Rock Lichen data from Sunset Crater

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# Data Summary

* This is an analysis of the effect of Pinyon Pine tree traits on the saxicole (lichen and moss) community on rocks under the canopy of the trees.
* Trees were sampled in a pairwise design in which pairs were comprised of one tree that is susceptible to the herbivory of a stem boring moth (*Diorictria abietella*) and an adjacent tree that is resistant to the moth.
* As tree resistance to the moth is genetically based, pairwise sampling was conducted in order to isolate this genetic effect.
* Some trees that were sampled were dead, these trees were removed from the analysis.
* Plant data were observed by R. Michalet
  + Vegetation.xlsx
  + Light penetration.xls
  + light\_&\_litter(1).xls

# Main Results

* Rock epiphyte communities were adequately sampled, based on species accumulation curves, with moth resistant trees accumulating slightly more lichen species.
* Several tree variables, including light availability, leaf litter abundance and rock abundance, were impacted by moth susceptibility, creating strong differences in sub-canopy conditions.
* Saxicole community abundance, richness, diversity, composition were significantly, generally negatively, affected by moth herbivory.
* Correlation analysis supported an indirect link between genetically based moth susceptibility and impacts on lichen communities via decreasing rock (i.e. habitat) availability through increased leaf abscission and accumulation on rocks under trees.

# Analysis and Results

Analyses were conducted in the **R** statistical programming language. The following section loads dependencies and custom functions used in the analysis.

## Dependencies

cran.pkgs <- c("reshape2", "vegan", "ecodist", "xtable", "knitr",  
 "semPlot", "lavaan", "piecewiseSEM", "distantia",   
 "tidySEM", "readxl", "psych")  
  
## install packages that are not installed  
if (any(!(cran.pkgs %in% installed.packages()[, 1]))){  
 sapply(cran.pkgs[which(!(cran.pkgs %in%   
 installed.packages()[, 1]))],   
 install.packages,   
 dependencies = TRUE,   
 repos = 'http://cran.us.r-project.org')  
}  
  
## Load libraries  
sapply(cran.pkgs, library, quietly = TRUE, character.only = TRUE)  
  
## Custom Functions  
  
## se: Calculate the standard error of a variable.  
se <- function(x){sd(x) / sqrt(length(x))}

## Load Data

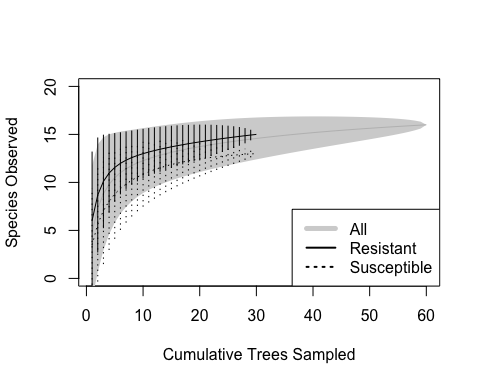
The following are variable descriptions (Variable, Type, Range, Definition):

* Moth,categorical,0 or 1,Was the tree susceptible (0) or resistant (1) to moth attack
* Live/Dead,categorical,0 or 1,Was the tree dead (0) or alive (1)
* Litter %,continuous,0 to 100,Percent cover inside quadrat
* Rocks > 3cm %,continuous,0 to 100,Percent cover of rocks > 3cm? inside quadrat
* Rocks < 3cm %,continuous,0 to 100,Percent cover of rocks < 3cm? inside quadrat
* Shrubs %,continuous,0 to 100,Percent cover of shrubs inside quadrat
* Grass %,continuous,0 to 100,Percent cover of grass inside quadrat
* Branches %,continuous,0 to 100,Percent cover of branches on ground inside quadrat
* Distance,continuous,0 to 100,“Distance from main trunk, converted to percent of crown radius at that azimuth”
* Azimuth,continuous,0 to 360,Compass direction from main trunk
* Slope,continuous,0 to 90,Topographical steepness
* Aspect,continuous,0 to 360,Compass direction of slope
* Light,continuous,,Amount of light available to epiliths

## Data are in ../data/scrl  
l.dat <- read.csv("./data/spp\_env\_combined.csv")  
  
## Fix species names  
colnames(l.dat)[colnames(l.dat) == "Acasup"] <- "Acaame"  
  
## Summary of data  
summary(l.dat)  
  
## remove dead trees  
l.dat <- l.dat[l.dat[, "Live.Dead"] != 0, ]  
  
## Lichen species list  
spp.l <- c("Acacon", "Acaame", "Acaobp", "Sterile.sp", "Brown.cr",  
"Lobalp", "Canros", "Calare", "Phydub", "Rhichr", "Xanlin", "Xanpli",  
"Xanele", "GrBr.cr", "Gray.cr")  
spp.moss <- c("Synrur", "Cerpur.Bryarg")  
  
## Create a community matrix  
com <- l.dat[, colnames(l.dat) %in% c(spp.l, spp.moss)]  
com.moss <- l.dat[, colnames(l.dat) %in% spp.moss]  
  
## Add the tree labels to the rownames  
rownames(com) <- paste(l.dat[, "Moth"], l.dat[, "Tree.pairs"], sep = "\_")  
rownames(com.moss) <- paste(l.dat[, "Moth"], l.dat[, "Tree.pairs"], sep = "\_")  
rownames(l.dat) <- paste(l.dat[, "Moth"], l.dat[, "Tree.pairs"], sep = "\_")  
  
## Paired environmental differences  
total.rocks <- apply(l.dat[, c("Big.rocks..", "Small.rocks..")], 1, sum)  
env <- l.dat[, c("Litter..", "Big.rocks..", "Small.rocks..",   
 "Shrubs..", "Grass..", "Branches..",   
 "Light...N", "Light...S", "Light...average")]  
env <- cbind(env, total.rocks)  
env.dif <- apply(env, 2, function(x, p) tapply(x, p, diff), p = l.dat[, "Tree.pairs"])

## Saxicole communities were sufficiently sampled

spa.all <- specaccum(com, method = "exact")  
spa.res <- specaccum(com[l.dat[, "Moth"] == 1, ], method = "exact")  
spa.sus <- specaccum(com[l.dat[, "Moth"] == 0, ], method = "exact")  
  
plot(spa.all,  
 ylim = c(0, 20),  
 xlab = "Cumulative Trees Sampled",  
 ylab = "Species Observed",   
 col = "grey", ci.col = 'lightgrey', ci.type = "poly", ci.lty = 0)  
plot(spa.res, ci.col = "black", ci.type = "bar", lty = 1, add = TRUE, ci.lty = 1)  
plot(spa.sus, ci.col = "black", ci.type = "bar", lty = 3, add = TRUE, ci.lty = 3)  
legend("bottomright",   
 legend = c("All", "Resistant", "Susceptible"),   
 lty = c(1, 1, 3), lwd = c(5, 2, 2), col = c("lightgrey", "black", "black"))



pdf("./results/scrl\_spp-accum.pdf", width = 5, height = 5)  
plot(spa.all,  
 ylim = c(0, 20),  
 xlab = "Cumulative Trees Sampled",  
 ylab = "Species Observed",   
 col = "grey", ci.col = 'lightgrey', ci.type = "poly", ci.lty = 0)  
plot(spa.res, ci.col = "black", ci.type = "bar", lty = 1, add = TRUE, ci.lty = 1)  
plot(spa.sus, ci.col = "black", ci.type = "bar", lty = 3, add = TRUE, ci.lty = 3)  
legend("bottomright",   
 legend = c("All", "Resistant", "Susceptible"),   
 lty = c(1, 1, 3), lwd = c(5, 2, 2), col = c("lightgrey", "black", "black"))  
dev.off()

## pdf   
## 2

## Moth trees have different microenvironments

env.test.l <- apply(env.dif, 2, t.test)  
env.test.l <- lapply(env.test.l, unlist)  
env.test.tab <- do.call(rbind, env.test.l)  
env.test.tab <- env.test.tab[, c(1, 2, 3, 6, 4, 5)]  
env.test.tab <- apply(env.test.tab, 2, as.numeric)  
rownames(env.test.tab) <- names(env.test.l)  
colnames(env.test.tab) <- c("t", "df", "p-value", "Mean Difference", "Lower CI 95%", "Upper CI 95%")  
kable(env.test.tab, digits = 4)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | t | df | p-value | Mean Difference | Lower CI 95% | Upper CI 95% |
| Litter.. | 2.8665 | 29 | 0.0077 | 15.0700 | 4.3178 | 25.8222 |
| Big.rocks.. | -2.4617 | 29 | 0.0200 | -9.6837 | -17.7289 | -1.6384 |
| Small.rocks.. | -2.0792 | 29 | 0.0466 | -4.9750 | -9.8688 | -0.0812 |
| Shrubs.. | -1.7605 | 29 | 0.0889 | -0.5147 | -1.1126 | 0.0832 |
| Grass.. | -1.0000 | 29 | 0.3256 | -0.0493 | -0.1502 | 0.0516 |
| Branches.. | 1.0000 | 29 | 0.3256 | 0.1420 | -0.1484 | 0.4324 |
| Light…N | -8.0191 | 29 | 0.0000 | -15.9767 | -20.0514 | -11.9019 |
| Light…S | -7.5187 | 29 | 0.0000 | -14.2900 | -18.1772 | -10.4028 |
| Light…average | -9.2728 | 29 | 0.0000 | -15.1333 | -18.4712 | -11.7955 |
| total.rocks | -2.8178 | 29 | 0.0086 | -14.6587 | -25.2983 | -4.0190 |

## Moth trees have different lichen communities

abun <- apply(com, 1, sum)  
rich <- apply(com, 1, function(x) sum(sign(x)))  
shan <- apply(com, 1, diversity, index = "shannon")  
tt.a <- t.test(tapply(abun, l.dat[, "Tree.pairs"], diff))  
tt.r <- t.test(tapply(rich, l.dat[, "Tree.pairs"], diff))  
tt.h <- t.test(tapply(shan, l.dat[, "Tree.pairs"], diff))  
tt.arh <- do.call(rbind,   
 list(a = unlist(tt.a),   
 r = unlist(tt.r),   
 h = unlist(tt.h)))  
tt.arh <- apply(tt.arh[, 1:6], 2, as.numeric)  
ard.mu <- rbind(tapply(abun, l.dat[, "Moth"], mean),  
 tapply(rich, l.dat[, "Moth"], mean),  
 tapply(shan, l.dat[, "Moth"], mean))  
ard.se <- rbind(tapply(abun, l.dat[, "Moth"], se),  
 tapply(rich, l.dat[, "Moth"], se),  
 tapply(shan, l.dat[, "Moth"], se))  
ard.tab <- cbind(ard.mu[, "0"], ard.se[, "0"],  
 ard.mu[, "1"], ard.se[, "1"])  
colnames(ard.tab) <- c("Susceptible Mean", "Susceptible SE",  
 "Resistant Mean", "Resistant SE")  
rownames(ard.tab) <- c("Abundance", "Richness", "Diversity (Shannon)")

kable(ard.tab, digits = 3)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Susceptible Mean | Susceptible SE | Resistant Mean | Resistant SE |
| Abundance | 1.210 | 0.351 | 2.754 | 0.567 |
| Richness | 3.500 | 0.542 | 6.033 | 0.662 |
| Diversity (Shannon) | 0.707 | 0.119 | 1.144 | 0.125 |

kable(tt.arh, digits = 3)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| statistic.t | parameter.df | p.value | conf.int1 | conf.int2 | estimate.mean of x |
| -2.249 | 29 | 0.032 | -2.948 | -0.140 | -1.544 |
| -2.955 | 29 | 0.006 | -4.287 | -0.780 | -2.533 |
| -2.447 | 29 | 0.021 | -0.802 | -0.072 | -0.437 |

Composition is different (PERMANOVA, in text and supplement)

com.ds <- cbind(com, ds = rep(0.0001, nrow(com)))  
com.ds.rel <- apply(com, 2, function(x) x/max(x))  
com.ds.rel <- cbind(com.ds.rel, ds = rep(0.0001, nrow(com)))  
com.ds.rel[is.na(com.ds.rel)] <- 0  
  
set.seed(123)  
ptab.moth <- adonis2(com.ds~ Moth, data = l.dat,   
 strata = l.dat[, "Tree.pairs"],   
 by = "margin", nperm = 100000)  
set.seed(123)  
ptab.moth.rel <- adonis2(com.ds.rel ~ Moth, data = l.dat,   
 strata = l.dat[, "Tree.pairs"],   
 by = "margin", nperm = 100000)  
  
kable(ptab.moth)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Df | SumOfSqs | R2 | F | Pr(>F) |
| Moth | 1 | 0.8329281 | 0.0389768 | 2.352343 | 0.023 |
| Residual | 58 | 20.5368939 | 0.9610232 | NA | NA |
| Total | 59 | 21.3698219 | 1.0000000 | NA | NA |

kable(ptab.moth.rel)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Df | SumOfSqs | R2 | F | Pr(>F) |
| Moth | 1 | 0.8791695 | 0.0405034 | 2.448363 | 0.021 |
| Residual | 58 | 20.8269063 | 0.9594966 | NA | NA |
| Total | 59 | 21.7060758 | 1.0000000 | NA | NA |

three main species were reduced by moths (FDR paired t-tests, in text + supplement)

ind.spp <- apply(com, 2, function(x, p) t.test(tapply(x, p, diff)), p = l.dat[, "Tree.pairs"])  
isp <- apply(do.call(rbind, lapply(ind.spp, unlist)), 2, as.numeric)

## Warning in apply(do.call(rbind, lapply(ind.spp, unlist)), 2, as.numeric): NAs  
## introduced by coercion  
  
## Warning in apply(do.call(rbind, lapply(ind.spp, unlist)), 2, as.numeric): NAs  
## introduced by coercion  
  
## Warning in apply(do.call(rbind, lapply(ind.spp, unlist)), 2, as.numeric): NAs  
## introduced by coercion

rownames(isp) <- names(ind.spp)  
isp[, "p.value"] <- p.adjust(isp[, "p.value"], method = "fdr")  
isp.all <- isp[, !(apply(isp, 2, function(x) all(is.na(x))))]  
isp <- isp[order(isp[, "p.value"]), ]

isp.all <- isp.all[, c(1, 2, 3, 6, 4, 5)]  
colnames(isp.all) <- c("t", "df", "p-value", "Mean Difference", "Lower CI 95%", "Upper CI 95%")  
kable(isp.all, digits = 4)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | t | df | p-value | Mean Difference | Lower CI 95% | Upper CI 95% |
| Acacon | -3.3776 | 29 | 0.0159 | -0.0447 | -0.0717 | -0.0176 |
| Acaame | -3.2421 | 29 | 0.0159 | -0.1607 | -0.2620 | -0.0593 |
| Acaobp | -1.0747 | 29 | 0.4341 | -0.2860 | -0.8303 | 0.2583 |
| Sterile.sp | -1.0000 | 29 | 0.4341 | -0.0020 | -0.0061 | 0.0021 |
| Brown.cr | NaN | 29 | NaN | 0.0000 | NaN | NaN |
| Lobalp | -2.0414 | 29 | 0.2016 | -0.0047 | -0.0093 | 0.0000 |
| Canros | -3.5819 | 29 | 0.0159 | -0.3837 | -0.6027 | -0.1646 |
| Calare | -1.6076 | 29 | 0.2563 | -0.0307 | -0.0697 | 0.0083 |
| Phydub | -1.9226 | 29 | 0.2061 | -0.1053 | -0.2174 | 0.0067 |
| Rhichr | -1.5803 | 29 | 0.2563 | -0.2310 | -0.5300 | 0.0680 |
| Xanlin | -0.6170 | 29 | 0.6672 | -0.2267 | -0.9781 | 0.5247 |
| Xanpli | -0.2598 | 29 | 0.8500 | -0.0277 | -0.2455 | 0.1901 |
| Xanele | -1.5662 | 29 | 0.2563 | -0.0473 | -0.1091 | 0.0145 |
| GrBr.cr | 1.0000 | 29 | 0.4341 | 0.0013 | -0.0014 | 0.0041 |
| Gray.cr | 0.1093 | 29 | 0.9137 | 0.0003 | -0.0059 | 0.0066 |
| Synrur | 0.3628 | 29 | 0.8221 | 0.0220 | -0.1020 | 0.1460 |
| Cerpur.Bryarg | -1.2357 | 29 | 0.4027 | -0.0173 | -0.0460 | 0.0114 |

write.csv(round(isp.all, 5), file = "results/scrl\_isp\_table.csv")

Calculate the average abundances of the indicators

isp.names <- as.character(na.omit(rownames(isp[isp[, "p.value"] < 0.05, ])))  
isp.com <- com[,colnames(com) %in% isp.names]  
isp.dif <- apply(isp.com, 2, function(x,y) tapply(x, y, diff), y = l.dat[ ,"Tree.pairs"])

Create a multi-bar plot figure for the community.

isp.dat <- melt(isp.dif)  
colnames(isp.dat) <- c("Tree.pairs", "Species", "diff")  
isp.mu <- tapply(isp.dat[, "diff"], isp.dat[, "Species"], mean)  
isp.se <- tapply(isp.dat[, "diff"], isp.dat[, "Species"], se)  
ard.dif <- cbind(tapply(abun, l.dat[, "Tree.pairs"], diff),   
 tapply(rich, l.dat[, "Tree.pairs"], diff),   
 tapply(shan, l.dat[, "Tree.pairs"], diff))  
colnames(ard.dif) <- c("Abundance", "Richness", "Diversity")  
ard.dif <- apply(ard.dif, 2, function(x) x / max(x))  
ard.dat <- melt(ard.dif)  
colnames(ard.dat) <- c("Tree.pairs", "Stat", "diff")  
ard.mu <- tapply(ard.dat[, "diff"], ard.dat[, "Stat"], mean)  
ard.se <- tapply(ard.dat[, "diff"], ard.dat[, "Stat"], se)  
  
pdf(file = "./results/plot\_ard\_isp.pdf", width = 9, height = 5)  
  
par(mfrow = c(1,2))  
bp.out <- barplot(ard.mu, col = "darkgrey", ylim = c(-0.4, 0),   
 ylab = "Relativized Difference (S - R)", border = "NA")  
segments(bp.out[, 1], ard.mu + ard.se,  
 bp.out[, 1], ard.mu - ard.se,   
 lwd = 1.5)  
bp.out <- barplot(isp.mu, col = "darkgrey", ylim = c(-0.5, 0),   
 ylab = "Difference (S - R)", border = "NA",  
 axisnames = TRUE,   
 names.arg = sapply(names(isp.mu),   
 function(x)   
 paste(c(substr(x, 1, 1),   
 substr(x, 4, 4)), collapse = "")))  
segments(bp.out[, 1], isp.mu + isp.se,  
 bp.out[, 1], isp.mu - isp.se,   
 lwd = 1.5)  
dev.off()

## pdf   
## 2

Create a plot of the two most indicative species

pdf(file = "./results/scrl\_complot.pdf", width = 7, height = 7)  
plot(com[, c("Acaame", "Canros")], pch = l.dat[, "Moth"] + 1, cex = 3, col = l.dat[, "Moth"] + 1)  
legend("topleft", title = "Tree Type", legend = c("Resistant", "Susceptible"), pch = c(2, 1), col = c(2, 1))  
dev.off()

## pdf   
## 2

Create plot with indicator taxa

pdf(file = "./results/scrl\_pdif.pdf", width = 7, height = 7)  
plot(melt(isp.dif)[-1], xlab = "Species", ylab = "Abundance Reduction")  
dev.off()

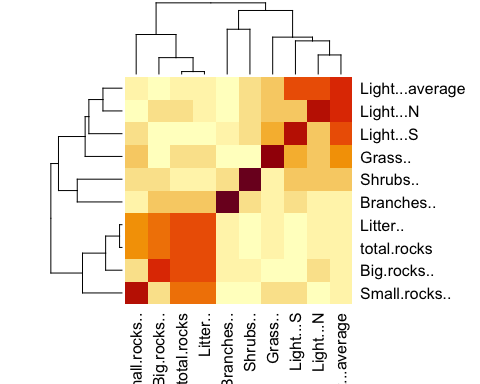
## pdf   
## 2

## Litter covering rocks was the main driver

Although light did significantly explain variation in the lichen community, this was not significant once the variation in litter was controlled for.

There was high correlation among environmental variables.

heatmap(abs(round(cor(env.dif), 3)))



set.seed(123)  
ptab.env <- adonis2(com.ds ~ Litter.. + Light...average, data = l.dat,   
 strata = l.dat[, "Tree.pairs"],   
 by = "margin", nperm = 100000)  
kable(ptab.env)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Df | SumOfSqs | R2 | F | Pr(>F) |
| Litter.. | 1 | 1.0035484 | 0.0469610 | 2.972456 | 0.007 |
| Light…average | 1 | 0.4114619 | 0.0192543 | 1.218728 | 0.243 |
| Residual | 57 | 19.2441042 | 0.9005271 | NA | NA |
| Total | 59 | 21.3698219 | 1.0000000 | NA | NA |

set.seed(123)  
ptab.env <- adonis2(com.ds ~ Light...average + Litter.. , data = l.dat,   
 strata = l.dat[, "Tree.pairs"],   
 by = "margin", nperm = 100000)  
kable(ptab.env)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Df | SumOfSqs | R2 | F | Pr(>F) |
| Light…average | 1 | 0.4114619 | 0.0192543 | 1.218728 | 0.243 |
| Litter.. | 1 | 1.0035484 | 0.0469610 | 2.972456 | 0.007 |
| Residual | 57 | 19.2441042 | 0.9005271 | NA | NA |
| Total | 59 | 21.3698219 | 1.0000000 | NA | NA |

set.seed(123)  
ptab.env <- adonis2(com.ds ~ Litter.. + Light...average + Litter.. \* Light...average, data = l.dat,   
 strata = l.dat[, "Tree.pairs"],   
 by = "margin", nperm = 100000)  
kable(ptab.env)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Df | SumOfSqs | R2 | F | Pr(>F) |
| Litter..:Light…average | 1 | 0.6021127 | 0.0281758 | 1.808729 | 0.077 |
| Residual | 56 | 18.6419916 | 0.8723513 | NA | NA |
| Total | 59 | 21.3698219 | 1.0000000 | NA | NA |

set.seed(123)  
ptab.env <- adonis2(com.ds ~ total.rocks ,  
 strata = l.dat[, "Tree.pairs"],   
 by = "term", nperm = 100000)  
  
kable(ptab.env)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Df | SumOfSqs | R2 | F | Pr(>F) |
| total.rocks | 1 | 1.664876 | 0.0779078 | 4.900435 | 0.002 |
| Residual | 58 | 19.704946 | 0.9220922 | NA | NA |
| Total | 59 | 21.369822 | 1.0000000 | NA | NA |

set.seed(123)  
ptab.env <- adonis2(com.ds ~ Big.rocks.. , data = l.dat,   
 strata = l.dat[, "Tree.pairs"],   
 by = "term", nperm = 100000)  
  
kable(ptab.env)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Df | SumOfSqs | R2 | F | Pr(>F) |
| Big.rocks.. | 1 | 2.428473 | 0.1136403 | 7.436188 | 0.001 |
| Residual | 58 | 18.941349 | 0.8863597 | NA | NA |
| Total | 59 | 21.369822 | 1.0000000 | NA | NA |

set.seed(123)  
ptab.env <- adonis2(com.ds ~ Small.rocks.. , data = l.dat,   
 strata = l.dat[, "Tree.pairs"],   
 by = "term", nperm = 100000)  
kable(ptab.env)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Df | SumOfSqs | R2 | F | Pr(>F) |
| Small.rocks.. | 1 | 0.2204425 | 0.0103156 | 0.604541 | 0.782 |
| Residual | 58 | 21.1493794 | 0.9896844 | NA | NA |
| Total | 59 | 21.3698219 | 1.0000000 | NA | NA |

set.seed(123)  
ptab.env <- adonis2(com.ds ~ Litter.. , data = l.dat,   
 strata = l.dat[, "Tree.pairs"],   
 by = "term", nperm = 100000)  
kable(ptab.env)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Df | SumOfSqs | R2 | F | Pr(>F) |
| Litter.. | 1 | 1.714256 | 0.0802185 | 5.058457 | 0.002 |
| Residual | 58 | 19.655566 | 0.9197815 | NA | NA |
| Total | 59 | 21.369822 | 1.0000000 | NA | NA |

Because light was significantly, negatively correlated with litter and large rocks.

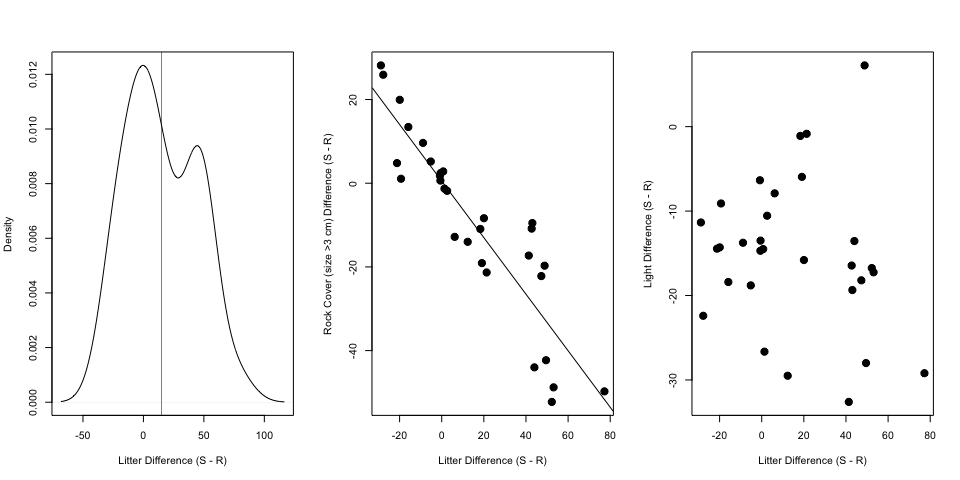
cor.test(env.dif[, "Big.rocks.."], env.dif[, "Litter.."])

##   
## Pearson's product-moment correlation  
##   
## data: env.dif[, "Big.rocks.."] and env.dif[, "Litter.."]  
## t = -11.106, df = 28, p-value = 9.054e-12  
## alternative hypothesis: true correlation is not equal to 0  
## 95 percent confidence interval:  
## -0.9530598 -0.8039735  
## sample estimates:  
## cor   
## -0.9027609

pdf("./results/scrl\_litterVbigrocks.pdf", width = 5, height = 5)  
dev.off()

## pdf   
## 2

par(mfrow = c(1,3))  
plot(density(tapply(l.dat[, "Litter.."], l.dat[, "Tree.pairs"], diff)),   
 main = "", xlab = "Litter Difference (S - R)")  
abline(v = mean(tapply(l.dat[, "Litter.."], l.dat[, "Tree.pairs"], diff)),  
 lwd = 0.5)  
plot(env.dif[, "Big.rocks.."] ~ env.dif[, "Litter.."],   
 xlab = "Litter Difference (S - R)", ylab = "Rock Cover (size >3 cm) Difference (S - R)",  
 pch = 19, cex = 1.5)  
abline(lm(env.dif[, "Big.rocks.."] ~ env.dif[, "Litter.."]))  
plot(tapply(l.dat[, "Litter.."], l.dat[, "Tree.pairs"], diff),   
 tapply(l.dat[, "Light...average"], l.dat[, "Tree.pairs"], diff),   
 xlab = "Litter Difference (S - R)", ylab = "Light Difference (S - R)",  
 pch = 19, cex = 1.5)



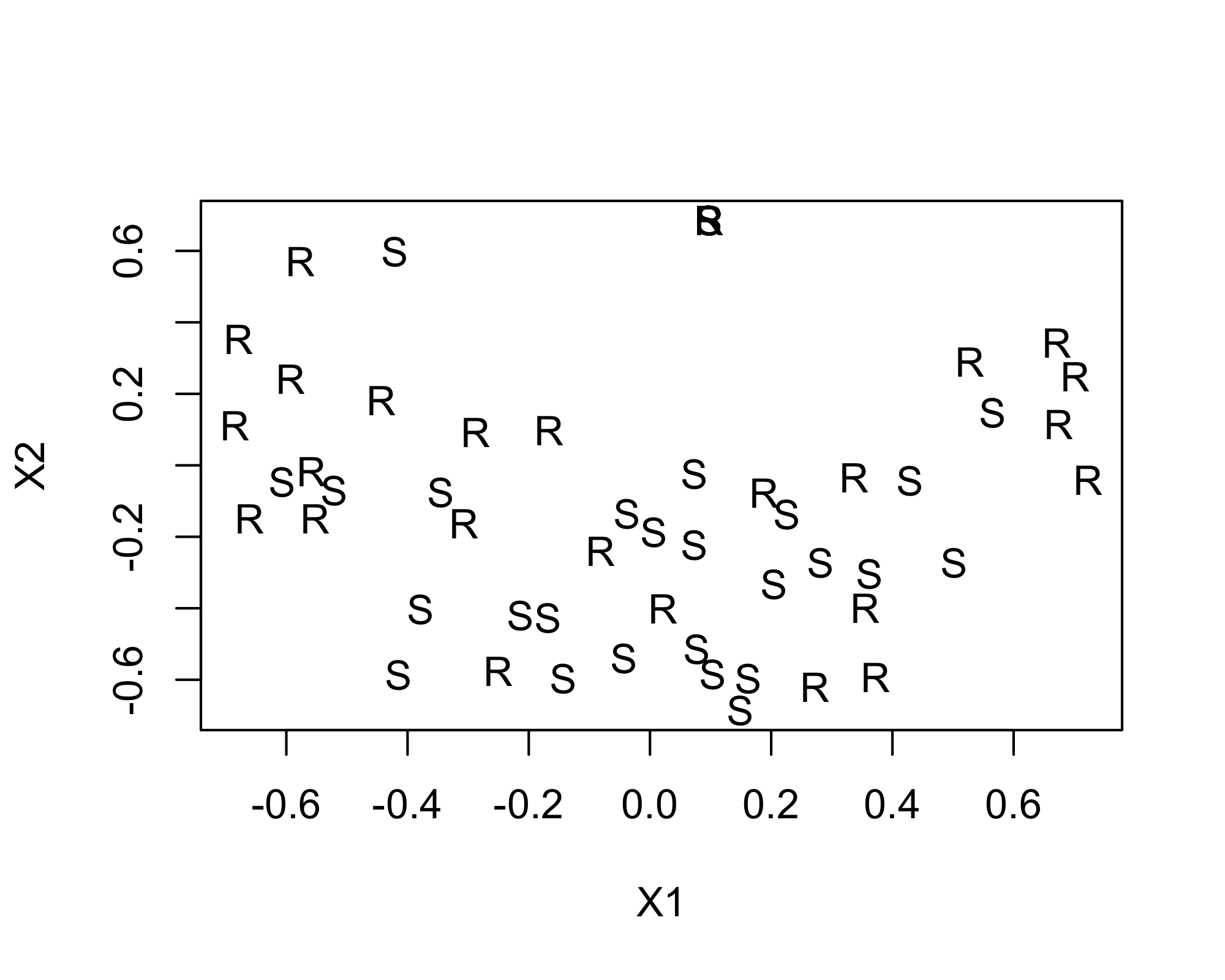
pdf("./results/scrl\_litter\_effects.pdf", width = 10, height = 5)  
par(mfrow = c(1,3))  
plot(density(tapply(l.dat[, "Litter.."], l.dat[, "Tree.pairs"], diff)),   
 main = "", xlab = "Litter Difference (S - R)")  
abline(v = mean(tapply(l.dat[, "Litter.."], l.dat[, "Tree.pairs"], diff)),  
 lwd = 0.5)  
plot(env.dif[, "Big.rocks.."] ~ env.dif[, "Litter.."],   
 xlab = "Litter Difference (S - R)", ylab = "Rock Cover (size >3 cm) Difference (S - R)",  
 pch = 19, cex = 1.5)  
abline(lm(env.dif[, "Big.rocks.."] ~ env.dif[, "Litter.."]))  
plot(tapply(l.dat[, "Litter.."], l.dat[, "Tree.pairs"], diff),   
 tapply(l.dat[, "Light...average"], l.dat[, "Tree.pairs"], diff),   
 xlab = "Litter Difference (S - R)", ylab = "Light Difference (S - R)",  
 pch = 19, cex = 1.5)  
dev.off()

## pdf   
## 2

nmds.out <- nmds(vegdist(com.ds), 2, 2)  
ord <- nmds.min(nmds.out, dims = 2)

## Minimum stress for given dimensionality: 0.2169355   
## r^2 for minimum stress configuration: 0.6416469

ord.pch <- c("R", "S")[(l.dat[, "Moth"] + 1)]  
plot(X2~ X1, data = ord, pch = ord.pch)



Litter not light was correlated with large rocks (dist cor, in text). Thus, higher amounts of litter under trees was not related to the penetration of light under the tree canopy.

cor.test(tapply(l.dat[, "Big.rocks.."], l.dat[, "Tree.pairs"], diff),  
 tapply(l.dat[, "Litter.."], l.dat[, "Tree.pairs"], diff))

##   
## Pearson's product-moment correlation  
##   
## data: tapply(l.dat[, "Big.rocks.."], l.dat[, "Tree.pairs"], diff) and tapply(l.dat[, "Litter.."], l.dat[, "Tree.pairs"], diff)  
## t = -11.106, df = 28, p-value = 9.054e-12  
## alternative hypothesis: true correlation is not equal to 0  
## 95 percent confidence interval:  
## -0.9530598 -0.8039735  
## sample estimates:  
## cor   
## -0.9027609

cor.test(tapply(l.dat[, "Big.rocks.."], l.dat[, "Tree.pairs"], diff),  
 tapply(l.dat[, "Light...average"], l.dat[, "Tree.pairs"], diff))

##   
## Pearson's product-moment correlation  
##   
## data: tapply(l.dat[, "Big.rocks.."], l.dat[, "Tree.pairs"], diff) and tapply(l.dat[, "Light...average"], l.dat[, "Tree.pairs"], diff)  
## t = 0.71624, df = 28, p-value = 0.4798  
## alternative hypothesis: true correlation is not equal to 0  
## 95 percent confidence interval:  
## -0.2376184 0.4716125  
## sample estimates:  
## cor   
## 0.1341335

cor.test(tapply(l.dat[, "Litter.."], l.dat[, "Tree.pairs"], diff),  
 tapply(l.dat[, "Light...average"], l.dat[, "Tree.pairs"], diff))

##   
## Pearson's product-moment correlation  
##   
## data: tapply(l.dat[, "Litter.."], l.dat[, "Tree.pairs"], diff) and tapply(l.dat[, "Light...average"], l.dat[, "Tree.pairs"], diff)  
## t = -0.92053, df = 28, p-value = 0.3652  
## alternative hypothesis: true correlation is not equal to 0  
## 95 percent confidence interval:  
## -0.5007401 0.2013096  
## sample estimates:  
## cor   
## -0.1713898

cor.test(tapply(l.dat[, "Small.rocks.."], l.dat[, "Tree.pairs"], diff),  
 tapply(l.dat[, "Litter.."], l.dat[, "Tree.pairs"], diff))

##   
## Pearson's product-moment correlation  
##   
## data: tapply(l.dat[, "Small.rocks.."], l.dat[, "Tree.pairs"], diff) and tapply(l.dat[, "Litter.."], l.dat[, "Tree.pairs"], diff)  
## t = -4.994, df = 28, p-value = 2.819e-05  
## alternative hypothesis: true correlation is not equal to 0  
## 95 percent confidence interval:  
## -0.8391386 -0.4332285  
## sample estimates:  
## cor   
## -0.6863699

# Vegetation Analysis

## Results Summary

* Both vegetation and light from the plant dataset respond to moth susceptibility (see t-tests below)
* Plant cover, richness and Shannon’s diversity respond to moth susceptibility (see t-tests below)
* Plant community composition using Bray-Curtis dissimiliarity and a PERMANOVA model that accounts for tree pairs is significantly affected by moth susceptibility (Tables 11-12)
* Using the light, littter and rock cover from the saxicole dataset, plant community composition is significantly correlated with light and litter but not rock cover. Light has a strong effect but the effect of litter is weak and is non-significant after controlling for the effect of light, suggesting that the effect of litter is due to the covariance between light and litter (Tables 13-16)
* Two main species of plant were indicators of moth susceptibility: Apache plume and *Asteraceae ovales*. Both showed reduced cover under moth susceptible trees (Table 17)
* Saxicole and plant communities were not multivariately correlated based on Mantel Tests on both un-relatvized and species max relativized cover (see Mantel Test below)

## From Richard Michalet

First sheet is the vegetation matrix with all relevés.

Second sheet are values of vegetation cover, rock cover and species richness in all replicates of all treatments + mean values of treatments and corresponding graphs.

From what I remember the methods were simple, quadrats of 1square meter in four treatments with a full factorial design, exposure (north and south of the tree), mortality (alive vs dead shrubs), tree susceptibility (resistant vs susceptible) and tree presence (below the canopy or outside the canopy in open conditions at the close vicinity of the trees).

You can see that without stats results are obvious: strong effect of tree susceptibility only below the tree and in both exposure for both alive and dead trees.

veg <- readxl::read\_xlsx("data/Vegetation.xlsx")  
veg <- as.data.frame(veg)  
l.raw <- read.csv("data/rawdata Sunset Crater for Matt.csv")  
l.raw <- l.raw[!(grepl("cover", l.raw[,1])),]  
le.raw <- read.csv("data/rawdata Sunset Crater for Matt\_env.csv")  
le.raw <- le.raw[!(grepl("cover", le.raw[,1])),]  
le.raw <- na.omit(le.raw)

## Observation checks

Do the saxicole community and environment data match?

## [1] TRUE

Are all of the trees in the saxicole dataset represented in the veg dataset?

## [1] TRUE

## Coalesce datasets

l.d <- data.frame(le.raw[, -2:-3], l.raw[, -1:-3])  
l.d <- split(l.d, l.d[, "Tree.ID"])  
l.d <- l.d[names(l.d) %in% le.raw[, "Tree.ID"]]  
l.d <- lapply(l.d, function(x) x[, -1])  
l.d <- lapply(l.d, apply, 2, mean)  
l.df <- do.call(rbind, l.d)  
trt <- strsplit(rownames(l.df), "")  
moth.alive <- lapply(trt, function(x) x[x %in% c(letters, LETTERS)][1:2])  
moth.alive <- do.call(rbind, moth.alive)  
tree <- lapply(trt, function(x) x[x %in% 0:9])  
tree <- as.numeric(unlist(lapply(tree, paste, collapse = "")))  
l.df <- data.frame(Tree.pairs = tree,   
 Moth = moth.alive[, 1],   
 Live.Dead = moth.alive[, 2],   
 l.df)  
l.df <- l.df[l.df[, "Live.Dead"] == "A", ]  
l.df[, "Moth"] <- as.character(l.df[, "Moth"])  
l.df[l.df[, "Moth"] == "R", "Moth"] <- 1  
l.df[l.df[, "Moth"] == "S", "Moth"] <- 0  
moth.tree <- paste(l.df[, "Moth"], l.df[, "Tree.pairs"], sep = "\_")  
l.df <- l.df[match(rownames(l.dat), moth.tree), ]

Check that l.dat and l.df are correctly coalesced:

## [1] TRUE

## [1] TRUE TRUE TRUE FALSE FALSE FALSE FALSE FALSE FALSE TRUE FALSE TRUE  
## [13] TRUE TRUE TRUE TRUE TRUE TRUE TRUE TRUE TRUE TRUE TRUE TRUE  
## [25] TRUE TRUE

Check that the values of the variables match, excluding light:

The following vector should work to match-up the saxicoles with the veg data:

Checking the vegetation and rock cover correlations. We find that vegetation cover is is significantly, but not strongly correlated with rock cover. Large rock cover measurements in the saxicole dataset is strongly correlated with total rock cover in the plant dataset.

Both vegetation and rock cover are strongly affected by moth susceptibility.

cor.test(v.dat[, "Vegetation.cover"], v.dat[, "Rock.cover"], alt = "greater")

##   
## Pearson's product-moment correlation  
##   
## data: v.dat[, "Vegetation.cover"] and v.dat[, "Rock.cover"]  
## t = 1.8835, df = 58, p-value = 0.03233  
## alternative hypothesis: true correlation is greater than 0  
## 95 percent confidence interval:  
## 0.0269872 1.0000000  
## sample estimates:  
## cor   
## 0.2400809

cor.test(l.dat[, "Big.rocks.."], v.dat[, "Rock.cover"], alt = "greater")

##   
## Pearson's product-moment correlation  
##   
## data: l.dat[, "Big.rocks.."] and v.dat[, "Rock.cover"]  
## t = 9.5342, df = 58, p-value = 8.816e-14  
## alternative hypothesis: true correlation is greater than 0  
## 95 percent confidence interval:  
## 0.6809688 1.0000000  
## sample estimates:  
## cor   
## 0.7813334

t.test(tapply(v.dat[, "Rock.cover"], v.dat[, "Tree.Pair"], diff))

##   
## One Sample t-test  
##   
## data: tapply(v.dat[, "Rock.cover"], v.dat[, "Tree.Pair"], diff)  
## t = -3.3582, df = 29, p-value = 0.002208  
## alternative hypothesis: true mean is not equal to 0  
## 95 percent confidence interval:  
## -27.621617 -6.711716  
## sample estimates:  
## mean of x   
## -17.16667

t.test(tapply(v.dat[, "Vegetation.cover"], v.dat[, "Tree.Pair"], diff))

##   
## One Sample t-test  
##   
## data: tapply(v.dat[, "Vegetation.cover"], v.dat[, "Tree.Pair"], diff)  
## t = -7.2026, df = 29, p-value = 6.269e-08  
## alternative hypothesis: true mean is not equal to 0  
## 95 percent confidence interval:  
## -28.67505 -15.99162  
## sample estimates:  
## mean of x   
## -22.33333

Both plant richness and Shannon’s Diversity index were significantly affected by moth susceptibility.

v.abun <- v.dat[, "Vegetation.cover"]  
v.rich <- apply(v.com, 1, function(x) sum(sign(x)))  
v.shan <- apply(v.com, 1, diversity)  
  
t.test(tapply(v.rich, l.dat[, "Tree.pairs"], diff))

##   
## One Sample t-test  
##   
## data: tapply(v.rich, l.dat[, "Tree.pairs"], diff)  
## t = -7.477, df = 29, p-value = 3.062e-08  
## alternative hypothesis: true mean is not equal to 0  
## 95 percent confidence interval:  
## -1.6555988 -0.9444012  
## sample estimates:  
## mean of x   
## -1.3

t.test(tapply(v.shan, l.dat[, "Tree.pairs"], diff))

##   
## One Sample t-test  
##   
## data: tapply(v.shan, l.dat[, "Tree.pairs"], diff)  
## t = -4.2192, df = 29, p-value = 0.00022  
## alternative hypothesis: true mean is not equal to 0  
## 95 percent confidence interval:  
## -0.4386895 -0.1522394  
## sample estimates:  
## mean of x   
## -0.2954645

v.ard <- rbind(tapply(v.dat[, "Vegetation.cover"], l.dat[, "Moth"], mean),  
 tapply(rich, l.dat[, "Moth"], mean),  
 tapply(shan, l.dat[, "Moth"], mean))  
v.ard <- rbind(tapply(v.dat[, "Vegetation.cover"], l.dat[, "Moth"], se),  
 tapply(rich, l.dat[, "Moth"], se),  
 tapply(shan, l.dat[, "Moth"], se))  
v.ard.tab <- cbind(v.ard[, "0"], v.ard[, "0"],  
 v.ard[, "1"], v.ard[, "1"])  
colnames(v.ard.tab) <- c("Susceptible Mean", "Susceptible SE",  
 "Resistant Mean", "Resistant SE")  
rownames(v.ard.tab) <- c("Abundance", "Richness", "Diversity (Shannon)")

kable(v.ard.tab, digits = 3)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Susceptible Mean | Susceptible SE | Resistant Mean | Resistant SE |
| Abundance | 1.511 | 1.511 | 2.758 | 2.758 |
| Richness | 0.542 | 0.542 | 0.662 | 0.662 |
| Diversity (Shannon) | 0.119 | 0.119 | 0.125 | 0.125 |

This is a multivariate analysis of the plant community response to moth susceptibility (PERMANOVA). This analysis uses a modified Bray-Curtis Dissimilarity metric, which permits the inclusion of quadrats that had no plants in them. The analysis also accounts for the paired structure of the data (i.e. pairs of moth susceptible and resistant trees).

set.seed(123)  
ptab.v.moth <- adonis2(v.com.ds ~ Moth, data = l.dat,   
 strata = v.dat[, "Tree.pairs"],   
 by = "margin", nperm = 100000)  
set.seed(123)  
ptab.v.moth.rel <- adonis2(v.com.ds.rel ~ Moth, data = l.dat,   
 strata = v.dat[, "Tree.pairs"],   
 by = "margin", nperm = 100000)

Here are the results of the multivariate plant community response.

kable(ptab.v.moth, caption = "PERMANOVA of plant community response to moth.")

PERMANOVA of plant community response to moth.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Df | SumOfSqs | R2 | F | Pr(>F) |
| Moth | 1 | 5.174376 | 0.3081168 | 25.82917 | 0.001 |
| Residual | 58 | 11.619181 | 0.6918832 | NA | NA |
| Total | 59 | 16.793557 | 1.0000000 | NA | NA |

Here are the results of the multivariate plant community response after relativizing by species max.

PERMANOVA of relativized plant community response to moth.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Df | SumOfSqs | R2 | F | Pr(>F) |
| Moth | 1 | 5.989174 | 0.288048 | 23.46617 | 0.001 |
| Residual | 58 | 14.803100 | 0.711952 | NA | NA |
| Total | 59 | 20.792275 | 1.000000 | NA | NA |

Do light, litter or rock cover influence plant communities?

set.seed(123)  
ptab.v.env <- adonis2(v.com.ds ~ Light...average + Litter.. + Big.rocks..,  
 data = l.dat,   
 strata = l.dat[, "Tree.pairs"],   
 by = "margin", nperm = 100000)  
set.seed(123)  
ptab.v.env.total.rocks <- adonis2(v.com.ds ~ Light...average + Litter.. + total.rocks,  
 data = l.dat,   
 strata = l.dat[, "Tree.pairs"],   
 by = "margin", nperm = 100000)  
set.seed(123)  
ptab.v.env.rel <- adonis2(v.com.ds.rel ~ Light...average + Litter.. + total.rocks,  
 data = l.dat,   
 strata = l.dat[, "Tree.pairs"],   
 by = "margin", nperm = 100000)  
set.seed(123)  
ptab.v.env.int <- adonis2(v.com.ds ~ Light...average + Litter.. + total.rocks +  
 Light...average \* Litter.. +  
 Light...average \* total.rocks +  
 Litter.. \* total.rocks,  
 data = l.dat,   
 strata = l.dat[, "Tree.pairs"],   
 by = "margin", nperm = 100000)  
set.seed(123)  
ptab.v.env.rel.int <- adonis2(v.com.ds.rel ~ Light...average + Litter.. + total.rocks +  
 Light...average \* Litter.. +  
 Light...average \* total.rocks +  
 Litter.. \* total.rocks,  
 data = l.dat,   
 strata = l.dat[, "Tree.pairs"],   
 by = "margin", nperm = 100000)

Light has a strong effect on the plant community. Litter also has an effect but it is small and marginally significant, either un-relativized or relativized, respectively.

PERMANOVA of plant community response to several environmental variables.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Df | SumOfSqs | R2 | F | Pr(>F) |
| Light…average | 1 | 2.8692870 | 0.1708564 | 12.696810 | 0.001 |
| Litter.. | 1 | 0.6890028 | 0.0410278 | 3.048889 | 0.049 |
| Big.rocks.. | 1 | 0.3621592 | 0.0215654 | 1.602582 | 0.189 |
| Residual | 56 | 12.6551530 | 0.7535719 | NA | NA |
| Total | 59 | 16.7935571 | 1.0000000 | NA | NA |

PERMANOVA of relativized plant community response to several environmental variables.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Df | SumOfSqs | R2 | F | Pr(>F) |
| Light…average | 1 | 3.4724258 | 0.1670056 | 12.245941 | 0.001 |
| Litter.. | 1 | 0.3437323 | 0.0165317 | 1.212215 | 0.291 |
| total.rocks | 1 | 0.3501066 | 0.0168383 | 1.234694 | 0.282 |
| Residual | 56 | 15.8792084 | 0.7637071 | NA | NA |
| Total | 59 | 20.7922745 | 1.0000000 | NA | NA |

set.seed(123)  
ptab.v.env.seq <- adonis2(v.com.ds ~ Light...average + Litter.. + total.rocks,  
 data = l.dat,   
 strata = l.dat[, "Tree.pairs"],   
 by = "term", nperm = 100000)  
set.seed(123)  
ptab.v.env.rel.seq <- adonis2(v.com.ds.rel ~ Light...average + Litter.. + total.rocks,  
 data = l.dat,   
 strata = l.dat[, "Tree.pairs"],   
 by = "term", nperm = 100000)

After controlling for the effect of light, the effect of litter is no longer significant, un-relatvizied or relativized, respectivley.

Sequential PERMANOVA of plant community response to several environmental variables. Variance is explained sequentially by factors entered into the model from top to bottom.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Df | SumOfSqs | R2 | F | Pr(>F) |
| Light…average | 1 | 3.2765116 | 0.1951053 | 14.567808 | 0.001 |
| Litter.. | 1 | 0.4997333 | 0.0297574 | 2.221881 | 0.098 |
| total.rocks | 1 | 0.4220991 | 0.0251346 | 1.876709 | 0.128 |
| Residual | 56 | 12.5952131 | 0.7500027 | NA | NA |
| Total | 59 | 16.7935571 | 1.0000000 | NA | NA |

Sequential PERMANOVA of relativized plant community response to several environmental variables. Variance is explained sequentially by factors entered into the model from top to bottom.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Df | SumOfSqs | R2 | F | Pr(>F) |
| Light…average | 1 | 3.8762571 | 0.1864278 | 13.670102 | 0.001 |
| Litter.. | 1 | 0.6867025 | 0.0330268 | 2.421742 | 0.060 |
| total.rocks | 1 | 0.3501066 | 0.0168383 | 1.234694 | 0.282 |
| Residual | 56 | 15.8792084 | 0.7637071 | NA | NA |
| Total | 59 | 20.7922745 | 1.0000000 | NA | NA |

* Indicator species

## Warning in apply(do.call(rbind, lapply(ind.spp.v, unlist)), 2, as.numeric): NAs  
## introduced by coercion  
  
## Warning in apply(do.call(rbind, lapply(ind.spp.v, unlist)), 2, as.numeric): NAs  
## introduced by coercion  
  
## Warning in apply(do.call(rbind, lapply(ind.spp.v, unlist)), 2, as.numeric): NAs  
## introduced by coercion

There are two species that are responding to moth susceptibility, Apache plume and *Asteraceae ovales*.

Indicator Species Analysis using False Discovery Rate (FDR) adjusted p-values from t-tests of paired differences between resistant and susceptible trees (Resistant - Susceptible).

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | t | df | p-value | Mean Difference | Lower CI 95% | Upper CI 95% |
| Apache.plume | -4.6010 | 29 | 0.0007 | -10.2667 | -14.8304 | -5.7029 |
| Asteraceae.ovales | -3.9581 | 29 | 0.0020 | -8.1333 | -12.3360 | -3.9307 |
| Rhus.trilobata | -1.8410 | 29 | 0.1869 | -3.1667 | -6.6847 | 0.3514 |
| Rabbit.brush | -1.0000 | 29 | 0.3256 | -0.6667 | -2.0302 | 0.6968 |
| Avena | -1.7951 | 29 | 0.1869 | -0.2000 | -0.4279 | 0.0279 |
| Juniperus.monosperma | -1.0000 | 29 | 0.3256 | -0.1667 | -0.5075 | 0.1742 |
| Plante.grise.allongée | -1.0000 | 29 | 0.3256 | -0.1000 | -0.3045 | 0.1045 |
| Scarlet.glia | -1.0000 | 29 | 0.3256 | -0.0667 | -0.2030 | 0.0697 |
| Bouteloua.gracilis | NaN | 29 | NaN | 0.0000 | NaN | NaN |
| Pinus.edulis.S | NaN | 29 | NaN | 0.0000 | NaN | NaN |
| Stipa.A | NaN | 29 | NaN | 0.0000 | NaN | NaN |
| Stipa.B | NaN | 29 | NaN | 0.0000 | NaN | NaN |
| Stipa.très.grand | NaN | 29 | NaN | 0.0000 | NaN | NaN |
| Ephedra | NaN | 29 | NaN | 0.0000 | NaN | NaN |
| Grande.grass.corymbe | NaN | 29 | NaN | 0.0000 | NaN | NaN |
| Boraginacée.rosette.grise | NaN | 29 | NaN | 0.0000 | NaN | NaN |
| Grass.à.nœud | NaN | 29 | NaN | 0.0000 | NaN | NaN |
| Brachypode | NaN | 29 | NaN | 0.0000 | NaN | NaN |
| Carex | NaN | 29 | NaN | 0.0000 | NaN | NaN |
| Cactus | NaN | 29 | NaN | 0.0000 | NaN | NaN |
| Hordeum | NaN | 29 | NaN | 0.0000 | NaN | NaN |
| Chenopodiaceae | NaN | 29 | NaN | 0.0000 | NaN | NaN |
| Ribes | NaN | 29 | NaN | 0.0000 | NaN | NaN |
| Aster.grise | NaN | 29 | NaN | 0.0000 | NaN | NaN |
| Rosette.frisée | NaN | 29 | NaN | 0.0000 | NaN | NaN |
| Chamaephyte.gris | NaN | 29 | NaN | 0.0000 | NaN | NaN |
| Castilleja | NaN | 29 | NaN | 0.0000 | NaN | NaN |
| Opuntia | NaN | 29 | NaN | 0.0000 | NaN | NaN |
| Rubiaceae | NaN | 29 | NaN | 0.0000 | NaN | NaN |
| Andropogon | NaN | 29 | NaN | 0.0000 | NaN | NaN |
| Pinus.edulis.R | 1.0000 | 29 | 0.3256 | 0.3333 | -0.3484 | 1.0151 |

v.isp.dat <- melt(d.v.isp)  
colnames(v.isp.dat) <- c("Tree.pairs", "Species", "diff")  
v.isp.mu <- tapply(v.isp.dat[, "diff"], v.isp.dat[, "Species"], mean)  
v.isp.se <- tapply(v.isp.dat[, "diff"], v.isp.dat[, "Species"], se)  
v.ard <- t(apply(v.com, 1, function(x) c(A = sum(x),   
 R = sum(sign(x)),   
 D = diversity(x))))  
v.ard.dif <- apply(v.ard, 2,   
 function(x, p) tapply(x, p, diff),   
 p = l.dat[, "Tree.pairs"])  
colnames(v.ard.dif) <- c("Abundance", "Richness", "Diversity")  
v.ard.dif <- apply(v.ard.dif, 2, function(x) x / max(x))  
v.ard.dat <- melt(v.ard.dif)  
colnames(v.ard.dat) <- c("Tree.pairs", "Stat", "diff")  
v.ard.mu <- tapply(v.ard.dat[, "diff"], v.ard.dat[, "Stat"], mean)  
v.ard.se <- tapply(v.ard.dat[, "diff"], v.ard.dat[, "Stat"], se)  
  
pdf(file = "./results/scrl\_isp\_ard\_plant.pdf", width = 9, height = 5)  
  
par(mfrow = c(1,2))  
bp.out <- barplot(v.ard.mu, col = "darkgrey", ylim = c(-3.0, 0),   
 ylab = "Relativized Difference (S - R)", border = "NA")  
segments(bp.out[, 1], v.ard.mu + v.ard.se,  
 bp.out[, 1], v.ard.mu - v.ard.se,   
 lwd = 1.5)  
bp.out <- barplot(v.isp.mu, col = "darkgrey", ylim = c(-13, 0),   
 ylab = "Difference (S - R)", border = "NA",  
 axisnames = TRUE,   
 names.arg = sapply(names(v.isp.mu),   
 function(x)   
 paste(c(substr(x, 1, 1),   
 substr(x, 4, 4)), collapse = "")))  
segments(bp.out[, 1], v.isp.mu + v.isp.se,  
 bp.out[, 1], v.isp.mu - v.isp.se,   
 lwd = 1.5)  
dev.off()

## pdf   
## 2

## Multivariate Correlation of Plants and Saxicoles

There is no significant multivariate correlation between the veg and saxicole communities, regardless of whether the community data are relativized. This is likely a result of the two communities responded to different variables with low correlation (i.e. rocks = saxicoles and light = plants). This was true either without or with relativization by species max.

v.d <- vegdist(v.com.ds)  
l.d <- vegdist(com.ds)  
  
mantel(v.d ~ l.d)

## mantelr pval1 pval2 pval3 llim.2.5% ulim.97.5%   
## -0.002762319 0.513000000 0.488000000 0.914000000 -0.034504235 0.032707393

v.d <- vegdist(v.com.ds.rel)  
l.d <- vegdist(com.ds.rel)  
  
mantel(v.d ~ l.d)

## mantelr pval1 pval2 pval3 llim.2.5% ulim.97.5%   
## 0.02328021 0.21200000 0.78900000 0.44300000 -0.01176642 0.05838093

# Structural Equation Modeling

com.prepared <- cbind(id = l.dat[, "Moth"], tree = l.dat[, "Tree.pairs"], com)  
v.com.prepared <- cbind(id = l.dat[, "Moth"], tree = l.dat[, "Tree.pairs"], v.com)  
  
l.dist.euc <- distancePairedSamples(  
 sequences = com.prepared,  
 grouping.column = "id",  
 time.column = "tree",  
 exclude.columns = NULL,  
 method = "euclidean",  
 sum.distances = FALSE,  
 parallel.execution = FALSE  
)  
  
l.dist.man <- distancePairedSamples(  
 sequences = com.prepared,  
 grouping.column = "id",  
 time.column = "tree",  
 exclude.columns = NULL,  
 method = "manhattan",  
 sum.distances = FALSE,  
 parallel.execution = FALSE  
)  
  
v.dist.euc <- distancePairedSamples(  
 sequences = v.com.prepared,  
 grouping.column = "id",  
 time.column = "tree",  
 exclude.columns = NULL,  
 method = "euclidean",  
 sum.distances = FALSE,  
 parallel.execution = FALSE  
)  
  
v.dist.man <- distancePairedSamples(  
 sequences = v.com.prepared,  
 grouping.column = "id",  
 time.column = "tree",  
 exclude.columns = NULL,  
 method = "manhattan",  
 sum.distances = FALSE,  
 parallel.execution = FALSE  
)  
  
cor(l.dist.man[[1]], l.dist.euc[[1]])

## [1] 0.9422796

cor(v.dist.man[[1]], v.dist.euc[[1]])

## [1] 0.9612754

d.litter <- tapply(l.dat[, "Litter.."], l.dat[, "Tree.pairs"], diff)  
d.rocks <- tapply((l.dat[, "Big.rocks.."] + l.dat[, "Small.rocks.."]),   
 l.dat[, "Tree.pairs"], diff)  
d.light <- tapply(l.dat[, "Light...average"], l.dat[, "Tree.pairs"], diff)  
d.com <- l.dist.man[[1]]  
d.abun <- tapply(abun, l.dat[, "Tree.pairs"], diff)  
d.rich <- tapply(rich, l.dat[, "Tree.pairs"], diff)  
d.shan <- tapply(shan, l.dat[, "Tree.pairs"], diff)  
d.isp <- apply(isp.com, 2, function(x, f) tapply(x, f, diff), f = l.dat[, "Tree.pairs"])  
colnames(d.isp) <- paste("d", colnames(isp.com), sep = ".")  
  
round(cor(cbind(d.litter, d.rocks, d.light, d.abun, d.rich, d.shan, d.com)), 3)

## d.litter d.rocks d.light d.abun d.rich d.shan d.com  
## d.litter 1.000 -0.998 -0.171 -0.530 -0.695 -0.651 0.154  
## d.rocks -0.998 1.000 0.196 0.513 0.694 0.656 -0.140  
## d.light -0.171 0.196 1.000 0.108 0.268 0.290 -0.133  
## d.abun -0.530 0.513 0.108 1.000 0.649 0.353 -0.448  
## d.rich -0.695 0.694 0.268 0.649 1.000 0.888 -0.143  
## d.shan -0.651 0.656 0.290 0.353 0.888 1.000 -0.071  
## d.com 0.154 -0.140 -0.133 -0.448 -0.143 -0.071 1.000

sem.dat <- data.frame(d.litter, d.rocks, d.light, d.abun, d.rich, d.shan, d.com, d.isp)  
sem.path <- matrix(c(0, 1, 1, 0,   
 1, 0, 0, 1,   
 0, 0, 0, 1,   
 0, 0, 0, 0), 4, 4, byrow = TRUE)  
rownames(sem.path) <- colnames(sem.path) <- c("d.litter", "d.light", "d.rocks", "d.com")  
  
model.com <- psem(lm(d.rocks ~ d.litter, sem.dat), lm(d.com ~ d.light + d.rocks, sem.dat))  
model.com1 <- psem(lm(d.rocks ~ d.litter, sem.dat), lm(d.com ~ d.litter + d.light + d.rocks, sem.dat))  
model.abun <- psem(lm(d.rocks ~ d.litter, sem.dat), lm(d.abun ~ d.light + d.rocks, sem.dat))  
model.rich <- psem(lm(d.rocks ~ d.litter, sem.dat), lm(d.rich ~ d.light + d.rocks, sem.dat))  
model.shan <- psem(lm(d.rocks ~ d.litter, sem.dat), lm(d.shan ~ d.light + d.rocks, sem.dat))  
model.Acacon <- psem(lm(d.rocks ~ d.litter, sem.dat), lm(d.Acacon ~ d.light + d.rocks, sem.dat))  
model.Acaame <- psem(lm(d.rocks ~ d.litter, sem.dat), lm(d.Acaame ~ d.light + d.rocks, sem.dat))  
model.Canros <- psem(lm(d.rocks ~ d.litter, sem.dat), lm(d.Canros ~ d.light + d.rocks, sem.dat))  
model.Canros1 <- psem(lm(d.rocks ~ d.litter, sem.dat), lm(d.Canros ~ d.light + d.rocks, sem.dat))

d.litter <- tapply(l.dat[, "Litter.."], l.dat[, "Tree.pairs"], diff)  
d.rocks <- tapply((l.dat[, "Big.rocks.."] + l.dat[, "Small.rocks.."]),   
 l.dat[, "Tree.pairs"], diff)  
d.light <- tapply(l.dat[, "Light...average"], l.dat[, "Tree.pairs"], diff)  
  
d.v.com <- v.dist.man[[1]]  
d.v.abun <- tapply(v.abun, l.dat[, "Tree.pairs"], diff)  
d.v.rich <- tapply(v.rich, l.dat[, "Tree.pairs"], diff)  
d.v.shan <- tapply(v.shan, l.dat[, "Tree.pairs"], diff)  
d.v.isp <- apply(v.isp.com, 2, function(x, f) tapply(x, f, diff), f = l.dat[, "Tree.pairs"])  
colnames(d.v.isp) <- paste("d", colnames(v.isp.com), sep = ".")  
v.sem.dat <- data.frame(d.litter, d.rocks, d.light, d.v.abun, d.v.rich, d.v.shan, d.v.com, d.v.isp)  
  
model.v.com <- psem(lm(d.rocks ~ d.litter, v.sem.dat), lm(d.v.com ~ d.light + d.rocks, v.sem.dat))  
model.v.com1 <- psem(lm(d.rocks ~ d.litter, v.sem.dat), lm(d.v.com ~ d.litter + d.light + d.rocks, v.sem.dat))  
model.v.abun <- psem(lm(d.rocks ~ d.litter, v.sem.dat), lm(d.v.abun ~ d.light + d.rocks, v.sem.dat))  
model.v.rich <- psem(lm(d.rocks ~ d.litter, v.sem.dat), lm(d.v.rich ~ d.light + d.rocks, v.sem.dat))  
model.v.shan <- psem(lm(d.rocks ~ d.litter, v.sem.dat), lm(d.v.shan ~ d.light + d.rocks, v.sem.dat))  
model.v.Apache.plume <- psem(lm(d.rocks ~ d.litter, v.sem.dat),   
 lm(d.Apache.plume ~ d.light + d.rocks, v.sem.dat))  
model.v.Asteraceae.ovales <- psem(lm(d.rocks ~ d.litter, v.sem.dat),   
 lm(d.Asteraceae.ovales ~ d.light + d.rocks, v.sem.dat))

# Independent Test Method

Using indeendent tests for different effects along the hypothesized causal model that moth susceptibility affects tree traits (litter production), which affect the local environment (light, rocks), which in turn affect lichen, bryophyte and plant communities (abundance, richness, diversity, indicator species, composition).

moth-susceptibility -> tree traits -> local environment -> community

We can do this by parsing independent tests for each effect OR by using a structural equation model (SEM).

Testing for the effect of moth susceptibility:

t.test(d.litter)

##   
## One Sample t-test  
##   
## data: d.litter  
## t = 2.8665, df = 29, p-value = 0.00765  
## alternative hypothesis: true mean is not equal to 0  
## 95 percent confidence interval:  
## 4.317792 25.822208  
## sample estimates:  
## mean of x   
## 15.07

t.test(d.light)

##   
## One Sample t-test  
##   
## data: d.light  
## t = -9.2728, df = 29, p-value = 3.557e-10  
## alternative hypothesis: true mean is not equal to 0  
## 95 percent confidence interval:  
## -18.47119 -11.79547  
## sample estimates:  
## mean of x   
## -15.13333

t.test(d.rocks)

##   
## One Sample t-test  
##   
## data: d.rocks  
## t = -2.8178, df = 29, p-value = 0.008617  
## alternative hypothesis: true mean is not equal to 0  
## 95 percent confidence interval:  
## -25.298305 -4.019028  
## sample estimates:  
## mean of x   
## -14.65867

Effects of tree traits on local environment and environment correlations:

cor.test(d.light, d.litter)

##   
## Pearson's product-moment correlation  
##   
## data: d.light and d.litter  
## t = -0.92053, df = 28, p-value = 0.3652  
## alternative hypothesis: true correlation is not equal to 0  
## 95 percent confidence interval:  
## -0.5007401 0.2013096  
## sample estimates:  
## cor   
## -0.1713898

cor.test(d.rocks, d.light)

##   
## Pearson's product-moment correlation  
##   
## data: d.rocks and d.light  
## t = 1.0584, df = 28, p-value = 0.2989  
## alternative hypothesis: true correlation is not equal to 0  
## 95 percent confidence interval:  
## -0.1766215 0.5196770  
## sample estimates:  
## cor   
## 0.1961275

summary(lm(d.rocks ~ d.litter))

##   
## Call:  
## lm(formula = d.rocks ~ d.litter)  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -2.4466 -0.7468 -0.3273 0.2442 6.9590   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) 0.22870 0.34616 0.661 0.514   
## d.litter -0.98788 0.01079 -91.529 <2e-16 \*\*\*  
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 1.674 on 28 degrees of freedom  
## Multiple R-squared: 0.9967, Adjusted R-squared: 0.9965   
## F-statistic: 8378 on 1 and 28 DF, p-value: < 2.2e-16

Effects of local environment on lichen, and possible direct effects of tree traits:

summary(lm(d.abun ~ d.rocks))

##   
## Call:  
## lm(formula = d.abun ~ d.rocks)  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -7.8587 -1.3596 0.5429 1.6415 5.8098   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) -0.55053 0.67673 -0.814 0.42279   
## d.rocks 0.06777 0.02140 3.166 0.00371 \*\*  
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 3.284 on 28 degrees of freedom  
## Multiple R-squared: 0.2637, Adjusted R-squared: 0.2374   
## F-statistic: 10.03 on 1 and 28 DF, p-value: 0.003706

summary(lm(d.rich ~ d.rocks))

##   
## Call:  
## lm(formula = d.rich ~ d.rocks)  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -5.7375 -2.3674 -0.1611 1.6950 7.5293   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) -0.85626 0.70878 -1.208 0.237   
## d.rocks 0.11441 0.02242 5.104 2.09e-05 \*\*\*  
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 3.44 on 28 degrees of freedom  
## Multiple R-squared: 0.4819, Adjusted R-squared: 0.4634   
## F-statistic: 26.05 on 1 and 28 DF, p-value: 2.089e-05

summary(lm(d.shan ~ d.rocks))

##   
## Call:  
## lm(formula = d.shan ~ d.rocks)  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -1.46785 -0.60402 0.04559 0.63369 1.38124   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) -0.106623 0.154747 -0.689 0.496   
## d.rocks 0.022537 0.004894 4.605 8.17e-05 \*\*\*  
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 0.751 on 28 degrees of freedom  
## Multiple R-squared: 0.4309, Adjusted R-squared: 0.4106   
## F-statistic: 21.2 on 1 and 28 DF, p-value: 8.167e-05

summary(lm(d.Acacon ~ d.rocks, sem.dat))

##   
## Call:  
## lm(formula = d.Acacon ~ d.rocks, data = sem.dat)  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -0.17556 -0.01439 0.01337 0.03252 0.09108   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) -0.0238762 0.0126055 -1.894 0.06858 .   
## d.rocks 0.0014183 0.0003987 3.557 0.00136 \*\*  
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 0.06117 on 28 degrees of freedom  
## Multiple R-squared: 0.3113, Adjusted R-squared: 0.2867   
## F-statistic: 12.66 on 1 and 28 DF, p-value: 0.001357

summary(lm(d.Acaame ~ d.rocks, sem.dat))

##   
## Call:  
## lm(formula = d.Acaame ~ d.rocks, data = sem.dat)  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -0.64206 -0.09675 0.03298 0.07873 0.56715   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) -0.068167 0.042641 -1.599 0.121   
## d.rocks 0.006310 0.001349 4.679 6.67e-05 \*\*\*  
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 0.2069 on 28 degrees of freedom  
## Multiple R-squared: 0.4388, Adjusted R-squared: 0.4188   
## F-statistic: 21.89 on 1 and 28 DF, p-value: 6.669e-05

summary(lm(d.Canros ~ d.rocks, sem.dat))

##   
## Call:  
## lm(formula = d.Canros ~ d.rocks, data = sem.dat)  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -1.04560 -0.22148 0.06461 0.28602 0.81105   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) -0.196087 0.096385 -2.034 0.051479 .   
## d.rocks 0.012797 0.003048 4.198 0.000247 \*\*\*  
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 0.4678 on 28 degrees of freedom  
## Multiple R-squared: 0.3863, Adjusted R-squared: 0.3643   
## F-statistic: 17.62 on 1 and 28 DF, p-value: 0.0002467

summary(lm(d.abun ~ d.light))

##   
## Call:  
## lm(formula = d.abun ~ d.light)  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -8.3371 -2.7395 0.6687 1.5171 8.1163   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)  
## (Intercept) -0.85872 1.38331 -0.621 0.540  
## d.light 0.04528 0.07905 0.573 0.571  
##   
## Residual standard error: 3.805 on 28 degrees of freedom  
## Multiple R-squared: 0.01159, Adjusted R-squared: -0.02372   
## F-statistic: 0.3282 on 1 and 28 DF, p-value: 0.5713

summary(lm(d.rich ~ d.light))

##   
## Call:  
## lm(formula = d.rich ~ d.light)  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -6.758 -3.199 -0.836 3.003 12.001   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)  
## (Intercept) -0.40551 1.67397 -0.242 0.810  
## d.light 0.14061 0.09565 1.470 0.153  
##   
## Residual standard error: 4.605 on 28 degrees of freedom  
## Multiple R-squared: 0.07164, Adjusted R-squared: 0.03848   
## F-statistic: 2.161 on 1 and 28 DF, p-value: 0.1527

summary(lm(d.shan ~ d.light))

##   
## Call:  
## lm(formula = d.shan ~ d.light)  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -1.5927 -0.7784 0.1074 0.5385 2.1225   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)  
## (Intercept) 0.04306 0.34638 0.124 0.902  
## d.light 0.03172 0.01979 1.603 0.120  
##   
## Residual standard error: 0.9528 on 28 degrees of freedom  
## Multiple R-squared: 0.08402, Adjusted R-squared: 0.05131   
## F-statistic: 2.568 on 1 and 28 DF, p-value: 0.1202

summary(lm(d.Acacon ~ d.light, sem.dat))

##   
## Call:  
## lm(formula = d.Acacon ~ d.light, data = sem.dat)  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -0.21083 -0.02561 0.02198 0.04135 0.09381   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) 0.007098 0.024294 0.292 0.7723   
## d.light 0.003421 0.001388 2.464 0.0201 \*  
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 0.06682 on 28 degrees of freedom  
## Multiple R-squared: 0.1782, Adjusted R-squared: 0.1489   
## F-statistic: 6.072 on 1 and 28 DF, p-value: 0.02014

summary(lm(d.Acaame ~ d.light, sem.dat))

##   
## Call:  
## lm(formula = d.Acaame ~ d.light, data = sem.dat)  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -0.85875 -0.06371 0.06088 0.15869 0.27225   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) 0.03200 0.09117 0.351 0.7283   
## d.light 0.01273 0.00521 2.444 0.0211 \*  
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 0.2508 on 28 degrees of freedom  
## Multiple R-squared: 0.1758, Adjusted R-squared: 0.1463   
## F-statistic: 5.972 on 1 and 28 DF, p-value: 0.0211

summary(lm(d.Canros ~ d.light, sem.dat))

##   
## Call:  
## lm(formula = d.Canros ~ d.light, data = sem.dat)  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -0.9699 -0.3253 0.1547 0.3191 1.2307   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) 0.03300 0.19704 0.168 0.868   
## d.light 0.02753 0.01126 2.445 0.021 \*  
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 0.542 on 28 degrees of freedom  
## Multiple R-squared: 0.176, Adjusted R-squared: 0.1466   
## F-statistic: 5.98 on 1 and 28 DF, p-value: 0.02101

summary(lm(d.abun ~ d.litter))

##   
## Call:  
## lm(formula = d.abun ~ d.litter)  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -7.380 -1.218 0.494 1.607 5.733   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) -0.50153 0.67144 -0.747 0.46132   
## d.litter -0.06917 0.02094 -3.304 0.00261 \*\*  
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 3.246 on 28 degrees of freedom  
## Multiple R-squared: 0.2805, Adjusted R-squared: 0.2548   
## F-statistic: 10.92 on 1 and 28 DF, p-value: 0.002612

summary(lm(d.rich ~ d.litter))

##   
## Call:  
## lm(formula = d.rich ~ d.litter)  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -5.7618 -2.0890 -0.0954 1.7166 7.5545   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) -0.82616 0.71101 -1.162 0.255   
## d.litter -0.11328 0.02217 -5.110 2.05e-05 \*\*\*  
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 3.438 on 28 degrees of freedom  
## Multiple R-squared: 0.4826, Adjusted R-squared: 0.4641   
## F-statistic: 26.11 on 1 and 28 DF, p-value: 2.053e-05

summary(lm(d.shan ~ d.litter))

##   
## Call:  
## lm(formula = d.shan ~ d.litter)  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -1.47085 -0.59769 0.03512 0.59650 1.39944   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) -0.103513 0.156232 -0.663 0.513   
## d.litter -0.022128 0.004871 -4.543 9.68e-05 \*\*\*  
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 0.7554 on 28 degrees of freedom  
## Multiple R-squared: 0.4243, Adjusted R-squared: 0.4037   
## F-statistic: 20.64 on 1 and 28 DF, p-value: 9.675e-05

summary(lm(d.Acacon ~ d.litter, sem.dat))

##   
## Call:  
## lm(formula = d.Acacon ~ d.litter, data = sem.dat)  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -0.17743 -0.01528 0.01435 0.03220 0.09098   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) -0.0240028 0.0127820 -1.878 0.07085 .   
## d.litter -0.0013712 0.0003985 -3.441 0.00184 \*\*  
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 0.0618 on 28 degrees of freedom  
## Multiple R-squared: 0.2971, Adjusted R-squared: 0.272   
## F-statistic: 11.84 on 1 and 28 DF, p-value: 0.001839

summary(lm(d.Acaame ~ d.litter, sem.dat))

##   
## Call:  
## lm(formula = d.Acaame ~ d.litter, data = sem.dat)  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -0.64969 -0.10426 0.03407 0.08146 0.56925   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) -0.067611 0.043169 -1.566 0.129   
## d.litter -0.006175 0.001346 -4.588 8.56e-05 \*\*\*  
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 0.2087 on 28 degrees of freedom  
## Multiple R-squared: 0.4291, Adjusted R-squared: 0.4087   
## F-statistic: 21.05 on 1 and 28 DF, p-value: 8.558e-05

summary(lm(d.Canros ~ d.litter, sem.dat))

##   
## Call:  
## lm(formula = d.Canros ~ d.litter, data = sem.dat)  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -1.06651 -0.21741 0.05103 0.27634 0.81235   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) -0.193646 0.097001 -1.996 0.055705 .   
## d.litter -0.012609 0.003024 -4.169 0.000267 \*\*\*  
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 0.469 on 28 degrees of freedom  
## Multiple R-squared: 0.383, Adjusted R-squared: 0.361   
## F-statistic: 17.38 on 1 and 28 DF, p-value: 0.0002666

SEM testing for this pathway, note that here community distance is the sum of squared differences for each tree pair (susceptible - resistant) for all species:

summary(model.abun, .progressBar = FALSE)

##   
## Structural Equation Model of model.abun   
##   
## Call:  
## d.rocks ~ d.litter  
## d.abun ~ d.light + d.rocks  
##   
## AIC BIC  
## 28.447 38.255  
##   
## ---  
## Tests of directed separation:  
##   
## Independ.Claim Test.Type DF Crit.Value P.Value   
## d.abun ~ d.litter + ... coef 26 -2.1260 0.0432 \*  
## d.rocks ~ d.light + ... coef 27 2.5465 0.0169 \*  
##   
## Global goodness-of-fit:  
##   
## Fisher's C = 14.447 with P-value = 0.006 and on 4 degrees of freedom  
##   
## ---  
## Coefficients:  
##   
## Response Predictor Estimate Std.Error DF Crit.Value P.Value Std.Estimate   
## d.rocks d.litter -0.9879 0.0108 28 -91.5294 0.0000 -0.9983 \*\*\*  
## d.abun d.light 0.0030 0.0709 27 0.0428 0.9662 0.0072   
## d.abun d.rocks 0.0676 0.0222 27 3.0408 0.0052 0.5121 \*\*  
##   
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05  
##   
## ---  
## Individual R-squared:  
##   
## Response method R.squared  
## d.rocks none 1.00  
## d.abun none 0.26

summary(model.rich, .progressBar = FALSE)

##   
## Structural Equation Model of model.rich   
##   
## Call:  
## d.rocks ~ d.litter  
## d.rich ~ d.light + d.rocks  
##   
## AIC BIC  
## 23.564 33.372  
##   
## ---  
## Tests of directed separation:  
##   
## Independ.Claim Test.Type DF Crit.Value P.Value   
## d.rich ~ d.litter + ... coef 26 -0.6906 0.4960   
## d.rocks ~ d.light + ... coef 27 2.5465 0.0169 \*  
##   
## Global goodness-of-fit:  
##   
## Fisher's C = 9.564 with P-value = 0.048 and on 4 degrees of freedom  
##   
## ---  
## Coefficients:  
##   
## Response Predictor Estimate Std.Error DF Crit.Value P.Value Std.Estimate   
## d.rocks d.litter -0.9879 0.0108 28 -91.5294 0.0000 -0.9983 \*\*\*  
## d.rich d.light 0.0718 0.0729 27 0.9854 0.3332 0.1368   
## d.rich d.rocks 0.1100 0.0229 27 4.8086 0.0001 0.6674 \*\*\*  
##   
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05  
##   
## ---  
## Individual R-squared:  
##   
## Response method R.squared  
## d.rocks none 1.0  
## d.rich none 0.5

summary(model.shan, .progressBar = FALSE)

##   
## Structural Equation Model of model.shan   
##   
## Call:  
## d.rocks ~ d.litter  
## d.shan ~ d.light + d.rocks  
##   
## AIC BIC  
## 22.182 31.99  
##   
## ---  
## Tests of directed separation:  
##   
## Independ.Claim Test.Type DF Crit.Value P.Value   
## d.shan ~ d.litter + ... coef 26 -0.0130 0.9897   
## d.rocks ~ d.light + ... coef 27 2.5465 0.0169 \*  
##   
## Global goodness-of-fit:  
##   
## Fisher's C = 8.182 with P-value = 0.085 and on 4 degrees of freedom  
##   
## ---  
## Coefficients:  
##   
## Response Predictor Estimate Std.Error DF Crit.Value P.Value Std.Estimate   
## d.rocks d.litter -0.9879 0.0108 28 -91.5294 0.0000 -0.9983 \*\*\*  
## d.shan d.light 0.0183 0.0158 27 1.1596 0.2563 0.1676   
## d.shan d.rocks 0.0214 0.0050 27 4.3156 0.0002 0.6236 \*\*\*  
##   
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05  
##   
## ---  
## Individual R-squared:  
##   
## Response method R.squared  
## d.rocks none 1.00  
## d.shan none 0.46

summary(model.com, .progressBar = FALSE)

##   
## Structural Equation Model of model.com   
##   
## Call:  
## d.rocks ~ d.litter  
## d.com ~ d.light + d.rocks  
##   
## AIC BIC  
## 27.066 36.874  
##   
## ---  
## Tests of directed separation:  
##   
## Independ.Claim Test.Type DF Crit.Value P.Value   
## d.com ~ d.litter + ... coef 26 1.7840 0.0861   
## d.rocks ~ d.light + ... coef 27 2.5465 0.0169 \*  
##   
## Global goodness-of-fit:  
##   
## Fisher's C = 13.066 with P-value = 0.011 and on 4 degrees of freedom  
##   
## ---  
## Coefficients:  
##   
## Response Predictor Estimate Std.Error DF Crit.Value P.Value Std.Estimate   
## d.rocks d.litter -0.9879 0.0108 28 -91.5294 0.0000 -0.9983 \*\*\*  
## d.com d.light -0.0350 0.0617 27 -0.5673 0.5752 -0.1096   
## d.com d.rocks -0.0119 0.0193 27 -0.6129 0.5450 -0.1184   
##   
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05  
##   
## ---  
## Individual R-squared:  
##   
## Response method R.squared  
## d.rocks none 1.00  
## d.com none 0.03

summary(model.Acacon, .progressBar = FALSE)

##   
## Structural Equation Model of model.Acacon   
##   
## Call:  
## d.rocks ~ d.litter  
## d.Acacon ~ d.light + d.rocks  
##   
## AIC BIC  
## 23.133 32.941  
##   
## ---  
## Tests of directed separation:  
##   
## Independ.Claim Test.Type DF Crit.Value P.Value   
## d.Acacon ~ d.litter + ... coef 26 0.5085 0.6154   
## d.rocks ~ d.light + ... coef 27 2.5465 0.0169 \*  
##   
## Global goodness-of-fit:  
##   
## Fisher's C = 9.133 with P-value = 0.058 and on 4 degrees of freedom  
##   
## ---  
## Coefficients:  
##   
## Response Predictor Estimate Std.Error DF Crit.Value P.Value Std.Estimate   
## d.rocks d.litter -0.9879 0.0108 28 -91.5294 0.0000 -0.9983 \*\*\*  
## d.Acacon d.light 0.0026 0.0012 27 2.1628 0.0396 0.3252 \*  
## d.Acacon d.rocks 0.0013 0.0004 27 3.2863 0.0028 0.4941 \*\*  
##   
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05  
##   
## ---  
## Individual R-squared:  
##   
## Response method R.squared  
## d.rocks none 1.00  
## d.Acacon none 0.41

summary(model.Acaame, .progressBar = FALSE)

##   
## Structural Equation Model of model.Acaame   
##   
## Call:  
## d.rocks ~ d.litter  
## d.Acaame ~ d.light + d.rocks  
##   
## AIC BIC  
## 22.423 32.231  
##   
## ---  
## Tests of directed separation:  
##   
## Independ.Claim Test.Type DF Crit.Value P.Value   
## d.Acaame ~ d.litter + ... coef 26 -0.1558 0.8774   
## d.rocks ~ d.light + ... coef 27 2.5465 0.0169 \*  
##   
## Global goodness-of-fit:  
##   
## Fisher's C = 8.423 with P-value = 0.077 and on 4 degrees of freedom  
##   
## ---  
## Coefficients:  
##   
## Response Predictor Estimate Std.Error DF Crit.Value P.Value Std.Estimate   
## d.rocks d.litter -0.9879 0.0108 28 -91.5294 0.0000 -0.9983 \*\*\*  
## d.Acaame d.light 0.0091 0.0041 27 2.2267 0.0345 0.3009 \*  
## d.Acaame d.rocks 0.0057 0.0013 27 4.4650 0.0001 0.6034 \*\*\*  
##   
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05  
##   
## ---  
## Individual R-squared:  
##   
## Response method R.squared  
## d.rocks none 1.00  
## d.Acaame none 0.53

summary(model.Canros, .progressBar = FALSE)

##   
## Structural Equation Model of model.Canros   
##   
## Call:  
## d.rocks ~ d.litter  
## d.Canros ~ d.light + d.rocks  
##   
## AIC BIC  
## 23.898 33.706  
##   
## ---  
## Tests of directed separation:  
##   
## Independ.Claim Test.Type DF Crit.Value P.Value   
## d.Canros ~ d.litter + ... coef 26 -0.8201 0.4196   
## d.rocks ~ d.light + ... coef 27 2.5465 0.0169 \*  
##   
## Global goodness-of-fit:  
##   
## Fisher's C = 9.898 with P-value = 0.042 and on 4 degrees of freedom  
##   
## ---  
## Coefficients:  
##   
## Response Predictor Estimate Std.Error DF Crit.Value P.Value Std.Estimate   
## d.rocks d.litter -0.9879 0.0108 28 -91.5294 0.0000 -0.9983 \*\*\*  
## d.Canros d.light 0.0203 0.0093 27 2.1836 0.0379 0.3095 \*  
## d.Canros d.rocks 0.0115 0.0029 27 3.9562 0.0005 0.5608 \*\*\*  
##   
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05  
##   
## ---  
## Individual R-squared:  
##   
## Response method R.squared  
## d.rocks none 1.00  
## d.Canros none 0.48

summary(lm(d.v.abun ~ d.rocks))

##   
## Call:  
## lm(formula = d.v.abun ~ d.rocks)  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -46.548 -9.167 -0.371 11.836 29.860   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) -23.61098 3.52322 -6.702 2.83e-07 \*\*\*  
## d.rocks -0.08716 0.11143 -0.782 0.441   
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 17.1 on 28 degrees of freedom  
## Multiple R-squared: 0.02138, Adjusted R-squared: -0.01357   
## F-statistic: 0.6118 on 1 and 28 DF, p-value: 0.4407

summary(lm(d.v.rich ~ d.rocks))

##   
## Call:  
## lm(formula = d.v.rich ~ d.rocks)  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -1.6195 -0.7375 0.2342 0.3760 2.3148   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) -1.259773 0.199030 -6.330 7.57e-07 \*\*\*  
## d.rocks 0.002744 0.006295 0.436 0.666   
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 0.9659 on 28 degrees of freedom  
## Multiple R-squared: 0.006742, Adjusted R-squared: -0.02873   
## F-statistic: 0.1901 on 1 and 28 DF, p-value: 0.6662

summary(lm(d.v.shan ~ d.rocks))

##   
## Call:  
## lm(formula = d.v.shan ~ d.rocks)  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -0.63077 -0.28155 0.02544 0.29568 0.97384   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) -0.335709 0.078745 -4.263 0.000207 \*\*\*  
## d.rocks -0.002745 0.002491 -1.102 0.279691   
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 0.3821 on 28 degrees of freedom  
## Multiple R-squared: 0.04159, Adjusted R-squared: 0.007366   
## F-statistic: 1.215 on 1 and 28 DF, p-value: 0.2797

summary(lm(d.Apache.plume ~ d.rocks, v.sem.dat))

##   
## Call:  
## lm(formula = d.Apache.plume ~ d.rocks, data = v.sem.dat)  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -28.028 -4.455 4.278 6.677 14.799   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) -12.13756 2.44690 -4.960 3.09e-05 \*\*\*  
## d.rocks -0.12763 0.07739 -1.649 0.11   
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 11.87 on 28 degrees of freedom  
## Multiple R-squared: 0.08854, Adjusted R-squared: 0.05598   
## F-statistic: 2.72 on 1 and 28 DF, p-value: 0.1103

summary(lm(d.Asteraceae.ovales ~ d.rocks, v.sem.dat))

##   
## Call:  
## lm(formula = d.Asteraceae.ovales ~ d.rocks, data = v.sem.dat)  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -31.976 -7.315 5.782 7.526 19.463   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) -7.44665 2.34354 -3.178 0.0036 \*\*  
## d.rocks 0.04684 0.07412 0.632 0.5325   
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 11.37 on 28 degrees of freedom  
## Multiple R-squared: 0.01406, Adjusted R-squared: -0.02115   
## F-statistic: 0.3994 on 1 and 28 DF, p-value: 0.5325

summary(lm(d.v.abun ~ d.litter))

##   
## Call:  
## lm(formula = d.v.abun ~ d.litter)  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -46.743 -8.907 0.019 11.943 30.269   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) -23.44568 3.54674 -6.610 3.6e-07 \*\*\*  
## d.litter 0.07381 0.11059 0.667 0.51   
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 17.15 on 28 degrees of freedom  
## Multiple R-squared: 0.01566, Adjusted R-squared: -0.01949   
## F-statistic: 0.4455 on 1 and 28 DF, p-value: 0.5099

summary(lm(d.v.rich ~ d.litter))

##   
## Call:  
## lm(formula = d.v.rich ~ d.litter)  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -1.6111 -0.7427 0.2214 0.3838 2.3153   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) -1.253709 0.199585 -6.282 8.61e-07 \*\*\*  
## d.litter -0.003072 0.006223 -0.494 0.625   
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 0.965 on 28 degrees of freedom  
## Multiple R-squared: 0.008626, Adjusted R-squared: -0.02678   
## F-statistic: 0.2436 on 1 and 28 DF, p-value: 0.6254

summary(lm(d.v.shan ~ d.litter))

##   
## Call:  
## lm(formula = d.v.shan ~ d.litter)  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -0.62023 -0.28853 0.04059 0.29668 0.97632   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) -0.332721 0.079334 -4.194 0.000249 \*\*\*  
## d.litter 0.002472 0.002474 0.999 0.326145   
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 0.3836 on 28 degrees of freedom  
## Multiple R-squared: 0.03444, Adjusted R-squared: -3.912e-05   
## F-statistic: 0.9989 on 1 and 28 DF, p-value: 0.3261

summary(lm(d.Apache.plume ~ d.litter, v.sem.dat))

##   
## Call:  
## lm(formula = d.Apache.plume ~ d.litter, data = v.sem.dat)  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -28.098 -4.465 4.364 6.975 14.577   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) -12.05623 2.46985 -4.881 3.84e-05 \*\*\*  
## d.litter 0.11875 0.07701 1.542 0.134   
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 11.94 on 28 degrees of freedom  
## Multiple R-squared: 0.07828, Adjusted R-squared: 0.04536   
## F-statistic: 2.378 on 1 and 28 DF, p-value: 0.1343

summary(lm(d.Asteraceae.ovales ~ d.litter, v.sem.dat))

##   
## Call:  
## lm(formula = d.Asteraceae.ovales ~ d.litter, data = v.sem.dat)  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -32.006 -7.296 5.653 7.482 19.553   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) -7.36833 2.34896 -3.137 0.00399 \*\*  
## d.litter -0.05076 0.07324 -0.693 0.49395   
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 11.36 on 28 degrees of freedom  
## Multiple R-squared: 0.01687, Adjusted R-squared: -0.01824   
## F-statistic: 0.4804 on 1 and 28 DF, p-value: 0.494

summary(lm(d.v.abun ~ d.light))

##   
## Call:  
## lm(formula = d.v.abun ~ d.light)  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -47.204 -7.755 1.085 11.993 31.908   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) -23.8611 6.2747 -3.803 0.000711 \*\*\*  
## d.light -0.1010 0.3585 -0.282 0.780349   
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 17.26 on 28 degrees of freedom  
## Multiple R-squared: 0.002823, Adjusted R-squared: -0.03279   
## F-statistic: 0.07928 on 1 and 28 DF, p-value: 0.7803

summary(lm(d.v.rich ~ d.light))

##   
## Call:  
## lm(formula = d.v.rich ~ d.light)  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -1.7203 -0.7086 0.2372 0.4718 2.3085   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) -1.10636 0.34979 -3.163 0.00374 \*\*  
## d.light 0.01280 0.01999 0.640 0.52727   
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 0.9622 on 28 degrees of freedom  
## Multiple R-squared: 0.01443, Adjusted R-squared: -0.02077   
## F-statistic: 0.4098 on 1 and 28 DF, p-value: 0.5273

summary(lm(d.v.shan ~ d.light))

##   
## Call:  
## lm(formula = d.v.shan ~ d.light)  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -0.5917 -0.3570 0.1214 0.2817 0.9857   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) -0.362101 0.141162 -2.565 0.016 \*  
## d.light -0.004403 0.008066 -0.546 0.589   
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 0.3883 on 28 degrees of freedom  
## Multiple R-squared: 0.01053, Adjusted R-squared: -0.02481   
## F-statistic: 0.298 on 1 and 28 DF, p-value: 0.5895

summary(lm(d.Apache.plume ~ d.light, v.sem.dat))

##   
## Call:  
## lm(formula = d.Apache.plume ~ d.light, data = v.sem.dat)  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -33.062 -4.319 4.807 9.297 16.737   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) -14.6411 4.4197 -3.313 0.00256 \*\*  
## d.light -0.2891 0.2525 -1.145 0.26208   
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 12.16 on 28 degrees of freedom  
## Multiple R-squared: 0.0447, Adjusted R-squared: 0.01058   
## F-statistic: 1.31 on 1 and 28 DF, p-value: 0.2621

summary(lm(d.Asteraceae.ovales ~ d.light, v.sem.dat))

##   
## Call:  
## lm(formula = d.Asteraceae.ovales ~ d.light, data = v.sem.dat)  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -31.874 -6.867 6.133 8.134 18.131   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) -8.1407349 4.1640687 -1.955 0.0606 .  
## d.light -0.0004891 0.2379432 -0.002 0.9984   
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 11.45 on 28 degrees of freedom  
## Multiple R-squared: 1.509e-07, Adjusted R-squared: -0.03571   
## F-statistic: 4.225e-06 on 1 and 28 DF, p-value: 0.9984

summary(model.v.com, .progressBar = FALSE)

##   
## Structural Equation Model of model.v.com   
##   
## Call:  
## d.rocks ~ d.litter  
## d.v.com ~ d.light + d.rocks  
##   
## AIC BIC  
## 28.300 38.108  
##   
## ---  
## Tests of directed separation:  
##   
## Independ.Claim Test.Type DF Crit.Value P.Value   
## d.v.com ~ d.litter + ... coef 26 2.0909 0.0465 \*  
## d.rocks ~ d.light + ... coef 27 2.5465 0.0169 \*  
##   
## Global goodness-of-fit:  
##   
## Fisher's C = 14.3 with P-value = 0.006 and on 4 degrees of freedom  
##   
## ---  
## Coefficients:  
##   
## Response Predictor Estimate Std.Error DF Crit.Value P.Value Std.Estimate   
## d.rocks d.litter -0.9879 0.0108 28 -91.5294 0.0000 -0.9983 \*\*\*  
## d.v.com d.light 0.0177 0.3475 27 0.0508 0.9598 0.0099   
## d.v.com d.rocks 0.0595 0.1090 27 0.5453 0.5900 0.1064   
##   
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05  
##   
## ---  
## Individual R-squared:  
##   
## Response method R.squared  
## d.rocks none 1.00  
## d.v.com none 0.01

summary(model.v.abun, .progressBar = FALSE)

##   
## Structural Equation Model of model.v.abun   
##   
## Call:  
## d.rocks ~ d.litter  
## d.v.abun ~ d.light + d.rocks  
##   
## AIC BIC  
## 28.663 38.471  
##   
## ---  
## Tests of directed separation:  
##   
## Independ.Claim Test.Type DF Crit.Value P.Value   
## d.v.abun ~ d.litter + ... coef 26 -2.1770 0.0387 \*  
## d.rocks ~ d.light + ... coef 27 2.5465 0.0169 \*  
##   
## Global goodness-of-fit:  
##   
## Fisher's C = 14.663 with P-value = 0.005 and on 4 degrees of freedom  
##   
## ---  
## Coefficients:  
##   
## Response Predictor Estimate Std.Error DF Crit.Value P.Value Std.Estimate   
## d.rocks d.litter -0.9879 0.0108 28 -91.5294 0.0000 -0.9983 \*\*\*  
## d.v.abun d.light -0.0483 0.3688 27 -0.1310 0.8967 -0.0254   
## d.v.abun d.rocks -0.0842 0.1157 27 -0.7277 0.4731 -0.1412   
##   
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05  
##   
## ---  
## Individual R-squared:  
##   
## Response method R.squared  
## d.rocks none 1.00  
## d.v.abun none 0.02

summary(model.v.rich, .progressBar = FALSE)

##   
## Structural Equation Model of model.v.rich   
##   
## Call:  
## d.rocks ~ d.litter  
## d.v.rich ~ d.light + d.rocks  
##   
## AIC BIC  
## 25.623 35.431  
##   
## ---  
## Tests of directed separation:  
##   
## Independ.Claim Test.Type DF Crit.Value P.Value   
## d.v.rich ~ d.litter + ... coef 26 -1.3873 0.1771   
## d.rocks ~ d.light + ... coef 27 2.5465 0.0169 \*  
##   
## Global goodness-of-fit:  
##   
## Fisher's C = 11.623 with P-value = 0.02 and on 4 degrees of freedom  
##   
## ---  
## Coefficients:  
##   
## Response Predictor Estimate Std.Error DF Crit.Value P.Value Std.Estimate   
## d.rocks d.litter -0.9879 0.0108 28 -91.5294 0.0000 -0.9983 \*\*\*  
## d.v.rich d.light 0.0115 0.0207 27 0.5561 0.5827 0.1082   
## d.v.rich d.rocks 0.0020 0.0065 27 0.3131 0.7566 0.0609   
##   
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05  
##   
## ---  
## Individual R-squared:  
##   
## Response method R.squared  
## d.rocks none 1.00  
## d.v.rich none 0.02

summary(model.v.shan, .progressBar = FALSE)

##   
## Structural Equation Model of model.v.shan   
##   
## Call:  
## d.rocks ~ d.litter  
## d.v.shan ~ d.light + d.rocks  
##   
## AIC BIC  
## 26.895 36.703  
##   
## ---  
## Tests of directed separation:  
##   
## Independ.Claim Test.Type DF Crit.Value P.Value   
## d.v.shan ~ d.litter + ... coef 26 -1.7395 0.0938   
## d.rocks ~ d.light + ... coef 27 2.5465 0.0169 \*  
##   
## Global goodness-of-fit:  
##   
## Fisher's C = 12.895 with P-value = 0.012 and on 4 degrees of freedom  
##   
## ---  
## Coefficients:  
##   
## Response Predictor Estimate Std.Error DF Crit.Value P.Value Std.Estimate   
## d.rocks d.litter -0.9879 0.0108 28 -91.5294 0.0000 -0.9983 \*\*\*  
## d.v.shan d.light -0.0028 0.0082 27 -0.3397 0.7367 -0.0651   
## d.v.shan d.rocks -0.0026 0.0026 27 -0.9971 0.3276 -0.1912   
##   
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05  
##   
## ---  
## Individual R-squared:  
##   
## Response method R.squared  
## d.rocks none 1.00  
## d.v.shan none 0.05

summary(model.v.Apache.plume, .progressBar = FALSE)

##   
## Structural Equation Model of model.v.Apache.plume   
##   
## Call:  
## d.rocks ~ d.litter  
## d.Apache.plume ~ d.light + d.rocks  
##   
## AIC BIC  
## 25.830 35.638  
##   
## ---  
## Tests of directed separation:  
##   
## Independ.Claim Test.Type DF Crit.Value P.Value   
## d.Apache.plume ~ d.litter + ... coef 26 -1.4474 0.1597   
## d.rocks ~ d.light + ... coef 27 2.5465 0.0169 \*  
##   
## Global goodness-of-fit:  
##   
## Fisher's C = 11.83 with P-value = 0.019 and on 4 degrees of freedom  
##   
## ---  
## Coefficients:  
##   
## Response Predictor Estimate Std.Error DF Crit.Value P.Value Std.Estimate  
## d.rocks d.litter -0.9879 0.0108 28 -91.5294 0.0000 -0.9983  
## d.Apache.plume d.light -0.2176 0.2527 27 -0.8611 0.3968 -0.1592  
## d.Apache.plume d.rocks -0.1142 0.0793 27 -1.4408 0.1611 -0.2663  
##   
## \*\*\*  
##   
##   
##   
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05  
##   
## ---  
## Individual R-squared:  
##   
## Response method R.squared  
## d.rocks none 1.00  
## d.Apache.plume none 0.11

summary(model.v.Asteraceae.ovales, .progressBar = FALSE)

##   
## Structural Equation Model of model.v.Asteraceae.ovales   
##   
## Call:  
## d.rocks ~ d.litter  
## d.Asteraceae.ovales ~ d.light + d.rocks  
##   
## AIC BIC  
## 24.690 34.498  
##   
## ---  
## Tests of directed separation:  
##   
## Independ.Claim Test.Type DF Crit.Value P.Value   
## d.Asteraceae.ovales ~ d.litter + ... coef 26 -1.0976 0.2824   
## d.rocks ~ d.light + ... coef 27 2.5465 0.0169 \*  
##   
## Global goodness-of-fit:  
##   
## Fisher's C = 10.69 with P-value = 0.03 and on 4 degrees of freedom  
##   
## ---  
## Coefficients:  
##   
## Response Predictor Estimate Std.Error DF Crit.Value P.Value  
## d.rocks d.litter -0.9879 0.0108 28 -91.5294 0.0000  
## d.Asteraceae.ovales d.light -0.0310 0.2453 27 -0.1262 0.9005  
## d.Asteraceae.ovales d.rocks 0.0488 0.0770 27 0.6335 0.5317  
## Std.Estimate   
## -0.9983 \*\*\*  
## -0.0246   
## 0.1234   
##   
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05  
##   
## ---  
## Individual R-squared:  
##   
## Response method R.squared  
## d.rocks none 1.00  
## d.Asteraceae.ovales none 0.01

# Analyses for Revisions

Tree -> Moth -> Trait -> Loc env -> Community (A, R, D, Comp)

Pair S/R Crown Litter Lichen Rocks Plants Light

## Lichen and plant community resposnes are not correlated

mantel(l.com.dif.d ~ v.com.dif.d)

## mantelr pval1 pval2 pval3 llim.2.5% ulim.97.5%   
## -0.11773949 0.79100000 0.21000000 0.43800000 -0.23133491 -0.03334609

mantel(l.com.dif.d ~ env.dif.d)

## mantelr pval1 pval2 pval3 llim.2.5% ulim.97.5%   
## 0.01150233 0.44800000 0.55300000 0.93900000 -0.03897137 0.08388580

mantel(l.com.dif.d ~ tra.dif.d)

## mantelr pval1 pval2 pval3 llim.2.5% ulim.97.5%   
## 0.2323704 0.0390000 0.9620000 0.0420000 0.1419806 0.3350468

mantel(v.com.dif.d ~ env.dif.d)

## mantelr pval1 pval2 pval3 llim.2.5% ulim.97.5%   
## -0.11698559 0.88400000 0.11700000 0.25100000 -0.15953527 -0.05108963

mantel(v.com.dif.d ~ tra.dif.d)

## mantelr pval1 pval2 pval3 llim.2.5% ulim.97.5%   
## -0.07840365 0.76400000 0.23700000 0.46000000 -0.13547720 -0.01712182

## Both lichen and vegetation respond to moth susceptibility

set.seed(12345)  
xtable::xtable(  
 adonis2(l.com.dif.d ~ crown.radius + rock.sm + rock.lg + light + litter,   
 data = data.frame(env.dif, tra.dif), by = "margin")  
 )

% latex table generated in R 4.0.4 by xtable 1.8-4 package % Mon May 3 18:38:47 2021

set.seed(12345)  
xtable::xtable(  
 adonis2(sqrt(v.com.dif.d) ~ litter + rock.sm + rock.lg + light + crown.radius,   
 data = data.frame(env.dif, tra.dif), by = "margin")  
 )

% latex table generated in R 4.0.4 by xtable 1.8-4 package % Mon May 3 18:38:47 2021

set.seed(12345)  
xtable::xtable(adonis2(com.ds ~ Moth,   
 strata = l.dat[, "Tree.pairs"],   
 data = l.dat,   
 perm = 9999)  
 )

% latex table generated in R 4.0.4 by xtable 1.8-4 package % Mon May 3 18:38:48 2021

set.seed(12345)  
xtable::xtable(adonis2(v.com.ds ~ Moth,   
 strata = l.dat[, "Tree.pairs"],   
 data = l.dat,   
 perm = 9999)  
 )

% latex table generated in R 4.0.4 by xtable 1.8-4 package % Mon May 3 18:38:49 2021

set.seed(12345)  
moth.perm.l <- adonis2(com.ds ~ Moth,   
 strata = l.dat[, "Tree.pairs"],   
 data = l.dat,   
 perm = 100000)  
  
set.seed(12345)  
moth.perm.v <- adonis2(v.com.ds ~ Moth,   
 strata = l.dat[, "Tree.pairs"],   
 data = l.dat,   
 perm = 100000)

tab.perm.l <- data.frame(moth.perm.l)  
tab.perm.v <- data.frame(moth.perm.v)  
  
tab.fact <- rownames(tab.perm.l)  
  
tab.perm.l <- apply(tab.perm.l, 2, as.numeric)  
tab.perm.v <- apply(tab.perm.v, 2, as.numeric)  
  
colnames(tab.perm.l) <- c("df", "SS", "R2", "pseudo-F", "p-value")  
colnames(tab.perm.v) <- c("df", "SS", "R2", "pseudo-F", "p-value")  
  
tab.perm.l[1, "p-value"] <- round(tab.perm.l[1, "p-value"], 4)  
tab.perm.v[1, "p-value"] <- round(tab.perm.v[1, "p-value"], 4)  
  
tab.perm.l[1, "pseudo-F"] <- round(tab.perm.l[1, "pseudo-F"], 2)  
tab.perm.v[1, "pseudo-F"] <- round(tab.perm.v[1, "pseudo-F"], 2)  
  
tab.perm.l[, "SS"] <- round(tab.perm.l[, "SS"], 2)  
tab.perm.v[, "SS"] <- round(tab.perm.v[, "SS"], 2)  
  
tab.perm.l[, "R2"] <- round(tab.perm.l[, "R2"], 2)  
tab.perm.v[, "R2"] <- round(tab.perm.v[, "R2"], 2)  
  
tab.perm.l[is.na(tab.perm.l)] <- ""  
tab.perm.v[is.na(tab.perm.v)] <- ""  
  
rownames(tab.perm.l) <- tab.fact  
rownames(tab.perm.v) <- tab.fact  
  
write.csv(file = "results/table\_perm\_moth\_lichen.csv", tab.perm.l)  
write.csv(file = "results/table\_perm\_moth\_plant.csv", tab.perm.v)

tab.ttest.ard <- do.call(rbind,   
 lapply(  
 apply(data.frame(l.ard.dif, v.ard.dif), 2,   
 t.test),   
 unlist))[, c(1, 2, 6, 3)]  
tab.lab <- rownames(tab.ttest.ard)  
tab.ttest.ard <- apply(tab.ttest.ard, 2, as.numeric)  
rownames(tab.ttest.ard) <- tab.lab  
xtable::xtable(tab.ttest.ard, digits = 5)

% latex table generated in R 4.0.4 by xtable 1.8-4 package % Thu May 6 12:56:04 2021

## Moth impacts tree traits and the local environment

tab.ttest.envtra <- do.call(rbind,   
 lapply(  
 apply(data.frame(tra.dif, env.dif), 2,   
 t.test),   
 unlist))[, c(1, 2, 6, 3)]  
tab.lab <- rownames(tab.ttest.envtra)  
tab.ttest.envtra <- apply(tab.ttest.envtra, 2, as.numeric)  
rownames(tab.ttest.envtra) <- tab.lab  
xtable::xtable(tab.ttest.envtra, digits = 5)

% latex table generated in R 4.0.4 by xtable 1.8-4 package % Thu May 6 12:56:04 2021

## Tree environment correlate with community

set.seed(12345)  
xtable::xtable(adonis2(com.ds ~ Big.rocks.. + Small.rocks.. + Light...average,  
 strata = l.dat[, "Tree.pairs"],   
 by = "margin",  
 data = data.frame(env, traits),  
 perm = 9999, rank = TRUE)  
 )

## % latex table generated in R 4.0.4 by xtable 1.8-4 package  
## % Fri Apr 23 17:34:36 2021  
## \begin{table}[ht]  
## \centering  
## \begin{tabular}{lrrrrr}  
## \hline  
## & Df & SumOfSqs & R2 & F & Pr($>$F) \\   
## \hline  
## Big.rocks.. & 1 & 1.79 & 0.08 & 5.47 & 0.0004 \\   
## Small.rocks.. & 1 & 0.27 & 0.01 & 0.81 & 0.5720 \\   
## Light...average & 1 & 0.39 & 0.02 & 1.20 & 0.2649 \\   
## Residual & 56 & 18.31 & 0.86 & & \\   
## Total & 59 & 21.37 & 1.00 & & \\   
## \hline  
## \end{tabular}  
## \end{table}

set.seed(12345)  
xtable::xtable(adonis2(v.com.ds ~ Light...average + Big.rocks.. + Small.rocks..,  
 strata = l.dat[, "Tree.pairs"],   
 by = "margin",  
 data = data.frame(env, traits),  
 perm = 9999)  
 )

## % latex table generated in R 4.0.4 by xtable 1.8-4 package  
## % Fri Apr 23 17:34:40 2021  
## \begin{table}[ht]  
## \centering  
## \begin{tabular}{lrrrrr}  
## \hline  
## & Df & SumOfSqs & R2 & F & Pr($>$F) \\   
## \hline  
## Light...average & 1 & 2.93 & 0.17 & 13.00 & 0.0001 \\   
## Big.rocks.. & 1 & 0.10 & 0.01 & 0.44 & 0.7243 \\   
## Small.rocks.. & 1 & 0.73 & 0.04 & 3.26 & 0.0290 \\   
## Residual & 56 & 12.61 & 0.75 & & \\   
## Total & 59 & 16.79 & 1.00 & & \\   
## \hline  
## \end{tabular}  
## \end{table}

summary(lm(l.A ~ rock.lg \* rock.sm \* light,  
 data = data.frame(l.ard.dif, tra.dif, env.dif)))

##   
## Call:  
## lm(formula = l.A ~ rock.lg \* rock.sm \* light, data = data.frame(l.ard.dif,   
## tra.dif, env.dif))  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -7.5443 -0.9009 0.3873 1.2621 4.7576   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) 1.2906171 1.9919281 0.648 0.5237   
## rock.lg 0.2672626 0.1144530 2.335 0.0291 \*  
## rock.sm -0.2489435 0.2305602 -1.080 0.2920   
## light 0.0964938 0.1233636 0.782 0.4424   
## rock.lg:rock.sm -0.0098077 0.0131545 -0.746 0.4638   
## rock.lg:light 0.0108967 0.0067177 1.622 0.1190   
## rock.sm:light -0.0130569 0.0118033 -1.106 0.2806   
## rock.lg:rock.sm:light -0.0002544 0.0005513 -0.461 0.6490   
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 3.337 on 22 degrees of freedom  
## Multiple R-squared: 0.4027, Adjusted R-squared: 0.2127   
## F-statistic: 2.119 on 7 and 22 DF, p-value: 0.08438

summary(lm(l.R ~ rock.lg \* rock.sm \* light,  
 data = data.frame(l.ard.dif, tra.dif, env.dif)))

##   
## Call:  
## lm(formula = l.R ~ rock.lg \* rock.sm \* light, data = data.frame(l.ard.dif,   
## tra.dif, env.dif))  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -5.4034 -1.7571 0.5585 2.0862 3.9423   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) 2.8682448 1.8246866 1.572 0.1302   
## rock.lg 0.3576352 0.1048436 3.411 0.0025 \*\*  
## rock.sm 0.0782553 0.2112024 0.371 0.7145   
## light 0.2596367 0.1130061 2.298 0.0315 \*   
## rock.lg:rock.sm 0.0060809 0.0120501 0.505 0.6188   
## rock.lg:light 0.0114837 0.0061537 1.866 0.0754 .   
## rock.sm:light 0.0050780 0.0108123 0.470 0.6432   
## rock.lg:rock.sm:light 0.0003271 0.0005050 0.648 0.5238   
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 3.057 on 22 degrees of freedom  
## Multiple R-squared: 0.6785, Adjusted R-squared: 0.5762   
## F-statistic: 6.634 on 7 and 22 DF, p-value: 0.0002762

summary(lm(l.D ~ rock.lg \* rock.sm \* light,  
 data = data.frame(l.ard.dif, tra.dif, env.dif)))

##   
## Call:  
## lm(formula = l.D ~ rock.lg \* rock.sm \* light, data = data.frame(l.ard.dif,   
## tra.dif, env.dif))  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -1.3539 -0.1798 0.1183 0.3590 0.9120   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) 7.064e-01 3.914e-01 1.805 0.0848 .  
## rock.lg 5.437e-02 2.249e-02 2.418 0.0243 \*  
## rock.sm 5.766e-02 4.530e-02 1.273 0.2163   
## light 6.085e-02 2.424e-02 2.511 0.0199 \*  
## rock.lg:rock.sm 2.179e-03 2.585e-03 0.843 0.4082   
## rock.lg:light 1.247e-03 1.320e-03 0.945 0.3552   
## rock.sm:light 3.242e-03 2.319e-03 1.398 0.1761   
## rock.lg:rock.sm:light 8.461e-05 1.083e-04 0.781 0.4431   
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 0.6557 on 22 degrees of freedom  
## Multiple R-squared: 0.6592, Adjusted R-squared: 0.5508   
## F-statistic: 6.079 on 7 and 22 DF, p-value: 0.0004929

summary(lm(l.A ~ light \*rock.lg \* rock.sm,  
 data = data.frame(l.ard.dif, tra.dif, env.dif)))

##   
## Call:  
## lm(formula = l.A ~ light \* rock.lg \* rock.sm, data = data.frame(l.ard.dif,   
## tra.dif, env.dif))  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -7.5443 -0.9009 0.3873 1.2621 4.7576   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) 1.2906171 1.9919281 0.648 0.5237   
## light 0.0964938 0.1233636 0.782 0.4424   
## rock.lg 0.2672626 0.1144530 2.335 0.0291 \*  
## rock.sm -0.2489435 0.2305602 -1.080 0.2920   
## light:rock.lg 0.0108967 0.0067177 1.622 0.1190   
## light:rock.sm -0.0130569 0.0118033 -1.106 0.2806   
## rock.lg:rock.sm -0.0098077 0.0131545 -0.746 0.4638   
## light:rock.lg:rock.sm -0.0002544 0.0005513 -0.461 0.6490   
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 3.337 on 22 degrees of freedom  
## Multiple R-squared: 0.4027, Adjusted R-squared: 0.2127   
## F-statistic: 2.119 on 7 and 22 DF, p-value: 0.08438

summary(lm(l.R ~ light \*rock.lg \* rock.sm,  
 data = data.frame(l.ard.dif, tra.dif, env.dif)))

##   
## Call:  
## lm(formula = l.R ~ light \* rock.lg \* rock.sm, data = data.frame(l.ard.dif,   
## tra.dif, env.dif))  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -5.4034 -1.7571 0.5585 2.0862 3.9423   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) 2.8682448 1.8246866 1.572 0.1302   
## light 0.2596367 0.1130061 2.298 0.0315 \*   
## rock.lg 0.3576352 0.1048436 3.411 0.0025 \*\*  
## rock.sm 0.0782553 0.2112024 0.371 0.7145   
## light:rock.lg 0.0114837 0.0061537 1.866 0.0754 .   
## light:rock.sm 0.0050780 0.0108123 0.470 0.6432   
## rock.lg:rock.sm 0.0060809 0.0120501 0.505 0.6188   
## light:rock.lg:rock.sm 0.0003271 0.0005050 0.648 0.5238   
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 3.057 on 22 degrees of freedom  
## Multiple R-squared: 0.6785, Adjusted R-squared: 0.5762   
## F-statistic: 6.634 on 7 and 22 DF, p-value: 0.0002762

summary(lm(l.D ~ light \*rock.lg \* rock.sm,  
 data = data.frame(l.ard.dif, tra.dif, env.dif)))

##   
## Call:  
## lm(formula = l.D ~ light \* rock.lg \* rock.sm, data = data.frame(l.ard.dif,   
## tra.dif, env.dif))  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -1.3539 -0.1798 0.1183 0.3590 0.9120   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) 7.064e-01 3.914e-01 1.805 0.0848 .  
## light 6.085e-02 2.424e-02 2.511 0.0199 \*  
## rock.lg 5.437e-02 2.249e-02 2.418 0.0243 \*  
## rock.sm 5.766e-02 4.530e-02 1.273 0.2163   
## light:rock.lg 1.247e-03 1.320e-03 0.945 0.3552   
## light:rock.sm 3.242e-03 2.319e-03 1.398 0.1761   
## rock.lg:rock.sm 2.179e-03 2.585e-03 0.843 0.4082   
## light:rock.lg:rock.sm 8.461e-05 1.083e-04 0.781 0.4431   
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 0.6557 on 22 degrees of freedom  
## Multiple R-squared: 0.6592, Adjusted R-squared: 0.5508   
## F-statistic: 6.079 on 7 and 22 DF, p-value: 0.0004929

summary(lm(l.A ~ rock.lg + rock.sm + light,  
 data = data.frame(l.ard.dif, tra.dif, env.dif)))

##   
## Call:  
## lm(formula = l.A ~ rock.lg + rock.sm + light, data = data.frame(l.ard.dif,   
## tra.dif, env.dif))  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -7.7485 -0.6511 0.6642 1.3935 5.4237   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) -0.427328 1.224495 -0.349 0.72991   
## rock.lg 0.088123 0.030432 2.896 0.00757 \*\*  
## rock.sm 0.022591 0.050663 0.446 0.65935   
## light 0.009973 0.071228 0.140 0.88972   
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 3.346 on 26 degrees of freedom  
## Multiple R-squared: 0.2904, Adjusted R-squared: 0.2085   
## F-statistic: 3.547 on 3 and 26 DF, p-value: 0.02821

summary(lm(l.R ~ rock.lg + rock.sm + light,  
 data = data.frame(l.ard.dif, tra.dif, env.dif)))

##   
## Call:  
## lm(formula = l.R ~ rock.lg + rock.sm + light, data = data.frame(l.ard.dif,   
## tra.dif, env.dif))  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -5.6550 -1.9714 0.6468 2.0461 6.0752   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) 0.371141 1.130676 0.328 0.745   
## rock.lg 0.162543 0.028100 5.784 4.3e-06 \*\*\*  
## rock.sm -0.005166 0.046781 -0.110 0.913   
## light 0.089614 0.065770 1.363 0.185   
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 3.089 on 26 degrees of freedom  
## Multiple R-squared: 0.6119, Adjusted R-squared: 0.5672   
## F-statistic: 13.67 on 3 and 26 DF, p-value: 1.515e-05

summary(lm(l.D ~ rock.lg + rock.sm + light,  
 data = data.frame(l.ard.dif, tra.dif, env.dif)))

##   
## Call:  
## lm(formula = l.D ~ rock.lg + rock.sm + light, data = data.frame(l.ard.dif,   
## tra.dif, env.dif))  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -1.20164 -0.37452 0.01855 0.38633 1.20307   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) 0.1937003 0.2527542 0.766 0.450   
## rock.lg 0.0315016 0.0062816 5.015 3.23e-05 \*\*\*  
## rock.sm -0.0007058 0.0104575 -0.067 0.947   
## light 0.0217497 0.0147024 1.479 0.151   
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 0.6906 on 26 degrees of freedom  
## Multiple R-squared: 0.5531, Adjusted R-squared: 0.5016   
## F-statistic: 10.73 on 3 and 26 DF, p-value: 9.066e-05

summary(lm(l.A ~ light +rock.lg + rock.sm,  
 data = data.frame(l.ard.dif, tra.dif, env.dif)))

##   
## Call:  
## lm(formula = l.A ~ light + rock.lg + rock.sm, data = data.frame(l.ard.dif,   
## tra.dif, env.dif))  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -7.7485 -0.6511 0.6642 1.3935 5.4237   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) -0.427328 1.224495 -0.349 0.72991   
## light 0.009973 0.071228 0.140 0.88972   
## rock.lg 0.088123 0.030432 2.896 0.00757 \*\*  
## rock.sm 0.022591 0.050663 0.446 0.65935   
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 3.346 on 26 degrees of freedom  
## Multiple R-squared: 0.2904, Adjusted R-squared: 0.2085   
## F-statistic: 3.547 on 3 and 26 DF, p-value: 0.02821

summary(lm(l.R ~ light +rock.lg + rock.sm,  
 data = data.frame(l.ard.dif, tra.dif, env.dif)))

##   
## Call:  
## lm(formula = l.R ~ light + rock.lg + rock.sm, data = data.frame(l.ard.dif,   
## tra.dif, env.dif))  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -5.6550 -1.9714 0.6468 2.0461 6.0752   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) 0.371141 1.130676 0.328 0.745   
## light 0.089614 0.065770 1.363 0.185   
## rock.lg 0.162543 0.028100 5.784 4.3e-06 \*\*\*  
## rock.sm -0.005166 0.046781 -0.110 0.913   
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 3.089 on 26 degrees of freedom  
## Multiple R-squared: 0.6119, Adjusted R-squared: 0.5672   
## F-statistic: 13.67 on 3 and 26 DF, p-value: 1.515e-05

summary(lm(l.D ~ light +rock.lg + rock.sm,  
 data = data.frame(l.ard.dif, tra.dif, env.dif)))

##   
## Call:  
## lm(formula = l.D ~ light + rock.lg + rock.sm, data = data.frame(l.ard.dif,   
## tra.dif, env.dif))  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -1.20164 -0.37452 0.01855 0.38633 1.20307   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) 0.1937003 0.2527542 0.766 0.450   
## light 0.0217497 0.0147024 1.479 0.151   
## rock.lg 0.0315016 0.0062816 5.015 3.23e-05 \*\*\*  
## rock.sm -0.0007058 0.0104575 -0.067 0.947   
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 0.6906 on 26 degrees of freedom  
## Multiple R-squared: 0.5531, Adjusted R-squared: 0.5016   
## F-statistic: 10.73 on 3 and 26 DF, p-value: 9.066e-05

summary(lm(p.A ~ rock.lg \* rock.sm \* light,  
 data = data.frame(v.ard.dif, tra.dif, env.dif)))

##   
## Call:  
## lm(formula = p.A ~ rock.lg \* rock.sm \* light, data = data.frame(v.ard.dif,   
## tra.dif, env.dif))  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -45.808 -8.565 2.356 11.435 25.518   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) -24.997498 10.598639 -2.359 0.0276 \*  
## rock.lg -0.322706 0.608981 -0.530 0.6015   
## rock.sm -0.574845 1.226763 -0.469 0.6440   
## light -0.068351 0.656392 -0.104 0.9180   
## rock.lg:rock.sm -0.027964 0.069993 -0.400 0.6934   
## rock.lg:light -0.026183 0.035744 -0.733 0.4716   
## rock.sm:light 0.006300 0.062803 0.100 0.9210   
## rock.lg:rock.sm:light -0.001141 0.002933 -0.389 0.7011   
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 17.76 on 22 degrees of freedom  
## Multiple R-squared: 0.1937, Adjusted R-squared: -0.06288   
## F-statistic: 0.7549 on 7 and 22 DF, p-value: 0.6297

summary(lm(p.R ~ rock.lg \* rock.sm \* light,  
 data = data.frame(v.ard.dif, tra.dif, env.dif)))

##   
## Call:  
## lm(formula = p.R ~ rock.lg \* rock.sm \* light, data = data.frame(v.ard.dif,   
## tra.dif, env.dif))  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -1.15006 -0.67011 -0.00113 0.40891 2.13338   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) -1.121e+00 5.309e-01 -2.111 0.0463 \*  
## rock.lg 1.329e-02 3.050e-02 0.436 0.6674   
## rock.sm -3.598e-03 6.145e-02 -0.059 0.9538   
## light 1.453e-02 3.288e-02 0.442 0.6629   
## rock.lg:rock.sm 1.782e-03 3.506e-03 0.508 0.6163   
## rock.lg:light -4.340e-04 1.790e-03 -0.242 0.8107   
## rock.sm:light 1.363e-03 3.146e-03 0.433 0.6690   
## rock.lg:rock.sm:light 5.302e-05 1.469e-04 0.361 0.7217   
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 0.8894 on 22 degrees of freedom  
## Multiple R-squared: 0.3383, Adjusted R-squared: 0.1278   
## F-statistic: 1.607 on 7 and 22 DF, p-value: 0.1857

summary(lm(p.D ~ rock.lg \* rock.sm \* light,  
 data = data.frame(v.ard.dif, tra.dif, env.dif)))

##   
## Call:  
## lm(formula = p.D ~ rock.lg \* rock.sm \* light, data = data.frame(v.ard.dif,   
## tra.dif, env.dif))  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -0.61818 -0.27861 -0.01608 0.24591 0.88670   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) -4.975e-01 2.268e-01 -2.194 0.0391 \*  
## rock.lg -9.983e-03 1.303e-02 -0.766 0.4518   
## rock.sm -1.668e-02 2.625e-02 -0.635 0.5317   
## light -1.037e-02 1.405e-02 -0.738 0.4680   
## rock.lg:rock.sm -3.217e-04 1.498e-03 -0.215 0.8319   
## rock.lg:light -7.732e-04 7.648e-04 -1.011 0.3230   
## rock.sm:light -2.122e-04 1.344e-03 -0.158 0.8759   
## rock.lg:rock.sm:light -2.246e-05 6.277e-05 -0.358 0.7239   
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 0.3799 on 22 degrees of freedom  
## Multiple R-squared: 0.2557, Adjusted R-squared: 0.01892   
## F-statistic: 1.08 on 7 and 22 DF, p-value: 0.4088

summary(lm(p.A ~ light \*rock.lg \* rock.sm,  
 data = data.frame(v.ard.dif, tra.dif, env.dif)))

##   
## Call:  
## lm(formula = p.A ~ light \* rock.lg \* rock.sm, data = data.frame(v.ard.dif,   
## tra.dif, env.dif))  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -45.808 -8.565 2.356 11.435 25.518   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) -24.997498 10.598639 -2.359 0.0276 \*  
## light -0.068351 0.656392 -0.104 0.9180   
## rock.lg -0.322706 0.608981 -0.530 0.6015   
## rock.sm -0.574845 1.226763 -0.469 0.6440   
## light:rock.lg -0.026183 0.035744 -0.733 0.4716   
## light:rock.sm 0.006300 0.062803 0.100 0.9210   
## rock.lg:rock.sm -0.027964 0.069993 -0.400 0.6934   
## light:rock.lg:rock.sm -0.001141 0.002933 -0.389 0.7011   
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 17.76 on 22 degrees of freedom  
## Multiple R-squared: 0.1937, Adjusted R-squared: -0.06288   
## F-statistic: 0.7549 on 7 and 22 DF, p-value: 0.6297

summary(lm(p.R ~ light \*rock.lg \* rock.sm,  
 data = data.frame(v.ard.dif, tra.dif, env.dif)))

##   
## Call:  
## lm(formula = p.R ~ light \* rock.lg \* rock.sm, data = data.frame(v.ard.dif,   
## tra.dif, env.dif))  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -1.15006 -0.67011 -0.00113 0.40891 2.13338   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) -1.121e+00 5.309e-01 -2.111 0.0463 \*  
## light 1.453e-02 3.288e-02 0.442 0.6629   
## rock.lg 1.329e-02 3.050e-02 0.436 0.6674   
## rock.sm -3.598e-03 6.145e-02 -0.059 0.9538   
## light:rock.lg -4.340e-04 1.790e-03 -0.242 0.8107   
## light:rock.sm 1.363e-03 3.146e-03 0.433 0.6690   
## rock.lg:rock.sm 1.782e-03 3.506e-03 0.508 0.6163   
## light:rock.lg:rock.sm 5.302e-05 1.469e-04 0.361 0.7217   
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 0.8894 on 22 degrees of freedom  
## Multiple R-squared: 0.3383, Adjusted R-squared: 0.1278   
## F-statistic: 1.607 on 7 and 22 DF, p-value: 0.1857

summary(lm(p.D ~ light \*rock.lg \* rock.sm,  
 data = data.frame(v.ard.dif, tra.dif, env.dif)))

##   
## Call:  
## lm(formula = p.D ~ light \* rock.lg \* rock.sm, data = data.frame(v.ard.dif,   
## tra.dif, env.dif))  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -0.61818 -0.27861 -0.01608 0.24591 0.88670   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) -4.975e-01 2.268e-01 -2.194 0.0391 \*  
## light -1.037e-02 1.405e-02 -0.738 0.4680   
## rock.lg -9.983e-03 1.303e-02 -0.766 0.4518   
## rock.sm -1.668e-02 2.625e-02 -0.635 0.5317   
## light:rock.lg -7.732e-04 7.648e-04 -1.011 0.3230   
## light:rock.sm -2.122e-04 1.344e-03 -0.158 0.8759   
## rock.lg:rock.sm -3.217e-04 1.498e-03 -0.215 0.8319   
## light:rock.lg:rock.sm -2.246e-05 6.277e-05 -0.358 0.7239   
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 0.3799 on 22 degrees of freedom  
## Multiple R-squared: 0.2557, Adjusted R-squared: 0.01892   
## F-statistic: 1.08 on 7 and 22 DF, p-value: 0.4088

summary(lm(p.A ~ rock.lg + rock.sm + light,  
 data = data.frame(v.ard.dif, tra.dif, env.dif)))

##   
## Call:  
## lm(formula = p.A ~ rock.lg + rock.sm + light, data = data.frame(v.ard.dif,   
## tra.dif, env.dif))  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -45.955 -8.621 2.115 12.151 28.829   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) -23.55502 6.14481 -3.833 0.000721 \*\*\*  
## rock.lg 0.11754 0.15271 0.770 0.448432   
## rock.sm -0.53383 0.25424 -2.100 0.045607 \*   
## light 0.02616 0.35744 0.073 0.942215   
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 16.79 on 26 degrees of freedom  
## Multiple R-squared: 0.1479, Adjusted R-squared: 0.04957   
## F-statistic: 1.504 on 3 and 26 DF, p-value: 0.2368

summary(lm(p.R ~ rock.lg + rock.sm + light,  
 data = data.frame(v.ard.dif, tra.dif, env.dif)))

##   
## Call:  
## lm(formula = p.R ~ rock.lg + rock.sm + light, data = data.frame(v.ard.dif,   
## tra.dif, env.dif))  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -1.09085 -0.72885 0.07251 0.43267 2.04097   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) -1.027067 0.302605 -3.394 0.00222 \*\*  
## rock.lg 0.019656 0.007521 2.614 0.01470 \*   
## rock.sm -0.036574 0.012520 -2.921 0.00712 \*\*  
## light 0.017481 0.017602 0.993 0.32981   
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 0.8268 on 26 degrees of freedom  
## Multiple R-squared: 0.3242, Adjusted R-squared: 0.2462   
## F-statistic: 4.157 on 3 and 26 DF, p-value: 0.01565

summary(lm(p.D ~ rock.lg + rock.sm + light,  
 data = data.frame(v.ard.dif, tra.dif, env.dif)))

##   
## Call:  
## lm(formula = p.D ~ rock.lg + rock.sm + light, data = data.frame(v.ard.dif,   
## tra.dif, env.dif))  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -0.48929 -0.33019 -0.02457 0.29568 0.88860   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) -0.3546159 0.1309685 -2.708 0.0118 \*  
## rock.lg 0.0027760 0.0032549 0.853 0.4015   
## rock.sm -0.0142947 0.0054187 -2.638 0.0139 \*  
## light -0.0009857 0.0076183 -0.129 0.8980   
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 0.3579 on 26 degrees of freedom  
## Multiple R-squared: 0.2196, Adjusted R-squared: 0.1296   
## F-statistic: 2.439 on 3 and 26 DF, p-value: 0.08707

summary(lm(p.A ~ light +rock.lg + rock.sm,  
 data = data.frame(v.ard.dif, tra.dif, env.dif)))

##   
## Call:  
## lm(formula = p.A ~ light + rock.lg + rock.sm, data = data.frame(v.ard.dif,   
## tra.dif, env.dif))  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -45.955 -8.621 2.115 12.151 28.829   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) -23.55502 6.14481 -3.833 0.000721 \*\*\*  
## light 0.02616 0.35744 0.073 0.942215   
## rock.lg 0.11754 0.15271 0.770 0.448432   
## rock.sm -0.53383 0.25424 -2.100 0.045607 \*   
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 16.79 on 26 degrees of freedom  
## Multiple R-squared: 0.1479, Adjusted R-squared: 0.04957   
## F-statistic: 1.504 on 3 and 26 DF, p-value: 0.2368

summary(lm(p.R ~ light +rock.lg + rock.sm,  
 data = data.frame(v.ard.dif, tra.dif, env.dif)))

##   
## Call:  
## lm(formula = p.R ~ light + rock.lg + rock.sm, data = data.frame(v.ard.dif,   
## tra.dif, env.dif))  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -1.09085 -0.72885 0.07251 0.43267 2.04097   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) -1.027067 0.302605 -3.394 0.00222 \*\*  
## light 0.017481 0.017602 0.993 0.32981   
## rock.lg 0.019656 0.007521 2.614 0.01470 \*   
## rock.sm -0.036574 0.012520 -2.921 0.00712 \*\*  
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 0.8268 on 26 degrees of freedom  
## Multiple R-squared: 0.3242, Adjusted R-squared: 0.2462   
## F-statistic: 4.157 on 3 and 26 DF, p-value: 0.01565

summary(lm(p.D ~ light +rock.lg + rock.sm,  
 data = data.frame(v.ard.dif, tra.dif, env.dif)))

##   
## Call:  
## lm(formula = p.D ~ light + rock.lg + rock.sm, data = data.frame(v.ard.dif,   
## tra.dif, env.dif))  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -0.48929 -0.33019 -0.02457 0.29568 0.88860   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) -0.3546159 0.1309685 -2.708 0.0118 \*  
## light -0.0009857 0.0076183 -0.129 0.8980   
## rock.lg 0.0027760 0.0032549 0.853 0.4015   
## rock.sm -0.0142947 0.0054187 -2.638 0.0139 \*  
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 0.3579 on 26 degrees of freedom  
## Multiple R-squared: 0.2196, Adjusted R-squared: 0.1296   
## F-statistic: 2.439 on 3 and 26 DF, p-value: 0.08707

## Structural Equation Models

l.com.dif <- split(com, l.dat[, "Tree.pairs"])  
l.com.dif <- lapply(l.com.dif, function(x) x[2, ] - x[1, ])  
l.com.dif <- do.call(rbind, l.com.dif)  
  
v.com.dif <- split(v.com, l.dat[, "Tree.pairs"])  
v.com.dif <- lapply(v.com.dif, function(x) x[2, ] - x[1, ])  
v.com.dif <- do.call(rbind, v.com.dif)  
  
l.com.dif.d <- dist(l.com.dif)  
v.com.dif.d <- dist(v.com.dif)  
  
l.com.dif.nms <- nmds(l.com.dif.d, 1, 2)  
l.com.dif.ord <- nmds.min(l.com.dif.nms, 2)

## Minimum stress for given dimensionality: 0.07460277   
## r^2 for minimum stress configuration: 0.9809944

l.com.dif.vec <- envfit(l.com.dif.ord,   
 data.frame(env.dif, tra.dif)[, c("rock.lg",  
 "rock.sm",  
 "light",  
 "litter")])  
  
v.com.dif.nms <- nmds(v.com.dif.d, 2, 3)  
v.com.dif.ord <- nmds.min(v.com.dif.nms, 3)

## Minimum stress for given dimensionality: 0.03324742   
## r^2 for minimum stress configuration: 0.9927886

v.com.dif.vec <- envfit(v.com.dif.ord,  
 data.frame(env.dif, tra.dif)[, c("rock.lg",  
 "rock.sm",  
 "light",  
 "litter")])  
  
colnames(l.com.dif.ord) <- paste0("l.", colnames(l.com.dif.ord))  
colnames(v.com.dif.ord) <- paste0("p.", colnames(v.com.dif.ord))

l.com.dif.ord.proc <- procrustes(env.dif[, "rock.lg"], l.com.dif.ord)$Yrot

## Warning in procrustes(env.dif[, "rock.lg"], l.com.dif.ord): X has fewer axes than Y: X adjusted to comform Y

v.com.dif.ord.proc <- procrustes(env.dif[, "rock.sm"], v.com.dif.ord)$Yrot

## Warning in procrustes(env.dif[, "rock.sm"], v.com.dif.ord): X has fewer axes than Y: X adjusted to comform Y

colnames(l.com.dif.ord.proc) <- paste0("rot.", colnames(l.com.dif.ord))  
colnames(v.com.dif.ord.proc) <- paste0("rot.", colnames(v.com.dif.ord))  
  
l.com.dif.vec.rot <- envfit(l.com.dif.ord.proc,   
 data.frame(env.dif[, -1], litter = tra.dif[, "litter"]))  
v.com.dif.vec.rot <- envfit(v.com.dif.ord.proc,   
 data.frame(env.dif[, -1], litter = tra.dif[, "litter"]))

sem.dat <- data.frame(tra.dif, env.dif, l.ard.dif, v.ard.dif, l.com.dif.ord, v.com.dif.ord, l.com.dif.ord.proc, v.com.dif.ord.proc)  
colnames(sem.dat)[colnames(sem.dat) == "crown.radius"] <- "crown"  
colnames(sem.dat)[colnames(sem.dat) == "trunk.radius"] <- "trunk"

tab.ttest.ldat <- do.call(rbind,   
 lapply(  
 apply(l.dat[, -1:-3], 2,   
 t.test),   
 unlist))[, c(1, 2, 6, 3)]  
tab.lab <- rownames(tab.ttest.ldat)  
tab.ttest.ldat <- apply(tab.ttest.ldat, 2, as.numeric)  
rownames(tab.ttest.ldat) <- tab.lab  
xtable::xtable(tab.ttest.ldat, digits = 5)

% latex table generated in R 4.0.4 by xtable 1.8-4 package % Thu May 6 12:56:05 2021

xtable::xtable(na.omit(tab.ttest.ldat[tab.ttest.ldat[, "p.value"] <= 0.05,]))

% latex table generated in R 4.0.4 by xtable 1.8-4 package % Thu May 6 12:56:05 2021

tab.ttest.vdat <- do.call(rbind,   
 lapply(  
 apply(v.dat[, -1:-8], 2,   
 t.test),   
 unlist))[, c(1, 2, 6, 3)]  
tab.lab <- rownames(tab.ttest.vdat)  
tab.ttest.vdat <- apply(tab.ttest.vdat, 2, as.numeric)  
rownames(tab.ttest.vdat) <- tab.lab  
xtable::xtable(tab.ttest.vdat, digits = 5)

% latex table generated in R 4.0.4 by xtable 1.8-4 package % Thu May 6 12:56:05 2021

xtable::xtable(na.omit(tab.ttest.vdat[tab.ttest.vdat[, "p.value"] <= 0.05,]))

% latex table generated in R 4.0.4 by xtable 1.8-4 package % Thu May 6 12:56:05 2021

lav.l.all <- 'light ~ crown  
 litter ~ crown  
 rock.lg ~ litter  
 l.A ~ light + rock.lg   
 l.R ~ light + rock.lg   
 l.D ~ light + rock.lg   
 l.X1 ~ light + rock.lg   
 l.X2 ~ light + rock.lg   
 l.A ~~ l.R  
 l.A ~~ l.D  
 l.R ~~ l.D  
 l.A ~~ l.X1  
 l.R ~~ l.X1  
 '  
lav.v.all <- 'light ~ crown  
 litter ~ crown  
 rock.sm ~ litter  
 p.A ~ light + rock.sm   
 p.R ~ light + rock.sm + litter   
 p.D ~ light + rock.sm   
 p.X1 ~ light + rock.sm   
 p.X2 ~ light + rock.sm   
 p.X3 ~ light + rock.sm   
 p.A ~~ p.X2  
 p.A ~~ p.R  
 p.A ~~ p.D  
 p.R ~~ p.D  
 p.A ~~ p.X1  
 p.R ~~ p.X1  
 '  
lav.l.rot.nolight <- 'litter ~ crown  
 rock.lg ~ litter  
 l.A ~ rock.lg   
 l.R ~ rock.lg   
 l.D ~ rock.lg   
 rot.l.X1 ~ rock.lg   
 rot.l.X2 ~ rock.lg   
 l.A ~~ l.R  
 l.A ~~ l.D  
 l.R ~~ l.D  
 l.A ~~ rot.l.X1  
 l.R ~~ rot.l.X1  
 '  
lav.v.rot.nolight <- 'litter ~ crown  
 rock.sm ~ litter  
 p.A ~ rock.sm   
 p.R ~ rock.sm  
 p.D ~ rock.sm   
 rot.p.X1 ~ rock.sm   
 rot.p.X2 ~ rock.sm   
 rot.p.X3 ~ rock.sm   
 p.A ~~ rot.p.X2  
 p.A ~~ p.R  
 p.A ~~ p.D  
 p.R ~~ p.D  
 p.A ~~ rot.p.X1  
 p.R ~~ rot.p.X1  
 '  
lav.l.rot.all <- 'light ~ crown  
 litter ~ crown  
 light ~ trunk  
 litter ~ trunk  
 rock.lg ~ litter  
 l.A ~ light + rock.lg   
 l.R ~ light + rock.lg   
 l.D ~ light + rock.lg   
 rot.l.X1 ~ light + rock.lg   
 rot.l.X2 ~ light + rock.lg   
 l.A ~~ l.R  
 l.A ~~ l.D  
 l.R ~~ l.D  
 l.A ~~ rot.l.X1  
 l.R ~~ rot.l.X1  
 '  
lav.v.rot.all <- 'light ~ crown  
 litter ~ crown  
 light ~ trunk  
 litter ~ trunk  
 rock.sm ~ litter  
 p.A ~ light + rock.sm   
 p.R ~ light + rock.sm  
 p.D ~ light + rock.sm   
 rot.p.X1 ~ light + rock.sm   
 rot.p.X2 ~ light + rock.sm   
 rot.p.X3 ~ light + rock.sm   
 p.A ~~ rot.p.X2  
 p.A ~~ p.R  
 p.A ~~ p.D  
 p.R ~~ p.D  
 p.A ~~ rot.p.X1  
 p.R ~~ rot.p.X1  
 '  
  
  
std <- function(x){(x - mean(x)) / sd(x)}  
  
set.seed(12345)  
fit.l.all.raw <- lavaan::sem(lav.l.all, data = sem.dat)  
set.seed(12345)  
fit.v.all.raw <- lavaan::sem(lav.v.all, data = sem.dat)

## Warning in lav\_data\_full(data = data, group = group, cluster = cluster, : lavaan  
## WARNING: some observed variances are (at least) a factor 1000 times larger than  
## others; use varTable(fit) to investigate

set.seed(12345)  
fit.l.all <- lavaan::sem(lav.l.all, data = apply(sem.dat, 2, std))  
set.seed(12345)  
fit.v.all <- lavaan::sem(lav.v.all, data = apply(sem.dat, 2, std))  
set.seed(12345)  
fit.l.rot.all <- lavaan::sem(lav.l.rot.all, data = apply(sem.dat, 2, std))  
set.seed(12345)  
fit.v.rot.all <- lavaan::sem(lav.v.rot.all, data = apply(sem.dat, 2, std))  
set.seed(12345)  
fit.l.rot.nolight <- lavaan::sem(lav.l.rot.nolight, data = apply(sem.dat, 2, std))  
set.seed(12345)  
fit.v.rot.nolight <- lavaan::sem(lav.v.rot.nolight, data = apply(sem.dat, 2, std))  
  
summary(fit.l.all.raw, rsquare = TRUE)

## lavaan 0.6-8 ended normally after 121 iterations  
##   
## Estimator ML  
## Optimization method NLMINB  
## Number of model parameters 31  
##   
## Number of observations 30  
##   
## Model Test User Model:  
##   
## Test statistic 18.541  
## Degrees of freedom 13  
## P-value (Chi-square) 0.138  
##   
## Parameter Estimates:  
##   
## Standard errors Standard  
## Information Expected  
## Information saturated (h1) model Structured  
##   
## Regressions:  
## Estimate Std.Err z-value P(>|z|)  
## light ~   
## crown -0.005 0.024 -0.204 0.839  
## litter ~   
## crown 0.216 0.065 3.341 0.001  
## rock.lg ~   
## litter -0.675 0.059 -11.495 0.000  
## l.A ~   
## light 0.016 0.065 0.239 0.811  
## rock.lg 0.092 0.027 3.417 0.001  
## l.R ~   
## light 0.088 0.060 1.478 0.139  
## rock.lg 0.162 0.025 6.518 0.000  
## l.D ~   
## light 0.022 0.013 1.615 0.106  
## rock.lg 0.031 0.006 5.661 0.000  
## l.X1 ~   
## light 0.029 0.040 0.709 0.479  
## rock.lg 0.037 0.017 2.244 0.025  
## l.X2 ~   
## light 0.025 0.034 0.736 0.462  
## rock.lg -0.024 0.014 -1.697 0.090  
##   
## Covariances:  
## Estimate Std.Err z-value P(>|z|)  
## .l.A ~~   
## .l.R 4.023 1.799 2.236 0.025  
## .l.D -0.127 0.368 -0.346 0.729  
## .l.R ~~   
## .l.D 1.363 0.420 3.250 0.001  
## .l.A ~~   
## .l.X1 4.221 1.347 3.132 0.002  
## .l.R ~~   
## .l.X1 2.448 1.111 2.204 0.028  
## .l.A ~~   
## .l.X2 -3.251 1.113 -2.919 0.004  
## .l.R ~~   
## .l.X2 -0.466 0.871 -0.534 0.593  
## .l.D ~~   
## .l.X1 0.048 0.227 0.213 0.832  
## .l.X2 0.196 0.197 0.994 0.320  
## .l.X1 ~~   
## .l.X2 0.297 0.586 0.507 0.612  
##   
## Variances:  
## Estimate Std.Err z-value P(>|z|)  
## .light 77.135 19.916 3.873 0.000  
## .litter 584.196 150.839 3.873 0.000  
## .rock.lg 83.027 21.438 3.873 0.000  
## .l.A 9.776 2.524 3.873 0.000  
## .l.R 8.276 2.137 3.873 0.000  
## .l.D 0.413 0.107 3.873 0.000  
## .l.X1 3.750 0.968 3.873 0.000  
## .l.X2 2.724 0.703 3.873 0.000  
##   
## R-Square:  
## Estimate  
## light 0.001  
## litter 0.271  
## rock.lg 0.815  
## l.A 0.282  
## l.R 0.600  
## l.D 0.538  
## l.X1 0.157  
## l.X2 0.101

summary(fit.v.all.raw, rsquare = TRUE)

## lavaan 0.6-8 ended normally after 235 iterations  
##   
## Estimator ML  
## Optimization method NLMINB  
## Number of model parameters 40  
##   
## Number of observations 30  
##   
## Model Test User Model:  
##   
## Test statistic 12.147  
## Degrees of freedom 14  
## P-value (Chi-square) 0.595  
##   
## Parameter Estimates:  
##   
## Standard errors Standard  
## Information Expected  
## Information saturated (h1) model Structured  
##   
## Regressions:  
## Estimate Std.Err z-value P(>|z|)  
## light ~   
## crown -0.005 0.024 -0.204 0.839  
## litter ~   
## crown 0.216 0.065 3.341 0.001  
## rock.sm ~   
## litter -0.312 0.060 -5.169 0.000  
## p.A ~   
## light 0.047 0.328 0.143 0.887  
## rock.sm -0.477 0.224 -2.128 0.033  
## p.R ~   
## light 0.020 0.016 1.217 0.224  
## rock.sm -0.046 0.012 -3.835 0.000  
## litter -0.013 0.003 -4.027 0.000  
## p.D ~   
## light -0.000 0.007 -0.071 0.944  
## rock.sm -0.013 0.005 -2.704 0.007  
## p.X1 ~   
## light 0.118 0.200 0.589 0.556  
## rock.sm 0.093 0.136 0.684 0.494  
## p.X2 ~   
## light -0.018 0.209 -0.086 0.931  
## rock.sm 0.164 0.142 1.151 0.250  
## p.X3 ~   
## light 0.191 0.248 0.771 0.441  
## rock.sm 0.356 0.169 2.108 0.035  
##   
## Covariances:  
## Estimate Std.Err z-value P(>|z|)  
## .p.A ~~   
## .p.X2 -89.124 33.272 -2.679 0.007  
## .p.R 5.236 2.439 2.147 0.032  
## .p.D 1.732 1.025 1.690 0.091  
## .p.R ~~   
## .p.D 0.229 0.064 3.602 0.000  
## .p.A ~~   
## .p.X1 -85.041 31.772 -2.677 0.007  
## .p.R ~~   
## .p.X1 -1.262 1.383 -0.913 0.361  
## .p.A ~~   
## .p.X3 -58.230 35.996 -1.618 0.106  
## .p.R ~~   
## .p.X2 -3.100 1.536 -2.019 0.044  
## .p.X3 0.231 1.692 0.137 0.891  
## .p.D ~~   
## .p.X1 -0.109 0.593 -0.184 0.854  
## .p.X2 -1.337 0.666 -2.007 0.045  
## .p.X3 0.241 0.736 0.328 0.743  
## .p.X1 ~~   
## .p.X2 8.347 17.700 0.472 0.637  
## .p.X3 -12.723 21.025 -0.605 0.545  
## .p.X2 ~~   
## .p.X3 -28.403 22.483 -1.263 0.206  
##   
## Variances:  
## Estimate Std.Err z-value P(>|z|)  
## .light 77.135 19.916 3.873 0.000  
## .litter 584.195 150.839 3.873 0.000  
## .rock.sm 87.816 22.674 3.873 0.000  
## .p.A 249.877 64.518 3.873 0.000  
## .p.R 0.605 0.156 3.873 0.000  
## .p.D 0.114 0.029 3.873 0.000  
## .p.X1 92.255 23.820 3.873 0.000  
## .p.X2 101.118 26.109 3.873 0.000  
## .p.X3 141.992 36.662 3.873 0.000  
##   
## R-Square:  
## Estimate  
## light 0.001  
## litter 0.271  
## rock.sm 0.471  
## p.A 0.131  
## p.R 0.265  
## p.D 0.196  
## p.X1 0.027  
## p.X2 0.042  
## p.X3 0.145

summary(fit.l.all, rsquare = TRUE)

## lavaan 0.6-8 ended normally after 58 iterations  
##   
## Estimator ML  
## Optimization method NLMINB  
## Number of model parameters 31  
##   
## Number of observations 30  
##   
## Model Test User Model:  
##   
## Test statistic 18.541  
## Degrees of freedom 13  
## P-value (Chi-square) 0.138  
##   
## Parameter Estimates:  
##   
## Standard errors Standard  
## Information Expected  
## Information saturated (h1) model Structured  
##   
## Regressions:  
## Estimate Std.Err z-value P(>|z|)  
## light ~   
## crown -0.037 0.182 -0.204 0.839  
## litter ~   
## crown 0.521 0.156 3.341 0.001  
## rock.lg ~   
## litter -0.903 0.079 -11.495 0.000  
## l.A ~   
## light 0.037 0.154 0.239 0.811  
## rock.lg 0.528 0.154 3.417 0.001  
## l.R ~   
## light 0.168 0.114 1.478 0.139  
## rock.lg 0.742 0.114 6.518 0.000  
## l.D ~   
## light 0.197 0.122 1.615 0.106  
## rock.lg 0.691 0.122 5.661 0.000  
## l.X1 ~   
## light 0.118 0.167 0.709 0.479  
## rock.lg 0.374 0.167 2.244 0.025  
## l.X2 ~   
## light 0.128 0.174 0.736 0.462  
## rock.lg -0.295 0.174 -1.697 0.090  
##   
## Covariances:  
## Estimate Std.Err z-value P(>|z|)  
## .l.A ~~   
## .l.R 0.228 0.102 2.236 0.025  
## .l.D -0.035 0.100 -0.346 0.729  
## .l.R ~~   
## .l.D 0.297 0.091 3.250 0.001  
## .l.A ~~   
## .l.X1 0.520 0.166 3.132 0.002  
## .l.R ~~   
## .l.X1 0.242 0.110 2.204 0.028  
## .l.A ~~   
## .l.X2 -0.490 0.168 -2.919 0.004  
## .l.R ~~   
## .l.X2 -0.056 0.105 -0.534 0.593  
## .l.D ~~   
## .l.X1 0.023 0.108 0.213 0.832  
## .l.X2 0.114 0.114 0.994 0.320  
## .l.X1 ~~   
## .l.X2 0.078 0.154 0.507 0.612  
##   
## Variances:  
## Estimate Std.Err z-value P(>|z|)  
## .light 0.965 0.249 3.873 0.000  
## .litter 0.705 0.182 3.873 0.000  
## .rock.lg 0.179 0.046 3.873 0.000  
## .l.A 0.691 0.178 3.873 0.000  
## .l.R 0.375 0.097 3.873 0.000  
## .l.D 0.432 0.112 3.873 0.000  
## .l.X1 0.806 0.208 3.873 0.000  
## .l.X2 0.876 0.226 3.873 0.000  
##   
## R-Square:  
## Estimate  
## light 0.001  
## litter 0.271  
## rock.lg 0.815  
## l.A 0.282  
## l.R 0.600  
## l.D 0.538  
## l.X1 0.157  
## l.X2 0.101

summary(fit.v.all, rsquare = TRUE)

## lavaan 0.6-8 ended normally after 52 iterations  
##   
## Estimator ML  
## Optimization method NLMINB  
## Number of model parameters 40  
##   
## Number of observations 30  
##   
## Model Test User Model:  
##   
## Test statistic 12.147  
## Degrees of freedom 14  
## P-value (Chi-square) 0.595  
##   
## Parameter Estimates:  
##   
## Standard errors Standard  
## Information Expected  
## Information saturated (h1) model Structured  
##   
## Regressions:  
## Estimate Std.Err z-value P(>|z|)  
## light ~   
## crown -0.037 0.182 -0.204 0.839  
## litter ~   
## crown 0.521 0.156 3.341 0.001  
## rock.sm ~   
## litter -0.686 0.133 -5.169 0.000  
## p.A ~   
## light 0.024 0.170 0.143 0.887  
## rock.sm -0.363 0.170 -2.128 0.033  
## p.R ~   
## light 0.184 0.152 1.217 0.224  
## rock.sm -0.634 0.165 -3.835 0.000  
## litter -0.386 0.096 -4.027 0.000  
## p.D ~   
## light -0.012 0.164 -0.071 0.944  
## rock.sm -0.442 0.164 -2.704 0.007  
## p.X1 ~   
## light 0.106 0.180 0.589 0.556  
## rock.sm 0.123 0.180 0.684 0.494  
## p.X2 ~   
## light -0.015 0.179 -0.086 0.931  
## rock.sm 0.206 0.179 1.151 0.250  
## p.X3 ~   
## light 0.129 0.167 0.771 0.441  
## rock.sm 0.353 0.167 2.108 0.035  
##   
## Covariances:  
## Estimate Std.Err z-value P(>|z|)  
## .p.A ~~   
## .p.X2 -0.495 0.185 -2.679 0.007  
## .p.R 0.319 0.149 2.147 0.032  
## .p.D 0.262 0.155 1.690 0.091  
## .p.R ~~   
## .p.D 0.628 0.174 3.602 0.000  
## .p.A ~~   
## .p.X1 -0.497 0.186 -2.677 0.007  
## .p.R ~~   
## .p.X1 -0.134 0.146 -0.913 0.361  
## .p.A ~~   
## .p.X3 -0.256 0.158 -1.618 0.106  
## .p.R ~~   
## .p.X2 -0.312 0.154 -2.019 0.044  
## .p.X3 0.018 0.134 0.137 0.891  
## .p.D ~~   
## .p.X1 -0.029 0.156 -0.184 0.854  
## .p.X2 -0.334 0.166 -2.007 0.045  
## .p.X3 0.048 0.145 0.328 0.743  
## .p.X1 ~~   
## .p.X2 0.080 0.171 0.472 0.637  
## .p.X3 -0.097 0.160 -0.605 0.545  
## .p.X2 ~~   
## .p.X3 -0.206 0.163 -1.263 0.206  
##   
## Variances:  
## Estimate Std.Err z-value P(>|z|)  
## .light 0.965 0.249 3.873 0.000  
## .litter 0.705 0.182 3.873 0.000  
## .rock.sm 0.511 0.132 3.873 0.000  
## .p.A 0.842 0.218 3.873 0.000  
## .p.R 0.667 0.172 3.873 0.000  
## .p.D 0.775 0.200 3.873 0.000  
## .p.X1 0.936 0.242 3.873 0.000  
## .p.X2 0.927 0.239 3.873 0.000  
## .p.X3 0.812 0.210 3.873 0.000  
##   
## R-Square:  
## Estimate  
## light 0.001  
## litter 0.271  
## rock.sm 0.471  
## p.A 0.131  
## p.R 0.265  
## p.D 0.196  
## p.X1 0.027  
## p.X2 0.042  
## p.X3 0.145

summary(fit.l.rot.all, rsquare = TRUE)

## lavaan 0.6-8 ended normally after 58 iterations  
##   
## Estimator ML  
## Optimization method NLMINB  
## Number of model parameters 33  
##   
## Number of observations 30  
##   
## Model Test User Model:  
##   
## Test statistic 26.681  
## Degrees of freedom 19  
## P-value (Chi-square) 0.112  
##   
## Parameter Estimates:  
##   
## Standard errors Standard  
## Information Expected  
## Information saturated (h1) model Structured  
##   
## Regressions:  
## Estimate Std.Err z-value P(>|z|)  
## light ~   
## crown -0.052 0.202 -0.256 0.798  
## litter ~   
## crown 0.594 0.170 3.506 0.000  
## light ~   
## trunk 0.034 0.202 0.169 0.866  
## litter ~   
## trunk -0.172 0.170 -1.016 0.309  
## rock.lg ~   
## litter -0.903 0.079 -11.495 0.000  
## l.A ~   
## light 0.037 0.154 0.239 0.811  
## rock.lg 0.528 0.154 3.417 0.001  
## l.R ~   
## light 0.168 0.114 1.478 0.139  
## rock.lg 0.742 0.114 6.518 0.000  
## l.D ~   
## light 0.197 0.122 1.615 0.106  
## rock.lg 0.691 0.122 5.661 0.000  
## rot.l.X1 ~   
## light 0.051 0.161 0.320 0.749  
## rock.lg 0.462 0.161 2.873 0.004  
## rot.l.X2 ~   
## light 0.174 0.180 0.966 0.334  
## rock.lg -0.023 0.180 -0.130 0.897  
##   
## Covariances:  
## Estimate Std.Err z-value P(>|z|)  
## .l.A ~~   
## .l.R 0.228 0.102 2.236 0.025  
## .l.D -0.035 0.100 -0.346 0.729  
## .l.R ~~   
## .l.D 0.297 0.091 3.250 0.001  
## .l.A ~~   
## .rot.l.X1 0.677 0.181 3.751 0.000  
## .l.R ~~   
## .rot.l.X1 0.241 0.106 2.266 0.023  
## .l.A ~~   
## .rot.l.X2 -0.098 0.148 -0.662 0.508  
## .l.R ~~   
## .rot.l.X2 0.095 0.110 0.866 0.386  
## .l.D ~~   
## .rot.l.X1 -0.028 0.104 -0.269 0.788  
## .rot.l.X2 0.106 0.118 0.904 0.366  
## .rot.l.X1 ~~   
## .rot.l.X2 0.154 0.156 0.987 0.324  
##   
## Variances:  
## Estimate Std.Err z-value P(>|z|)  
## .light 0.964 0.249 3.873 0.000  
## .litter 0.681 0.176 3.873 0.000  
## .rock.lg 0.179 0.046 3.873 0.000  
## .l.A 0.691 0.178 3.873 0.000  
## .l.R 0.375 0.097 3.873 0.000  
## .l.D 0.432 0.112 3.873 0.000  
## .rot.l.X1 0.751 0.194 3.873 0.000  
## .rot.l.X2 0.938 0.242 3.873 0.000  
##   
## R-Square:  
## Estimate  
## light 0.002  
## litter 0.295  
## rock.lg 0.815  
## l.A 0.282  
## l.R 0.601  
## l.D 0.539  
## rot.l.X1 0.219  
## rot.l.X2 0.031

summary(fit.v.rot.all, rsquare = TRUE)

## lavaan 0.6-8 ended normally after 48 iterations  
##   
## Estimator ML  
## Optimization method NLMINB  
## Number of model parameters 41  
##   
## Number of observations 30  
##   
## Model Test User Model:  
##   
## Test statistic 30.762  
## Degrees of freedom 22  
## P-value (Chi-square) 0.101  
##   
## Parameter Estimates:  
##   
## Standard errors Standard  
## Information Expected  
## Information saturated (h1) model Structured  
##   
## Regressions:  
## Estimate Std.Err z-value P(>|z|)  
## light ~   
## crown -0.052 0.202 -0.256 0.798  
## litter ~   
## crown 0.594 0.170 3.506 0.000  
## light ~   
## trunk 0.034 0.202 0.169 0.866  
## litter ~   
## trunk -0.172 0.170 -1.016 0.309  
## rock.sm ~   
## litter -0.686 0.133 -5.169 0.000  
## p.A ~   
## light 0.024 0.170 0.143 0.887  
## rock.sm -0.363 0.170 -2.127 0.033  
## p.R ~   
## light 0.197 0.169 1.165 0.244  
## rock.sm -0.372 0.169 -2.202 0.028  
## p.D ~   
## light -0.012 0.164 -0.071 0.944  
## rock.sm -0.442 0.164 -2.704 0.007  
## rot.p.X1 ~   
## light 0.142 0.160 0.888 0.375  
## rock.sm 0.433 0.160 2.711 0.007  
## rot.p.X2 ~   
## light 0.063 0.182 0.344 0.731  
## rock.sm -0.013 0.182 -0.071 0.944  
## rot.p.X3 ~   
## light 0.070 0.182 0.387 0.699  
## rock.sm -0.014 0.182 -0.080 0.937  
##   
## Covariances:  
## Estimate Std.Err z-value P(>|z|)  
## .p.A ~~   
## .rot.p.X2 -0.344 0.176 -1.953 0.051  
## .p.R 0.363 0.166 2.187 0.029  
## .p.D 0.262 0.155 1.690 0.091  
## .p.R ~~   
## .p.D 0.672 0.191 3.524 0.000  
## .p.A ~~   
## .rot.p.X1 -0.511 0.172 -2.973 0.003  
## .p.R ~~   
## .rot.p.X1 -0.115 0.144 -0.799 0.425  
## .p.A ~~   
## .rot.p.X3 0.300 0.173 1.731 0.083  
## .p.R ~~   
## .rot.p.X2 -0.134 0.165 -0.814 0.416  
## .rot.p.X3 0.311 0.172 1.807 0.071  
## .p.D ~~   
## .rot.p.X1 -0.068 0.139 -0.486 0.627  
## .rot.p.X2 -0.008 0.158 -0.048 0.962  
## .rot.p.X3 0.300 0.167 1.798 0.072  
## .rot.p.X1 ~~   
## .rot.p.X2 -0.107 0.155 -0.687 0.492  
## .rot.p.X3 0.215 0.159 1.350 0.177  
## .rot.p.X2 ~~   
## .rot.p.X3 -0.181 0.179 -1.011 0.312  
##   
## Variances:  
## Estimate Std.Err z-value P(>|z|)  
## .light 0.964 0.249 3.873 0.000  
## .litter 0.681 0.176 3.873 0.000  
## .rock.sm 0.511 0.132 3.873 0.000  
## .p.A 0.842 0.218 3.873 0.000  
## .p.R 0.825 0.213 3.873 0.000  
## .p.D 0.775 0.200 3.873 0.000  
## .rot.p.X1 0.741 0.191 3.873 0.000  
## .rot.p.X2 0.963 0.249 3.873 0.000  
## .rot.p.X3 0.962 0.248 3.873 0.000  
##   
## R-Square:  
## Estimate  
## light 0.002  
## litter 0.295  
## rock.sm 0.471  
## p.A 0.131  
## p.R 0.170  
## p.D 0.196  
## rot.p.X1 0.215  
## rot.p.X2 0.004  
## rot.p.X3 0.005

summary(fit.l.rot.nolight, rsquare = TRUE)

## lavaan 0.6-8 ended normally after 54 iterations  
##   
## Estimator ML  
## Optimization method NLMINB  
## Number of model parameters 24  
##   
## Number of observations 30  
##   
## Model Test User Model:  
##   
## Test statistic 17.024  
## Degrees of freedom 11  
## P-value (Chi-square) 0.107  
##   
## Parameter Estimates:  
##   
## Standard errors Standard  
## Information Expected  
## Information saturated (h1) model Structured  
##   
## Regressions:  
## Estimate Std.Err z-value P(>|z|)  
## litter ~   
## crown 0.521 0.156 3.341 0.001  
## rock.lg ~   
## litter -0.903 0.079 -11.495 0.000  
## l.A ~   
## rock.lg 0.533 0.155 3.446 0.001  
## l.R ~   
## rock.lg 0.764 0.118 6.489 0.000  
## l.D ~   
## rock.lg 0.718 0.127 5.643 0.000  
## rot.l.X1 ~   
## rock.lg 0.469 0.161 2.911 0.004  
## rot.l.X2 ~   
## rock.lg 0.000 0.183 0.000 1.000  
##   
## Covariances:  
## Estimate Std.Err z-value P(>|z|)  
## .l.A ~~   
## .l.R 0.234 0.105 2.218 0.027  
## .l.D -0.028 0.104 -0.266 0.790  
## .l.R ~~   
## .l.D 0.328 0.099 3.303 0.001  
## .l.A ~~   
## .rot.l.X1 0.679 0.181 3.751 0.000  
## .l.R ~~   
## .rot.l.X1 0.250 0.110 2.261 0.024  
## .l.A ~~   
## .rot.l.X2 -0.092 0.150 -0.612 0.541  
## .l.R ~~   
## .rot.l.X2 0.123 0.116 1.058 0.290  
## .l.D ~~   
## .rot.l.X1 -0.018 0.109 -0.169 0.866  
## .rot.l.X2 0.139 0.126 1.107 0.268  
## .rot.l.X1 ~~   
## .rot.l.X2 0.162 0.159 1.023 0.306  
##   
## Variances:  
## Estimate Std.Err z-value P(>|z|)  
## .litter 0.705 0.182 3.873 0.000  
## .rock.lg 0.179 0.046 3.873 0.000  
## .l.A 0.692 0.179 3.873 0.000  
## .l.R 0.402 0.104 3.873 0.000  
## .l.D 0.469 0.121 3.873 0.000  
## .rot.l.X1 0.754 0.195 3.873 0.000  
## .rot.l.X2 0.967 0.250 3.873 0.000  
##   
## R-Square:  
## Estimate  
## litter 0.271  
## rock.lg 0.815  
## l.A 0.284  
## l.R 0.584  
## l.D 0.515  
## rot.l.X1 0.220  
## rot.l.X2 0.000

summary(fit.v.rot.nolight, rsquare = TRUE)

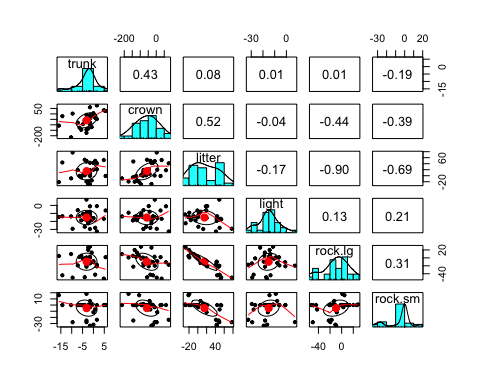
## lavaan 0.6-8 ended normally after 41 iterations  
##   
## Estimator ML  
## Optimization method NLMINB  
## Number of model parameters 31  
##   
## Number of observations 30  
##   
## Model Test User Model:  
##   
## Test statistic 20.525  
## Degrees of freedom 13  
## P-value (Chi-square) 0.083  
##   
## Parameter Estimates:  
##   
## Standard errors Standard  
## Information Expected  
## Information saturated (h1) model Structured  
##   
## Regressions:  
## Estimate Std.Err z-value P(>|z|)  
## litter ~   
## crown 0.521 0.156 3.341 0.001  
## rock.sm ~   
## litter -0.686 0.133 -5.169 0.000  
## p.A ~   
## rock.sm -0.358 0.170 -2.098 0.036  
## p.R ~   
## rock.sm -0.331 0.172 -1.921 0.055  
## p.D ~   
## rock.sm -0.445 0.164 -2.719 0.007  
## rot.p.X1 ~   
## rock.sm 0.463 0.162 2.859 0.004  
## rot.p.X2 ~   
## rock.sm -0.000 0.183 -0.000 1.000  
## rot.p.X3 ~   
## rock.sm 0.000 0.183 0.000 1.000  
##   
## Covariances:  
## Estimate Std.Err z-value P(>|z|)  
## .p.A ~~   
## .rot.p.X2 -0.342 0.176 -1.942 0.052  
## .p.R 0.367 0.169 2.169 0.030  
## .p.D 0.262 0.155 1.688 0.091  
## .p.R ~~   
## .p.D 0.670 0.193 3.474 0.001  
## .p.A ~~   
## .rot.p.X1 -0.508 0.173 -2.933 0.003  
## .p.R ~~   
## .rot.p.X1 -0.089 0.149 -0.602 0.547  
## .p.A ~~   
## .rot.p.X3 0.301 0.174 1.735 0.083  
## .p.R ~~   
## .rot.p.X2 -0.123 0.168 -0.730 0.466  
## .rot.p.X3 0.324 0.177 1.834 0.067  
## .p.D ~~   
## .rot.p.X1 -0.069 0.141 -0.491 0.623  
## .rot.p.X2 -0.008 0.158 -0.052 0.958  
## .rot.p.X3 0.299 0.167 1.790 0.074  
## .rot.p.X1 ~~   
## .rot.p.X2 -0.099 0.157 -0.626 0.532  
## .rot.p.X3 0.224 0.162 1.385 0.166  
## .rot.p.X2 ~~   
## .rot.p.X3 -0.177 0.179 -0.985 0.325  
##   
## Variances:  
## Estimate Std.Err z-value P(>|z|)  
## .litter 0.705 0.182 3.873 0.000  
## .rock.sm 0.511 0.132 3.873 0.000  
## .p.A 0.843 0.218 3.873 0.000  
## .p.R 0.861 0.222 3.873 0.000  
## .p.D 0.776 0.200 3.873 0.000  
## .rot.p.X1 0.760 0.196 3.873 0.000  
## .rot.p.X2 0.967 0.250 3.873 0.000  
## .rot.p.X3 0.967 0.250 3.873 0.000  
##   
## R-Square:  
## Estimate  
## litter 0.271  
## rock.sm 0.471  
## p.A 0.128  
## p.R 0.110  
## p.D 0.198  
## rot.p.X1 0.214  
## rot.p.X2 0.000  
## rot.p.X3 0.000

## SEM Variable R-Squares

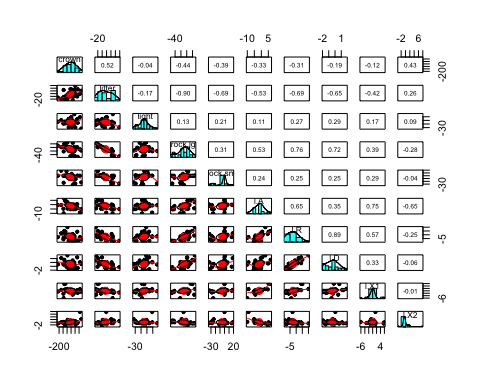
get\_R2 <- function(x){  
 out <- capture.output(summary(x, rsquare = TRUE))  
 out <- out[grep("R-Square:",out):length(out)]  
 out <- out[!(grepl("R-Square:", out)) & !(grepl("Estimate", out))]  
 out <- out[out != ""]  
 out <- strsplit(out, " ")  
 out <- lapply(out, function(x) x[x != ""])  
 out <- do.call(rbind, out)  
 out.names <- out[, 1]  
 out <- as.numeric(out[, 2])  
 names(out) <- out.names  
 return(out)  
}  
  
r2.l.rot.all <- get\_R2(fit.l.rot.all)  
r2.v.rot.all <- get\_R2(fit.v.rot.all)

## SEM variable inter-correlations plot

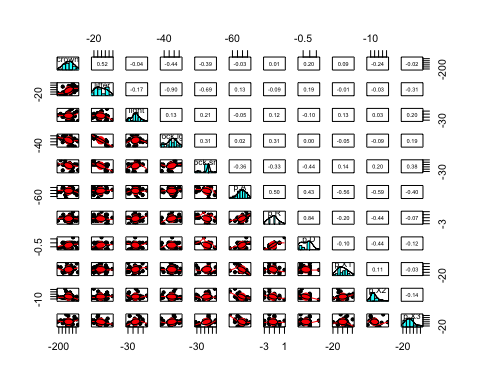
pairs.panels(sem.dat[, c("trunk", "crown", "litter", "light", "rock.lg", "rock.sm")])



pairs.panels(sem.dat[, c("crown", "litter", "light", "rock.lg", "rock.sm",  
 "l.A", "l.R", "l.D", "l.X1", "l.X2")])



pairs.panels(sem.dat[, c("crown", "litter", "light", "rock.lg", "rock.sm",  
 "p.A", "p.R", "p.D", "p.X1", "p.X2", "p.X3")])



## SEM Skew-Kurtosis Check

skc.sem <- skew\_kurtosis(sem.dat)  
skc.sem.flags <- skc.sem[(abs(skc.sem[, "skew\_2se"]) > 1 |  
 abs(skc.sem[, "kurt\_2se"]) > 1), ]  
kable(skc.sem.flags)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | skew | skew\_2se | kurt | kurt\_2se |
| l.X1 | 0.3854049 | 0.4514075 | 2.683946 | 1.6115042 |
| l.X2 | 2.6079952 | 3.0546283 | 9.344848 | 5.6108660 |
| p.X2 | 1.2498696 | 1.4639165 | 1.705619 | 1.0240934 |
| rot.l.X2 | 1.9574132 | 2.2926307 | 5.705369 | 3.4256372 |
| rot.p.X1 | 1.1461696 | 1.3424572 | 1.444625 | 0.8673866 |

## SEM Modification Indices

xtable::xtable(modindices(fit.l.rot.all))

% latex table generated in R 4.0.4 by xtable 1.8-4 package % Thu May 6 12:56:10 2021

xtable::xtable(modindices(fit.v.rot.all))

% latex table generated in R 4.0.4 by xtable 1.8-4 package % Thu May 6 12:56:10 2021

## SEM Parameter Estimates

xtable::xtable(table\_results(fit.l.all))

% latex table generated in R 4.0.4 by xtable 1.8-4 package % Thu May 6 12:56:10 2021

xtable::xtable(table\_results(fit.v.all))

% latex table generated in R 4.0.4 by xtable 1.8-4 package % Thu May 6 12:56:11 2021

xtable::xtable(table\_results(fit.l.rot.all))

% latex table generated in R 4.0.4 by xtable 1.8-4 package % Thu May 6 12:56:11 2021

xtable::xtable(table\_results(fit.v.rot.all))

% latex table generated in R 4.0.4 by xtable 1.8-4 package % Thu May 6 12:56:11 2021

## SEM Model Fit Measures

sem.fm.l.all <- fitMeasures(fit.l.all)  
sem.fm.v.all <- fitMeasures(fit.v.all)  
sem.fm.l.rot.all <- fitMeasures(fit.l.rot.all)  
sem.fm.v.rot.all <- fitMeasures(fit.v.rot.all)  
  
sem.fm.tab.all <- rbind(sem.fm.l.all[c("chisq", "df", "pvalue")],  
 sem.fm.v.all[c("chisq", "df", "pvalue")])  
rownames(sem.fm.tab.all) <- c("Lichens", "Plants")  
colnames(sem.fm.tab.all) <- c("$\\chi^{2}$", "\\textit{df}", "\\textit{p}-value")  
sem.fm.tab.rot.all <- rbind(sem.fm.l.rot.all[c("chisq", "df", "pvalue")],  
 sem.fm.v.rot.all[c("chisq", "df", "pvalue")])  
rownames(sem.fm.tab.rot.all) <- c("Lichens", "Plants")  
colnames(sem.fm.tab.rot.all) <- c("$\\chi^{2}$", "\\textit{df}", "\\textit{p}-value")  
  
print(xtable::xtable(sem.fm.tab.all, digits = 3),   
 sanitize.text.function = function(x) {x})

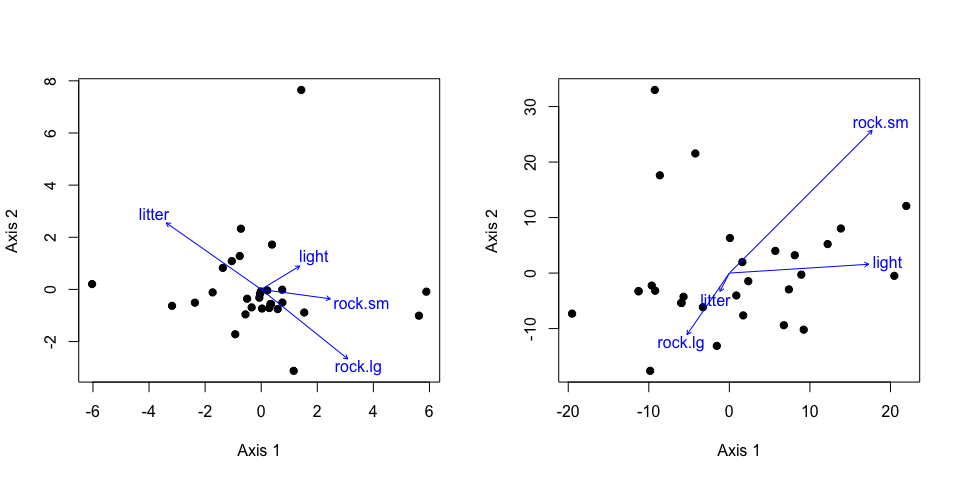
% latex table generated in R 4.0.4 by xtable 1.8-4 package % Thu May 6 12:56:11 2021

print(xtable::xtable(sem.fm.tab.rot.all, digits = 3),   
 sanitize.text.function = function(x) {x})

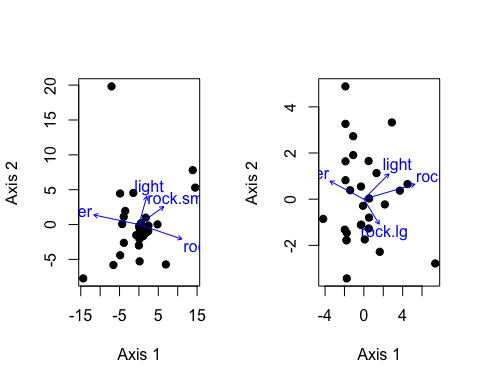
% latex table generated in R 4.0.4 by xtable 1.8-4 package % Thu May 6 12:56:11 2021

## Ordination Plots

par(mfrow = c(1,2))  
plot(l.com.dif.ord[, 1:2], xlab = "Axis 1", ylab = "Axis 2", pch = 19)  
plot(l.com.dif.vec, add = TRUE)  
plot(v.com.dif.ord[, 1:2], xlab = "Axis 1", ylab = "Axis 2", pch = 19)  
plot(v.com.dif.vec, add = TRUE)



par(mfrow = c(1,2))  
plot(l.com.dif.ord.proc[, 1:2], xlab = "Axis 1", ylab = "Axis 2", pch = 19)  
plot(l.com.dif.vec.rot, add = TRUE)  
plot(v.com.dif.ord.proc[, 1:2], xlab = "Axis 1", ylab = "Axis 2", pch = 19)  
plot(v.com.dif.vec.rot, add = TRUE)



## SEM Plots

apriori.dat <- data.frame(crown = rnorm(30),  
 light = rnorm(30),  
 litter = rnorm(30),  
 rock.lg = rnorm(30),  
 rock.sm = rnorm(30),  
 richness = rnorm(30),  
 abundance = rnorm(30),  
 diversity = rnorm(30),  
 ordination = rnorm(30))  
lav.apriori <- 'light ~ crown  
 litter ~ crown  
 rock.lg ~ litter  
 abundance ~ light + rock.lg + rock.sm  
 richness ~ light + rock.lg + rock.sm  
 diversity ~ light + rock.lg + rock.sm  
 ordination ~ light + rock.lg + rock.sm  
 rock.lg ~~ rock.sm  
 '  
fit.apriori <- lavaan::sem(lav.apriori, data = apriori.dat)

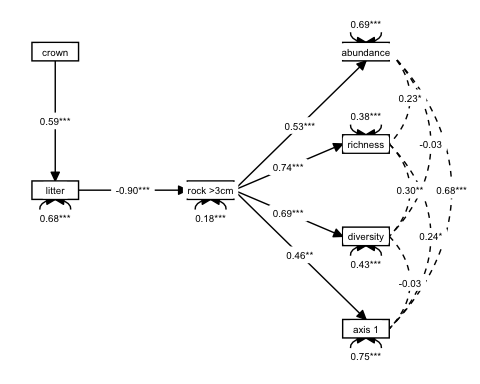
## Warning in lav\_partable\_vnames(FLAT, "ov.x", warn = TRUE): lavaan WARNING:  
## model syntax contains variance/covariance/intercept formulas  
## involving (an) exogenous variable(s): [rock.sm]; These variables  
## will now be treated as random introducing additional free  
## parameters. If you wish to treat those variables as fixed, remove  
## these formulas from the model syntax. Otherwise, consider adding  
## the fixed.x = FALSE option.

lay.apriori <- get\_layout("crown", "", "light", "", "abundance",  
 "", "", "", "", "",  
 "", "", "", "", "richness",  
 "litter", "", "rock.lg", "", "",   
 "", "", "", "", "diversity",  
 "", "", "rock.sm", "", "",   
 "", "", "", "", "",  
 "", "", "", "", "ordination",  
 rows = 8)  
  
tg.apriori <- prepare\_graph(fit.apriori,  
 layout = lay.apriori,  
 text\_size = 2.5)  
nodes(tg.apriori)[nodes(tg.apriori)[, "name"] ==   
 "rock.lg", "label"] <- "rock >3cm"  
nodes(tg.apriori)[nodes(tg.apriori)[, "name"] ==   
 "rock.sm", "label"] <- "rock <3cm"  
edges(tg.apriori)[, "label"] <- ""

lay <- get\_layout("crown", "", "", "", "l.A",  
 "", "", "", "", "",  
 "", "", "", "", "l.R",  
 "litter", "", "rock.lg", "", "",   
 "", "", "", "", "l.D",  
 "", "", "", "", "",   
 "", "", "", "", "rot.l.X1",  
 rows = 7)  
tg.l.rot.all <- prepare\_graph(fit.l.rot.all,   
 layout = lay,  
 text\_size = 2.6)

## Some edges involve nodes not in layout. These were dropped.

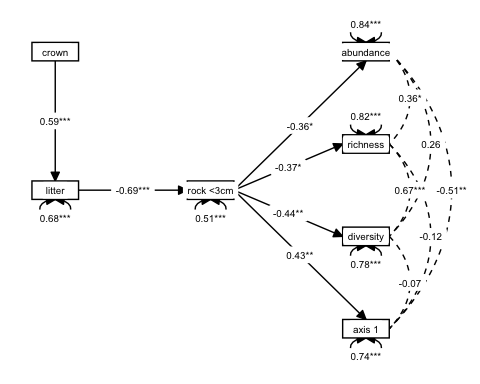
nodes(tg.l.rot.all)[nodes(tg.l.rot.all)[, "name"] ==   
 "l.A", "label"] <- "abundance"  
nodes(tg.l.rot.all)[nodes(tg.l.rot.all)[, "name"] ==   
 "l.R", "label"] <- "richness"  
nodes(tg.l.rot.all)[nodes(tg.l.rot.all)[, "name"] ==   
 "l.D", "label"] <- "diversity"  
nodes(tg.l.rot.all)[nodes(tg.l.rot.all)[, "name"] ==   
 "rock.lg", "label"] <- "rock >3cm"  
nodes(tg.l.rot.all)[nodes(tg.l.rot.all)[, "name"] ==   
 "rot.l.X1", "label"] <- "axis 1"  
plot(tg.l.rot.all)



lay <- get\_layout("crown", "", "", "", "p.A",  
 "", "", "", "", "",  
 "", "", "", "", "p.R",  
 "litter", "", "rock.sm", "", "",   
 "", "", "", "", "p.D",  
 "", "", "", "", "",   
 "", "", "", "", "rot.p.X1",  
 rows = 7)  
tg.v.rot.all <- prepare\_graph(fit.v.rot.all,   
 layout = lay,  
 text\_size = 2.6)

## Some edges involve nodes not in layout. These were dropped.

nodes(tg.v.rot.all)[nodes(tg.v.rot.all)[, "name"] ==   
 "p.A", "label"] <- "abundance"  
nodes(tg.v.rot.all)[nodes(tg.v.rot.all)[, "name"] ==   
 "p.R", "label"] <- "richness"  
nodes(tg.v.rot.all)[nodes(tg.v.rot.all)[, "name"] ==   
 "p.D", "label"] <- "diversity"  
nodes(tg.v.rot.all)[nodes(tg.v.rot.all)[, "name"] ==   
 "rock.sm", "label"] <- "rock <3cm"  
nodes(tg.v.rot.all)[nodes(tg.v.rot.all)[, "name"] ==   
 "rot.p.X1", "label"] <- "axis 1"  
plot(tg.v.rot.all)



## Community Analyses

To examine the lichen and plant community responses to moth susceptibility we analyzed both univariate and multivariate community metrics. All univariate metrics, which included total abundance (as total % cover), species richness and Shannon’s diversity, were analyzed using *t*-tests of the differences between susceptible and resistant trees as done for the tree traits (Pearson 1895). Mulivariate community responses were analyzed with paired PERMANOVAs (Anderson 2001) using Bray-Curtis dissimilarity (Bray & Curtis 1957) adjusted to include zero-sum observations and 10,000 permutations. Mantel correlation was conducted to test for multivariate similarity of lichen and plant community responses to moth susceptibility.

## SEM Methods

We used non-metric Multi-Dimensional Scaling (NMDS) to generate ordinations of the community differences between tree pairs. For both communities (lichens and plants) ordinations were conducted using 100 random initial configurations with a maximum of 1000 iterations and a change in stress threshold of less than 10. This was repeated for one to four dimension configurations, and the configuration with the lowest dimensionality and an unexplained variation less than 10% was selected. Ordinated scores were then rotated for maximum correlation with the tree trait variables using a procrustes rotation (Oksanen et al. 2019).

Applying an ecological causal modeling approach (Grace and Bollen 2008), we constructed *a priori* models based on our hypotheses of the effects of tree traits on the two communities, lichens and plants (Figure Supplemental *a priori models*). We used the differences beteween moth susceptible and resistant trees for all variables in structural model using linear regressions with only the measured variables. Models were fit to the standardized variables using a maximum likelihood estimator and a goodness of fit test. We modeled the two communities (lichens and plants) separately because we found no significant correlation between the response of the two communities to moth herbivory (see Results).

## Moth Susceptibility Impacted Lichen and Plant Communities

We found significant lichen and plant community differences between moth susceptibile and resistant trees. Abundance, richness and diversity were all lower under susceptible trees for both communities (TABLE abundance richness and diversity t-tests). As a whole both lichen ( = 0.04, *p*-value = 0.031) and plant (*R^2* = 0.31, *p*-value = 0.0001) communities were signifcantly predicted by moth susceptibility. Although the moth effect was significant for both lichens and plants, their multivariate differences were not correlated (Mantel *r* = -0.12, *p*-value = 0.44).

## Causal Pathway of Moth Susceptibility Effects on Communities

Moth susceptiblity indirectly influenced lichen and plants community composition by impacting local environmental conditions via altered tree traits. Both SEMs fit the lichen ( = 19, = 26.6808212, -value = 0.1123101) and plant ( = 22, = 30.7624162, -value = 0.1010805) data well, as neither model showed significant differences from their observed covariance matrices based on their respective Goodness of Fit tests. Moth crown herbivory effects on litter explained significant amounts of community variation in differences in lichen abundance ( = 0.282), richness ( = 0.601) and diversity ( = 0.539), as well as in plant community differences in abundance ( = 0.131), richness ( = 0.131) and diversity ( = 0.196). Whole community differences between moth susceptible and resistant trees were also signifcantly explained by crown size differences for both lichens ( = 0.219) and plants ( = 0.215). Together, both of the SEM support a causal pathway from moth crown herbivory increased litter, which altered the abundance of rocks of different size classes, ultimately impacting the lichen and plant communities (Fig. SEM PATH DIAGRAM). However, causal pathways involving light differences between resulting from moth susceptibility were not supported in either the lichen or the plant SEM (SUPPLEMENTARY TABLE SEM path coefficents).

## Software and Data

All analyses were done with R version 4.0.4 (R Core Team 2021). Univariate *t*-tests were conducted using the *stats* package (R Core Team 2021). Multivariate analyses were conducted using the *ecodist* package for distance calculations (Goslee & Urban 2007) and the *vegan* package (Oksanen et al. 2019) for PERMANOVA and Mantel tests and to conduct the ordination and procrustes rotation. The structural equation modeling was conducted using the *lavaan* (Rosseel 2012) and *tidygraph* (Pedersen 2020) packages. Data and software for all the analyses are deposited as a reproducible workflow using the drake package (Landau 2018) at Zenodo (<https://zenodo.org/record/4531170>).

## Citations

Grace, James B. and Bollen, Kenneth A. 2008. Representing general theoretical concepts in structural equation models: the role of composite variables. Environmental and Ecological Statistics, Vol. 15, Issue. 2, p. 191.

Oksanen, Jari F. Guillaume Blanchet, Michael Friendly, Roeland Kindt, Pierre Legendre, Dan McGlinn, Peter R. Minchin, R. B. O’Hara, Gavin L. Simpson, Peter Solymos, M. Henry H. Stevens, Eduard Szoecs and Helene Wagner (2019). vegan: Community Ecology Package. R package version 2.5-6.

Pedersen, Thomas Lin (2020). tidygraph: A Tidy API for Graph Manipulation. R package version 1.2.0.

R Core Team (2021). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Rosseel, Yves (2012). lavaan: An R Package for Structural Equation Modeling. Journal of Statistical Software, 48(2), 1-36.

## Figure Captions

Path diagrams of the structural equation models (SEM) for the (A) lichen and (B) plant communities. Boxes are measured variables and single-headed arrows show the directed hypothesized causal link between variables with the standardized path coeffiecients overlayed onto their respective arrows. Double-headed arrows and undirected dashed lines show the variances and co-variances, respectively. Only variables with at least one significant path coefficient are shown for clarity and estimates for all modeled pathways can be found in Supplementary Table ????.

Bivariate plots of the procrustes rotated ordinations for the (A) lichen and (B) plant communities. Overlaid vectors show the magnitude and direction of the correlations for variables indicated by their respective labels.

## Table Legends

Combined results from the univariate *t*-tests of the differences of the community metrics (abundance, richness and diversity) between moth susceptible and resistiant trees (S -R).

tab.ard.combined <- tab.ttest.ard  
community <- do.call(rbind,   
 strsplit(rownames(tab.ard.combined), "\\."))[, 1]  
community <- gsub("l", "lichens", community)  
community <- gsub("p", "plants", community)  
metric <- do.call(rbind,   
 strsplit(rownames(tab.ard.combined), "\\."))[, 2]  
metric <- gsub("A", "abundance", metric)  
metric <- gsub("R", "richness", metric)  
metric <- gsub("D", "diversity", metric)  
tab.ard.combined <- data.frame(community, metric, tab.ard.combined)  
colnames(tab.ard.combined)[colnames(tab.ard.combined) == "statistic.t"] <- "t"  
colnames(tab.ard.combined)[colnames(tab.ard.combined) == "parameter.df"] <- "df"  
colnames(tab.ard.combined)[colnames(tab.ard.combined) == "estimate.mean.of.x"] <- "mean"  
tab.ard.combined[, "t"] <- round(tab.ard.combined[, "t"], 3)  
tab.ard.combined[, "df"] <- round(tab.ard.combined[, "df"], 0)  
tab.ard.combined[, "mean"] <- round(tab.ard.combined[, "mean"], 3)  
tab.ard.combined[, "p.value"] <- round(tab.ard.combined[, "p.value"], 4)  
write.csv(file = "results/table\_ard\_combined.csv", tab.ard.combined)  
print(xtable::xtable(tab.ard.combined,   
 digits = c(0, 0, 0, 3, 0, 3, 4)),  
 include.rownames = FALSE)

% latex table generated in R 4.0.4 by xtable 1.8-4 package % Thu May 6 12:56:15 2021

Standardized path coefficients, variance and covariance statistics from the Lavann structural equation modeling (SEM) for the lichen community. The labels show the pathway for path coefficients with the directionality indicated by “ON” and covariances are indicated by “WITH”. Paths common to both models are only shown once while other varialbes specific to each model are preceded by “l” for lichen and “p” for plant community. The *est\_sig* column contains the standardize path coefficient and possibly asterisks indicating the level of significance. The standard error and *p*-value for the linear regression for each path are in the following columns *se* and *pval*, respectively.

sem.combined <- rbind(  
 table\_results(fit.l.rot.all)[, c("label", "est\_sig", "se", "pval")],  
 table\_results(fit.v.rot.all)[, c("label", "est\_sig", "se", "pval")])  
sem.combined <- sem.combined[!(duplicated(sem.combined[, 1])), ]  
sem.combined[,1] <- gsub("rot.", "", sem.combined[, 1])  
sem.combined[,1] <- gsub(".A.", ".abundance.", sem.combined[, 1])  
sem.combined[,1] <- gsub(".R.", ".richness.", sem.combined[, 1])  
sem.combined[,1] <- gsub(".D.", ".diversity.", sem.combined[, 1])  
sem.combined[,1] <- gsub(".X", ".axis", sem.combined[, 1])

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | label | est\_sig | se | pval |
| 1 | light.ON.crown | -0.05 | 0.20 | 0.80 |
| 2 | litter.ON.crown | 0.59\*\*\* | 0.17 | 0.00 |
| 3 | light.ON.trunk | 0.03 | 0.20 | 0.87 |
| 4 | litter.ON.trunk | -0.17 | 0.17 | 0.31 |
| 5 | rock.lg.ON.litter | -0.90\*\*\* | 0.08 | 0.00 |
| 6 | l.abundance.ON.light | 0.04 | 0.15 | 0.81 |
| 7 | l.abundance.ON.rock.lg | 0.53\*\*\* | 0.15 | 0.00 |
| 8 | l.richness.ON.light | 0.17 | 0.11 | 0.14 |
| 9 | l.richness.ON.rock.lg | 0.74\*\*\* | 0.11 | 0.00 |
| 10 | l.diversity.ON.light | 0.20 | 0.12 | 0.11 |
| 11 | l.diversity.ON.rock.lg | 0.69\*\*\* | 0.12 | 0.00 |
| 12 | l.axis1.ON.light | 0.05 | 0.16 | 0.75 |
| 13 | l.axis1.ON.rock.lg | 0.46\*\* | 0.16 | 0.00 |
| 14 | l.axis2.ON.light | 0.17 | 0.18 | 0.33 |
| 15 | l.axis2.ON.rock.lg | -0.02 | 0.18 | 0.90 |
| 16 | l.abundance.WITH.l.R | 0.23\* | 0.10 | 0.03 |
| 17 | l.abundance.WITH.l.D | -0.03 | 0.10 | 0.73 |
| 18 | l.richness.WITH.l.D | 0.30\*\* | 0.09 | 0.00 |
| 19 | l.abundance.WITH.l.axis1 | 0.68\*\*\* | 0.18 | 0.00 |
| 20 | l.richness.WITH.l.axis1 | 0.24\* | 0.11 | 0.02 |
| 21 | Variances.light | 0.96\*\*\* | 0.25 | 0.00 |
| 22 | Variances.litter | 0.68\*\*\* | 0.18 | 0.00 |
| 23 | Variances.rock.lg | 0.18\*\*\* | 0.05 | 0.00 |
| 24 | Variances.l.A | 0.69\*\*\* | 0.18 | 0.00 |
| 25 | Variances.l.R | 0.38\*\*\* | 0.10 | 0.00 |
| 26 | Variances.l.D | 0.43\*\*\* | 0.11 | 0.00 |
| 27 | Variances.l.axis1 | 0.75\*\*\* | 0.19 | 0.00 |
| 28 | Variances.l.axis2 | 0.94\*\*\* | 0.24 | 0.00 |
| 29 | l.abundance.WITH.l.axis2 | -0.10 | 0.15 | 0.51 |
| 30 | l.richness.WITH.l.axis2 | 0.10 | 0.11 | 0.39 |
| 31 | l.diversity.WITH.l.axis1 | -0.03 | 0.10 | 0.79 |
| 32 | l.diversity.WITH.l.axis2 | 0.11 | 0.12 | 0.37 |
| 33 | l.axis1.WITH.l.axis2 | 0.15 | 0.16 | 0.32 |
| 34 | Variances.crown | 0.97 | 0.00 | NA |
| 35 | crown.WITH.trunk | 0.41 | 0.00 | NA |
| 36 | Variances.trunk | 0.97 | 0.00 | NA |
| 41 | rock.sm.ON.litter | -0.69\*\*\* | 0.13 | 0.00 |
| 42 | p.abundance.ON.light | 0.02 | 0.17 | 0.89 |
| 43 | p.abundance.ON.rock.sm | -0.36\* | 0.17 | 0.03 |
| 44 | p.richness.ON.light | 0.20 | 0.17 | 0.24 |
| 45 | p.richness.ON.rock.sm | -0.37\* | 0.17 | 0.03 |
| 46 | p.diversity.ON.light | -0.01 | 0.16 | 0.94 |
| 47 | p.diversity.ON.rock.sm | -0.44\*\* | 0.16 | 0.01 |
| 48 | p.axis1.ON.light | 0.14 | 0.16 | 0.37 |
| 49 | p.axis1.ON.rock.sm | 0.43\*\* | 0.16 | 0.01 |
| 50 | p.axis2.ON.light | 0.06 | 0.18 | 0.73 |
| 51 | p.axis2.ON.rock.sm | -0.01 | 0.18 | 0.94 |
| 52 | p.axis3.ON.light | 0.07 | 0.18 | 0.70 |
| 53 | p.axis3.ON.rock.sm | -0.01 | 0.18 | 0.94 |
| 54 | p.abundance.WITH.p.axis2 | -0.34 | 0.18 | 0.05 |
| 55 | p.abundance.WITH.p.R | 0.36\* | 0.17 | 0.03 |
| 56 | p.abundance.WITH.p.D | 0.26 | 0.16 | 0.09 |
| 57 | p.richness.WITH.p.D | 0.67\*\*\* | 0.19 | 0.00 |
| 58 | p.abundance.WITH.p.axis1 | -0.51\*\* | 0.17 | 0.00 |
| 59 | p.richness.WITH.p.axis1 | -0.12 | 0.14 | 0.42 |
| 62 | Variances.rock.sm | 0.51\*\*\* | 0.13 | 0.00 |
| 63 | Variances.p.A | 0.84\*\*\* | 0.22 | 0.00 |
| 64 | Variances.p.R | 0.82\*\*\* | 0.21 | 0.00 |
| 65 | Variances.p.D | 0.78\*\*\* | 0.20 | 0.00 |
| 66 | Variances.p.axis1 | 0.74\*\*\* | 0.19 | 0.00 |
| 67 | Variances.p.axis2 | 0.96\*\*\* | 0.25 | 0.00 |
| 68 | Variances.p.axis3 | 0.96\*\*\* | 0.25 | 0.00 |
| 69 | p.abundance.WITH.p.axis3 | 0.30 | 0.17 | 0.08 |
| 70 | p.richness.WITH.p.axis2 | -0.13 | 0.16 | 0.42 |
| 71 | p.richness.WITH.p.axis3 | 0.31 | 0.17 | 0.07 |
| 72 | p.diversity.WITH.p.axis1 | -0.07 | 0.14 | 0.63 |
| 73 | p.diversity.WITH.p.axis2 | -0.01 | 0.16 | 0.96 |
| 74 | p.diversity.WITH.p.axis3 | 0.30 | 0.17 | 0.07 |
| 75 | p.axis1.WITH.p.axis2 | -0.11 | 0.16 | 0.49 |
| 76 | p.axis1.WITH.p.axis3 | 0.21 | 0.16 | 0.18 |
| 77 | p.axis2.WITH.p.axis3 | -0.18 | 0.18 | 0.31 |

write.csv(file = "results/sem\_results\_combined.csv",  
 sem.combined,  
 row.names = FALSE)