Appendix: Principle Components Analysis (PCA)

Principle Components Analysis

This is the appendix of principle components analysis plot output. This section is organized as follows:

- Numerical Tables for Plot Generation
- Scree Plots
- Individual Plots
- Variable Plots
- Biplot graphs
- Individual Plots with Overlaid Categorical Ellipses
- R Code

Numerical Tables for Plot Generation

Three types of tables are calculated in order to derive the points for plot generation. These are:

- **Coordinates -** The coordinates of each variable that are used to create a scatter plot. Note, there are seven values for each variable, meaning we can plot them into seven dimensions. For ease of interpretation, we will limit ourselves to just two dimensions.
- **Quality of Represenation -** This is the square of the coordinate of each variable. This number is the sum of square distance of the observation when the original data point is projected onto a component.
- **Contribution -** For each relative principal component, this is a variable's percent contribution to that specific dimension.

PCA Coordinates

Table 1: Pre-Construction Variable Coordinates

	PC1	PC2	PC3	PC4	PC5	PC6	PC7
month	-0.1229866	0.7842005	-0.4306890	0.2521996	-0.2768383	-0.0384252	0.2066162
count	0.2551599	0.0721583	0.6594669	0.6639405	-0.1864401	0.1384550	0.0065798
hour	0.3897387	0.4127161	0.3268349	-0.6341311	-0.2316353	0.3391538	0.0120669
pcip	-0.4220547	0.6568835	0.2182412	0.0396880	0.5743218	0.0903102	-0.0562858
tmax	0.8088372	-0.2189521	-0.1757404	0.0937489	0.3428593	0.2513561	0.2782739
tmin	0.7972627	0.2474817	-0.3807353	0.1933024	0.0179767	0.0915389	-0.3348092

Table 2: Post-Construction Variable Coordinates

	PC1	PC2	PC3	PC4	PC5	PC6	PC7
month	-0.3918502	0.3414729	-0.5260843	0.1940435	-0.6425560	-0.0458815	-0.0211850
count	-0.0862071	0.5312588	-0.6146900	-0.2258718	0.4462131	0.2868939	0.0075080
hour..	0.1341212	0.6304476	0.5365995	0.2002354	-0.1474247	0.4837964	-0.0268525
pcip	-0.5007996	0.1874130	0.2684132	-0.7732041	-0.1778896	-0.0716370	-0.0860778
tmax	0.9313850	-0.0141383	-0.1679939	-0.0989815	-0.0957820	-0.0193320	-0.2911269
tmin	0.8617055	0.0889783	-0.0770919	-0.3329779	-0.2568937	0.0190124	0.2576301

Numerical Tables for Plot Generation (Continued)

Variable Quality of Representation

Table 3: Pre-Construction Variable Quality of Representation

	PC1	PC2	PC3	PC4	PC5	PC6	PC7
month	0.0151257	0.6149704	0.1854930	0.0636047	0.0766395	0.0014765	0.0426903
count	0.0651066	0.0052068	0.4348967	0.4408170	0.0347599	0.0191698	0.0000433
hour	0.1518963	0.1703346	0.1068210	0.4021222	0.0536549	0.1150253	0.0001456
pcip	0.1781302	0.4314960	0.0476292	0.0015751	0.3298455	0.0081559	0.0031681
tmax	0.6542177	0.0479400	0.0308847	0.0087889	0.1175525	0.0631799	0.0774363
tmin	0.6356278	0.0612472	0.1449594	0.0373658	0.0003232	0.0083794	0.1120972

Table 4: Post-Construction Variable Quality of Representation

	PC1	PC2	PC3	PC4	PC5	PC6	PC7
month	0.1535466	0.1166037	0.2767647	0.0376529	0.4128782	0.0021051	0.0004488
count	0.0074317	0.2822359	0.3778438	0.0510181	0.1991061	0.0823081	0.0000564
hour..	0.0179885	0.3974641	0.2879391	0.0400942	0.0217340	0.2340590	0.0007211
pcip	0.2508002	0.0351236	0.0720456	0.5978446	0.0316447	0.0051319	0.0074094
tmax	0.8674780	0.0001999	0.0282220	0.0097973	0.0091742	0.0003737	0.0847549
tmin	0.7425363	0.0079171	0.0059432	0.1108743	0.0659944	0.0003615	0.0663733

Variable Contribution

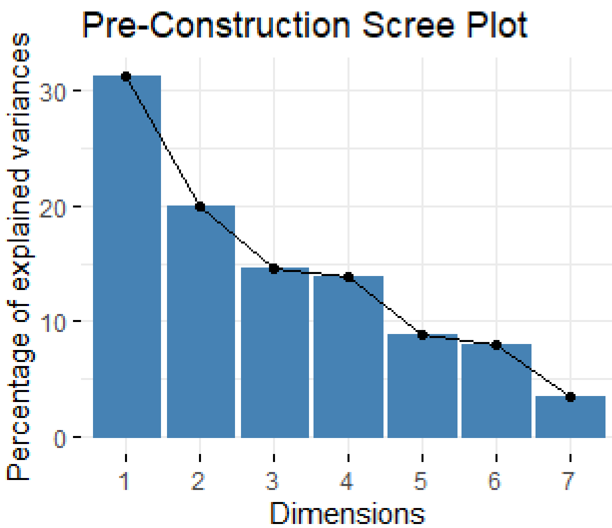
Table 5: Pre-Construction Variable Dimension Contribution (%)

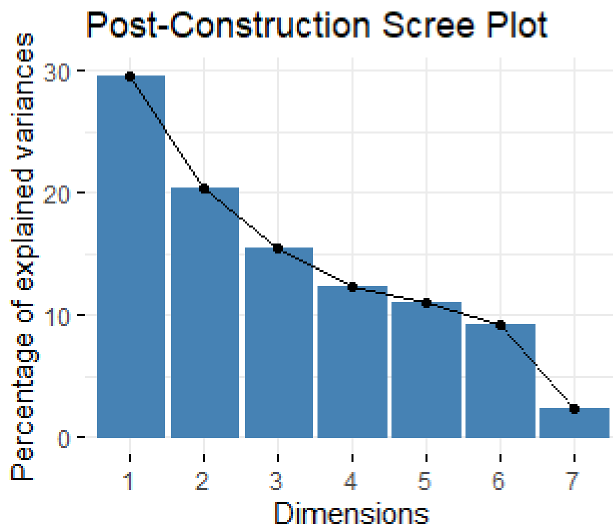
	PC1	PC2	PC3	PC4	PC5	PC6	PC7
month	0.6915456	44.1313877	18.111798	6.5124343	12.3835031	0.2631166	17.9062149
count	2.9766660	0.3736513	42.463924	45.1349260	5.6165492	3.4161245	0.0181594
hour	6.9446840	12.2235186	10.430157	41.1729987	8.6696295	20.4979366	0.0610755
pcip	8.1440944	30.9649315	4.650583	0.1612770	53.2968557	1.4534173	1.3288410
tmax	29.9107713	3.4402623	3.015624	0.8998848	18.9942870	11.2588932	32.4802774
tmin	29.0608467	4.3952106	14.154039	3.8258599	0.0522169	1.4932337	47.0185931

Table 6: Post-Construction Variable Dimension Contribution (%)

	PC1	PC2	PC3	PC4	PC5	PC6	PC7
month	7.4295347	8.1907856	25.7628526	4.354842	53.653097	0.3282287	0.2806589
count	0.3595900	19.8255560	35.1718859	5.900627	25.873632	12.8334585	0.0352512
hour..	0.8703948	27.9197238	26.8030303	4.637201	2.824316	36.4944207	0.4509127
pcip	12.1352683	2.4672459	6.7064228	69.145262	4.112198	0.8001575	4.6334461
tmax	41.9739552	0.0140413	2.6270633	1.133137	1.192177	0.0582712	53.0013553
tmin	35.9285045	0.5561370	0.5532236	12.823452	8.575897	0.0563602	41.5064255

Scree Plots

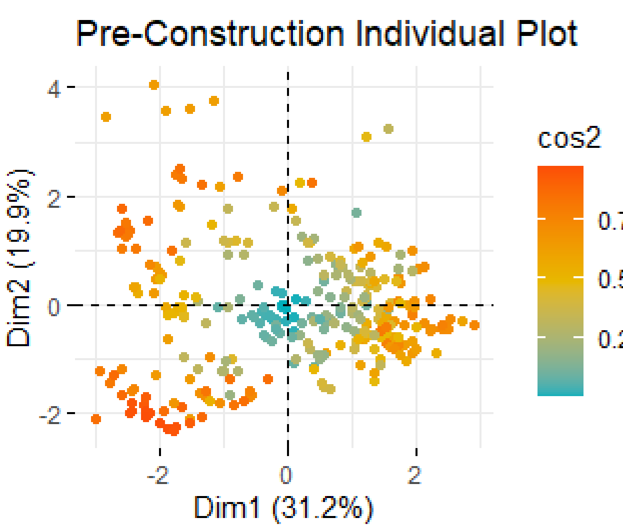


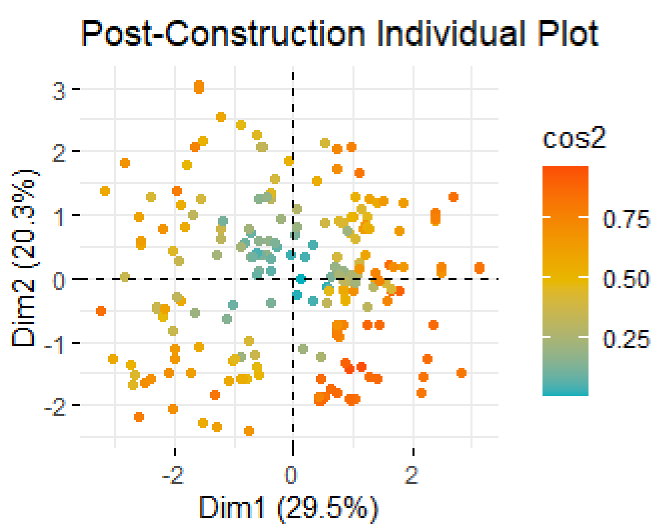


As seen above, the scree plots for both pre and post-construction show many principle dimensions. This is unideal as we cannot readily visualize k=4 or k=6 on a two-dimensional plane. Although there exists a fair amount of noise is our dataset, we can still utilize the next prinicple components analysis steps to visualize variance clustering, albiet only in two-dimensions.

The following plots will only be shown in two dimensions for ease of interpretation. For three-dimensional principle components plots, please refer to the R-code at the end of this section.

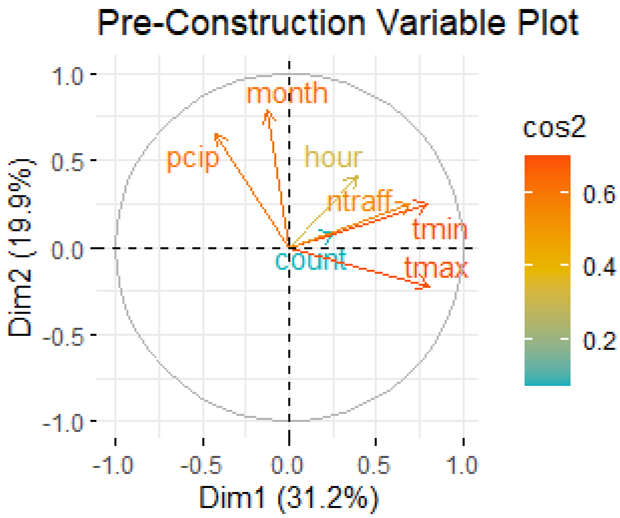
Principal Components Individual Plots

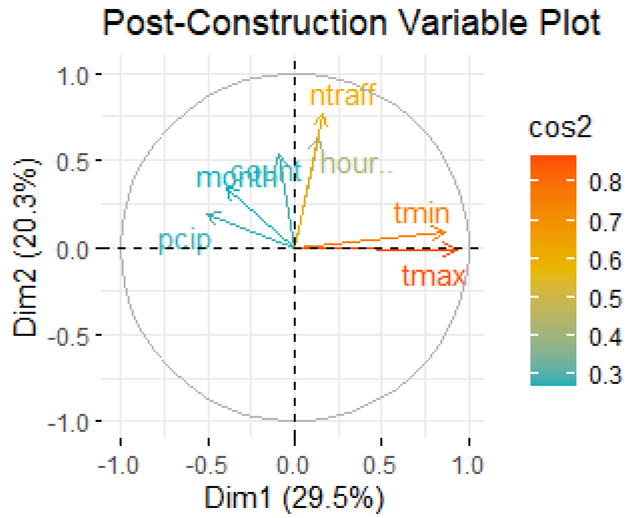




These are the principle components individual contribution plots. The color indicates greater contribution to the dimensions in question. In this case, red means that an individual observation contributes a greater percentage of variation to a particular dimension. Conversely, the turqoise coloring indicates that a particular observation does not contribute much at all.

Principal Components Variable Plots

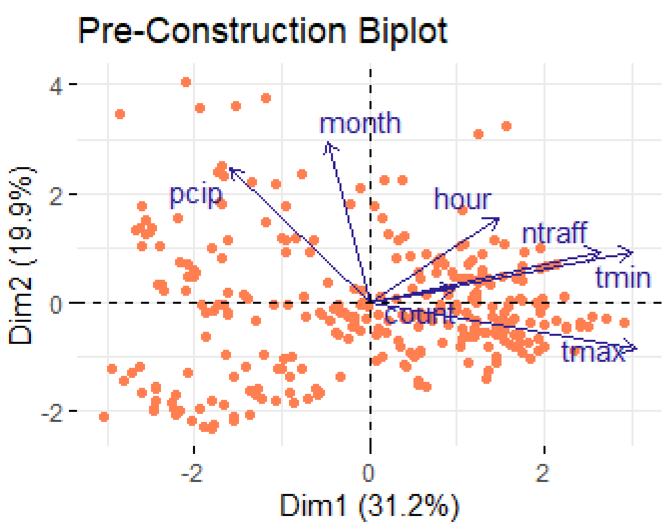


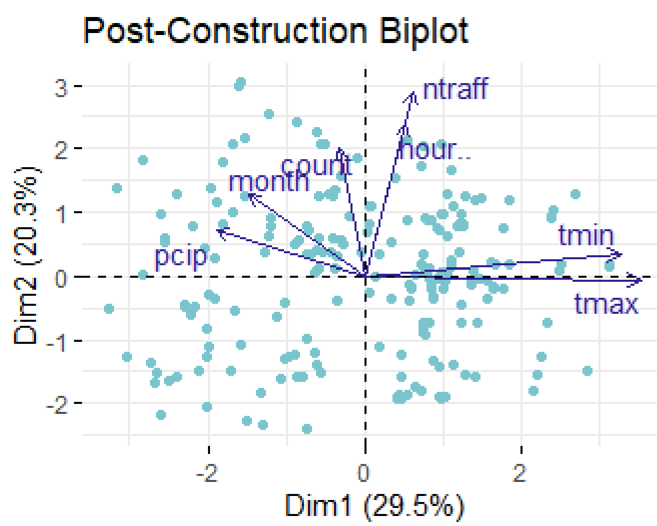


Similar to the individual contribution plots above, these variable plots measure only the contribution that each collected category has to each other. Arrows that point away from each other indicate non-correlated predicates. Arrows that point in the same direction are more correlated with each other.

In this particular case, we note that precipitation and month are highly correlated. This makes sense give that seasonal changes in the year are related to the weather. Additionally, we see strong correlation between daily minimum and maximum temperature. Again, this is not surprising as we expect to see fairly consist differences between daily highs and lows. Traffic appears to correlated with hour in both plots, again, this is to be expected.

Principal Components Biplots





These two biplots overlay the indivudal observcations ontop of the variable contributions for a singular plot. This provides a succinct way to quickly view how the observations may group according to the variables.

Individual Plots with Overlaid Categorical Ellipses

The following plots show the relative grouping of several categorical variables onto the individual principle components plot. Each generated ellipse has a center that is the mean of all relative points. For example, in the 'Pre-Construction: Species Groupings' plot, we see that deer and coyote have overlapping ellipses.

This is useful for a snap shot of how the species interact. Upon closer examination, we see more dense groupings of deer and coyotes that are further away from each other. It's clear that outliers pull the ellipses closer together, but note that majority of the coyote and deet are not particularly similar.

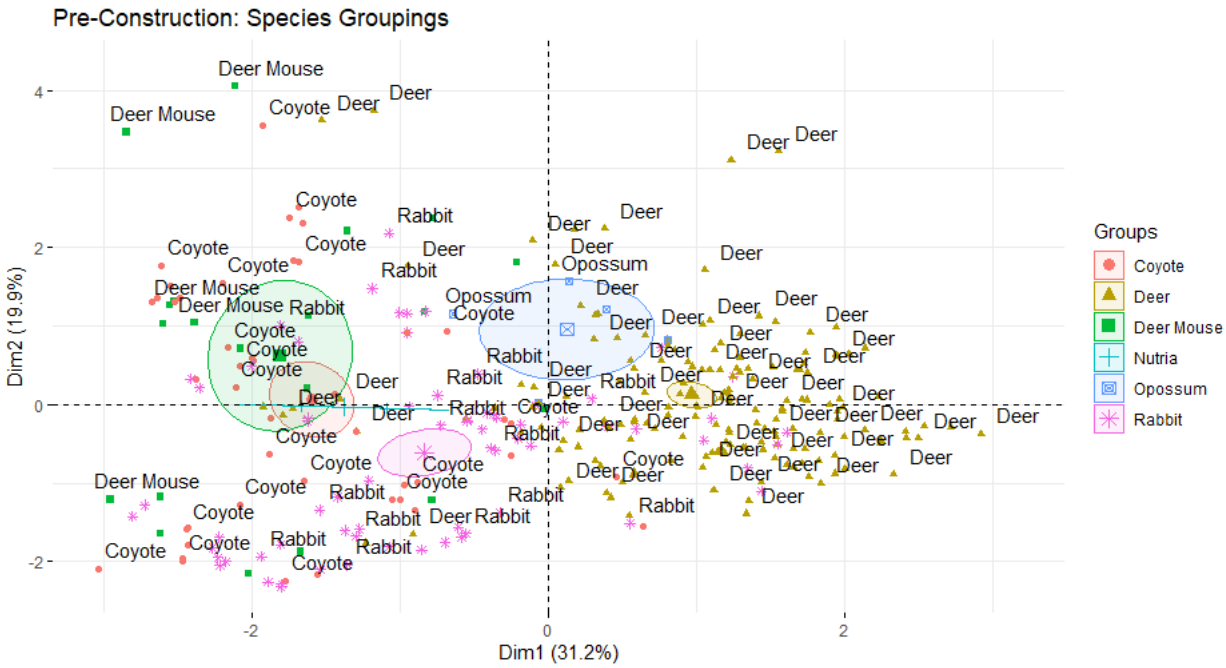
Each page will have pre-construction and post-construction plots adjacent to each other. Please note that due to variation in sampling methodology, direct comparison is be to approach with a degree of skepticism.

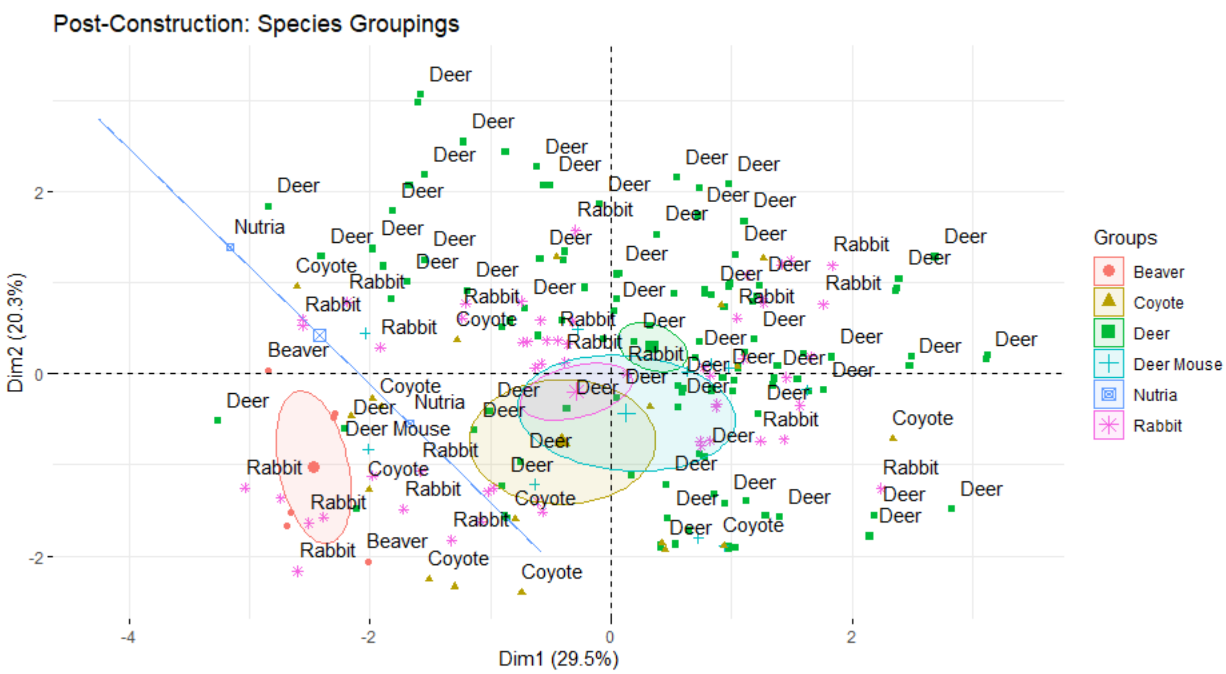
The plots are in this order:

- Species Groupings
- Mammlian Groupings
- Crepuscular/Nocturnal Groupings
- Traffic Preference

Categorical Plots: Species

The individual plots, below, show how each species interacts with each other. This could provide a useful framework to approach future culvert design to better improve usability for specific groups instead of specific species. Generally speaking, we can see that deer and coyote form two distinct groups. Additionally, we see that deer mice and coyote are simiarly grouped. This could suggest a predator-prey relationship as well as behavior due to size and culvert usage.

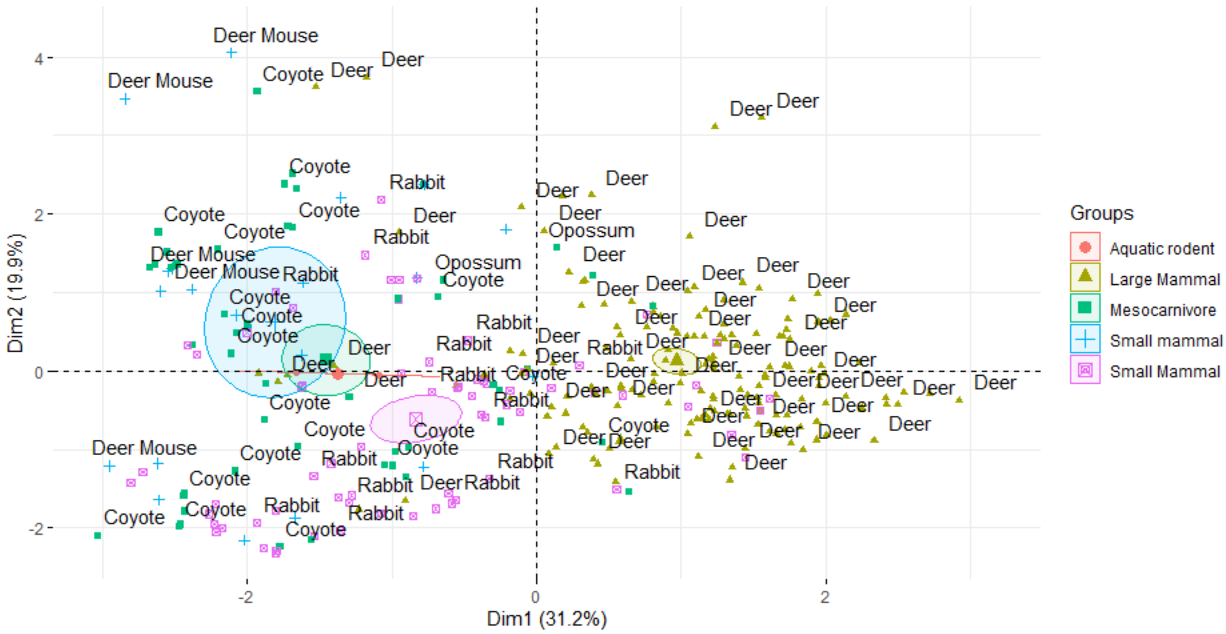




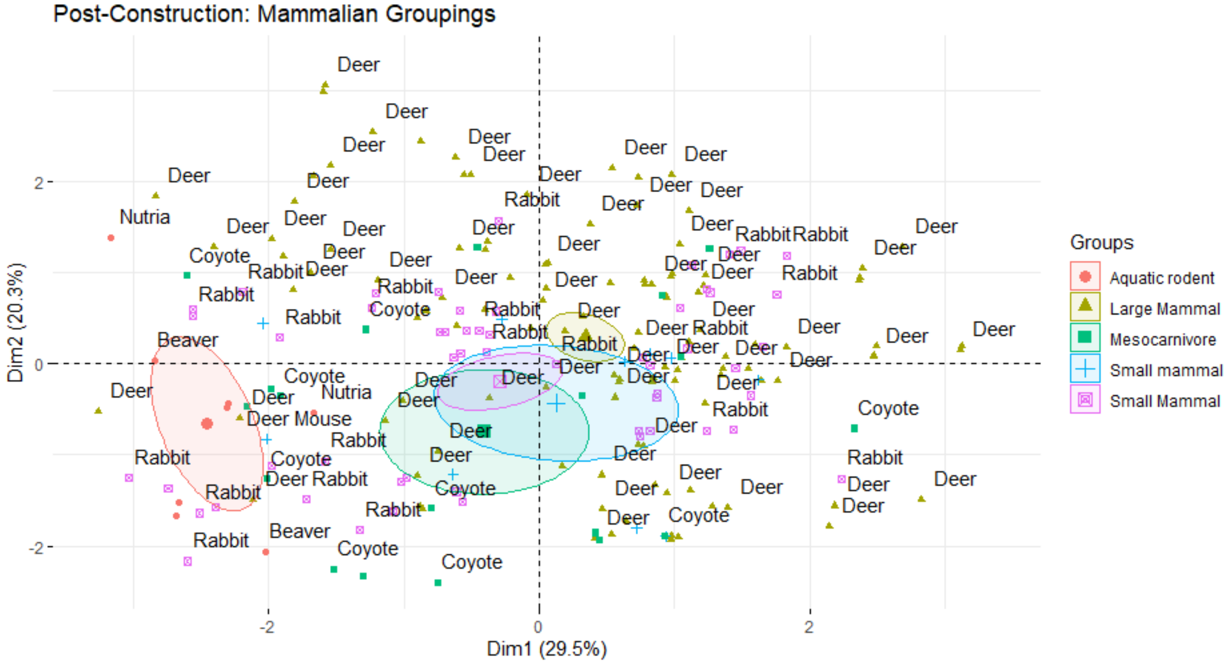
Categorical Plots: Mammalian Groups

Simiar to the species plots above, we broaden our scope of definition and sort our counts by mammalian group. Each species observation is still noted, but the colors here refer to the key seen on the right-hand side of the plots. Pre-construction shows a clear grouping of deer while every other mammalian group are more similar to each other. In post-construction, we see the variation start to move closer. This could indicate the presence of a funneling effect.

Pre-Construction: Mammalian Groupings

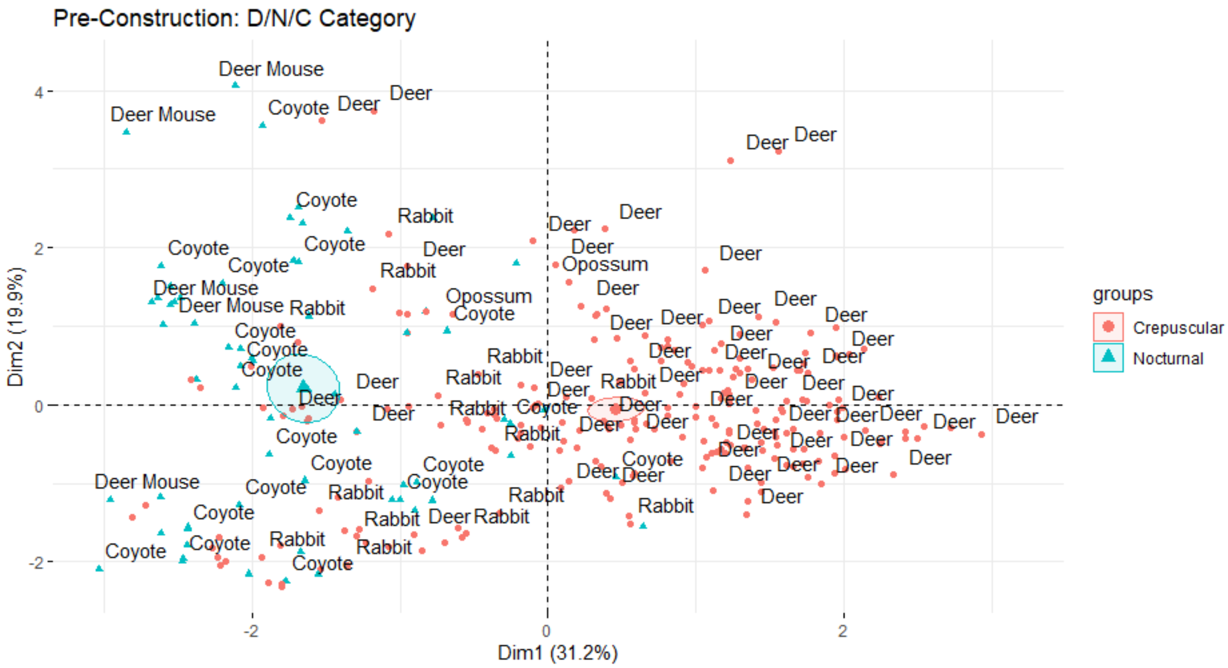


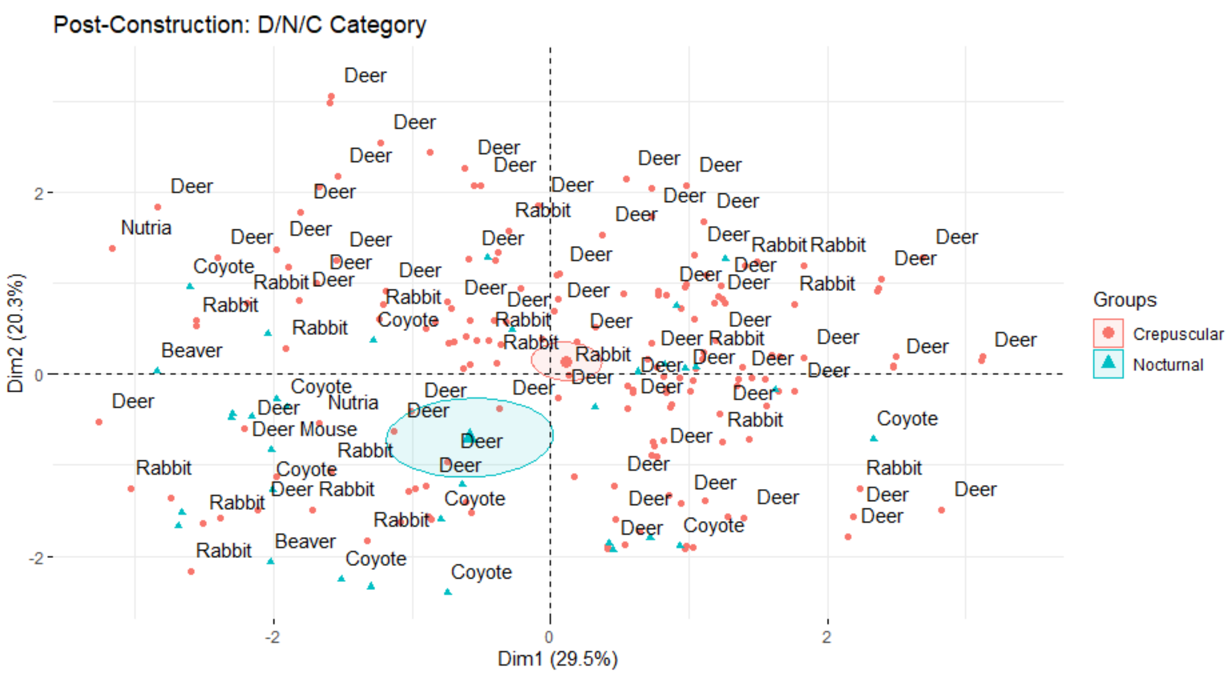
Post-Construction: Mammalian Groupings



Categorical Plots: Crepuscular/Nocturnal

Here, we can further our scope from mammalian group, into only hours of activity. There are two groups - crepuscular and nocturnal. Crepuscular animals are more active during the evening and dawn hours while nocturnal animals are more active during nighttime hours. In pre-construction, we see two distinct grouping - as is expected. These groupings still exist in post-construction, yet the variability is more evenly mixed. If these two groups are merging, then it could suppport the notion that the road crossing provide funneling effects.

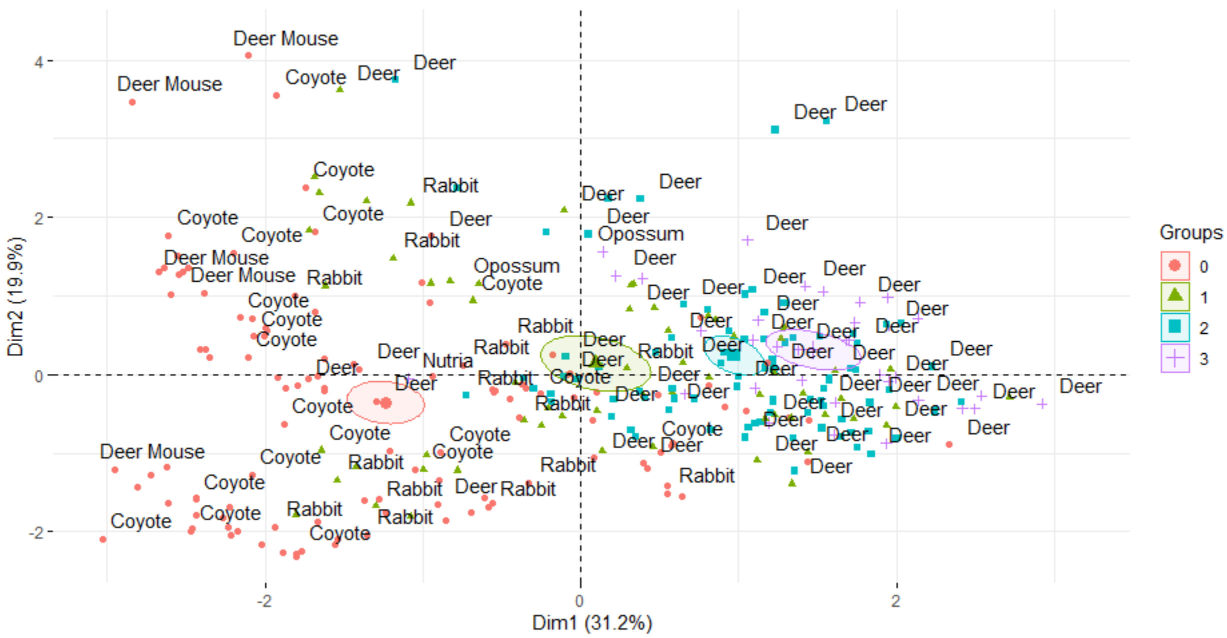




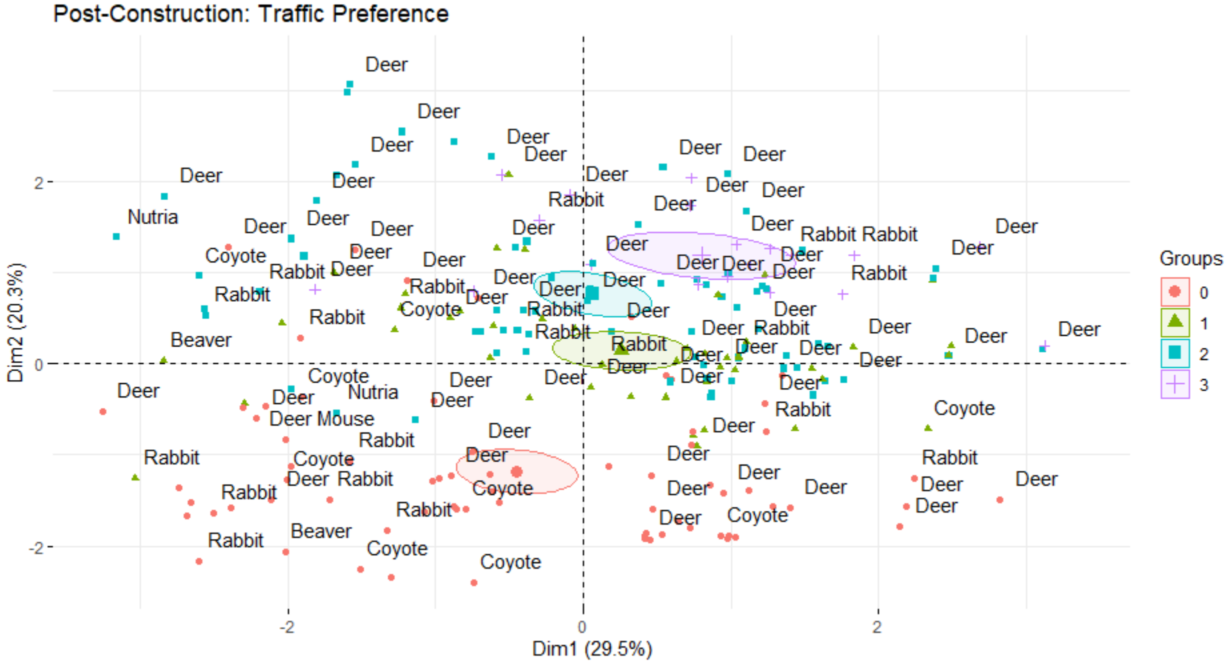
Categorical Plots: Traffic

When overlaid with recent traffic onto our historical data, we can see some relationship with the presence of traffic. Pre-construction shows that deer have almost no traffic preference and will be present regardless of automobile activity. The converse is true for the other species. In post-construction, we see a similar trend. However, it seems that only coyotes have this preference for traffic while every other species does not seem effected. The datasets used for this are severely mismatched and the results here should only be used to encourage addtional study with standardized sampling methods.

Pre-Construction: Traffic Preference



Post-Construction: Traffic Preference



R Code (1 of 8)

```
# Import data set from github
# Github Access URL: https://github.com/Kinsman-Road/rcode.git
library(readxl)
pre <- read_excel("PCA/pca.xlsx", sheet = "pca.pre.c")
post <- read_excel("PCA/pca.xlsx", sheet = "pca.post.c")

# Prepare dataframes
pre <- data.frame(pre)
post <- data.frame(post)

pre.n <- pre[1:7]      #create dataframes with only numerical columns from pre
post.n <- post[1:7]    #create dataframs with only numerical columns from post

# Performing principal components analysis
library(factoextra)
library(FactoMineR)

pca.pre <- prcomp(pre.n, scale = TRUE)   #singular value decomposition
pca.post <- prcomp(post.n, scale = TRUE)   #singular value decomposition
pre.eig <- get_eigenvalue(pca.pre)
post.eig <- get_eigenvalue(pca.post)

# Calculate PCA coordinates

# Pre-Construction PCA Coordinates
pre.vcf <- function(pre.load, comp.sdev){pre.load*comp.sdev}
pre.load <- pca.pre$rotation
pre.sdev <- pca.pre$sdev
pre.vcoord <- t(apply(pre.load, 1, pre.vcf, pre.sdev ))
pre.vc <- head(pre.vcoord[,1:7])   #1:7 number of dimensions

# Post-Construction PCA Coordinates
post.vcf <- function(post.load, comp.sdev){post.load*comp.sdev}
post.load <- pca.post$rotation
post.sdev <- pca.post$sdev
post.vcoord <- t(apply(post.load, 1, post.vcf, post.sdev))
post.vc <- head(post.vcoord[,1:7])   #1:7 number of dimensions

pre.vc      #table of pre pca coords
post.vc     #table of post pca coords

# PCA Qualtity of Representation
pre.cos2 <- pre.vcoord^2
post.cos2 <- post.vcoord^2

pre.cos2     #table of contribution to each dimension
post.cos2    #table of contribution to each dimension
```

R Code (2 of 8)

```r
# PCA Contributions to Each Given Component
pre.cc2 <- apply(pre.cos2, 2, sum)
contrib <- function(pre.cos2, pre.cc2){pre.cos2*100/pre.cc2}
pre.varc <- t(apply(pre.cos2, 1, contrib, pre.cc2))
pre.vcontrib <- head(pre.varc[,1:7])    #1:7 number of dimensions

post.cc2 <- apply(post.cos2, 2, sum)
contrib <- function(post.cos2, post.cc2){post.cos2*100/post.cc2}
post.varc <- t(apply(post.cos2, 1, contrib, post.cc2))
post.vcontrib <- head(post.varc[,1:7])    #1:7 number of dimensions

pre.vcontrib
post.vcontrib

# Creating a scree plot to determine principal dimensions of interest
pre.scree <- fviz_eig(pca.pre,
                      title = "Pre-Construction Scree Plot")

post.scree <- fviz_eig(pca.post,
                       title = "Post-Construction Scree Plot")
pre.scree
post.scree

# Creating contribution plot for individual observations
pre.ind <- fviz_pca_ind(pca.pre,
                        col.ind = "cos2",
                        gradient.cols = c("#00AFBB", "#E7B800", "#FC4E07"),
                        repel = TRUE,
                        label = "none",
                        title = "Pre-Construction Individual Plot")

post.ind <- fviz_pca_ind(pca.post,
                        col.ind = "cos2",
                        gradient.cols = c("#00AFBB", "#E7B800", "#FC4E07"),
                        repel = TRUE,
                        label = "none",
                        title = "Post-Construction Individual Plot")
pre.ind
post.ind
```

R Code (3 of 8)

```r
# Creating contribution plot for variable contributions
pre.var <- fviz_pca_var(pca.pre,
                        col.var = "cos2",
                        gradient.cols = c("#00AFBB", "#E7B800", "#FC4E07"),
                        repel = TRUE,
                        title = "Pre-Construction Variable Plot")

post.var <- fviz_pca_var(pca.post,
                         col.var = "cos2",
                         gradient.cols = c("#00AFBB", "#E7B800", "#FC4E07"),
                         repel = TRUE,
                         title = "Post-Construction Variable Plot")
pre.var
post.var

# Creating a biplot(combination of ind + var plots)
pre.bp <- fviz_pca_biplot(pca.pre,
                         col.ind = "coral",
                         col.var = "#2f2091",
                         label = "var",
                         repel = TRUE,
                         title = "Pre-Construction Biplot")

post.bp <- fviz_pca_biplot(pca.post,
                           col.ind = "cadetblue3",
                           col.var = "#2f2091",
                           label = "var",
                           repel = TRUE,
                           title = "Post-Construction Biplot")
pre.bp
post.bp

# Creating 3D Observation Plots
library(pca3d)

pre3d.species <- pca3d(pca.pre, group=pre$species)
pre3d.mcat <- pca3d(pca.pre, group=pre$category)
pre3d.dnc <- pca3d(pca.pre, group=pre$dnc)
pre3d.traffic <- pca3d(pca.pre, group=pre$traffic)

post3d.species <- pca3d(pca.post, group=post$species)
post3d.mcat <- pca3d(pca.post, group=post$category)
post3d.dnc <- pca3d(pca.post, group=post$dnc)
post3d.traffic <- pca3d(pca.post, group=post$traffic)
```

R Code (4 of 8)

```
# Creating an individual PCA plot with ellipses for categories
# (1) First define categories as factors

# (1a) Pre categories
pre.g.species <- as.factor(pre$species[1:351])
pre.g.solar <- as.factor(pre$solar[1:351])
pre.g.cat <- as.factor(pre$category[1:351])
pre.g.cam <- as.factor(pre$camera[1:351])
pre.g.traffic <- as.factor(pre$traffic[1:351])
pre.g.dnc <- as.factor(pre$dnc[1:351])

# (1b) Post categories
post.g.species <- as.factor(post$species[1:221])
post.g.solar <- as.factor(post$solar[1:221])
post.g.cat <- as.factor(post$category[1:221])
post.g.cam <- as.factor(post$camera[1:221])
post.g.traffic <- as.factor(post$traffic[1:221])
post.g.dnc <- as.factor(post$dnc[1:221])

# (2) Produce ellipses PCA graphs for every factor

# (2a) Pre-Construction Ellipses PCA categories
pre.species <- fviz_pca_ind(pca.pre,
                            col.ind = pre.g.species,
                            palette = c( ),
                            addEllipses = TRUE,
                            ellipse.type = "confidence",
                            legend.title = "Groups",
                            repel = TRUE,
                            label = "none",
                            title = "Pre-Construction: Species Groupings") +
                   geom_text(
                            label=pre$species,
                            nudge_x = 0.25, nudge_y = 0.25,
                            check_overlap = T)

pre.solar <- fviz_pca_ind(pca.pre,
                            col.ind = pre.g.solar,
                            palette = c( ),
                            addEllipses = TRUE,
                            ellipse.type = "confidence",
                            legend.title = "Groups",
                            repel = TRUE,
                            label = "none",
                            title = "Pre-Construction: Daylight Preference") +
                   geom_text(
                            label=pre$species,
                            nudge_x = 0.25, nudge_y = 0.25,
                            check_overlap = T)
```

R Code (5 of 8)

```r
# (2a) Pre-Construction Ellipses PCA categories (Continued)
pre.cat <- fviz_pca_ind(pca.pre,
                            col.ind = pre.g.cat,
                            palette = c( ),
                            addEllipses = TRUE,
                            ellipse.type = "confidence",
                            legend.title = "Groups",
                            repel = TRUE,
                            label = "none",
                            title = "Pre-Construction: Mammalian Groupings") +
                   geom_text(
                            label=pre$species,
                            nudge_x = 0.25, nudge_y = 0.25,
                            check_overlap = T)

pre.cam <- fviz_pca_ind(pca.pre,
                            col.ind = pre.g.cam,
                            palette = c( ),
                            addEllipses = TRUE,
                            ellipse.type = "confidence",
                            legend.title = "Groups",
                            repel = TRUE,
                            label = "none",
                            title = "Pre-Construction: Camera Preference") +
                   geom_text(
                            label=pre$species,
                            nudge_x = 0.25, nudge_y = 0.25,
                            check_overlap = T)

pre.traffic <- fviz_pca_ind(pca.pre,
                           col.ind = pre.g.traffic,
                           palette = c( ),
                           addEllipses = TRUE,
                           ellipse.type = "confidence",
                           legend.title = "Groups",
                           repel = TRUE,
                           label = "none",
                           title = "Pre-Construction: Traffic Preference") +
                  geom_text(
                           label=pre$species,
                           nudge_x = 0.25, nudge_y = 0.25,
                           check_overlap = T)
```

R Code (6 of 8)

```
# (2a) Pre-Construction Ellipses PCA categories (Continued)
pre.dnc <- fviz_pca_ind(pca.pre,
                            col.ind = pre.g.dnc,
                            palette = c(""),
                            addEllipses = TRUE,
                            ellipse.type = "confidence",
                            legend.title = "groups",
                            repel = TRUE,
                            label = "none",
                            title = "Pre-Construction: D/N/C Category") +
                   geom_text(
                            label=pre$species,
                            nudge_x = 0.25, nudge_y = 0.25,
                            check_overlap = T)

# (2b) Post-Construction Ellipses PCA categories
post.species <- fviz_pca_ind(pca.post,
                            col.ind = post.g.species,
                            palette = c( ),
                            addEllipses = TRUE,
                            ellipse.type = "confidence",
                            legend.title = "Groups",
                            repel = TRUE,
                            label = "none",
                            title = "Post-Construction: Species Groupings") +
                   geom_text(
                            label=post$species,
                            nudge_x = 0.25, nudge_y = 0.25,
                            check_overlap = T)

post.solar <- fviz_pca_ind(pca.post,
                          col.ind = post.g.solar,
                          palette = c( ),
                          addEllipses = TRUE,
                          ellipse.type = "confidence",
                          legend.title = "Groups",
                          repel = TRUE,
                          label = "none",
                          title = "Post-Construction: Daylight preference") +
                 geom_text(
                          label=post$species,
                          nudge_x = 0.25, nudge_y = 0.25,
                          check_overlap = T)
```

R Code (7 of 8)

```r
# (2b) Post-Construction Ellipses PCA categories (Continued)
post.cat <- fviz_pca_ind(pca.post,
                        col.ind = post.g.cat,
                        palette = c( ),
                        addEllipses = TRUE,
                        ellipse.type = "confidence",
                        legend.title = "Groups",
                        repel = TRUE,
                        label = "none",
                        title = "Post-Construction: Mammalian Groupings") +
               geom_text(
                        label=post$species,
                        nudge_x = 0.25, nudge_y = 0.25,
                        check_overlap = T)

post.cam <- fviz_pca_ind(pca.post,
                        col.ind = post.g.cam,
                        palette = c( ),
                        addEllipses = TRUE,
                        ellipse.type = "confidence",
                        legend.title = "Groups",
                        repel = TRUE,
                        label = "none",
                        title = "Post-Construction: Camera Preference") +
               geom_text(
                        label=post$species,
                        nudge_x = 0.25, nudge_y = 0.25,
                        check_overlap = T)

post.traffic <- fviz_pca_ind(pca.post,
                            col.ind = post.g.traffic,
                            palette = c( ),
                            addEllipses = TRUE,
                            ellipse.type = "confidence",
                            legend.title = "Groups",
                            repel = TRUE,
                            label = "none",
                            title = "Post-Construction: Traffic Preference") +
                   geom_text(
                            label=post$species,
                            nudge_x = 0.25, nudge_y = 0.25,
                            check_overlap = T)
```

R Code (8 of 8)

```r
# (2b) Post-Construction Ellipses PCA categories (Continued)
post.dnc <- fviz_pca_ind(pca.post,
                             col.ind = post.g.dnc,
                             palette = c( ),
                             addEllipses = TRUE,
                             ellipse.type = "confidence",
                             legend.title = "Groups",
                             repel = TRUE,
                             label = "none",
                             title = "Post-Construction: D/N/C Category") +
                    geom_text(
                             label=post$species,
                             nudge_x = 0.25, nudge_y = 0.25,
                             check_overlap = T)

# Generate Plots
pre.scree
pre.ind
pre.var
pre.bp
pre.species
pre.solar
pre.cat
pre.cam
pre.traffic
pre.dnc

post.scree
post.ind
post.var
post.bp
post.species
post.solar
post.cat
post.cam
post.traffic
post.dnc
```