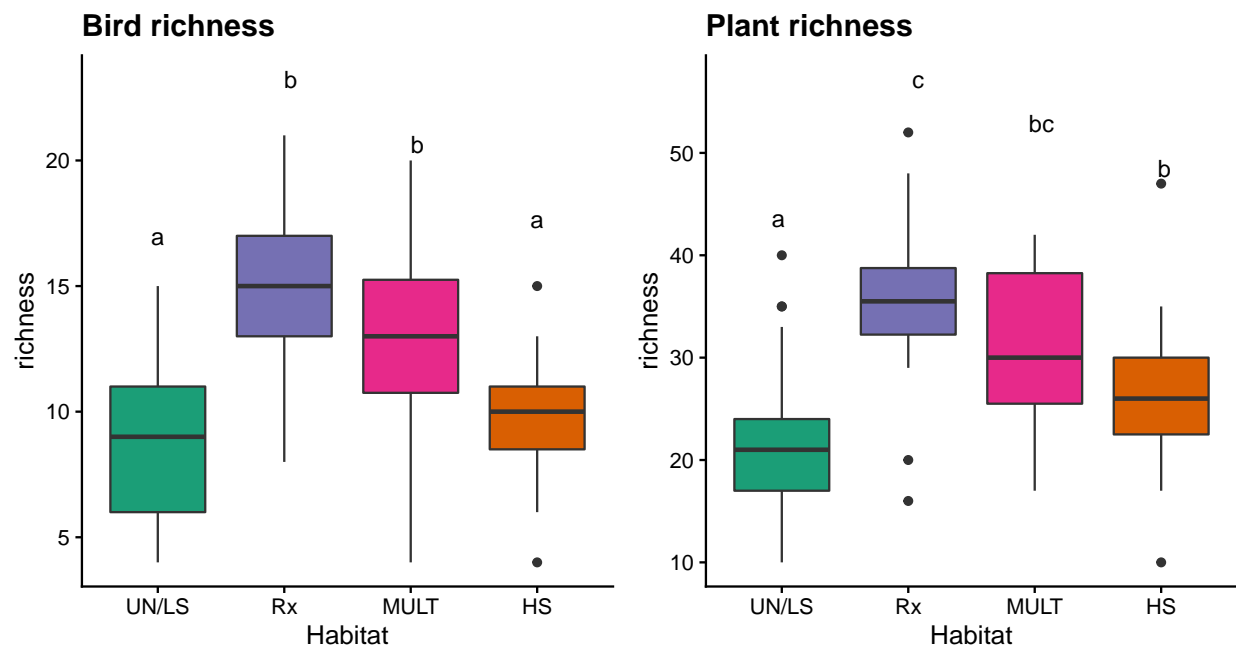
Fig.2: Plant and bird species richness

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.
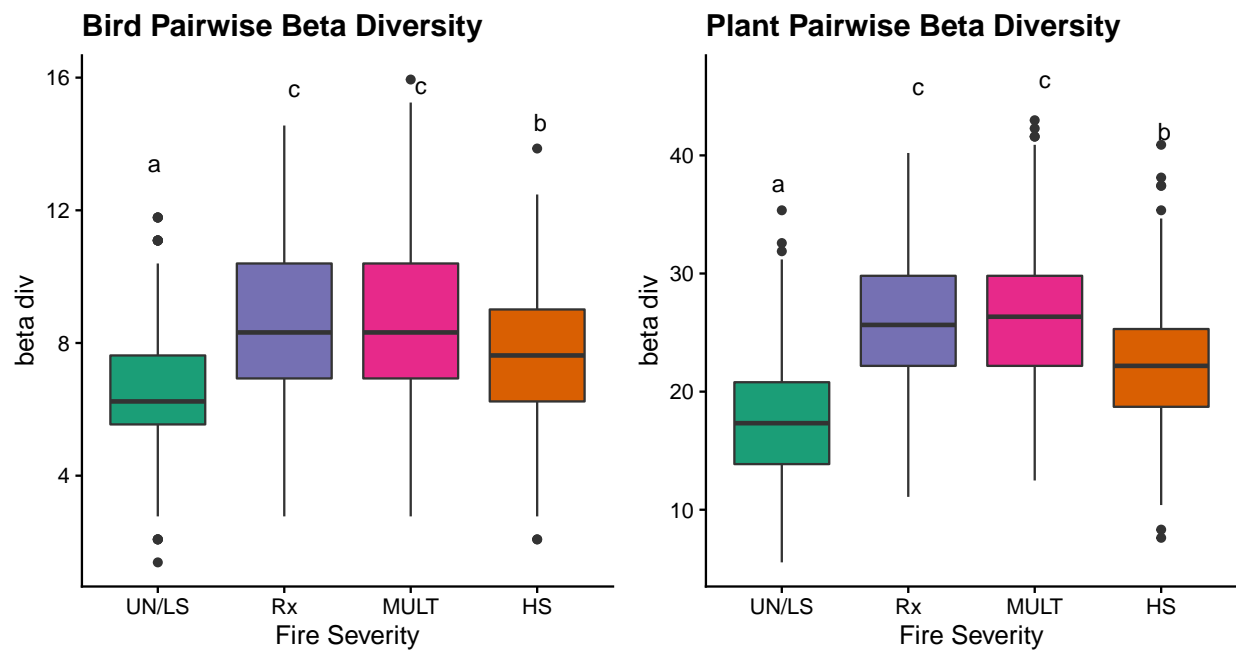
Fig.3: Plant and bird beta diversity

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 gegraphically clustered).
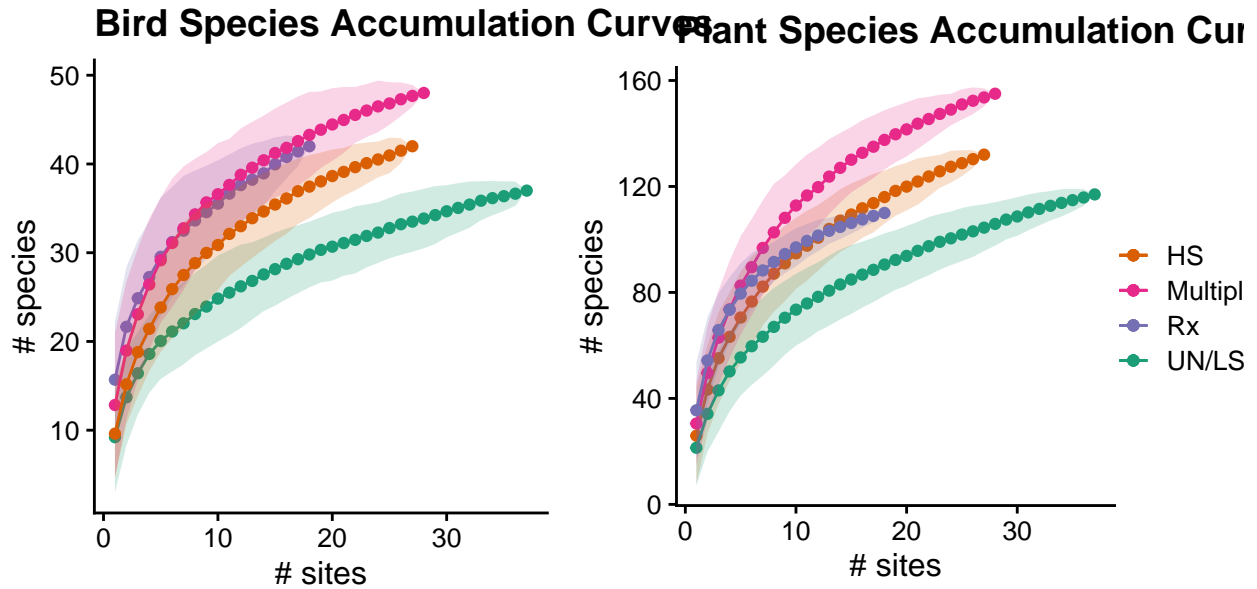
Fig.4: Plant and bird species accumulation curves

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: 6
##  Number of species associated to 1 group: 6
##
##  List of species associated to each combination:
##
##  Group h  #sps.  6
##             stat p.value
##  Homoptera  0.909   0.01 **
##  Coleoptera 0.872   0.01 **
##  Aculeata   0.860   0.01 **
```

```
## Brachycera  0.819    0.04 *
## Orthoptera  0.674    0.03 *
## Heteroptera 0.642    0.01 **
## ---
## 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 fequency 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 prefering 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 60 species (birds, plants and lichens combined) that seem to favor HS, and 35 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: 22 species (63%) prefering UN/LS also favor MULT, while 27 (77%) also favor Rx. Conversely, 49 species (82%) that prefer HS also favor MULT, and 40 (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.
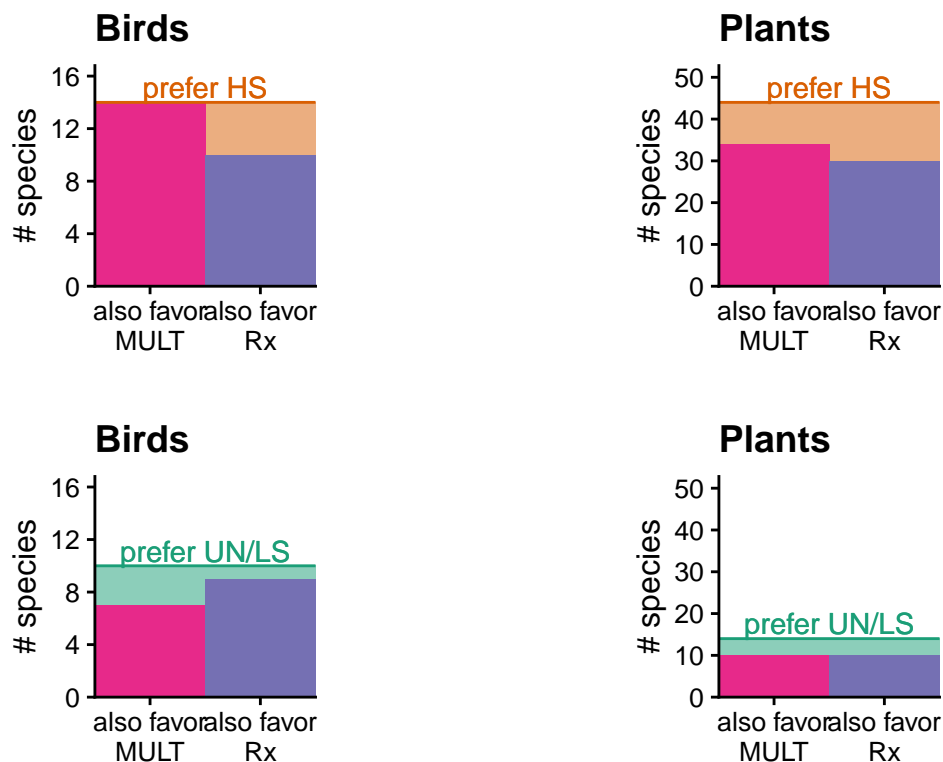

Fig. 5: Most species that prefer HS or UNLS also favor MULT and Rx

Discussion

Fire suppressed stands have lower biodiversity than high severity burn stands, and low severity burns do little 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 protecting or maximizing other values and ecosystem services.

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