8. Worksheet: Among Site (Beta) Diversity – Part 2

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19 April, 2021

OVERVIEW

In this worksheet, we continue to explore concepts, statistics, and visualizations related to β-diversity. Now that you know how to formally quantify β-diversity, we will learn how to test hypotheses about β-diversity using multivariate statistics.

Directions:

1. In the Markdown version of this document in your cloned repo, change "Student Name" on line 3 (above) with your name.
2. Complete as much of the worksheet as possible during class.
3. Use the handout as a guide; it contains a more complete description of data sets along with examples of proper scripting needed to carry out the exercises.
4. Answer questions in the worksheet. Space for your answers is provided in this document and is indicated by the ">" character. If you need a second paragraph be sure to start the first line with ">". You should notice that the answer is highlighted in green by RStudio (color may vary if you changed the editor theme).
5. Before you leave the classroom today, it is *imperative* that you **push** this file to your GitHub repo, at whatever stage you are. This will enable you to pull your work onto your own computer.
6. When you have completed the worksheet, **Knit** the text and code into a single PDF file by pressing the `Knit` button in the RStudio scripting panel. This will save the PDF output in your '8.BetaDiversity' folder.
7. After Knitting, please submit the worksheet by making a **push** to your GitHub repo and then create a **pull request** via GitHub. Your pull request should include this file (**8.BetaDiversity_2_Worksheet.Rmd**) with all code blocks filled out and questions answered) and the PDF output of `Knitr` (**8.BetaDiversity_2_Worksheet.pdf**).

The completed exercise is due on **Wednesday, April 23rd, 2021 before 09:00 AM**.

1) R SETUP

Typically, the first thing you will do in either an R script or an RMarkdown file is setup your environment. This includes things such as setting the working directory and loading any packages that you will need.

In the R code chunk below, provide the code to:

1. clear your R environment,
2. print your current working directory,
3. set your working directory to your "*/8.BetaDiversity*" folder, and

4. load the `vegan` R package (be sure to install if needed).

```
# clear working directory and environment, then set working directory
rm(list = ls())
getwd()
```

```
## [1] "C:/Users/Rich Hull/GitHub/QB2021_Hull/2.Worksheets/8.BetaDiversity"
```

```
setwd("C:/Users/Rich Hull/GitHub/QB2021_Hull/2.Worksheets/8.BetaDiversity")
# load packages
require(vegan)
```

```
## Loading required package: vegan

## Loading required package: permute

## Loading required package: lattice

## This is vegan 2.5-7
```

2) LOADING DATA

Load dataset

In the R code chunk below, load the `doubs` dataset from the `ade4` package

```
# note, pleae do not print the dataset when submitting
# load data
require(ade4)
```

```
## Loading required package: ade4

## Warning: package 'ade4' was built under R version 4.0.5
```

```
data(doubs)
# create fish
fish <- doubs$fish
fish <- fish[-8, ]
```

3) HYPOTHESIS TESTING

A. Multivariate Procedures for Categorical Designs

Earlier work done in the Doubs River suggested that the river has four distinct regions of habitat quality: the first region (sites 1-14) of "high quality"; the second (sites 15 - 19) and fourth (sites 26 - 30) of "moderate quality"; and the third (sites 20 - 25) of "low quality".

In the code chunk below, test the hypothesis that fish community composition varies with river quality.

1. create a factor vector that categorizes habitat quality in the Doubs River,
2. use the multivariate analyses for categorical predictors to describe how fish community structure relates to habitat quality.

```r
# create factors vector
quality <- c(rep("HQ", 13), rep("MQ", 5), rep("LQ", 6), rep("MQ", 5))
# run PERMANOVA with adonis function
adonis(fish ~ quality, method = "bray", permutations = 999)
```

```
##
## Call:
## adonis(formula = fish ~ quality, permutations = 999, method = "bray")
##
## Permutation: free
## Number of permutations: 999
##
## Terms added sequentially (first to last)
##
##           Df SumsOfSqs MeanSqs F.Model      R2 Pr(>F)
## quality    2    3.0947 1.54733   10.97 0.45765  0.001 ***
## Residuals 26    3.6674 0.14105         0.54235
## Total     28    6.7621                 1.00000
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```r
# species site group associations
require(indicspecies)
```

```
## Loading required package: indicspecies
```

```
## Warning: package 'indicspecies' was built under R version 4.0.5
```

```r
indval <- multipatt(fish, cluster = quality, func = "IndVal.g", control = how(nperm = 999))
summary(indval)
```

```
##
##  Multilevel pattern analysis
##  ---------------------------
##
##  Association function: IndVal.g
##  Significance level (alpha): 0.05
##
##  Total number of species: 27
##  Selected number of species: 23
##  Number of species associated to 1 group: 1
##  Number of species associated to 2 groups: 22
##
##  List of species associated to each combination:
##
##  Group MQ  #sps.  1
##       stat p.value
```

```
## Teso 0.686   0.018 *
##
##  Group HQ+MQ  #sps.  2
##       stat p.value
## Satr 0.860   0.004 **
## Phph 0.859   0.011 *
##
##  Group LQ+MQ  #sps.  20
##       stat p.value
## Alal 0.935   0.001 ***
## Gogo 0.933   0.001 ***
## Ruru 0.916   0.001 ***
## Legi 0.901   0.001 ***
## Baba 0.895   0.001 ***
## Chna 0.866   0.001 ***
## Spbi 0.866   0.001 ***
## Cyca 0.866   0.001 ***
## Acce 0.866   0.001 ***
## Lele 0.863   0.003 **
## Titi 0.853   0.004 **
## Chto 0.829   0.002 **
## Rham 0.829   0.002 **
## Anan 0.829   0.001 ***
## Eslu 0.827   0.021 *
## Pefl 0.806   0.013 *
## Blbj 0.791   0.003 **
## Scer 0.766   0.006 **
## Abbr 0.750   0.008 **
## Icme 0.661   0.022 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```r
# habitat tests
fish.rel <- decostand(fish, method = "total")
phi <- multipatt(fish.rel, cluster = quality, func = "r.g", control = how(nperm = 999))
summary(phi)
```

```
##
##  Multilevel pattern analysis
##  ---------------------------
##
##  Association function: r.g
##  Significance level (alpha): 0.05
##
##  Total number of species: 27
##  Selected number of species: 18
##  Number of species associated to 1 group: 9
##  Number of species associated to 2 groups: 9
##
##  List of species associated to each combination:
##
##  Group HQ  #sps.  3
##       stat p.value
## Phph 0.802   0.001 ***
```

```
## Neba 0.734   0.001 ***
## Satr 0.650   0.001 ***
##
##  Group LQ  #sps.  2
##       stat p.value
## Alal 0.693   0.001 ***
## Ruru 0.473   0.027 *
##
##  Group MQ  #sps.  4
##       stat p.value
## Anan 0.571   0.011 *
## Spbi 0.557   0.011 *
## Chto 0.542   0.015 *
## Icme 0.475   0.034 *
##
##  Group LQ+MQ  #sps.  9
##       stat p.value
## Legi 0.658   0.007 **
## Baba 0.645   0.005 **
## Rham 0.600   0.006 **
## Acce 0.594   0.008 **
## Cyca 0.586   0.006 **
## Chna 0.571   0.009 **
## Blbj 0.571   0.012 *
## Gogo 0.523   0.009 **
## Abbr 0.499   0.029 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Question 1: Based on the PERMANOVA, IndVal, and phi coefficient analyses, what did you learn about the relationship between habitat quality and the fish species composition? Are the different analyses consistent with one another and do they agree with the visualizations (heat maps, cluster dendograms, ordinations) that you created?

> ***Answer 1***: The PERMANOVA test finds that there is a significant correlation between species composition and water quality. The IndVal and phi tests go into greater detail and cluster species based on water quality, but differ from each other slightly: they show the same general trend of one or two small groups with statistical signficance and then one large group of species with statistical significance, as well as a similar number of species with statistical significance (23 and 18, respectively), but the former groups species into three groups while the latter groups species into three groups. We can tell, however, that a large number of species are significantly associated with water quality (at least 18 out of 27). Furthermore, the species identified via the phi and IndVal tests are fairly consistent with the results of the PCoA analysis conducted last week.

B. Multivariate Procedures for Continuous Designs

i. Mantel Test

In the R code chunk below, do the following:

1. create distance matrices for both fish communities and environmental factors, and
2. use a Mantel test to test the hypothesis that fish assemblages are correlated with stream environmental variables.

```r
# define matrices
fish.dist <- vegdist(doubs$fish[-8, ], method = "bray")
env.dist <- vegdist(scale(doubs$env[-8, ]), method = "euclid")
# mantel test
mantel(fish.dist, env.dist)
```

```
##
## Mantel statistic based on Pearson's product-moment correlation
##
## Call:
## mantel(xdis = fish.dist, ydis = env.dist)
##
## Mantel statistic r: 0.604
##       Significance: 0.001
##
## Upper quantiles of permutations (null model):
##   90%   95% 97.5%   99%
## 0.108 0.143 0.167 0.195
## Permutation: free
## Number of permutations: 999
```

Question 2: What do the results from our Mantel test suggest about fish diversity and stream environmental conditions? How does this relate to your hypothesis about stream quality influencing fish communities?

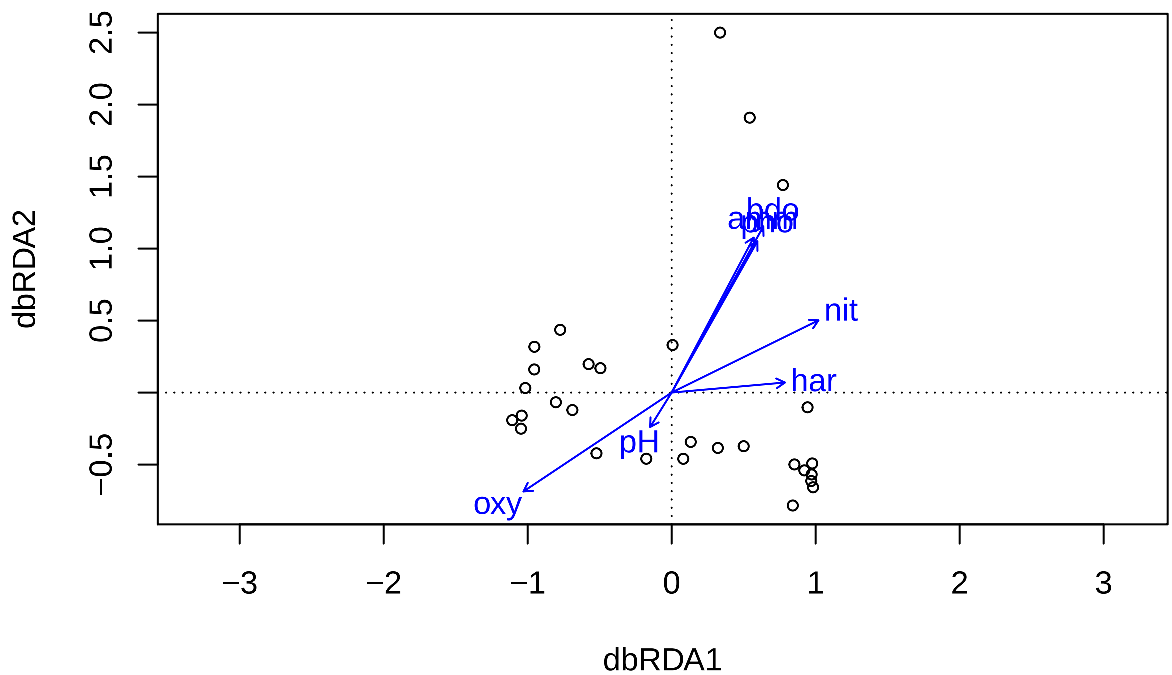
> ***Answer 2***: Fish diversity and stream environmental conditions are indeed correlated to one another, with the mantel test producing a p-value of 0.001. This suggests that stream quality, a component of stream environment, is also likely correlated to species composition.

ii. Constrained Ordination

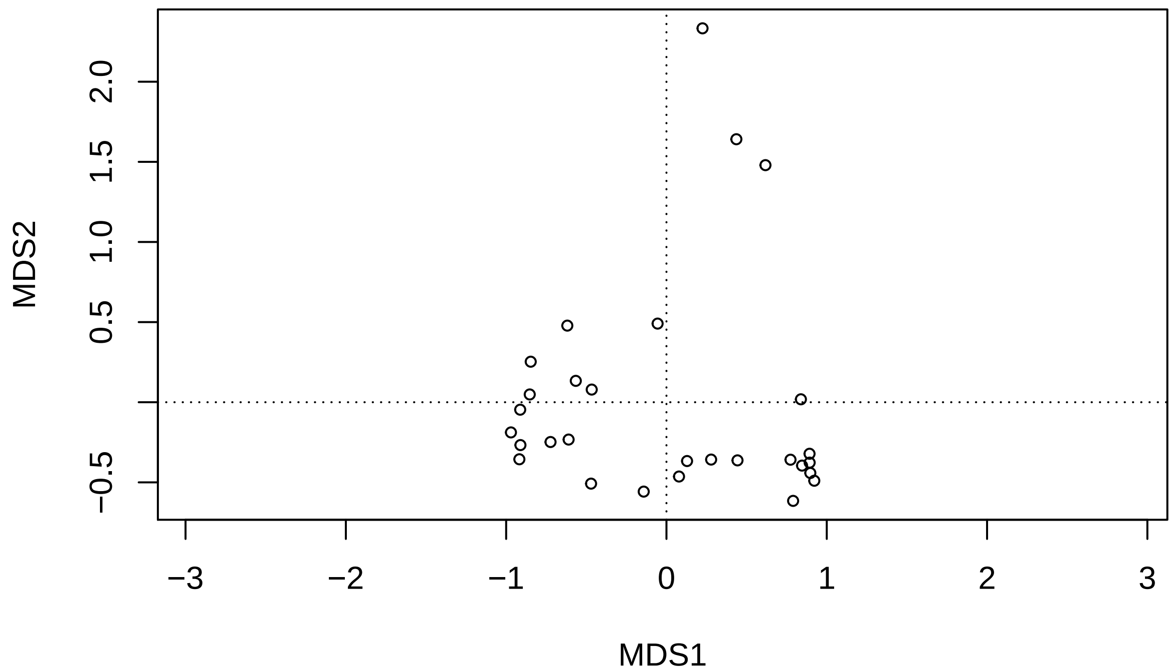
In the R code chunk below, do the following:

1. create an environmental matrix of the water chemistry data included in the `doubs` dataset using forward and reverse selection of variables,
2. conduct a redundancy analysis on the fish assemblages of the Doubs River,
3. use a permutation test to determine the significance of the constrained analysis,
4. use a permutation test to determine the correlation of each environmental factor on the constrained axes,
5. calculate the explained variation on the first and second constrained axes,
6. plot the constrained ordination results including labeled points for each site, and
7. add vectors that demonstrate the influence of each environmental factor the constrained ordination.

```r
# define and env matrix
env.chem <- as.matrix(doubs$env[-8, 5:11])
# perform dbRDA
fish.db <- vegdist(fish, method = "bray")
doubs.dbrda <- dbrda(fish.db ~ ., as.data.frame(env.chem))
ordiplot(doubs.dbrda)
```




```r
# model only intercept
doubs.dbrda.mod0 <- dbrda(fish.db ~ 1, as.data.frame(env.chem))
ordiplot(doubs.dbrda.mod0)
```




```r
# model full model
doubs.dbrda.mod1 <- dbrda(fish.db ~ ., as.data.frame(env.chem))
# redundancy
doubs.dbrda <- ordiR2step(doubs.dbrda.mod0, doubs.dbrda.mod1, perm.max = 200)
```

```
## Step: R2.adj= 0
## Call: fish.db ~ 1
##
##                  R2.adjusted
## <All variables>  0.53032584
## + oxy            0.27727176
## + nit            0.25755208
## + bdo            0.17477787
## + pho            0.14568614
## + har            0.14174915
## + amm            0.14142804
## <none>           0.00000000
## + pH            -0.01827054
##
##        Df    AIC      F Pr(>F)
## + oxy   1 47.939 11.742  0.002 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Step: R2.adj= 0.2772718
## Call: fish.db ~ oxy
```

```
##
##                  R2.adjusted
## <All variables>   0.5303258
## + bdo             0.4009000
## + amm             0.3474192
## + pho             0.3452702
## + har             0.3331357
## + nit             0.3316120
## <none>            0.2772718
## + pH              0.2586983
##
##       Df    AIC      F Pr(>F)
## + bdo  1 43.404 6.5716  0.002 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Step: R2.adj= 0.4009
## Call: fish.db ~ oxy + bdo
##
##                  R2.adjusted
## <All variables>   0.5303258
## + nit             0.4980793
## + har             0.4695121
## <none>            0.4009000
## + pho             0.3938042
## + amm             0.3869134
## + pH              0.3865240
##
##       Df    AIC     F Pr(>F)
## + nit  1 39.134 6.034  0.004 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Step: R2.adj= 0.4980793
## Call: fish.db ~ oxy + bdo + nit
##
##                  R2.adjusted
## + amm             0.5415705
## <All variables>   0.5303258
## + pho             0.5277128
## + har             0.5218852
## <none>            0.4980793
## + pH              0.4843267
```

```r
# visualize selected model
doubs.dbrda$call
```

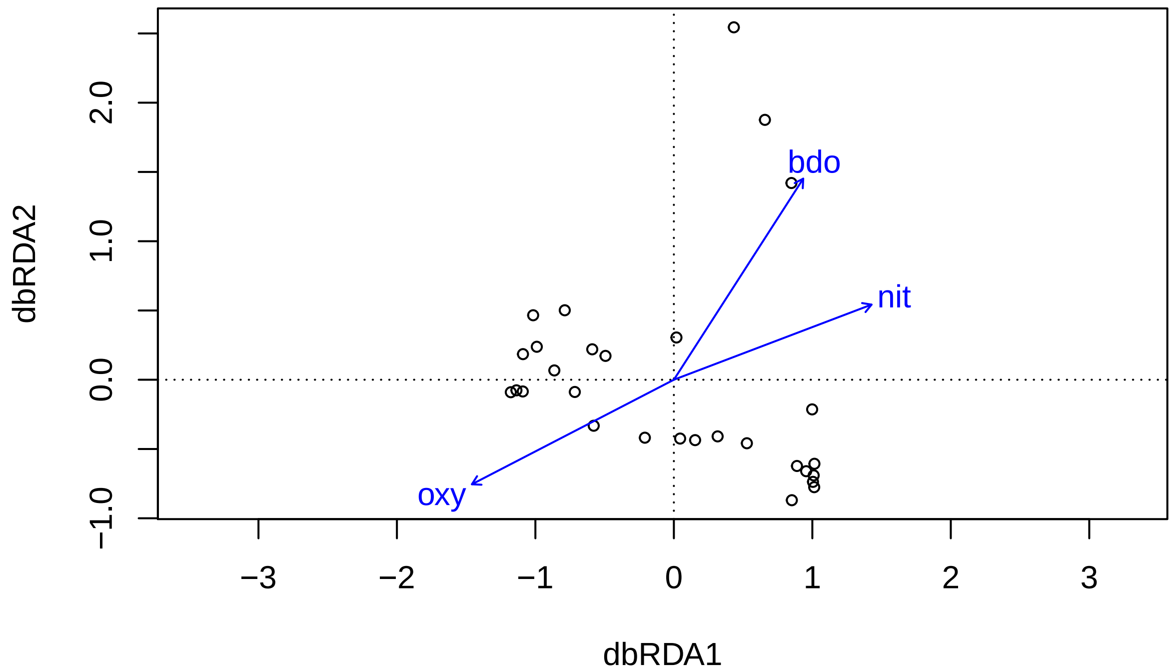
```
## dbrda(formula = fish.db ~ oxy + bdo + nit, data = as.data.frame(env.chem))
```

```r
doubs.dbrda$anova
```

```
##                   R2.adj Df    AIC       F Pr(>F)
## + oxy            0.27727  1 47.939 11.7421  0.002 **
```

```
## + bdo           0.40090  1 43.404  6.5716  0.002 **
## + nit           0.49808  1 39.134  6.0340  0.004 **
## <All variables> 0.53033
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```r
ordiplot(doubs.dbrda)
```



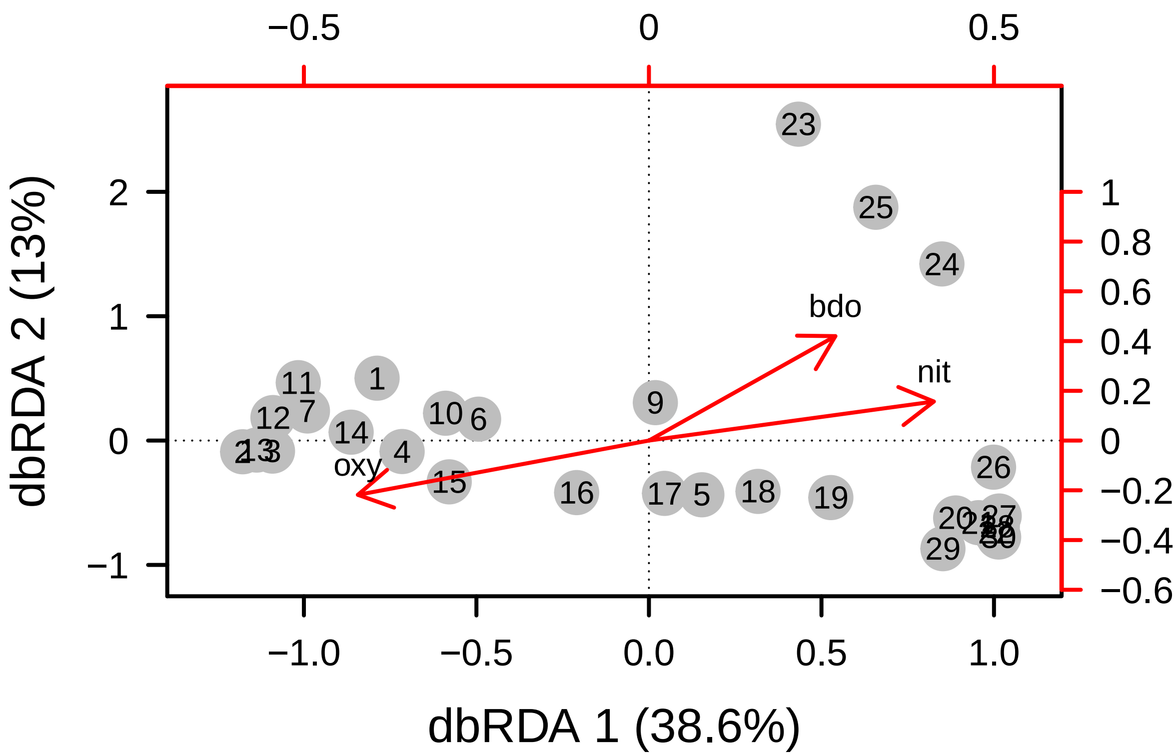

```r
# permutate
permutest(doubs.dbrda, permutations = 999)
```

```
##
## Permutation test for dbrda under reduced model
##
## Permutation: free
## Number of permutations: 999
##
## Model: dbrda(formula = fish.db ~ oxy + bdo + nit, data =
## as.data.frame(env.chem))
## Permutation test for all constrained eigenvalues
##          Df Inertia      F Pr(>F)
## Model     3  3.7317 10.262  0.001 ***
## Residual 25  3.0304
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```r
envfit(doubs.dbrda, env.chem[,c(4,6,7)], perm = 999)
```

```
##
## ***VECTORS
##
##       dbRDA1   dbRDA2     r2 Pr(>r)
## nit  0.87724  0.48005 0.6431  0.001 ***
## oxy -0.82864 -0.55979 0.7656  0.001 ***
## bdo  0.55603  0.83116 0.8939  0.001 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## Permutation: free
## Number of permutations: 999
```

```r
# calculate explained variables
dbrda.explainvar1 <- round(doubs.dbrda$CCA$eig[1] / sum(c(doubs.dbrda$CCA$eig, doubs.dbrda$CA$eig)), 3)
dbrda.explainvar2 <- round(doubs.dbrda$CCA$eig[2] / sum(c(doubs.dbrda$CCA$eig, doubs.dbrda$CA$eig)), 3)
# plot
par(mar = c(5,5,4,4)+ 0.1)
plot(scores(doubs.dbrda, display = "wa"), xlim = c(-1.3, 1.1), ylim = c(-1.1,2.7), xlab = paste("dbRDA 
# add axes
axis(side = 1, labels = T, lwd.ticks = 2, cex.axis = 1.2, las = 1)
axis(side = 2, labels = T, lwd.ticks = 2, cex.axis = 1.2, las = 1)
abline(h = 0, v = 0, lty = 3)
box(lwd = 2)
# add points and labels
points(scores(doubs.dbrda, display = "wa"), pch = 19, cex = 3, bg = "gray", col = "gray")
text(scores(doubs.dbrda, display = "wa"), labels = row.names(scores(doubs.dbrda, display = "wa")))
# add env vectors
vectors <- scores(doubs.dbrda, display = "bp")
arrows(0, 0, vectors[,1], vectors[,2], lwd = 2, lty = 1, length = 0.2, col = "red")
text(vectors[,1], vectors[,2], pos = 3, labels = row.names(vectors))
axis(side = 3, lwd.ticks = 2, cex.axis = 1.2, las = 1, col = "red", lwd = 2.2, at = pretty(range(vector
axis(side = 4, lwd.ticks = 2, cex.axis = 1.2, las = 1, col = "red", lwd = 2.2, at = pretty(range(vector
```



Question 3: Based on the constrained ordination, what are the environmental variables (or groups of correlated variables) that seem to be contributing to variation in fish community structure?

> ***Answer 3***: It appears that three environmental variables significantly affect variation in fish community structure: Oxygen levels, Nitrogen levels, and BDO.

iii. Variation Partitioning

In the code chunk below,

1. Create a matrix model of the selected environmental variables,
2. Create a matrix model of the selected PCNM axes,
3. Perform constrained and partial constrained ordinations using the spatial and environmental models you just created,
4. Test the significance of each of your constrained ordinations using permutation tests,
5. Partition the variation among sites into the relative importance of space, environment, spatially structured environment, and residuals,
6. Plot the variation partitioning output to visualize it.

```
# create matrix model for env data
env.mod <- model.matrix(~ oxy + bdo + nit, as.data.frame(env.chem))[,-1]
# weight each site
rs <- rowSums(fish)/sum(fish)
# perform PCNM
doubs.pcnmw <- pcnm(dist(doubs$xy[-8,]), w = rs, dist.ret = T)
doubs.pcnmw$values > 0
```

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

```r
doubs.space <- as.data.frame(scores(doubs.pcnmw))
doubs.pcnm.mod0 <- dbrda(fish.db ~ 1, doubs.space)
doubs.pcnm.mod1 <- dbrda(fish.db ~ ., doubs.space)
step.pcnm <- ordiR2step(doubs.pcnm.mod0, doubs.pcnm.mod1, perm.max = 200)
```

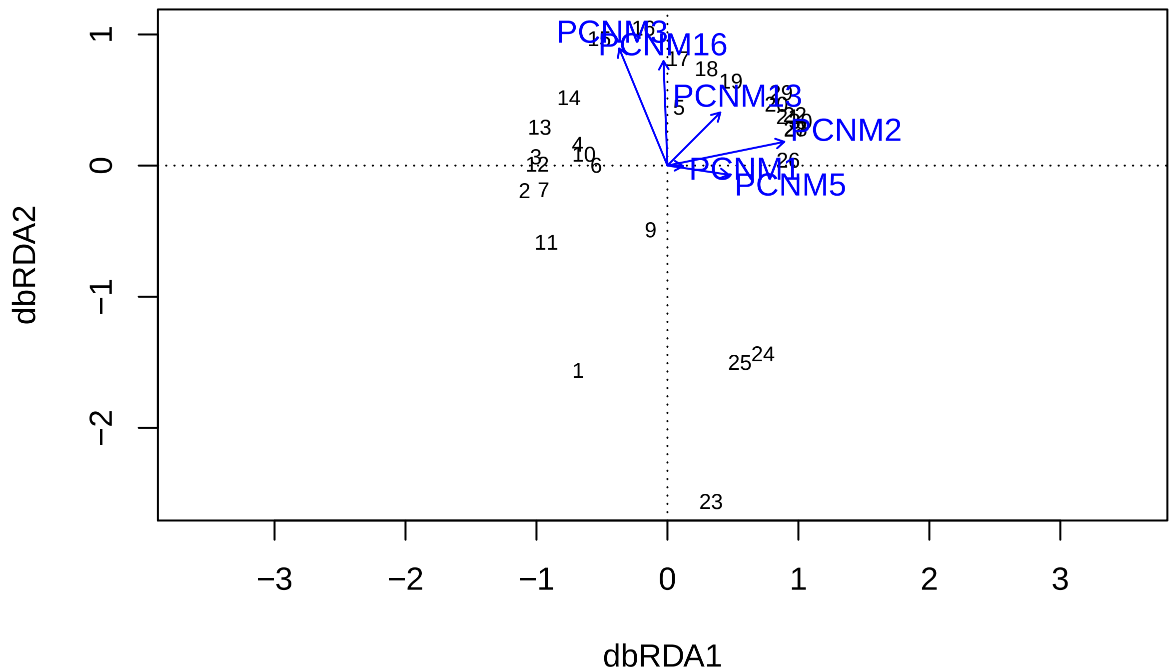
```
## Step: R2.adj= 0
## Call: fish.db ~ 1
##
##                  R2.adjusted
## <All variables>  0.626011301
## + PCNM2          0.235370423
## + PCNM3          0.078394885
## + PCNM13         0.065305668
## + PCNM5          0.046185074
## + PCNM6          0.032809156
## + PCNM16         0.030486700
## + PCNM14         0.029680999
## + PCNM9          0.020357410
## + PCNM15         0.013632610
## + PCNM8          0.009411968
## + PCNM1          0.003986221
## + PCNM17         0.002415012
## + PCNM10         0.001326442
## <none>           0.000000000
## + PCNM7         -0.001861430
## + PCNM11        -0.006841522
## + PCNM4         -0.007089863
## + PCNM12        -0.014396973
##
##         Df    AIC     F Pr(>F)
## + PCNM2  1 49.574 9.619  0.002 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Step: R2.adj= 0.2353704
## Call: fish.db ~ PCNM2
##
##                 R2.adjusted
## <All variables>   0.6260113
## + PCNM3           0.3429270
## + PCNM5           0.3057368
## + PCNM1           0.2885396
## + PCNM16          0.2786746
## + PCNM14          0.2744520
## + PCNM15          0.2692809
## + PCNM6           0.2659866
## + PCNM13          0.2636194
## + PCNM9           0.2517847
## + PCNM8           0.2496240
## + PCNM10          0.2434688
```

```
## + PCNM7           0.2431476
## + PCNM17          0.2404343
## + PCNM11          0.2366833
## <none>            0.2353704
## + PCNM12          0.2288789
## + PCNM4           0.2189522
##
##         Df    AIC      F Pr(>F)
## + PCNM3  1 46.083 5.4196  0.002 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Step: R2.adj= 0.342927
## Call: fish.db ~ PCNM2 + PCNM3
##
##                  R2.adjusted
## <All variables>   0.6260113
## + PCNM5           0.4076020
## + PCNM1           0.3970300
## + PCNM16          0.3853210
## + PCNM15          0.3828748
## + PCNM14          0.3781827
## + PCNM13          0.3770376
## + PCNM6           0.3595644
## + PCNM8           0.3556885
## + PCNM7           0.3541631
## + PCNM10          0.3526775
## + PCNM17          0.3513683
## + PCNM9           0.3433672
## <none>            0.3429270
## + PCNM11          0.3416399
## + PCNM12          0.3396547
## + PCNM4           0.3311509
##
##         Df    AIC      F Pr(>F)
## + PCNM5  1 43.941 3.8385  0.012 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Step: R2.adj= 0.407602
## Call: fish.db ~ PCNM2 + PCNM3 + PCNM5
##
##                  R2.adjusted
## <All variables>   0.6260113
## + PCNM1           0.4721469
## + PCNM16          0.4631976
## + PCNM15          0.4589111
## + PCNM14          0.4535248
## + PCNM13          0.4511582
## + PCNM6           0.4305640
## + PCNM7           0.4261965
## + PCNM8           0.4224505
## + PCNM17          0.4181666
## + PCNM10          0.4154485
```

```
## + PCNM11          0.4112178
## + PCNM9           0.4111995
## + PCNM12          0.4087602
## <none>            0.4076020
## + PCNM4           0.3976526
##
##         Df    AIC     F Pr(>F)
## + PCNM1  1 41.411 4.057  0.006 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Step: R2.adj= 0.4721469
## Call: fish.db ~ PCNM2 + PCNM3 + PCNM5 + PCNM1
##
##                 R2.adjusted
## <All variables>   0.6260113
## + PCNM13          0.5212427
## + PCNM16          0.5208668
## + PCNM15          0.5161770
## + PCNM14          0.5147355
## + PCNM6           0.4999020
## + PCNM7           0.4936559
## + PCNM8           0.4904113
## + PCNM17          0.4856884
## + PCNM10          0.4835952
## + PCNM11          0.4760087
## + PCNM9           0.4751424
## + PCNM12          0.4747221
## <none>            0.4721469
## + PCNM4           0.4651218
##
##          Df    AIC      F Pr(>F)
## + PCNM13  1 39.346 3.4612  0.008 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Step: R2.adj= 0.5212427
## Call: fish.db ~ PCNM2 + PCNM3 + PCNM5 + PCNM1 + PCNM13
##
##                 R2.adjusted
## <All variables>   0.6260113
## + PCNM16          0.5767968
## + PCNM15          0.5715331
## + PCNM14          0.5698343
## + PCNM6           0.5475140
## + PCNM7           0.5392074
## + PCNM8           0.5379134
## + PCNM11          0.5281106
## + PCNM9           0.5267003
## + PCNM10          0.5265029
## + PCNM12          0.5255581
## <none>            0.5212427
## + PCNM17          0.5171800
## + PCNM4           0.5152311
```

```
##
##          Df   AIC      F Pr(>F)
## + PCNM16  1 36.48 4.0192   0.01 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Step: R2.adj= 0.5767968
## Call: fish.db ~ PCNM2 + PCNM3 + PCNM5 + PCNM1 + PCNM13 + PCNM16
##
##                 R2.adjusted
## <All variables>   0.6260113
## + PCNM6           0.6043089
## + PCNM8           0.5970286
## + PCNM12          0.5946888
## + PCNM7           0.5946475
## + PCNM9           0.5883735
## + PCNM10          0.5851333
## + PCNM15          0.5846468
## <none>            0.5767968
## + PCNM17          0.5748533
## + PCNM4           0.5733749
## + PCNM11          0.5711176
## + PCNM14          0.5652509
##
##         Df    AIC      F Pr(>F)
## + PCNM6  1 35.182 2.5296  0.052 .
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
# plot
plot(step.pcnm)
```




```
# anova
step.pcnm$anova
```

```
##                  R2.adj Df    AIC      F Pr(>F)
## + PCNM2         0.23537  1 49.574 9.6190  0.002 **
## + PCNM3         0.34293  1 46.083 5.4196  0.002 **
## + PCNM5         0.40760  1 43.941 3.8385  0.012 *
## + PCNM1         0.47215  1 41.411 4.0570  0.006 **
## + PCNM13        0.52124  1 39.346 3.4612  0.008 **
## + PCNM16        0.57680  1 36.480 4.0192  0.010 **
## <All variables> 0.62601
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
# construct spatial model
space.mod <- model.matrix(~ PCNM2 + PCNM3 + PCNM5 + PCNM1 + PCNM13 + PCNM16 + PCNM16 + PCNM6, doubs.spa
# conduct constrained ordinations
doubs.total.env <- dbrda(fish.db ~ env.mod)
doubs.total.space <- dbrda(fish.db ~ space.mod)
# construct partial constrained ordinations
doubs.env.cond.space <- dbrda(fish.db ~ env.mod + Condition(space.mod))
doubs.space.cond.env <- dbrda(fish.db ~ space.mod + Condition(env.mod))
# test for significance
permutest(doubs.env.cond.space, permutations = 999)
```

```
##
```

```
## Permutation test for dbrda under reduced model
##
## Permutation: free
## Number of permutations: 999
##
## Model: dbrda(formula = fish.db ~ env.mod + Condition(space.mod))
## Permutation test for all constrained eigenvalues
##          Df Inertia     F Pr(>F)
## Model     3 0.85158 4.423  0.001 ***
## Residual 18 1.15519
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```r
permutest(doubs.space.cond.env, permutations = 999)
```

```
##
## Permutation test for dbrda under reduced model
##
## Permutation: free
## Number of permutations: 999
##
## Model: dbrda(formula = fish.db ~ space.mod + Condition(env.mod))
## Permutation test for all constrained eigenvalues
##          Df Inertia      F Pr(>F)
## Model     7  1.8752 4.1741  0.001 ***
## Residual 18  1.1552
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```r
permutest(doubs.total.env, permutations = 999)
```

```
##
## Permutation test for dbrda under reduced model
##
## Permutation: free
## Number of permutations: 999
##
## Model: dbrda(formula = fish.db ~ env.mod)
## Permutation test for all constrained eigenvalues
##          Df Inertia      F Pr(>F)
## Model     3  3.7317 10.262  0.001 ***
## Residual 25  3.0304
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```r
permutest(doubs.total.space, permutations = 999)
```

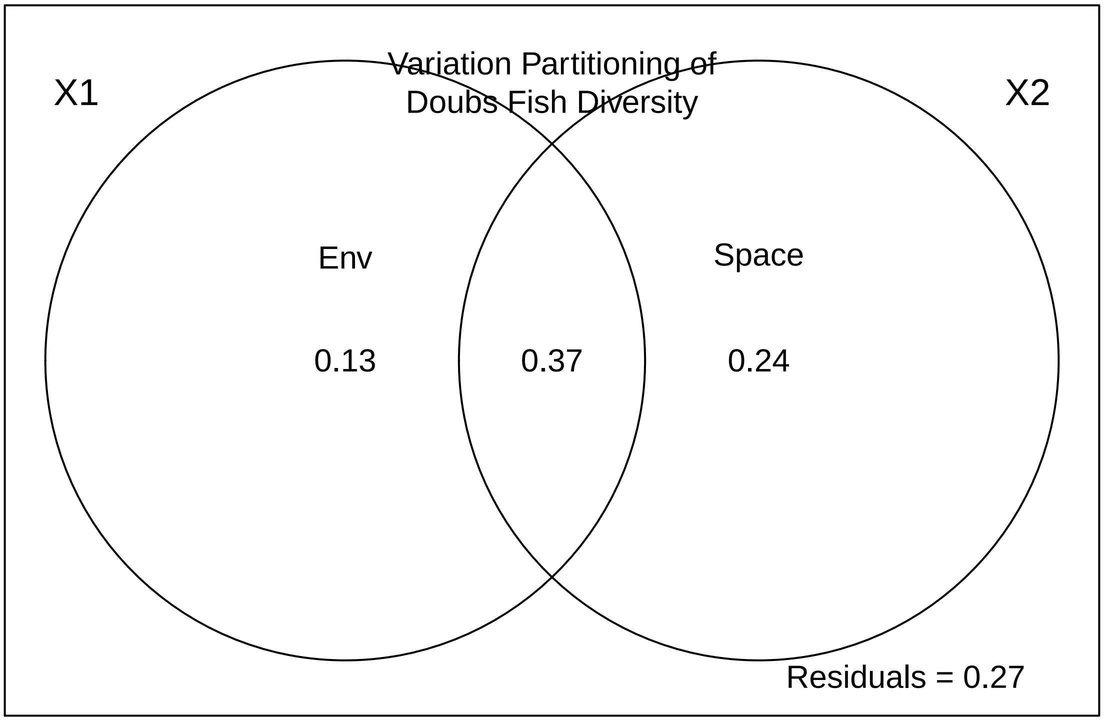
```
##
## Permutation test for dbrda under reduced model
##
## Permutation: free
## Number of permutations: 999
```

```
##
## Model: dbrda(formula = fish.db ~ space.mod)
## Permutation test for all constrained eigenvalues
##          Df Inertia      F Pr(>F)
## Model     7  4.7553 7.1089  0.001 ***
## Residual 21  2.0068
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
# calculate fraction var
doubs.varpart <- varpart(fish.db, env.mod, space.mod)
doubs.varpart
```

```
##
## Partition of squared Bray distance in dbRDA
##
## Call: varpart(Y = fish.db, X = env.mod, space.mod)
##
## Explanatory tables:
## X1:  env.mod
## X2:  space.mod
##
## No. of explanatory tables: 2
## Total variation (SS): 6.7621
## No. of observations: 29
##
## Partition table:
##                      Df R.squared Adj.R.squared Testable
## [a+b] = X1            3   0.55186       0.49808     TRUE
## [b+c] = X2            7   0.70323       0.60431     TRUE
## [a+b+c] = X1+X2      10   0.82917       0.73426     TRUE
## Individual fractions
## [a] = X1|X2           3                 0.12995     TRUE
## [b]                   0                 0.36813    FALSE
## [c] = X2|X1           7                 0.23618     TRUE
## [d] = Residuals                         0.26574    FALSE
## ---
## Use function 'dbrda' to test significance of fractions of interest
```

```
par(mar = c(2,2,2,2))
plot(doubs.varpart)
text(1, 0.25, "Space")
text(0, 0.25, "Env")
mtext("Variation Partitioning of\nDoubs Fish Diversity", side = 3, line = -3)
```



Question 4: Interpret the variation partitioning results.

> ***Answer 4***: Fish variation among sites is accounted for by 13% environmental factors, 24% spatial factors, 37% a combination of the two, and 27% unassigned.

SYNTHESIS

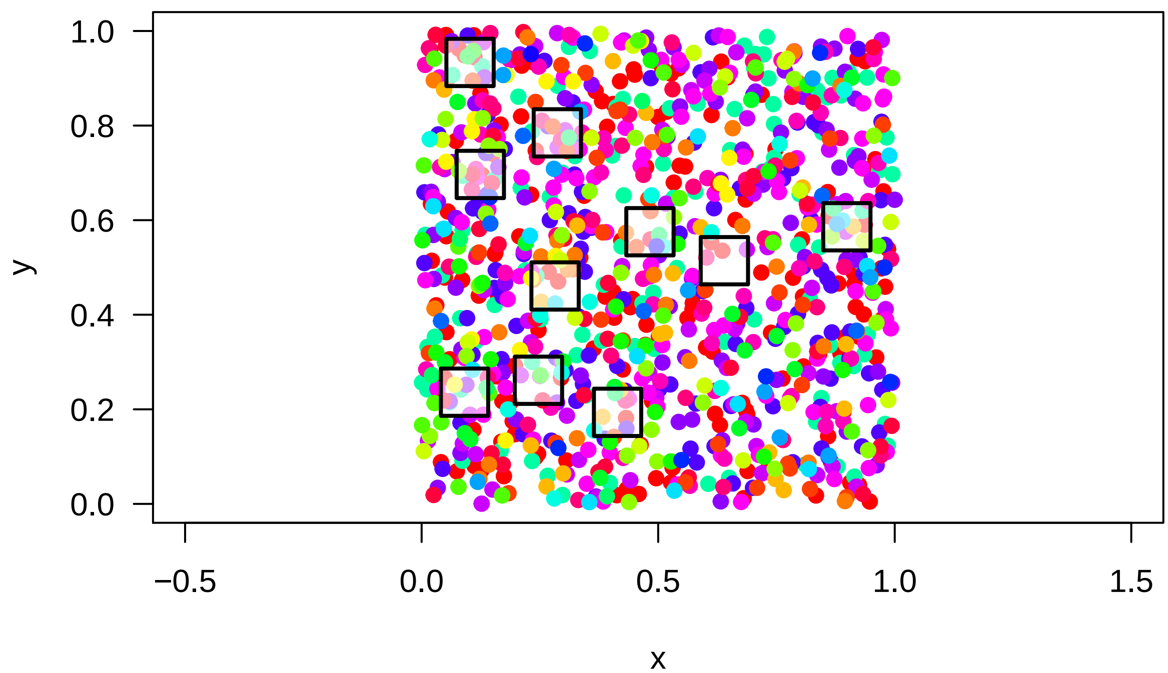
As in the previous worksheet, use the `mobsim` package from the DataWrangling module to simulate two local communities each containing 1000 individuals (N) and 25 species (S), but with one having a random spatial distribution and the other having a patchy spatial distribution. Take ten (10) subsamples from each site using the quadrat function and answer the following questions:

```
# simulate random spatial distribution comm
require(mobsim)
```

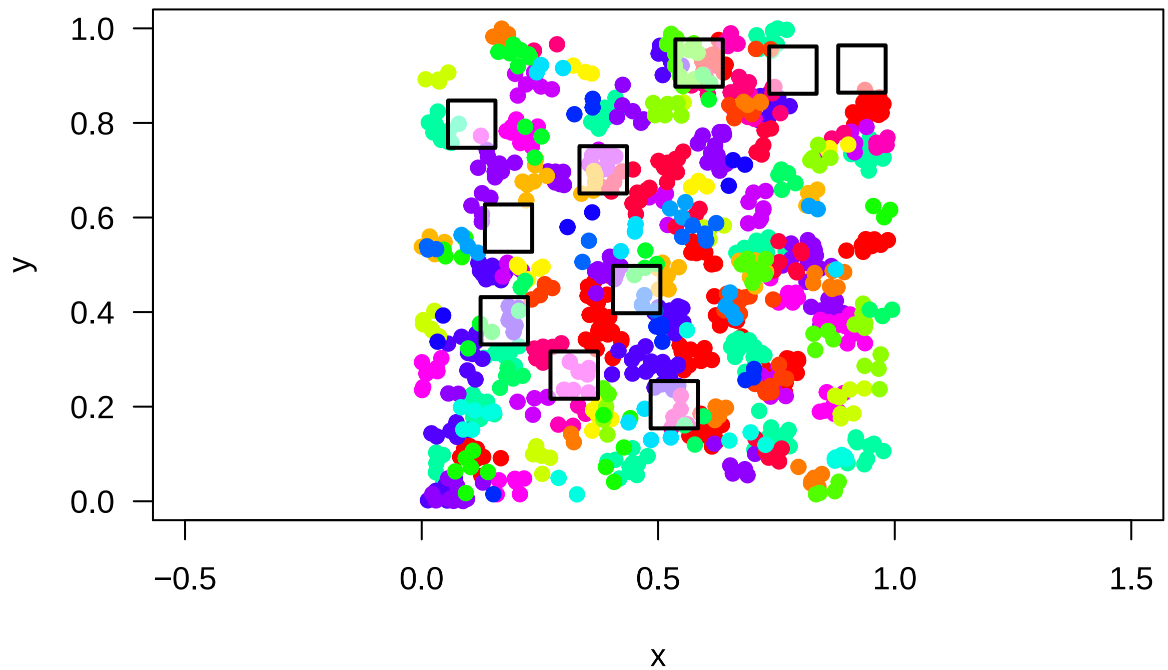
```
## Loading required package: mobsim
```

```
com1 <- sim_poisson_community(s_pool = 25, n_sim = 1000, sad_type = "lnorm",
        sad_coef = list("meanlog" = 2, "sdlog" = 1))
# simulate patchy spatial distribution
com2 <- sim_thomas_community(s_pool = 25, n_sim = 1000, sad_type = "lnorm",
        sad_coef = list("meanlog" = 2, "sdlog" = 1))
# divide both communities into 10 quadrats of the same size
# Lay down sampling quadrats on the community
```

```
comm_mat1 <- sample_quadrats(com1, n_quadrats = 10, quadrat_area = 0.01,
               method = "random", avoid_overlap = T)
```




```
# Rename sampled areas as quadrats
quads1 <- c("quad1", "quad2", "quad3", "quad4", "quad5", "quad6", "quad7",
            "quad8", "quad9", "quad10")
row.names(comm_mat1$xy_dat) <- quads1
row.names(comm_mat1$spec_dat) <- quads1
# Lay down sampling quadrats on the community
comm_mat2 <- sample_quadrats(com2, n_quadrats = 10, quadrat_area = 0.01,
               method = "random", avoid_overlap = T)
```




```r
# Rename sampled areas as quadrats
quads2 <- c("quad1", "quad2", "quad3", "quad4", "quad5", "quad6", "quad7",
            "quad8", "quad9", "quad10")
row.names(comm_mat2$xy_dat) <- quads2
row.names(comm_mat2$spec_dat) <- quads2
```

1) Perform a PERMANOVA to test whether or not the spatial distribution of species affects species composition.

```r
# run PERMANOVA with adonis function for random community
adonis(comm_mat1$spec_dat ~ quads1, method = "bray", permutations = 999)
```

```
##
## Call:
## adonis(formula = comm_mat1$spec_dat ~ quads1, permutations = 999,      method = "bray")
##
## Permutation: free
## Number of permutations: 999
##
## Terms added sequentially (first to last)
##
##           Df SumsOfSqs MeanSqs F.Model R2 Pr(>F)
## quads1     9    1.7466       0       0  1      1
## Residuals  0    0.0000     Inf          0
## Total      9    1.7466                  1
```

```r
# run PERMANOVA with adonis function for patchy community
adonis(comm_mat2$spec_dat ~ quads2, method = "bray", permutations = 999)
```

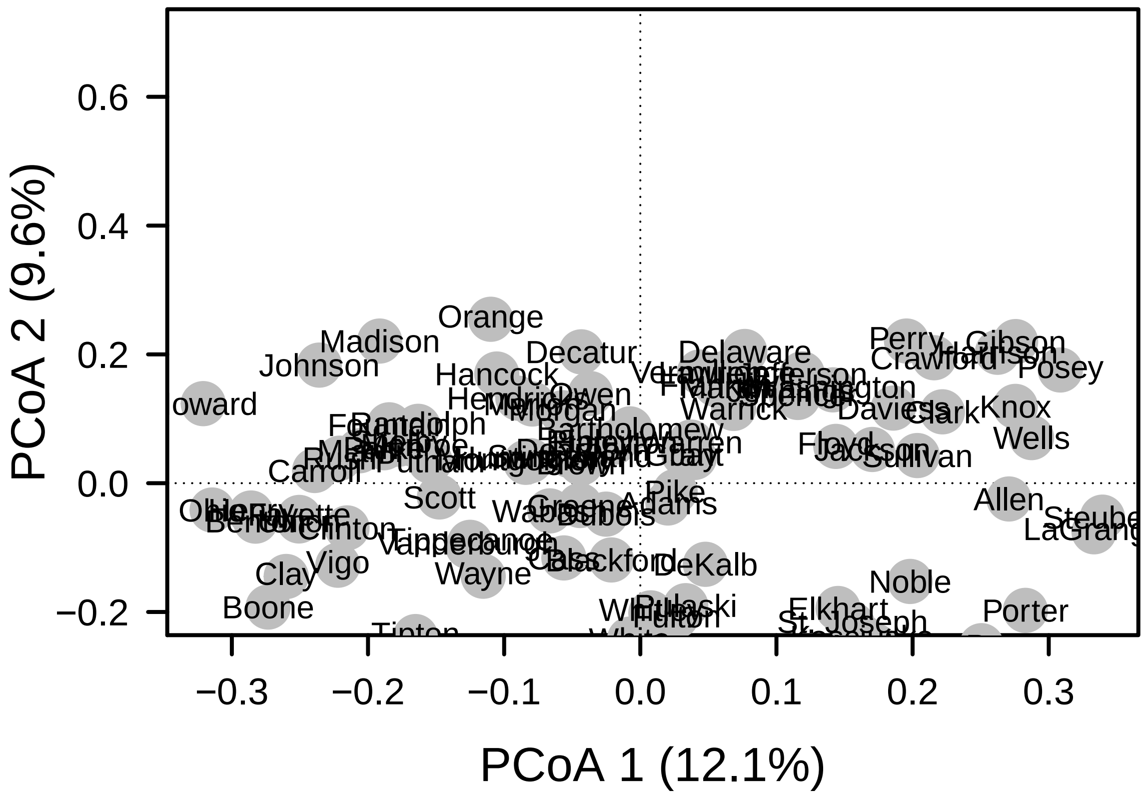
```
## Warning in vegdist(lhs, method = method, ...): you have empty rows: their
## dissimilarities may be meaningless in method "bray"
```

```
##
## Call:
## adonis(formula = comm_mat2$spec_dat ~ quads2, permutations = 999,      method = "bray")
##
## Permutation: free
## Number of permutations: 999
##
## Terms added sequentially (first to last)
##
##           Df SumsOfSqs MeanSqs F.Model R2 Pr(>F)
## quads2     9    4.0442       0       0  1      1
## Residuals  0    0.0000     Inf          0
## Total      9    4.0442                  1
```

```r
# Neither community has a siginificant result, meaning that the community structure does not vary due t
```

2) Load the dataset you are using for your Team Project. Perform an ordination to visualize your dataset. Using this ordination, develop some hypotheses relevant to β-diversity. Use a statistic to test one of these hypotheses. Succinctly explain the finding and its relevance to your system.

```r
# Load site species matrix of Indiana woody plants (sites are counties)
sitespmatrix <- read.csv("Woody_Tree_SiteSpMatrix_IN_4-19-2021.csv", header = TRUE, row.names = 1)
# calculate bray curtis distance
woodytree.db <- vegdist(sitespmatrix, method = "bray")
# perform pcoa
woodytree.pcoa <- cmdscale(woodytree.db, eig = TRUE, k = 3)
# interpret output
explainvar1 <- round(woodytree.pcoa$ eig[1] / sum(woodytree.pcoa$eig), 3) * 100
explainvar2 <- round(woodytree.pcoa$ eig[2] / sum(woodytree.pcoa$eig), 3) * 100
explainvar3 <- round(woodytree.pcoa$ eig[3] / sum(woodytree.pcoa$eig), 3) * 100
sum.eig <- sum(explainvar1, explainvar2, explainvar3)
# create plot
# plot PCoA ordination
par(mar = c(5, 5, 1, 2) + 0.1)
plot(woodytree.pcoa$points[ ,1], woodytree.pcoa$points[ ,2], ylim = c(-0.2, 0.7), xlab = paste("PCoA 1
axis(side =1, labels = T, lwd.ticks = 2, cex.axis = 1.2, las = 1)
axis(side =2, labels = T, lwd.ticks = 2, cex.axis = 1.2, las = 1)
abline(h = 0, v=0, lty = 3)
box(lwd = 2)
points(woodytree.pcoa$points[ ,1], woodytree.pcoa$points[ ,2],
       pch = 19, cex = 3, bg = "gray", col = "gray")
text(woodytree.pcoa$points[ ,1], woodytree.pcoa$points[ ,2], labels = row.names(woodytree.pcoa$points))
```




```
# counties that are close to each other spatially are somewhat similar in composition, so we can test t
# weight each site
rs <- rowSums(sitespmatrix)/sum(sitespmatrix)
# upload geographic data for each county (site)
siteco <- read.csv("Site_coord.csv", header = TRUE)
# perform PCNM
woodytree.pcnmw <- pcnm(dist(siteco), w = rs, dist.ret = T)
woodytree.pcnmw$values > 0
```

```
##  [1]  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE
## [13]  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE
## [25]  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE
## [37]  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE
## [49]  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE
## [61] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
## [73] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
## [85] FALSE FALSE FALSE FALSE FALSE FALSE FALSE
```

```
woodytree.space <- as.data.frame(scores(woodytree.pcnmw))
woodytree.pcnm.mod0 <- dbrda(woodytree.db ~ 1, woodytree.space)
woodytree.pcnm.mod1 <- dbrda(woodytree.db ~ ., woodytree.space)
woodytree.step.pcnm <- ordiR2step(woodytree.pcnm.mod0, woodytree.pcnm.mod1, perm.max = 200)
```

```
## Step: R2.adj= 0
## Call: woodytree.db ~ 1
```

```
##
##                    R2.adjusted
## <All variables>  2.722710e-01
## + PCNM10         2.513492e-02
## + PCNM4          2.464968e-02
## + PCNM12         1.797759e-02
## + PCNM2          1.488679e-02
## + PCNM46         1.391272e-02
## + PCNM60         1.070533e-02
## + PCNM57         9.000953e-03
## + PCNM17         8.666101e-03
## + PCNM3          8.626980e-03
## + PCNM24         8.528931e-03
## + PCNM6          7.811001e-03
## + PCNM48         7.732894e-03
## + PCNM56         7.658795e-03
## + PCNM26         7.517288e-03
## + PCNM52         7.375122e-03
## + PCNM14         6.474103e-03
## + PCNM13         5.382008e-03
## + PCNM15         5.320253e-03
## + PCNM28         5.276343e-03
## + PCNM50         5.112304e-03
## + PCNM1          3.907587e-03
## + PCNM44         3.876267e-03
## + PCNM38         3.829827e-03
## + PCNM21         3.579736e-03
## + PCNM55         3.378648e-03
## + PCNM27         3.252264e-03
## + PCNM19         3.070629e-03
## + PCNM43         2.413102e-03
## + PCNM11         2.162432e-03
## + PCNM47         1.998923e-03
## + PCNM20         1.959049e-03
## + PCNM49         1.784312e-03
## + PCNM31         8.614308e-04
## + PCNM39         8.004636e-04
## + PCNM53         5.658962e-04
## + PCNM29         3.699709e-04
## + PCNM18         3.267055e-04
## + PCNM9          2.562375e-04
## + PCNM16         2.047439e-04
## + PCNM5          2.182327e-05
## <none>           0.000000e+00
## + PCNM7         -2.087504e-04
## + PCNM41        -3.746999e-04
## + PCNM32        -7.205924e-04
## + PCNM40        -1.164705e-03
## + PCNM37        -1.215421e-03
## + PCNM51        -1.245709e-03
## + PCNM8         -1.457718e-03
## + PCNM33        -1.623707e-03
## + PCNM23        -2.009918e-03
## + PCNM54        -2.129774e-03
```

```
## + PCNM42        -2.149543e-03
## + PCNM36        -2.437936e-03
## + PCNM59        -2.604801e-03
## + PCNM25        -2.953606e-03
## + PCNM34        -4.181246e-03
## + PCNM45        -4.449119e-03
## + PCNM35        -5.535012e-03
## + PCNM30        -6.066801e-03
## + PCNM22        -6.471504e-03
## + PCNM58        -7.618044e-03
##
##          Df   AIC      F Pr(>F)
## + PCNM10  1 285.7 3.3463  0.002 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Step: R2.adj= 0.02513492
## Call: woodytree.db ~ PCNM10
##
##                 R2.adjusted
## <All variables>  0.27227096
## + PCNM4          0.05269350
## + PCNM12         0.04108705
## + PCNM2          0.04003022
## + PCNM46         0.03913638
## + PCNM60         0.03600603
## + PCNM57         0.03463311
## + PCNM3          0.03402043
## + PCNM17         0.03367599
## + PCNM24         0.03353029
## + PCNM6          0.03339274
## + PCNM56         0.03316050
## + PCNM48         0.03300806
## + PCNM52         0.03279092
## + PCNM26         0.03243313
## + PCNM14         0.03176414
## + PCNM15         0.03097689
## + PCNM28         0.03074474
## + PCNM13         0.03058047
## + PCNM50         0.03017839
## + PCNM1          0.02936823
## + PCNM55         0.02921245
## + PCNM21         0.02904226
## + PCNM38         0.02900344
## + PCNM44         0.02884189
## + PCNM27         0.02858797
## + PCNM43         0.02813317
## + PCNM11         0.02749910
## + PCNM19         0.02737925
## + PCNM20         0.02736855
## + PCNM49         0.02699844
## + PCNM47         0.02682629
## + PCNM39         0.02628534
## + PCNM31         0.02625743
```

```
## + PCNM9          0.02606006
## + PCNM53         0.02596795
## + PCNM29         0.02583386
## + PCNM18         0.02548701
## + PCNM16         0.02544259
## + PCNM41         0.02541866
## <none>           0.02513492
## + PCNM7          0.02469491
## + PCNM5          0.02465791
## + PCNM32         0.02443674
## + PCNM40         0.02436236
## + PCNM51         0.02428581
## + PCNM8          0.02415109
## + PCNM37         0.02414328
## + PCNM33         0.02394024
## + PCNM23         0.02360120
## + PCNM54         0.02326444
## + PCNM42         0.02323217
## + PCNM36         0.02289850
## + PCNM59         0.02276165
## + PCNM25         0.02246387
## + PCNM34         0.02136829
## + PCNM45         0.02103012
## + PCNM35         0.02008049
## + PCNM30         0.01927701
## + PCNM22         0.01861608
## + PCNM58         0.01780367
##
##         Df    AIC      F Pr(>F)
## + PCNM4  1 284.04 3.6182  0.002 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Step: R2.adj= 0.0526935
## Call: woodytree.db ~ PCNM10 + PCNM4
##
##                 R2.adjusted
## <All variables>  0.27227096
## + PCNM2          0.06930868
## + PCNM12         0.06807808
## + PCNM46         0.06718269
## + PCNM3          0.06388188
## + PCNM60         0.06377518
## + PCNM57         0.06205797
## + PCNM6          0.06190151
## + PCNM17         0.06166961
## + PCNM56         0.06103905
## + PCNM48         0.06101041
## + PCNM24         0.06083762
## + PCNM52         0.06020094
## + PCNM14         0.05977400
## + PCNM26         0.05930769
## + PCNM15         0.05851764
## + PCNM28         0.05850365
```

```
## + PCNM13         0.05847567
## + PCNM50         0.05821633
## + PCNM55         0.05768568
## + PCNM38         0.05693593
## + PCNM27         0.05681846
## + PCNM21         0.05681417
## + PCNM1          0.05668012
## + PCNM44         0.05661023
## + PCNM43         0.05608876
## + PCNM19         0.05508092
## + PCNM11         0.05498910
## + PCNM20         0.05496569
## + PCNM47         0.05486149
## + PCNM49         0.05477847
## + PCNM9          0.05410950
## + PCNM39         0.05404788
## + PCNM31         0.05394489
## + PCNM53         0.05384890
## + PCNM29         0.05372388
## + PCNM18         0.05330699
## + PCNM16         0.05295222
## + PCNM37         0.05294893
## + PCNM41         0.05272079
## <none>           0.05269350
## + PCNM32         0.05251240
## + PCNM40         0.05248680
## + PCNM7          0.05239082
## + PCNM51         0.05212075
## + PCNM33         0.05182782
## + PCNM8          0.05164685
## + PCNM23         0.05158957
## + PCNM54         0.05144669
## + PCNM5          0.05109042
## + PCNM42         0.05106622
## + PCNM59         0.05058924
## + PCNM36         0.05046127
## + PCNM25         0.05031554
## + PCNM34         0.04909778
## + PCNM45         0.04886172
## + PCNM35         0.04773737
## + PCNM30         0.04700010
## + PCNM22         0.04636720
## + PCNM58         0.04565128
##
##         Df    AIC      F Pr(>F)
## + PCNM2  1 283.37 2.5889  0.002 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Step: R2.adj= 0.06930868
## Call: woodytree.db ~ PCNM10 + PCNM4 + PCNM2
##
##                 R2.adjusted
## <All variables>  0.27227096
```

```
## + PCNM12          0.08494812
## + PCNM46          0.08415582
## + PCNM60          0.08043493
## + PCNM3           0.08024934
## + PCNM57          0.07899740
## + PCNM56          0.07813716
## + PCNM48          0.07796469
## + PCNM24          0.07766064
## + PCNM17          0.07732672
## + PCNM52          0.07701329
## + PCNM6           0.07684559
## + PCNM14          0.07672317
## + PCNM26          0.07616375
## + PCNM13          0.07548697
## + PCNM28          0.07539466
## + PCNM50          0.07510022
## + PCNM15          0.07453403
## + PCNM55          0.07437893
## + PCNM27          0.07368441
## + PCNM38          0.07363086
## + PCNM44          0.07348566
## + PCNM1           0.07345202
## + PCNM21          0.07331691
## + PCNM43          0.07272514
## + PCNM19          0.07195929
## + PCNM20          0.07180487
## + PCNM11          0.07175128
## + PCNM47          0.07169278
## + PCNM49          0.07159492
## + PCNM9           0.07101782
## + PCNM53          0.07081115
## + PCNM29          0.07078247
## + PCNM39          0.07067502
## + PCNM31          0.07021716
## + PCNM18          0.07012524
## + PCNM37          0.06994587
## + PCNM16          0.06959518
## + PCNM41          0.06951064
## + PCNM8           0.06936366
## <none>            0.06930868
## + PCNM40          0.06929001
## + PCNM51          0.06914548
## + PCNM32          0.06888238
## + PCNM7           0.06884315
## + PCNM33          0.06853492
## + PCNM23          0.06852934
## + PCNM5           0.06833736
## + PCNM54          0.06829349
## + PCNM42          0.06819452
## + PCNM59          0.06736159
## + PCNM36          0.06715732
## + PCNM25          0.06661202
## + PCNM34          0.06600973
## + PCNM45          0.06557008
```

```
## + PCNM35         0.06430330
## + PCNM30         0.06393630
## + PCNM22         0.06312158
## + PCNM58         0.06232554
##
##          Df    AIC     F Pr(>F)
## + PCNM12  1 282.76 2.504  0.002 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Step: R2.adj= 0.08494812
## Call: woodytree.db ~ PCNM10 + PCNM4 + PCNM2 + PCNM12
##
##                 R2.adjusted
## <All variables>  0.27227096
## + PCNM46         0.10014876
## + PCNM3          0.09620792
## + PCNM60         0.09587260
## + PCNM57         0.09552102
## + PCNM56         0.09406549
## + PCNM48         0.09341350
## + PCNM52         0.09311086
## + PCNM17         0.09306044
## + PCNM24         0.09276130
## + PCNM26         0.09271896
## + PCNM6          0.09268293
## + PCNM14         0.09228264
## + PCNM13         0.09146685
## + PCNM28         0.09126951
## + PCNM50         0.09069643
## + PCNM55         0.09017274
## + PCNM15         0.08954207
## + PCNM38         0.08951629
## + PCNM1          0.08946947
## + PCNM44         0.08933774
## + PCNM21         0.08916673
## + PCNM27         0.08907856
## + PCNM19         0.08889607
## + PCNM43         0.08857184
## + PCNM11         0.08770183
## + PCNM47         0.08738142
## + PCNM20         0.08732774
## + PCNM49         0.08691055
## + PCNM9          0.08689984
## + PCNM53         0.08662933
## + PCNM39         0.08651691
## + PCNM29         0.08640580
## + PCNM37         0.08619919
## + PCNM18         0.08595658
## + PCNM41         0.08564122
## + PCNM40         0.08563820
## + PCNM31         0.08561349
## + PCNM16         0.08519015
## + PCNM8          0.08514844
```

```
## + PCNM51         0.08496651
## <none>           0.08494812
## + PCNM23         0.08468880
## + PCNM32         0.08463429
## + PCNM7          0.08453138
## + PCNM33         0.08429093
## + PCNM5          0.08423566
## + PCNM42         0.08413696
## + PCNM54         0.08401963
## + PCNM59         0.08316669
## + PCNM36         0.08278808
## + PCNM25         0.08229363
## + PCNM34         0.08167297
## + PCNM45         0.08133220
## + PCNM35         0.08005561
## + PCNM30         0.07968714
## + PCNM22         0.07880013
## + PCNM58         0.07808636
##
##          Df    AIC      F Pr(>F)
## + PCNM46  1 282.16 2.4696  0.004 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Step: R2.adj= 0.1001488
## Call: woodytree.db ~ PCNM10 + PCNM4 + PCNM2 + PCNM12 + PCNM46
##
##                  R2.adjusted
## <All variables>  0.27227096
## + PCNM3          0.11154891
## + PCNM60         0.11111043
## + PCNM56         0.10895524
## + PCNM52         0.10877732
## + PCNM17         0.10836160
## + PCNM6          0.10827515
## + PCNM26         0.10824144
## + PCNM57         0.10803212
## + PCNM24         0.10747101
## + PCNM14         0.10740123
## + PCNM13         0.10687129
## + PCNM28         0.10665755
## + PCNM48         0.10648649
## + PCNM55         0.10600189
## + PCNM43         0.10590840
## + PCNM15         0.10500165
## + PCNM50         0.10483012
## + PCNM1          0.10465710
## + PCNM21         0.10438203
## + PCNM44         0.10432398
## + PCNM27         0.10419547
## + PCNM38         0.10385145
## + PCNM19         0.10381272
## + PCNM11         0.10315442
## + PCNM9          0.10284099
```

```
## + PCNM20         0.10266162
## + PCNM29         0.10190804
## + PCNM39         0.10166621
## + PCNM37         0.10160139
## + PCNM53         0.10148637
## + PCNM18         0.10110730
## + PCNM47         0.10104867
## + PCNM31         0.10093274
## + PCNM41         0.10075656
## + PCNM8          0.10069337
## + PCNM40         0.10066948
## + PCNM49         0.10066213
## <none>           0.10014876
## + PCNM16         0.10009260
## + PCNM32         0.10001209
## + PCNM7          0.09993725
## + PCNM23         0.09983039
## + PCNM5          0.09977697
## + PCNM42         0.09950610
## + PCNM51         0.09928028
## + PCNM33         0.09925647
## + PCNM54         0.09910860
## + PCNM59         0.09850484
## + PCNM36         0.09815007
## + PCNM25         0.09782692
## + PCNM34         0.09728249
## + PCNM45         0.09598599
## + PCNM35         0.09568756
## + PCNM30         0.09492557
## + PCNM22         0.09408743
## + PCNM58         0.09335694
##
##         Df    AIC      F Pr(>F)
## + PCNM3  1 281.91 2.1035  0.002 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Step: R2.adj= 0.1115489
## Call: woodytree.db ~ PCNM10 + PCNM4 + PCNM2 + PCNM12 + PCNM46 + PCNM3
##
##                 R2.adjusted
## <All variables>   0.2722710
## + PCNM60          0.1227635
## + PCNM56          0.1205862
## + PCNM52          0.1204228
## + PCNM6           0.1199105
## + PCNM26          0.1198422
## + PCNM57          0.1196750
## + PCNM17          0.1196492
## + PCNM24          0.1188638
## + PCNM13          0.1187677
## + PCNM14          0.1185998
## + PCNM28          0.1180690
## + PCNM48          0.1180535
```

```
## + PCNM43          0.1172823
## + PCNM55          0.1167431
## + PCNM50          0.1164330
## + PCNM1           0.1162696
## + PCNM15          0.1162027
## + PCNM44          0.1159488
## + PCNM21          0.1159087
## + PCNM27          0.1157393
## + PCNM38          0.1154828
## + PCNM19          0.1153852
## + PCNM11          0.1145959
## + PCNM9           0.1143922
## + PCNM20          0.1142218
## + PCNM29          0.1136506
## + PCNM37          0.1134966
## + PCNM39          0.1133987
## + PCNM53          0.1130202
## + PCNM18          0.1125581
## + PCNM47          0.1125299
## + PCNM31          0.1124981
## + PCNM41          0.1123265
## + PCNM40          0.1122125
## + PCNM49          0.1121883
## + PCNM8           0.1121506
## + PCNM5           0.1115867
## <none>            0.1115489
## + PCNM7           0.1115110
## + PCNM32          0.1114927
## + PCNM16          0.1114592
## + PCNM23          0.1113805
## + PCNM42          0.1111559
## + PCNM51          0.1107747
## + PCNM54          0.1106185
## + PCNM33          0.1105111
## + PCNM59          0.1099745
## + PCNM36          0.1097562
## + PCNM25          0.1093146
## + PCNM34          0.1083283
## + PCNM45          0.1075125
## + PCNM35          0.1071271
## + PCNM30          0.1064667
## + PCNM22          0.1056075
## + PCNM58          0.1048250
##
##          Df    AIC      F Pr(>F)
## + PCNM60  1 281.65 2.0866  0.004 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Step: R2.adj= 0.1227635
## Call: woodytree.db ~ PCNM10 + PCNM4 + PCNM2 + PCNM12 + PCNM46 + PCNM3 +      PCNM60
##
##                  R2.adjusted
## <All variables>   0.2722710
```

```
## + PCNM56           0.1318690
## + PCNM52           0.1317793
## + PCNM17           0.1313196
## + PCNM26           0.1313077
## + PCNM6            0.1311478
## + PCNM57           0.1310942
## + PCNM24           0.1307271
## + PCNM13           0.1301450
## + PCNM14           0.1294414
## + PCNM28           0.1293359
## + PCNM48           0.1285655
## + PCNM55           0.1282092
## + PCNM43           0.1281225
## + PCNM50           0.1279786
## + PCNM1            0.1276846
## + PCNM15           0.1275062
## + PCNM27           0.1274849
## + PCNM21           0.1273507
## + PCNM38           0.1268805
## + PCNM19           0.1266786
## + PCNM44           0.1266100
## + PCNM9            0.1263795
## + PCNM11           0.1257202
## + PCNM20           0.1257065
## + PCNM53           0.1250655
## + PCNM29           0.1250227
## + PCNM37           0.1248815
## + PCNM39           0.1246058
## + PCNM40           0.1244979
## + PCNM18           0.1241222
## + PCNM49           0.1238939
## + PCNM31           0.1237642
## + PCNM41           0.1236096
## + PCNM8            0.1235579
## + PCNM47           0.1230293
## + PCNM5            0.1229548
## + PCNM7            0.1229443
## <none>             0.1227635
## + PCNM23           0.1226957
## + PCNM32           0.1226727
## + PCNM42           0.1224417
## + PCNM51           0.1221240
## + PCNM33           0.1218601
## + PCNM54           0.1215026
## + PCNM59           0.1212464
## + PCNM36           0.1209748
## + PCNM25           0.1206272
## + PCNM16           0.1206210
## + PCNM34           0.1194360
## + PCNM45           0.1188046
## + PCNM35           0.1185087
## + PCNM30           0.1178018
## + PCNM22           0.1168969
## + PCNM58           0.1160845
```

```
##
##          Df    AIC     F Pr(>F)
## + PCNM56  1 281.59 1.881  0.008 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Step: R2.adj= 0.131869
## Call: woodytree.db ~ PCNM10 + PCNM4 + PCNM2 + PCNM12 + PCNM46 + PCNM3 +      PCNM60 + PCNM56
##
##                  R2.adjusted
## <All variables>   0.2722710
## + PCNM52          0.1411514
## + PCNM24          0.1406622
## + PCNM17          0.1405975
## + PCNM6           0.1404699
## + PCNM26          0.1402838
## + PCNM13          0.1392871
## + PCNM28          0.1390292
## + PCNM14          0.1389239
## + PCNM57          0.1388891
## + PCNM48          0.1376430
## + PCNM55          0.1375441
## + PCNM1           0.1372094
## + PCNM50          0.1371939
## + PCNM43          0.1369622
## + PCNM27          0.1368058
## + PCNM15          0.1367233
## + PCNM21          0.1366619
## + PCNM38          0.1362535
## + PCNM9           0.1357597
## + PCNM19          0.1355376
## + PCNM11          0.1349987
## + PCNM20          0.1348305
## + PCNM44          0.1347738
## + PCNM53          0.1343146
## + PCNM29          0.1342420
## + PCNM37          0.1341751
## + PCNM40          0.1335254
## + PCNM31          0.1335060
## + PCNM39          0.1334631
## + PCNM8           0.1329554
## + PCNM47          0.1328012
## + PCNM42          0.1327694
## + PCNM49          0.1326421
## + PCNM18          0.1324639
## + PCNM41          0.1323547
## + PCNM7           0.1322019
## + PCNM5           0.1320950
## + PCNM23          0.1318883
## <none>            0.1318690
## + PCNM32          0.1318031
## + PCNM51          0.1313498
## + PCNM59          0.1313379
## + PCNM33          0.1308781
```

```
## + PCNM54          0.1304930
## + PCNM36          0.1302585
## + PCNM25          0.1297396
## + PCNM16          0.1295922
## + PCNM34          0.1285984
## + PCNM45          0.1279047
## + PCNM35          0.1277913
## + PCNM30          0.1271354
## + PCNM22          0.1260997
## + PCNM58          0.1252235
##
##          Df    AIC      F Pr(>F)
## + PCNM52  1 281.48 1.8971  0.014 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Step: R2.adj= 0.1411514
## Call: woodytree.db ~ PCNM10 + PCNM4 + PCNM2 + PCNM12 + PCNM46 + PCNM3 +      PCNM60 + PCNM56 + PCNM52
##
##                  R2.adjusted
## <All variables>   0.2722710
## + PCNM17          0.1503762
## + PCNM24          0.1500544
## + PCNM6           0.1498405
## + PCNM26          0.1496401
## + PCNM28          0.1483402
## + PCNM14          0.1483324
## + PCNM13          0.1482803
## + PCNM48          0.1474989
## + PCNM1           0.1467282
## + PCNM57          0.1464837
## + PCNM43          0.1463748
## + PCNM55          0.1463177
## + PCNM50          0.1461856
## + PCNM15          0.1461499
## + PCNM27          0.1458782
## + PCNM21          0.1458626
## + PCNM38          0.1455060
## + PCNM9           0.1450576
## + PCNM19          0.1449739
## + PCNM20          0.1442854
## + PCNM11          0.1440905
## + PCNM44          0.1439752
## + PCNM29          0.1438898
## + PCNM37          0.1434920
## + PCNM53          0.1434453
## + PCNM39          0.1428217
## + PCNM31          0.1426989
## + PCNM8           0.1424016
## + PCNM47          0.1423051
## + PCNM41          0.1421091
## + PCNM42          0.1420633
## + PCNM40          0.1419617
## + PCNM7           0.1417727
```

```
## + PCNM18          0.1415314
## + PCNM5           0.1414487
## + PCNM23          0.1412642
## <none>            0.1411514
## + PCNM32          0.1409383
## + PCNM59          0.1402711
## + PCNM33          0.1402678
## + PCNM49          0.1402192
## + PCNM36          0.1396276
## + PCNM54          0.1392359
## + PCNM51          0.1389304
## + PCNM25          0.1388980
## + PCNM16          0.1386620
## + PCNM34          0.1379310
## + PCNM35          0.1370553
## + PCNM45          0.1370034
## + PCNM30          0.1360032
## + PCNM22          0.1352119
## + PCNM58          0.1345674
##
##          Df    AIC      F Pr(>F)
## + PCNM17  1 281.36 1.8903   0.01 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Step: R2.adj= 0.1503762
## Call: woodytree.db ~ PCNM10 + PCNM4 + PCNM2 + PCNM12 + PCNM46 + PCNM3 +      PCNM60 + PCNM56 + PCNM5
##
##                 R2.adjusted
## <All variables>   0.2722710
## + PCNM24          0.1595587
## + PCNM6           0.1592392
## + PCNM26          0.1590972
## + PCNM28          0.1577894
## + PCNM13          0.1577554
## + PCNM14          0.1575495
## + PCNM48          0.1566223
## + PCNM1           0.1563270
## + PCNM43          0.1556786
## + PCNM27          0.1555681
## + PCNM15          0.1555411
## + PCNM50          0.1553229
## + PCNM57          0.1553152
## + PCNM9           0.1550308
## + PCNM55          0.1549719
## + PCNM38          0.1549558
## + PCNM21          0.1548608
## + PCNM19          0.1543616
## + PCNM11          0.1536747
## + PCNM20          0.1535438
## + PCNM44          0.1532807
## + PCNM29          0.1531791
## + PCNM53          0.1529162
## + PCNM37          0.1526631
```

```
## + PCNM39          0.1522299
## + PCNM31          0.1521549
## + PCNM42          0.1517332
## + PCNM41          0.1516976
## + PCNM47          0.1516487
## + PCNM40          0.1513670
## + PCNM8           0.1512385
## + PCNM18          0.1509892
## + PCNM7           0.1509102
## + PCNM5           0.1507459
## <none>            0.1503762
## + PCNM23          0.1503384
## + PCNM32          0.1502167
## + PCNM49          0.1496843
## + PCNM33          0.1496042
## + PCNM59          0.1495960
## + PCNM36          0.1492825
## + PCNM54          0.1485410
## + PCNM51          0.1482527
## + PCNM25          0.1481347
## + PCNM16          0.1479102
## + PCNM34          0.1472795
## + PCNM35          0.1463615
## + PCNM45          0.1462811
## + PCNM30          0.1450938
## + PCNM22          0.1444529
## + PCNM58          0.1438358
##
##          Df    AIC     F Pr(>F)
## + PCNM24  1 281.22 1.885  0.014 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Step: R2.adj= 0.1595587
## Call: woodytree.db ~ PCNM10 + PCNM4 + PCNM2 + PCNM12 + PCNM46 + PCNM3 +      PCNM60 + PCNM56 + PCNM5
##
##                 R2.adjusted
## <All variables>   0.2722710
## + PCNM6           0.1685947
## + PCNM28          0.1671609
## + PCNM26          0.1670018
## + PCNM13          0.1669946
## + PCNM14          0.1662704
## + PCNM48          0.1657857
## + PCNM1           0.1657229
## + PCNM15          0.1650784
## + PCNM43          0.1649995
## + PCNM27          0.1649288
## + PCNM57          0.1647175
## + PCNM9           0.1644185
## + PCNM50          0.1643535
## + PCNM38          0.1642647
## + PCNM55          0.1641645
## + PCNM21          0.1640841
```

```
## + PCNM19          0.1637889
## + PCNM20          0.1630147
## + PCNM11          0.1626542
## + PCNM29          0.1624535
## + PCNM53          0.1622809
## + PCNM44          0.1620660
## + PCNM39          0.1616380
## + PCNM37          0.1615568
## + PCNM31          0.1614866
## + PCNM42          0.1611988
## + PCNM41          0.1610023
## + PCNM47          0.1608132
## + PCNM40          0.1607069
## + PCNM8           0.1604598
## + PCNM18          0.1603125
## + PCNM7           0.1602091
## + PCNM5           0.1600593
## <none>            0.1595587
## + PCNM32          0.1595045
## + PCNM23          0.1594268
## + PCNM59          0.1591303
## + PCNM49          0.1591143
## + PCNM33          0.1588981
## + PCNM36          0.1581645
## + PCNM54          0.1575229
## + PCNM51          0.1573866
## + PCNM25          0.1573501
## + PCNM16          0.1571804
## + PCNM34          0.1568512
## + PCNM45          0.1555036
## + PCNM35          0.1554801
## + PCNM30          0.1544004
## + PCNM22          0.1536717
## + PCNM58          0.1530521
##
##          Df    AIC      F Pr(>F)
## + PCNM6  1 281.07 1.8695  0.008 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Step: R2.adj= 0.1685947
## Call: woodytree.db ~ PCNM10 + PCNM4 + PCNM2 + PCNM12 + PCNM46 + PCNM3 +      PCNM60 + PCNM56 + PCNM5
##
##                  R2.adjusted
## <All variables>   0.2722710
## + PCNM28          0.1764008
## + PCNM26          0.1761021
## + PCNM13          0.1760633
## + PCNM14          0.1753354
## + PCNM48          0.1750865
## + PCNM1           0.1749751
## + PCNM43          0.1743287
## + PCNM15          0.1741544
## + PCNM27          0.1741018
```

```
## + PCNM57          0.1738823
## + PCNM38          0.1734676
## + PCNM50          0.1734600
## + PCNM21          0.1732942
## + PCNM11          0.1730275
## + PCNM9           0.1729995
## + PCNM19          0.1729044
## + PCNM55          0.1728855
## + PCNM20          0.1723268
## + PCNM29          0.1715224
## + PCNM44          0.1712786
## + PCNM39          0.1708158
## + PCNM37          0.1707792
## + PCNM31          0.1706440
## + PCNM42          0.1706098
## + PCNM8           0.1702390
## + PCNM41          0.1701981
## + PCNM53          0.1701059
## + PCNM47          0.1700914
## + PCNM40          0.1698665
## + PCNM18          0.1695647
## + PCNM5           0.1694730
## + PCNM32          0.1687105
## <none>            0.1685947
## + PCNM23          0.1685869
## + PCNM7           0.1683650
## + PCNM49          0.1682079
## + PCNM59          0.1681413
## + PCNM33          0.1680339
## + PCNM36          0.1674527
## + PCNM25          0.1666231
## + PCNM54          0.1665413
## + PCNM16          0.1664062
## + PCNM51          0.1663243
## + PCNM34          0.1660172
## + PCNM45          0.1646989
## + PCNM35          0.1646215
## + PCNM30          0.1635032
## + PCNM22          0.1628135
## + PCNM58          0.1621304
##
##          Df    AIC      F Pr(>F)
## + PCNM28  1 281.03 1.7488   0.02 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Step: R2.adj= 0.1764008
## Call: woodytree.db ~ PCNM10 + PCNM4 + PCNM2 + PCNM12 + PCNM46 + PCNM3 +      PCNM60 + PCNM56 + PCNM5
##
##                  R2.adjusted
## <All variables>   0.2722710
## + PCNM26          0.1840960
## + PCNM13          0.1840749
## + PCNM14          0.1834046
```

```
## + PCNM48          0.1831752
## + PCNM1           0.1829224
## + PCNM57          0.1824487
## + PCNM43          0.1824106
## + PCNM15          0.1820992
## + PCNM27          0.1814880
## + PCNM21          0.1813718
## + PCNM55          0.1809436
## + PCNM9           0.1809354
## + PCNM38          0.1808969
## + PCNM19          0.1808652
## + PCNM50          0.1808640
## + PCNM11          0.1808513
## + PCNM20          0.1804595
## + PCNM29          0.1794711
## + PCNM31          0.1787752
## + PCNM44          0.1786323
## + PCNM39          0.1785871
## + PCNM42          0.1781986
## + PCNM8           0.1781845
## + PCNM37          0.1781307
## + PCNM41          0.1779990
## + PCNM53          0.1777258
## + PCNM40          0.1777178
## + PCNM47          0.1775771
## + PCNM18          0.1775338
## + PCNM5           0.1773992
## + PCNM32          0.1766874
## + PCNM23          0.1764602
## <none>            0.1764008
## + PCNM7           0.1762679
## + PCNM49          0.1761886
## + PCNM59          0.1758611
## + PCNM33          0.1758500
## + PCNM36          0.1753332
## + PCNM25          0.1745409
## + PCNM16          0.1742853
## + PCNM54          0.1742406
## + PCNM34          0.1739347
## + PCNM51          0.1739077
## + PCNM45          0.1725210
## + PCNM35          0.1724794
## + PCNM30          0.1715315
## + PCNM22          0.1706667
## + PCNM58          0.1699558
##
##          Df    AIC      F Pr(>F)
## + PCNM26  1 280.98 1.7357  0.026 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Step: R2.adj= 0.184096
## Call: woodytree.db ~ PCNM10 + PCNM4 + PCNM2 + PCNM12 + PCNM46 + PCNM3 +      PCNM60 + PCNM56 + PCNM52
##
```

```
##                  R2.adjusted
## <All variables>   0.2722710
## + PCNM13          0.1920733
## + PCNM14          0.1912551
## + PCNM48          0.1910582
## + PCNM1           0.1908086
## + PCNM43          0.1903325
## + PCNM57          0.1902112
## + PCNM15          0.1896742
## + PCNM21          0.1892977
## + PCNM27          0.1891474
## + PCNM50          0.1890758
## + PCNM11          0.1887747
## + PCNM55          0.1887555
## + PCNM9           0.1887410
## + PCNM38          0.1883279
## + PCNM20          0.1882726
## + PCNM29          0.1872497
## + PCNM31          0.1868867
## + PCNM39          0.1864571
## + PCNM44          0.1864512
## + PCNM42          0.1860602
## + PCNM41          0.1860186
## + PCNM8           0.1859936
## + PCNM19          0.1858582
## + PCNM53          0.1855642
## + PCNM18          0.1853504
## + PCNM5           0.1851572
## + PCNM47          0.1851537
## + PCNM40          0.1851014
## + PCNM37          0.1844881
## + PCNM32          0.1843909
## + PCNM23          0.1843661
## <none>            0.1840960
## + PCNM7           0.1840746
## + PCNM49          0.1838435
## + PCNM33          0.1836680
## + PCNM59          0.1836505
## + PCNM36          0.1830763
## + PCNM25          0.1823032
## + PCNM51          0.1821587
## + PCNM16          0.1820317
## + PCNM54          0.1819163
## + PCNM34          0.1816958
## + PCNM45          0.1804926
## + PCNM35          0.1802372
## + PCNM22          0.1792154
## + PCNM30          0.1792033
## + PCNM58          0.1776667
##
##          Df    AIC      F Pr(>F)
## + PCNM13  1 280.87 1.7603  0.014 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
##
## Step: R2.adj= 0.1920733
## Call: woodytree.db ~ PCNM10 + PCNM4 + PCNM2 + PCNM12 + PCNM46 + PCNM3 +      PCNM60 + PCNM56 + PCNM5
##
##                   R2.adjusted
## <All variables>   0.2722710
## + PCNM14          0.1989587
## + PCNM48          0.1989188
## + PCNM43          0.1985333
## + PCNM57          0.1983465
## + PCNM1           0.1982057
## + PCNM15          0.1976913
## + PCNM27          0.1975606
## + PCNM50          0.1972366
## + PCNM55          0.1971927
## + PCNM9           0.1971777
## + PCNM38          0.1964744
## + PCNM20          0.1962758
## + PCNM11          0.1962272
## + PCNM29          0.1953763
## + PCNM21          0.1950302
## + PCNM31          0.1949888
## + PCNM39          0.1945321
## + PCNM44          0.1944622
## + PCNM42          0.1943341
## + PCNM8           0.1943255
## + PCNM41          0.1940682
## + PCNM19          0.1940055
## + PCNM53          0.1934530
## + PCNM18          0.1933616
## + PCNM40          0.1932410
## + PCNM5           0.1931859
## + PCNM47          0.1931616
## + PCNM37          0.1926012
## + PCNM32          0.1924820
## + PCNM7           0.1924227
## + PCNM23          0.1921601
## <none>            0.1920733
## + PCNM59          0.1920234
## + PCNM49          0.1918606
## + PCNM33          0.1917371
## + PCNM36          0.1912181
## + PCNM51          0.1902494
## + PCNM25          0.1901718
## + PCNM16          0.1901328
## + PCNM54          0.1899564
## + PCNM34          0.1898080
## + PCNM45          0.1887894
## + PCNM35          0.1882720
## + PCNM22          0.1876658
## + PCNM30          0.1874791
## + PCNM58          0.1856464
##
##          Df    AIC      F Pr(>F)
```

```
## + PCNM14  1 280.86 1.6533  0.014 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Step: R2.adj= 0.1989587
## Call: woodytree.db ~ PCNM10 + PCNM4 + PCNM2 + PCNM12 + PCNM46 + PCNM3 +      PCNM60 + PCNM56 + PCNM5
##
##                  R2.adjusted
## <All variables>   0.2722710
## + PCNM48          0.2061505
## + PCNM57          0.2056330
## + PCNM43          0.2055618
## + PCNM1           0.2050064
## + PCNM9           0.2047429
## + PCNM15          0.2047139
## + PCNM27          0.2046036
## + PCNM50          0.2042833
## + PCNM55          0.2042429
## + PCNM38          0.2034620
## + PCNM20          0.2030449
## + PCNM11          0.2026592
## + PCNM29          0.2026113
## + PCNM21          0.2021334
## + PCNM31          0.2020091
## + PCNM44          0.2017592
## + PCNM39          0.2015383
## + PCNM8           0.2014096
## + PCNM42          0.2011996
## + PCNM19          0.2009571
## + PCNM41          0.2008325
## + PCNM53          0.2002289
## + PCNM5           0.2002221
## + PCNM47          0.2002165
## + PCNM40          0.2001215
## + PCNM49          0.1996988
## + PCNM32          0.1994521
## + PCNM37          0.1994446
## + PCNM7           0.1994021
## + PCNM23          0.1990956
## + PCNM18          0.1990433
## + PCNM59          0.1990020
## <none>            0.1989587
## + PCNM33          0.1987207
## + PCNM36          0.1980177
## + PCNM51          0.1971073
## + PCNM25          0.1970534
## + PCNM16          0.1970483
## + PCNM54          0.1969070
## + PCNM34          0.1968437
## + PCNM45          0.1957562
## + PCNM35          0.1951617
## + PCNM22          0.1946652
## + PCNM30          0.1942172
## + PCNM58          0.1925726
```

```
##
##          Df   AIC      F Pr(>F)
## + PCNM48  1 280.8 1.6794  0.012 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Step: R2.adj= 0.2061505
## Call: woodytree.db ~ PCNM10 + PCNM4 + PCNM2 + PCNM12 + PCNM46 + PCNM3 +      PCNM60 + PCNM56 + PCNM5
##
##                  R2.adjusted
## <All variables>   0.2722710
## + PCNM43          0.2125808
## + PCNM1           0.2123163
## + PCNM9           0.2121791
## + PCNM27          0.2121748
## + PCNM15          0.2120318
## + PCNM55          0.2115574
## + PCNM50          0.2111784
## + PCNM57          0.2109256
## + PCNM20          0.2104379
## + PCNM38          0.2103275
## + PCNM29          0.2098829
## + PCNM31          0.2096342
## + PCNM11          0.2095742
## + PCNM21          0.2089932
## + PCNM44          0.2089024
## + PCNM39          0.2088403
## + PCNM42          0.2087133
## + PCNM8           0.2082812
## + PCNM19          0.2082624
## + PCNM41          0.2077372
## + PCNM53          0.2076429
## + PCNM47          0.2075259
## + PCNM40          0.2074272
## + PCNM5           0.2074125
## + PCNM49          0.2073922
## + PCNM18          0.2067249
## + PCNM37          0.2066506
## + PCNM32          0.2065996
## + PCNM7           0.2065429
## + PCNM23          0.2062702
## <none>            0.2061505
## + PCNM33          0.2058629
## + PCNM36          0.2052523
## + PCNM59          0.2051615
## + PCNM51          0.2044180
## + PCNM34          0.2043646
## + PCNM25          0.2041916
## + PCNM16          0.2039777
## + PCNM54          0.2035500
## + PCNM45          0.2029967
## + PCNM35          0.2025463
## + PCNM22          0.2019000
## + PCNM30          0.2012337
```

```
## + PCNM58          0.1998000
##
##          Df    AIC      F Pr(>F)
## + PCNM43  1 280.8 1.6043  0.036 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Step: R2.adj= 0.2125808
## Call: woodytree.db ~ PCNM10 + PCNM4 + PCNM2 + PCNM12 + PCNM46 + PCNM3 +      PCNM60 + PCNM56 + PCNM52
##
##                  R2.adjusted
## <All variables>   0.2722710
## + PCNM57          0.2188869
## + PCNM1           0.2188709
## + PCNM9           0.2188113
## + PCNM15          0.2186444
## + PCNM55          0.2186155
## + PCNM27          0.2182975
## + PCNM50          0.2176353
## + PCNM38          0.2169403
## + PCNM31          0.2164635
## + PCNM29          0.2164504
## + PCNM11          0.2161122
## + PCNM39          0.2159472
## + PCNM21          0.2154618
## + PCNM42          0.2152563
## + PCNM40          0.2150535
## + PCNM20          0.2149910
## + PCNM47          0.2149559
## + PCNM8           0.2148452
## + PCNM19          0.2148020
## + PCNM53          0.2142836
## + PCNM44          0.2141294
## + PCNM5           0.2138774
## + PCNM49          0.2138095
## + PCNM18          0.2134382
## + PCNM32          0.2131793
## + PCNM41          0.2130832
## + PCNM7           0.2129398
## + PCNM37          0.2128840
## + PCNM23          0.2128450
## <none>            0.2125808
## + PCNM33          0.2120092
## + PCNM36          0.2119098
## + PCNM59          0.2114210
## + PCNM34          0.2109277
## + PCNM51          0.2109217
## + PCNM25          0.2108657
## + PCNM16          0.2104517
## + PCNM54          0.2100438
## + PCNM45          0.2095346
## + PCNM35          0.2089024
## + PCNM22          0.2083665
## + PCNM30          0.2078011
```

```
## + PCNM58          0.2062358
##
##          Df    AIC      F Pr(>F)
## + PCNM57  1 280.79 1.5893  0.018 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Step: R2.adj= 0.2188869
## Call: woodytree.db ~ PCNM10 + PCNM4 + PCNM2 + PCNM12 + PCNM46 + PCNM3 +      PCNM60 + PCNM56 + PCNM5
##
##                  R2.adjusted
## <All variables>   0.2722710
## + PCNM1           0.2253554
## + PCNM15          0.2253091
## + PCNM9           0.2252924
## + PCNM27          0.2246927
## + PCNM50          0.2240423
## + PCNM38          0.2230348
## + PCNM29          0.2229124
## + PCNM55          0.2228398
## + PCNM31          0.2228281
## + PCNM39          0.2223831
## + PCNM11          0.2223146
## + PCNM21          0.2219234
## + PCNM42          0.2219111
## + PCNM40          0.2218364
## + PCNM20          0.2214069
## + PCNM47          0.2213029
## + PCNM8           0.2212585
## + PCNM19          0.2211863
## + PCNM53          0.2209919
## + PCNM44          0.2205456
## + PCNM5           0.2203085
## + PCNM49          0.2202326
## + PCNM18          0.2195659
## + PCNM32          0.2195320
## + PCNM7           0.2192205
## + PCNM23          0.2191482
## + PCNM37          0.2189916
## <none>            0.2188869
## + PCNM41          0.2184654
## + PCNM33          0.2183555
## + PCNM51          0.2181586
## + PCNM36          0.2179737
## + PCNM25          0.2172261
## + PCNM34          0.2171958
## + PCNM16          0.2168473
## + PCNM59          0.2163300
## + PCNM54          0.2151831
## + PCNM35          0.2149270
## + PCNM45          0.2149215
## + PCNM22          0.2145016
## + PCNM30          0.2138558
## + PCNM58          0.2125623
```

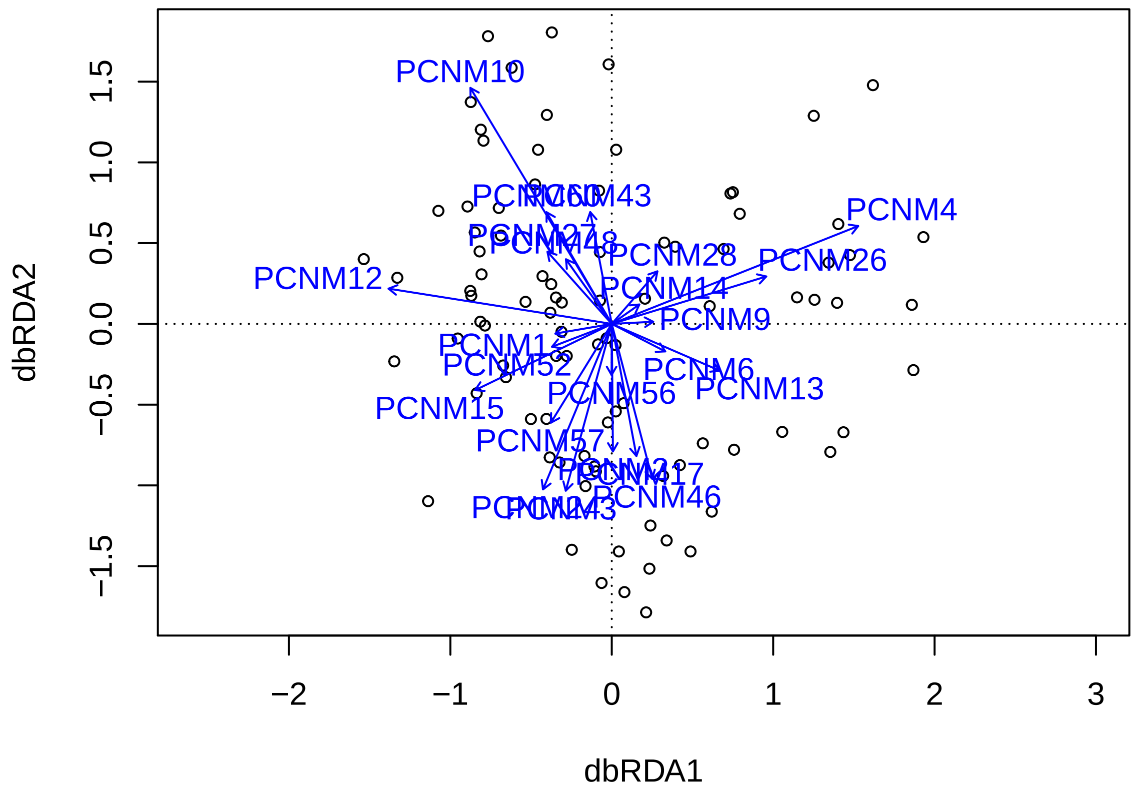
```
##
##         Df    AIC      F Pr(>F)
## + PCNM1  1 280.74 1.6012  0.026 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Step: R2.adj= 0.2253554
## Call: woodytree.db ~ PCNM10 + PCNM4 + PCNM2 + PCNM12 + PCNM46 + PCNM3 +      PCNM60 + PCNM56 + PCNM5
##
##                 R2.adjusted
## <All variables>   0.2722710
## + PCNM15          0.2318713
## + PCNM9           0.2314703
## + PCNM27          0.2313459
## + PCNM50          0.2306696
## + PCNM38          0.2296886
## + PCNM29          0.2295109
## + PCNM55          0.2294154
## + PCNM31          0.2294053
## + PCNM21          0.2289125
## + PCNM11          0.2288011
## + PCNM39          0.2287116
## + PCNM42          0.2285359
## + PCNM40          0.2280670
## + PCNM20          0.2279497
## + PCNM8           0.2278582
## + PCNM47          0.2278244
## + PCNM19          0.2277934
## + PCNM53          0.2276719
## + PCNM44          0.2270243
## + PCNM5           0.2264299
## + PCNM49          0.2261710
## + PCNM32          0.2261622
## + PCNM23          0.2256087
## + PCNM18          0.2255959
## + PCNM7           0.2255919
## + PCNM37          0.2254550
## <none>            0.2253554
## + PCNM41          0.2250012
## + PCNM33          0.2249390
## + PCNM51          0.2247949
## + PCNM36          0.2244331
## + PCNM25          0.2237388
## + PCNM34          0.2236922
## + PCNM16          0.2233790
## + PCNM59          0.2229170
## + PCNM54          0.2216320
## + PCNM45          0.2215101
## + PCNM35          0.2214642
## + PCNM22          0.2205841
## + PCNM30          0.2203367
## + PCNM58          0.2190332
##
##          Df    AIC      F Pr(>F)
```

```
## + PCNM15  1 280.66 1.6023   0.03 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Step: R2.adj= 0.2318713
## Call: woodytree.db ~ PCNM10 + PCNM4 + PCNM2 + PCNM12 + PCNM46 + PCNM3 +      PCNM60 + PCNM56 + PCNM5
##
##                  R2.adjusted
## <All variables>   0.2722710
## + PCNM27          0.2383847
## + PCNM9           0.2377757
## + PCNM50          0.2371499
## + PCNM38          0.2363339
## + PCNM29          0.2361054
## + PCNM31          0.2360376
## + PCNM55          0.2359526
## + PCNM21          0.2358715
## + PCNM11          0.2353713
## + PCNM39          0.2353680
## + PCNM42          0.2351854
## + PCNM40          0.2347167
## + PCNM20          0.2346972
## + PCNM19          0.2345058
## + PCNM8           0.2344524
## + PCNM47          0.2344110
## + PCNM53          0.2342275
## + PCNM44          0.2337022
## + PCNM32          0.2328054
## + PCNM49          0.2326612
## + PCNM23          0.2324950
## + PCNM7           0.2323873
## + PCNM18          0.2322699
## + PCNM41          0.2319643
## + PCNM37          0.2319371
## <none>            0.2318713
## + PCNM33          0.2316541
## + PCNM51          0.2314479
## + PCNM5           0.2313324
## + PCNM36          0.2309408
## + PCNM16          0.2302666
## + PCNM25          0.2302346
## + PCNM34          0.2301633
## + PCNM59          0.2294914
## + PCNM54          0.2282622
## + PCNM45          0.2280852
## + PCNM35          0.2278129
## + PCNM22          0.2272941
## + PCNM30          0.2268498
## + PCNM58          0.2259116
##
##          Df    AIC      F Pr(>F)
## + PCNM27  1 280.55 1.5986  0.032 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
##
## Step: R2.adj= 0.2383847
## Call: woodytree.db ~ PCNM10 + PCNM4 + PCNM2 + PCNM12 + PCNM46 + PCNM3 +      PCNM60 + PCNM56 + PCNM5
##
##                  R2.adjusted
## <All variables>   0.2722710
## + PCNM9           0.2443171
## + PCNM50          0.2438801
## + PCNM38          0.2429690
## + PCNM29          0.2428503
## + PCNM31          0.2427197
## + PCNM55          0.2423707
## + PCNM39          0.2422494
## + PCNM11          0.2418333
## + PCNM21          0.2417852
## + PCNM42          0.2417745
## + PCNM40          0.2416451
## + PCNM19          0.2411891
## + PCNM8           0.2410620
## + PCNM20          0.2410450
## + PCNM53          0.2410198
## + PCNM47          0.2409826
## + PCNM44          0.2391436
## + PCNM32          0.2391381
## + PCNM49          0.2391149
## + PCNM23          0.2390853
## + PCNM7           0.2389333
## + PCNM18          0.2388234
## + PCNM41          0.2385799
## + PCNM37          0.2384173
## <none>            0.2383847
## + PCNM33          0.2382877
## + PCNM5           0.2379074
## + PCNM51          0.2376476
## + PCNM36          0.2376427
## + PCNM34          0.2375355
## + PCNM59          0.2366524
## + PCNM16          0.2365243
## + PCNM25          0.2362151
## + PCNM54          0.2350396
## + PCNM45          0.2347989
## + PCNM35          0.2343632
## + PCNM22          0.2341645
## + PCNM30          0.2332773
## + PCNM58          0.2324299
##
##         Df    AIC      F Pr(>F)
## + PCNM9  1 280.49 1.5417  0.048 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Step: R2.adj= 0.2443171
## Call: woodytree.db ~ PCNM10 + PCNM4 + PCNM2 + PCNM12 + PCNM46 + PCNM3 +      PCNM60 + PCNM56 + PCNM5
##
```

```
##                   R2.adjusted
## <All variables>   0.2722710
## + PCNM50          0.2499736
## + PCNM29          0.2491138
## + PCNM38          0.2490993
## + PCNM31          0.2487599
## + PCNM55          0.2483135
## + PCNM39          0.2481744
## + PCNM42          0.2477759
## + PCNM40          0.2477097
## + PCNM19          0.2473900
## + PCNM20          0.2473455
## + PCNM53          0.2472748
## + PCNM21          0.2472524
## + PCNM47          0.2469371
## + PCNM11          0.2466557
## + PCNM8           0.2462035
## + PCNM23          0.2452048
## + PCNM32          0.2451082
## + PCNM44          0.2449707
## + PCNM49          0.2449512
## + PCNM7           0.2449391
## + PCNM18          0.2448570
## + PCNM41          0.2447121
## + PCNM37          0.2445781
## + PCNM33          0.2443197
## <none>            0.2443171
## + PCNM5           0.2442792
## + PCNM34          0.2437107
## + PCNM51          0.2436427
## + PCNM36          0.2435167
## + PCNM59          0.2426803
## + PCNM16          0.2423306
## + PCNM25          0.2417209
## + PCNM54          0.2408102
## + PCNM45          0.2407519
## + PCNM35          0.2403140
## + PCNM22          0.2401665
## + PCNM30          0.2393330
## + PCNM58          0.2382803
##
##            Df    AIC      F Pr(>F)
## + PCNM50   1 280.43 1.5128  0.078 .
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
# plot
plot(woodytree.step.pcnm)
```




```r
# anova
woodytree.step.pcnm$anova
```

```
##                  R2.adj Df    AIC      F Pr(>F)
## + PCNM10       0.025135  1 285.70 3.3463  0.002 **
## + PCNM4        0.052693  1 284.04 3.6182  0.002 **
## + PCNM2        0.069309  1 283.37 2.5889  0.002 **
## + PCNM12       0.084948  1 282.76 2.5040  0.002 **
## + PCNM46       0.100149  1 282.16 2.4696  0.004 **
## + PCNM3        0.111549  1 281.91 2.1035  0.002 **
## + PCNM60       0.122764  1 281.65 2.0866  0.004 **
## + PCNM56       0.131869  1 281.59 1.8810  0.008 **
## + PCNM52       0.141151  1 281.48 1.8971  0.014 *
## + PCNM17       0.150376  1 281.36 1.8903  0.010 **
## + PCNM24       0.159559  1 281.22 1.8850  0.014 *
## + PCNM6        0.168595  1 281.07 1.8695  0.008 **
## + PCNM28       0.176401  1 281.03 1.7488  0.020 *
## + PCNM26       0.184096  1 280.98 1.7357  0.026 *
## + PCNM13       0.192073  1 280.87 1.7603  0.014 *
## + PCNM14       0.198959  1 280.86 1.6533  0.014 *
## + PCNM48       0.206150  1 280.80 1.6794  0.012 *
## + PCNM43       0.212581  1 280.80 1.6043  0.036 *
## + PCNM57       0.218887  1 280.79 1.5893  0.018 *
## + PCNM1        0.225355  1 280.74 1.6012  0.026 *
## + PCNM15       0.231871  1 280.66 1.6023  0.030 *
## + PCNM27       0.238385  1 280.55 1.5986  0.032 *
```

```
## + PCNM9         0.244317  1 280.49 1.5417  0.048 *
## <All variables> 0.272271
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
# witht this test and all explanatory variables there was a p-value of 0.002, suggesting that there is
# can determine percent that contributes
space.mod <- model.matrix(~ PCNM10 + PCNM4 + PCNM12 + PCNM2 + PCNM46 + PCNM60 + PCNM57 + PCNM17 + PCNM3
+ PCNM28 + PCNM50 + PCNM1 + PCNM44 + PCNM38 + PCNM21 + PCNM55 + PCNM27 + PCNM19 + PCNM43 + PCNM11 + PCN
# conduct constrained ordination
woodytree.total.space <- dbrda(woodytree.db ~ space.mod)
# test for significance of dbRDA fraction
permutest(woodytree.total.space, permutations = 999)
```

```
##
## Permutation test for dbrda under reduced model
##
## Permutation: free
## Number of permutations: 999
##
## Model: dbrda(formula = woodytree.db ~ space.mod)
## Permutation test for all constrained eigenvalues
##          Df Inertia      F Pr(>F)
## Model    60 16.8534 1.5674  0.001 ***
## Residual 31  5.5553
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
# this model was significant (pvalue 0.001), supporting the hypothesis that spatial arrangment of sites
```