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 (*Dioryctria 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):

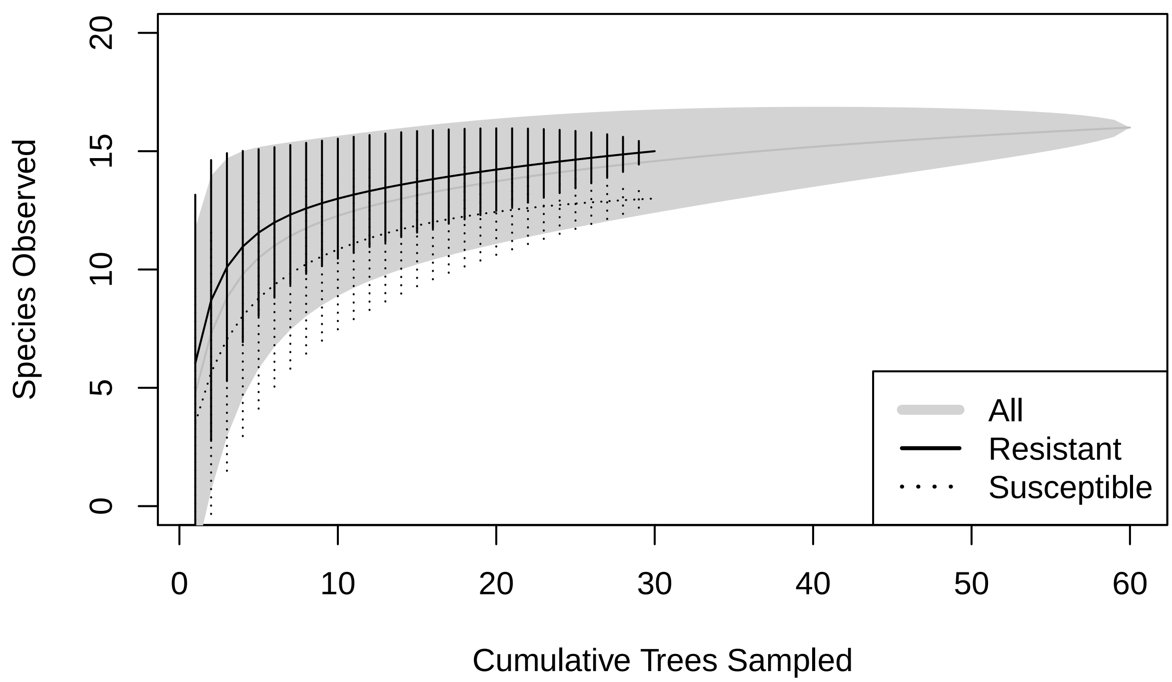
- Moth,categorical,0 or 1,Was the tree susceptible (0) or resistant (1) to moth attack
- Live/Dead,categorical,0 or 1,Was the tree dead (0) or alive (1)
- Litter %,continuous,0 to 100,Percent cover inside quadrat
- Rocks > 3cm %,continuous,0 to 100,Percent cover of rocks > 3cm? inside quadrat
- Rocks < 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)
```

```r
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)")
```

```r
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

```r
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)

```r
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

```r
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)

```r
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
```

```r
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"]), ]
```

```r
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

```r
write.csv(round(isp.all, 5), file = "results/scrl_isp_table.csv")
```

Calculate the average abundances of the indicators

```r
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.

```r
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(abs(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_plant_isp.pdf", width = 9, height = 5)

par(mfrow = c(1,2))
bp.out <- barplot(ard.mu, col = "darkgrey", ylim = c(-1.0, 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

```r
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
dev.off()
```

```
## pdf
##   2
```

Create plot with indicator taxa

```r
pdf(file = "./results/scrl_pdif.pdf", width = 7, height = 7)
plot(melt(isp.dif)[-1], xlab = "Species", ylab = "Abundance Reduction")
```

```r
dev.off()
```

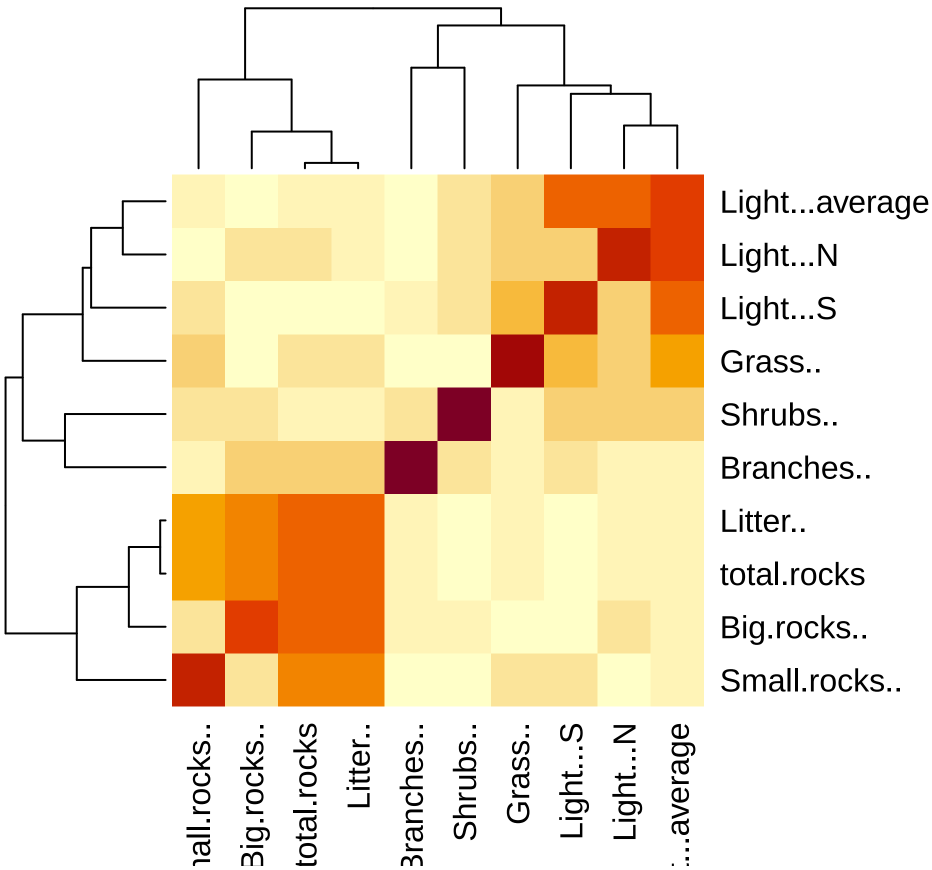
```
## pdf 
##   2
```

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.

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




```r
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

```r
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

```r
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

```r
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

```r
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

```r
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

```r
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.

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

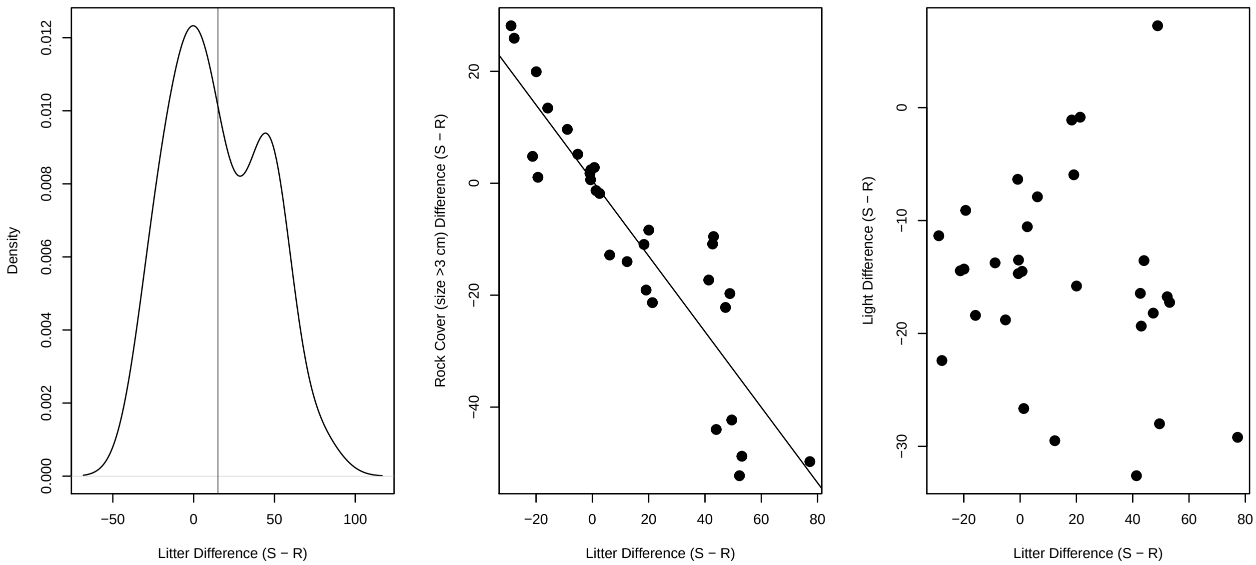
```
##
##  Pearson's product-moment correlation
##
## data:  env.dif[, "Big.rocks.."] and env.dif[, "Litter.."]
## t = -11.106, df = 28, p-value = 9.054e-12
## alternative hypothesis: true correlation is not equal to 0
## 95 percent confidence interval:
##  -0.9530598 -0.8039735
## sample estimates: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

```r
pdf("./results/scrl_litterVbigrocks.pdf", width = 5, height = 5)
dev.off()
```

```
## pdf
##   2
```

```r
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)
```

```r
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)
```



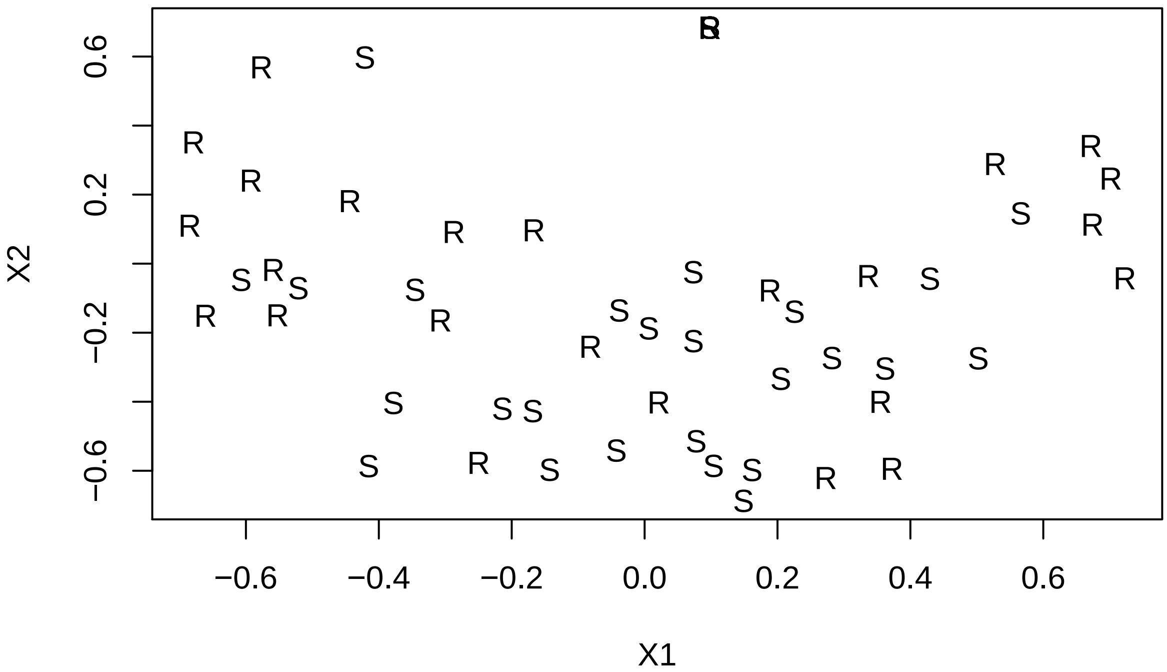

```r
pdf("./results/scrl_litter_effects.pdf", width = 10, height = 5)
par(mfrow = c(1,3))
plot(density(tapply(l.dat[, "Litter.."], l.dat[, "Tree.pairs"], diff)),
    main = "", xlab = "Litter Difference (S - R)")
abline(v = mean(tapply(l.dat[, "Litter.."], l.dat[, "Tree.pairs"], diff)),
    lwd = 0.5)
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
```

```r
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
```

```r
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
## 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...avera
## 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
```

```r
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"]
## 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
```

```r
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.."],
## 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

	Susceptible Mean	Susceptible SE	Resistant Mean	Resistant SE
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.")
```

Table 15: 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.

Table 16: 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)
```

```r
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.

Table 17: 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

Table 18: 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

```r
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.

Table 19: 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

Table 20: 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*.

Table 21: 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

	t	df	p-value	Mean Difference	Lower CI 95%	Upper CI 95%
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

```r
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(abs(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(-1.0, 0),
                  ylab = "Relativized Difference (S - R)", border = "NA")
segments(bp.out[, 1], v.ard.mu + v.ard.se,
```

```r
         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.

```r
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
```

```r
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

```r
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
)
```

```r
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
```

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

```
## [1] 0.9612754
```

```r
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.se
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:

```r
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
```

```r
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
```

```r
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:

```r
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
```

```r
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
```

```r
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:

```r
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
```

```r
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
```

```r
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
```

```r
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
```

```r
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
```

```r
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
```

```r
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
```

```r
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
```

```r
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
```

```r
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
```

```r
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
```

```r
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
```

```r
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
```

```r
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
```

```r
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
```

```r
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
```

```r
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
```

```r
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
```

```r
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
```

```r
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
```

```r
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
```

```r
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
```

```r
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
```

```r
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
```

```r
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
```

```r
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
```

```r
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
```

```r
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
```

```r
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
```

```r
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
```

```r
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
```

```r
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
```

```r
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
```

```r
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
```

```r
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
```

```r
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
```

```r
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
```

```r
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
```

```r
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

```r
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
```

```r
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
```

```r
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
```

```r
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
```

```r
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

```r
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 18:38:04 2021

	Df	SumOfSqs	R2	F	Pr(>F)
crown.radius	1	4.68	0.02	0.74	0.4920
rock.sm	1	30.45	0.13	4.78	0.0290
rock.lg	1	29.53	0.13	4.64	0.0270
light	1	2.01	0.01	0.32	0.7820
litter	1	29.47	0.13	4.63	0.0260
Residual	24	152.87	0.67		
Total	29	226.87	1.00		

```r
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 18:38:04 2021

	Df	SumOfSqs	R2	F	Pr(>F)
litter	1	11.61	0.03	0.94	0.4480
rock.sm	1	12.98	0.04	1.05	0.3730
rock.lg	1	11.43	0.03	0.92	0.4540
light	1	7.27	0.02	0.59	0.8290
crown.radius	1	11.07	0.03	0.89	0.5230
Residual	24	297.41	0.83		
Total	29	358.29	1.00		

```r
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 18:38:05 2021

	Df	SumOfSqs	R2	F	Pr(>F)
Moth	1	0.83	0.04	2.35	0.0305
Residual	58	20.54	0.96		
Total	59	21.37	1.00		

```
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 18:38:09 2021

	Df	SumOfSqs	R2	F	Pr(>F)
Moth	1	5.17	0.31	25.83	0.0001
Residual	58	11.62	0.69		
Total	59	16.79	1.00		

```
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 % Fri May 7 17:47:20 2021

	statistic.t	parameter.df	estimate.mean of x	p.value
l.A	-2.24873	29.00000	-1.54400	0.03230
l.R	-2.95490	29.00000	-2.53333	0.00615
l.D	-2.44677	29.00000	-0.43698	0.02071
p.A	-7.13460	29.00000	-22.43333	0.00000
p.R	-7.47696	29.00000	-1.30000	0.00000
p.D	-4.21918	29.00000	-0.29546	0.00022

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 % Fri May 7 17:47:20 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"],
```

	statistic.t	parameter.df	estimate.mean of x	p.value
trunk.radius	-3.59977	29.00000	-3.13667	0.00117
crown.radius	-4.61833	29.00000	-58.48667	0.00007
litter	2.86654	29.00000	15.07000	0.00765
rocks	-2.81780	29.00000	-14.65867	0.00862
rock.lg	-2.46174	29.00000	-9.68367	0.02001
rock.sm	-2.07917	29.00000	-4.97500	0.04655
light	-9.27275	29.00000	-15.13333	0.00000

```
                       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
## % Wed Apr 21 12:26:26 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
## % Wed Apr 21 12:26:30 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}
```

```r
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
```

```r
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
```

```r
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
```

```r
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
```

```r
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
```

```r
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
```

```r
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
```

```r
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
```

```r
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
```

```r
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
```

```r
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
```

```r
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
```

```r
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
```

```r
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
```

```r
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
```

```r
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
```

```r
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
```

```r
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)
```

```r
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
```

```r
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
```

```r
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))
```

```r
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 c
```

```r
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 c
```

```r
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"]))
```

```r
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.o
colnames(sem.dat)[colnames(sem.dat) == "crown.radius"] <- "crown"
colnames(sem.dat)[colnames(sem.dat) == "trunk.radius"] <- "trunk"
```

```r
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 % Fri May 7 17:47:21 2021

	statistic.t	parameter.df	estimate.mean of x	p.value
Litter..	30.56225	59.00000	79.80633	0.00000
Big.rocks..	7.69468	59.00000	14.90117	0.00000
Small.rocks..	3.84706	59.00000	4.79783	0.00030
Shrubs..	2.61579	59.00000	0.40567	0.01129
Grass..	1.00000	59.00000	0.02467	0.32139
Branches..	1.00000	59.00000	0.07100	0.32139
Light...N	12.09160	59.00000	17.67833	0.00000
Light...S	12.00919	59.00000	17.80833	0.00000
Light...average	13.30890	59.00000	17.74333	0.00000
Acacon	3.91476	59.00000	0.02833	0.00024
Acaame	4.79957	59.00000	0.14000	0.00001
Acaobp	1.12174	59.00000	0.14933	0.26652
Sterile.sp	1.00000	59.00000	0.00100	0.32139
Brown.cr		59.00000	0.00000	
Lobalp	1.98868	59.00000	0.00233	0.05138
Canros	5.70908	59.00000	0.32017	0.00000
Calare	2.04690	59.00000	0.01967	0.04513
Phydub	3.55666	59.00000	0.09633	0.00075
Rhichr	3.82975	59.00000	0.29150	0.00031
Xanlin	3.63277	59.00000	0.62233	0.00059
Xanpli	4.25869	59.00000	0.21150	0.00007
Xanele	2.54509	59.00000	0.03867	0.01356
GrBr.cr	1.00000	59.00000	0.00067	0.32139
Gray.cr	1.69236	59.00000	0.00250	0.09585
Synrur	1.67611	59.00000	0.04933	0.09901
Cerpur.Bryarg	1.23020	59.00000	0.00867	0.22350

```
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 % Fri May 7 17:47:21 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 % Fri May 7 17:47:21 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 % Fri May 7 17:47:21 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
```

	statistic.t	parameter.df	estimate.mean of x	p.value
Litter..	30.56	59.00	79.81	0.00
Big.rocks..	7.69	59.00	14.90	0.00
Small.rocks..	3.85	59.00	4.80	0.00
Shrubs..	2.62	59.00	0.41	0.01
Light...N	12.09	59.00	17.68	0.00
Light...S	12.01	59.00	17.81	0.00
Light...average	13.31	59.00	17.74	0.00
Acacon	3.91	59.00	0.03	0.00
Acaame	4.80	59.00	0.14	0.00
Canros	5.71	59.00	0.32	0.00
Calare	2.05	59.00	0.02	0.05
Phydub	3.56	59.00	0.10	0.00
Rhichr	3.83	59.00	0.29	0.00
Xanlin	3.63	59.00	0.62	0.00
Xanpli	4.26	59.00	0.21	0.00
Xanele	2.55	59.00	0.04	0.01

```
              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
```

	statistic.t	parameter.df	estimate.mean of x	p.value
Apache.plume	4.64843	59.00000	6.53333	0.00002
Juniperus.monosperma	1.00000	59.00000	0.08333	0.32139
Rhus.trilobata	1.80478	59.00000	1.58333	0.07621
Asteraceae.ovales	4.64433	59.00000	6.23333	0.00002
Bouteloua.gracilis		59.00000	0.00000	
Pinus.edulis.R	1.00000	59.00000	0.16667	0.32139
Pinus.edulis.S		59.00000	0.00000	
Stipa.A		59.00000	0.00000	
Stipa.B		59.00000	0.00000	
Stipa.très.grand		59.00000	0.00000	
Ephedra		59.00000	0.00000	
Rabbit.brush	1.00000	59.00000	0.33333	0.32139
Grande.grass.corymbe		59.00000	0.00000	
Boraginacée.rosette.grise		59.00000	0.00000	
Avena	1.76218	59.00000	0.10000	0.08322
Grass.à.nœud		59.00000	0.00000	
Brachypode		59.00000	0.00000	
Carex		59.00000	0.00000	
Cactus		59.00000	0.00000	
Hordeum		59.00000	0.00000	
Chenopodiaceae		59.00000	0.00000	
Ribes		59.00000	0.00000	
Aster.grise		59.00000	0.00000	
Rosette.frisée		59.00000	0.00000	
Chamaephyte.gris		59.00000	0.00000	
Castilleja		59.00000	0.00000	
Opuntia		59.00000	0.00000	
Rubiaceae		59.00000	0.00000	
Plante.grise.allongée	1.00000	59.00000	0.05000	0.32139
Scarlet.glia	1.00000	59.00000	0.03333	0.32139
Andropogon		59.00000	0.00000	

	statistic.t	parameter.df	estimate.mean of x	p.value
Apache.plume	4.65	59.00	6.53	0.00
Asteraceae.ovales	4.64	59.00	6.23	0.00

```
                  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))
```

```r
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
```

```r
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
```

```r
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
```

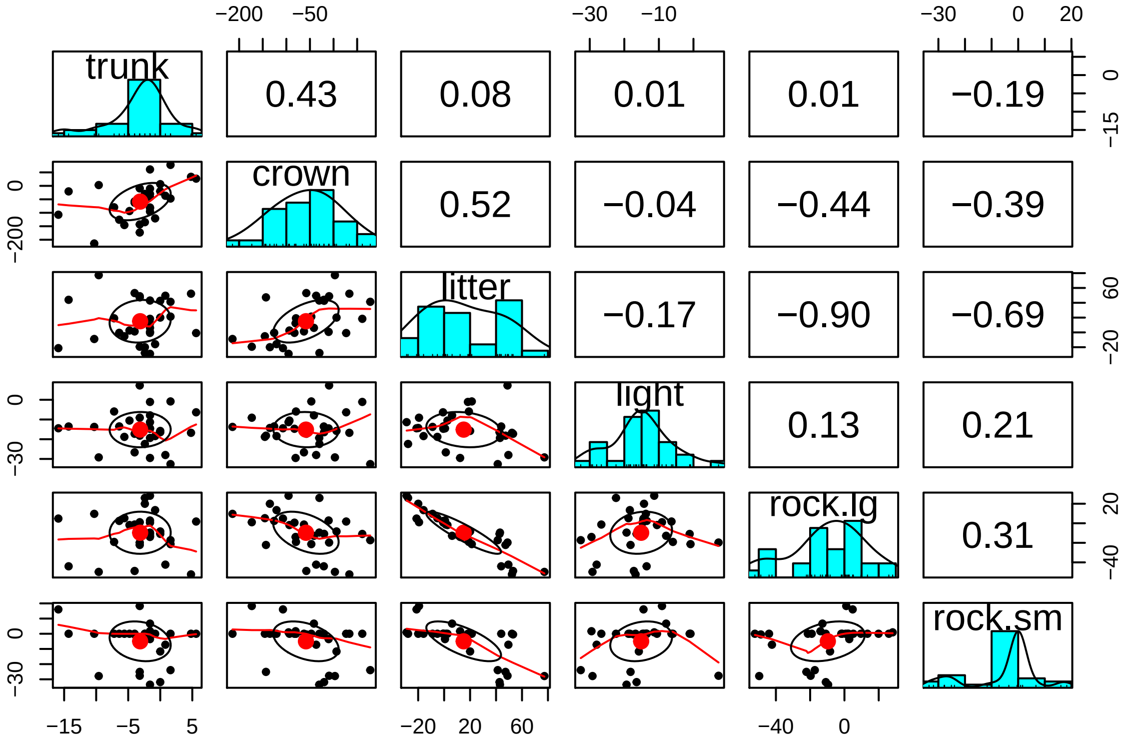
SEM Variable R-Squares

```
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, " ")
```

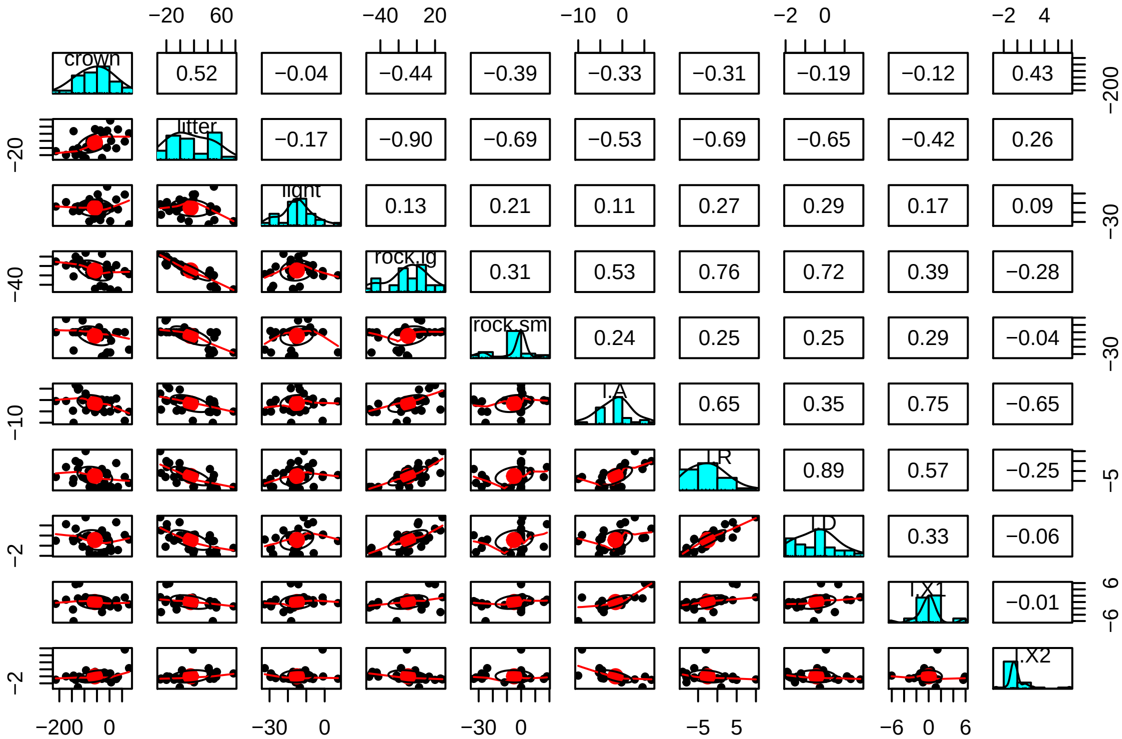
```r
    out <- lapply(out, function(x) x[x != ""])
    out <- do.call(rbind, out)
    out.names <- out[, 1]
    out <- as.numeric(out[, 2])
    names(out) <- out.names
    return(out)
}

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

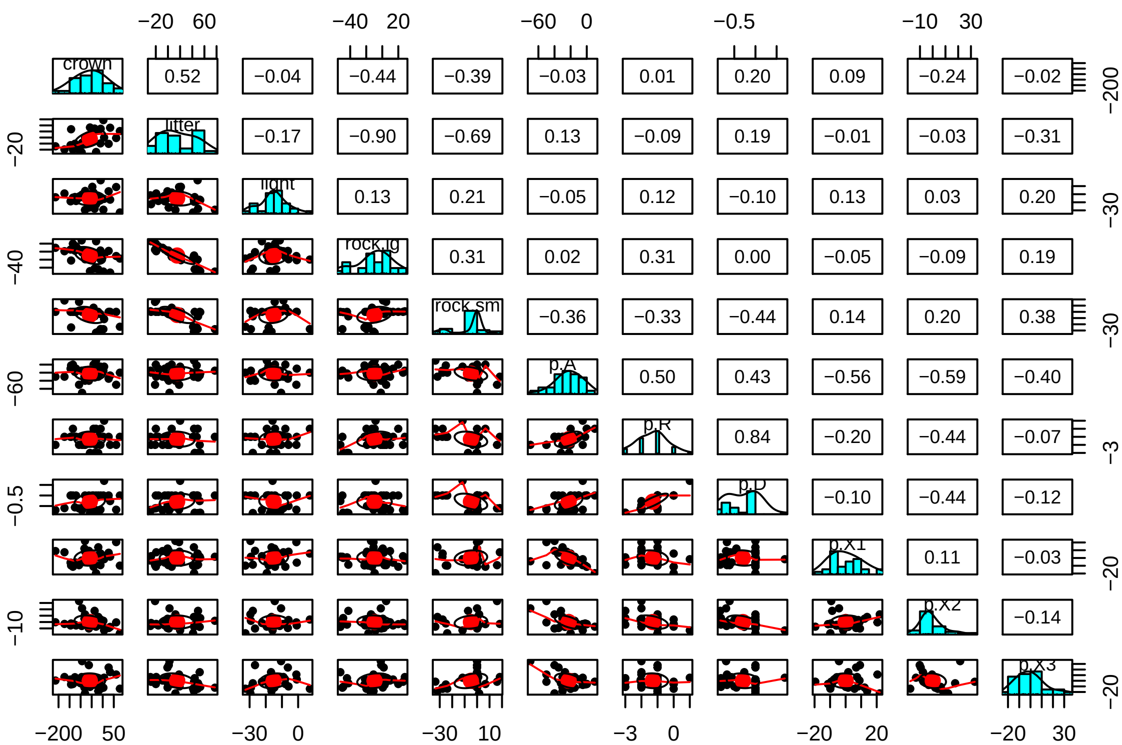
```r
pairs.panels(sem.dat[, c("trunk", "crown", "litter", "light", "rock.lg", "rock.sm")])
```




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



```r
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

```r
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

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

% latex table generated in R 4.0.4 by xtable 1.8-4 package % Fri May 7 17:47:28 2021

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

% latex table generated in R 4.0.4 by xtable 1.8-4 package % Fri May 7 17:47:28 2021

SEM Parameter Estimates

```r
xtable::xtable(table_results(fit.l.all))
```

% latex table generated in R 4.0.4 by xtable 1.8-4 package % Fri May 7 17:47:28 2021

```r
xtable::xtable(table_results(fit.v.all))
```

% latex table generated in R 4.0.4 by xtable 1.8-4 package % Fri May 7 17:47:28 2021

```r
xtable::xtable(table_results(fit.l.rot.all))
```

% latex table generated in R 4.0.4 by xtable 1.8-4 package % Fri May 7 17:47:29 2021

```r
xtable::xtable(table_results(fit.v.rot.all))
```

% latex table generated in R 4.0.4 by xtable 1.8-4 package % Fri May 7 17:47:29 2021

SEM Model Fit Measures

```r
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")
```

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

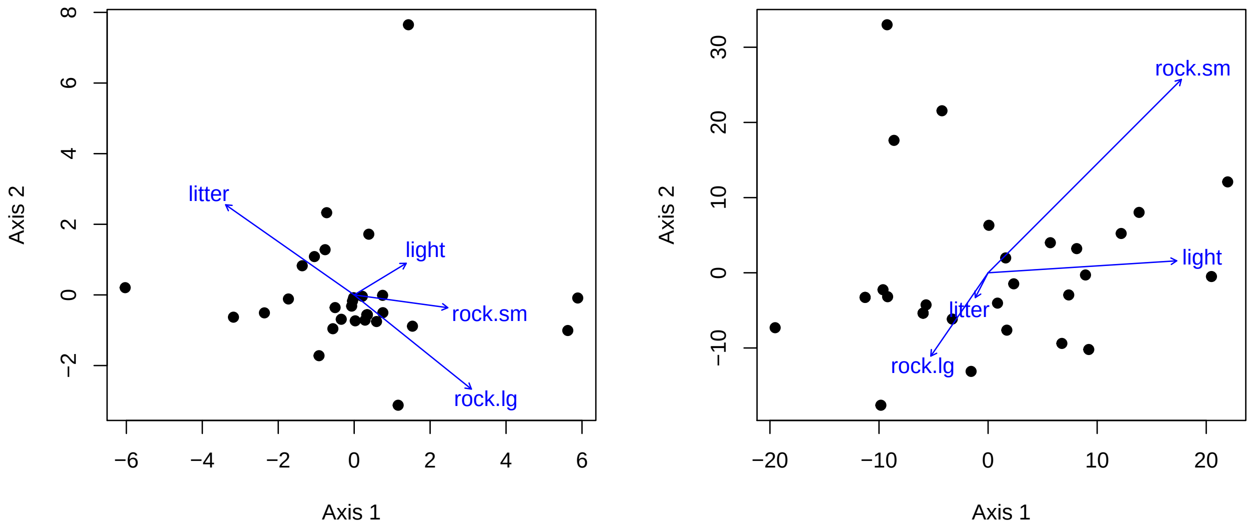
% latex table generated in R 4.0.4 by xtable 1.8-4 package % Fri May 7 17:47:29 2021

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

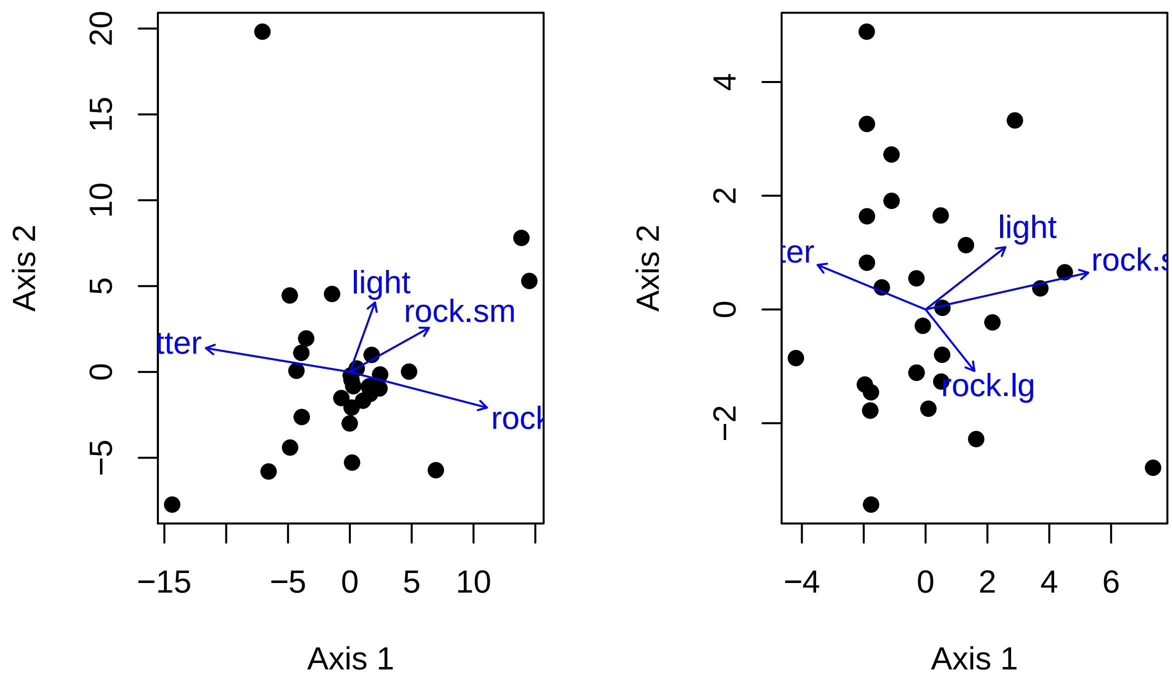
% latex table generated in R 4.0.4 by xtable 1.8-4 package % Fri May 7 17:47:29 2021

Ordination Plots

```r
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)
```




```r
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)
```



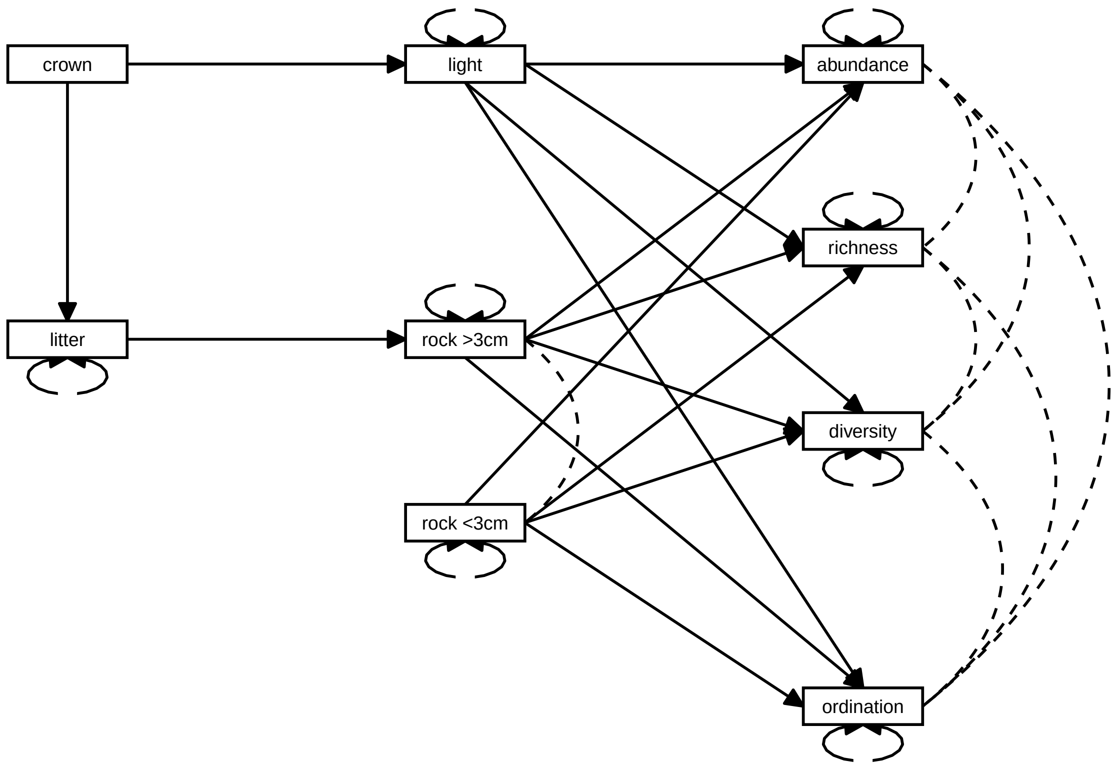
SEM Plots

```
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"] <- ""

plot(tg.apriori)
```

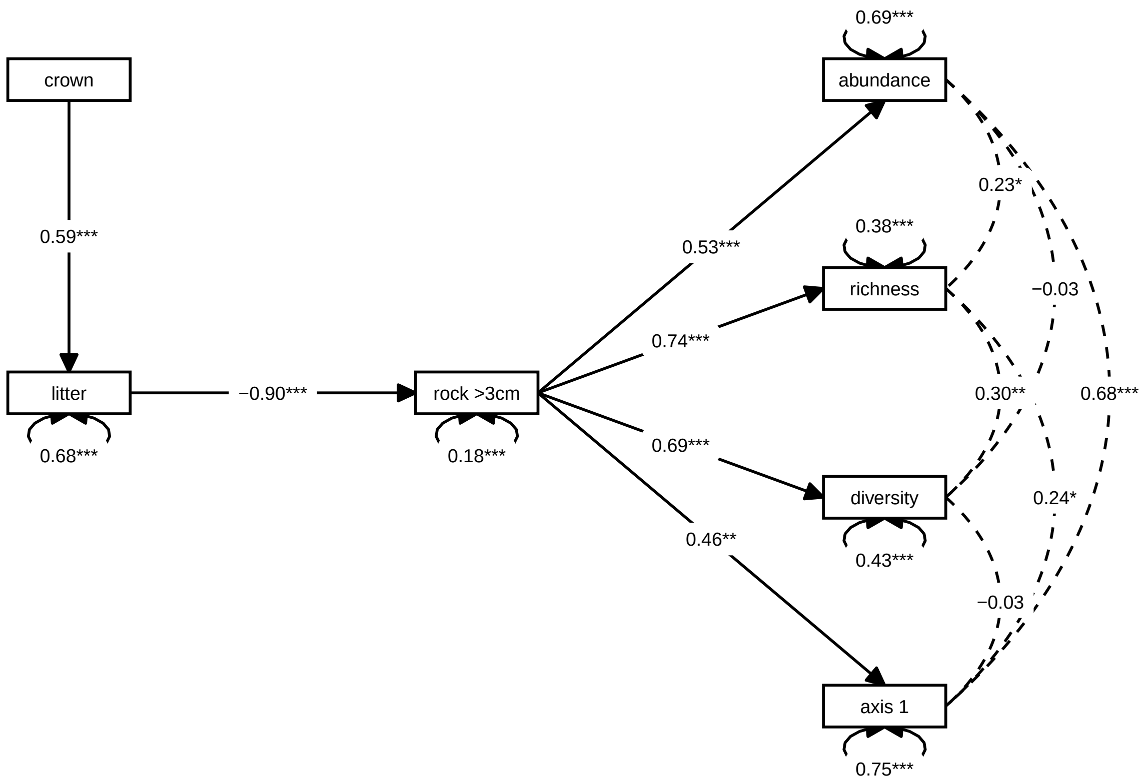



```
lay <- get_layout("crown", "", "", "",      "l.A",
                  "", "",        "", "", "",
                  "", "",        "", "",          "l.R",
                  "litter", "", "rock.lg", "", "",
                  "", "",        "", "", "l.D",
                  "", "", "", "", "",
                  "", "",        "", "",     "rot.l.X1",
                  rows = 7)
tg.l.rot.all <- prepare_graph(fit.l.rot.all,
                              layout = lay,
```

```r
                              text_size = 2.6)
```

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

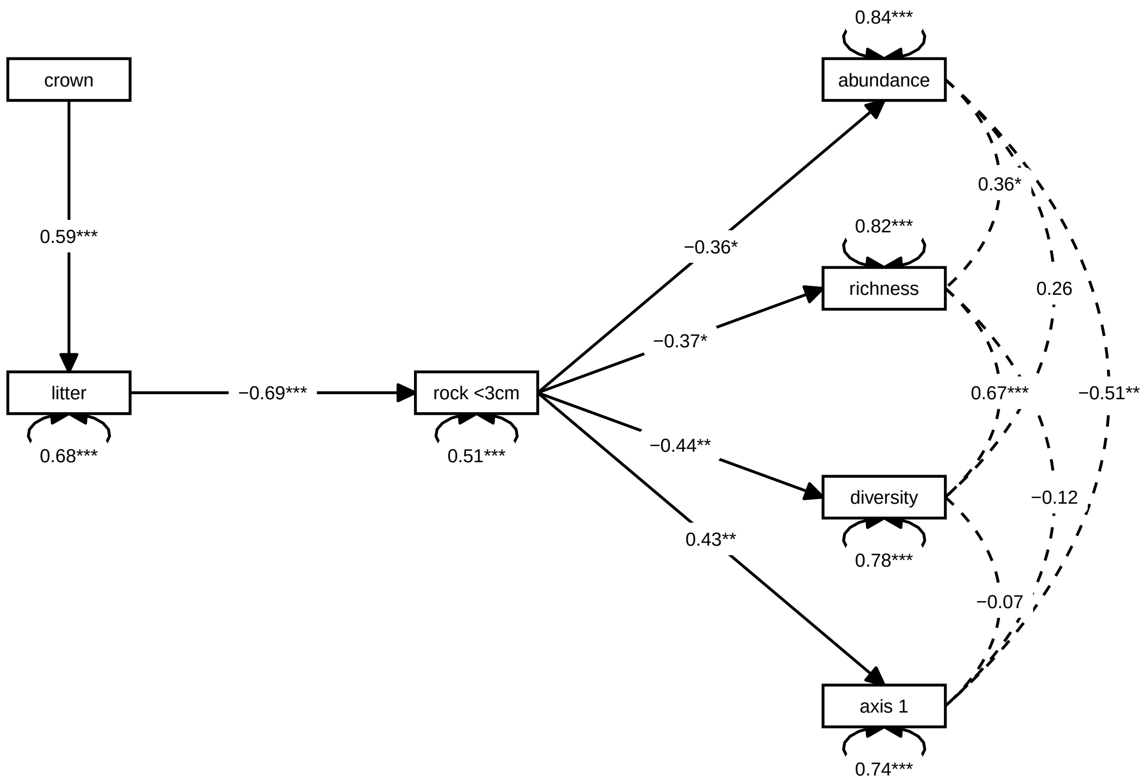
```r
nodes(tg.l.rot.all)[nodes(tg.l.rot.all)[, "name"] ==
                    "l.A", "label"] <- "abundance"
nodes(tg.l.rot.all)[nodes(tg.l.rot.all)[, "name"] ==
                    "l.R", "label"] <- "richness"
nodes(tg.l.rot.all)[nodes(tg.l.rot.all)[, "name"] ==
                    "l.D", "label"] <- "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)
```




```r
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^{-12}. 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 X^2 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 ($R^2 = 0.04$, p-value = 0.031) and plant (*R ˆ2* = 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 (*df* = 19, $X^2 = 26.6808212$, p-value = 0.1123101) and plant (*df* = 22, $X^2 = 30.7624162$, p-value = 0.1010805) data well, as neither model showed significant differences from their observed covariance matrices based on their respective X^2 Goodness of Fit tests. Moth crown herbivory effects on litter explained significant amounts of community variation in differences in lichen abundance ($R^2 = 0.282$), richness ($R^2 = 0.601$) and diversity ($R^2 = 0.539$), as well as in plant community differences in abundance ($R^2 = 0.131$), richness ($R^2 = 0.131$) and diversity ($R^2 = 0.196$). Whole community differences between moth susceptible and resistant trees were also signifcantly explained by crown size differences for both lichens ($R^2 = 0.219$) and plants ($R^2 = 0.215$). 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

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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).

```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 % Fri May 7 17:47:35 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.

```r
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

	label	est_sig	se	pval
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

```r
write.csv(file = "results/sem_results_combined.csv",
          sem.combined,
          row.names = FALSE)
```

	lhs	op	rhs	mi	epc	sepc.lv	sepc.all	sepc.nox
34	crown	~~	crown	0.00	0.00	0.00	0.00	0.00
35	crown	~~	trunk	0.00	-0.00	-0.00		-0.00
36	trunk	~~	trunk	0.00	0.00	0.00	0.00	0.00
37	light	~~	litter	0.93	-0.14	-0.14	-0.18	-0.18
38	light	~~	rock.lg	0.08	-0.02	-0.02	-0.05	-0.05
39	light	~~	l.A	3.81	1.06	1.06	1.30	1.30
40	light	~~	l.R	0.61	-0.90	-0.90	-1.49	-1.49
41	light	~~	l.D	0.01	-0.12	-0.12	-0.18	-0.18
42	light	~~	rot.l.X1	4.26	-1.18	-1.18	-1.39	-1.39
43	light	~~	rot.l.X2	6.42	4.61	4.61	4.85	4.85
44	litter	~~	rock.lg	0.02	-0.02	-0.02	-0.05	-0.05
45	litter	~~	l.A	2.49	-0.05	-0.05	-0.07	-0.07
46	litter	~~	l.R	2.41	0.10	0.10	0.20	0.20
47	litter	~~	l.D	1.29	-0.09	-0.09	-0.16	-0.16
48	litter	~~	rot.l.X1	1.88	0.04	0.04	0.06	0.06
49	litter	~~	rot.l.X2	4.51	-0.21	-0.21	-0.27	-0.27
50	rock.lg	~~	l.A	0.54	0.01	0.01	0.02	0.02
51	rock.lg	~~	l.R	0.62	0.02	0.02	0.07	0.07
52	rock.lg	~~	l.D	0.53	-0.02	-0.02	-0.07	-0.07
53	rock.lg	~~	rot.l.X1	1.06	-0.01	-0.01	-0.03	-0.03
54	rock.lg	~~	rot.l.X2	0.42	0.02	0.02	0.06	0.06
55	light	~	litter	0.93	-0.21	-0.21	-0.21	-0.21
56	light	~	rock.lg	0.49	0.15	0.15	0.15	0.15
57	light	~	l.A	0.36	0.24	0.24	0.24	0.24
58	light	~	l.R	0.42	0.18	0.18	0.18	0.18
59	light	~	l.D	0.45	0.20	0.20	0.20	0.20
60	light	~	rot.l.X1	0.35	0.27	0.27	0.27	0.27
61	light	~	rot.l.X2	0.93	3.73	3.73	3.74	3.74
62	litter	~	light	0.93	-0.15	-0.15	-0.15	-0.15
63	litter	~	rock.lg	0.02	-0.09	-0.09	-0.09	-0.09
64	litter	~	l.A	0.05	0.06	0.06	0.06	0.06
65	litter	~	l.R	0.00	0.01	0.01	0.01	0.01
66	litter	~	l.D	0.42	-0.20	-0.20	-0.19	-0.19
67	litter	~	rot.l.X1	0.01	-0.02	-0.02	-0.02	-0.02
68	litter	~	rot.l.X2	3.62	-0.44	-0.44	-0.44	-0.44
69	rock.lg	~	light	0.07	-0.02	-0.02	-0.02	-0.02
70	rock.lg	~	l.A	0.52	-0.07	-0.07	-0.07	-0.07
71	rock.lg	~	l.R	0.00	-0.00	-0.00	-0.00	-0.00
72	rock.lg	~	l.D	0.00	0.00	0.00	0.00	0.00
73	rock.lg	~	rot.l.X1	0.93	-0.09	-0.09	-0.09	-0.09
74	rock.lg	~	rot.l.X2	0.11	-0.03	-0.03	-0.03	-0.03
75	rock.lg	~	crown	0.23	0.04	0.04	0.04	0.04
76	rock.lg	~	trunk	1.07	0.08	0.08	0.08	0.08
77	l.A	~	litter	0.54	0.04	0.04	0.04	0.04
82	l.A	~	crown	6.63	0.07	0.07	0.07	0.07
83	l.A	~	trunk	0.98	0.02	0.02	0.02	0.02
84	l.R	~	litter	0.62	0.09	0.09	0.10	0.10
89	l.R	~	crown	1.36	-0.07	-0.07	-0.07	-0.07
90	l.R	~	trunk	0.34	-0.03	-0.03	-0.03	-0.03
91	l.D	~	litter	0.53	-0.11	-0.11	-0.11	-0.11
96	l.D	~	crown	1.25	0.08	0.08	0.08	0.08
97	l.D	~	trunk	2.60	0.10	0.10	0.10	0.10
98	rot.l.X1	~	litter	1.06	-0.06	-0.06	-0.06	-0.06
103	rot.l.X1	~	crown	6.42	-0.07	-0.07	-0.07	-0.07
104	rot.l.X1	~	trunk	0.63	-0.02	-0.02	-0.02	-0.02
105	rot.l.X2	~	litter	0.42	0.12	0.12	0.12	0.12
110	rot.l.X2	~	crown	9.20	0.28	0.28	0.28	0.28
111	rot.l.X2	~	trunk	0.76	0.07	0.07	0.07	0.07
112	crown	~	light	0.00	0.01	0.01	0.01	0.01

	lhs	op	rhs	mi	epc	sepc.lv	sepc.all	sepc.nox
42	crown	~~	crown	0.00	-0.00	0.00	0.00	0.00
43	crown	~~	trunk	0.00	0.00	0.00		0.00
44	trunk	~~	trunk	0.00	0.00	0.00	0.00	0.00
45	light	~~	litter	0.93	-0.14	-0.14	-0.18	-0.18
46	light	~~	rock.sm	0.47	0.09	0.09	0.13	0.13
47	light	~~	p.A	2.22	-2.13	-2.13	-2.37	-2.37
48	light	~~	p.R	1.48	-2.22	-2.22	-2.49	-2.49
49	light	~~	p.D	0.40	1.16	1.16	1.34	1.34
50	light	~~	rot.p.X1	1.45	-1.81	-1.81	-2.14	-2.14
51	light	~~	rot.p.X2	0.77	-2.35	-2.35	-2.44	-2.44
52	light	~~	rot.p.X3	1.18	2.71	2.71	2.81	2.81
53	litter	~~	rock.sm	0.00	-0.01	-0.01	-0.02	-0.02
54	litter	~~	p.A	1.90	0.09	0.09	0.12	0.12
55	litter	~~	p.R	4.87	-0.19	-0.19	-0.25	-0.25
56	litter	~~	p.D	2.09	0.12	0.12	0.17	0.17
57	litter	~~	rot.p.X1	0.94	0.07	0.07	0.10	0.10
58	litter	~~	rot.p.X2	0.29	0.07	0.07	0.08	0.08
59	litter	~~	rot.p.X3	2.17	-0.17	-0.17	-0.21	-0.21
60	rock.sm	~~	p.A	0.00	0.00	0.00	0.01	0.01
61	rock.sm	~~	p.R	9.48	-0.27	-0.27	-0.42	-0.42
62	rock.sm	~~	p.D	4.53	0.19	0.19	0.30	0.30
63	rock.sm	~~	rot.p.X1	0.02	-0.01	-0.01	-0.02	-0.02
64	rock.sm	~~	rot.p.X2	0.02	-0.02	-0.02	-0.03	-0.03
65	rock.sm	~~	rot.p.X3	0.01	-0.01	-0.01	-0.02	-0.02
66	light	~	litter	0.93	-0.21	-0.21	-0.21	-0.21
67	light	~	rock.sm	1.29	0.22	0.22	0.22	0.22
68	light	~	p.A	1.76	-0.71	-0.71	-0.71	-0.71
69	light	~	p.R	1.82	-0.71	-0.71	-0.72	-0.72
70	light	~	p.D	1.55	-0.55	-0.55	-0.55	-0.55
71	light	~	rot.p.X1	1.40	0.53	0.53	0.53	0.53
72	light	~	rot.p.X2	0.06	0.94	0.94	0.94	0.94
73	light	~	rot.p.X3	0.54	-2.85	-2.85	-2.85	-2.85
74	litter	~	light	0.93	-0.15	-0.15	-0.15	-0.15
75	litter	~	rock.sm	0.00	-0.02	-0.02	-0.02	-0.02
76	litter	~	p.A	0.00	-0.00	-0.00	-0.00	-0.00
77	litter	~	p.R	3.55	-0.36	-0.36	-0.37	-0.37
78	litter	~	p.D	0.50	-0.14	-0.14	-0.14	-0.14
79	litter	~	rot.p.X1	0.28	-0.11	-0.11	-0.11	-0.11
80	litter	~	rot.p.X2	0.02	0.03	0.03	0.03	0.03
81	litter	~	rot.p.X3	1.84	-0.25	-0.25	-0.25	-0.25
82	rock.sm	~	light	0.44	0.09	0.09	0.09	0.09
83	rock.sm	~	p.A	0.85	-0.19	-0.19	-0.19	-0.19
84	rock.sm	~	p.R	5.06	-0.45	-0.45	-0.46	-0.46
85	rock.sm	~	p.D	1.04	-0.22	-0.22	-0.22	-0.22
86	rock.sm	~	rot.p.X1	0.07	0.06	0.06	0.06	0.06
87	rock.sm	~	rot.p.X2	0.53	0.14	0.14	0.14	0.14
88	rock.sm	~	rot.p.X3	0.63	-0.15	-0.15	-0.15	-0.15
89	rock.sm	~	crown	0.08	-0.05	-0.05	-0.05	-0.05
90	rock.sm	~	trunk	1.01	-0.13	-0.13	-0.13	-0.14
91	p.A	~	litter	0.00	0.01	0.01	0.01	0.01
97	p.A	~	crown	3.30	-0.13	-0.13	-0.13	-0.13
98	p.A	~	trunk	0.36	-0.04	-0.04	-0.04	-0.04
99	p.R	~	litter	9.48	-0.36	-0.36	-0.36	-0.36
105	p.R	~	crown	2.08	-0.13	-0.13	-0.13	-0.13
106	p.R	~	trunk	0.18	-0.04	-0.04	-0.04	-0.04
107	p.D	~	litter	4.53	0.25	0.25	0.25	0.25
113	p.D	~	crown	1.74	0.12	0.12	0.12	0.12
114	p.D	~	trunk	1.06	0.09	0.09	0.09	0.09
115	rot.p.X1	~	litter	0.02	-0.01	-0.01	-0.01	-0.01

	label	est_sig	se	pval	confint
1	light.ON.crown	-0.04	0.18	0.84	[-0.39, 0.32]
2	litter.ON.crown	0.52***	0.16	0.00	[0.22, 0.83]
3	rock.lg.ON.litter	-0.90***	0.08	0.00	[-1.06, -0.75]
4	l.A.ON.light	0.04	0.15	0.81	[-0.27, 0.34]
5	l.A.ON.rock.lg	0.53***	0.15	0.00	[0.22, 0.83]
6	l.R.ON.light	0.17	0.11	0.14	[-0.05, 0.39]
7	l.R.ON.rock.lg	0.74***	0.11	0.00	[0.52, 0.96]
8	l.D.ON.light	0.20	0.12	0.11	[-0.04, 0.44]
9	l.D.ON.rock.lg	0.69***	0.12	0.00	[0.45, 0.93]
10	l.X1.ON.light	0.12	0.17	0.48	[-0.21, 0.45]
11	l.X1.ON.rock.lg	0.37*	0.17	0.02	[0.05, 0.70]
12	l.X2.ON.light	0.13	0.17	0.46	[-0.21, 0.47]
13	l.X2.ON.rock.lg	-0.30	0.17	0.09	[-0.64, 0.05]
14	l.A.WITH.l.R	0.23*	0.10	0.03	[0.03, 0.43]
15	l.A.WITH.l.D	-0.03	0.10	0.73	[-0.23, 0.16]
16	l.R.WITH.l.D	0.30**	0.09	0.00	[0.12, 0.48]
17	l.A.WITH.l.X1	0.52**	0.17	0.00	[0.19, 0.85]
18	l.R.WITH.l.X1	0.24*	0.11	0.03	[0.03, 0.46]
19	Variances.light	0.97***	0.25	0.00	[0.48, 1.45]
20	Variances.litter	0.70***	0.18	0.00	[0.35, 1.06]
21	Variances.rock.lg	0.18***	0.05	0.00	[0.09, 0.27]
22	Variances.l.A	0.69***	0.18	0.00	[0.34, 1.04]
23	Variances.l.R	0.38***	0.10	0.00	[0.19, 0.57]
24	Variances.l.D	0.43***	0.11	0.00	[0.21, 0.65]
25	Variances.l.X1	0.81***	0.21	0.00	[0.40, 1.21]
26	Variances.l.X2	0.88***	0.23	0.00	[0.43, 1.32]
27	l.A.WITH.l.X2	-0.49**	0.17	0.00	[-0.82, -0.16]
28	l.R.WITH.l.X2	-0.06	0.11	0.59	[-0.26, 0.15]
29	l.D.WITH.l.X1	0.02	0.11	0.83	[-0.19, 0.23]
30	l.D.WITH.l.X2	0.11	0.11	0.32	[-0.11, 0.34]
31	l.X1.WITH.l.X2	0.08	0.15	0.61	[-0.22, 0.38]
32	Variances.crown	0.97	0.00		[0.97, 0.97]

	label	est_sig	se	pval	confint
1	light.ON.crown	-0.04	0.18	0.84	[-0.39, 0.32]
2	litter.ON.crown	0.52***	0.16	0.00	[0.22, 0.83]
3	rock.sm.ON.litter	-0.69***	0.13	0.00	[-0.95, -0.43]
4	p.A.ON.light	0.02	0.17	0.89	[-0.31, 0.36]
5	p.A.ON.rock.sm	-0.36*	0.17	0.03	[-0.70, -0.03]
6	p.R.ON.light	0.18	0.15	0.22	[-0.11, 0.48]
7	p.R.ON.rock.sm	-0.63***	0.17	0.00	[-0.96, -0.31]
8	p.R.ON.litter	-0.39***	0.10	0.00	[-0.57, -0.20]
9	p.D.ON.light	-0.01	0.16	0.94	[-0.33, 0.31]
10	p.D.ON.rock.sm	-0.44**	0.16	0.01	[-0.76, -0.12]
11	p.X1.ON.light	0.11	0.18	0.56	[-0.25, 0.46]
12	p.X1.ON.rock.sm	0.12	0.18	0.49	[-0.23, 0.48]
13	p.X2.ON.light	-0.02	0.18	0.93	[-0.37, 0.34]
14	p.X2.ON.rock.sm	0.21	0.18	0.25	[-0.14, 0.56]
15	p.X3.ON.light	0.13	0.17	0.44	[-0.20, 0.46]
16	p.X3.ON.rock.sm	0.35*	0.17	0.03	[0.02, 0.68]
17	p.A.WITH.p.X2	-0.50**	0.18	0.01	[-0.86, -0.13]
18	p.A.WITH.p.R	0.32*	0.15	0.03	[0.03, 0.61]
19	p.A.WITH.p.D	0.26	0.16	0.09	[-0.04, 0.57]
20	p.R.WITH.p.D	0.63***	0.17	0.00	[0.29, 0.97]
21	p.A.WITH.p.X1	-0.50**	0.19	0.01	[-0.86, -0.13]
22	p.R.WITH.p.X1	-0.13	0.15	0.36	[-0.42, 0.15]
23	Variances.light	0.97***	0.25	0.00	[0.48, 1.45]
24	Variances.litter	0.70***	0.18	0.00	[0.35, 1.06]
25	Variances.rock.sm	0.51***	0.13	0.00	[0.25, 0.77]
26	Variances.p.A	0.84***	0.22	0.00	[0.42, 1.27]
27	Variances.p.R	0.67***	0.17	0.00	[0.33, 1.00]
28	Variances.p.D	0.78***	0.20	0.00	[0.38, 1.17]
29	Variances.p.X1	0.94***	0.24	0.00	[0.46, 1.41]
30	Variances.p.X2	0.93***	0.24	0.00	[0.46, 1.40]
31	Variances.p.X3	0.81***	0.21	0.00	[0.40, 1.22]
32	p.A.WITH.p.X3	-0.26	0.16	0.11	[-0.57, 0.05]
33	p.R.WITH.p.X2	-0.31*	0.15	0.04	[-0.61, -0.01]
34	p.R.WITH.p.X3	0.02	0.13	0.89	[-0.24, 0.28]
35	p.D.WITH.p.X1	-0.03	0.16	0.85	[-0.33, 0.28]
36	p.D.WITH.p.X2	-0.33*	0.17	0.04	[-0.66, -0.01]
37	p.D.WITH.p.X3	0.05	0.15	0.74	[-0.24, 0.33]
38	p.X1.WITH.p.X2	0.08	0.17	0.64	[-0.25, 0.42]
39	p.X1.WITH.p.X3	-0.10	0.16	0.55	[-0.41, 0.22]
40	p.X2.WITH.p.X3	-0.21	0.16	0.21	[-0.52, 0.11]
41	Variances.crown	0.97	0.00		[0.97, 0.97]

	label	est_sig	se	pval	confint
1	light.ON.crown	-0.05	0.20	0.80	[-0.45, 0.34]
2	litter.ON.crown	0.59***	0.17	0.00	[0.26, 0.93]
3	light.ON.trunk	0.03	0.20	0.87	[-0.36, 0.43]
4	litter.ON.trunk	-0.17	0.17	0.31	[-0.50, 0.16]
5	rock.lg.ON.litter	-0.90***	0.08	0.00	[-1.06, -0.75]
6	l.A.ON.light	0.04	0.15	0.81	[-0.27, 0.34]
7	l.A.ON.rock.lg	0.53***	0.15	0.00	[0.22, 0.83]
8	l.R.ON.light	0.17	0.11	0.14	[-0.05, 0.39]
9	l.R.ON.rock.lg	0.74***	0.11	0.00	[0.52, 0.96]
10	l.D.ON.light	0.20	0.12	0.11	[-0.04, 0.44]
11	l.D.ON.rock.lg	0.69***	0.12	0.00	[0.45, 0.93]
12	rot.l.X1.ON.light	0.05	0.16	0.75	[-0.26, 0.37]
13	rot.l.X1.ON.rock.lg	0.46**	0.16	0.00	[0.15, 0.78]
14	rot.l.X2.ON.light	0.17	0.18	0.33	[-0.18, 0.53]
15	rot.l.X2.ON.rock.lg	-0.02	0.18	0.90	[-0.38, 0.33]
16	l.A.WITH.l.R	0.23*	0.10	0.03	[0.03, 0.43]
17	l.A.WITH.l.D	-0.03	0.10	0.73	[-0.23, 0.16]
18	l.R.WITH.l.D	0.30**	0.09	0.00	[0.12, 0.48]
19	l.A.WITH.rot.l.X1	0.68***	0.18	0.00	[0.32, 1.03]
20	l.R.WITH.rot.l.X1	0.24*	0.11	0.02	[0.03, 0.45]
21	Variances.light	0.96***	0.25	0.00	[0.48, 1.45]
22	Variances.litter	0.68***	0.18	0.00	[0.34, 1.03]
23	Variances.rock.lg	0.18***	0.05	0.00	[0.09, 0.27]
24	Variances.l.A	0.69***	0.18	0.00	[0.34, 1.04]
25	Variances.l.R	0.38***	0.10	0.00	[0.19, 0.57]
26	Variances.l.D	0.43***	0.11	0.00	[0.21, 0.65]
27	Variances.rot.l.X1	0.75***	0.19	0.00	[0.37, 1.13]
28	Variances.rot.l.X2	0.94***	0.24	0.00	[0.46, 1.41]
29	l.A.WITH.rot.l.X2	-0.10	0.15	0.51	[-0.39, 0.19]
30	l.R.WITH.rot.l.X2	0.10	0.11	0.39	[-0.12, 0.31]
31	l.D.WITH.rot.l.X1	-0.03	0.10	0.79	[-0.23, 0.18]
32	l.D.WITH.rot.l.X2	0.11	0.12	0.37	[-0.12, 0.34]
33	rot.l.X1.WITH.rot.l.X2	0.15	0.16	0.32	[-0.15, 0.46]
34	Variances.crown	0.97	0.00		[0.97, 0.97]
35	crown.WITH.trunk	0.41	0.00		[0.41, 0.41]
36	Variances.trunk	0.97	0.00		[0.97, 0.97]

	label	est_sig	se	pval	confint
1	light.ON.crown	-0.05	0.20	0.80	[-0.45, 0.34]
2	litter.ON.crown	0.59***	0.17	0.00	[0.26, 0.93]
3	light.ON.trunk	0.03	0.20	0.87	[-0.36, 0.43]
4	litter.ON.trunk	-0.17	0.17	0.31	[-0.50, 0.16]
5	rock.sm.ON.litter	-0.69***	0.13	0.00	[-0.95, -0.43]
6	p.A.ON.light	0.02	0.17	0.89	[-0.31, 0.36]
7	p.A.ON.rock.sm	-0.36*	0.17	0.03	[-0.70, -0.03]
8	p.R.ON.light	0.20	0.17	0.24	[-0.13, 0.53]
9	p.R.ON.rock.sm	-0.37*	0.17	0.03	[-0.70, -0.04]
10	p.D.ON.light	-0.01	0.16	0.94	[-0.33, 0.31]
11	p.D.ON.rock.sm	-0.44**	0.16	0.01	[-0.76, -0.12]
12	rot.p.X1.ON.light	0.14	0.16	0.37	[-0.17, 0.46]
13	rot.p.X1.ON.rock.sm	0.43**	0.16	0.01	[0.12, 0.75]
14	rot.p.X2.ON.light	0.06	0.18	0.73	[-0.29, 0.42]
15	rot.p.X2.ON.rock.sm	-0.01	0.18	0.94	[-0.37, 0.34]
16	rot.p.X3.ON.light	0.07	0.18	0.70	[-0.29, 0.43]
17	rot.p.X3.ON.rock.sm	-0.01	0.18	0.94	[-0.37, 0.34]
18	p.A.WITH.rot.p.X2	-0.34	0.18	0.05	[-0.69, 0.00]
19	p.A.WITH.p.R	0.36*	0.17	0.03	[0.04, 0.69]
20	p.A.WITH.p.D	0.26	0.16	0.09	[-0.04, 0.57]
21	p.R.WITH.p.D	0.67***	0.19	0.00	[0.30, 1.05]
22	p.A.WITH.rot.p.X1	-0.51**	0.17	0.00	[-0.85, -0.17]
23	p.R.WITH.rot.p.X1	-0.12	0.14	0.42	[-0.40, 0.17]
24	Variances.light	0.96***	0.25	0.00	[0.48, 1.45]
25	Variances.litter	0.68***	0.18	0.00	[0.34, 1.03]
26	Variances.rock.sm	0.51***	0.13	0.00	[0.25, 0.77]
27	Variances.p.A	0.84***	0.22	0.00	[0.42, 1.27]
28	Variances.p.R	0.82***	0.21	0.00	[0.41, 1.24]
29	Variances.p.D	0.78***	0.20	0.00	[0.38, 1.17]
30	Variances.rot.p.X1	0.74***	0.19	0.00	[0.37, 1.12]
31	Variances.rot.p.X2	0.96***	0.25	0.00	[0.48, 1.45]
32	Variances.rot.p.X3	0.96***	0.25	0.00	[0.48, 1.45]
33	p.A.WITH.rot.p.X3	0.30	0.17	0.08	[-0.04, 0.64]
34	p.R.WITH.rot.p.X2	-0.13	0.16	0.42	[-0.46, 0.19]
35	p.R.WITH.rot.p.X3	0.31	0.17	0.07	[-0.03, 0.65]
36	p.D.WITH.rot.p.X1	-0.07	0.14	0.63	[-0.34, 0.20]
37	p.D.WITH.rot.p.X2	-0.01	0.16	0.96	[-0.32, 0.30]
38	p.D.WITH.rot.p.X3	0.30	0.17	0.07	[-0.03, 0.63]
39	rot.p.X1.WITH.rot.p.X2	-0.11	0.16	0.49	[-0.41, 0.20]
40	rot.p.X1.WITH.rot.p.X3	0.21	0.16	0.18	[-0.10, 0.53]
41	rot.p.X2.WITH.rot.p.X3	-0.18	0.18	0.31	[-0.53, 0.17]
42	Variances.crown	0.97	0.00		[0.97, 0.97]
43	crown.WITH.trunk	0.41	0.00		[0.41, 0.41]
44	Variances.trunk	0.97	0.00		[0.97, 0.97]

	χ^2	*df*	*p*-value
Lichens	18.541	13.000	0.138
Plants	12.147	14.000	0.595

	χ^2	*df*	*p*-value
Lichens	26.681	19.000	0.112
Plants	30.762	22.000	0.101

community	metric	t	df	mean	p.value
lichens	abundance	-2.249	29	-1.544	0.0323
lichens	richness	-2.955	29	-2.533	0.0062
lichens	diversity	-2.447	29	-0.437	0.0207
plants	abundance	-7.135	29	-22.433	0.0000
plants	richness	-7.477	29	-1.300	0.0000
plants	diversity	-4.219	29	-0.295	0.0002