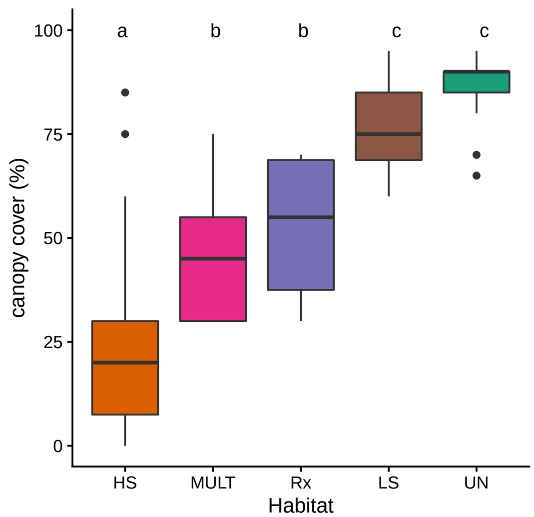
Results

Chris Adlam

Results

Fig.2: Canopy cover in each severity category



Pairwise PERMANOVA results

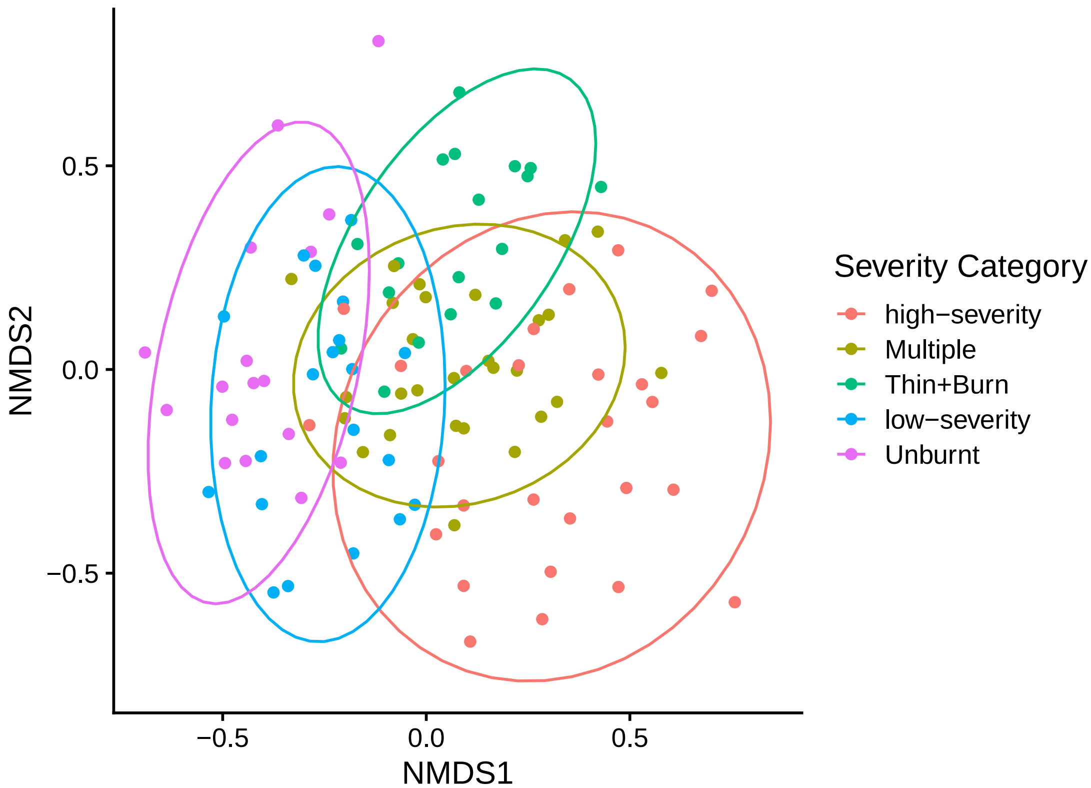
	plants		birds		lichens	
Pair	F_model	p_adj	F_model	p_adj	F_model	p_adj
HS vs LS	7.321	0.01	6.45	0.01	16.3	0.01
HS vs MULT	3.200	0.01	1.72	0.90	25.1	0.01
HS vs Rx	7.432	0.01	8.11	0.01	18.1	0.01
HS vs UN	9.946	0.01	12.06	0.01	16.5	0.01
LS vs MULT	5.986	0.01	4.52	0.01	3.4	0.01
LS vs Rx	6.849	0.01	6.53	0.01	6.6	0.02
LS vs UN	1.996	0.21	2.68	0.12	1.0	1.00
MULT vs Rx	4.152	0.01	5.90	0.01	6.4	0.01
MULT vs UN	6.984	0.01	8.79	0.01	3.7	0.01
UN vs RX	5.680	0.01	8.73	0.01	7.5	0.01

Variation in community composition across habitats

Effect of fire history on species composition

The main PERMANOVA revealed that species composition varies for all taxa in response to the severity category ($p < 0.001$). Using pairwise PERMANOVAs to compare the habitats, there is no detectable difference between plant and lichen communities of low-severity and unburnt stands, while the difference in bird communities was only marginally significant (Table 1). In addition, bird communities of high-severity burns and multiple burns are not detectably different. For lichens, contrary to expectations, the communities of multiple burns, thin+burn and low severity differed significantly.

Figure 3: NMDS for all species. Ellipses represent 90% CI.



Species assemblage ordination

The NMDS confirms a considerable overlap in species communities of long-unburnt and low-severity burn stands. high-severity stands have distinct species communities, while the communities in thinned and burnt stands and multiple burn stands appear to be intermediate between the high-severity stands and long-unburnt/low-severity stands. Figure 3 shows the first two dimensions of a 3-dimensional ordination that found convergent solutions with a stress of 0.176 ("stress" represents the degree of distortion required to reduce the dimensionality of the data; a stress of <0.20 is considered acceptable).

Alpha, Beta, Gamma diversity patterns

Alpha diversity

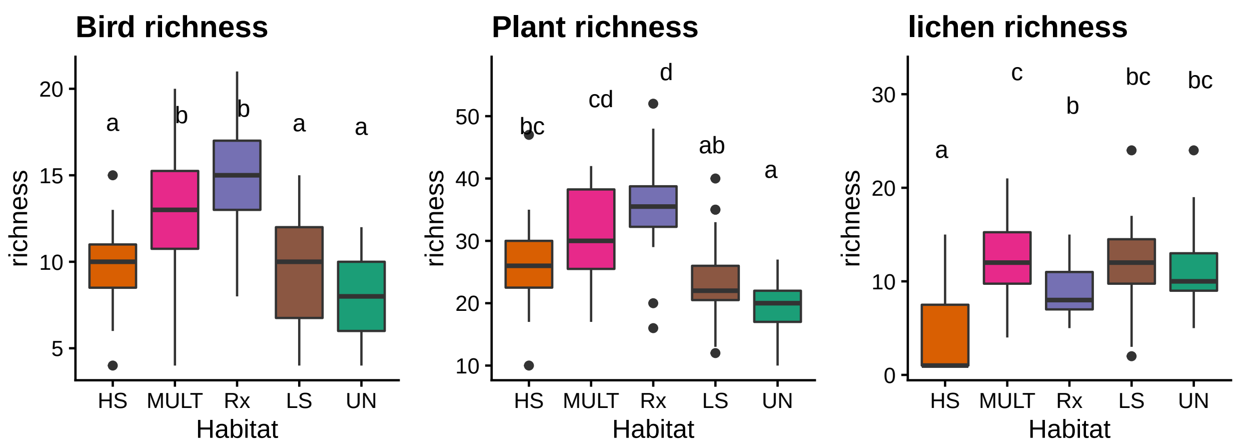


Fig.4: Bird, plant and lichen species richness

Bird and plant species richness were highest in the multiple burns and thinned and burnt stands (for plants the difference between high-severity burns and multiple burns was not significant) (Figure 4). Bird and plant richness in low-severity burns and unburnt plots was slightly lower than in high-severity burns, but the difference was overall not significant. Lichens were predictably less diverse in the high-severity stands, but richness in the other severity categories was similar.

Within the multiple burns and thinned and burnt stands, canopy cover was negatively correlated with plant richness ($F_{(1,44)} = 8.561$, $p = 0.005$) and bird richness ($F_{(1,44)} = 5.302$, $p = 0.026$). In the low-severity and long-unburnt stands, canopy cover was negatively correlated with bird richness ($F_{(1,35)} = 10.191$, $p = 0.003$), but only weakly correlated with plant richness ($F_{(1,35)} = 2.254$, $p = 0.142$). In the high-severity stands, canopy cover was not correlated with either plant or bird richness ($F_{(1,25)} = 2.382$, $p = 0.135$ and $F_{(1,25)} = 1.863$, $p = 0.184$ respectively).

Beta Diversity

Beta diversity was highest in the high-severity burns and multiple burns for birds and plants, and lowest for the thinned and burnt stands, possibly because they were spatially clustered rather than because of an effect of treatment (figure 5). For lichens, high-severity burns had the highest beta diversity, likely not because of a high level of species turnover between sites, but rather because of the variation in species richness between plots with no surviving trees and those that had surviving trees, and therefore lichens.

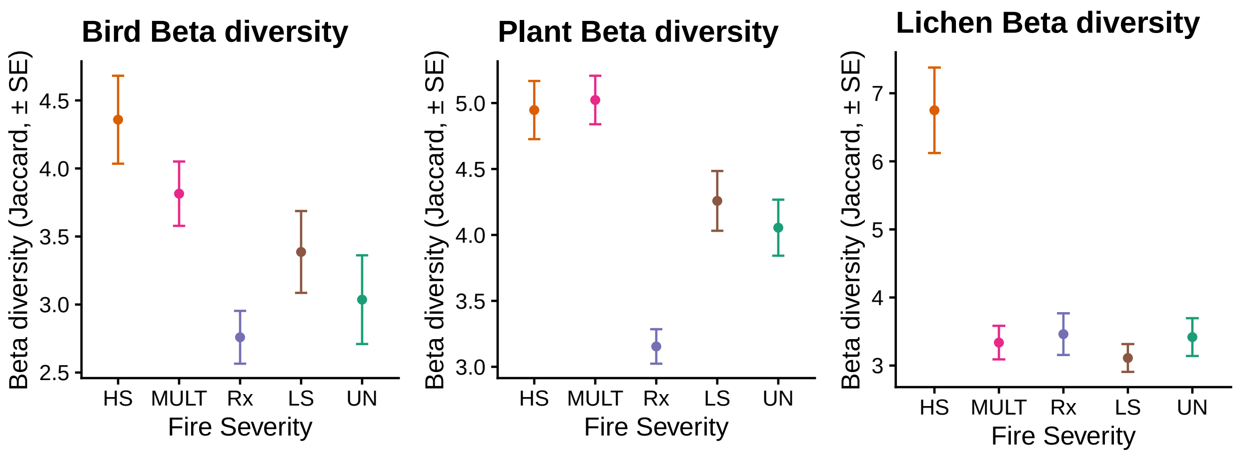


Fig.5: Bird, plant and lichen beta diversity (1−Jaccard)

Gamma diversity

Based on the extrapolated species richness, the total pool of species for birds appears to be largest in the multiple burns and thinned and burnt stands, intermediate in the high-severity burns, and lowest in the low-severity and long-unburnt stands (Fig. 5). For plants, the pattern is the same except that species pool from the thinned and burnt stands appears smaller than the high-severity burns, and more similar to the low-severity stands instead. high-severity fire eliminates lichens and most of their substrate [@millerAlteredFireRegimes2018], and their species pool is smaller in the high-severity stands than in the other severity categories, which are similar.

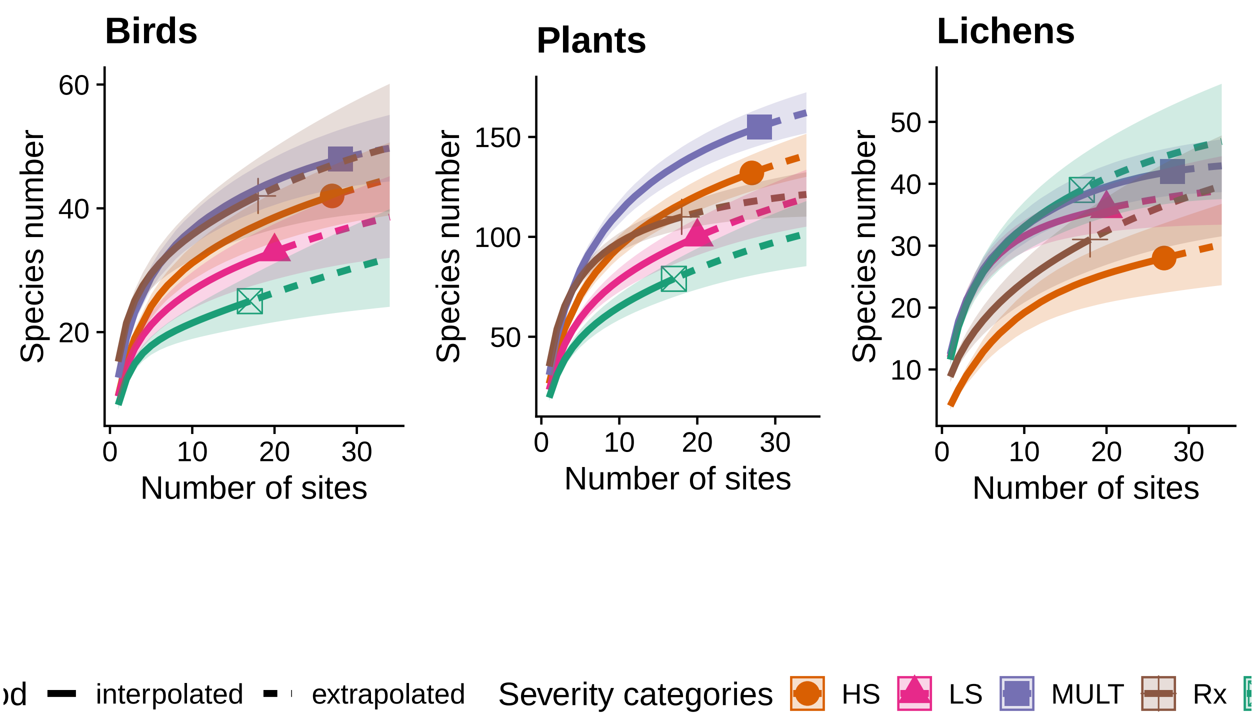


Figure 6: Gamma diversity, extrapolated based on species richness.
Shaded area represents 95% confidence intervals.

Insect Indicator Species Analysis

Six insect taxa (order or suborder) were indicators of the high-severity habitats (table 2). These were 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 high-severity burns.

Insect indicators of early-seral habitat

	IndVal	P-value
Homoptera	0.91	0.001
Coleoptera	0.87	0.001
Aculeata	0.86	0.006
Brachycera	0.82	0.014
Orthoptera	0.67	0.047
Heteroptera	0.64	0.011

```
## Warning: NAs introduced by coercion
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## Joining, by = "species"
## Joining, by = "species"
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## Warning: NAs introduced by coercion

## Joining, by = "species"
## Joining, by = "species"
```

Table 3: Indicator species for high severity burns and low severity/unburnt stands. Species highlighted in gray also favored multiple burns and/or thinned and burnt stands. Species in bold have a highly significant *p*-value (≤0.01). Letters following species names indicate Karuk traditional uses: for plants, M = Medicinal, F = Food, B = Building materials (includes cordage and tools); for birds, R= Regalia, C = Ceremony, S = Spiritual and/or Story-telling (see text for sources).

Species	IndVal	*p*-value	Species	IndVal	*p*-value
Plants			**Birds**		
Indicators of high severity burns					
Ceanothus integerrimus **M,B**	**82**	**0.001**	**Spotted Towhee S**	**79**	**0.001**
Madia **spp.**	**73**	**0.001**	**Lazuli Bunting R,C**	**69**	**0.001**
Ribes **spp.F**	**65**	**0.01**	Nashville Warbler R,C	62	0.012
Melica spp.	62	0.046	**Western Wood-Pewee**	**61**	**0.001**
Elymus glaucus **F,M**	**61**	**0.003**	**Northern Flicker R,C,S**	**57**	**0.01**
Festuca microstachys	**59**	**0.001**	**MacGillivray's Warbler R,C**	**54**	**0.008**
Rubus leucodermis F	59	0.02	**Wrentit**	**54**	**0.001**
Asyneuma prenanthoides	**58**	**0.001**	House Wren	48	0.011
Solanum parishii	**56**	**0.002**	**Hummingbird sp. R,C,S**	**48**	**0.01**
Rubus ursinus F	54	0.012	Acorn Woodpecker R,C	44	0.085
Collomia heterophylla	53	0.06	Purple Finch	44	0.082
Rubus parviflorus F,M	51	0.08	Lesser Goldfinch R,C	38	0.021
Agoseris spp. F	48	0.012	Bewick's Wren	33	0.076
Calystegia occidentalis M	48	0.011	Bushtit	33	0.067
Chamerion angustifolium	**48**	**0.005**			
Silene spp.M	45	0.034			
Arctostaphylos spp. F,B	44	0.081			
Quercus garryana F,M	44	0.078			
Bromus carinatus **F**	**43**	**0.01**			
Daucus pusillus	**43**	**0.005**			
Eriophyllum lanatum	**43**	**0.007**			
Achillea millefollium M	40	0.072			
Dichelostemma spp. F	38	0.026			
Hosackia crassifolia	38	0.032			
Fragaria vesca F	33	0.075			
Sambucus nigra F,B,M	33	0.067			
Indicators of low severity/unburnt stands					
Pseudotsuga menziesii **B,M**	**74**	**0.008**	Black-throated Gray/ Hermit Warbler R,C	68	0.031
Anisocarpus madioides	**65**	**0.005**	Cassin's Vireo	66	0.033
Iris spp.C	63	0.039	**Red-breasted Nuthatch**	**63**	**0.001**
Adenocaulon bicolor	**59**	**0.004**	**Chestnut-backed Chickadee**	**61**	**0.006**
Pinus lambertiana F,B	57	0.036	**Hutton's Vireo**	**61**	**0.008**
Pyrola **spp. M**	**56**	**0.009**	**Brown Creeper**	**59**	**0.009**
Osmorrhiza berteroi M	52	0.043	Hermit Thrush	40	0.025
Chimaphila umbellata **M**	**49**	**0.004**			

Early and late seral species in actively and passively managed stands

The indicator analysis for birds and plants of high-severity and low-severity/unburnt stands suggests distinct communities in each habitat (Table 2). Plants preferring such stands were predictably shade-tolerant species (e.g. *Goodyera oblongifolia* (rattlesnake plantain), *Pyrola spp.* (wintergreen), *Adenocaulon bicolor* (pathfinder), *Anisocarpus madioides* (woodland tarweed)), whereas these stands were favored by bark-gleaning (Red-breasted Nuthatch and Brown Creeper) and canopy-dwelling birds (Chestnut-backed Chickadee, Black-throated Gray/Hermit Warbler, Cassin's Vireo). In contrast, species that preferred early-seral conditions created by high-severity fire included shrubs (e.g. *Ceanothus integerrimus* (deerbrush), *Rubus spp.* (blackberries, raspberries and thimbleberries), *Arctostaphylos spp.* (manzanita), *Solanum parishii* (Parish's nightshade)), grasses (e.g. *Melica spp.* (oniongrass), *Elymus glaucus* (blue wildrye), *Bromus carinatus* (California brome)), annual forbs (e.g. *Madia spp.* (tarweeds), *Collomia heterophylla* (vari-leaved collomia), *Cryptantha spp.* (popcorn flower), *Epilobium spp.* (willowherbs)) and perennial forbs (e.g. *Asyneuma prenanthoides* (California harebell), *Eriophyllum lanatum* (woolly sunflower), *Dichelostemma spp.* (blue dicks/Indian potatoes), *Chamerion angustifolium* (fireweed), *Hosackia crassifolia* (big deervetch)). Birds that favored these stands tended to be species associated with shrubs and deciduous tree cover (e.g. Spotted Towhee, Wrentit, Nashville Warbler, MacGillivray's Warbler, Anna's/Rufous Hummingbirds, Black-headed Grosbeak), open habitat species (Lesser Goldfinch, Lazuli Bunting), and cavity nesters (Acorn Woodpeckers, House Wren, Northern Flicker). This classification into early and late seral species agrees with other regional studies for those species for which information is available [@donatoVegetationResponseShort2009; @fontaineBirdCommunitiesFollowing2009].

I identified 61 species (birds, plants and lichens combined) that seemed to favor high-severity burns (occurring at least twice as frequently in that habitat compared to low-severity and unburnt stands), and 45 species that favored low-severity and unburnt stands (occurring at least twice as frequently in that habitat compared to high-severity burns). These habitat associations correspond to the findings of other fire ecology studies [@fontaineBirdCommunitiesFollowing2009]. Additionally, most species that have a preference for either of these habitats exhibited the same affinity for multiple burns and thinned and burnt sites: 34 species (75.5555556%) preferring low-severity and unburnt stands also favor multiple burns, while 31 (68.8888889%) also favor thinned and burnt sites. Conversely, 49 species (80.3278689%) that prefer high-severity burns also favor multiple burns, and 41 (67.2131148%) also favor thinned and burnt sites. Figure 7 (a and b) displays graphically the proportion of plants and birds that prefer high-severity burns or unburnt and low-severity stands that also favor multiple burns and thin+burn sites.

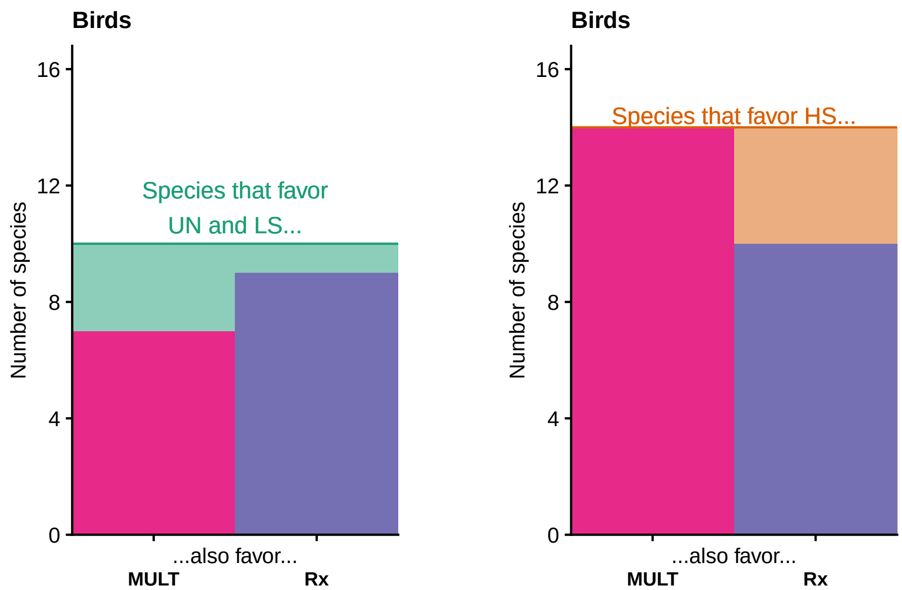

Fig. 7a: Most bird species that favor high−severity and low−severity/unburnt stands also favor multiple burns and thin+burn stands

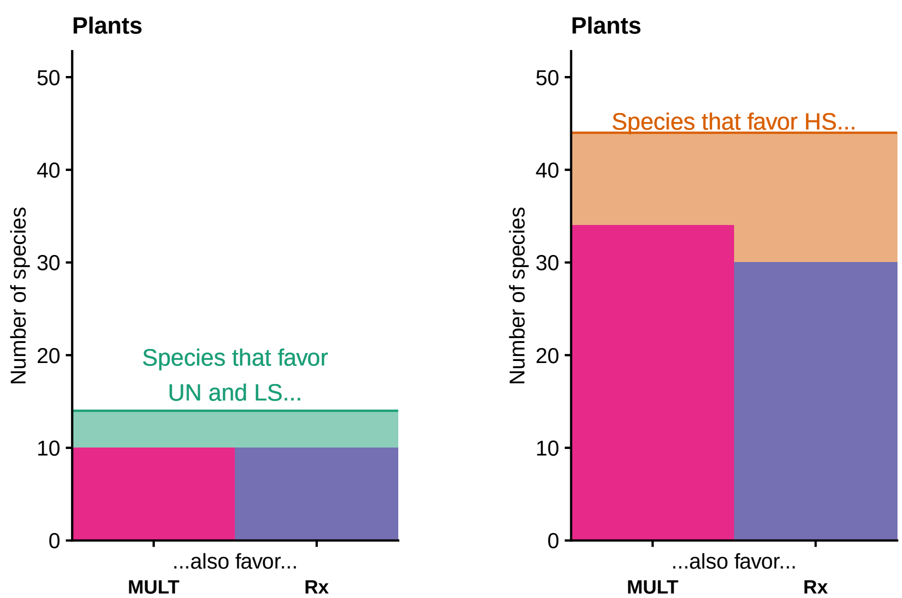

Fig. 7a: Most plant species that favor high−severity and low−severity/unburnt stands also favor multiple burns and thin+burn stands

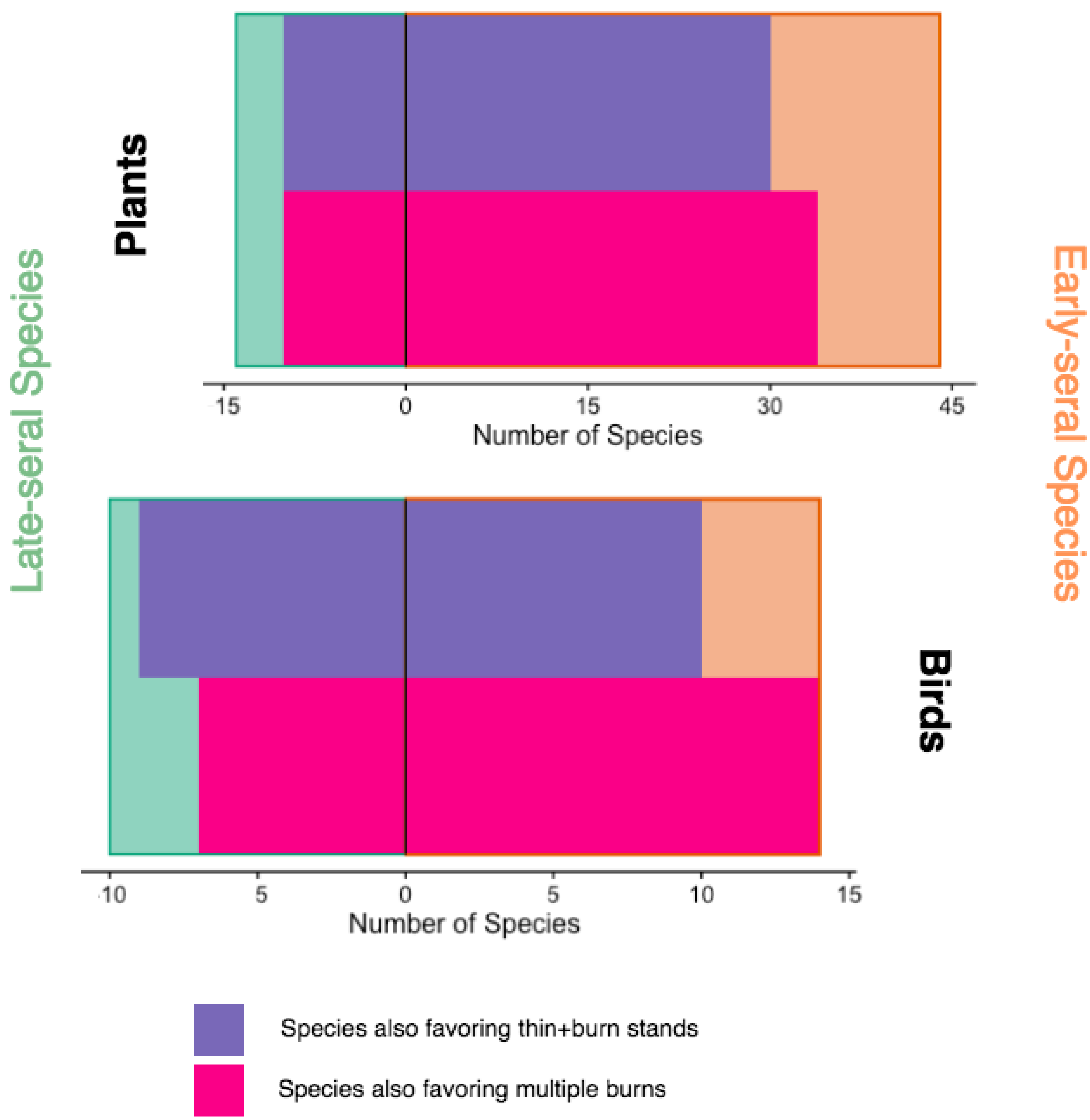

Figure 7: A large proportion of species classified both as early seral (right) and late seral also favor multiple burns (pink) and thin+burn stands (purple

```
#mult_bird <- rbind(UNLS_mult_bird, HS_mult_bird)
#Rx_bird <- rbind(UNLS_Rx_bird, HS_Rx_bird)


#source("https://bioconductor.org/biocLite.R"); biocLite(c("RBGL","graph"))
```

```r
#BiocManager::install("RBGL")

#if (!requireNamespace("BiocManager", quietly = TRUE))
#    install.packages("BiocManager")
#BiocManager::install(version = "3.11")

#install.packages("devtools")
#library(devtools)
#install_github("js229/Vennerable"); library(Vennerable)

#data(StemCell)
#str(StemCell)


#x = list(UNLS_pref_bird$species, HS_pref_bird$species, mult_bird$species, Rx_bird$species)
#VennRaw <- Venn(x)

#birds
ppp <- ggplot() +
  geom_rect(aes(xmin = 0, xmax = 14, ymin = 0, ymax = 5), color = HS_col, fill= HS_col, alpha = .5) +
  geom_rect(aes(xmin = -10, xmax = 0, ymin = 0, ymax = 5), fill = UNLS_col, alpha = .5) +
  geom_rect(aes(xmin = -7, xmax = 14, ymin = 0, ymax = 2.5), fill = mult_col) +
  geom_rect(aes(xmin = -9, xmax = 10, ymin = 2.5, ymax = 5), fill = Rx_col) +
  #geom_rect(aes(xmin = 0, xmax = 10, ymin = 2.5, ymax = 5), fill = Rx_col) +
#  geom_rect(aes(xmin = 0, xmax = 14, ymin = 0, ymax = 2.55), fill = mult_col) +
  geom_rect(aes(xmin = 0, xmax = 14, ymin = 0, ymax = 5), color = HS_col, fill= NA) +
#  geom_rect(aes(xmin = -5, xmax = 6, ymin = 0, ymax = 5), fill = "slateblue") +
#  geom_segment(aes(x=-10, y=0, xend = -10, yend = 5), color = UNLS_col) +
#  geom_segment(aes(x=-9, y=0, xend = -9, yend = 5), color = Rx_col) +
#  geom_segment(aes(x=-7, y=0, xend = -7, yend = 5), color = mult_col) +
#  geom_segment(aes(x=10, y=0, xend = 10, yend = 5), color = Rx_col) +
#  geom_segment(aes(x=14, y=0, xend = 14, yend = 5), color = HS_col) +
  geom_rect(aes(xmin = -10, xmax = 0, ymin = 0, ymax = 5), color = UNLS_col, fill= NA, alpha = .5) +
  geom_rect(aes(xmin = 0, xmax = 14, ymin = 0, ymax = 5), color = HS_col, fill= NA, alpha = .5) +
  geom_segment(aes(x=-0, y=0, xend = -0, yend = 5), color = "black") +
  theme_cowplot(12) + theme(aspect.ratio=0.5) + theme(axis.title.y=element_blank(),
        axis.text.y=element_blank(),
        axis.ticks.y=element_blank()) +
  scale_x_continuous(name="Number of Species", breaks = seq(-10, 15, by = 5))

#plants
pp<- ggplot() +
  geom_rect(aes(xmin = 0, xmax = 44, ymin = 0, ymax = 5), color = HS_col, fill= HS_col, alpha = .5) +
  geom_rect(aes(xmin = -14, xmax = 0, ymin = 0, ymax = 5), fill = UNLS_col, alpha = .5) +
  geom_rect(aes(xmin = -10, xmax = 34, ymin = 0, ymax = 2.5, fill="Multiple"), fill = mult_col) +
  geom_rect(aes(xmin = -10, xmax = 30, ymin = 2.5, ymax = 5), fill = Rx_col) +
  #geom_rect(aes(xmin = 0, xmax = 10, ymin = 2.5, ymax = 5), fill = Rx_col) +
#  geom_rect(aes(xmin = 0, xmax = 14, ymin = 0, ymax = 2.55), fill = mult_col) +
#  geom_rect(aes(xmin = 0, xmax = 44, ymin = 0, ymax = 5), color = HS_col, fill= NA) +
#  geom_rect(aes(xmin = -5, xmax = 6, ymin = 0, ymax = 5), fill = "slateblue") +
#  geom_segment(aes(x=-10, y=0, xend = -10, yend = 5), color = UNLS_col) +
#  geom_segment(aes(x=-9, y=0, xend = -9, yend = 5), color = Rx_col) +
#  geom_segment(aes(x=-7, y=0, xend = -7, yend = 5), color = mult_col) +
```

```
#  geom_segment(aes(x=10, y=0, xend = 10, yend = 5), color = Rx_col) +
#  geom_segment(aes(x=14, y=0, xend = 14, yend = 5), color = HS_col) +
  geom_rect(aes(xmin = -14, xmax = 0, ymin = 0, ymax = 5), color = UNLS_col, fill= NA, alpha = .5) +
  geom_rect(aes(xmin = 0, xmax = 44, ymin = 0, ymax = 5), color = HS_col, fill= NA, alpha = .5) +
  geom_segment(aes(x=-0, y=0, xend = -0, yend = 5), color = "black") +
  theme_cowplot(12) +
  theme(aspect.ratio=0.5) + theme(axis.title.y=element_blank(),
        axis.text.y=element_blank(),
        axis.ticks.y=element_blank()) +
  scale_x_continuous(name="Number of Species", breaks = seq(-15, 45, by = 15)) +
  scale_fill_manual('Multiple',
                    values = mult_col,
                    labels = "mult")
# guide = guide_legend(override.aes = list(alpha = 0.5)))

#remove y axis
#change x axis to show only specific species numbers
# add x axis name
```