

Deep Dive Into Gradients








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Material required for this chapter

Type	Name	Link
Read- ing	Smit et al. (2017)	 Smit_et_al_2017.pdf
	Smit et al. (2013)	 Smit_et_al_2013.pdf
	Supp. to Smit et al. (2017)	 Smit_the_seaweed_data.pdf
Re- lated	Appendices to Smit et al. (2017)	 Appendices
Data	The seaweed environmental data	 SeaweedEnv.RData
	The seaweed species data	 dists_mat.RData
	The bioregions	 bioregions.csv

In the previous chapter we looked at calculations involving biodiversity (specifically the dissimilarity matrices made from a species table) and environmental variables (distances) from the paper

by Smit et al. (2017). What can we do with the two forms of contemporary β -diversity? What do they mean? Can we look to environmental distances for more insight?

Let's do a deeper analysis and create a figure to demonstrate these findings. I regress β_{SOR} on the spatial distance between section pairs (see below) and on the environmental distance β_{E} in each bioregion and used the magnitude of the slope (per 100 km) of this relationship as a metric of β -diversity or 'distance decay' of dissimilarity.

What these lines of code do is recreate Figure 5 in Smit et al. (2017). Please read the paper for an interpretation of this figure as this is critical for an understanding of the role that gradients play in structuring patterns of biodiversity.

(To be updated...)

```
## Setting up the analysis environment
library(tidyverse)
library(plyr)
library(vegan)
library(betapart) # for partitioning beta-diversity
```

1 Load and Prepare All the Data

1.1 The environmental data

```
# load the environmental data...
load("../data/seaweed/SeaweedEnv.RData")
env <- as.data.frame(env)
# keep only some...
env <- env[, c("annMean", "annRange", "annSD", "febMean", "febRange",
              "febSD", "augMean", "augRange", "augSD")]
```

1.2 The bioregional classification

Various bioregions have been defined for South African marine biota. I prefer to use the one made by Bolton and Stegenga (2002):

```
# load the bioregions data...
bioreg <- read.csv("../data/seaweed/bioregions.csv",
                  header = TRUE)
rbind(head(bioreg, 3), tail(bioreg, 3))
```

	spal.prov	spal.ecoreg	lombard	bolton
1	BMP	NE	NamBR	BMP
2	BMP	NE	NamBR	BMP
3	BMP	NE	NamBR	BMP
56	AMP	NE	NBR	ECTZ

57	AMP	NE	NBR	ECTZ
58	AMP	NE	NBR	ECTZ

1.3 The geographic distances

Since the connectivity between sections is constrained by their location along a shoreline, we calculated the distances between sections not as ‘as the crow flies’ distances (e.g. Section 1 is not connected in a straight line to Section 58 because of the intervening land in-between), but as the great circle geodesic distances between each pair of sections along a ‘route’. Travelling from **1** to **58** therefore requires visiting **2**, then **3**, and eventually all the way up to **58**. The total distance between a pair of arbitrary sections is thus the cumulative sum of the great circle distances between each consecutive pair of intervening sections along the route. These data are contained in `dists_mat.RData` (I prepared it earlier):

```
# load the distances matrix...
load("../data/seaweed/dists_mat.RData")
# loaded as dists_mat
dists.mat[1:10, 1:8]
```

	1	2	3	4	5	6	7	8
1	0.000	51.138	104.443	153.042	207.386	253.246	305.606	359.799
2	51.138	0.000	53.305	101.904	156.248	202.108	254.468	308.661
3	104.443	53.305	0.000	48.599	102.943	148.803	201.163	255.356
4	153.042	101.904	48.599	0.000	54.344	100.204	152.564	206.757
5	207.386	156.248	102.943	54.344	0.000	45.860	98.220	152.413
6	253.246	202.108	148.803	100.204	45.860	0.000	52.360	106.553
7	305.606	254.468	201.163	152.564	98.220	52.360	0.000	54.193
8	359.799	308.661	255.356	206.757	152.413	106.553	54.193	0.000
9	409.263	358.125	304.820	256.221	201.877	156.017	103.657	49.464
10	457.857	406.719	353.414	304.815	250.471	204.611	152.251	98.058

Make a copy of the original matrix of distances between pairs of sites to create a full matrix which constrains pairwise comparisons to pairs within bioregions:

```
bioreg_mat <- dists.mat
bioreg_mat[1:58, 1:58] <- "out"
bioreg_mat[1:16, 1:16] <- "BMP"
bioreg_mat[17:21, 17:21] <- "B-ATZ"
bioreg_mat[22:41, 22:41] <- "AMP"
bioreg_mat[42:58, 42:58] <- "ECTZ"
dim(bioreg_mat)
```

```
[1] 58 58
```

```
# see what is inside the matrix...
bioreg_mat[1:3, 1:10]
```

```
  1    2    3    4    5    6    7    8    9   10
1 "BMP" "BMP" "BMP" "BMP" "BMP" "BMP" "BMP" "BMP" "BMP" "BMP"
2 "BMP" "BMP" "BMP" "BMP" "BMP" "BMP" "BMP" "BMP" "BMP" "BMP"
3 "BMP" "BMP" "BMP" "BMP" "BMP" "BMP" "BMP" "BMP" "BMP" "BMP"
```

```
bioreg_mat[56:58, 53:58]
```

```
  53    54    55    56    57    58
56 "ECTZ" "ECTZ" "ECTZ" "ECTZ" "ECTZ" "ECTZ"
57 "ECTZ" "ECTZ" "ECTZ" "ECTZ" "ECTZ" "ECTZ"
58 "ECTZ" "ECTZ" "ECTZ" "ECTZ" "ECTZ" "ECTZ"
```

```
# convert to show only the lower left triangle (not used later)
# requires the gdata package...
bioreg_tri <- gdata::lowerTriangle(bioreg_mat, diag = FALSE)
```

In `bioreg_mat`, pairs of sites that do not fall within any of the bioregions are labelled 'out':

```
# print output below...
bioreg_mat[1:3, 53:58]
```

```
  53    54    55    56    57    58
1 "out" "out" "out" "out" "out" "out"
2 "out" "out" "out" "out" "out" "out"
3 "out" "out" "out" "out" "out" "out"
```

We extract the slices (groups of rows) of the original species table into separate dataframes, one for each of the four bioregions:

```
env_BMP <- env[1:16, ]
env_BATZ <- env[17:21, ]
env_AMP <- env[22:41, ]
env_ECTZ <- env[42:58, ]
```

Now we make an environmental dataframe for use with plots of pairwise correlations etc.:

```
env_df <- data.frame(bio = bioreg$bolton, round(env, 3))
rbind(head(env_df, 3), tail(env_df, 3))
```

	bio	annMean	annRange	annSD	febMean	febRange	febSD	augMean	augRange	augSD
1	BMP	12.335	1.249	1.255	13.001	6.070	1.626	11.752	2.502	0.767
2	BMP	12.388	1.802	1.402	13.379	5.889	1.754	11.577	2.973	0.897
3	BMP	12.243	2.068	1.475	13.362	5.431	1.704	11.294	3.084	0.941
56	ECTZ	23.729	4.609	1.942	26.227	3.474	1.191	21.618	2.163	0.663
57	ECTZ	24.710	4.969	1.976	27.328	3.372	1.143	22.359	1.584	0.499
58	ECTZ	25.571	5.574	2.023	28.457	3.267	1.000	22.883	1.098	0.349

1.4 The seaweed species data

```
# load the seaweed data...
spp <- read.csv('../data/seaweed/SeaweedSpp.csv')
spp <- dplyr::select(spp, -1)
spp[1:10, 1:10]
```

	ACECAL	ACEMOE	ACRVIR	AROSP1	ANAWRI	AVRSP1	BIDMAG	BIDMIN	BOEFOR	BOOCOM
1	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0

2 Calculate β -Diversity Indices

Calculate β -diversity using the Sørensen index of dissimilarity. This is used throughout; binary Bray-Curtis is equivalent to Sørensen in **vegan**. I then extract the subdiagonal from this matrix of species dissimilarities. The subdiagonal refers to the elements immediately below the main diagonal. For a matrix Y with elements y_{ij} , the subdiagonal elements are $y_{i,i+1}$.

```
# ---- Sorensen-index ----
## this is used throughout...
Y <- vegdist(spp, binary = TRUE)
Y_mat <- as.matrix(Y)
# extract the subdiagonal...
Y_diag <- diag(Y_mat[-1, -nrow(Y_mat)])
# add a zero in front...
Y_diag <- append(0, Y_diag, after = 1)
```

Decompose into turnover and nestedness-resultant beta-diversity:

```
# ---- do-betapart ----
## Calculations with betapart...
Y.core <- betapart.core(spp)

# Using the Sørensen index, compute three distance matrices accounting for
# the (i) turnover (replacement), (ii) nestedness-resultant component, and
# (iii) total dissimilarity (i.e. the sum of both components)
# use for pairwise plotting...
Y.pair <- beta.pair(Y.core, index.family = "sor")
```

Extract the subdiagonal for plotting later on:

```
# Y1 will be the turnover component
Y1_mat <- as.matrix(Y.pair$beta.sim)
# extract the subdiagonal...
Y1_diag <- diag(Y1_mat [-1, -nrow(Y1_mat)])
# add a zero in front...
Y1_diag <- append(0, Y1_diag, after = 1)

# Y2 will be the nestedness-resultant component
Y2_mat <- as.matrix(Y.pair$beta.sne)
Y2_diag <- diag(Y2_mat [-1, -nrow(Y2_mat)])
Y2_diag <- append(0, Y2_diag, after = 1)
```

Create separate matrices for each bioregion:

```
# ---- spp-bioregion ----
spp.BMP <- spp[1:16, ]
Y.BMP <- vegdist(spp.BMP, binary = TRUE)
spp.core.BMP <- betapart.core(spp.BMP)
# use below for pairwise plotting...
Y.pair.BMP <- beta.pair(spp.core.BMP, index.family = "sor")

spp.BATZ <- spp[17:21, ]
Y.BATZ <- vegdist(spp.BATZ, binary = TRUE)
spp.core.BATZ <- betapart.core(spp.BATZ)
# use below for pairwise plotting...
Y.pair.BATZ <- beta.pair(spp.core.BATZ, index.family = "sor")

spp.AMP <- spp[22:41, ]
Y.AMP <- vegdist(spp.AMP, binary = TRUE)
spp.core.AMP <- betapart.core(spp.AMP)
# use below for pairwise plotting...
Y.pair.AMP <- beta.pair(spp.core.AMP, index.family = "sor")

spp.ECTZ <- spp[42:58, ]
Y.ECTZ <- vegdist(spp.ECTZ, binary = TRUE)
```

```
spp.core.ECTZ <- betapart.core(spp.ECTZ)
# use below for pairwise plotting...
Y.pair.ECTZ <- beta.pair(spp.core.ECTZ, index.family = "sor")
```

Calculate species richness (α -diversity):

```
# ---- do-species-richness ----
spp.richness.site <- specnumber(spp)
```

Calculate the environmental distances:

```
# ---- environmental-distance ----
# Euclidian distances on temperatures
# first make a copy so we can use untransformed data later on...
env_raw <- env
# calculate z-scores...
env <- decostand(env, method = "standardize")
```

Using individual thermal variables, calculate Euclidian distances, make a matrix, and extract the subdiagonal. The data have already been standardised in env:

```
# augMean
# to be used in env_rda2...
env4_mat <- env |>
  dplyr::select(augMean) |>
  vegdist(method = 'euclidian') |>
  as.matrix()

env4_diag <- diag(env4_mat[-1, -nrow(env4_mat)])
env4_diag <- append(0, env4_diag, after = 1)
```

```
# febRange
# to be used in env_rda2...
env5_mat <- env |>
  dplyr::select(febRange) |>
  vegdist(method = 'euclidian') |>
  as.matrix()

env5_diag <- diag(env5_mat[-1, -nrow(env5_mat)])
env5_diag <- append(0, env5_diag, after = 1)
```

```
# febSD
# to be used in env_rda2...
env6_mat <- env |>
```

```

dplyr::select(febSD) |>
vegdist(method = 'euclidian') |>
as.matrix()

env6_diag <- diag(env6_mat[-1, -nrow(env6_mat)])
env6_diag <- append(0, env6_diag, after = 1)

```

```

# augSD
# to be used in env_rda2...
env7_mat <- env |>
dplyr::select(augSD) |>
vegdist(method = 'euclidian') |>
as.matrix()

env7_diag <- diag(env7_mat[-1, -nrow(env7_mat)])
env7_diag <- append(0, env7_diag, after = 1)

```

```

# annMean
# to be used in env_rda2...
env8_mat <- env |>
dplyr::select(annMean) |>
vegdist(method = 'euclidian') |>
as.matrix()

env8_diag <- diag(env8_mat[-1, -nrow(env8_mat)])
env8_diag <- append(0, env8_diag, after = 1)

```

```

# combined variables selected with the db-RDA
# these have a far poorer fit...
env_comb_mat <- env |>
dplyr::select(augMean, febRange, febSD, augSD) |>
vegdist(method = 'euclidian') |>
as.matrix()

env_comb_diag <- diag(env_comb_mat[-1, -nrow(env_comb_mat)])
env_comb_diag <- append(0, env_comb_diag, after = 1)

```

```

# ---- do-figure-5 ----
# assemble data frame for plotting...
spp_df <- data.frame(dist = as.vector(dists.mat),
                     bio = as.vector(bioreg.mat),
                     augMean = as.vector(env4_mat),
                     febRange = as.vector(env5_mat),
                     febSD = as.vector(env6_mat),

```



```

augSD = as.vector(env7_mat),
annMean = as.vector(env8_mat),
Y = as.vector(Y_mat),
Y1 = as.vector(Y1_mat),
Y2 = as.vector(Y2_mat))

# include only site pairs that fall within bioregions...
spp_df2 <- droplevels(subset(spp_df, bio != "out"))
rbind(head(spp_df2, 3), tail(spp_df2, 3))

```

	dist	bio	augMean	febRange	febSD	augSD	annMean
1	0.000	BMP	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
2	51.138	BMP	0.05741369	0.09884404	0.16295271	0.3132800	0.01501846
3	104.443	BMP	0.15043904	0.34887754	0.09934163	0.4188239	0.02602247
3362	102.649	ECTZ	0.41496099	0.11330069	0.24304493	0.7538546	0.52278161
3363	49.912	ECTZ	0.17194242	0.05756093	0.18196664	0.3604341	0.24445006
3364	0.000	ECTZ	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
		Y	Y1	Y2			
1	0.00000000	0.00000000	0.00000000				
2	0.003610108	0.00000000	0.003610108				
3	0.003610108	0.00000000	0.003610108				
3362	0.198728140	0.1948882	0.003839961				
3363	0.069337442	0.0443038	0.025033645				
3364	0.000000000	0.00000000	0.000000000				

I'll save this file with the combined data for use later in the Multiple Regression Chapter:

```
write.csv(spp_df2, file = "../data/seaweed/spp_df2.csv")
```

Do the various linear regressions of Sørensen dissimilarities (β_{sor}), turnover (β_{sim}) and nestedness-related β -diversity (β_{sne}) as a function of the various thermal distances. I only display the results of the linear regression for Y1 regressed on geographical distance, dist, but do all the calculations:

```

# turnover...
Y1_lm1 <- dplyr(spp_df2, .(bio), function(x) lm(Y1 ~ dist, data = x))
lapply(Y1_lm1, summary)

```

\$AMP

Call:

```
lm(formula = Y1 ~ dist, data = x)
```

Residuals:

	Min	1Q	Median	3Q	Max
	-0.059575	-0.019510	-0.004546	0.015061	0.067655

```

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept) -5.175e-03  2.406e-03  -2.151   0.0321 *
dist         2.939e-04  6.567e-06  44.751  <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

```

```

Residual standard error: 0.02786 on 398 degrees of freedom
Multiple R-squared:  0.8342,    Adjusted R-squared:  0.8338
F-statistic: 2003 on 1 and 398 DF,  p-value: < 2.2e-16

```

```
$`B-ATZ`
```

```

Call:
lm(formula = Y1 ~ dist, data = x)

```

```

Residuals:
      Min       1Q   Median       3Q      Max
-0.070629 -0.024865  0.008058  0.022698  0.059443

```

```

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept) -0.008058   0.013645  -0.591   0.561
dist         0.001093   0.000159   6.873 5.23e-07 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

```

```

Residual standard error: 0.0411 on 23 degrees of freedom
Multiple R-squared:  0.6726,    Adjusted R-squared:  0.6583
F-statistic: 47.24 on 1 and 23 DF,  p-value: 5.229e-07

```

```
$BMP
```

```

Call:
lm(formula = Y1 ~ dist, data = x)

```

```

Residuals:
      Min       1Q   Median       3Q      Max
-0.037751 -0.027462 -0.023894  0.001529  0.269377

```

```

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept) 2.392e-02  5.500e-03  4.350 1.97e-05 ***
dist        7.095e-05  1.826e-05  3.886 0.00013 ***
---

```

```
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
Residual standard error: 0.05129 on 254 degrees of freedom
Multiple R-squared:  0.05613,    Adjusted R-squared:  0.05241
F-statistic: 15.1 on 1 and 254 DF,  p-value: 0.0001299
```

```
$ECTZ
```

```
Call:
lm(formula = Y1 ~ dist, data = x)
```

```
Residuals:
    Min       1Q   Median       3Q      Max
-0.11882 -0.02685  0.00540  0.02440  0.11961
```

```
Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) -5.400e-03  4.257e-03  -1.268    0.206
dist         7.860e-04  1.209e-05  65.033 <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
Residual standard error: 0.04194 on 287 degrees of freedom
Multiple R-squared:  0.9365,    Adjusted R-squared:  0.9362
F-statistic: 4229 on 1 and 287 DF,  p-value: < 2.2e-16
```

```
Y1_lm2 <- dply(spp_df2, .(bio), function(x) lm(Y1 ~ augMean , data = x))
# lapply(Y1_lm2, summary)
Y1_lm3 <- dply(spp_df2, .(bio), function(x) lm(Y1 ~ augSD , data = x))
# lapply(Y1_lm3, summary)
Y1_lm4 <- dply(spp_df2, .(bio), function(x) lm(Y1 ~ febRange , data = x))
# lapply(Y1_lm4, summary)
Y1_lm5 <- dply(spp_df2, .(bio), function(x) lm(Y1 ~ febSD , data = x))
# lapply(Y1_lm5, summary)

# nestedness-resultant...
Y2_lm1 <- dply(spp_df2, .(bio), function(x) lm(Y2 ~ dist, data = x))
# lapply(Y2_lm1, summary)
Y2_lm2 <- dply(spp_df2, .(bio), function(x) lm(Y2 ~ annMean , data = x))
# lapply(Y2_lm2, summary)
```

3 Make the Plots

Now assemble **Figure 5.** in Smit et al. (2017). It is a plot of pairwise (a) Sørensen dissimilarities ($\beta_{s\text{or}}$), (b) turnover (β_{sim}) and (c) nestedness-related β -diversity (β_{sne}) (Baselga 2010) as a function of distance between sections. Section pairs falling within individual bioregions are colour-coded;

where the pairs include sections across different bioregions the symbols are coloured grey and labeled 'out'.

Combine the data in a way that makes for easy plotting:

```
# Plots...
spp_long <- spp_df %>%
  gather(beta, dissim, Y:Y2) %>%
  gather(metric, distance, c(dist, augMean:annMean))
spp_long$metric = factor(spp_long$metric,
  levels = c('dist', 'augMean', 'febRange',
    'febSD', 'augSD', 'annMean'))
```

The repetitive portions of code needed to create each of the panels. I was too lazy to write neater and more concise code:

```
# sim as a function of geographic distance...
plt5a <- spp_long %>%
  dplyr::filter(beta %in% "Y1" & metric %in% "dist") %>%
  ggplot(aes(x = distance, y = dissim, group = bio)) +
  geom_point(aes(colour = bio, shape = bio), size = 1.2, alpha = 0.8) +
  geom_point(aes(colour = bio, size = bio, alpha = bio, shape = bio)) +
  geom_line(stat = "smooth", method = "lm", formula = y ~ x, alpha = 1.0,
    size = 0.6, colour = "black", aes(linetype = bio)) +
  scale_linetype_manual(name = "Bioregion",
    values = c("dashed", "solid", "dotted",
      "longdash", "blank")) +
  scale_colour_brewer(name = "Bioregion",
    palette = "Set1") +
  scale_shape_manual(name = "Bioregion",
    values = c(0, 19, 2, 5, 46)) +
  scale_size_manual(name = "Bioregion",
    values = c(1.0, 1.2, 1.0, 1.0, 0.6)) +
  scale_alpha_manual(name = "Bioregion",
    values = c(0.85, 1.0, 0.85, 0.85, 0.1)) +
  xlab(expression(paste("Distance (km)"))) +
  ylab(expression(paste(beta[sim]))) +
  scale_y_continuous(limits = c(0, 0.75)) +
  scale_x_continuous(limits = c(0, 1000)) +
  theme_grey() +
  theme(panel.grid.minor = element_line(colour = NA),
    plot.title = element_text(hjust = 0, size = 10),
    # legend.position = c(0.2, 0.7),
    # legend.direction = "vertical",
    aspect.ratio = 0.6) +
  ggtitle(expression(paste(beta[sim], " as a function of distance")))
```

```

# sim as a function of augMean...
plt5b <- spp_long %>%
  dplyr::filter(beta %in% "Y1" & metric %in% "augMean") %>%
  ggplot(aes(x = distance, y = dissim, group = bio)) +
  geom_point(aes(colour = bio, shape = bio), size = 1.2, alpha = 0.8) +
  # geom_point(aes(colour = bio, size = bio, alpha = bio, shape = bio)) +
  geom_line(stat = "smooth", method = "lm", formula = y ~ x,
            alpha = 1.0, size = 0.6, colour = "black", aes(linetype = bio)) +
  scale_linetype_manual(values = c("dashed", "solid", "dotted",
                                   "longdash", "blank")) +
  scale_colour_brewer(palette = "Set1") +
  scale_shape_manual(values = c(0, 19, 2, 5, 46)) +
  scale_size_manual(values = c(1.0, 1.2, 1.0, 1.0, 0.6)) +
  scale_alpha_manual(values = c(0.85, 1.0, 0.85, 0.85, 0.1)) +
  xlab(expression(paste(d[E]))) +
  ylab(expression(paste(beta[sim]))) +
  scale_y_continuous(limits = c(0, 0.75)) +
  scale_x_continuous(limits = c(0, 2)) +
  theme_grey() +
  theme(panel.grid.minor = element_line(colour = NA),
        plot.title = element_text(hjust = 0, size = 10),
        legend.position = "none",
        # legend.title = element_blank(),
        legend.title = element_text(size = 8),
        legend.text = element_text(size = 8),
        legend.key = element_blank(),
        legend.key.height = unit(.22, "cm"),
        legend.background = element_blank(),
        aspect.ratio = 0.6) +
  ggtitle(expression(paste(beta[sim], " as a function of augMean")))

```

```

# sim as a function of febRange...
plt5c <- spp_long %>%
  dplyr::filter(beta %in% "Y1" & metric %in% "febRange") %>%
  ggplot(aes(x = distance, y = dissim, group = bio)) +
  geom_point(aes(colour = bio, shape = bio), size = 1.2, alpha = 0.8) +
  # geom_point(aes(colour = bio, size = bio, alpha = bio, shape = bio)) +
  geom_line(stat = "smooth", method = "lm", formula = y ~ x,
            alpha = 1.0, size = 0.6, colour = "black", aes(linetype = bio)) +
  scale_linetype_manual(values = c("dashed", "solid", "dotted",
                                   "longdash", "blank")) +
  scale_colour_brewer(palette = "Set1") +
  scale_shape_manual(values = c(0, 19, 2, 5, 46)) +
  scale_size_manual(values = c(1.0, 1.2, 1.0, 1.0, 0.6)) +
  scale_alpha_manual(values = c(0.85, 1.0, 0.85, 0.85, 0.1)) +
  xlab(expression(paste(d[E]))) +
  ylab(expression(paste(beta[sim]))) +

```

```

scale_y_continuous(limits = c(0, 0.75)) +
scale_x_continuous(limits = c(0, 4)) +
theme_grey() +
theme(panel.grid.minor = element_line(colour = NA),
      plot.title = element_text(hjust = 0, size = 10),
      legend.position = "none",
      aspect.ratio = 0.6) +
ggtitle(expression(paste(beta[sim], " as a function of febRange")))

```

```

# sim as a function of febSD...
plt5d <- spp_long %>%
  dplyr::filter(beta %in% "Y1" & metric %in% "febSD") %>%
  ggplot(aes(x = distance, y = dissim, group = bio)) +
  geom_point(aes(colour = bio, shape = bio), size = 1.2, alpha = 0.8) +
  # geom_point(aes(colour = bio, size = bio, alpha = bio, shape = bio)) +
  geom_line(stat = "smooth", method = "lm", formula = y ~ x,
            alpha = 1.0, size = 0.6, colour = "black", aes(linetype = bio)) +
  scale_linetype_manual(values = c("dashed", "solid", "dotted",
                                   "longdash", "blank")) +
  scale_colour_brewer(palette = "Set1") +
  scale_shape_manual(values = c(0, 19, 2, 5, 46)) +
  scale_size_manual(values = c(1.0, 1.2, 1.0, 1.0, 0.6)) +
  scale_alpha_manual(values = c(0.85, 1.0, 0.85, 0.85, 0.1)) +
  xlab(expression(paste(d[E]))) +
  ylab(expression(paste(beta[sim]))) +
  scale_y_continuous(limits = c(0, 0.75)) +
  scale_x_continuous(limits = c(0, 3)) +
  theme_grey() +
  theme(panel.grid.minor = element_line(colour = NA),
        plot.title = element_text(hjust = 0, size = 10),
        legend.position = "none",
        aspect.ratio = 0.6) +
  ggtitle(expression(paste(beta[sim], " as a function of febSD")))

```

```

# sim as a function of augSD...
plt5e <- spp_long %>%
  dplyr::filter(beta %in% "Y1" & metric %in% "augSD") %>%
  ggplot(aes(x = distance, y = dissim, group = bio)) +
  geom_point(aes(colour = bio, shape = bio), size = 1.2, alpha = 0.8) +
  # geom_point(aes(colour = bio, size = bio, alpha = bio, shape = bio)) +
  geom_line(stat = "smooth", method = "lm", formula = y ~ x,
            alpha = 1.0, size = 0.6, colour = "black", aes(linetype = bio)) +
  scale_linetype_manual(values = c("dashed", "solid", "dotted",
                                   "longdash", "blank")) +
  scale_colour_brewer(palette = "Set1") +
  scale_shape_manual(values = c(0, 19, 2, 5, 46)) +

```

```

scale_size_manual(values = c(1.0, 1.2, 1.0, 1.0, 0.6)) +
scale_alpha_manual(values = c(0.85, 1.0, 0.85, 0.85, 0.1)) +
xlab(expression(paste(d[E]))) +
ylab(expression(paste(beta[sim]))) +
scale_y_continuous(limits = c(0, 0.75)) +
scale_x_continuous(limits = c(0, 3)) +
theme_grey() +
theme(panel.grid.minor = element_line(colour = NA),
      plot.title = element_text(hjust = 0, size = 10),
      legend.position = "none",
      aspect.ratio = 0.6) +
ggtitle(expression(paste(beta[sim], " as a function of augSD")))

```

```

# sne as a function of distance...
plt5f <- spp_long %>%
  dplyr::filter(beta %in% "Y2" & metric %in% "dist") %>%
  ggplot(aes(x = distance, y = dissim, group = bio)) +
  geom_point(aes(colour = bio, shape = bio), size = 1.2, alpha = 0.8) +
  # geom_point(aes(colour = bio, size = bio, alpha = bio, shape = bio)) +
  geom_line(stat = "smooth", method = "lm", formula = y ~ x,
           alpha = 1.0, size = 0.6, colour = "black", aes(linetype = bio)) +
  scale_linetype_manual(values = c("dashed", "solid", "dotted",
                                   "longdash", "blank")) +
  scale_colour_brewer(palette = "Set1") +
  scale_shape_manual(values = c(0, 19, 2, 5, 46)) +
  scale_size_manual(values = c(1.0, 1.2, 1.0, 1.0, 0.6)) +
  scale_alpha_manual(values = c(0.85, 1.0, 0.85, 0.85, 0.1)) +
  xlab(expression(paste("Distance (km)"))) +
  ylab(expression(paste(beta[sne]))) +
  scale_y_continuous(limits = c(0, 0.22)) +
  scale_x_continuous(limits = c(0, 1000)) +
  theme_grey() +
  theme(panel.grid.minor = element_line(colour = NA),
        plot.title = element_text(hjust = 0, size = 10),
        legend.position = "none",
        aspect.ratio = 0.6) +
  ggtitle(expression(paste(beta[sne], " as a function of distance")))

```

```

# sne as a function of annMean...
plt5g <- spp_long %>%
  dplyr::filter(beta %in% "Y2" & metric %in% "annMean") %>%
  ggplot(aes(x = distance, y = dissim, group = bio)) +
  geom_point(aes(colour = bio, shape = bio), size = 1.2, alpha = 0.8) +
  # geom_point(aes(colour = bio, size = bio, alpha = bio, shape = bio)) +
  geom_line(stat = "smooth", method = "lm", formula = y~x, alpha = 1.0, size =
0.6,

```

```

    colour = "black",
    aes(linetype = bio)) +
  scale_linetype_manual(values = c("dashed", "solid", "dotted", "longdash",
"blank")) +
  scale_colour_brewer(palette = "Set1") +
  scale_shape_manual(values = c(0, 19, 2, 5, 46)) +
  scale_size_manual(values = c(1.0, 1.2, 1.0, 1.0, 0.6)) +
  scale_alpha_manual(values = c(0.85, 1.0, 0.85, 0.85, 0.1)) +
  xlab(expression(paste(d[E]))) +
  ylab(expression(paste(beta[sne]))) +
  scale_y_continuous(limits = c(0, 0.22)) +
  scale_x_continuous(limits = c(0, 2)) +
  theme_grey() +
  theme(panel.grid.minor = element_line(colour = NA),
    plot.title = element_text(hjust = 0, size = 10),
    legend.position = "none",
    aspect.ratio = 0.6) +
  ggtitle(expression(paste(beta[sne], " as a function of annMean")))

```

```

plt5h <- ggplot(spp_long, aes(x = distance, y = dissim)) +
  geom_blank() +
  theme(plot.background = element_blank(),
    panel.grid.major = element_blank(),
    panel.grid.minor = element_blank(),
    panel.border = element_blank(),
    panel.background = element_blank(),
    axis.title.x = element_blank(),
    axis.title.y = element_blank(),
    axis.text.x = element_blank(),
    axis.text.y = element_blank(),
    axis.ticks = element_blank(),
    axis.line = element_blank())

```

Assemble using the **cowplot** package:

```

library(cowplot)

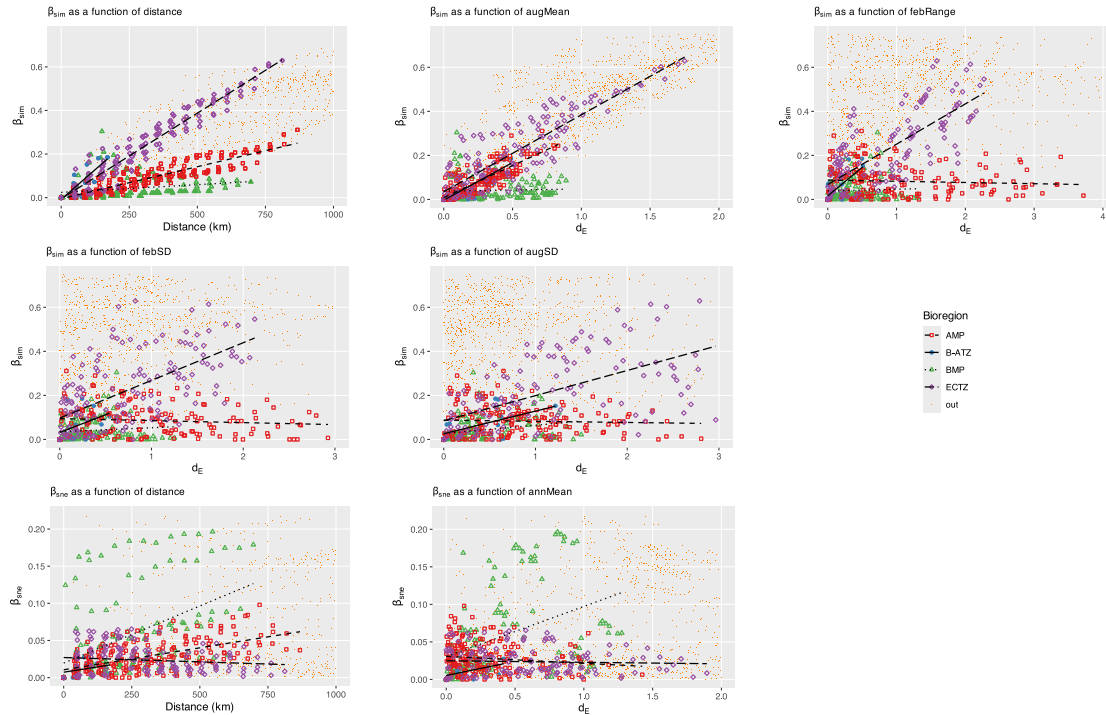
# turn off warnings...
oldw <- getOption("warn")
options(warn = -1)

l <- get_legend(plt5a)
# pdf("Fig5.pdf", width = 9, height = 6.5)
ggdraw() +
  draw_plot(plot_grid(plt5a + theme(legend.position = 'none'), plt5b, plt5c,
    plt5d, plt5e, l,
    plt5f, plt5g, plt5h,

```



```
ncol = 3, align = 'hv'),
width = 1.0)
```



4 References

Bibliography

- Baselga A (2010) Partitioning the turnover and nestedness components of beta diversity. *Global Ecology and Biogeography* 19:134–143.
- Bolton J, Stegenga H (2002) Seaweed species diversity in South Africa. *South African Journal of Marine Science* 24:9–18.
- Smit AJ, Bolton JJ, Anderson RJ (2017) Seaweeds in two oceans: beta-diversity. *Frontiers in Marine Science* 4:404.