6. Worksheet: Among Site (Beta) Diversity – Part 1

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OVERVIEW

In this worksheet, we move beyond the investigation of within-site α-diversity. We will explore β-diversity, which is defined as the diversity that occurs among sites. This requires that we examine the compositional similarity of assemblages that vary in space or time.

After completing this exercise you will know how to:

1. formally quantify β-diversity
2. visualize β-diversity with heatmaps, cluster analysis, and ordination
3. 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, **push** this file to your GitHub repo.
6. For the assignment portion of the worksheet, follow the directions at the bottom of this file.
7. When you are done, **Knit** the text and code into a PDF file.
8. After Knitting, submit the completed exercise by creating a **pull request** via GitHub. Your pull request should include this file (**6.BetaDiversity_1_Worksheet.Rmd**) with all code blocks filled out and questions answered) and the PDF output of `Knitr` (**6.BetaDiversity_1_Worksheet.pdf**).

The completed exercise is due on **Wednesday, February 5th, 2025 before 12:00 PM (noon)**.

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, please provide the code to:

1) Clear your R environment,
2) Print your current working directory,
3) Set your working directory to your `Week3-Beta/` folder folder, and
4) Load the `vegan` R package (be sure to install first if you have not already).

```r
rm(list = ls())

getwd()
```

```
## [1] "/cloud/project/QB2025_Brown/Week3-Beta"
```

```r
setwd("/cloud/project/QB2025_Brown/Week3-Beta")

package.list <- c('vegan', 'ade4', 'viridis', 'gplots', 'BiodiversityR', 'indicspecies')
library(vegan)
```

```
## Loading required package: permute

## Loading required package: lattice

## This is vegan 2.6-8
```

```r
library(ade4)
library(viridis)
```

```
## Loading required package: viridisLite
```

```r
library(gplots)
```

```
##
## Attaching package: 'gplots'

## The following object is masked from 'package:stats':
##
##     lowess
```

```r
library(indicspecies)
```

2) LOADING DATA

Load dataset

In the R code chunk below, do the following:

1. load the doubs dataset from the ade4 package, and
2. explore the structure of the dataset.

```r
# note, please do not print the dataset when submitting
data(doubs)

length(doubs)
```

```
## [1] 4
```

```r
str(doubs, max.level = 1)
```

```
## List of 4
##  $ env    :'data.frame': 30 obs. of  11 variables:
##  $ fish   :'data.frame': 30 obs. of  27 variables:
##  $ xy     :'data.frame': 30 obs. of  2 variables:
##  $ species:'data.frame': 27 obs. of  4 variables:
```

```r
head(doubs$env)
```

```
##    dfs alt   slo flo pH har pho nit amm oxy bdo
## 1    3 934 6.176  84 79  45   1  20   0 122  27
```

```
## 2  22 932 3.434 100 80  40   2  20  10 103  19
## 3 102 914 3.638 180 83  52   5  22   5 105  35
## 4 185 854 3.497 253 80  72  10  21   0 110  13
## 5 215 849 3.178 264 81  84  38  52  20  80  62
## 6 324 846 3.497 286 79  60  20  15   0 102  53
```

Question 1: Describe some of the attributes of the `doubs` dataset.

a. How many objects are in `doubs`?
b. How many fish species are there in the `doubs` dataset?
c. How many sites are in the `doubs` dataset?

> ***Answer 1a***: There are 4 objects. ***Answer 1b***: There are 27 fish species. ***Answer 1c***: There are 30 sites.

Visualizing the Doubs River Dataset

Question 2: Answer the following questions based on the spatial patterns of richness (i.e., α-diversity) and Brown Trout (*Salmo trutta*) abundance in the Doubs River.

a. How does fish richness vary along the sampled reach of the Doubs River?
b. How does Brown Trout (*Salmo trutta*) abundance vary along the sampled reach of the Doubs River?
c. What do these patterns say about the limitations of using richness when examining patterns of biodiversity?

> ***Answer 2a***: Fish richness seems to be the highest downstream and then slightly decreases as you appraoch the middle of the sampled reach. However, once you reach the middle of the stream, fish richness increases significantly. Then, as you appraoch upstream, fish richness decreases. ***Answer 2b***: Brown trout abundance is almost non-existent downstream; however, it does increase slightly as you approach the middle of the sampled reach. Abundance then continues to increase, except for at a few sites, as you go upstream. From the graph you can clearly see that brown trout are much more abundant upstream than downstream. ***Answer 2c***: When only using richness, you cannot tell exactly what species are present and in what quantities. You could have two different sites, both with a richness of 10; yet, the 10 species at each site could be completely different from one another. It is also does not give you much insight into the structure of the community you are examining. It is best to use richness along with a combination of other methods of examining biodiversity.

3) QUANTIFYING BETA-DIVERSITY

In the R code chunk below, do the following:

1. write a function (`beta.w()`) to calculate Whittaker's β-diversity (i.e., β_w) that accepts a site-by-species matrix with optional arguments to specify pairwise turnover between two sites, and
2. use this function to analyze various aspects of β-diversity in the Doubs River.

```r
beta.w <- function(site.by.species = "", sitenum1 = "", sitenum2 = "",
  pairwise = FALSE){
  if (pairwise == TRUE){
    if (sitenum1 == "" | sitenum2 == ""){
      print("Error: please specify sites to compare")
      return(NA)}
    site1 = site.by.species[sitenum1, ]
    site2 = site.by.species[sitenum2, ]
    site1 = subset(site1, select = site1 > 0)
    site2 = subset(site2, select = site2 > 0)
    gamma = union(colnames(site1), colnames(site2))
    s     = length(gamma)
```

```r
    a.bar = mean(c(specnumber(site1), specnumber(site2)))
    b.w   = round(s/a.bar - 1, 3)
    return(b.w)
   }
  else{
    SbyS.pa <- decostand(site.by.species, method = "pa")
    S <- ncol(SbyS.pa[,which(colSums(SbyS.pa) > 0)])
    a.bar <- mean(specnumber(SbyS.pa))
    b.w <- round(S/a.bar, 3)
    return(b.w)
  }
}

beta.w(doubs$fish, 1, 5, pairwise = TRUE)
```

```
## [1] 0.833
```

```r
beta.w(doubs$fish, 1, 2, pairwise = TRUE)
```

```
## [1] 0.5
```

```r
beta.w(doubs$fish, 1, 10, pairwise = TRUE)
```

```
## [1] 0.714
```

Question 3: Using your `beta.w()` function above, answer the following questions:

a. Describe how local richness (α) and turnover (β) contribute to regional (γ) fish diversity in the Doubs.
b. Is the fish assemblage at site 1 more similar to the one at site 2 or site 10?
c. Using your understanding of the equation $\beta_w = \gamma/\alpha$, how would your interpretation of β change if we instead defined beta additively (i.e., $\beta = \gamma - \alpha$)?

> ***Answer 3a***: Gamma diversity is defined as the total species diversity across an entire landscape and alpha and beta diversity contribute to this. Alpha diversity is a measure of the amount of species present in a particular site and beta diversity measures how similiar and/or different sites are from one another. In the Doubs data, the alpha diversity of each site and the beta diversity between those sites will impact the gamma diversity. For example, if alpha diversity is extremely high but beta diversity is relatively low, gamma diversity may be lower. On the other hand, a very high beta diversity could result in a high gamma diversity, even if species richness is low. There can be a lot of variation in gamma diversity based on what the alpha and beta diversity for your site(s) are.
> ***Answer 3b***: The fish assemblage at site 1 is more similiar to site 2 because a lower Whittaker's species turnover value corresponds to species that are more similiar to one another. Site 1 and site 2 had a value of 0.5 and site 1 and site 10 had a value of 0.714. ***Answer 3c***: If you subtracted gamma and alpha as opposed to dividing them, it would not provide as accurate information. Subtracting alpha diversity from gamma diversity would just subtract the species richness from the regional diversity. The ultimate goal of beta diversity is to determine differences between sites and subtracting alpha diversity would not allow you to infer anything about how sites differ from one another.

The Resemblance Matrix

In order to quantify β-diversity for more than two samples, we need to introduce a new primary ecological data structure: the **Resemblance Matrix**.

Question 4: How do incidence- and abundance-based metrics differ in their treatment of rare species?

Answer 4: Incidence-based metrics treat rare species the same as common species. The goal of incidence-based metrics is to determine if a species is present or absent in the community. It does not take into account how many individuals of that species are present or what species it is. On the other hand, abundance-based metrics examine how many individuals of a species are present. Therefore, a species with more individuals present will be seen differently, and in a greater context, than a species with only a few individuals present. If there is a rare species present in large numbers, it will be treated differently than a common species with only a few individuals.

In the R code chunk below, do the following:

1. make a new object, `fish`, containing the fish abundance data for the Doubs River,
2. remove any sites where no fish were observed (i.e., rows with sum of zero),
3. construct a resemblance matrix based on Sørensen's Similarity ("fish.ds"), and
4. construct a resemblance matrix based on Bray-Curtis Distance ("fish.db").

```
fish <- doubs$fish
fish <- fish[-8,]

fish.dj <- vegdist(fish, method = "jaccard", binary = TRUE)

fish.db <- vegdist(fish, method = "bray")

fish.ds <- vegdist(fish, method = "bray", binary = TRUE)

fish.ds
```

```
##             1          2          3          4          5          6          7
## 2  0.50000000
## 3  0.60000000 0.14285714
## 4  0.77777778 0.45454545 0.33333333
## 5  0.83333333 0.57142857 0.46666667 0.15789474
## 6  0.81818182 0.53846154 0.42857143 0.11111111 0.04761905
## 7  0.66666667 0.25000000 0.33333333 0.38461538 0.37500000 0.33333333
## 9  1.00000000 0.50000000 0.55555556 0.38461538 0.37500000 0.33333333 0.40000000
## 10 0.71428571 0.33333333 0.40000000 0.28571429 0.29411765 0.25000000 0.09090909
## 11 0.71428571 0.33333333 0.40000000 0.42857143 0.52941176 0.50000000 0.27272727
## 12 0.71428571 0.33333333 0.40000000 0.42857143 0.52941176 0.50000000 0.27272727
## 13 0.71428571 0.33333333 0.40000000 0.57142857 0.64705882 0.62500000 0.45454545
## 14 0.81818182 0.53846154 0.42857143 0.33333333 0.42857143 0.40000000 0.46666667
## 15 0.83333333 0.57142857 0.60000000 0.36842105 0.36363636 0.33333333 0.37500000
## 16 0.88888889 0.70000000 0.61904762 0.36000000 0.28571429 0.25925926 0.54545455
## 17 0.91304348 0.76000000 0.69230769 0.46666667 0.39393939 0.37500000 0.62962963
## 18 0.91666667 0.76923077 0.70370370 0.48387097 0.41176471 0.39393939 0.64285714
## 19 1.00000000 0.84615385 0.77777778 0.54838710 0.41176471 0.45454545 0.71428571
## 20 1.00000000 0.84000000 0.76923077 0.53333333 0.39393939 0.43750000 0.70370370
## 21 1.00000000 0.84615385 0.77777778 0.54838710 0.41176471 0.45454545 0.71428571
## 22 1.00000000 0.92000000 0.84615385 0.60000000 0.45454545 0.50000000 0.77777778
## 23 1.00000000 1.00000000 1.00000000 0.81818182 0.71428571 0.69230769 0.75000000
## 24 1.00000000 1.00000000 1.00000000 0.75000000 0.68421053 0.66666667 0.84615385
## 25 1.00000000 1.00000000 0.83333333 0.62500000 0.36842105 0.44444444 0.69230769
## 26 1.00000000 0.91666667 0.84000000 0.58620690 0.43750000 0.48387097 0.76923077
## 27 1.00000000 0.92000000 0.84615385 0.60000000 0.45454545 0.50000000 0.77777778
## 28 1.00000000 0.92000000 0.84615385 0.60000000 0.45454545 0.50000000 0.77777778
## 29 0.92592593 0.79310345 0.73333333 0.52941176 0.40540541 0.44444444 0.67741935
## 30 1.00000000 1.00000000 0.92000000 0.65517241 0.50000000 0.54838710 0.84615385
```

```
##             9         10         11         12         13         14         15
## 2                                                                             
## 3                                                                             
## 4                                                                             
## 5                                                                             
## 6                                                                             
## 7                                                                             
## 9                                                                             
## 10 0.45454545                                                                 
## 11 0.45454545 0.33333333                                                      
## 12 0.45454545 0.33333333 0.00000000                                           
## 13 0.63636364 0.50000000 0.16666667 0.16666667                                
## 14 0.60000000 0.37500000 0.25000000 0.25000000 0.25000000                     
## 15 0.50000000 0.29411765 0.29411765 0.29411765 0.29411765 0.14285714          
## 16 0.54545455 0.47826087 0.56521739 0.56521739 0.56521739 0.33333333 0.28571429
## 17 0.62962963 0.57142857 0.57142857 0.57142857 0.57142857 0.37500000 0.33333333
## 18 0.64285714 0.58620690 0.58620690 0.58620690 0.58620690 0.39393939 0.35294118
## 19 0.64285714 0.65517241 0.79310345 0.79310345 0.79310345 0.57575758 0.52941176
## 20 0.62962963 0.64285714 0.78571429 0.78571429 0.85714286 0.62500000 0.57575758
## 21 0.64285714 0.65517241 0.79310345 0.79310345 0.86206897 0.63636364 0.58823529
## 22 0.70370370 0.71428571 0.85714286 0.85714286 0.92857143 0.68750000 0.63636364
## 23 0.50000000 0.77777778 0.77777778 0.77777778 1.00000000 0.84615385 0.85714286
## 24 0.69230769 0.71428571 0.85714286 0.85714286 1.00000000 0.77777778 0.78947368
## 25 0.69230769 0.57142857 0.85714286 0.85714286 1.00000000 0.66666667 0.68421053
## 26 0.69230769 0.70370370 0.85185185 0.85185185 0.92592593 0.67741935 0.62500000
## 27 0.70370370 0.71428571 0.85714286 0.85714286 0.92857143 0.68750000 0.63636364
## 28 0.70370370 0.71428571 0.85714286 0.85714286 0.92857143 0.68750000 0.63636364
## 29 0.67741935 0.62500000 0.68750000 0.68750000 0.68750000 0.50000000 0.45945946
## 30 0.76923077 0.77777778 0.92592593 0.92592593 1.00000000 0.74193548 0.68750000
##            16         17         18         19         20         21         22
## 2                                                                             
## 3                                                                             
## 4                                                                             
## 5                                                                             
## 6                                                                             
## 7                                                                             
## 9                                                                             
## 10                                                                            
## 11                                                                            
## 12                                                                            
## 13                                                                            
## 14                                                                            
## 15                                                                            
## 16                                                                            
## 17 0.12820513                                                                 
## 18 0.15000000 0.02222222                                                      
## 19 0.25000000 0.15555556 0.13043478                                           
## 20 0.28205128 0.18181818 0.15555556 0.02222222                                
## 21 0.30000000 0.20000000 0.17391304 0.04347826 0.02222222                     
## 22 0.33333333 0.22727273 0.20000000 0.06666667 0.04545455 0.02222222          
## 23 0.80000000 0.76000000 0.76923077 0.76923077 0.76000000 0.76923077 0.76000000
## 24 0.68000000 0.60000000 0.54838710 0.48387097 0.46666667 0.48387097 0.46666667
## 25 0.60000000 0.60000000 0.54838710 0.48387097 0.46666667 0.48387097 0.46666667
## 26 0.36842105 0.25581395 0.22727273 0.09090909 0.06976744 0.04545455 0.02325581
```

```
## 27 0.33333333 0.22727273 0.20000000 0.06666667 0.04545455 0.02222222 0.00000000
## 28 0.33333333 0.22727273 0.20000000 0.06666667 0.04545455 0.02222222 0.00000000
## 29 0.25581395 0.12500000 0.10204082 0.06122449 0.08333333 0.06122449 0.08333333
## 30 0.36842105 0.25581395 0.22727273 0.09090909 0.06976744 0.04545455 0.02325581
##            23         24         25         26         27         28         29
## 2
## 3
## 4
## 5
## 6
## 7
## 9
## 10
## 11
## 12
## 13
## 14
## 15
## 16
## 17
## 18
## 19
## 20
## 21
## 22
## 23
## 24 0.45454545
## 25 0.45454545 0.37500000
## 26 0.75000000 0.44827586 0.44827586
## 27 0.76000000 0.46666667 0.46666667 0.02325581
## 28 0.76000000 0.46666667 0.46666667 0.02325581 0.00000000
## 29 0.79310345 0.52941176 0.52941176 0.10638298 0.08333333 0.08333333
## 30 0.75000000 0.44827586 0.44827586 0.04761905 0.02325581 0.02325581 0.10638298
```

```
fish.db
```

```
##             1          2          3          4          5          6          7
## 2  0.60000000
## 3  0.68421053 0.14285714
## 4  0.75000000 0.33333333 0.18918919
## 5  0.89189189 0.69565217 0.68000000 0.49090909
## 6  0.75000000 0.39393939 0.29729730 0.19047619 0.41818182
## 7  0.68421053 0.14285714 0.12500000 0.24324324 0.64000000 0.24324324
## 9  1.00000000 0.69230769 0.73333333 0.65714286 0.58333333 0.54285714 0.66666667
## 10 0.88235294 0.38461538 0.40000000 0.37142857 0.54166667 0.25714286 0.26666667
## 11 0.57142857 0.30434783 0.40740741 0.43750000 0.68888889 0.43750000 0.33333333
## 12 0.71428571 0.20000000 0.23529412 0.33333333 0.69230769 0.38461538 0.17647059
## 13 0.72727273 0.29032258 0.31428571 0.45000000 0.73584906 0.55000000 0.37142857
## 14 0.80645161 0.40000000 0.31818182 0.34693878 0.67741935 0.42857143 0.36363636
## 15 0.83333333 0.51111111 0.46938776 0.40740741 0.55223881 0.37037037 0.38775510
## 16 0.86046512 0.65384615 0.57142857 0.47540984 0.45945946 0.37704918 0.53571429
## 17 0.91489362 0.67857143 0.63333333 0.50769231 0.51282051 0.44615385 0.60000000
## 18 0.95555556 0.74074074 0.72413793 0.58730159 0.50000000 0.52380952 0.68965517
## 19 1.00000000 0.79310345 0.70967742 0.61194030 0.50000000 0.52238806 0.67741935
## 20 1.00000000 0.91176471 0.88888889 0.74025974 0.48888889 0.68831169 0.86111111
```

```
## 21 1.00000000 0.94594595 0.92307692 0.78313253 0.50000000 0.73493976 0.89743590
## 22 1.00000000 0.97619048 0.95454545 0.82795699 0.52830189 0.78494624 0.93181818
## 23 1.00000000 1.00000000 1.00000000 0.92000000 0.89473684 0.84000000 0.90000000
## 24 1.00000000 1.00000000 1.00000000 0.88888889 0.79591837 0.77777778 0.93548387
## 25 1.00000000 1.00000000 0.92592593 0.81250000 0.68888889 0.68750000 0.85185185
## 26 1.00000000 0.96363636 0.93220339 0.78125000 0.55844156 0.68750000 0.89830508
## 27 1.00000000 0.97333333 0.94936709 0.83333333 0.56701031 0.76190476 0.92405063
## 28 1.00000000 0.97560976 0.95348837 0.82417582 0.57692308 0.78021978 0.93023256
## 29 0.97777778 0.93939394 0.92233010 0.81481481 0.53719008 0.77777778 0.90291262
## 30 1.00000000 1.00000000 0.98095238 0.87272727 0.59349593 0.83636364 0.96190476
##             9         10         11         12         13         14         15
## 2
## 3
## 4
## 5
## 6
## 7
## 9
## 10 0.57142857
## 11 0.76000000 0.44000000
## 12 0.68750000 0.37500000 0.24137931
## 13 0.81818182 0.57575758 0.33333333 0.18918919
## 14 0.76190476 0.47619048 0.43589744 0.21739130 0.19148936
## 15 0.65957447 0.40425532 0.50000000 0.33333333 0.38461538 0.24590164
## 16 0.70370370 0.51851852 0.64705882 0.55172414 0.59322034 0.44117647 0.26027397
## 17 0.68965517 0.51724138 0.63636364 0.58064516 0.61904762 0.50000000 0.40259740
## 18 0.64285714 0.57142857 0.69811321 0.66666667 0.70491803 0.60000000 0.46666667
## 19 0.66666667 0.63333333 0.82456140 0.75000000 0.81538462 0.67567568 0.56962025
## 20 0.68571429 0.77142857 0.91044776 0.89189189 0.92000000 0.83333333 0.70786517
## 21 0.76315789 0.81578947 0.91780822 0.92500000 0.95061728 0.86666667 0.76842105
## 22 0.76744186 0.86046512 0.95180723 0.95555556 0.97802198 0.90000000 0.77142857
## 23 0.77777778 0.88888889 0.86666667 0.90909091 1.00000000 0.93750000 0.94594595
## 24 0.72413793 0.79310345 0.92307692 0.93939394 1.00000000 0.90697674 0.87500000
## 25 0.84000000 0.76000000 0.90909091 0.93103448 1.00000000 0.84615385 0.81818182
## 26 0.71929825 0.82456140 0.92592593 0.93442623 0.96774194 0.85915493 0.76315789
## 27 0.76623377 0.84415584 0.94594595 0.95061728 0.97560976 0.89010989 0.77083333
## 28 0.76190476 0.85714286 0.95061728 0.95454545 0.97752809 0.89795918 0.78640777
## 29 0.78217822 0.84158416 0.89795918 0.90476190 0.90566038 0.84347826 0.73333333
## 30 0.84466019 0.90291262 0.98000000 0.98130841 1.00000000 0.93162393 0.81967213
##            16         17         18         19         20         21         22
## 2
## 3
## 4
## 5
## 6
## 7
## 9
## 10
## 11
## 12
## 13
## 14
## 15
## 16
```

```
## 17 0.26190476
## 18 0.34146341 0.13953488
## 19 0.39534884 0.31111111 0.25000000
## 20 0.58333333 0.42000000 0.32653061 0.23529412
## 21 0.62745098 0.49056604 0.40384615 0.29629630 0.10169492
## 22 0.66071429 0.55172414 0.47368421 0.38983051 0.18750000 0.10447761
## 23 0.90909091 0.83333333 0.82608696 0.84000000 0.86666667 0.87878788 0.89473684
## 24 0.81818182 0.69491525 0.64912281 0.63934426 0.57746479 0.61038961 0.65517241
## 25 0.76470588 0.74545455 0.66037736 0.61403509 0.67164179 0.69863014 0.73493976
## 26 0.63855422 0.54022989 0.45882353 0.32584270 0.21212121 0.20000000 0.25217391
## 27 0.66990291 0.57009346 0.48571429 0.37614679 0.19327731 0.13600000 0.12592593
## 28 0.69090909 0.57894737 0.50000000 0.41379310 0.22222222 0.16666667 0.12676056
## 29 0.65354331 0.51145038 0.44186047 0.41353383 0.24475524 0.18120805 0.11949686
## 30 0.72093023 0.57894737 0.52671756 0.48148148 0.29655172 0.23178808 0.18012422
##            23         24         25         26         27         28         29
## 2
## 3
## 4
## 5
## 6
## 7
## 9
## 10
## 11
## 12
## 13
## 14
## 15
## 16
## 17
## 18
## 19
## 20
## 21
## 22
## 23
## 24 0.57894737
## 25 0.46666667 0.46153846
## 26 0.82978723 0.48275862 0.59259259
## 27 0.88059701 0.61538462 0.70270270 0.18867925
## 28 0.89189189 0.64705882 0.72839506 0.23893805 0.09774436
## 29 0.91208791 0.70588235 0.77551020 0.33846154 0.18666667 0.14649682
## 30 0.91397849 0.71153846 0.78000000 0.36363636 0.19736842 0.15723270 0.14772727
```

```r
fish.db <- vegdist(fish, method = "bray", upper = TRUE, diag = TRUE)
```

Question 5: Using the distance matrices from above, answer the following questions:

a. Does the resemblance matrix (`fish.db`) represent similarity or dissimilarity? What information in the resemblance matrix led you to arrive at your answer?
b. Compare the resemblance matrices (`fish.db` or `fish.ds`) you just created. How does the choice of the Sørensen or Bray-Curtis distance influence your interpretation of site (dis)similarity?

> ***Answer 5a***: The resemblance matrix `fish.db` represents dissimilarity and this is known since the matrix was created using the Bray-Curtis index. This index is used specifically to measure dissimilarity. ***Answer 5b***: When looking at the matrices, it is important to know what exactly

both are measuring to properly interpret it. The Sorensen matrix is determining if the sites you are comparing have the same species present. Therefore when looking at the matrix, if two sites have a score close to 1, then they share a lot of species. On the other hand, the Bray-Curtis matrix is also taking abundance into account along with richness. Meaning that two sites with similiar species richness and even abundance will have a score closer to 1. Based on the questions you are asking, it is acceptable to use one or the other, but it is important to know what exactly you are inferring. If you are looking at two sites that have a high Sorensen index but a low Bray-Curtis index, then that means that species richness is high but the abundance is not evenly distributed.

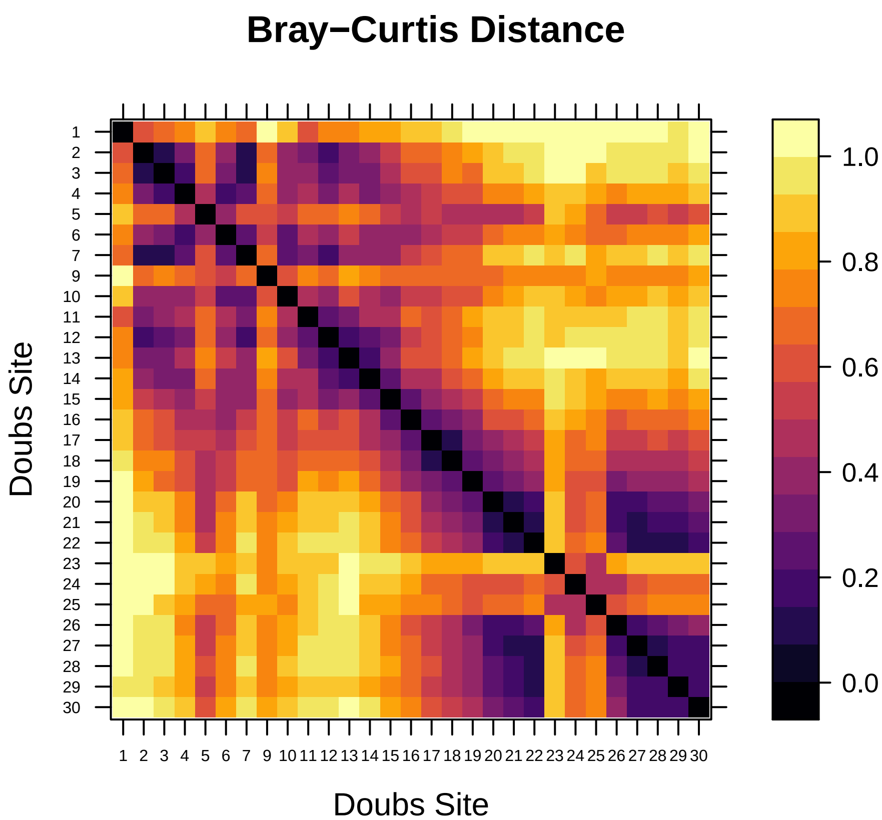
4) VISUALIZING BETA-DIVERSITY

A. Heatmaps

In the R code chunk below, do the following:

1. define a color palette,
2. define the order of sites in the Doubs River, and
3. use the `levelplot()` function to create a heatmap of fish abundances in the Doubs River.

```
order <- rev(attr(fish.db, "Labels"))

levelplot(as.matrix(fish.db)[, order], aspect = "iso", col.regions = inferno,
          xlab = "Doubs Site", ylab = "Doubs Site", scales = list(cex = 0.5),
          main = "Bray-Curtis Distance")
```



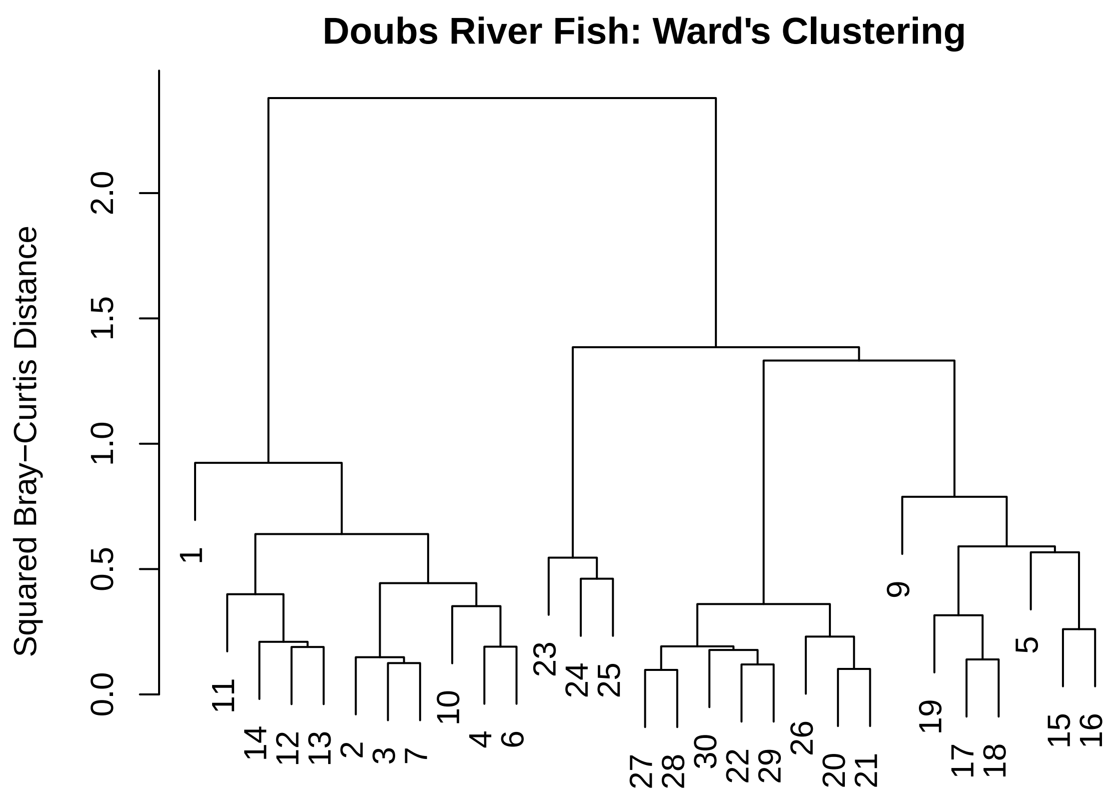
B. Cluster Analysis

In the R code chunk below, do the following:

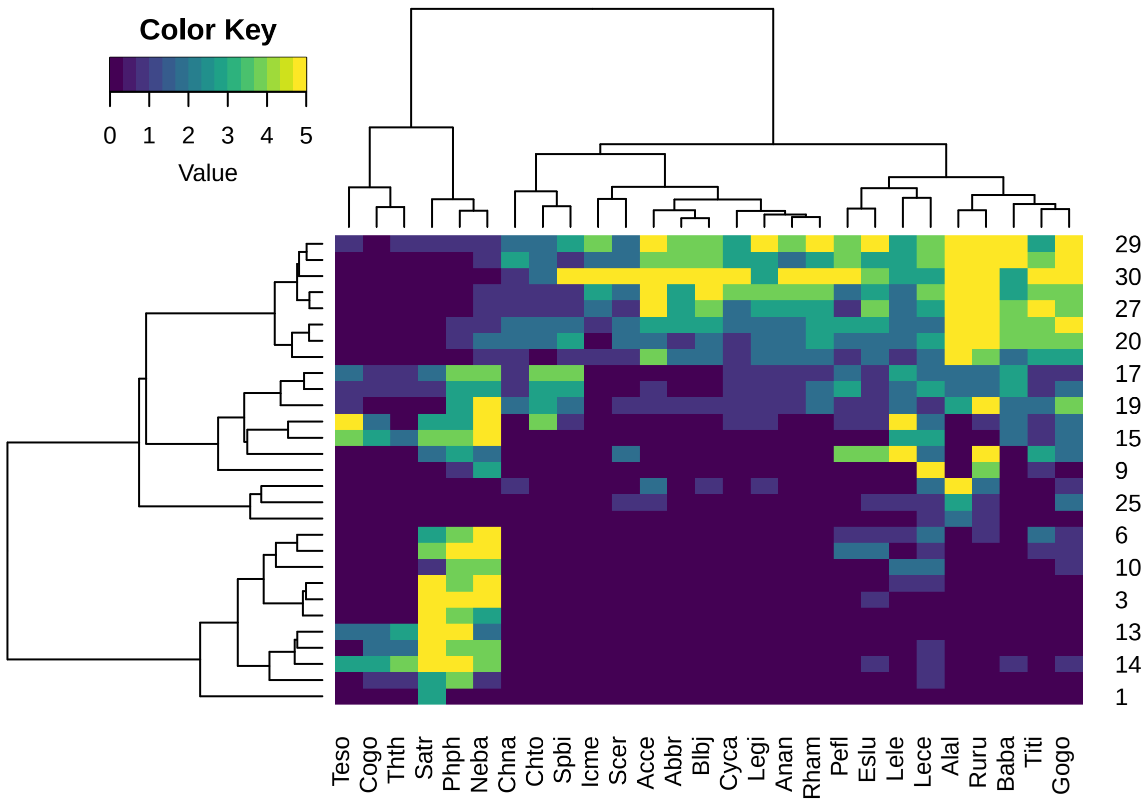
1. perform a cluster analysis using Ward's Clustering, and

2. plot your cluster analysis (use either `hclust` or `heatmap.2`).

```r
fish.ward <- hclust(fish.db, method = "ward.D2")

par(mar = c(1, 5, 2, 2) + 0.1)
plot(fish.ward, main = "Doubs River Fish: Ward's Clustering",
     ylab = "Squared Bray-Curtis Distance")
```




```r
gplots::heatmap.2(as.matrix(fish),
                  distfun = function(x) vegdist(x, method = "bray"),
                  hclustfun = function(x) hclust(x, method = "ward.D2"),
                  col = viridis, trace = "none", density.info = "none")
```



Question 6: Based on cluster analyses and the introductory plots that we generated after loading the data, develop an ecological hypothesis for fish diversity the `doubs` data set?

> ***Answer 6***: Fish diversity is relatively high within the `doubs` data set and species are more similiar to one another in neighboring sites and become more dissimiliar as site distance increases.

C. Ordination

Principal Coordinates Analysis (PCoA)

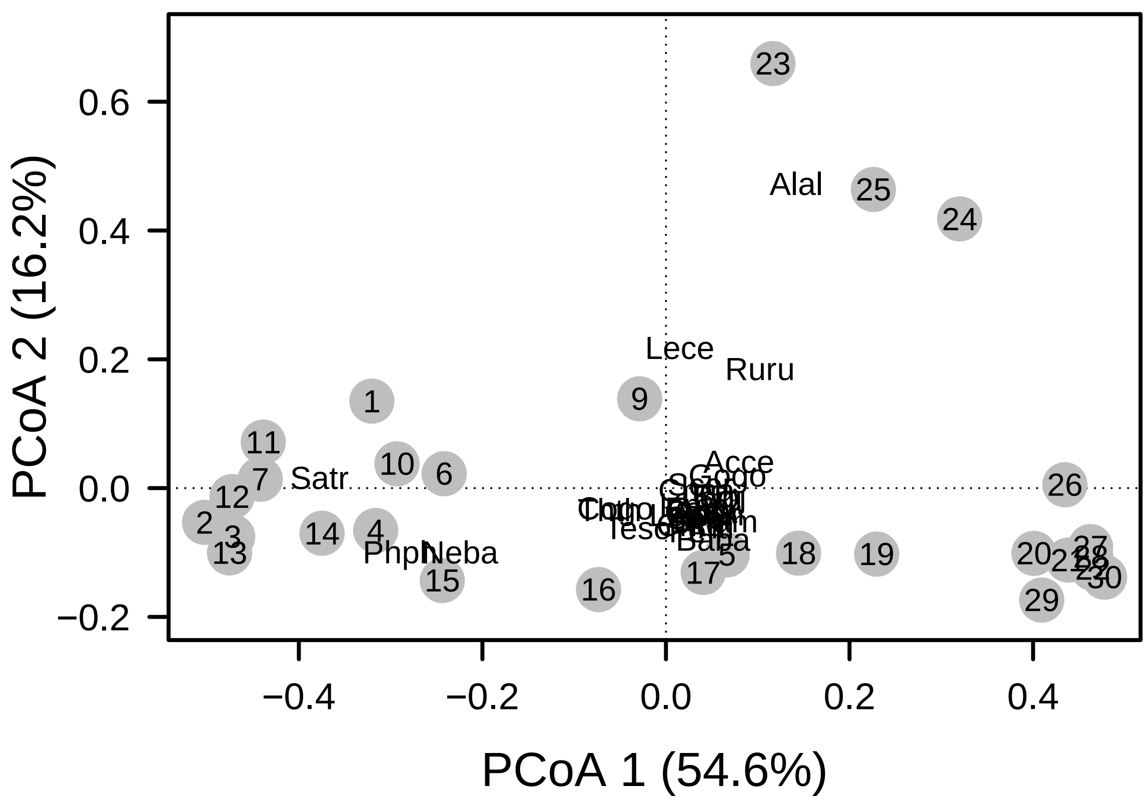
In the R code chunk below, do the following:

1. perform a Principal Coordinates Analysis to visualize beta-diversity
2. calculate the variation explained by the first three axes in your ordination
3. plot the PCoA ordination,
4. label the sites as points using the Doubs River site number, and
5. identify influential species and add species coordinates to PCoA plot.

```r
fish.pcoa <- cmdscale(fish.db, eig = TRUE, k = 3)

explainvar1 <- round(fish.pcoa$eig[1] / sum(fish.pcoa$eig), 3) * 100
explainvar2 <- round(fish.pcoa$eig[2] / sum(fish.pcoa$eig), 3) * 100
explainvar3 <- round(fish.pcoa$eig[3] / sum(fish.pcoa$eig), 3) * 100
sum.eig <- sum(explainvar1, explainvar2, explainvar3)

par(mar = c(5,5,1,2) + 0.1)

plot(fish.pcoa$points[ ,1], fish.pcoa$points[ ,2], ylim = c(-0.2, 0.7),
     xlab = paste("PCoA 1 (", explainvar1, "%)", sep = ""),
     ylab = paste("PCoA 2 (", explainvar2, "%)", sep = ""),
     pch = 16, cex = 2.0, type = "n", cex.lab = 1.5,
```

```r
     cex.axis = 1.2, axes = FALSE)

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(fish.pcoa$points[ ,1], fish.pcoa$points[ ,2],
       pch = 19, cex = 3, bg = "gray", col = "gray")
text(fish.pcoa$points[ ,1], fish.pcoa$points[ ,2],
     labels = row.names(fish.pcoa$points))

fishREL <- fish
  for(i in 1:nrow(fish)){
    fishREL[i, ] = fish[i, ] / sum(fish[i, ])
  }

library(vegan)

`add.spec.scores.class` <-
  function(ordi,comm,method="cor.scores",multi=1,Rscale=F,scaling="1") {
    ordiscores <- scores(ordi,display="sites")
    n <- ncol(comm)
    p <- ncol(ordiscores)
    specscores <- array(NA,dim=c(n,p))
    rownames(specscores) <- colnames(comm)
    colnames(specscores) <- colnames(ordiscores)
    if (method == "cor.scores") {
      for (i in 1:n) {
        for (j in 1:p) {specscores[i,j] <- cor(comm[,i],ordiscores[,j],method="pearson")}
      }
    }
    if (method == "wa.scores") {specscores <- wascores(ordiscores,comm)}
    if (method == "pcoa.scores") {
      rownames(ordiscores) <- rownames(comm)
      eigenv <- ordi$eig
      accounted <- sum(eigenv)
      tot <- 2*(accounted/ordi$GOF[2])-(accounted/ordi$GOF[1])
      eigen.var <- eigenv/(nrow(comm)-1)
      neg <- length(eigenv[eigenv<0])
      pos <- length(eigenv[eigenv>0])
      tot <- tot/(nrow(comm)-1)
      eigen.percen <- 100*eigen.var/tot
      eigen.cumpercen <- cumsum(eigen.percen)
      constant <- ((nrow(comm)-1)*tot)^0.25
      ordiscores <- ordiscores * (nrow(comm)-1)^-0.5 * tot^-0.5 * constant
      p1 <- min(p, pos)
      for (i in 1:n) {
        for (j in 1:p1) {
          specscores[i,j] <- cor(comm[,i],ordiscores[,j])*sd(comm[,i])/sd(ordiscores[,j])
          if(is.na(specscores[i,j])) {specscores[i,j]<-0}
        }
      }
```

```
      if (Rscale==T && scaling=="2") {
        percen <- eigen.var/tot
        percen <- percen^0.5
        ordiscores <- sweep(ordiscores,2,percen,"/")
        specscores <- sweep(specscores,2,percen,"*")
      }
      if (Rscale==F) {
        specscores <- specscores / constant
        ordiscores <- ordi$points
      }
      ordi$points <- ordiscores
      ordi$eig <- eigen.var
      ordi$eig.percen <- eigen.percen
      ordi$eig.cumpercen <- eigen.cumpercen
      ordi$eigen.total <- tot
      ordi$R.constant <- constant
      ordi$Rscale <- Rscale
      ordi$scaling <- scaling
    }
    specscores <- specscores * multi
    ordi$cproj <- specscores
    return(ordi)
  }

fish.pcoa <- add.spec.scores.class(fish.pcoa,fishREL,method = "pcoa.scores")
text(fish.pcoa$cproj[ ,1], fish.pcoa$cproj[, 2],
     labels = row.names(fish.pcoa$cproj), col = "black")
```



In the R code chunk below, do the following:

1. identify influential species based on correlations along each PCoA axis (use a cutoff of 0.70), and
2. use a permutation test (999 permutations) to test the correlations of each species along each axis.

```
spe.corr <- add.spec.scores.class(fish.pcoa, fishREL, method = "cor.scores")$cproj
corrcut <- 0.7
imp.spp <- spe.corr[abs(spe.corr[, 1]) >= corrcut | abs(spe.corr[, 2]) >= corrcut, ]

fit <- envfit(fish.pcoa, fishREL, perm = 999)
```

Question 7: Address the following questions about the ordination results of the `doubs` data set:

a. Describe the grouping of sites in the Doubs River based on fish community composition.
b. Generate a hypothesis about which fish species are potential indicators of river quality.

> ***Answer 7a***: Based on the ordination plot, sites 2, 3, 7,11, 12, and 13 share very similiar abundances and fish communities. Sites 1, 4, 6, 10, 14, and 15 are all also graphed close to those sites as well. These sites likely have similiar fish composiitons that vary slightly from the first grouping listed. Following these two groupings, there is a gap in the plot, which signifies a increase in variance between the sites. The next grouping is sites 5, 16, 17, 18, and 19; with 9 being a slight outlier of that group. I find this interesting that site 5 has a more similiar fish community than sites 1-4, 6, and 7. Sites 23, 24, and 25 appear to be outliers of the entire graph, and although being somewhat close in proximity to one another, they are far away from other sites. This likely means that there is high variance between their fish communities and the fish communities of the other sites. Lastly, the most tight grouping consists of sites 8, 20, 21, 22, 26, 27, 29, and 30. These groups overlap signifcantly on the graph, meaning they likely have an extremely small amount of variance between each other and have very similiar fish communities. Additionally, with them being located on the far bottom right corner of the plot, their fish communities appear to vary significantly compared to the first two groupings listed earlier that appear on the far bottom left of the plot. ***Answer 7b***: Given their strong negative values in Dim 1, Phph and Neba appear to be strong indicator species of low quality river conditions. In contrast, Rham, Legi, Cyca, Abbr, Acce, Blbj, and Anan have strong positive values in Dim 1, which suggests they are good indicator species that river qulity conditions are high.

SYNTHESIS

Load the dataset from that you and your partner are using for the team project. Use one of the tools introduced in the beta diversity module to visualize your data. Describe any interesting patterns and identify a hypothesis is relevant to the principles of biodiversity.

```
fish_data <- read.csv("/cloud/project/QB2025_Brown/Fish_Dataset.csv")

fish_data$Latitude <- cut(fish_data$Latitude, breaks=c(20, 25, 30, 35, 40, 45, 50),
                          labels=c("20-25", "25-30", "30-35", "35-40", "40-45", "45-50"),
                          include.lowest=TRUE)

Fish_lat <- cbind(fish_data[ ,2] ,fish_data[ ,23:658])
Fish_lat <- data.frame(Latitude = fish_data$Latitude, Fish_lat)

result <- aggregate(. ~ Latitude, data=Fish_lat, sum, na.rm = TRUE)

print(result)
```

```
##   Latitude fish_data...2. Acantharchus.pomotis Acanthogobius.flavimanus
## 1    25-30             96                    0                        0
## 2    30-35           1413                   20                        0
```

```
## 3   35-40          3612                  6                       9
## 4   40-45          4975                  0                       0
## 5   45-50          2016                  0                       0
##   Acipenser.brevirostrum Acipenser.fulvescens Acrocheilus.alutaceus
## 1                      0                    0                     0
## 2                      0                    0                     0
## 3                      0                    0                     0
## 4                      1                    0                    45
## 5                      0                    2                    51
##   Agosia.chrysogaster Alosa.aestivalis Alosa.alabamae Alosa.chrysochloris
## 1                   0                0              2                   5
## 2                 616              136              0                  47
## 3                   0              622              0                 198
## 4                   0              323              0                   3
## 5                   0                0              0                   6
##   Alosa.mediocris Alosa.pseudoharengus Alosa.sapidissima Ambloplites.ariommus
## 1               0                    0                 0                    0
## 2               6                  140               138                   77
## 3               5                  116                51                   61
## 4               0                 1661              1640                    0
## 5               0                    2                 0                    0
##   Ambloplites.cavifrons Ambloplites.constellatus Ambloplites.rupestris
## 1                     0                        0                     0
## 2                     0                        0                   147
## 3                    23                      207                  5623
## 4                     0                        0                  6579
## 5                     0                        0                   723
##   Ameiurus.brunneus Ameiurus.catus Ameiurus.melas Ameiurus.natalis
## 1                 0              4              1               37
## 2               570             16            362             1053
## 3               262            220            215             1175
## 4                 0             52           1577             1048
## 5                 0              0            749               60
##   Ameiurus.nebulosus Ameiurus.platycephalus Ameiurus.serracanthus Amia.calva
## 1                  5                      0                     0        132
## 2                  8                     50                     4        314
## 3                 85                     62                     0         96
## 4                977                      0                     0        126
## 5                 30                      0                     0         17
##   Ammocrypta.beanii Ammocrypta.clara Ammocrypta.pellucida Ammocrypta.vivax
## 1                 0                0                    0                0
## 2                45                0                    0               13
## 3                 0                0                    4                1
## 4                 0                6                    1                0
## 5                 0               18                    0                0
##   Anchoa.mitchilli Anguilla.rostrata Aphredoderus.sayanus Aplodinotus.grunniens
## 1              575                10                   13                    60
## 2              314               460                  977                   942
## 3               53              1601                  570                  2831
## 4               73              4569                   25                  1972
## 5                0                35                    0                   150
##   Archoplites.interruptus Archosargus.probatocephalus Ascaphus.truei
## 1                       0                           2              0
## 2                       0                           0              0
```

```
## 3                     0                            0              0
## 4                     0                            0              0
## 5                     0                            0              0
##   Astyanax.mexicanus Atractosteus.spatula Awaous.banana Brevoortia.patronus
## 1                108                    5             0                1127
## 2                  2                  138             0                 420
## 3                  0                   13             0                   0
## 4                  0                    0             0                   0
## 5                  0                    0             0                   0
##   Brevoortia.tyrannus Campostoma.anomalum Campostoma.oligolepis
## 1                   0                 214                     0
## 2                   0                4516                  6921
## 3                   3               27654                  6962
## 4                   2               11407                    36
## 5                   0                 837                    10
##   Campostoma.pauciradii Carassius.auratus Carpiodes.carpio Carpiodes.cyprinus
## 1                     0                 0                0                  1
## 2                   398               105             1113                153
## 3                     0               114             1672                184
## 4                     0                61             3204                512
## 5                     0                 1              224                 10
##   Carpiodes.velifer Catostomus.ardens Catostomus.catostomus Catostomus.clarkii
## 1                 0                 0                     0                  0
## 2               164                 0                     0                 29
## 3                25                39                   186                 51
## 4               140               251                   403                  0
## 5                 3                 0                   556                  0
##   Catostomus.columbianus Catostomus.commersonii Catostomus.discobolus
## 1                      0                      0                     0
## 2                      0                    264                    24
## 3                      0                   4889                   425
## 4                     36                  25840                     9
## 5                    130                   6652                     0
##   Catostomus.insignis Catostomus.latipinnis Catostomus.macrocheilus
## 1                   0                     0                       0
## 2                  49                     0                       0
## 3                   0                   755                       0
## 4                   0                    21                     209
## 5                   0                     0                     387
##   Catostomus.occidentalis Catostomus.platyrhynchus Catostomus.plebeius
## 1                       0                        0                   0
## 2                       0                        0                   0
## 3                     419                      656                  25
## 4                     185                     1217                   0
## 5                       0                      347                   0
##   Catostomus.rimiculus Catostomus.santaanae Catostomus.snyderi
## 1                    0                    0                  0
## 2                    0                    0                  0
## 3                    0                    0                  0
## 4                   52                    0                 23
## 5                    0                    0                  0
##   Catostomus.tahoensis Centrarchus.macropterus Centropomus.parallelus
## 1                    0                       2                      0
## 2                    0                     273                      0
```

```
## 3                  16                    73                      0
## 4                   0                     0                      0
## 5                   0                     0                      0
##   Centropomus.undecimalis Chaenobryttus.gulosus Channa.argus
## 1                       4                    26            0
## 2                       0                   243            0
## 3                       0                   129            1
## 4                       0                     2            0
## 5                       0                     0            0
##   Chologaster.cornuta Chrosomus.cumberlandensis Chrosomus.eos
## 1                   0                         0             0
## 2                  15                         0             0
## 3                   3                         0             0
## 4                   0                         0           246
## 5                   0                         0           435
##   Chrosomus.erythrogaster Chrosomus.neogaeus Chrosomus.oreas
## 1                       0                  0               0
## 2                       0                  0               0
## 3                     917                  0             443
## 4                     192                  1               0
## 5                       9                  7               0
##   Chrosomus.tennesseensis Cichlasoma.cyanoguttatum Cichlasoma.urophthalmus
## 1                       0                      204                       7
## 2                       0                       35                       0
## 3                      84                        0                       0
## 4                       0                        0                       0
## 5                       0                        0                       0
##   Citharichthys.spilopterus Clarias.batrachus Clinostomus.elongatus
## 1                         2                28                     0
## 2                         5                 0                     0
## 3                         0                 0                   106
## 4                         0                 0                   251
## 5                         0                 0                     0
##   Clinostomus.funduloides Conger.conger Coregonus.clupeaformis Cottus.aleuticus
## 1                       0             0                      0                0
## 2                      11             0                      0                0
## 3                    2695             0                      0                0
## 4                       0             0                      0               44
## 5                       0             0                      2             3175
##   Cottus.asper Cottus.bairdii Cottus.beldingii Cottus.caeruleomentum
## 1            0              0                0                     0
## 2            0            224                0                     0
## 3          539           5432               66                  1337
## 4          108           5608             1476                     0
## 5          645           1824               73                     0
##   Cottus.carolinae Cottus.chattahoochee Cottus.cognatus Cottus.confusus
## 1                0                    0               0               0
## 2              752                    1               0               0
## 3             4550                    0               0               0
## 4                1                    0            1609              73
## 5                0                    0             143            1581
##   Cottus.girardi Cottus.gulosus Cottus.hubbsi Cottus.hypselurus Cottus.kanawhae
## 1              0              0             0                 0               0
## 2              0              0             0                 0               0
```

```
## 3           191           198             0                396               68
## 4             0           395             0                  0                0
## 5             0           174             0                  0                0
##   Cottus.klamathensis Cottus.leiopomus Cottus.perplexus Cottus.rhotheus
## 1                   0                0                0               0
## 2                   0                0                0               0
## 3                   0                0                0               0
## 4                  21                0             1790             572
## 5                   0                0             7796            2988
##   Cottus.tenuis Couesius.plumbeus Crystallaria.asprella Ctenogobius.shufeldti
## 1             0                 0                     0                     1
## 2             0                 0                    41                     8
## 3             0                 0                     0                     0
## 4             1                 2                     0                     0
## 5             0               461                     0                     0
##   Ctenopharyngodon.idella Culaea.inconstans Cycleptus.elongatus
## 1                       2                 0                   0
## 2                      62                 0                  35
## 3                      33                 2                  24
## 4                      47              3223                  75
## 5                       0              1412                   4
##   Cycleptus.meridionalis Cyprinella.analostana Cyprinella.callisema
## 1                      0                     0                    0
## 2                      1                   160                  187
## 3                      0                  1332                    0
## 4                      0                   700                    0
## 5                      0                     0                    0
##   Cyprinella.callistia Cyprinella.camura Cyprinella.chloristia
## 1                    0                 0                     0
## 2                  130                71                   234
## 3                    0               174                   179
## 4                    0                 0                     0
## 5                    0                 0                     0
##   Cyprinella.formosa Cyprinella.galactura Cyprinella.gibbsi Cyprinella.leedsi
## 1                  0                    0                 0                 2
## 2                  0                   68                 0               521
## 3                  0                 3416                 0                 0
## 4                  0                    0                 0                 0
## 5                  0                    0                 0                 0
##   Cyprinella.lepida Cyprinella.lutrensis Cyprinella.nivea
## 1                 5                  941                0
## 2                 1                16061             1767
## 3                 0                24936               40
## 4                 0                10189                0
## 5                 0                   34                0
##   Cyprinella.pyrrhomelas Cyprinella.spiloptera Cyprinella.trichroistia
## 1                      0                     0                       0
## 2                     69                   313                     407
## 3                      1                  7581                       0
## 4                      0                 16334                       0
## 5                      0                  2364                       0
##   Cyprinella.venusta Cyprinella.whipplei Cyprinella.xaenura
## 1                669                   0                  0
## 2               9828                 550                 42
```

```
## 3              813                 455                 0
## 4                0                  23                 0
## 5                0                   0                 0
##   Cyprinodon.rubrofluviatilis Cyprinodon.variegatus Cyprinus.carpio
## 1                           0                    71              65
## 2                        2671                   178             798
## 3                        1672                     0            2999
## 4                           0                     0            5718
## 5                           0                     0            1791
##   Dicamptodon.tenebrosus Dionda.nigrotaeniata Dionda.serena
## 1                      0                    0            19
## 2                      0                   43             0
## 3                      0                    0             0
## 4                      0                    0             0
## 5                      0                    0             0
##   Dormitator.maculatus Dorosoma.cepedianum Dorosoma.petenense
## 1                    1                 655                791
## 2                    0                8636              15304
## 3                    0               14290               2116
## 4                    0                6728                  6
## 5                    0                 771                  0
##   Elassoma.evergladei Elassoma.zonatum Elops.saurus Elotris.amblyopsis
## 1                   0                9          153                  0
## 2                   0              117            6                  1
## 3                   0                3            0                  0
## 4                   0                0            0                  0
## 5                   0                0            0                  0
##   Enneacanthus.chaetodon Enneacanthus.gloriosus Enneacanthus.obesus
## 1                      0                      0                   0
## 2                      0                     31                   4
## 3                      0                    230                   3
## 4                      0                      1                   3
## 5                      0                      0                   0
##   Entosphenus.lethophagus Entosphenus.tridentatus Erimonax.monachus
## 1                       0                       0                 0
## 2                       0                       0                 0
## 3                       0                       0                16
## 4                       6                      61                 0
## 5                       0                       1                 0
##   Erimystax.dissimilis Erimystax.harryi Erimystax.insignis
## 1                    0                0                  0
## 2                    1                0                  9
## 3                  212               21                146
## 4                  283                0                  0
## 5                    0                0                  0
##   Erimystax.x.punctatus Erimyzon.oblongus Erimyzon.sucetta Erimyzon.tenuis
## 1                     0                 0               15               0
## 2                     0               336               39               4
## 3                   230               616                9               0
## 4                    44               129               17               0
## 5                     0                 0                0               0
##   Esox.americanus Esox.americanus.americanus Esox.americanus.vermiculatus
## 1               0                          0                            0
## 2             321                         73                            0
```

```
## 3             59                          114                          24
## 4            571                           62                          24
## 5              0                            0                           0
##   Esox.lucius Esox.masquinongy Esox.niger Etheostoma.acuticeps
## 1           0                0          9                    0
## 2           0                0        148                    0
## 3          14                9        101                   34
## 4         396               37        781                    0
## 5         359               30         18                    0
##   Etheostoma.aquali Etheostoma.artesiae Etheostoma.asprigene
## 1                 0                   0                    0
## 2                 0                  59                    4
## 3                29                  22                   12
## 4                 0                   0                   29
## 5                 0                   0                    0
##   Etheostoma.autumnale Etheostoma.baileyi Etheostoma.barrenense
## 1                    0                  0                     0
## 2                    0                  0                     0
## 3                   39                  4                     7
## 4                    0                  0                     0
## 5                    0                  0                     0
##   Etheostoma.bellum Etheostoma.blennioides Etheostoma.blennius
## 1                 0                      0                   0
## 2                 0                     99                   0
## 3                47                   3805                 457
## 4                 0                   2804                   0
## 5                 0                      0                   0
##   Etheostoma.boschungi Etheostoma.caeruleum Etheostoma.camurum
## 1                    0                    0                  0
## 2                    1                  390                  0
## 3                    0                 6085                321
## 4                    0                 2672                 16
## 5                    0                  239                  0
##   Etheostoma.chlorobranchium Etheostoma.chlorosomum Etheostoma.chuckwachatte
## 1                          0                     10                        0
## 2                          0                     29                        0
## 3                        240                      6                        0
## 4                          0                      0                        0
## 5                          0                      0                        0
##   Etheostoma.cinereum Etheostoma.collettei Etheostoma.collis
## 1                   0                    0                 0
## 2                   0                   15                 8
## 3                   4                    0                10
## 4                   0                    0                 0
## 5                   0                    0                 0
##   Etheostoma.colorosum Etheostoma.coosae Etheostoma.cragini
## 1                    0                 0                  0
## 2                    6               129                  0
## 3                    0                 0                181
## 4                    0                 0                  0
## 5                    0                 0                  0
##   Etheostoma.crossopterum Etheostoma.derivativum Etheostoma.ditrema
## 1                       0                      0                  0
## 2                       1                      0                 31
```

```
## 3                     77                    1                0
## 4                      0                    0                0
## 5                      0                    0                0
##   Etheostoma.duryi Etheostoma.edwini Etheostoma.euzonum Etheostoma.exile
## 1                0                 0                  0                0
## 2              399                 8                  0                0
## 3              385                 0                 24                2
## 4                0                 0                  0              121
## 5                0                 0                  0              194
##   Etheostoma.flabellare Etheostoma.flavum Etheostoma.fragi Etheostoma.fricksium
## 1                     0                 0                0                    0
## 2                    23                 0                0                    0
## 3                  5754               609               11                    0
## 4                  2140                 0                0                    0
## 5                    60                 0                0                    0
##   Etheostoma.fusiforme Etheostoma.gracile Etheostoma.gutselli
## 1                    0                 18                   0
## 2                    4                133                   0
## 3                    1                 41                   1
## 4                    1                  0                   0
## 5                    0                  0                   0
##   Etheostoma.histrio Etheostoma.hopkinsi Etheostoma.inscriptum
## 1                  0                   0                     0
## 2                 31                 186                   273
## 3                 12                   0                     0
## 4                  0                   0                     0
## 5                  0                   0                     0
##   Etheostoma.jessiae Etheostoma.jordani Etheostoma.juliae
## 1                  0                  0                 0
## 2                 16                 76                 0
## 3                 65                  0                60
## 4                  0                  0                 0
## 5                  0                  0                 0
##   Etheostoma.kantuckeense Etheostoma.kennicotti Etheostoma.lachneri
## 1                       0                     0                   0
## 2                       0                    56                   5
## 3                       5                     0                   0
## 4                       0                     0                   0
## 5                       0                     0                   0
##   Etheostoma.lepidum Etheostoma.longimanum Etheostoma.luteovinctum
## 1                 27                     0                       0
## 2                 27                     0                       0
## 3                  0                    35                      63
## 4                  0                     0                       0
## 5                  0                     0                       0
##   Etheostoma.lynceum Etheostoma.maculatum Etheostoma.mariae Etheostoma.mihileze
## 1                  0                    0                 0                   0
## 2                 21                    0                 0                   0
## 3                  1                   27                 0                  27
## 4                  0                   10                 0                   0
## 5                  0                    0                 0                   0
##   Etheostoma.neopterum Etheostoma.nigripinne Etheostoma.nigrum
## 1                    0                     0                 0
## 2                    0                    48                12
```

```
## 3                    1                    77             2039
## 4                    0                     0             6833
## 5                    0                     0             1360
##   Etheostoma.occidentale Etheostoma.olmstedi Etheostoma.oophylax
## 1                      0                   0                   0
## 2                      0                 221                   0
## 3                      9                1983                  24
## 4                      0                4994                   0
## 5                      0                   0                   0
##   Etheostoma.osburni Etheostoma.parvipinne Etheostoma.podostemone
## 1                  0                     0                      0
## 2                  0                    27                      0
## 3                  1                     2                     21
## 4                  0                     0                      0
## 5                  0                     0                      0
##   Etheostoma.proeliare Etheostoma.punctulatum Etheostoma.radiosum
## 1                    0                      0                   0
## 2                   16                      0                 270
## 3                    0                     66                   0
## 4                    0                      0                   0
## 5                    0                      0                   0
##   Etheostoma.rafinesquei Etheostoma.ramseyi Etheostoma.rufilineatum
## 1                      0                  0                       0
## 2                      0                 68                     148
## 3                      7                  0                    7504
## 4                      0                  0                       0
## 5                      0                  0                       0
##   Etheostoma.rupestre Etheostoma.sanguifluum Etheostoma.scotti
## 1                   0                      0                 0
## 2                  34                      0               100
## 3                   0                     24                 0
## 4                   0                      0                 0
## 5                   0                      0                 0
##   Etheostoma.serrifer Etheostoma.simoterum Etheostoma.spectabile
## 1                   0                    0                     1
## 2                   4                  183                   358
## 3                   3                  745                  4531
## 4                   0                    0                   156
## 5                   0                    0                     0
##   Etheostoma.squamiceps Etheostoma.stigmaeum Etheostoma.swaini
## 1                     0                    0                 0
## 2                     0                  103               154
## 3                   140                   63                 6
## 4                     0                    0                 0
## 5                     0                    0                 0
##   Etheostoma.swannanoa Etheostoma.tallapoosae Etheostoma.tetrazonum
## 1                    0                      0                     0
## 2                    0                      0                     0
## 3                  158                      0                    67
## 4                    0                      0                     0
## 5                    0                      0                     0
##   Etheostoma.thalassinum Etheostoma.tippecanoe Etheostoma.variatum
## 1                      0                     0                   0
## 2                     56                     0                   0
```

```
## 3                    11                    35                 181
## 4                     0                     2                 135
## 5                     0                     0                   0
##   Etheostoma.virgatum Etheostoma.vitreum Etheostoma.vulneratum
## 1                   0                  0                     0
## 2                   0                  0                     0
## 3                  19                 80                    25
## 4                   0                  0                     0
## 5                   0                  0                     0
##   Etheostoma.whipplei Etheostoma.zonale Etheostoma.zonistium
## 1                   0                 0                    0
## 2                  68                 0                    0
## 3                  77              1585                    2
## 4                   0              1986                    0
## 5                   0                 3                    0
##   Eucinostomus.argenteus Exoglossum.laurae Exoglossum.maxillingua
## 1                      0                 0                      0
## 2                     14                 0                      0
## 3                      0                 4                    366
## 4                      0                15                   2828
## 5                      0                 0                      0
##   Forbesichthys.agassizii Fundulus.catenatus Fundulus.chrysotus
## 1                       0                  0                 18
## 2                       0                 31                  8
## 3                       1                824                  0
## 4                       0                  0                  0
## 5                       0                  0                  0
##   Fundulus.diaphanus Fundulus.dispar Fundulus.euryzonus Fundulus.grandis
## 1                  0               0                  0               42
## 2                  2               0                  0               84
## 3                605               0                  0                0
## 4               1196              33                  0                0
## 5                 25               0                  0                0
##   Fundulus.heteroclitus Fundulus.kansae Fundulus.lineolatus Fundulus.notatus
## 1                     0               0                   0               26
## 2                     4               0                   0              219
## 3                    22              36                  19              312
## 4                     6               0                   0              280
## 5                     0               0                   0                0
##   Fundulus.olivaceus Fundulus.rathbuni Fundulus.sciadicus Fundulus.seminolis
## 1                  0                 0                  0                128
## 2                623                 0                  0                  1
## 3                552                65                  7                  0
## 4                  0                 0                139                  0
## 5                  0                 0                  0                  0
##   Fundulus.stellifer Fundulus.stellifera Fundulus.zebrinus Gambusia.affinis
## 1                  0                   0                 0             2036
## 2                 34                  15               705             7148
## 3                  0                   0              1353             7250
## 4                  0                   0               497              310
## 5                  0                   0                 0               13
##   Gambusia.holbrooki Gasterosteus.aculeatus Gerres.cinereus Gila.atraria
## 1               1094                      0               0            0
## 2                385                      0               0            0
```

```
## 3               255                    200               0          188
## 4                47                     20               0            7
## 5                 0                    167               0            0
##   Gila.bicolor Gila.cypha Gila.elegans Gila.orcuttii Gila.pandora Gila.robusta
## 1            0          0            0             0            0            0
## 2            0          0            0             0          287            0
## 3            0          7            0             0           28          269
## 4           49          0            0             0            0            7
## 5            0          0            0             0            0            0
##   Gila.seminuda Gobioides.broussonnetii Gobiomorus.dormitor Gobiosoma.bosc
## 1             0                       1                  13              0
## 2             0                       0                   0             23
## 3             0                       0                   0              0
## 4             0                       0                   0              0
## 5             0                       0                   0              0
##   Hemitremia.flammea Herichthys.cyanoguttatum Hesperoleucus.symmetricus
## 1                  0                       25                         0
## 2                  2                        0                         0
## 3                 11                        0                      1108
## 4                  0                        0                       133
## 5                  0                        0                         0
##   Heterandria.formosa Hiodon.alosoides Hiodon.tergisus Hoplosternum.littorale
## 1                  30                0               0                      6
## 2                  71              253               0                      0
## 3                   0              148              53                      0
## 4                   0              156              63                      0
## 5                   0              419               5                      0
##   Hybognathus.amarus Hybognathus.argyritis Hybognathus.hankinsoni
## 1                  0                     0                      0
## 2                  6                     0                      0
## 3                  0                     0                     50
## 4                  0                   182                   1057
## 5                  0                    99                    442
##   Hybognathus.hayi Hybognathus.nuchalis Hybognathus.placitus Hybognathus.regius
## 1                0                    0                    0                  0
## 2                4                  998                  743               1001
## 3              130                 1047                 1582                714
## 4                0                  483                  324                 39
## 5                0                    0                    3                  0
##   Hybopsis.amblops Hybopsis.amnis Hybopsis.dorsalis Hybopsis.hypsinotus
## 1                0              0                 0                   0
## 2               87              3                 0                  46
## 3             2278             17               463                 162
## 4              282              0              5754                   0
## 5                0              0               841                   0
##   Hybopsis.lineapunctata Hybopsis.rubrifrons Hybopsis.winchelli Hybopsis.zanema
## 1                      0                   0                  0               0
## 2                      0                 325                197              45
## 3                      0                   4                  0               0
## 4                      0                   0                  0               0
## 5                      0                   0                  0               0
##   Hypentelium.etowanum Hypentelium.nigricans Hypentelium.roanokense
## 1                    0                     0                      0
## 2                  829                   381                      0
```

```
## 3                    0                   4948                       8
## 4                    0                   4960                       0
## 5                    0                    345                       0
##   Hypophthalmichthys.molitrix Hypophthalmichthys.nobilis Hypostomus.plecostomus
## 1                           3                          0                      2
## 2                          83                          0                      0
## 3                         454                          5                      0
## 4                          48                         14                      0
## 5                           0                          0                      0
##   Hysterocarpus.traskii Ichthyomyzon.bdellium Ichthyomyzon.castaneus
## 1                     0                     0                      0
## 2                     0                     0                      6
## 3                    83                    37                     24
## 4                     0                    26                     62
## 5                     0                     0                     27
##   Ichthyomyzon.fossor Ichthyomyzon.gagei Ichthyomyzon.greeleyi
## 1                   0                  0                     0
## 2                   0                180                     0
## 3                   1                  0                   128
## 4                   5                  0                     0
## 5                  11                  0                     0
##   Ichthyomyzon.unicuspis Ictalurus.furcatus Ictalurus.punctatus
## 1                      0                 18                 244
## 2                      0                455                1264
## 3                      4                176                3463
## 4                     12                  1                3578
## 5                     12                  0                 976
##   Ictiobus.bubalus Ictiobus.cyprinellus Ictiobus.niger Iotichthys.phlegethontis
## 1               68                    3              0                        0
## 2              867                  103             39                        0
## 3             1379                  207             88                        0
## 4              352                  157             28                        4
## 5               29                   24              0                        0
##   Labidesthes.sicculus Lampetra.aepyptera Lethenteron.appendix
## 1                   96                  0                    0
## 2                 1331                 12                    5
## 3                  627                 98                  185
## 4                  263                  2                  135
## 5                    3                  0                   25
##   Lampetra.richardsoni Lampetra.tridentata Lavinia.exilicauda
## 1                    0                   0                  0
## 2                    0                   0                  0
## 3                    0                   0                  2
## 4                    2                   0                  0
## 5                    9                  23                  0
##   Leiostomus.xanthurus Lepidomeda.copei Lepidomeda.mollispinis
## 1                    0                0                      0
## 2                    4                0                      0
## 3                    1              370                      0
## 4                    0                0                      0
## 5                    0                0                      0
##   Lepidomeda.vittata Lepisosteus.oculatus Lepisosteus.osseus
## 1                  0                  120                 78
## 2                  1                  758                778
```

```
## 3                   0                   115                  700
## 4                   0                    10                  148
## 5                   0                     0                    0
##   Lepisosteus.platostomus Lepisosteus.platyrhincus Lepomis.auritus
## 1                       1                      248             213
## 2                     147                       26            6312
## 3                     588                        0            9422
## 4                     258                        0            5270
## 5                       0                        0              10
##   Lepomis.cyanellus Lepomis.gibbosus Lepomis.gulosus Lepomis.humilis
## 1               400                0             279               4
## 2              5496               89             953            2106
## 3              9914              954             197            1777
## 4              6798             6044              16            1693
## 5              1034              151               0             165
##   Lepomis.macrochirus Lepomis.marginatus Lepomis.megalotis Lepomis.microlophus
## 1                1821                  0              1421                 714
## 2               14025                534             13583                1288
## 3               11990                 35             13841                 539
## 4               10269                  0              2114                  17
## 5                 726                  0                 0                  12
##   Lepomis.miniatus Lepomis.punctatus Lepomis.symmetricus Lota.lota
## 1               42               326                  76         0
## 2              412               694                  36         0
## 3               35                 1                   1         0
## 4                0                 0                   0       128
## 5                0                 0                   0       174
##   Lucania.goodei Lucania.parva Luxilus.albeolus Luxilus.cardinalis
## 1             42             1                0                  0
## 2              0             0                0                  0
## 3              0             0             1214               1654
## 4              0             0                0                  0
## 5              0             0                0                  0
##   Luxilus.cerasinus Luxilus.chrysocephalus Luxilus.coccogenis Luxilus.cornutus
## 1                 0                      0                  0                0
## 2                 0                   1700                  4              168
## 3               269                   6000               2326             1182
## 4                 0                   1966                  0            10826
## 5                 0                      9                  0             8379
##   Luxilus.pilsbryi Luxilus.zonatus Luxilus.zonistius Lythrurus.ardens
## 1                0               0                 0                0
## 2                0               0                97               84
## 3             1637            3316                 0              297
## 4                0               0                 0               30
## 5                0               0                 0                0
##   Lythrurus.atrapiculus Lythrurus.bellus Lythrurus.fasciolaris Lythrurus.fumeus
## 1                     0                0                     0                2
## 2                     1               40                   949               93
## 3                     0                0                  1347              139
## 4                     0                0                   168                0
## 5                     0                0                     0                0
##   Lythrurus.lirus Lythrurus.roseipinnis Lythrurus.umbratilis
## 1               0                     0                    0
## 2              45                    80                  133
```

```
## 3           731                    0                    972
## 4             0                    0                    279
## 5             0                    0                      0
##   Macrhybopsis.aestivalis Macrhybopsis.australis Macrhybopsis.hyostoma
## 1                       0                      0                     0
## 2                      16                     35                   157
## 3                       1                      0                    16
## 4                       6                      0                     4
## 5                       0                      0                     0
##   Macrhybopsis.marconis Macrhybopsis.meeki Macrhybopsis.storeriana
## 1                     1                  0                       0
## 2                     0                  0                     271
## 3                     0                  0                      69
## 4                     0                  0                     149
## 5                     0                  0                       2
##   Margariscus.margarita Margariscus.nachtriebi Membras.martinica Menidia.audens
## 1                     0                      0                55              3
## 2                     0                      0                 0             79
## 3                     0                      0                 0            119
## 4                  2528                      0                 0              0
## 5                   156                     21                 0              0
##   Menidia.beryllina Menidia.menidia Microgadus.tomcod Microgobius.gulosus
## 1               155               0                 0                   0
## 2               934               0                 0                   2
## 3               464               3                 0                   0
## 4                 2               0                 2                   0
## 5                 0               0                 0                   0
##   Micropterus.cataractae Micropterus.coosae Micropterus.dolomieu
## 1                      0                  0                    7
## 2                     43                215                   75
## 3                      0                  5                 4401
## 4                      0                  0                12200
## 5                      0                  0                 2885
##   Micropterus.notius Micropterus.punctulatus Micropterus.salmoides
## 1                 26                     230                   763
## 2                  2                    2192                  3407
## 3                  0                    2427                  2855
## 4                  0                     129                  4154
## 5                  0                       0                   279
##   Micropterus.treculii Minytrema.melanops Misgurnus.anguillicaudatus
## 1                  108                103                          1
## 2                   31                720                          0
## 3                    0                385                          0
## 4                    0                247                          1
## 5                    0                  0                          1
##   Morone.americana Morone.chrysops Morone.mississippiensis Morone.saxatilis
## 1                0               7                      11                4
## 2               52             218                      37               69
## 3             1512             428                      62              158
## 4              891             374                       8              413
## 5                1              73                       0                0
##   Moxostoma.anisurum Moxostoma.breviceps Moxostoma.carinatum Moxostoma.cervinum
## 1                  0                   0                   0                  0
## 2                 13                   0                  67                  0
```

```
## 3              339               501               377               178
## 4             1378               222               141                 0
## 5              435                 0                19                 0
##   Moxostoma.collapsum Moxostoma.congestum Moxostoma.duquesnii
## 1                   0                  62                   0
## 2                 221                  32                 152
## 3                 138                   0                1745
## 4                   0                   0                 797
## 5                   0                   0                   0
##   Moxostoma.erythrurum Moxostoma.lachneri Moxostoma.macrolepidotum
## 1                    0                  0                        0
## 2                  407                 33                       43
## 3                 4562                  0                      640
## 4                 3919                  0                     3145
## 5                  877                  0                     1490
##   Moxostoma.pappillosum Moxostoma.pisolabrum Moxostoma.poecilurum
## 1                     0                    0                    0
## 2                     0                    0                  493
## 3                    44                   20                   37
## 4                     0                    0                    0
## 5                     0                    0                    0
##   Moxostoma.robustum Moxostoma.rupiscartes Moxostoma.valenciennesi
## 1                  0                     0                       0
## 2                  1                   122                       0
## 3                  0                    76                      26
## 4                  0                     0                      99
## 5                  0                     0                     124
##   Mugil.cephalus Mugil.curema Mylocheilus.caurinus Mylopharodon.conocephalus
## 1            460            0                    0                         0
## 2           1475            0                    0                         0
## 3             10            0                    0                       152
## 4              1            0                    2                        65
## 5              0            0                    7                         0
##   Mylopharyngodon.piceus Myrophis.punctatus Neogobius.melanostomus
## 1                      0                  0                      0
## 2                      0                  4                      0
## 3                      0                  0                      0
## 4                      5                  0                    432
## 5                      0                  0                      0
##   Nocomis.asper Nocomis.biguttatus Nocomis.effusus Nocomis.leptocephalus
## 1             0                  0               0                     0
## 2             0                142               0                  2066
## 3           207                587              49                  2614
## 4             0               1300               0                     0
## 5             0               1622               0                     0
##   Nocomis.micropogon Nocomis.platyrhynchus Nocomis.raneyi
## 1                  0                     0              0
## 2                  0                     0              0
## 3               2901                   460            188
## 4               1445                     0              0
## 5                 41                     0              0
##   Notemigonus.crysoleucas Notropis.alborus Notropis.altipinnis
## 1                      55                0                   0
## 2                     814                4                  20
```

```
## 3                     516               61                105
## 4                    2095                0                  0
## 5                     170                0                  0
##   Notropis.amabilis Notropis.ammophilus Notropis.amoenus Notropis.amplamala
## 1                30                   0                0                  0
## 2                11                  62                0                 13
## 3                 0                   0              149                  0
## 4                 0                   0               51                  0
## 5                 0                   0                0                  0
##   Notropis.ariommus Notropis.atherinoides Notropis.atrocaudalis
## 1                 0                     3                     0
## 2                 0                  3730                    49
## 3               162                  9300                     0
## 4                 0                 29384                     0
## 5                 0                  1352                     0
##   Notropis.baileyi Notropis.bairdi Notropis.bifrenatus Notropis.blennius
## 1                0               0                   0                 0
## 2               88             480                   0                 3
## 3                0             634                   1               937
## 4                0               0                  30              2255
## 5                0               0                   1                 0
##   Notropis.boops Notropis.braytoni Notropis.buccatus Notropis.buccula
## 1              0                 3                 0                0
## 2            536                 0               169               69
## 3           1312                 0               872                0
## 4             88                 0               402                0
## 5              0                 0                 0                0
##   Notropis.buchanani Notropis.cahabae Notropis.candidus Notropis.chalybaeus
## 1                  0                0                 0                   0
## 2                108               39               147                  56
## 3                 57                0                 0                   3
## 4                  2                0                 0                   8
## 5                  0                0                 0                   0
##   Notropis.chiliticus Notropis.chlorocephalus Notropis.chrosomus
## 1                   0                       0                  0
## 2                   0                     122                131
## 3                  72                       2                  2
## 4                   0                       0                  0
## 5                   0                       0                  0
##   Notropis.cummingsae Notropis.edwardraneyi Notropis.girardi Notropis.greenei
## 1                   0                     0                0                0
## 2                 257                    31                0                0
## 3                  26                     0               18              111
## 4                   0                     0                0                0
## 5                   0                     0                0                0
##   Notropis.harperi Notropis.heterodon Notropis.heterolepis Notropis.hudsonius
## 1                0                  0                    0                  0
## 2              242                  0                    0                438
## 3                0                  0                    2               3678
## 4                0                  0                   98              12309
## 5                0                 86                  591                312
##   Notropis.hypsilepis Notropis.leuciodus Notropis.longirostris
## 1                   0                  0                     0
## 2                  31                  5                   662
```

```
## 3                   0               2663                     6
## 4                   0                  0                     0
## 5                   0                  0                     0
##   Notropis.lutipinnis Notropis.maculatus Notropis.micropteryx Notropis.nubilus
## 1                   0                  0                    0                0
## 2                1910                 15                    0               13
## 3                  74                  0                  167             1322
## 4                   0                  0                    0                5
## 5                   0                  0                    0                0
##   Notropis.oxyrhynchus Notropis.ozarcanus Notropis.percobromus
## 1                    0                  0                    0
## 2                  143                  0                    0
## 3                    0                  1                  239
## 4                    0                  0                  173
## 5                    0                  0                   84
##   Notropis.perpallidus Notropis.petersoni Notropis.photogenis Notropis.potteri
## 1                    0                204                   0                0
## 2                    0               1336                   9                0
## 3                    0                  0                 575                2
## 4                    0                  0                 407                0
## 5                    0                  0                   0                0
##   Notropis.procne Notropis.rafinesquei Notropis.rubellus Notropis.rubricroceus
## 1               0                    0                 0                     0
## 2              53                    5                 6                     0
## 3            1230                    0              3036                    91
## 4             975                    0              1437                     0
## 5               0                    0                42                     0
##   Notropis.sabinae Notropis.scabriceps Notropis.scepticus Notropis.semperasper
## 1                0                   0                  0                    0
## 2               57                   0                186                    0
## 3                0                   5                 57                   20
## 4                0                   0                  0                    0
## 5                0                   0                  0                    0
##   Notropis.shumardi Notropis.simus Notropis.spectrunculus Notropis.stilbius
## 1                 0              0                      0                 0
## 2               215              0                      0               105
## 3                 4              8                    109                 0
## 4                 0              0                      0                 0
## 5                 0              0                      0                 0
##   Notropis.stramineus Notropis.suttkusi Notropis.telescopus Notropis.texanus
## 1                   3                 0                   0                0
## 2                  63                12                  10             2640
## 3                7835                 0                4835                1
## 4               16648                 0                   0               12
## 5                2594                 0                   0                0
##   Notropis.topeka Notropis.uranoscopus Notropis.volucellus Notropis.wickliffi
## 1               0                    0                  45                  0
## 2               0                  161                 574                  0
## 3              36                    0                2835                619
## 4               4                    0               10368               1253
## 5               0                    0                 961                  0
##   Notropis.xaenocephalus Noturus.albater Noturus.elegans Noturus.eleutherus
## 1                      0               0               0                  0
## 2                    150               0               0                  5
```

```
## 3                     0              158              52                 139
## 4                     0                0               0                  10
## 5                     0                0               0                   0
##   Noturus.exilis Noturus.flavater Noturus.flavus Noturus.funebris
## 1              0                0              0                0
## 2            110                0              0               27
## 3           1008               12            219                0
## 4              1                0            388                0
## 5              0                0            140                0
##   Noturus.gyrinus Noturus.hildebrandi Noturus.insignis Noturus.lachneri
## 1               2                   0                0                0
## 2              73                  11              173                3
## 3              27                   0             1224                0
## 4             100                   0             1407                0
## 5             121                   0              155                0
##   Noturus.leptacanthus Noturus.miurus Noturus.munitus Noturus.nocturnus
## 1                    1              0               0                 0
## 2                  181             46               3               124
## 3                    0             62               0                42
## 4                    0             16               0                13
## 5                    0              0               0                 0
##   Noturus.phaeus Noturus.stigmosus Oncorhynchus.clarkii
## 1              0                 0                    0
## 2             67                 0                    0
## 3             12                 0                   18
## 4              0                 2                  191
## 5              0                 0                 2218
##   Oncorhynchus.clarkii.bouvieri Oncorhynchus.clarkii.clarkii
## 1                             0                            0
## 2                             0                            0
## 3                             0                            0
## 4                           116                            0
## 5                             2                            1
##   Oncorhynchus.clarkii.henshawi Oncorhynchus.clarkii.lewisi
## 1                             0                           0
## 2                             0                           0
## 3                            20                           0
## 4                             0                           0
## 5                             0                           2
##   Oncorhynchus.clarkii.pleuriticus Oncorhynchus.clarkii.utah
## 1                                0                         0
## 2                                0                         0
## 3                                8                         0
## 4                                0                        11
## 5                                0                         0
##   Oncorhynchus.clarkii.virginalis Oncorhynchus.kisutch Oncorhynchus.mykiss
## 1                               0                    0                   0
## 2                               0                    0                 353
## 3                               0                    0                 761
## 4                               0                  104                2308
## 5                               0                 1792                1432
##   Oncorhynchus.mykiss.gairdnerii Oncorhynchus.nerka Oncorhynchus.tshawytscha
## 1                              0                  0                        0
## 2                              0                  0                        0
```

```
## 3                          0                 20                         5
## 4                          0                  0                       245
## 5                          0                  0                      1093
##   Opsopoeodus.emiliae Oreochromis.aureus Oreochromis.mossambicus
## 1                  78                 50                       0
## 2                 297                  0                       0
## 3                   5                  0                       0
## 4                   0                  0                       0
## 5                   0                  0                       0
##   Orthodon.microlepidotus Paralichthys.lethostigma Perca.flavescens
## 1                       0                        0                0
## 2                       0                       16              119
## 3                      12                        1              560
## 4                       0                        0             6705
## 5                       0                        0             1661
##   Percina.aurantiaca Percina.aurolineata Percina.burtoni Percina.caprodes
## 1                  0                   0               0                0
## 2                  0                   6               1              218
## 3                147                   0              15             1651
## 4                  0                   0               0             1541
## 5                  0                   0               0              879
##   Percina.carbonaria Percina.copelandi Percina.crassa Percina.cymatotaenia
## 1                 49                 0              0                    0
## 2                 37                 1             47                    0
## 3                  0                29             28                    5
## 4                  0                15              0                    0
## 5                  0                 0              0                    0
##   Percina.evides Percina.gymnocephala Percina.kathae Percina.lenticula
## 1              0                    0              0                0
## 2              1                    0             96                3
## 3            340                   46              0                0
## 4             24                    0              0                0
## 5             13                    0              0                0
##   Percina.macrocephala Percina.macrolepida Percina.maculata Percina.nasuta
## 1                    0                   6                0              0
## 2                    0                 155               16              0
## 3                   74                  21              152             36
## 4                  330                   0             1424              0
## 5                    0                   0              835              0
##   Percina.nevisense Percina.nigrofasciata Percina.notogramma
## 1                 0                     3                  0
## 2                 0                  3659                  0
## 3                11                     0                 26
## 4                 0                     0                  1
## 5                 0                     0                  0
##   Percina.oxyrhynchus Percina.palmaris Percina.pantherina Percina.peltata
## 1                   0                0                  0               0
## 2                   0               19                  2               0
## 3                  46                0                  0              60
## 4                   0                0                  0             692
## 5                   0                0                  0               0
##   Percina.phoxocephala Percina.rex Percina.roanoka Percina.sciera
## 1                    0           0               0              0
## 2                   25           0               0            209
```

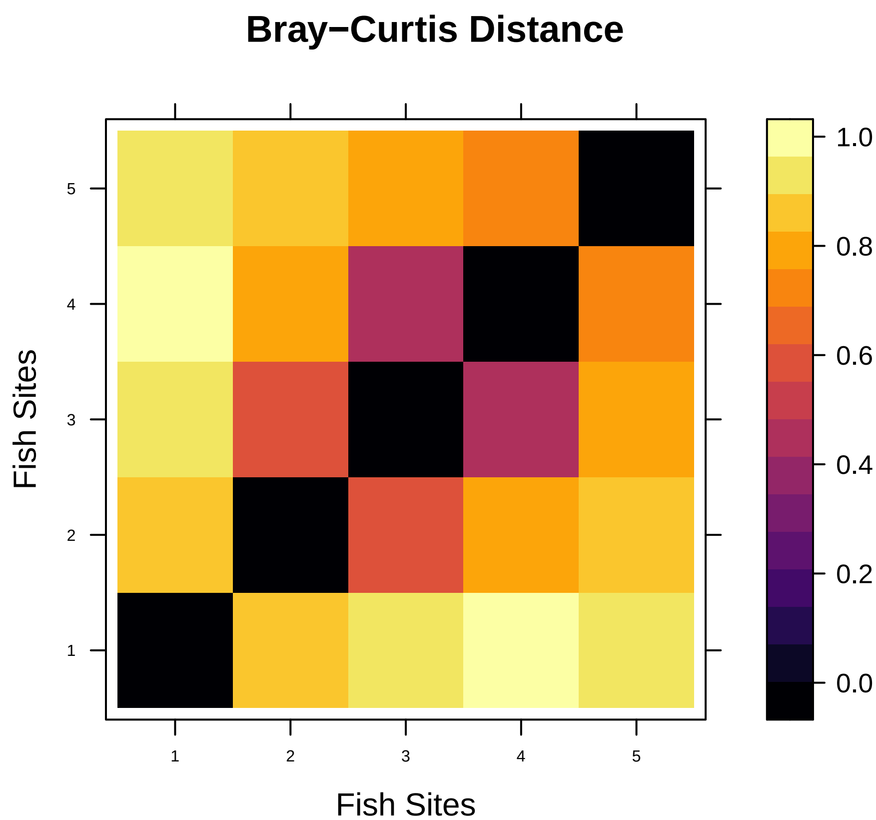
```
## 3                  209           5             477            174
## 4                  179           0               0             11
## 5                   10           0               0              0
##   Percina.shumardi Percina.squamata Percina.stictogaster Percina.suttkusi
## 1                0                0                    0                0
## 2               16                0                    0               14
## 3               15                6                    2                0
## 4                3                0                    0                0
## 5                5                0                    0                0
##   Percina.tanasi Percina.uranidea Percina.vigil Percopsis.omiscomaycus
## 1              0                0             0                      0
## 2              0                1             1                      0
## 3              7                0             2                    166
## 4              0                0             0                    287
## 5              0                0             0                    494
##   Percopsis.transmontana Petromyzon.marinus Phenacobius.catostomus
## 1                      0                  0                      0
## 2                      0                  0                     12
## 3                      0                 60                      0
## 4                      9                135                      0
## 5                      2                 33                      0
##   Phenacobius.crassilabrum Phenacobius.mirabilis Phenacobius.teretulus
## 1                        0                     0                     0
## 2                        0                   112                     0
## 3                       23                  1159                    11
## 4                        0                   367                     0
## 5                        0                     0                     0
##   Phenacobius.uranops Phoxinus.eos Phoxinus.erythrogaster Phoxinus.oreas
## 1                   0            0                      0              0
## 2                   0            0                      0              0
## 3                  69            0                    543             58
## 4                   0            0                    484              0
## 5                   0           13                      0              0
##   Pimephales.notatus Pimephales.promelas Pimephales.tenellus Pimephales.vigilax
## 1                  0                   0                   0                215
## 2                980                 840                   1               6330
## 3              16819                5430                 165               3763
## 4              18156                8186                   0                509
## 5                755                4632                   0                  0
##   Plagopterus.argentissimus Platichthys.stellatus Platygobio.gracilis
## 1                         0                     0                   0
## 2                         0                     0                  10
## 3                         0                     0                 594
## 4                         0                     0                 302
## 5                         0                     0                 979
##   Poecilia.latipinna Poecilia.sphenops Pogonichthys.macrolepidotus
## 1                785                 1                           0
## 2                294                 0                           0
## 3                  0                 0                           2
## 4                  0                 0                           0
## 5                  0                 0                           0
##   Polyodon.spathula Pomoxis.annularis Pomoxis.nigromaculatus
## 1                 0                67                     26
## 2                 2               460                    310
```

```
## 3                0                261                    188
## 4                2                140                    637
## 5                0                  9                    223
##   Prosopium.cylindraceum Prosopium.williamsoni Pteronotropis.euryzonus
## 1                      0                     0                       0
## 2                      0                     0                       1
## 3                      0                   100                       0
## 4                      0                   515                       0
## 5                      0                   672                       0
##   Pteronotropis.grandipinnis Pteronotropis.hypselopterus
## 1                          0                           0
## 2                          8                         395
## 3                          0                           0
## 4                          0                           0
## 5                          0                           0
##   Pteronotropis.signipinnis Pteronotropis.stonei Pterygoplichthys.disjunctivus
## 1                         0                    0                            46
## 2                         0                  121                             0
## 3                         0                    0                             0
## 4                         0                    0                             0
## 5                         0                    0                             0
##   Pterygoplichthys.multiradiatus Ptychocheilus.grandis Ptychocheilus.lucius
## 1                              1                     0                    0
## 2                              0                     0                    0
## 3                              0                   404                    2
## 4                              0                   139                    0
## 5                              0                     0                    0
##   Ptychocheilus.oregonensis Pungitius.pungitius Pylodictis.olivaris
## 1                         0                   0                  20
## 2                         0                   0                 502
## 3                         0                   0                1009
## 4                        66                   0                 248
## 5                       474                  20                   0
##   Rhinichthys.atratulus Rhinichthys.cataractae Rhinichthys.cobitis
## 1                     0                      0                   0
## 2                    21                      2                   4
## 3                  5987                   3721                   0
## 4                 22513                  12148                   0
## 5                  1597                   3224                   0
##   Rhinichthys.falcatus Rhinichthys.obtusus Rhinichthys.osculus
## 1                    0                   0                   0
## 2                    0                   0                 533
## 3                   36                2051                2318
## 4                    0                2663                2804
## 5                    0                1145                2964
##   Rhinichthys.umatilla Richardsonius.balteatus Richardsonius.egregius
## 1                    0                       0                      0
## 2                    0                       0                      0
## 3                    0                     408                     47
## 4                  103                    1740                     27
## 5                    2                    1017                      0
##   Salmo.salar Salmo.trutta Salvelinus.confluentus Salvelinus.fontinalis
## 1           0            0                      0                     0
## 2           0          342                      0                    25
```

```
## 3          0        1314                          0                   214
## 4        410        4360                          0                  2733
## 5          8        1434                          8                   893
##   Salvelinus.malma Sander.canadensis Sander.vitreus Scaphirhynchus.platorynchus
## 1                0                 0              0                           0
## 2                0                 7             20                           0
## 3                0               212             55                          18
## 4                0               161           1255                          59
## 5                0               121            402                           8
##   Sciaenops.ocellatus Semotilus.atromaculatus Semotilus.corporalis
## 1                   0                       0                    0
## 2                   4                    1857                    0
## 3                  44                   14206                  448
## 4                   0                   23365                 9261
## 5                   0                    3858                 1243
##   Semotilus.lumbee Semotilus.thoreauianus Strongylura.marina Taricha.granulosa
## 1                0                      0                  9                 0
## 2                0                    101                 39                 0
## 3                5                      0                 11                 0
## 4                0                      0                  0                 0
## 5                0                      0                  0                 0
##   Thaleichthys.pacificus Thoburnia.atripinnis Thoburnia.rhothoeca
## 1                      0                    0                   0
## 2                      0                    0                   0
## 3                      0                    5                 402
## 4                      0                    0                   0
## 5                      0                    0                   0
##   Thymallus.arcticus Tinca.tinca Trinectes.maculatus Umbra.limi Umbra.pygmaea
## 1                  0           0                  23          0             0
## 2                  0           0                 121          0             3
## 3                  0           0                  21          1           139
## 4                  0           0                   3       3000            67
## 5                  0           4                   0        594             0
##   Xyrauchen.texanus
## 1                 0
## 2                 0
## 3                 5
## 4                 0
## 5                 0
```

```
result <- cbind(result[ ,1], result[,3:638])

new_result <- result[ ,2:637]

colnames(result)[1] <- "Latitude Group"

new_result <- result[ ,2:637]

fish.db1 <- vegdist(new_result, method = "bray", upper = TRUE, diag = TRUE)

Fishdbmatrix <- as.matrix(fish.db1)

order2 <- rev(rownames(Fishdbmatrix))
```

```
levelplot(Fishdbmatrix,
          aspect = "iso",
          col.regions = inferno,
          xlab = "Fish Sites",
          ylab = "Fish Sites",
          scales = list(cex = 0.5),
          main = "Bray-Curtis Distance")
```



Synthesis Question > Answer : The graph above represents the five sites that we divided our data into. We did this because having over 2,700 sites made it very difficult to properly visualize the data. We grouped the data by the latitude at which the fish data was collected. Site 1 represents latitudes 25-30. Site 2 represents latitudes 30-35. Site 3 represents latitudes 35-40. Site 4 represents latitudes 40-45. Site 5 represents latitudes 45-50. The figure shows that the fish communities were most similar between sites 3 and 4. Sites 2 and 3 were somewhat similar. Comparisons between the rest of the combinations of other sites show much dissimilarity. This implies that fish communities are most similar at latitudes between 35 and 45, which corresponds to the central region of the United States. On the other hand, fish communities in the north are more dissimilar compared to the southern communities. Something I found interesting was that fish communities at sites 1 and 2 and 4 and 5 were more dissimilar. Meaning that even though they are in the same geographic region, they are not as similar. This could be since species living in very northern or southern regions must have the ability to endure very hot and cold temperatures, resulting in less species being able to live in those areas. Based on this information, I hypothesize that biodiversity is lower in the northern southern latitudes due to extreme weather conditions preventing many species from inhabiting that area.

```
#fish.cluster <- hclust(fish.db1, method = "ward.D2")

#par(mar = c(1, 5, 2, 2) + 0.1)
#plot(fish.cluster, main = "Fish Sites by Latitude",
     #ylab = "Squared Bray-Curtis Distance")
```