

Rock Lichen data from Sunset Crater

M.K. Lau

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Data Summary

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

Main Results

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

Analysis and Results

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

Dependencies

```
cran.pkgs <- c("reshape2", "vegan", "ecodist", "xtable", "knitr",  
              "semPlot", "lavaan", "piecewiseSEM", "distantia",  
              "tidySEM", "readxl", "psych")  
  
## install packages that are not installed  
if (any(!(cran.pkgs %in% installed.packages()[, 1]))){
```

```

sapply(cran.pkgs[which(!(cran.pkgs %in%
                        installed.packages()[, 1]))],
       install.packages,
       dependencies = TRUE,
       repos = 'http://cran.us.r-project.org')
}

## Load libraries
sapply(cran.pkgs, library, quietly = TRUE, character.only = TRUE)

## Custom Functions

## se: Calculate the standard error of a variable.
se <- function(x){sd(x) / sqrt(length(x))}

```

Load Data

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

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

```

## Data are in ../data/scrl
l.dat <- read.csv("../data/spp_env_combined.csv")

## Fix species names
colnames(l.dat)[colnames(l.dat) == "Acasup"] <- "Acaame"

## Summary of data
summary(l.dat)

## remove dead trees
l.dat <- l.dat[l.dat[, "Live.Dead"] != 0, ]

## Lichen species list
spp.l <- c("Acacon", "Acaame", "Acaobp", "Sterile.sp", "Brown.cr",
"Lobalp", "Canros", "Calare", "Phydub", "Rhichr", "Xanlin", "Xanpli",
"Xanele", "GrBr.cr", "Gray.cr")
spp.moss <- c("Synrur", "Cerpur.Bryarg")

## Create a community matrix
com <- l.dat[, colnames(l.dat) %in% c(spp.l, spp.moss)]

```

```

com.moss <- l.dat[, colnames(l.dat) %in% spp.moss]

## Add the tree labels to the rownames
rownames(com) <- paste(l.dat[, "Moth"], l.dat[, "Tree.pairs"], sep = "_")
rownames(com.moss) <- paste(l.dat[, "Moth"], l.dat[, "Tree.pairs"], sep = "_")
rownames(l.dat) <- paste(l.dat[, "Moth"], l.dat[, "Tree.pairs"], sep = "_")

## Paired environmental differences
total.rocks <- apply(l.dat[, c("Big.rocks..", "Small.rocks..")], 1, sum)
env <- l.dat[, c("Litter..", "Big.rocks..", "Small.rocks..",
               "Shrubs..", "Grass..", "Branches..",
               "Light...N", "Light...S", "Light...average")]
env <- cbind(env, total.rocks)
env.dif <- apply(env, 2, function(x, p) tapply(x, p, diff), p = l.dat[, "Tree.pairs"])

```

Saxicole communities were sufficiently sampled

```

spa.all <- specaccum(com, method = "exact")
spa.res <- specaccum(com[l.dat[, "Moth"] == 1, ], method = "exact")
spa.sus <- specaccum(com[l.dat[, "Moth"] == 0, ], method = "exact")

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

```



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

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

Moth trees have different microenvironments

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

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

Moth trees have different lichen communities

```
abun <- apply(com, 1, sum)
rich <- apply(com, 1, function(x) sum(sign(x)))
shan <- apply(com, 1, diversity, index = "shannon")
tt.a <- t.test(tapply(abun, l.dat[, "Tree.pairs"], diff))
tt.r <- t.test(tapply(rich, l.dat[, "Tree.pairs"], diff))
tt.h <- t.test(tapply(shan, l.dat[, "Tree.pairs"], diff))
tt.arh <- do.call(rbind,
     list(a = unlist(tt.a),
          r = unlist(tt.r),
          h = unlist(tt.h)))
tt.arh <- apply(tt.arh[, 1:6], 2, as.numeric)
```

```

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

kable(ard.tab, digits = 3)

```

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

```
kable(tt.arh, digits = 3)
```

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

Composition is different (PERMANOVA, in text and supplement)

```

com.ds <- cbind(com, ds = rep(0.0001, nrow(com)))
com.ds.rel <- apply(com, 2, function(x) x/max(x))
com.ds.rel <- cbind(com.ds.rel, ds = rep(0.0001, nrow(com)))
com.ds.rel[is.na(com.ds.rel)] <- 0

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

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

kable(ptab.moth)

```

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

```
kable(ptab.moth.rel)
```

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

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

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

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

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

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

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

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

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

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

Calculate the average abundances of the indicators

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

Create a multi-bar plot figure for the community.

```
isp.dat <- melt(isp.dif)
colnames(isp.dat) <- c("Tree.pairs", "Species", "diff")
isp.mu <- tapply(isp.dat[, "diff"], isp.dat[, "Species"], mean)
isp.se <- tapply(isp.dat[, "diff"], isp.dat[, "Species"], se)
ard.dif <- cbind(tapply(abun, l.dat[, "Tree.pairs"], diff),
                tapply(rich, l.dat[, "Tree.pairs"], diff),
                tapply(shan, l.dat[, "Tree.pairs"], diff))
colnames(ard.dif) <- c("Abundance", "Richness", "Diversity")
ard.dif <- apply(ard.dif, 2, function(x) x / max(x))
ard.dat <- melt(ard.dif)
colnames(ard.dat) <- c("Tree.pairs", "Stat", "diff")
ard.mu <- tapply(ard.dat[, "diff"], ard.dat[, "Stat"], mean)
ard.se <- tapply(ard.dat[, "diff"], ard.dat[, "Stat"], se)

pdf(file = "./results/scrl_isp_ard.pdf", width = 9, height = 5)

par(mfrow = c(1,2))
bp.out <- barplot(ard.mu, col = "darkgrey", ylim = c(-0.4, 0),
                 ylab = "Relativized Difference (S - R)", border = "NA")
segments(bp.out[, 1], ard.mu + ard.se,
         bp.out[, 1], ard.mu - ard.se,
         lwd = 1.5)
bp.out <- barplot(isp.mu, col = "darkgrey", ylim = c(-0.5, 0),
                 ylab = "Difference (S - R)", border = "NA",
                 axisnames = TRUE,
                 names.arg = sapply(names(isp.mu),
                                     function(x)
                                         paste(c(substr(x, 1, 1),
                                                substr(x, 4, 4)), collapse = "")))
segments(bp.out[, 1], isp.mu + isp.se,
         bp.out[, 1], isp.mu - isp.se,
         lwd = 1.5)
dev.off()
```

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

Create a plot of the two most indicative species

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

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

Create plot with indicator taxa

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

```
dev.off()
```

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

Litter covering rocks was the main driver

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

There was high correlation among environmental variables.

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



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

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


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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

```
abline(lm(env.dif[, "Big.rock.."] ~ env.dif[, "Litter.."]))
plot(tapply(l.dat[, "Litter.."], l.dat[, "Tree.pairs"], diff),
      tapply(l.dat[, "Light...average"], l.dat[, "Tree.pairs"], diff),
      xlab = "Litter Difference (S - R)", ylab = "Light Difference (S - R)",
      pch = 19, cex = 1.5)
```



```
pdf("./results/scrl_litter_effects.pdf", width = 10, height = 5)
par(mfrow = c(1,3))
plot(density(tapply(l.dat[, "Litter.."], l.dat[, "Tree.pairs"], diff)),
      main = "", xlab = "Litter Difference (S - R)")
abline(v = mean(tapply(l.dat[, "Litter.."], l.dat[, "Tree.pairs"], diff)),
      lwd = 0.5)
plot(env.dif[, "Big.rock.."] ~ 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.rock.."] ~ env.dif[, "Litter.."]))
plot(tapply(l.dat[, "Litter.."], l.dat[, "Tree.pairs"], diff),
      tapply(l.dat[, "Light...average"], l.dat[, "Tree.pairs"], diff),
      xlab = "Litter Difference (S - R)", ylab = "Light Difference (S - R)",
      pch = 19, cex = 1.5)
dev.off()
```

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

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

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

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



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

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

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

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

```

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

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

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

##
## Pearson's product-moment correlation
##
## data:  tapply(l.dat[, "Small.rocks.."], l.dat[, "Tree.pairs"], diff) and tapply(l.dat[, "Litter.."],
## 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 dissimilarity and a PERMANOVA model that accounts for tree pairs is significantly affected by moth susceptibility (Tables 11-12)
- Using the light, litter 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 ovaes*. 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-relativized 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 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 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.rock.."], v.dat[, "Rock.cover"], alt = "greater")
```

```
##
## Pearson's product-moment correlation
##
## data: l.dat[, "Big.rock.."] 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.rock...,
                      data = l.dat,
                      strata = l.dat[, "Tree.pairs"],
                      by = "margin", nperm = 100000)

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

```

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

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

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

```

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

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

```

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-relativized or relativized, respectively.

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 ovaes*.

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.ovaes	-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

```

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 = 1.dat[, "Tree.pairs"])
colnames(v.ard.dif) <- c("Abundance", "Richness", "Diversity")
v.ard.dif <- apply(v.ard.dif, 2, function(x) x / max(x))
v.ard.dat <- melt(v.ard.dif)
colnames(v.ard.dat) <- c("Tree.pairs", "Stat", "diff")
v.ard.mu <- tapply(v.ard.dat[, "diff"], v.ard.dat[, "Stat"], mean)
v.ard.se <- tapply(v.ard.dat[, "diff"], v.ard.dat[, "Stat"], se)

pdf(file = "./results/scrl_isp_ard_plant.pdf", width = 9, height = 5)

par(mfrow = c(1,2))
bp.out <- barplot(v.ard.mu, col = "darkgrey", ylim = c(-3.0, 0),
                  ylab = "Relativized Difference (S - R)", border = "NA")
segments(bp.out[, 1], v.ard.mu + v.ard.se,

```

```

      bp.out[, 1], v.ard.mu - v.ard.se,
      lwd = 1.5)
bp.out <- barplot(v.isp.mu, col = "darkgrey", ylim = c(-13, 0),
      ylab = "Difference (S - R)", border = "NA",
      axisnames = TRUE,
      names.arg = sapply(names(v.isp.mu),
      function(x)
        paste(c(substr(x, 1, 1),
        substr(x, 4, 4)), collapse = "")))
segments(bp.out[, 1], v.isp.mu + v.isp.se,
      bp.out[, 1], v.isp.mu - v.isp.se,
      lwd = 1.5)
dev.off()

## pdf
## 2

```

Multivariate Correlation of Plants and Saxicoles

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

```

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

mantel(v.d ~ l.d)

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

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

mantel(v.d ~ l.d)

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

```

Structural Equation Modeling

```

com.prepared <- cbind(id = l.dat[, "Moth"], tree = l.dat[, "Tree.pairs"], com)
v.com.prepared <- cbind(id = l.dat[, "Moth"], tree = l.dat[, "Tree.pairs"], v.com)

l.dist.euc <- distancePairedSamples(
  sequences = com.prepared,
  grouping.column = "id",
  time.column = "tree",
  exclude.columns = NULL,
  method = "euclidean",
  sum.distances = FALSE,
  parallel.execution = FALSE
)

```

```

l.dist.man <- distancePairedSamples(
  sequences = com.prepared,
  grouping.column = "id",
  time.column = "tree",
  exclude.columns = NULL,
  method = "manhattan",
  sum.distances = FALSE,
  parallel.execution = FALSE
)

v.dist.euc <- distancePairedSamples(
  sequences = v.com.prepared,
  grouping.column = "id",
  time.column = "tree",
  exclude.columns = NULL,
  method = "euclidean",
  sum.distances = FALSE,
  parallel.execution = FALSE
)

v.dist.man <- distancePairedSamples(
  sequences = v.com.prepared,
  grouping.column = "id",
  time.column = "tree",
  exclude.columns = NULL,
  method = "manhattan",
  sum.distances = FALSE,
  parallel.execution = FALSE
)

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

## [1] 0.9422796

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

## [1] 0.9612754

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

round(cor(cbind(d.litter, d.rocks, d.light, d.abun, d.rich, d.shan, d.com)), 3)

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

```

```
## d.abun      -0.530   0.513   0.108   1.000   0.649   0.353  -0.448
## d.rich      -0.695   0.694   0.268   0.649   1.000   0.888  -0.143
## d.shan      -0.651   0.656   0.290   0.353   0.888   1.000  -0.071
## d.com        0.154  -0.140  -0.133  -0.448  -0.143  -0.071   1.000

sem.dat <- data.frame(d.litter, d.rocks, d.light, d.abun, d.rich, d.shan, d.com, d.isp)
sem.path <- matrix(c(0, 1, 1, 0,
                    1, 0, 0, 1,
                    0, 0, 0, 1,
                    0, 0, 0, 0), 4, 4, byrow = TRUE)
rownames(sem.path) <- colnames(sem.path) <- c("d.litter", "d.light", "d.rocks", "d.com")

model.com <- psem(lm(d.rocks ~ d.litter, sem.dat), lm(d.com ~ d.light + d.rocks, sem.dat))
model.com1 <- psem(lm(d.rocks ~ d.litter, sem.dat), lm(d.com ~ d.litter + d.light + d.rocks, sem.dat))
model.abun <- psem(lm(d.rocks ~ d.litter, sem.dat), lm(d.abun ~ d.light + d.rocks, sem.dat))
model.rich <- psem(lm(d.rocks ~ d.litter, sem.dat), lm(d.rich ~ d.light + d.rocks, sem.dat))
model.shan <- psem(lm(d.rocks ~ d.litter, sem.dat), lm(d.shan ~ d.light + d.rocks, sem.dat))
model.Acacon <- psem(lm(d.rocks ~ d.litter, sem.dat), lm(d.Acacon ~ d.light + d.rocks, sem.dat))
model.Acaame <- psem(lm(d.rocks ~ d.litter, sem.dat), lm(d.Acaame ~ d.light + d.rocks, sem.dat))
model.Canros <- psem(lm(d.rocks ~ d.litter, sem.dat), lm(d.Canros ~ d.light + d.rocks, sem.dat))
model.Canros1 <- psem(lm(d.rocks ~ d.litter, sem.dat), lm(d.Canros ~ d.light + d.rocks, sem.dat))

d.litter <- tapply(l.dat[, "Litter.."], l.dat[, "Tree.pairs"], diff)
d.rocks <- tapply((l.dat[, "Big.rocks.."] + l.dat[, "Small.rocks.."]),
                 l.dat[, "Tree.pairs"], diff)
d.light <- tapply(l.dat[, "Light...average"], l.dat[, "Tree.pairs"], diff)

d.v.com <- v.dist.man[[1]]
d.v.abun <- tapply(v.abun, l.dat[, "Tree.pairs"], diff)
d.v.rich <- tapply(v.rich, l.dat[, "Tree.pairs"], diff)
d.v.shan <- tapply(v.shan, l.dat[, "Tree.pairs"], diff)
d.v.isp <- apply(v.isp.com, 2, function(x, f) tapply(x, f, diff), f = l.dat[, "Tree.pairs"])
colnames(d.v.isp) <- paste("d", colnames(v.isp.com), sep = ".")
v.sem.dat <- data.frame(d.litter, d.rocks, d.light, d.v.abun, d.v.rich, d.v.shan, d.v.com, d.v.isp)

model.v.com <- psem(lm(d.rocks ~ d.litter, v.sem.dat), lm(d.v.com ~ d.light + d.rocks, v.sem.dat))
model.v.com1 <- psem(lm(d.rocks ~ d.litter, v.sem.dat), lm(d.v.com ~ d.litter + d.light + d.rocks, v.sem.dat))
model.v.abun <- psem(lm(d.rocks ~ d.litter, v.sem.dat), lm(d.v.abun ~ d.light + d.rocks, v.sem.dat))
model.v.rich <- psem(lm(d.rocks ~ d.litter, v.sem.dat), lm(d.v.rich ~ d.light + d.rocks, v.sem.dat))
model.v.shan <- psem(lm(d.rocks ~ d.litter, v.sem.dat), lm(d.v.shan ~ d.light + d.rocks, v.sem.dat))
model.v.Apache.plume <- psem(lm(d.rocks ~ d.litter, v.sem.dat),
                             lm(d.Apache.plume ~ d.light + d.rocks, v.sem.dat))
model.v.Asteraceae.ovales <- psem(lm(d.rocks ~ d.litter, v.sem.dat),
                                  lm(d.Asteraceae.ovales ~ d.light + d.rocks, v.sem.dat))
```

Independent Test Method

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

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

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

Testing for the effect of moth susceptibility:

```
t.test(d.litter)
```

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

```
t.test(d.light)
```

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

```
t.test(d.rocks)
```

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

Effects of tree traits on local environment and environment correlations:

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

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



```
## -0.1713898
```

```
cor.test(d.rock, d.light)
```

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

```
summary(lm(d.rock ~ d.litter))
```

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

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

```
summary(lm(d.abun ~ d.rock))
```

```
##
## Call:
## lm(formula = d.abun ~ d.rock)
##
## 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.rock       0.06777    0.02140   3.166  0.00371 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 3.284 on 28 degrees of freedom
```

```
## Multiple R-squared:  0.2637, Adjusted R-squared:  0.2374
## F-statistic: 10.03 on 1 and 28 DF,  p-value: 0.003706
summary(lm(d.rich ~ d.rocks))

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

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

##
## Call:
## lm(formula = d.Acacon ~ d.rocks, data = sem.dat)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.17556 -0.01439  0.01337  0.03252  0.09108
##
## Coefficients:
```

```
##               Estimate Std. Error t value Pr(>|t|)
## (Intercept) -0.0238762  0.0126055  -1.894  0.06858 .
## d.rocks      0.0014183  0.0003987   3.557  0.00136 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.06117 on 28 degrees of freedom
## Multiple R-squared:  0.3113, Adjusted R-squared:  0.2867
## F-statistic: 12.66 on 1 and 28 DF,  p-value: 0.001357
summary(lm(d.Acaame ~ d.rocks, sem.dat))
```

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

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

```
##
## Call:
```

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

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

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

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

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

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

```
##
```

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

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

```
##
## Call:
## lm(formula = d.Canros ~ d.light, data = sem.dat)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.9699 -0.3253  0.1547  0.3191  1.2307
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  0.03300   0.19704   0.168   0.868
## d.light      0.02753   0.01126   2.445   0.021 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
##
## Residual standard error: 0.542 on 28 degrees of freedom
## Multiple R-squared:  0.176, Adjusted R-squared:  0.1466
## F-statistic:  5.98 on 1 and 28 DF,  p-value: 0.02101
summary(lm(d.abun ~ d.litter))

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

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

##
## Call:
## lm(formula = d.shan ~ d.litter)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -1.47085 -0.59769  0.03512  0.59650  1.39944
```

```
##
## Coefficients:
##           Estimate Std. Error t value Pr(>|t|)
## (Intercept) -0.103513   0.156232  -0.663   0.513
## d.litter    -0.022128   0.004871  -4.543 9.68e-05 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.7554 on 28 degrees of freedom
## Multiple R-squared:  0.4243, Adjusted R-squared:  0.4037
## F-statistic: 20.64 on 1 and 28 DF,  p-value: 9.675e-05
summary(lm(d.Acacon ~ d.litter, sem.dat))
```

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

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

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

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

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

```
##
## Structural Equation Model of model.abun
##
## Call:
##      d.rocks ~ d.litter
##      d.abun ~ d.light + d.rocks
##
##      AIC      BIC
## 28.447  38.255
##
## ---
## Tests of directed separation:
##
##      Independ.Claim Test.Type DF Crit.Value P.Value
## d.abun ~ d.litter + ...      coef 26    -2.1260 0.0432 *
## d.rocks ~ d.light + ...      coef 27     2.5465 0.0169 *
##
## Global goodness-of-fit:
##
## Fisher's C = 14.447 with P-value = 0.006 and on 4 degrees of freedom
##
## ---
## Coefficients:
##
##      Response Predictor Estimate Std.Error DF Crit.Value P.Value Std.Estimate
##      d.rocks d.litter  -0.9879   0.0108 28   -91.5294 0.0000   -0.9983 ***
##      d.abun  d.light   0.0030   0.0709 27     0.0428 0.9662    0.0072
##      d.abun  d.rocks   0.0676   0.0222 27     3.0408 0.0052    0.5121 **
##
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05
```



```
## ---
## Individual R-squared:
##
##   Response method R.squared
##   d.rocks      none        1.00
##   d.abun       none        0.26
summary(model.rich, .progressBar = FALSE)

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

##
## Structural Equation Model of model.shan
##
## Call:
##   d.rocks ~ d.litter
##   d.shan ~ d.light + d.rocks
```

```

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

##
## Structural Equation Model of model.com
##
## Call:
## d.rocks ~ d.litter
## d.com ~ d.light + d.rocks
##
##      AIC      BIC
## 27.066  36.874
##
## ---
## Tests of directed separation:
##
##      Independ.Claim Test.Type DF Crit.Value P.Value
## d.com ~ d.litter + ...      coef 26    1.7840  0.0861
## d.rocks ~ d.light + ...      coef 27    2.5465  0.0169 *
##
## Global goodness-of-fit:
##
## Fisher's C = 13.066 with P-value = 0.011 and on 4 degrees of freedom
##

```

```
## ---
## Coefficients:
##
##   Response Predictor Estimate Std.Error DF Crit.Value P.Value Std.Estimate
##   d.rocks d.litter -0.9879  0.0108 28   -91.5294  0.0000   -0.9983 ***
##   d.com d.light -0.0350  0.0617 27    -0.5673  0.5752   -0.1096
##   d.com d.rocks -0.0119  0.0193 27    -0.6129  0.5450   -0.1184
##
##   Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05
##
## ---
## Individual R-squared:
##
##   Response method R.squared
##   d.rocks none 1.00
##   d.com none 0.03
```

```
summary(model.Acacon, .progressBar = FALSE)
```

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

```

##    d.Acacon    none      0.41
summary(model.Acaame, .progressBar = FALSE)

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

##
## Structural Equation Model of model.Canros
##
## Call:
##    d.rocks ~ d.litter
##    d.Canros ~ d.light + d.rocks
##
##      AIC      BIC
## 23.898  33.706
##
## ---

```

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

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

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

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

```
##
## Call:
## lm(formula = d.v.rich ~ d.rocks)
##
## Residuals:
```

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

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

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

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

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

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

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

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

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

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

```
##
## Call:
## lm(formula = d.v.rich ~ d.litter)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -1.6111  -0.7427   0.2214   0.3838   2.3153
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept) -1.253709   0.199585  -6.282 8.61e-07 ***
```

```

## d.litter      -0.003072   0.006223  -0.494    0.625
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.965 on 28 degrees of freedom
## Multiple R-squared:  0.008626,    Adjusted R-squared:  -0.02678
## F-statistic: 0.2436 on 1 and 28 DF,  p-value: 0.6254
summary(lm(d.v.shan ~ d.litter))

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

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

##
## Call:
## lm(formula = d.Asteraceae.ovales ~ d.litter, data = v.sem.dat)
##

```



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

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

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

```
## F-statistic: 0.4098 on 1 and 28 DF, p-value: 0.5273
summary(lm(d.v.shan ~ d.light))

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

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

##
## Call:
## lm(formula = d.Asteraceae.ovales ~ d.light, data = v.sem.dat)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -31.874  -6.867   6.133   8.134  18.131
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
```

```

## (Intercept) -8.1407349  4.1640687  -1.955  0.0606 .
## d.light      -0.0004891  0.2379432  -0.002  0.9984
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 11.45 on 28 degrees of freedom
## Multiple R-squared:  1.509e-07, Adjusted R-squared:  -0.03571
## F-statistic: 4.225e-06 on 1 and 28 DF, p-value: 0.9984
summary(model.v.com, .progressBar = FALSE)

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

##
## Structural Equation Model of model.v.abun
##
## Call:

```

```

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

```

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

```

##
## Structural Equation Model of model.v.rich
##
## Call:
## d.rocks ~ d.litter
## d.v.rich ~ d.light + d.rocks
##
##      AIC      BIC
## 25.623  35.431
##
## ---
## Tests of directed separation:
##
##           Independ.Claim Test.Type DF Crit.Value P.Value
## d.v.rich ~ d.litter + ...      coef 26    -1.3873  0.1771
## d.rocks ~ d.light + ...      coef 27     2.5465  0.0169 *
##
## Global goodness-of-fit:
##

```

```

## Fisher's C = 11.623 with P-value = 0.02 and on 4 degrees of freedom
##
## ---
## Coefficients:
##
## Response Predictor Estimate Std.Error DF Crit.Value P.Value Std.Estimate
## d.rocks d.litter -0.9879 0.0108 28 -91.5294 0.0000 -0.9983 ***
## d.v.rich d.light 0.0115 0.0207 27 0.5561 0.5827 0.1082
## d.v.rich d.rocks 0.0020 0.0065 27 0.3131 0.7566 0.0609
##
## Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05
##
## ---
## Individual R-squared:
##
## Response method R.squared
## d.rocks none 1.00
## d.v.rich none 0.02
summary(model.v.shan, .progressBar = FALSE)

##
## Structural Equation Model of model.v.shan
##
## Call:
## d.rocks ~ d.litter
## d.v.shan ~ d.light + d.rocks
##
## AIC BIC
## 26.895 36.703
##
## ---
## Tests of directed separation:
##
## Independ.Claim Test.Type DF Crit.Value P.Value
## d.v.shan ~ d.litter + ... coef 26 -1.7395 0.0938
## d.rocks ~ d.light + ... coef 27 2.5465 0.0169 *
##
## Global goodness-of-fit:
##
## Fisher's C = 12.895 with P-value = 0.012 and on 4 degrees of freedom
##
## ---
## Coefficients:
##
## Response Predictor Estimate Std.Error DF Crit.Value P.Value Std.Estimate
## d.rocks d.litter -0.9879 0.0108 28 -91.5294 0.0000 -0.9983 ***
## d.v.shan d.light -0.0028 0.0082 27 -0.3397 0.7367 -0.0651
## d.v.shan d.rocks -0.0026 0.0026 27 -0.9971 0.3276 -0.1912
##
## Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05
##
## ---
## Individual R-squared:
##

```

```
## Response method R.squared
## d.rocks none 1.00
## d.v.shan none 0.05
```

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

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

```
summary(model.v.Asteraceae.ovals, .progressBar = FALSE)
```

```
##
## Structural Equation Model of model.v.Asteraceae.ovals
##
## Call:
## d.rocks ~ d.litter
```

```
## d.Asteraceae.ovales ~ d.light + d.rock
##
##      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.rock ~ 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.rock 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.rock   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.rock 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 responses are not correlated

```
"{r mantel-l-v}"
```

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

```
## Both lichen and vegetation respond to moth susceptibility
```

```
```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 % Tue Apr 20 17:11:44 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 % Tue Apr 20 17:11:45 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		

```
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 % Wed Apr 28 11:19:00 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 % Wed Apr 28 11:19:00 2021

	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

## Tree environment correlate with community

```

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

```

```

% latex table generated in R 4.0.4 by xtable 1.8-4 package
% 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}

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

##
Call:
lm(formula = l.A ~ rock.lg * rock.sm * light, data = data.frame(l.ard.dif,
tra.dif, env.dif))
##
Residuals:
Min 1Q Median 3Q Max
-7.5443 -0.9009 0.3873 1.2621 4.7576
##
Coefficients:
Estimate Std. Error t value Pr(>|t|)
(Intercept) 1.2906171 1.9919281 0.648 0.5237
rock.lg 0.2672626 0.1144530 2.335 0.0291 *
rock.sm -0.2489435 0.2305602 -1.080 0.2920
light 0.0964938 0.1233636 0.782 0.4424
rock.lg:rock.sm -0.0098077 0.0131545 -0.746 0.4638
rock.lg:light 0.0108967 0.0067177 1.622 0.1190
rock.sm:light -0.0130569 0.0118033 -1.106 0.2806
rock.lg:rock.sm:light -0.0002544 0.0005513 -0.461 0.6490

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
Residual standard error: 3.337 on 22 degrees of freedom
Multiple R-squared: 0.4027, Adjusted R-squared: 0.2127
F-statistic: 2.119 on 7 and 22 DF, p-value: 0.08438

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

##
Call:
lm(formula = l.R ~ rock.lg * rock.sm * light, data = data.frame(l.ard.dif,
tra.dif, env.dif))
##
Residuals:
Min 1Q Median 3Q Max
-5.4034 -1.7571 0.5585 2.0862 3.9423
##
```

```
Coefficients:
Estimate Std. Error t value Pr(>|t|)
(Intercept) 2.8682448 1.8246866 1.572 0.1302
rock.lg 0.3576352 0.1048436 3.411 0.0025 **
rock.sm 0.0782553 0.2112024 0.371 0.7145
light 0.2596367 0.1130061 2.298 0.0315 *
rock.lg:rock.sm 0.0060809 0.0120501 0.505 0.6188
rock.lg:light 0.0114837 0.0061537 1.866 0.0754 .
rock.sm:light 0.0050780 0.0108123 0.470 0.6432
rock.lg:rock.sm:light 0.0003271 0.0005050 0.648 0.5238

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
Residual standard error: 3.057 on 22 degrees of freedom
Multiple R-squared: 0.6785, Adjusted R-squared: 0.5762
F-statistic: 6.634 on 7 and 22 DF, p-value: 0.0002762
summary(lm(l.D ~ rock.lg * rock.sm * light,
 data = data.frame(l.ard.dif, tra.dif, env.dif)))

##
Call:
lm(formula = l.D ~ rock.lg * rock.sm * light, data = data.frame(l.ard.dif,
tra.dif, env.dif))
##
Residuals:
Min 1Q Median 3Q Max
-1.3539 -0.1798 0.1183 0.3590 0.9120
##
Coefficients:
Estimate Std. Error t value Pr(>|t|)
(Intercept) 7.064e-01 3.914e-01 1.805 0.0848 .
rock.lg 5.437e-02 2.249e-02 2.418 0.0243 *
rock.sm 5.766e-02 4.530e-02 1.273 0.2163
light 6.085e-02 2.424e-02 2.511 0.0199 *
rock.lg:rock.sm 2.179e-03 2.585e-03 0.843 0.4082
rock.lg:light 1.247e-03 1.320e-03 0.945 0.3552
rock.sm:light 3.242e-03 2.319e-03 1.398 0.1761
rock.lg:rock.sm:light 8.461e-05 1.083e-04 0.781 0.4431

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
Residual standard error: 0.6557 on 22 degrees of freedom
Multiple R-squared: 0.6592, Adjusted R-squared: 0.5508
F-statistic: 6.079 on 7 and 22 DF, p-value: 0.0004929
summary(lm(l.A ~ light * rock.lg * rock.sm,
 data = data.frame(l.ard.dif, tra.dif, env.dif)))

##
Call:
lm(formula = l.A ~ light * rock.lg * rock.sm, data = data.frame(l.ard.dif,
tra.dif, env.dif))
##
Residuals:
```

```
Min 1Q Median 3Q Max
-7.5443 -0.9009 0.3873 1.2621 4.7576
##
Coefficients:
Estimate Std. Error t value Pr(>|t|)
(Intercept) 1.2906171 1.9919281 0.648 0.5237
light 0.0964938 0.1233636 0.782 0.4424
rock.lg 0.2672626 0.1144530 2.335 0.0291 *
rock.sm -0.2489435 0.2305602 -1.080 0.2920
light:rock.lg 0.0108967 0.0067177 1.622 0.1190
light:rock.sm -0.0130569 0.0118033 -1.106 0.2806
rock.lg:rock.sm -0.0098077 0.0131545 -0.746 0.4638
light:rock.lg:rock.sm -0.0002544 0.0005513 -0.461 0.6490

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
Residual standard error: 3.337 on 22 degrees of freedom
Multiple R-squared: 0.4027, Adjusted R-squared: 0.2127
F-statistic: 2.119 on 7 and 22 DF, p-value: 0.08438

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

##
Call:
lm(formula = l.R ~ light * rock.lg * rock.sm, data = data.frame(l.ard.dif,
tra.dif, env.dif))
##
Residuals:
Min 1Q Median 3Q Max
-5.4034 -1.7571 0.5585 2.0862 3.9423
##
Coefficients:
Estimate Std. Error t value Pr(>|t|)
(Intercept) 2.8682448 1.8246866 1.572 0.1302
light 0.2596367 0.1130061 2.298 0.0315 *
rock.lg 0.3576352 0.1048436 3.411 0.0025 **
rock.sm 0.0782553 0.2112024 0.371 0.7145
light:rock.lg 0.0114837 0.0061537 1.866 0.0754 .
light:rock.sm 0.0050780 0.0108123 0.470 0.6432
rock.lg:rock.sm 0.0060809 0.0120501 0.505 0.6188
light:rock.lg:rock.sm 0.0003271 0.0005050 0.648 0.5238

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
Residual standard error: 3.057 on 22 degrees of freedom
Multiple R-squared: 0.6785, Adjusted R-squared: 0.5762
F-statistic: 6.634 on 7 and 22 DF, p-value: 0.0002762

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

##
Call:
lm(formula = l.D ~ light * rock.lg * rock.sm, data = data.frame(l.ard.dif,
```

```
tra.dif, env.dif))
##
Residuals:
Min 1Q Median 3Q Max
-1.3539 -0.1798 0.1183 0.3590 0.9120
##
Coefficients:
Estimate Std. Error t value Pr(>|t|)
(Intercept) 7.064e-01 3.914e-01 1.805 0.0848 .
light 6.085e-02 2.424e-02 2.511 0.0199 *
rock.lg 5.437e-02 2.249e-02 2.418 0.0243 *
rock.sm 5.766e-02 4.530e-02 1.273 0.2163
light:rock.lg 1.247e-03 1.320e-03 0.945 0.3552
light:rock.sm 3.242e-03 2.319e-03 1.398 0.1761
rock.lg:rock.sm 2.179e-03 2.585e-03 0.843 0.4082
light:rock.lg:rock.sm 8.461e-05 1.083e-04 0.781 0.4431

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
Residual standard error: 0.6557 on 22 degrees of freedom
Multiple R-squared: 0.6592, Adjusted R-squared: 0.5508
F-statistic: 6.079 on 7 and 22 DF, p-value: 0.0004929
summary(lm(l.A ~ rock.lg + rock.sm + light,
 data = data.frame(l.ard.dif, tra.dif, env.dif)))

##
Call:
lm(formula = l.A ~ rock.lg + rock.sm + light, data = data.frame(l.ard.dif,
tra.dif, env.dif))
##
Residuals:
Min 1Q Median 3Q Max
-7.7485 -0.6511 0.6642 1.3935 5.4237
##
Coefficients:
Estimate Std. Error t value Pr(>|t|)
(Intercept) -0.427328 1.224495 -0.349 0.72991
rock.lg 0.088123 0.030432 2.896 0.00757 **
rock.sm 0.022591 0.050663 0.446 0.65935
light 0.009973 0.071228 0.140 0.88972

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
Residual standard error: 3.346 on 26 degrees of freedom
Multiple R-squared: 0.2904, Adjusted R-squared: 0.2085
F-statistic: 3.547 on 3 and 26 DF, p-value: 0.02821
summary(lm(l.R ~ rock.lg + rock.sm + light,
 data = data.frame(l.ard.dif, tra.dif, env.dif)))

##
Call:
lm(formula = l.R ~ rock.lg + rock.sm + light, data = data.frame(l.ard.dif,
tra.dif, env.dif))
```

```
##
Residuals:
Min 1Q Median 3Q Max
-5.6550 -1.9714 0.6468 2.0461 6.0752
##
Coefficients:
Estimate Std. Error t value Pr(>|t|)
(Intercept) 0.371141 1.130676 0.328 0.745
rock.lg 0.162543 0.028100 5.784 4.3e-06 ***
rock.sm -0.005166 0.046781 -0.110 0.913
light 0.089614 0.065770 1.363 0.185

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
Residual standard error: 3.089 on 26 degrees of freedom
Multiple R-squared: 0.6119, Adjusted R-squared: 0.5672
F-statistic: 13.67 on 3 and 26 DF, p-value: 1.515e-05
summary(lm(l.D ~ rock.lg + rock.sm + light,
 data = data.frame(l.ard.dif, tra.dif, env.dif)))

##
Call:
lm(formula = l.D ~ rock.lg + rock.sm + light, data = data.frame(l.ard.dif,
tra.dif, env.dif))
##
Residuals:
Min 1Q Median 3Q Max
-1.20164 -0.37452 0.01855 0.38633 1.20307
##
Coefficients:
Estimate Std. Error t value Pr(>|t|)
(Intercept) 0.1937003 0.2527542 0.766 0.450
rock.lg 0.0315016 0.0062816 5.015 3.23e-05 ***
rock.sm -0.0007058 0.0104575 -0.067 0.947
light 0.0217497 0.0147024 1.479 0.151

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
Residual standard error: 0.6906 on 26 degrees of freedom
Multiple R-squared: 0.5531, Adjusted R-squared: 0.5016
F-statistic: 10.73 on 3 and 26 DF, p-value: 9.066e-05
summary(lm(l.A ~ light + rock.lg + rock.sm,
 data = data.frame(l.ard.dif, tra.dif, env.dif)))

##
Call:
lm(formula = l.A ~ light + rock.lg + rock.sm, data = data.frame(l.ard.dif,
tra.dif, env.dif))
##
Residuals:
Min 1Q Median 3Q Max
-7.7485 -0.6511 0.6642 1.3935 5.4237
##
```

```
Coefficients:
Estimate Std. Error t value Pr(>|t|)
(Intercept) -0.427328 1.224495 -0.349 0.72991
light 0.009973 0.071228 0.140 0.88972
rock.lg 0.088123 0.030432 2.896 0.00757 **
rock.sm 0.022591 0.050663 0.446 0.65935

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
Residual standard error: 3.346 on 26 degrees of freedom
Multiple R-squared: 0.2904, Adjusted R-squared: 0.2085
F-statistic: 3.547 on 3 and 26 DF, p-value: 0.02821

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

##
Call:
lm(formula = l.R ~ light + rock.lg + rock.sm, data = data.frame(l.ard.dif,
tra.dif, env.dif))
##
Residuals:
Min 1Q Median 3Q Max
-5.6550 -1.9714 0.6468 2.0461 6.0752
##
Coefficients:
Estimate Std. Error t value Pr(>|t|)
(Intercept) 0.371141 1.130676 0.328 0.745
light 0.089614 0.065770 1.363 0.185
rock.lg 0.162543 0.028100 5.784 4.3e-06 ***
rock.sm -0.005166 0.046781 -0.110 0.913

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
Residual standard error: 3.089 on 26 degrees of freedom
Multiple R-squared: 0.6119, Adjusted R-squared: 0.5672
F-statistic: 13.67 on 3 and 26 DF, p-value: 1.515e-05

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

##
Call:
lm(formula = l.D ~ light + rock.lg + rock.sm, data = data.frame(l.ard.dif,
tra.dif, env.dif))
##
Residuals:
Min 1Q Median 3Q Max
-1.20164 -0.37452 0.01855 0.38633 1.20307
##
Coefficients:
Estimate Std. Error t value Pr(>|t|)
(Intercept) 0.1937003 0.2527542 0.766 0.450
light 0.0217497 0.0147024 1.479 0.151
rock.lg 0.0315016 0.0062816 5.015 3.23e-05 ***
```

```
rock.sm -0.0007058 0.0104575 -0.067 0.947

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
Residual standard error: 0.6906 on 26 degrees of freedom
Multiple R-squared: 0.5531, Adjusted R-squared: 0.5016
F-statistic: 10.73 on 3 and 26 DF, p-value: 9.066e-05
summary(lm(p.A ~ rock.lg * rock.sm * light,
 data = data.frame(v.ard.dif, tra.dif, env.dif)))

##
Call:
lm(formula = p.A ~ rock.lg * rock.sm * light, data = data.frame(v.ard.dif,
tra.dif, env.dif))
##
Residuals:
Min 1Q Median 3Q Max
-45.808 -8.565 2.356 11.435 25.518
##
Coefficients:
Estimate Std. Error t value Pr(>|t|)
(Intercept) -24.997498 10.598639 -2.359 0.0276 *
rock.lg -0.322706 0.608981 -0.530 0.6015
rock.sm -0.574845 1.226763 -0.469 0.6440
light -0.068351 0.656392 -0.104 0.9180
rock.lg:rock.sm -0.027964 0.069993 -0.400 0.6934
rock.lg:light -0.026183 0.035744 -0.733 0.4716
rock.sm:light 0.006300 0.062803 0.100 0.9210
rock.lg:rock.sm:light -0.001141 0.002933 -0.389 0.7011

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
Residual standard error: 17.76 on 22 degrees of freedom
Multiple R-squared: 0.1937, Adjusted R-squared: -0.06288
F-statistic: 0.7549 on 7 and 22 DF, p-value: 0.6297
summary(lm(p.R ~ rock.lg * rock.sm * light,
 data = data.frame(v.ard.dif, tra.dif, env.dif)))

##
Call:
lm(formula = p.R ~ rock.lg * rock.sm * light, data = data.frame(v.ard.dif,
tra.dif, env.dif))
##
Residuals:
Min 1Q Median 3Q Max
-1.15006 -0.67011 -0.00113 0.40891 2.13338
##
Coefficients:
Estimate Std. Error t value Pr(>|t|)
(Intercept) -1.121e+00 5.309e-01 -2.111 0.0463 *
rock.lg 1.329e-02 3.050e-02 0.436 0.6674
rock.sm -3.598e-03 6.145e-02 -0.059 0.9538
light 1.453e-02 3.288e-02 0.442 0.6629
```



```
rock.lg:rock.sm 1.782e-03 3.506e-03 0.508 0.6163
rock.lg:light -4.340e-04 1.790e-03 -0.242 0.8107
rock.sm:light 1.363e-03 3.146e-03 0.433 0.6690
rock.lg:rock.sm:light 5.302e-05 1.469e-04 0.361 0.7217

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
Residual standard error: 0.8894 on 22 degrees of freedom
Multiple R-squared: 0.3383, Adjusted R-squared: 0.1278
F-statistic: 1.607 on 7 and 22 DF, p-value: 0.1857

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

##
Call:
lm(formula = p.D ~ rock.lg * rock.sm * light, data = data.frame(v.ard.dif,
tra.dif, env.dif))
##
Residuals:
Min 1Q Median 3Q Max
-0.61818 -0.27861 -0.01608 0.24591 0.88670
##
Coefficients:
Estimate Std. Error t value Pr(>|t|)
(Intercept) -4.975e-01 2.268e-01 -2.194 0.0391 *
rock.lg -9.983e-03 1.303e-02 -0.766 0.4518
rock.sm -1.668e-02 2.625e-02 -0.635 0.5317
light -1.037e-02 1.405e-02 -0.738 0.4680
rock.lg:rock.sm -3.217e-04 1.498e-03 -0.215 0.8319
rock.lg:light -7.732e-04 7.648e-04 -1.011 0.3230
rock.sm:light -2.122e-04 1.344e-03 -0.158 0.8759
rock.lg:rock.sm:light -2.246e-05 6.277e-05 -0.358 0.7239

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
Residual standard error: 0.3799 on 22 degrees of freedom
Multiple R-squared: 0.2557, Adjusted R-squared: 0.01892
F-statistic: 1.08 on 7 and 22 DF, p-value: 0.4088

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

##
Call:
lm(formula = p.A ~ light * rock.lg * rock.sm, data = data.frame(v.ard.dif,
tra.dif, env.dif))
##
Residuals:
Min 1Q Median 3Q Max
-45.808 -8.565 2.356 11.435 25.518
##
Coefficients:
Estimate Std. Error t value Pr(>|t|)
(Intercept) -24.997498 10.598639 -2.359 0.0276 *
```

```

light -0.068351 0.656392 -0.104 0.9180
rock.lg -0.322706 0.608981 -0.530 0.6015
rock.sm -0.574845 1.226763 -0.469 0.6440
light:rock.lg -0.026183 0.035744 -0.733 0.4716
light:rock.sm 0.006300 0.062803 0.100 0.9210
rock.lg:rock.sm -0.027964 0.069993 -0.400 0.6934
light:rock.lg:rock.sm -0.001141 0.002933 -0.389 0.7011

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
Residual standard error: 17.76 on 22 degrees of freedom
Multiple R-squared: 0.1937, Adjusted R-squared: -0.06288
F-statistic: 0.7549 on 7 and 22 DF, p-value: 0.6297
summary(lm(p.R ~ light *rock.lg * rock.sm,
 data = data.frame(v.ard.dif, tra.dif, env.dif)))

##
Call:
lm(formula = p.R ~ light * rock.lg * rock.sm, data = data.frame(v.ard.dif,
tra.dif, env.dif))
##
Residuals:
Min 1Q Median 3Q Max
-1.15006 -0.67011 -0.00113 0.40891 2.13338
##
Coefficients:
Estimate Std. Error t value Pr(>|t|)
(Intercept) -1.121e+00 5.309e-01 -2.111 0.0463 *
light 1.453e-02 3.288e-02 0.442 0.6629
rock.lg 1.329e-02 3.050e-02 0.436 0.6674
rock.sm -3.598e-03 6.145e-02 -0.059 0.9538
light:rock.lg -4.340e-04 1.790e-03 -0.242 0.8107
light:rock.sm 1.363e-03 3.146e-03 0.433 0.6690
rock.lg:rock.sm 1.782e-03 3.506e-03 0.508 0.6163
light:rock.lg:rock.sm 5.302e-05 1.469e-04 0.361 0.7217

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
Residual standard error: 0.8894 on 22 degrees of freedom
Multiple R-squared: 0.3383, Adjusted R-squared: 0.1278
F-statistic: 1.607 on 7 and 22 DF, p-value: 0.1857
summary(lm(p.D ~ light *rock.lg * rock.sm,
 data = data.frame(v.ard.dif, tra.dif, env.dif)))

##
Call:
lm(formula = p.D ~ light * rock.lg * rock.sm, data = data.frame(v.ard.dif,
tra.dif, env.dif))
##
Residuals:
Min 1Q Median 3Q Max
-0.61818 -0.27861 -0.01608 0.24591 0.88670
##

```

```
Coefficients:
Estimate Std. Error t value Pr(>|t|)
(Intercept) -4.975e-01 2.268e-01 -2.194 0.0391 *
light -1.037e-02 1.405e-02 -0.738 0.4680
rock.lg -9.983e-03 1.303e-02 -0.766 0.4518
rock.sm -1.668e-02 2.625e-02 -0.635 0.5317
light:rock.lg -7.732e-04 7.648e-04 -1.011 0.3230
light:rock.sm -2.122e-04 1.344e-03 -0.158 0.8759
rock.lg:rock.sm -3.217e-04 1.498e-03 -0.215 0.8319
light:rock.lg:rock.sm -2.246e-05 6.277e-05 -0.358 0.7239

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
Residual standard error: 0.3799 on 22 degrees of freedom
Multiple R-squared: 0.2557, Adjusted R-squared: 0.01892
F-statistic: 1.08 on 7 and 22 DF, p-value: 0.4088
summary(lm(p.A ~ rock.lg + rock.sm + light,
 data = data.frame(v.ard.dif, tra.dif, env.dif)))

##
Call:
lm(formula = p.A ~ rock.lg + rock.sm + light, data = data.frame(v.ard.dif,
tra.dif, env.dif))
##
Residuals:
Min 1Q Median 3Q Max
-45.955 -8.621 2.115 12.151 28.829
##
Coefficients:
Estimate Std. Error t value Pr(>|t|)
(Intercept) -23.55502 6.14481 -3.833 0.000721 ***
rock.lg 0.11754 0.15271 0.770 0.448432
rock.sm -0.53383 0.25424 -2.100 0.045607 *
light 0.02616 0.35744 0.073 0.942215

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
Residual standard error: 16.79 on 26 degrees of freedom
Multiple R-squared: 0.1479, Adjusted R-squared: 0.04957
F-statistic: 1.504 on 3 and 26 DF, p-value: 0.2368
summary(lm(p.R ~ rock.lg + rock.sm + light,
 data = data.frame(v.ard.dif, tra.dif, env.dif)))

##
Call:
lm(formula = p.R ~ rock.lg + rock.sm + light, data = data.frame(v.ard.dif,
tra.dif, env.dif))
##
Residuals:
Min 1Q Median 3Q Max
-1.09085 -0.72885 0.07251 0.43267 2.04097
##
Coefficients:
```

```

Estimate Std. Error t value Pr(>|t|)
(Intercept) -1.027067 0.302605 -3.394 0.00222 **
rock.lg 0.019656 0.007521 2.614 0.01470 *
rock.sm -0.036574 0.012520 -2.921 0.00712 **
light 0.017481 0.017602 0.993 0.32981

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
Residual standard error: 0.8268 on 26 degrees of freedom
Multiple R-squared: 0.3242, Adjusted R-squared: 0.2462
F-statistic: 4.157 on 3 and 26 DF, p-value: 0.01565
summary(lm(p.D ~ rock.lg + rock.sm + light,
 data = data.frame(v.ard.dif, tra.dif, env.dif)))

##
Call:
lm(formula = p.D ~ rock.lg + rock.sm + light, data = data.frame(v.ard.dif,
tra.dif, env.dif))
##
Residuals:
Min 1Q Median 3Q Max
-0.48929 -0.33019 -0.02457 0.29568 0.88860
##
Coefficients:
Estimate Std. Error t value Pr(>|t|)
(Intercept) -0.3546159 0.1309685 -2.708 0.0118 *
rock.lg 0.0027760 0.0032549 0.853 0.4015
rock.sm -0.0142947 0.0054187 -2.638 0.0139 *
light -0.0009857 0.0076183 -0.129 0.8980

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
Residual standard error: 0.3579 on 26 degrees of freedom
Multiple R-squared: 0.2196, Adjusted R-squared: 0.1296
F-statistic: 2.439 on 3 and 26 DF, p-value: 0.08707
summary(lm(p.A ~ light + rock.lg + rock.sm,
 data = data.frame(v.ard.dif, tra.dif, env.dif)))

##
Call:
lm(formula = p.A ~ light + rock.lg + rock.sm, data = data.frame(v.ard.dif,
tra.dif, env.dif))
##
Residuals:
Min 1Q Median 3Q Max
-45.955 -8.621 2.115 12.151 28.829
##
Coefficients:
Estimate Std. Error t value Pr(>|t|)
(Intercept) -23.55502 6.14481 -3.833 0.000721 ***
light 0.02616 0.35744 0.073 0.942215
rock.lg 0.11754 0.15271 0.770 0.448432
rock.sm -0.53383 0.25424 -2.100 0.045607 *

```

```

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
Residual standard error: 16.79 on 26 degrees of freedom
Multiple R-squared: 0.1479, Adjusted R-squared: 0.04957
F-statistic: 1.504 on 3 and 26 DF, p-value: 0.2368
summary(lm(p.R ~ light +rock.lg + rock.sm,
 data = data.frame(v.ard.dif, tra.dif, env.dif)))

##
Call:
lm(formula = p.R ~ light + rock.lg + rock.sm, data = data.frame(v.ard.dif,
tra.dif, env.dif))
##
Residuals:
Min 1Q Median 3Q Max
-1.09085 -0.72885 0.07251 0.43267 2.04097
##
Coefficients:
Estimate Std. Error t value Pr(>|t|)
(Intercept) -1.027067 0.302605 -3.394 0.00222 **
light 0.017481 0.017602 0.993 0.32981
rock.lg 0.019656 0.007521 2.614 0.01470 *
rock.sm -0.036574 0.012520 -2.921 0.00712 **

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
Residual standard error: 0.8268 on 26 degrees of freedom
Multiple R-squared: 0.3242, Adjusted R-squared: 0.2462
F-statistic: 4.157 on 3 and 26 DF, p-value: 0.01565
summary(lm(p.D ~ light +rock.lg + rock.sm,
 data = data.frame(v.ard.dif, tra.dif, env.dif)))

##
Call:
lm(formula = p.D ~ light + rock.lg + rock.sm, data = data.frame(v.ard.dif,
tra.dif, env.dif))
##
Residuals:
Min 1Q Median 3Q Max
-0.48929 -0.33019 -0.02457 0.29568 0.88860
##
Coefficients:
Estimate Std. Error t value Pr(>|t|)
(Intercept) -0.3546159 0.1309685 -2.708 0.0118 *
light -0.0009857 0.0076183 -0.129 0.8980
rock.lg 0.0027760 0.0032549 0.853 0.4015
rock.sm -0.0142947 0.0054187 -2.638 0.0139 *

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
Residual standard error: 0.3579 on 26 degrees of freedom
Multiple R-squared: 0.2196, Adjusted R-squared: 0.1296
```

```
F-statistic: 2.439 on 3 and 26 DF, p-value: 0.08707
```

## Structural Equation Models

```
l.com.dif <- split(com, l.dat[, "Tree.pairs"])
l.com.dif <- lapply(l.com.dif, function(x) x[2,] - x[1,])
l.com.dif <- do.call(rbind, l.com.dif)

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

l.com.dif.d <- dist(l.com.dif)
v.com.dif.d <- dist(v.com.dif)

l.com.dif.nms <- nmds(l.com.dif.d, 1, 2)
l.com.dif.ord <- nmds.min(l.com.dif.nms, 2)
```

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

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

v.com.dif.nms <- nmds(v.com.dif.d, 2, 3)
v.com.dif.ord <- nmds.min(v.com.dif.nms, 3)
```

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

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

colnames(l.com.dif.ord) <- paste0("l.", colnames(l.com.dif.ord))
colnames(v.com.dif.ord) <- paste0("p.", colnames(v.com.dif.ord))
```

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

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

```
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
```

```
colnames(l.com.dif.ord.proc) <- paste0("rot.", colnames(l.com.dif.ord))
colnames(v.com.dif.ord.proc) <- paste0("rot.", colnames(v.com.dif.ord))
```

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

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

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

% latex table generated in R 4.0.4 by xtable 1.8-4 package % Wed Apr 28 11:19:01 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 % Wed Apr 28 11:19:01 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)
```

	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

```
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 % Wed Apr 28 11:19:01 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 % Wed Apr 28 11:19:01 2021

```
lav.l.all <- 'light ~ crown
 litter ~ crown
 rock.lg ~ litter
 l.A ~ light + rock.lg
 l.R ~ light + rock.lg
 l.D ~ light + rock.lg
 l.X1 ~ light + rock.lg
 l.X2 ~ light + rock.lg
 l.A ~~ l.R
 l.A ~~ l.D
 l.R ~~ l.D
 l.A ~~ l.X1
 l.R ~~ l.X1
 '
lav.v.all <- 'light ~ crown
 litter ~ crown
 rock.sm ~ litter
 p.A ~ light + rock.sm
 p.R ~ light + rock.sm + litter
 p.D ~ light + rock.sm
 p.X1 ~ light + rock.sm
 p.X2 ~ light + rock.sm
 p.X3 ~ light + rock.sm
 p.A ~~ p.X2
 p.A ~~ p.R
 p.A ~~ p.D
 p.R ~~ p.D
 '
```



	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

```

p.A ~~ p.X1
p.R ~~ p.X1
,
lav.l.rot.nolight <- 'litter ~ crown
rock.lg ~ litter
l.A ~ rock.lg
l.R ~ rock.lg
l.D ~ rock.lg
rot.l.X1 ~ rock.lg
rot.l.X2 ~ rock.lg
l.A ~~ l.R
l.A ~~ l.D
l.R ~~ l.D
l.A ~~ rot.l.X1
l.R ~~ rot.l.X1
,
```

```

lav.v.rot.nolight <- 'litter ~ crown
 rock.sm ~ litter
 p.A ~ rock.sm
 p.R ~ rock.sm
 p.D ~ rock.sm
 rot.p.X1 ~ rock.sm
 rot.p.X2 ~ rock.sm
 rot.p.X3 ~ rock.sm
 p.A ~~ rot.p.X2
 p.A ~~ p.R
 p.A ~~ p.D
 p.R ~~ p.D
 p.A ~~ rot.p.X1
 p.R ~~ rot.p.X1
 '

lav.l.rot.all <- 'light ~ crown
 litter ~ crown
 light ~ trunk
 litter ~ trunk
 rock.lg ~ litter
 l.A ~ light + rock.lg
 l.R ~ light + rock.lg
 l.D ~ light + rock.lg
 rot.l.X1 ~ light + rock.lg
 rot.l.X2 ~ light + rock.lg
 l.A ~~ l.R
 l.A ~~ l.D
 l.R ~~ l.D
 l.A ~~ rot.l.X1
 l.R ~~ rot.l.X1
 '

lav.v.rot.all <- 'light ~ crown
 litter ~ crown
 light ~ trunk
 litter ~ trunk
 rock.sm ~ litter
 p.A ~ light + rock.sm
 p.R ~ light + rock.sm
 p.D ~ light + rock.sm
 rot.p.X1 ~ light + rock.sm
 rot.p.X2 ~ light + rock.sm
 rot.p.X3 ~ light + rock.sm
 p.A ~~ rot.p.X2
 p.A ~~ p.R
 p.A ~~ p.D
 p.R ~~ p.D
 p.A ~~ rot.p.X1
 p.R ~~ rot.p.X1
 '

std <- function(x){(x - mean(x)) / sd(x)}

```

```

set.seed(12345)
fit.l.all.raw <- lavaan::sem(lav.l.all, data = sem.dat)
set.seed(12345)
fit.v.all.raw <- lavaan::sem(lav.v.all, data = sem.dat)

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

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

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

lavaan 0.6-8 ended normally after 121 iterations
##
Estimator ML
Optimization method NLMINB
Number of model parameters 31
##
Number of observations 30
##
Model Test User Model:
##
Test statistic 18.541
Degrees of freedom 13
P-value (Chi-square) 0.138
##
Parameter Estimates:
##
Standard errors Standard
Information Expected
Information saturated (h1) model Structured
##
Regressions:
Estimate Std.Err z-value P(>|z|)
light ~
crown -0.005 0.024 -0.204 0.839
litter ~
crown 0.216 0.065 3.341 0.001
rock.lg ~
litter -0.675 0.059 -11.495 0.000
l.A ~
light 0.016 0.065 0.239 0.811

```

```

rock.lg 0.092 0.027 3.417 0.001
1.R ~
light 0.088 0.060 1.478 0.139
rock.lg 0.162 0.025 6.518 0.000
1.D ~
light 0.022 0.013 1.615 0.106
rock.lg 0.031 0.006 5.661 0.000
1.X1 ~
light 0.029 0.040 0.709 0.479
rock.lg 0.037 0.017 2.244 0.025
1.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|)
.1.A ~~
.1.R 4.023 1.799 2.236 0.025
.1.D -0.127 0.368 -0.346 0.729
.1.R ~~
.1.D 1.363 0.420 3.250 0.001
.1.A ~~
.1.X1 4.221 1.347 3.132 0.002
.1.R ~~
.1.X1 2.448 1.111 2.204 0.028
.1.A ~~
.1.X2 -3.251 1.113 -2.919 0.004
.1.R ~~
.1.X2 -0.466 0.871 -0.534 0.593
.1.D ~~
.1.X1 0.048 0.227 0.213 0.832
.1.X2 0.196 0.197 0.994 0.320
.1.X1 ~~
.1.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
.1.A 9.776 2.524 3.873 0.000
.1.R 8.276 2.137 3.873 0.000
.1.D 0.413 0.107 3.873 0.000
.1.X1 3.750 0.968 3.873 0.000
.1.X2 2.724 0.703 3.873 0.000
##
R-Square:
Estimate
light 0.001
litter 0.271
rock.lg 0.815
1.A 0.282
1.R 0.600
1.D 0.538

```

```
1.X1 0.157
1.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
1.A ~
light 0.037 0.154 0.239 0.811
rock.lg 0.528 0.154 3.417 0.001
1.R ~
light 0.168 0.114 1.478 0.139
rock.lg 0.742 0.114 6.518 0.000
1.D ~
light 0.197 0.122 1.615 0.106
rock.lg 0.691 0.122 5.661 0.000
1.X1 ~
light 0.118 0.167 0.709 0.479
rock.lg 0.374 0.167 2.244 0.025
1.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|)
.1.A ~~
.1.R 0.228 0.102 2.236 0.025
.1.D -0.035 0.100 -0.346 0.729
.1.R ~~
.1.D 0.297 0.091 3.250 0.001
.1.A ~~
.1.X1 0.520 0.166 3.132 0.002
.1.R ~~
.1.X1 0.242 0.110 2.204 0.028
.1.A ~~
.1.X2 -0.490 0.168 -2.919 0.004
.1.R ~~

```

```

.l.X2 -0.056 0.105 -0.534 0.593
.l.D ~~
.l.X1 0.023 0.108 0.213 0.832
.l.X2 0.114 0.114 0.994 0.320
.l.X1 ~~
.l.X2 0.078 0.154 0.507 0.612
##
Variances:
Estimate Std.Err z-value P(>|z|)
.light 0.965 0.249 3.873 0.000
.litter 0.705 0.182 3.873 0.000
.rock.lg 0.179 0.046 3.873 0.000
.l.A 0.691 0.178 3.873 0.000
.l.R 0.375 0.097 3.873 0.000
.l.D 0.432 0.112 3.873 0.000
.l.X1 0.806 0.208 3.873 0.000
.l.X2 0.876 0.226 3.873 0.000
##
R-Square:
Estimate
light 0.001
litter 0.271
rock.lg 0.815
l.A 0.282
l.R 0.600
l.D 0.538
l.X1 0.157
l.X2 0.101

```

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

```

lavaan 0.6-8 ended normally after 52 iterations
##
Estimator ML
Optimization method NLMINB
Number of model parameters 40
##
Number of observations 30
##
Model Test User Model:
##
Test statistic 12.147
Degrees of freedom 14
P-value (Chi-square) 0.595
##
Parameter Estimates:
##
Standard errors Standard
Information Expected
Information saturated (h1) model Structured
##
Regressions:
Estimate Std.Err z-value P(>|z|)
light ~
crown -0.037 0.182 -0.204 0.839

```



```

litter ~
crown 0.521 0.156 3.341 0.001
rock.sm ~
litter -0.686 0.133 -5.169 0.000
p.A ~
light 0.024 0.170 0.143 0.887
rock.sm -0.363 0.170 -2.128 0.033
p.R ~
light 0.184 0.152 1.217 0.224
rock.sm -0.634 0.165 -3.835 0.000
litter -0.386 0.096 -4.027 0.000
p.D ~
light -0.012 0.164 -0.071 0.944
rock.sm -0.442 0.164 -2.704 0.007
p.X1 ~
light 0.106 0.180 0.589 0.556
rock.sm 0.123 0.180 0.684 0.494
p.X2 ~
light -0.015 0.179 -0.086 0.931
rock.sm 0.206 0.179 1.151 0.250
p.X3 ~
light 0.129 0.167 0.771 0.441
rock.sm 0.353 0.167 2.108 0.035
##
Covariances:
Estimate Std.Err z-value P(>|z|)
.p.A ~~
.p.X2 -0.495 0.185 -2.679 0.007
.p.R 0.319 0.149 2.147 0.032
.p.D 0.262 0.155 1.690 0.091
.p.R ~~
.p.D 0.628 0.174 3.602 0.000
.p.A ~~
.p.X1 -0.497 0.186 -2.677 0.007
.p.R ~~
.p.X1 -0.134 0.146 -0.913 0.361
.p.A ~~
.p.X3 -0.256 0.158 -1.618 0.106
.p.R ~~
.p.X2 -0.312 0.154 -2.019 0.044
.p.X3 0.018 0.134 0.137 0.891
.p.D ~~
.p.X1 -0.029 0.156 -0.184 0.854
.p.X2 -0.334 0.166 -2.007 0.045
.p.X3 0.048 0.145 0.328 0.743
.p.X1 ~~
.p.X2 0.080 0.171 0.472 0.637
.p.X3 -0.097 0.160 -0.605 0.545
.p.X2 ~~
.p.X3 -0.206 0.163 -1.263 0.206
##
Variances:
Estimate Std.Err z-value P(>|z|)
.light 0.965 0.249 3.873 0.000

```

```
.litter 0.705 0.182 3.873 0.000
.rock.sm 0.511 0.132 3.873 0.000
.p.A 0.842 0.218 3.873 0.000
.p.R 0.667 0.172 3.873 0.000
.p.D 0.775 0.200 3.873 0.000
.p.X1 0.936 0.242 3.873 0.000
.p.X2 0.927 0.239 3.873 0.000
.p.X3 0.812 0.210 3.873 0.000
```

```
##
R-Square:
Estimate
light 0.001
litter 0.271
rock.sm 0.471
p.A 0.131
p.R 0.265
p.D 0.196
p.X1 0.027
p.X2 0.042
p.X3 0.145
```

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

```
lavaan 0.6-8 ended normally after 58 iterations
```

```
##
Estimator ML
Optimization method NLMINB
Number of model parameters 33
##
Number of observations 30
##
Model Test User Model:
##
Test statistic 26.681
Degrees of freedom 19
P-value (Chi-square) 0.112
##
```

```
Parameter Estimates:
##
Standard errors Standard
Information Expected
Information saturated (h1) model Structured
##
```

```
Regressions:
Estimate Std.Err z-value P(>|z|)
light ~
crown -0.052 0.202 -0.256 0.798
litter ~
crown 0.594 0.170 3.506 0.000
light ~
trunk 0.034 0.202 0.169 0.866
litter ~
trunk -0.172 0.170 -1.016 0.309
rock.lg ~
litter -0.903 0.079 -11.495 0.000
```

```

1.A ~
light 0.037 0.154 0.239 0.811
rock.lg 0.528 0.154 3.417 0.001
1.R ~
light 0.168 0.114 1.478 0.139
rock.lg 0.742 0.114 6.518 0.000
1.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|)
.1.A ~~
.1.R 0.228 0.102 2.236 0.025
.1.D -0.035 0.100 -0.346 0.729
.1.R ~~
.1.D 0.297 0.091 3.250 0.001
.1.A ~~
.rot.l.X1 0.677 0.181 3.751 0.000
.1.R ~~
.rot.l.X1 0.241 0.106 2.266 0.023
.1.A ~~
.rot.l.X2 -0.098 0.148 -0.662 0.508
.1.R ~~
.rot.l.X2 0.095 0.110 0.866 0.386
.1.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
.1.A 0.691 0.178 3.873 0.000
.1.R 0.375 0.097 3.873 0.000
.1.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
1.A 0.282

```

```
1.R 0.601
1.D 0.539
rot.1.X1 0.219
rot.1.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
1.A ~
rock.lg 0.533 0.155 3.446 0.001
1.R ~
rock.lg 0.764 0.118 6.489 0.000
1.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|)
.1.A ~~
.1.R 0.234 0.105 2.218 0.027
.1.D -0.028 0.104 -0.266 0.790
.1.R ~~
.1.D 0.328 0.099 3.303 0.001
.1.A ~~
.rot.l.X1 0.679 0.181 3.751 0.000
.1.R ~~
.rot.l.X1 0.250 0.110 2.261 0.024
.1.A ~~
.rot.l.X2 -0.092 0.150 -0.612 0.541
.1.R ~~
.rot.l.X2 0.123 0.116 1.058 0.290
```

```

.l.D ~~
.rot.l.X1 -0.018 0.109 -0.169 0.866
.rot.l.X2 0.139 0.126 1.107 0.268
.rot.l.X1 ~~
.rot.l.X2 0.162 0.159 1.023 0.306
##
Variances:
Estimate Std.Err z-value P(>|z|)
.litter 0.705 0.182 3.873 0.000
.rock.lg 0.179 0.046 3.873 0.000
.l.A 0.692 0.179 3.873 0.000
.l.R 0.402 0.104 3.873 0.000
.l.D 0.469 0.121 3.873 0.000
.rot.l.X1 0.754 0.195 3.873 0.000
.rot.l.X2 0.967 0.250 3.873 0.000
##
R-Square:
Estimate
.litter 0.271
.rock.lg 0.815
.l.A 0.284
.l.R 0.584
.l.D 0.515
.rot.l.X1 0.220
.rot.l.X2 0.000

```

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

```

lavaan 0.6-8 ended normally after 41 iterations
##
Estimator ML
Optimization method NLMINB
Number of model parameters 31
##
Number of observations 30
##
Model Test User Model:
##
Test statistic 20.525
Degrees of freedom 13
P-value (Chi-square) 0.083
##
Parameter Estimates:
##
Standard errors Standard
Information Expected
Information saturated (h1) model Structured
##
Regressions:
Estimate Std.Err z-value P(>|z|)
.litter ~
.crown 0.521 0.156 3.341 0.001
.rock.sm ~
.litter -0.686 0.133 -5.169 0.000
.p.A ~

```

```

rock.sm -0.358 0.170 -2.098 0.036
p.R ~
rock.sm -0.331 0.172 -1.921 0.055
p.D ~
rock.sm -0.445 0.164 -2.719 0.007
rot.p.X1 ~
rock.sm 0.463 0.162 2.859 0.004
rot.p.X2 ~
rock.sm -0.000 0.183 -0.000 1.000
rot.p.X3 ~
rock.sm 0.000 0.183 0.000 1.000
##
Covariances:
Estimate Std.Err z-value P(>|z|)
.p.A ~~
.rot.p.X2 -0.342 0.176 -1.942 0.052
.p.R 0.367 0.169 2.169 0.030
.p.D 0.262 0.155 1.688 0.091
.p.R ~~
.p.D 0.670 0.193 3.474 0.001
.p.A ~~
.rot.p.X1 -0.508 0.173 -2.933 0.003
.p.R ~~
.rot.p.X1 -0.089 0.149 -0.602 0.547
.p.A ~~
.rot.p.X3 0.301 0.174 1.735 0.083
.p.R ~~
.rot.p.X2 -0.123 0.168 -0.730 0.466
.rot.p.X3 0.324 0.177 1.834 0.067
.p.D ~~
.rot.p.X1 -0.069 0.141 -0.491 0.623
.rot.p.X2 -0.008 0.158 -0.052 0.958
.rot.p.X3 0.299 0.167 1.790 0.074
.rot.p.X1 ~~
.rot.p.X2 -0.099 0.157 -0.626 0.532
.rot.p.X3 0.224 0.162 1.385 0.166
.rot.p.X2 ~~
.rot.p.X3 -0.177 0.179 -0.985 0.325
##
Variances:
Estimate Std.Err z-value P(>|z|)
.litter 0.705 0.182 3.873 0.000
.rock.sm 0.511 0.132 3.873 0.000
.p.A 0.843 0.218 3.873 0.000
.p.R 0.861 0.222 3.873 0.000
.p.D 0.776 0.200 3.873 0.000
.rot.p.X1 0.760 0.196 3.873 0.000
.rot.p.X2 0.967 0.250 3.873 0.000
.rot.p.X3 0.967 0.250 3.873 0.000
##
R-Square:
Estimate
litter 0.271
rock.sm 0.471

```



```
p.A 0.128
p.R 0.110
p.D 0.198
rot.p.X1 0.214
rot.p.X2 0.000
rot.p.X3 0.000
```

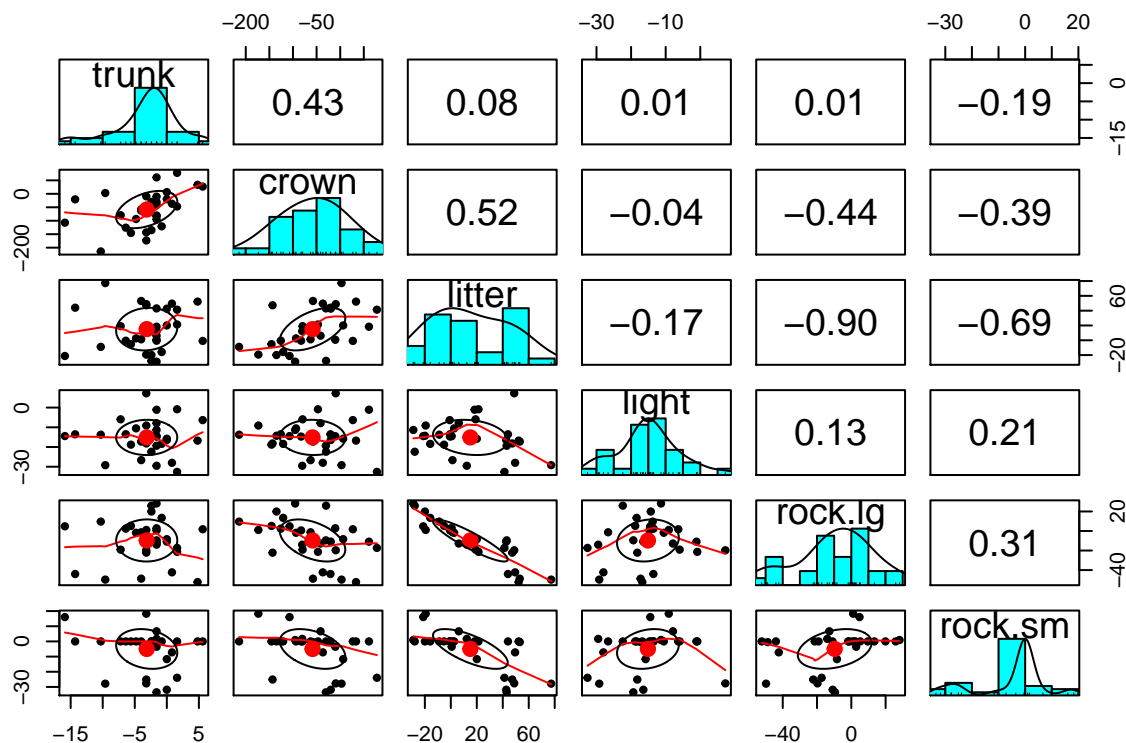
## SEM Variable R-Squares

```
get_R2 <- function(x){
 out <- capture.output(summary(x, rsquare = TRUE))
 out <- out[grep("R-Square:",out):length(out)]
 out <- out[!(grepl("R-Square:", out)) & !(grepl("Estimate", out))]
 out <- out[out != ""]
 out <- strsplit(out, " ")
 out <- lapply(out, function(x) x[x != ""])
 out <- do.call(rbind, out)
 out.names <- out[, 1]
 out <- as.numeric(out[, 2])
 names(out) <- out.names
 return(out)
}

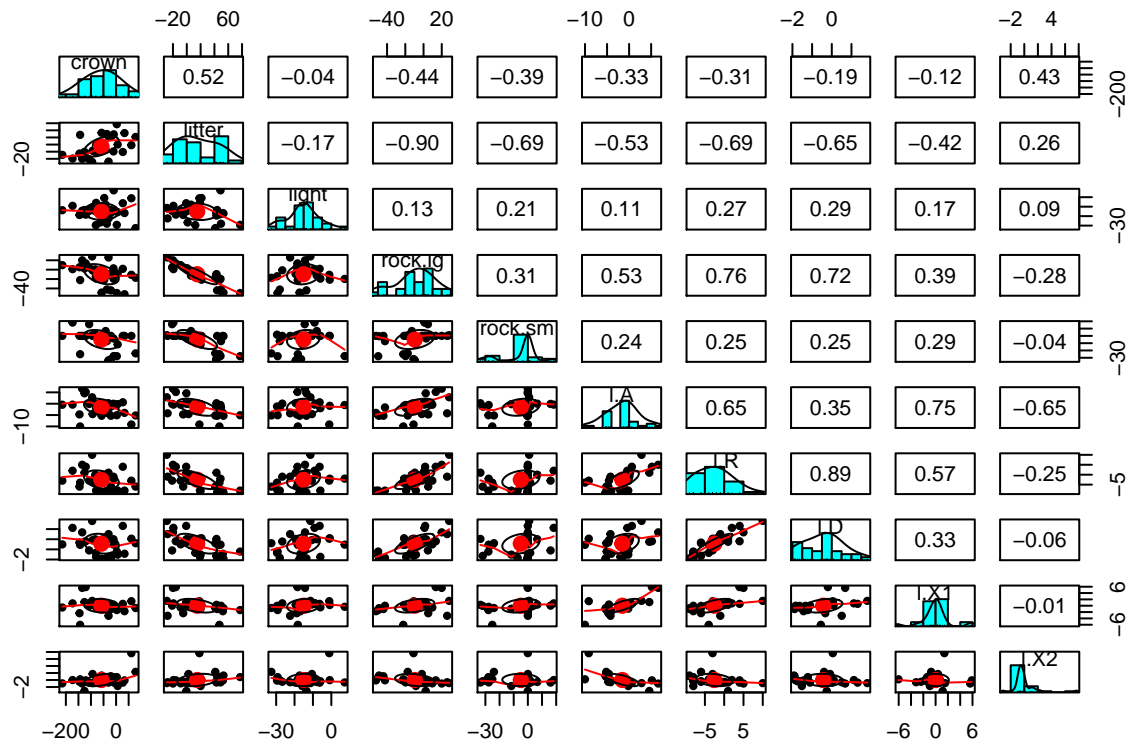
r2.l.rot.all <- get_R2(fit.l.rot.all)
r2.v.rot.all <- get_R2(fit.v.rot.all)
```

## SEM variable inter-correlations plot

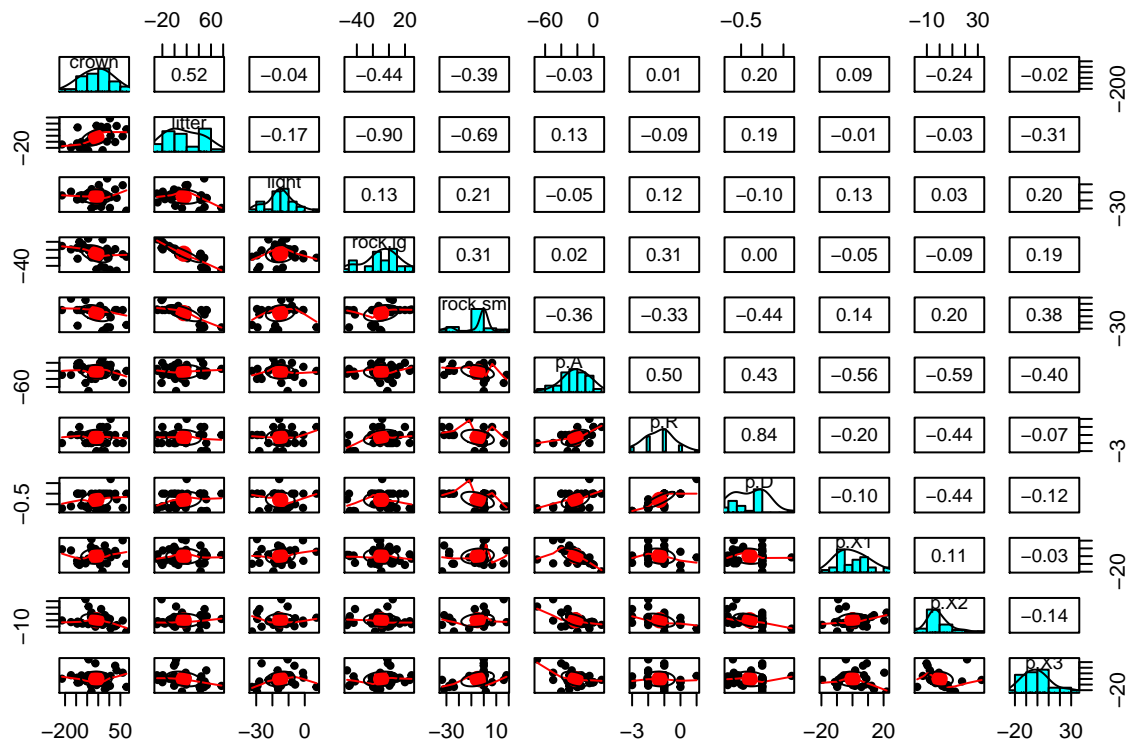
```
pairs.panels(sem.dat[, c("trunk", "crown", "litter", "light", "rock.lg", "rock.sm")])
```



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



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



## SEM Skew-Kurtosis Check

```
skc.sem <- skew_kurtosis(sem.dat)
skc.sem.flags <- skc.sem[(abs(skc.sem[, "skew_2se"]) > 1 |
 abs(skc.sem[, "kurt_2se"]) > 1),]
kable(skc.sem.flags)
```

	skew	skew_2se	kurt	kurt_2se
l.X1	0.3854049	0.4514075	2.683946	1.6115042
l.X2	2.6079952	3.0546283	9.344848	5.6108660
p.X2	1.2498696	1.4639165	1.705619	1.0240934
rot.l.X2	1.9574132	2.2926307	5.705369	3.4256372
rot.p.X1	1.1461696	1.3424572	1.444625	0.8673866

## SEM Modification Indices

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

% latex table generated in R 4.0.4 by xtable 1.8-4 package % Wed Apr 28 11:19:07 2021

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

% latex table generated in R 4.0.4 by xtable 1.8-4 package % Wed Apr 28 11:19:07 2021

## SEM Parameter Estimates

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

% latex table generated in R 4.0.4 by xtable 1.8-4 package % Wed Apr 28 11:19:07 2021

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

% latex table generated in R 4.0.4 by xtable 1.8-4 package % Wed Apr 28 11:19:08 2021

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

% latex table generated in R 4.0.4 by xtable 1.8-4 package % Wed Apr 28 11:19:08 2021

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

% latex table generated in R 4.0.4 by xtable 1.8-4 package % Wed Apr 28 11:19:08 2021

## SEM Model Fit Measures

```
sem.fm.l.all <- fitMeasures(fit.l.all)
sem.fm.v.all <- fitMeasures(fit.v.all)
sem.fm.l.rot.all <- fitMeasures(fit.l.rot.all)
sem.fm.v.rot.all <- fitMeasures(fit.v.rot.all)

sem.fm.tab.all <- rbind(sem.fm.l.all[c("chisq", "df", "pvalue")],
 sem.fm.v.all[c("chisq", "df", "pvalue")])
rownames(sem.fm.tab.all) <- c("Lichens", "Plants")
colnames(sem.fm.tab.all) <- c("$\\chi^2$", "\\textit{df}", "\\textit{p}-value")
sem.fm.tab.rot.all <- rbind(sem.fm.l.rot.all[c("chisq", "df", "pvalue")],
 sem.fm.v.rot.all[c("chisq", "df", "pvalue")])
```

```
rownames(sem.fm.tab.rot.all) <- c("Lichens", "Plants")
colnames(sem.fm.tab.rot.all) <- c("$\\chi^2$", "\\textit{df}", "\\textit{p}-value")

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

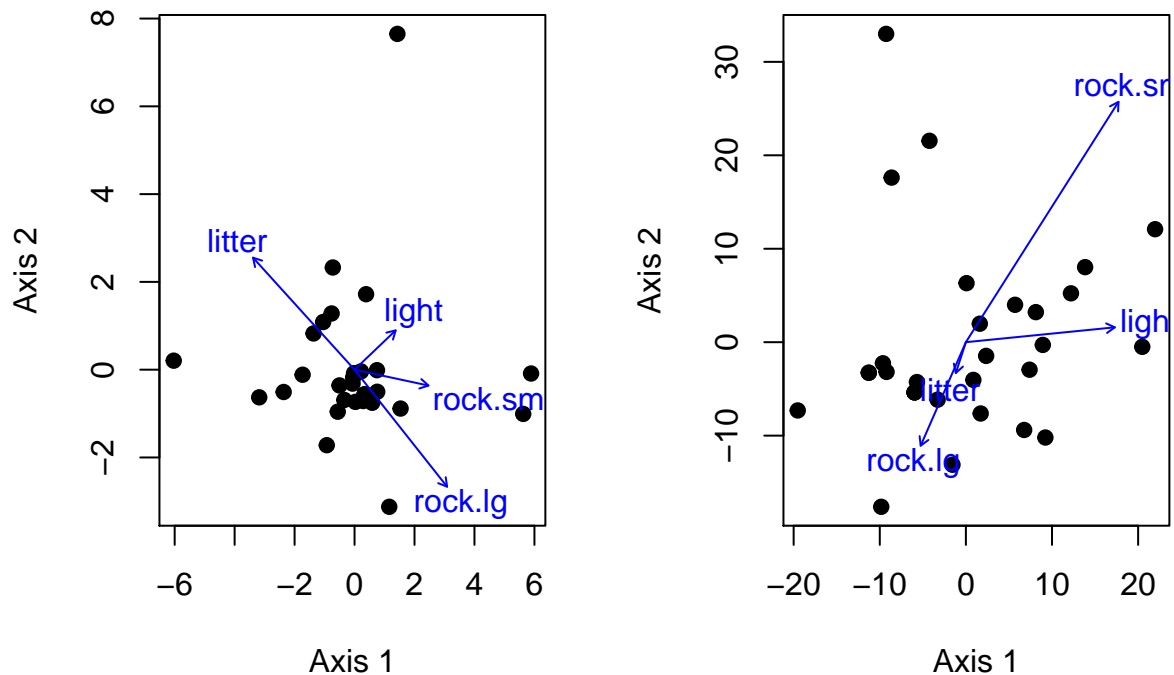
% latex table generated in R 4.0.4 by xtable 1.8-4 package % Wed Apr 28 11:19:08 2021

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

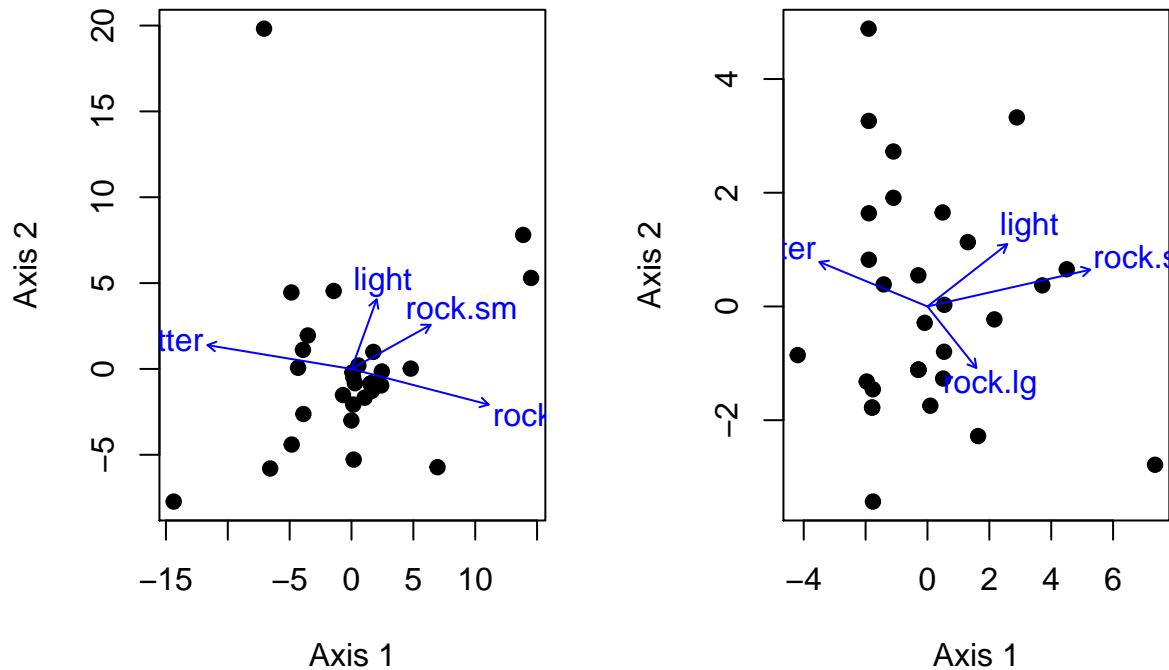
% latex table generated in R 4.0.4 by xtable 1.8-4 package % Wed Apr 28 11:19:08 2021

## Ordination Plots

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



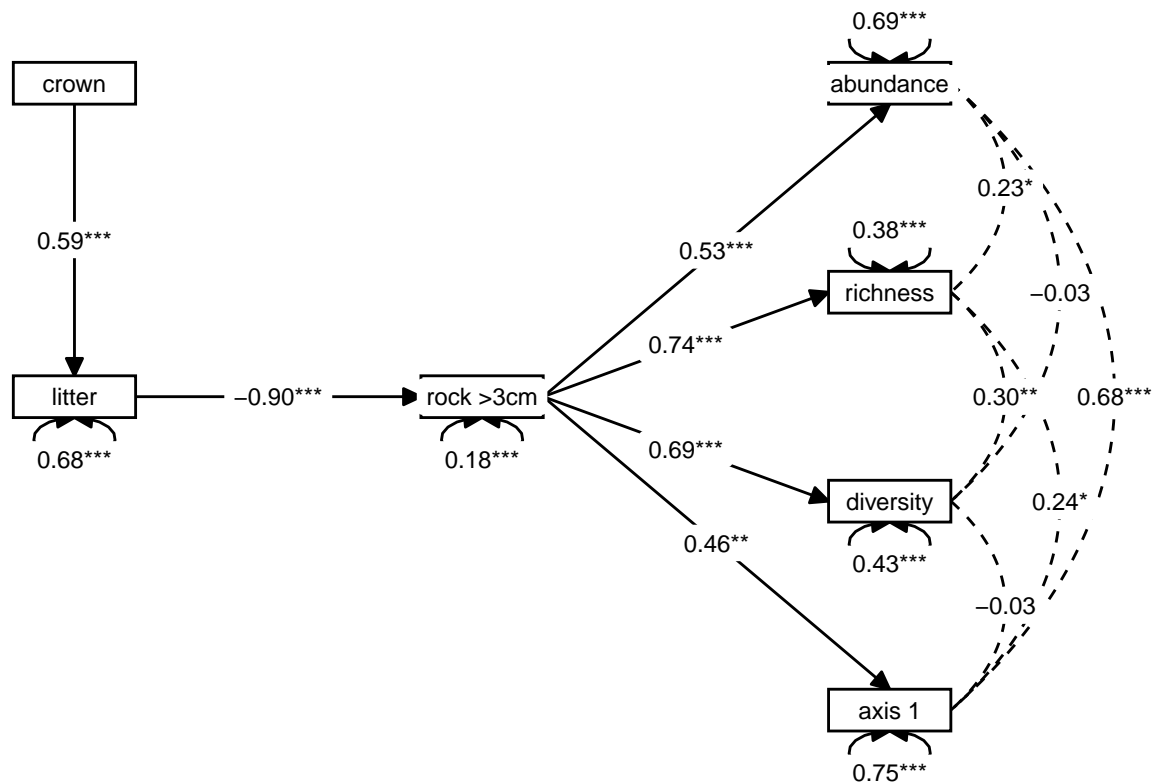
```
par(mfrow = c(1,2))
plot(l.com.dif.ord.proc[, 1:2], xlab = "Axis 1", ylab = "Axis 2", pch = 19)
plot(l.com.dif.vec.rot, add = TRUE)
plot(v.com.dif.ord.proc[, 1:2], xlab = "Axis 1", ylab = "Axis 2", pch = 19)
plot(v.com.dif.vec.rot, add = TRUE)
```



## SEM Plots

```
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)

Some edges involve nodes not in layout. These were dropped.
nodes(tg.l.rot.all)[nodes(tg.l.rot.all)[, "name"] ==
 "l.A", "label"] <- "abundance"
nodes(tg.l.rot.all)[nodes(tg.l.rot.all)[, "name"] ==
 "l.R", "label"] <- "richness"
nodes(tg.l.rot.all)[nodes(tg.l.rot.all)[, "name"] ==
 "l.D", "label"] <- "diversity"
nodes(tg.l.rot.all)[nodes(tg.l.rot.all)[, "name"] ==
 "rock.lg", "label"] <- "rock >3cm"
nodes(tg.l.rot.all)[nodes(tg.l.rot.all)[, "name"] ==
 "rot.l.X1", "label"] <- "axis 1"
tg.l.rot.all[["rect_height"]] <- tg.l.rot.all[["rect_height"]] * 2
tg.l.rot.all[["rect_width"]] <- tg.l.rot.all[["rect_width"]] * 2
tg.l.rot.all[["text_size"]] <- tg.l.rot.all[["text_size"]] * 0.75
plot(tg.l.rot.all)
```

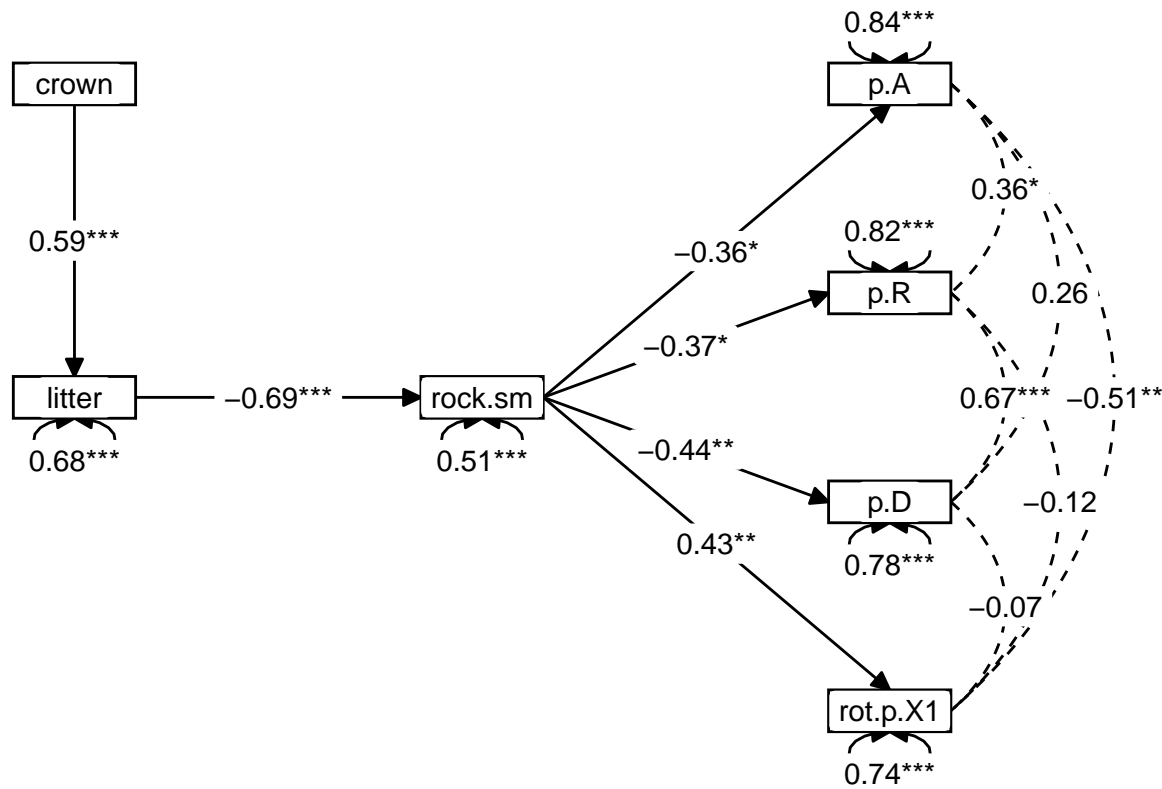


```

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

Some edges involve nodes not in layout. These were dropped.
plot(tg.v.rot.all)

```



## 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 via the *vegan* package (Oksanen et al. 2019), 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).

We constructed *a priori* models based on our hypotheses of the effects of tree traits on the two communities, lichens and plants. We used the differences between 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 using the *Lavaan* package in R (Rosseel 2012).

Jari Oksanen, 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. <https://CRAN.R-project.org/package=vegan>.

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

## Causal Pathway of Moth Susceptibility Effects on Communities

- Moth susceptibility indirectly influences plants and lichen
  1. Crown effect of moth increases litter effects but does not affect light differences
  2. Differences in litter between moth susceptible and resistant trees decreases the differences of both large and small rocks

3. Differences in large rocks increases lichen community differences (abundance, richness, diversity, composition) and the difference in small rocks decreases the plant community differences (abundance richness, diversity and composition) between susceptible and resistant trees
- Both SEMs fit the data lichen ( $df = 19$ ,  $X^2 = 26.6808212$ ,  $p$ -value = 0.1123101) nor the plant ( $df = 22$ ,  $X^2 = 30.7624162$ ,  $p$ -value = 0.1010805) models showing significant differences from their observed covariance matrices based on  $X^2$  Goodness of Fit tests.
- Ultimately, moth induced changes 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 significantly explained by crown size differences for both lichens ( $R^2 = 0.219$ ) and plants ( $R^2 = 0.215$ ).
- See SEM path diagrams
- The effects can be interpreted as so:
  - As crown differences increase, litter differences increase
  - As litter differences increase, large rock differences decrease
  - As litter differences increase, small rock differences decrease
  - As large rock differences increase, lichen differences increase
  - As small rock differences increase, plant differences decrease

```
write.csv(file = "results/sem_results_lichen.csv",
 table_results(fit.l.rot.all)[, c("label", "est_sig", "se", "pval")],
 row.names = FALSE)
write.csv(file = "results/sem_results_plant.csv",
 table_results(fit.v.rot.all)[, c("label", "est_sig", "se", "pval")],
 row.names = FALSE)
```

label	est_sig	se	pval	confint
light.ON.crown	-0.05	0.20	0.80	[-0.45, 0.34]
litter.ON.crown	0.59***	0.17	0.00	[0.26, 0.93]
light.ON.trunk	0.03	0.20	0.87	[-0.36, 0.43]
litter.ON.trunk	-0.17	0.17	0.31	[-0.50, 0.16]
rock.lg.ON.litter	-0.90***	0.08	0.00	[-1.06, -0.75]
l.A.ON.light	0.04	0.15	0.81	[-0.27, 0.34]
l.A.ON.rock.lg	0.53***	0.15	0.00	[0.22, 0.83]
l.R.ON.light	0.17	0.11	0.14	[-0.05, 0.39]
l.R.ON.rock.lg	0.74***	0.11	0.00	[0.52, 0.96]
l.D.ON.light	0.20	0.12	0.11	[-0.04, 0.44]
l.D.ON.rock.lg	0.69***	0.12	0.00	[0.45, 0.93]
rot.l.X1.ON.light	0.05	0.16	0.75	[-0.26, 0.37]
rot.l.X1.ON.rock.lg	0.46**	0.16	0.00	[0.15, 0.78]
rot.l.X2.ON.light	0.17	0.18	0.33	[-0.18, 0.53]
rot.l.X2.ON.rock.lg	-0.02	0.18	0.90	[-0.38, 0.33]
l.A.WITH.l.R	0.23*	0.10	0.03	[0.03, 0.43]
l.A.WITH.l.D	-0.03	0.10	0.73	[-0.23, 0.16]
l.R.WITH.l.D	0.30**	0.09	0.00	[0.12, 0.48]
l.A.WITH.rot.l.X1	0.68***	0.18	0.00	[0.32, 1.03]
l.R.WITH.rot.l.X1	0.24*	0.11	0.02	[0.03, 0.45]
Variances.light	0.96***	0.25	0.00	[0.48, 1.45]
Variances.litter	0.68***	0.18	0.00	[0.34, 1.03]
Variances.rock.lg	0.18***	0.05	0.00	[0.09, 0.27]
Variances.l.A	0.69***	0.18	0.00	[0.34, 1.04]
Variances.l.R	0.38***	0.10	0.00	[0.19, 0.57]
Variances.l.D	0.43***	0.11	0.00	[0.21, 0.65]
Variances.rot.l.X1	0.75***	0.19	0.00	[0.37, 1.13]



label	est_sig	se	pval	confint
Variances.rot.l.X2	0.94***	0.24	0.00	[0.46, 1.41]
l.A.WITH.rot.l.X2	-0.10	0.15	0.51	[-0.39, 0.19]
l.R.WITH.rot.l.X2	0.10	0.11	0.39	[-0.12, 0.31]
l.D.WITH.rot.l.X1	-0.03	0.10	0.79	[-0.23, 0.18]
l.D.WITH.rot.l.X2	0.11	0.12	0.37	[-0.12, 0.34]
rot.l.X1.WITH.rot.l.X2	0.15	0.16	0.32	[-0.15, 0.46]
Variances.crown	0.97	0.00	NA	[0.97, 0.97]
crown.WITH.trunk	0.41	0.00	NA	[0.41, 0.41]
Variances.trunk	0.97	0.00	NA	[0.97, 0.97]

label	est_sig	se	pval	confint
light.ON.crown	-0.05	0.20	0.80	[-0.45, 0.34]
litter.ON.crown	0.59***	0.17	0.00	[0.26, 0.93]
light.ON.trunk	0.03	0.20	0.87	[-0.36, 0.43]
litter.ON.trunk	-0.17	0.17	0.31	[-0.50, 0.16]
rock.sm.ON.litter	-0.69***	0.13	0.00	[-0.95, -0.43]
p.A.ON.light	0.02	0.17	0.89	[-0.31, 0.36]
p.A.ON.rock.sm	-0.36*	0.17	0.03	[-0.70, -0.03]
p.R.ON.light	0.20	0.17	0.24	[-0.13, 0.53]
p.R.ON.rock.sm	-0.37*	0.17	0.03	[-0.70, -0.04]
p.D.ON.light	-0.01	0.16	0.94	[-0.33, 0.31]
p.D.ON.rock.sm	-0.44**	0.16	0.01	[-0.76, -0.12]
rot.p.X1.ON.light	0.14	0.16	0.37	[-0.17, 0.46]
rot.p.X1.ON.rock.sm	0.43**	0.16	0.01	[0.12, 0.75]
rot.p.X2.ON.light	0.06	0.18	0.73	[-0.29, 0.42]
rot.p.X2.ON.rock.sm	-0.01	0.18	0.94	[-0.37, 0.34]
rot.p.X3.ON.light	0.07	0.18	0.70	[-0.29, 0.43]
rot.p.X3.ON.rock.sm	-0.01	0.18	0.94	[-0.37, 0.34]
p.A.WITH.rot.p.X2	-0.34	0.18	0.05	[-0.69, 0.00]
p.A.WITH.p.R	0.36*	0.17	0.03	[0.04, 0.69]
p.A.WITH.p.D	0.26	0.16	0.09	[-0.04, 0.57]
p.R.WITH.p.D	0.67***	0.19	0.00	[0.30, 1.05]
p.A.WITH.rot.p.X1	-0.51**	0.17	0.00	[-0.85, -0.17]
p.R.WITH.rot.p.X1	-0.12	0.14	0.42	[-0.40, 0.17]
Variances.light	0.96***	0.25	0.00	[0.48, 1.45]
Variances.litter	0.68***	0.18	0.00	[0.34, 1.03]
Variances.rock.sm	0.51***	0.13	0.00	[0.25, 0.77]
Variances.p.A	0.84***	0.22	0.00	[0.42, 1.27]
Variances.p.R	0.82***	0.21	0.00	[0.41, 1.24]
Variances.p.D	0.78***	0.20	0.00	[0.38, 1.17]
Variances.rot.p.X1	0.74***	0.19	0.00	[0.37, 1.12]
Variances.rot.p.X2	0.96***	0.25	0.00	[0.48, 1.45]
Variances.rot.p.X3	0.96***	0.25	0.00	[0.48, 1.45]
p.A.WITH.rot.p.X3	0.30	0.17	0.08	[-0.04, 0.64]
p.R.WITH.rot.p.X2	-0.13	0.16	0.42	[-0.46, 0.19]
p.R.WITH.rot.p.X3	0.31	0.17	0.07	[-0.03, 0.65]
p.D.WITH.rot.p.X1	-0.07	0.14	0.63	[-0.34, 0.20]
p.D.WITH.rot.p.X2	-0.01	0.16	0.96	[-0.32, 0.30]
p.D.WITH.rot.p.X3	0.30	0.17	0.07	[-0.03, 0.63]
rot.p.X1.WITH.rot.p.X2	-0.11	0.16	0.49	[-0.41, 0.20]
rot.p.X1.WITH.rot.p.X3	0.21	0.16	0.18	[-0.10, 0.53]

label	est_sig	se	pval	confint
rot.p.X2.WITH.rot.p.X3	-0.18	0.18	0.31	[-0.53, 0.17]
Variances.crown	0.97	0.00	NA	[0.97, 0.97]
crown.WITH.trunk	0.41	0.00	NA	[0.41, 0.41]
Variances.trunk	0.97	0.00	NA	[0.97, 0.97]

	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	0.4291	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]

	$\chi^2$	df	p-value
Lichens	18.541	13.000	0.138
Plants	12.147	14.000	0.595

	$\chi^2$	df	p-value
Lichens	26.681	19.000	0.112
Plants	30.762	22.000	0.101