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# Leveraging Land Condition Trend Analysis (LCTA) Data to Understand Vegetation Change on Military Installations: Phase I Transfer Plan

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# Leveraging Land Condition Trend Analysis (LCTA) Data to Understand Vegetation Change on Military Installations: Phase I Transfer Plan

DoD Legacy Project 13-623

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## Introduction

In this project we began to apply new analytical techniques to historical vegetation data. We focused specifically on data from Land Cover Trend Analysis (LCTA) plots. LCTA plots are permanently marked and were implemented with a standard methodology (Tazik et al. 1992), ensuring that the resulting data are robust. In addition, the plots span remarkable spatial extents and data have been collected over long time series.

Some LCTA data have been analyzed (e.g., Jones & Kunze 2003), but since then many analytical techniques have been developed and other techniques have become feasible as computing power increased. We are using these techniques to leverage historical vegetation data and understand how military activities have affected plant communities (Bakker & Mitchell 2015). This transfer plan provides initial guidance on how the approaches used in this project could be applied to LCTA data from other military installations, and to data from other permanent plot series. We will prepare additional and more detailed guidance as part of Department of Defense Legacy projects 14-623 and 15-623.

## Data Files

These analyses were based on three data files:

1. **Composition Data**: Cover of each taxon on each of the 201 plots in each year (1989, 2002). Cover was calculated as the number of points on which the taxon occurred divided by the total number of points in the plot. These data were obtained from the YTC LCTA database. This file contained 402 rows (plot-year combinations) and 132 columns (taxa).
2. **Environmental Data**: Abiotic and climatic variables about individual plots, along with other descriptive information about them. Most of these data were obtained from

the YTC LCTA database or from GIS. This file contained 201 rows (plots) and 52 columns (variables).

3. **Plant Trait Data**: Functional trait and other information about the common taxa present on these plots. These data were obtained from the USDA Plants database. This file contained 30 rows (taxa) and 8 columns (traits).

Other users would have to establish similar data files, though of course the exact size and contents of these files would depend on the dataset.

All files were saved in CSV format.

## R Script

All analyses were conducted in R software (v. 3.1.2) as accessed through RStudio (v. 0.98.1028) on a PC platform. Commands and analytical capabilities may differ among software versions.

The script used to generate these analyses is provided beginning on page 4. While this script will provide a helpful starting point for other users, it includes details that are specific to the YTC LCTA dataset, such as the identification of plots that were not measured in both 1989 and 2002. Other users would have to adjust the code to fit the particular details of their dataset. Also, please note that the script includes code from some exploratory analyses that were not included in the final report.

## References

Bakker, J.D. and R.M. Mitchell. 2015. *Leveraging Land Condition Trend Analysis (LCTA) Data to Understand Vegetation Change on Military Installations: Phase I Report*. Project 13-623. Department of Defense, Legacy Resource Management Program.

Jones, D.S., and M. Kunze. 2003. *Land Condition-Trend Analysis (LCTA) Technical Report: 1989-2002, Yakima Training Center, WA*. CEMML TPS 03-10. The Center for Environmental Management of Military Lands, Colorado State University, Fort Collins, CO.

Tazik, D.J., S.D. Warren, V.E. Diersing, R.B. Shaw, R.J. Brozka, C.F. Bagley, and W.R. Whitworth. 1992. *U.S. Army Land Condition Trend Analysis (LCTA) Plot Inventory Field Methods*. USACERL Technical Report N-92/03. US Army Corps of Engineers, Construction Engineering Research Laboratory.

```
## Analyses and Figure Generation for YTC LCTA data, Years 1989 and 2002
## Legacy Project 13-623
## JD Bakker and RM Mitchell
## 150630

##### Load Relevant Packages
library(labdsv)
library(vegan)
library(gtools)
library(indicspecies)
library(ggplot2)
library(plyr)
library(reshape2)
library(grid)
library(lsmeans)
library(mvpart)
#load TITAN functions 'titan' and 'plot.taxaz'
# source = http://onlinelibrary.wiley.com/doi/10.1111/j.2041-210X.2009.00007.x/suppinfo
#'...\TITAN\titan.R.2.9.2.txt'
#'...\TITAN\plot.taxaz.R.2.9.2.txt'


##### Load Data Files
#setwd('C:/Users/jbakker/Dropbox/Active Projects/DoD Legacy')
setwd('C://Users/Jonathan/Dropbox/Active Projects/DoD Legacy')

cov <- read.csv('Raw.Data.140807.csv', header=T) # Choose file 'Raw.Data.140807.csv'; 471 x 139
backup <- cov

env <- read.csv('plot.data.150105.csv', header = TRUE) #Choose 'plot.data.150105.csv'; 202 x 52
env2 <- env

plants <- read.csv('plant.trait.attributes.141216.csv', header = TRUE)
#Choose 'plant.trait.attributes.141216.csv'; 30 x 8
plants2 <- plants

##### Data Processing
```

```
#drop plots not measured in both years
cov <- cov[cov$PLOTID != 57 & cov$PLOTID < 203, ]
env <- env[env$PLOTID != 57 & env$PLOTID < 203, ]

#replace NAs with zero
cov[is.na(cov)] <- 0

#combine ASPU9 and ASPUG2 (latter is subspecies of former)
cov$ASPU9 <- cov$ASPU9 + cov$ASPUG2
cov$ASPUG2 <- NULL

#remove substrates
cov <- cov[, ! colnames(cov) %in% c("L", "LG", "LS", "MOSS")]

#create new object for plot/year, and Remove PlotID and Year from cover
plot.year <- cov[,c("PLOTID", "YEAR")]
cov <- cov[, ! colnames(cov) %in% colnames(plot.year)]

#eliminate rare species; 30 species retained
cov.red <- vegtab(taxa=cov, minval=(.05*402))
dim(cov.red)
colnames(cov.red)

#List of species names
spp <- colnames(cov.red)

#Relativize data
cov.std <- decostand(cov.red, method = "total")

#Append plot ID and Year for subsetting
cov.all <- cbind(plot.year, cov.std)

#Subset by year and remove PLOTID and YEAR from data
cov.89 <- cov.all[cov.all$YEAR == "1989", colnames(cov.all) %in% spp]
cov.02 <- cov.all[cov.all$YEAR == "2002", colnames(cov.all) %in% spp]
```

```
##### OBJECTIVE 1 (CLASSIFY COMMUNITIES IN 1989 AND 2002) #####

##### Cluster Analysis
#Cluster analysis
cov.clust.89<-hclust(d = vegdist(cov.89, method = "bray"), method = "ward.D2")
cov.clust.02<-hclust(d = vegdist(cov.02, method = "bray"), method = "ward.D2")

#Examine scree plots for each year
heights.89 <- cbind(cov.clust.89$height, cov.clust.89$merge)
colnames(heights.89) <- c("Height", "JoinsThis", "WithThis")
plot(x = 10:1, y = heights.89[(nrow(heights.89)-9):nrow(heights.89),1],
     xlab = "Number of groups", ylab = "Height", main = "1989")
#scree plot shows 3 (or 5) groups

heights.02 <- cbind(cov.clust.02$height, cov.clust.02$merge)
colnames(heights.02) <- c("Height", "JoinsThis", "WithThis")
plot(x = 10:1, y = heights.02[(nrow(heights.02)-9):nrow(heights.02),1],
     xlab = "Number of groups", ylab = "Height", main = "2002")
# scree plot shows 4 groups

#Create initial groupings based on scree plot
plot(cov.clust.89, hang=-1)
group.89 <- rect.hclust(cov.clust.89, k= 3)
group.89

plot(cov.clust.02, hang=-1)
group.02 <- rect.hclust(cov.clust.02, k=4)
group.02

#get group identity
groups.89 <- data.frame(G89 = cutree(cov.clust.89, k=3))
groups.89$Group.89[groups.89$G89 == 1] <- "89A"
groups.89$Group.89[groups.89$G89 == 2] <- "89B"
groups.89$Group.89[groups.89$G89 == 3] <- "89C"
groups.89 <- merge(x = plot.year, y = groups.89, by = "row.names")
groups.89$Group <- groups.89$Group.89
```

```
groups.02 <- data.frame(G02 = cutree(cov.clust.02, k=4))
groups.02$Group.02[groups.02$G02 == 1] <- "02A"
groups.02$Group.02[groups.02$G02 == 2] <- "02B"
groups.02$Group.02[groups.02$G02 == 3] <- "02C"
groups.02$Group.02[groups.02$G02 == 4] <- "02D"
groups.02$Group.02[groups.02$G02 == 5] <- "02E"
groups.02 <- merge(x = plot.year, y = groups.02, by = "row.names")
groups.02$Group <- groups.02$Group.02

#combine group IDs
Groups <- merge(x = plot.year, y = groups.89[,c("PLOTID", "G89", "Group.89")],
                by = "PLOTID", all.x = TRUE)
Groups <- merge(x = Groups, y = groups.02[,c("PLOTID", "G02", "Group.02")],
                by = "PLOTID", all.x = TRUE)
Groups <- merge(x = Groups, y = rbind(groups.89[,c("Row.names", "PLOTID", "YEAR", "Group")],
                                      groups.02[,c("Row.names", "PLOTID", "YEAR", "Group")]),
                by = c("PLOTID", "YEAR"), all.x = TRUE)
Groups$Transition <- paste(Groups$Group.89, Groups$Group.02, sep = "_")

# Cross-classification matrix
tab <- table(factor(Groups$Group.89), factor(Groups$Group.02))
tab <- rbind(tab, colSums(tab)); tab <- cbind(tab, rowSums(tab))
tab/2 #because Groups contains both years

#Output group identities of each plot in each year
write.table(Groups, file=file.choose(), sep=",", row.names=F)
# saved as 'cluster.analysis.groups.150105.txt'


##### Identify Dominant and Iindicator Species of each Community
#1989 vs 2002
master <- merge(x = Groups, y = cov.std, by.x = "Row.names", by.y = "row.names")
row.names(master) <- as.numeric(master$Row.names)
master <- master[order(as.numeric(master$PLOTID), as.numeric(master$YEAR)), ]
(dom <- ddply(master[ , colnames(master) %in% spp], .(YEAR = master$YEAR), numcolwise(mean)))
ISA.89v02 <- multipatt(x = master[,colnames(master) %in% spp], cluster = master$YEAR,
                       control = how(nperm = 999))
```

```
summary(ISA.89v02, indvalcomp = TRUE, minstat = 0.5)

#1989
master.89 <- master[master$YEAR == "1989", ]
(dom.89 <- ddply(master.89[ , colnames(master.89) %in% spp], .(Group.89 = master.89$Group.89),
                 numcolwise(mean)))
ISA.89 <- multipatt(x = master.89[,colnames(master.89) %in% spp], cluster = master.89$Group.89,
                    control=how(nperm=999))
summary(ISA.89, indvalcomp = TRUE, minstat = 0.5)

#2002
master.02 <- master[master$YEAR == "2002", ]
(dom.02 <- ddply(master.02[ , colnames(master.02) %in% spp], .(Group.02 = master.02$Group.02),
                 numcolwise(mean)))
ISA.02 <- multipatt(x = master.02[,colnames(master.02) %in% spp], cluster = master.02$Group.02,
                    control=how(nperm=999))
summary(ISA.02, indvalcomp = TRUE, minstat = 0.5)


##### NMDS ordinations
#1989 communities
NMDS.1989 <- metaMDS(cov.89, distance = "bray", k = 2, autotransform = F,
                     trymax = 1000, model = "global", engine = "monoMDS", maxit = 500)
stressplot(NMDS.1989)
NMDS.1989$stress

out.MDS.1989 <- data.frame(MDS1 = NMDS.1989$points[,1], MDS2 = NMDS.1989$points[,2])
out.MDS.1989 <- merge(x = master.89[, ! colnames(master.89) %in% spp], y = out.MDS.1989,
                      by.x = "Row.names", by.y = "row.names")

find_hull <- function(out.MDS.1989) out.MDS.1989[chull(out.MDS.1989$MDS1, out.MDS.1989$MDS2), ]
hulls.89 <- ddply(out.MDS.1989, .(Group.89), find_hull)

ord.all.1989 <- ggplot(data = out.MDS.1989, aes(MDS1, MDS2, color = Group.89,
                                                linetype = Group.89, shape = Group.89,
                                                fill = Group.89)) +
  geom_polygon(data = hulls.89, fill = "grey", alpha = 0.1) +
```

```
  geom_point(size = 2, alpha = 0.75) +
  scale_color_manual(name = "Community", values = c("black", "black", "black"),
                     labels=c("Big Sagebrush/Grass", "Big Sagebrush/Exotic", "Dwarf Shrub")) +
  scale_linetype_manual(name = "Community", values=c("solid", "dotted", "dashed"),
                        labels = c("Big Sagebrush/Grass", "Big Sagebrush/Exotic",
                                   "Dwarf Shrub")) +
  scale_shape_manual(name = "Community", values = c(24, 21, 22),
                     labels = c("Big Sagebrush/Grass", "Big Sagebrush/Exotic",
                                "Dwarf Shrub")) +
  scale_fill_manual(name = "Community", values = c("black", "grey", "white"),
                    labels = c("Big Sagebrush/Grass", "Big Sagebrush/Exotic",
                               "Dwarf Shrub")) +
  theme_bw() + #set background theme for plot
  theme(plot.background=element_blank(), panel.grid.major=element_blank(),
        panel.grid.minor=element_blank(), panel.background=element_blank(),
        axis.ticks = element_blank(), axis.text = element_blank(),
        axis.title = element_blank())
ord.all.1989

png("1989_NMDS.png", width = 6.5, height = 4, units = 'in', res = 800)
plot(ord.all.1989) # output high-resolution plot
dev.off()

#2002 communities
NMDS.2002 <- metaMDS(cov.02, distance = "bray", k = 2, autotransform = F,
                     trymax = 1000, model = "global", engine = "monoMDS", maxit = 500)
stressplot(NMDS.2002)
NMDS.2002$stress

out.MDS.2002 <- data.frame(MDS1 = NMDS.2002$points[,1], MDS2 = NMDS.2002$points[,2])
out.MDS.2002 <- merge(x = master.02[, ! colnames(master.02) %in% spp], y = out.MDS.2002,
                      by.x = "Row.names", by.y = "row.names")

find_hull <- function(out.MDS.2002) out.MDS.2002[chull(out.MDS.2002$MDS1, out.MDS.2002$MDS2), ]
hulls.02 <- ddply(out.MDS.2002, .(Group.02), find_hull)

ord.all.2002 <- ggplot(data = out.MDS.2002, aes(MDS1, MDS2, color = Group.02,
```

```
                                                  linetype = Group.02, shape = Group.02,
                                                  fill = Group.02)) +
  geom_polygon(data = hulls.02, fill = "grey", alpha = 0.1) +
  geom_point(size = 2, alpha = 0.75) +
  scale_color_manual(name = "Community", values = c("black", "black", "black", "black"),
                     labels=c("Grass Steppe", "Exotic", "Big Sagebrush/Grass", "Dwarf Shrub")) +
  scale_linetype_manual(name = "Community", values=c("solid", "dotted", "dashed", "twodash"),
                        labels=c("Grass Steppe", "Exotic", "Big Sagebrush/Grass",
                                 "Dwarf Shrub")) +
  scale_shape_manual(name = "Community", values=c(24, 21, 25, 22),
                     labels=c("Grass Steppe", "Exotic", "Big Sagebrush/Grass",
                              "Dwarf Shrub")) +
  scale_fill_manual(name = "Community", values = c("black", "grey", "white", "white"),
                    labels=c("Grass Steppe", "Exotic", "Big Sagebrush/Grass",
                             "Dwarf Shrub")) +
  theme_bw() + #set background theme for plot
  theme(plot.background=element_blank(), panel.grid.major=element_blank(),
        panel.grid.minor=element_blank(), panel.background=element_blank(),
        axis.ticks = element_blank(), axis.text = element_blank(),
        axis.title = element_blank())
ord.all.2002

png("2002_NMDS.png", width = 6.5, height = 4, units = 'in', res = 800)
plot(ord.all.2002) # output high-resolution plot
dev.off()


#NMDS of all plot-year combinations
NMDS.all <- metaMDS(cov.all[, colnames(cov.all) %in% spp], distance = "bray",
                    k = 2, autotransform = F, trymax = 1000, model = "global",
                    engine = "monoMDS", maxit = 500)
stressplot(NMDS.all)
NMDS.all$stress

out <- data.frame(MDS1 = NMDS.all$points[,1], MDS2 = NMDS.all$points[,2])
out <- merge(x = master[, ! colnames(master) %in% spp], y = out, by.x = "Row.names",
             by.y = "row.names")
```

```
grp_labeller <- function(var, value){
  value <- as.character(value)
  if (var=="Group.89") {
    value[value=="89A"] <- "Big Sagebrush/Grass"
    value[value=="89B"] <- "Big Sagebrush/Exotic"
    value[value=="89C"] <- "Dwarf Shrub"
  }
  if(var=="Group.02") {
    value[value=="02A"] <- "Grass Steppe"
    value[value=="02B"] <- "Exotic"
    value[value=="02C"] <- "Big Sagebrush/Grass"
    value[value=="02D"] <- "Dwarf Shrub"
  }
  return(value)
}

ord.trans <- ggplot(data = out, aes(MDS1, MDS2, group = PLOTID)) +
  facet_grid(Group.89 ~ Group.02, labeller = grp_labeller) +
  geom_line(alpha = I(0.6), arrow = arrow(angle = 30, length = unit(0.04, "inches"),
                                          type = "closed")) +
  theme_bw() +
  theme(plot.background=element_blank(), panel.grid.major=element_blank(),
        panel.grid.minor=element_blank(), panel.background=element_blank(),
        axis.ticks = element_blank(), axis.text = element_blank(),
        axis.title = element_blank()) +
  theme(legend.position = "none")
ord.trans

png("1989_2002_transitions_NMDS.png", width = 6.5, height = 5, units = 'in', res = 800)
plot(ord.trans) # output high-resolution plot
dev.off()


##### Testing Differences in Environmental Variables among Communities
env.master <- merge(x = master.89[, ! colnames(master.89) %in% spp], y = env, by = "PLOTID")
```

```
#1989
summary(Elevation.89.res <- aov(Elevation ~ factor(Group.89), data = env.master))
lsmeans(Elevation.89.res, specs = pairwise ~ Group.89, adj = "none")
summary(HLI.89.res <- aov(Heat.Load.Index ~ factor(Group.89), data = env.master))
lsmeans(HLI.89.res, specs = pairwise ~ Group.89, adj = "none")
summary(Sand.89.res <- aov(Mean.Percent.Sand ~ factor(Group.89), data = env.master))
lsmeans(Sand.89.res, specs = pairwise ~ Group.89, adj = "none")
summary(Soil.Depth.89.res <- aov(Soil.Depth ~ factor(Group.89), data = env.master))
lsmeans(Soil.Depth.89.res, specs = pairwise ~ Group.89, adj = "none")

(ddply(env.master, .(Group.89), numcolwise(mean)))
(ddply(env.master, .(Group.89), numcolwise(min)))
(ddply(env.master, .(Group.89), numcolwise(max)))
(ddply(env.master, .(Group.89), nrow))

#2002
summary(Elevation.02.res <- aov(Elevation ~ factor(Group.02), data = env.master))
lsmeans(Elevation.02.res, specs = pairwise ~ Group.02, adj = "none")
summary(HLI.02.res <- aov(Heat.Load.Index ~ factor(Group.02), data = env.master))
lsmeans(HLI.02.res, specs = pairwise ~ Group.02, adj = "none")
summary(Sand.02.res <- aov(Mean.Percent.Sand ~ factor(Group.02), data = env.master))
lsmeans(Sand.02.res, specs = pairwise ~ Group.02, adj = "none")
summary(Soil.Depth.02.res <- aov(Soil.Depth ~ factor(Group.02), data = env.master))
lsmeans(Soil.Depth.02.res, specs = pairwise ~ Group.02, adj = "none")

(ddply(env.master, .(Group.02), numcolwise(mean)))
(ddply(env.master, .(Group.02), numcolwise(min)))
(ddply(env.master, .(Group.02), numcolwise(max)))
(ddply(env.master, .(Group.02), nrow))


##### Comparing Functional Groups Among Communities
#link functional group data with abundance data
temp1 <- dematrify(cov.all[, colnames(cov.all) %in% spp])
temp2 <- merge(x = temp1, by.x = "species", all.x = TRUE, y = plants, by.y = "Code",
               all.y = TRUE)
Func.Group <- matrify(ddply(temp2, .(sample, Functional.Group), summarise,
```

```
                            Rel.Abund = sum(abundance)))
Variables <- data.frame("TotalCover.Common" = rowSums(cov[,colnames(cov) %in% spp]),
                        "TotalCover" = rowSums(cov), "SppRich" = specnumber(cov))
#Key.Spp <- cov.all[, c("ARTR2", "ARTR4", "ARRI2", "BRTE", "POSE")]

Traits <- merge(x = master[, ! colnames(master) %in% spp], y = Func.Group,
                by.x = "Row.names", by.y = "row.names")
Traits <- merge(x = Traits, y = Variables, by.x = "Row.names", by.y = "row.names")
#Traits <- merge(x = Traits, y = Key.Spp, by.x = "Row.names", by.y = "row.names")

Traits.summary <- ddply(Traits, .(YEAR, Group), summarise,
                        N = length(!is.na(E)),
                        meanE = mean(E) * 100,
                        meanNF = mean(NF) * 100,
                        meanNG = mean(NG) * 100,
                        meanS = mean(S) * 100,
                        meanTotalCover.Common = mean(TotalCover.Common),
                        meanTotalCover = mean(TotalCover),
                        meanSppRich = mean(SppRich))

#Save functional group and other abundance-weighted data
write.table(Traits, file.choose())
# File called 'Vegetation.response.variables.150106.csv'; 402 x 16

# Analyze differences among communities in 1989
Traits.89 <- Traits[Traits$YEAR == 1989, ]

summary(TotalCover.89.res <- aov(TotalCover ~ factor(Group.89), data = Traits.89))
lsmeans(TotalCover.89.res, specs = pairwise ~ Group.89, adj = "none")
summary(SppRich.89.res <- aov(SppRich ~ factor(Group.89), data = Traits.89))
lsmeans(SppRich.89.res, specs = pairwise ~ Group.89, adj = "none")
summary(E.89.res <- aov(E ~ factor(Group.89), data = Traits.89))
lsmeans(E.89.res, specs = pairwise ~ Group.89, adj = "none")
summary(NF.89.res <- aov(NF ~ factor(Group.89), data = Traits.89))
lsmeans(NF.89.res, specs = pairwise ~ Group.89, adj = "none")
summary(NG.89.res <- aov(NG ~ factor(Group.89), data = Traits.89))
lsmeans(NG.89.res, specs = pairwise ~ Group.89, adj = "none")
```

```
summary(S.89.res <- aov(S ~ factor(Group.89), data = Traits.89))
lsmeans(S.89.res, specs = pairwise ~ Group.89, adj = "none")

# Analyze differences among communities in 2002
Traits.02 <- Traits[Traits$YEAR == 2002, ]

summary(TotalCover.02.res <- aov(TotalCover ~ factor(Group.02), data = Traits.02))
lsmeans(TotalCover.02.res, specs = pairwise ~ Group.02, adj = "none")
summary(SppRich.02.res <- aov(SppRich ~ factor(Group.02), data = Traits.02))
lsmeans(SppRich.02.res, specs = pairwise ~ Group.02, adj = "none")
summary(E.02.res <- aov(E ~ factor(Group.02), data = Traits.02))
lsmeans(E.02.res, specs = pairwise ~ Group.02, adj = "none")
summary(NF.02.res <- aov(NF ~ factor(Group.02), data = Traits.02))
lsmeans(NF.02.res, specs = pairwise ~ Group.02, adj = "none")
summary(NG.02.res <- aov(NG ~ factor(Group.02), data = Traits.02))
lsmeans(NG.02.res, specs = pairwise ~ Group.02, adj = "none")
summary(S.02.res <- aov(S ~ factor(Group.02), data = Traits.02))
lsmeans(S.02.res, specs = pairwise ~ Group.02, adj = "none")


##### OBJECTIVE 2 - TRANSITIONS AND AMOUNTS OF CHANGE #####

##### Bray-Curtis distances for each plot between 1989 and 2002
#Calculate and extract distances
temp <- merge(x = Groups, y = cov.std, by.x = "Row.names", by.y = "row.names")
temp$plot.year <- paste(temp$PLOTID, temp$YEAR, sep = "_")
rownames(temp) <- temp$plot.year
temp <- temp[order(temp$YEAR, temp$PLOTID), ]
cov.dist <- as.matrix(vegdist(temp[, colnames(temp) %in% spp], "bray", diag=T, upper=T))
change.89v02 <- cov.dist[row(cov.dist) == (col(cov.dist) + 201)]
dist.89.02 <- data.frame("Dist" = change.89v02,
                         "From" = rownames(cov.dist[1:201, ]),
                         "To" = colnames(cov.dist[ ,202:402]))
dist.89.02 <- merge(x = dist.89.02, y = temp[,c("plot.year", "PLOTID", "Group.89",
                                                "Group.02", "Transition")],
                    by.x = "From", by.y = "plot.year", all.y = FALSE)
ddply(dist.89.02, .(Transition), summarize,
```

```
      mean.Dist = mean(Dist),
      min.Dist = min(Dist),
      max.Dist = max(Dist),
      N = length(Dist))

#Save B-C distances
write.table(dist.89.02, file.choose())
#File called 'BC.distances.150106.txt'; 201 x 7

##### Test for differences in B-C distance by transition, analyzing each 1989 community
#separately
#Ignoring uncommon transitions (1-3 plots)

#Transitions from 1989 group 89A (Longleaf Phlox)
D89A <- dist.89.02[dist.89.02$Group.89 == "89A", ]
summary(Dist.89A.res <- aov(Dist ~ factor(Group.02), data = D89A)) #P = 0.092
#lsmeans(Dist.89A.res, specs = pairwise ~ Group.02)

#Transitions from 1989 group 89B (Big Sagebrush/Exotic)
D89B <- dist.89.02[dist.89.02$Group.89 == "89B" & dist.89.02$Transition != "89B_02D", ]
summary(Dist.89B.res <- aov(Dist ~ factor(Group.02), data = D89B)) #P = 0.071

#Transitions from 1989 group 89C (Dwarf Shrub)
D89C <- dist.89.02[dist.89.02$Group.89 == "89C", ]
summary(Dist.89C.res <- aov(Dist ~ factor(Group.02), data = D89C)) #P = 0.0011
lsmeans(Dist.89C.res, specs = pairwise ~ Group.02, adj = "none")


##### Functional group abundance, analyzing each 1989 community separately
#ignoring uncommon transitions (1-3 plots)

#Transitions from 1989 group 89A (Longleaf Phlox)
T89A <- Traits[Traits$Group.89 == "89A", ]
summary(TotalCover.89A.res <- aov(TotalCover ~ Group.02 + YEAR + Group.02:YEAR +
                                    Error(factor(PLOTID)), data = T89A)) #YEAR significant
summary(SppRich.89A.res <- aov(SppRich ~ Group.02 + YEAR + Group.02:YEAR +
                                 Error(factor(PLOTID)), data = T89A)) #YEAR significant
```

```
summary(E.89A.res <- aov(E ~ Group.02 + YEAR + Group.02:YEAR + Error(factor(PLOTID)),
                         data = T89A)) #Group.02, YEAR, Group02:YEAR significant
summary(aov(E ~ YEAR + Error(factor(PLOTID)), data = T89A[T89A$Group.02 == "02A",])) #NS
summary(aov(E ~ YEAR + Error(factor(PLOTID)), data = T89A[T89A$Group.02 == "02B",]))
#significant
summary(aov(E ~ YEAR + Error(factor(PLOTID)), data = T89A[T89A$Group.02 == "02C",])) #NS

summary(NF.89A.res <- aov(NF ~ Group.02 + YEAR + Group.02:YEAR + Error(factor(PLOTID)),
                          data = T89A)) #Group.02, YEAR significant

summary(NG.89A.res <- aov(NG ~ Group.02 + YEAR + Group.02:YEAR + Error(factor(PLOTID)),
                          data = T89A)) #Group.02, Group.02:YEAR significant
summary(aov(NG ~ YEAR + Error(factor(PLOTID)), data = T89A[T89A$Group.02 == "02A",])) #NS
summary(aov(NG ~ YEAR + Error(factor(PLOTID)), data = T89A[T89A$Group.02 == "02B",]))
#significant
summary(aov(NG ~ YEAR + Error(factor(PLOTID)), data = T89A[T89A$Group.02 == "02C",])) #NS

summary(S.89A.res <- aov(S ~ Group.02 + YEAR + Group.02:YEAR + Error(factor(PLOTID)),
                         data = T89A)) #Group.02, YEAR, Group.02:YEAR significant
summary(aov(S ~ YEAR + Error(factor(PLOTID)), data = T89A[T89A$Group.02 == "02A",]))
#significant
summary(aov(S ~ YEAR + Error(factor(PLOTID)), data = T89A[T89A$Group.02 == "02B",])) #NS
summary(aov(S ~ YEAR + Error(factor(PLOTID)), data = T89A[T89A$Group.02 == "02C",])) #NS

# Transitions from 1989 group 89B (Big Sagebrush/Exotic)
T89B <- Traits[Traits$Group.89 == "89B" & Traits$Transition != "89B_02D", ]
summary(TotalCover.89B.res <- aov(TotalCover ~ Group.02 + YEAR + Group.02:YEAR +
                                  Error(factor(PLOTID)), data = T89B)) #YEAR significant
summary(SppRich.89B.res <- aov(SppRich ~ Group.02 + YEAR + Group.02:YEAR +
                               Error(factor(PLOTID)), data = T89B)) #Group.02 significant

summary(E.89B.res <- aov(E ~ Group.02 + YEAR + Group.02:YEAR + Error(factor(PLOTID)),
                         data = T89B)) #Group.02, YEAR, Group02:YEAR significant
summary(aov(E ~ YEAR + Error(factor(PLOTID)), data = T89B[T89B$Group.02 == "02B",])) #NS
summary(aov(E ~ YEAR + Error(factor(PLOTID)), data = T89B[T89B$Group.02 == "02C",]))
#significant
```

```
summary(NF.89B.res <- aov(NF ~ Group.02 + YEAR + Group.02:YEAR + Error(factor(PLOTID)),
                          data = T89B)) #all NS
summary(aov(NF ~ YEAR + Error(factor(PLOTID)), data = T89B[T89B$Group.02 == "02B",])) #NS
summary(aov(NF ~ YEAR + Error(factor(PLOTID)), data = T89B[T89B$Group.02 == "02C",]))
#significant

summary(NG.89B.res <- aov(NG ~ Group.02 + YEAR + Group.02:YEAR + Error(factor(PLOTID)),
                          data = T89B)) #Group.02, YEAR, Group.02:YEAR significant
summary(aov(NG ~ YEAR + Error(factor(PLOTID)), data = T89B[T89B$Group.02 == "02B",])) #NS
summary(aov(NG ~ YEAR + Error(factor(PLOTID)), data = T89B[T89B$Group.02 == "02C",]))
#significant

summary(S.89B.res <- aov(S ~ Group.02 + YEAR + Group.02:YEAR + Error(factor(PLOTID)),
                         data = T89B)) #Group.02 significant

# Transitions from 1989 group 89C (Dwarf Shrub)
T89C <- Traits[Traits$Group.89 == "89C", ]
summary(TotalCover.89C.res <- aov(TotalCover ~ Group.02 + YEAR + Group.02:YEAR +
                                    Error(factor(PLOTID)), data = T89C))
#Group.02, YEAR significant
summary(SppRich.89C.res <- aov(SppRich ~ Group.02 + YEAR + Group.02:YEAR +
                                 Error(factor(PLOTID)), data = T89C)) #Group.02 significant

summary(E.89C.res <- aov(E ~ Group.02 + YEAR + Group.02:YEAR + Error(factor(PLOTID)),
                         data = T89C)) #Group.02, YEAR, Group.02:YEAR significant
summary(aov(E ~ YEAR + Error(factor(PLOTID)), data = T89C[T89C$Group.02 == "02A",])) #NS
summary(aov(E ~ YEAR + Error(factor(PLOTID)), data = T89C[T89C$Group.02 == "02B",]))
#significant
summary(aov(E ~ YEAR + Error(factor(PLOTID)), data = T89C[T89C$Group.02 == "02C",])) #NS
summary(aov(E ~ YEAR + Error(factor(PLOTID)), data = T89C[T89C$Group.02 == "02D",])) #NS

summary(NF.89C.res <- aov(NF ~ Group.02 + YEAR + Group.02:YEAR + Error(factor(PLOTID)),
                          data = T89C)) #Group.02 significant

summary(NG.89C.res <- aov(NG ~ Group.02 + YEAR + Group.02:YEAR + Error(factor(PLOTID)),
                          data = T89C)) #Group.02, YEAR, Group.02:YEAR significant
```

```
summary(aov(NG ~ YEAR + Error(factor(PLOTID)), data = T89C[T89C$Group.02 == "02A",])) #NS
summary(aov(NG ~ YEAR + Error(factor(PLOTID)), data = T89C[T89C$Group.02 == "02B",]))
#significant
summary(aov(NG ~ YEAR + Error(factor(PLOTID)), data = T89C[T89C$Group.02 == "02C",]))
#significant
summary(aov(NG ~ YEAR + Error(factor(PLOTID)), data = T89C[T89C$Group.02 == "02D",]))
#significant

summary(S.89C.res <- aov(S ~ Group.02 + YEAR + Group.02:YEAR + Error(factor(PLOTID)),
                         data = T89C)) #Group.02 significant

transition.summary <- ddply(Traits, .(Transition, YEAR), summarise,
                            N = length(!is.na(E)),
                            meanE = mean(E) * 100,
                            meanNF = mean(NF) * 100,
                            meanNG = mean(NG) * 100,
                            meanS = mean(S) * 100,
                            sdE = sd(E) * 100,
                            sdNF = sd(NF) * 100,
                            sdNG = sd(NG) * 100,
                            sdS = sd(S) * 100,
                            Group.89 =
                              unique(Group.89)[which.max(tabulate(match(Group.89,
                                                                        unique(Group.89))))],
                            Group.02 =
                              unique(Group.02)[which.max(tabulate(match(Group.02,
                                                                        unique(Group.02))))],
                            meanTotalCover = mean(TotalCover),
                            meanSppRich = mean(SppRich))
transition.summary[transition.summary$Group.89 == "89A", ]

##### Create graph of functional group abundances
temp.mean <- transition.summary
colnames(temp.mean)[which(colnames(temp.mean) == "meanE")] <- "Exotic"
colnames(temp.mean)[which(colnames(temp.mean) == "meanNF")] <- "Native Forb"
colnames(temp.mean)[which(colnames(temp.mean) == "meanNG")] <- "Native Grass"
colnames(temp.mean)[which(colnames(temp.mean) == "meanS")] <- "Shrub"
```

```
func.grp.sum2 <- melt(data = temp.mean, id.vars = c("Transition", "YEAR", "Group.89",
                                                    "Group.02"),
                      measure.vars = c("Exotic", "Native Forb", "Native Grass", "Shrub"),
                      variable.name = "FunctionalGroup", value.name = "Cover")
temp.sd <- transition.summary
colnames(temp.sd)[which(colnames(temp.sd) == "sdE")] <- "Exotic"
colnames(temp.sd)[which(colnames(temp.sd) == "sdNF")] <- "Native Forb"
colnames(temp.sd)[which(colnames(temp.sd) == "sdNG")] <- "Native Grass"
colnames(temp.sd)[which(colnames(temp.sd) == "sdS")] <- "Shrub"
func.grp.sum3 <- melt(data = temp.sd, id.vars = c("Transition", "YEAR", "Group.89", "Group.02"),
                      measure.vars = c("Exotic", "Native Forb", "Native Grass", "Shrub"),
                      variable.name = "FunctionalGroup", value.name = "SD.Cover")
func.grp.sum <- merge(x = func.grp.sum2, y = func.grp.sum3,
                      by = c("Transition", "YEAR", "Group.89", "Group.02", "FunctionalGroup"))

pd <- position_dodge(1)
transitions.figure <- ggplot(data = func.grp.sum,
                             aes(x = FunctionalGroup, y = Cover, fill = factor(YEAR),
                                 group = factor(YEAR))) +
  geom_bar(stat = "identity", position = position_dodge(), color = "black") +
  scale_fill_manual(values=c("black", "gray")) +
  geom_errorbar(aes(ymin = Cover, ymax = Cover+SD.Cover), color = "black", width = 0.5,
                position = pd) +
  scale_x_discrete(name = "Functional Group") +
  scale_y_continuous(name = "Relative Cover") +
  facet_grid(Group.89 ~ Group.02, labeller = grp_labeller) +
  theme_bw() +
  theme(panel.background = element_blank(), plot.background = element_blank(),
        panel.grid.major= element_blank(), panel.grid.minor = element_blank()) +
  theme(axis.text.x = element_text(angle = 90, vjust = 0.4, hjust = 1)) +
  theme(legend.position = "none")
transitions.figure

png("1989_2002_transitions.png", width = 6.5, height = 6, units = 'in', res = 800)
plot(transitions.figure) # output high-resolution plot
dev.off()
```

```
##### Indicator species of changes from 1989 to 2002
ISA.89A_02A <- multipatt(x = master[master$Transition == "89A_02A", colnames(master) %in% spp],
                         cluster = master[master$Transition == "89A_02A", "YEAR"],
                         control = how(nperm = 9999))
summary(ISA.89A_02A, indvalcomp = TRUE, minstat = 0.5) #LUSE4 (2002)

ISA.89A_02B <- multipatt(x = master[master$Transition == "89A_02B", colnames(master) %in% spp],
                         cluster = master[master$Transition == "89A_02B", "YEAR"],
                         control = how(nperm = 9999))
summary(ISA.89A_02B, indvalcomp = TRUE, minstat = 0.5) #SIAL2 (2002)

ISA.89A_02C <- multipatt(x = master[master$Transition == "89A_02C", colnames(master) %in% spp],
                         cluster = master[master$Transition == "89A_02C", "YEAR"],
                         control = how(nperm = 9999))
summary(ISA.89A_02C, indvalcomp = TRUE, minstat = 0.5) #LUSE4 (2002)

ISA.89B_02B <- multipatt(x = master[master$Transition == "89B_02B", colnames(master) %in% spp],
                         cluster = master[master$Transition == "89B_02B", "YEAR"],
                         control = how(nperm = 9999))
summary(ISA.89B_02B, indvalcomp = TRUE, minstat = 0.5) #SAKA (1989)

ISA.89B_02C <- multipatt(x = master[master$Transition == "89B_02C", colnames(master) %in% spp],
                         cluster = master[master$Transition == "89B_02C", "YEAR"],
                         control = how(nperm = 9999))
summary(ISA.89B_02C, indvalcomp = TRUE, minstat = 0.5) #BRTE (1989)

ISA.89C_02A <- multipatt(x = master[master$Transition == "89C_02A", colnames(master) %in% spp],
                         cluster = master[master$Transition == "89C_02A", "YEAR"],
                         control = how(nperm = 9999))
summary(ISA.89C_02A, indvalcomp = TRUE, minstat = 0.5) #None

ISA.89C_02B <- multipatt(x = master[master$Transition == "89C_02B", colnames(master) %in% spp],
                         cluster = master[master$Transition == "89C_02B", "YEAR"],
                         control = how(nperm = 9999))
summary(ISA.89C_02B, indvalcomp = TRUE, minstat = 0.5) #None
```

```
ISA.89C_02C <- multipatt(x = master[master$Transition == "89C_02C", colnames(master) %in% spp],
                         cluster = master[master$Transition == "89C_02C", "YEAR"],
                         control = how(nperm = 9999))
summary(ISA.89C_02C, indvalcomp = TRUE, minstat = 0.5) #ERLI (2002)

ISA.89C_02D <- multipatt(x = master[master$Transition == "89C_02D", colnames(master) %in% spp],
                         cluster = master[master$Transition == "89C_02D", "YEAR"],
                         control = how(nperm = 9999))
summary(ISA.89C_02D, indvalcomp = TRUE, minstat = 0.5) #None

ISA.spp.summary <- ddply(master, .(Transition, YEAR), summarise,
                         N = length(!is.na(PLOTID)),
                         meanLUSE4 = mean(LUSE4),
                         meanSIAL2 = mean(SIAL2),
                         meanSAKA = mean(SAKA),
                         meanBRTE = mean(BRTE),
                         meanERLI = mean(ERLI))
ISA.spp.summary


##### OBJECTIVE 3: QUANTIFYING ROLE OF DISTURBANCE #####
temp.89 <- Traits.89[order(Traits.89$PLOTID),]
temp.02 <- Traits.02[order(Traits.02$PLOTID),]
which(temp.89$PLOTID != temp.02$PLOTID) #confirm data are in same order in both objects
change <- data.frame(temp.89[ , c("PLOTID", "Group.89", "Group.02", "Transition", "E",
                                  "NF", "NG", "S", "TotalCover", "SppRich")],
                     E.change = temp.02$E - temp.89$E,
                     NF.change = temp.02$NF - temp.89$NF,
                     NG.change = temp.02$NG - temp.89$NG,
                     S.change = temp.02$S - temp.89$S,
                     TotalCover.change = temp.02$TotalCover - temp.89$TotalCover,
                     SppRich.change = temp.02$SppRich - temp.89$SppRich)
env.master2 <- merge(x = env.master, y = dist.89.02[ , c("PLOTID", "Dist")], by = "PLOTID")
env.master2 <- merge(x = env.master2, y = change,
                     by = c("PLOTID", "Group.89", "Group.02", "Transition"))
env.master2$Training <- factor(env.master2$Training, ordered = TRUE,
                               levels = c("None", "Low", "Moderate", "High"))
```

```
env.master2$TA.Usage <- factor(env.master2$TA.Usage, ordered = TRUE,
                               levels = c("Low", "Moderate", "High"))
env.master2$Road <- factor(env.master2$Road, ordered = TRUE,
                           levels = c("Low", "Moderate", "High"))
env.master2$Grazing <- factor(env.master2$Grazing, ordered = TRUE,
                              levels = c("Low", "Moderate", "High"))
env.master2$Fire <- factor(env.master2$Fire, ordered = TRUE,
                           levels = c("Burned", "Unburned"))
env.master2$Maintenance <- factor(env.master2$Maintenance, ordered = TRUE,
                                  levels = c("Yes", "No"))
env.master2$Disturbance <- factor(env.master2$Disturbance, ordered = TRUE,
                                  levels = c("Low", "Moderate", "High"))
#may be useful to conduct separate analyses for subsets (dominant transitions from
#each Group.89 level)
E89A.plots <- env.master2$Group.89 == "89A"
E89B.plots <- env.master2$Group.89 == "89B" & env.master2$Transition != "89B_02D"
E89C.plots <- env.master2$Group.89 == "89C"
uncommon.transitions <- "89B_02D"
Common.Transition.plots <- ! env.master2$Transition %in% uncommon.transitions


#B-C distance from 1989 to 2002
m0 <- aov(Dist ~ 1, data = env.master2,)
Dist.res.BIC <- stepAIC(m0, scope = list(upper = ~ factor(Group.89) * factor(Group.02) *
                                         Military.Training.Total.Intensity *
                                         TA.Usage * Distance.to.Road.ft * Grazing.Years *
                                         Fire * Maintenance, lower = ~ 1),
                        direction = "both", k = log(nrow(env.master2)))
summary(Dist.res.BIC) # Military.Training.Total.Intensity, Grazing.Years
qplot(data = env.master2, x = Military.Training.Total.Intensity, y = Dist,
      color = Grazing.Years)

Dist.grid <- with(env.master2, expand.grid(
  Military.Training.Total.Intensity = seq(min(Military.Training.Total.Intensity),
                                          max(Military.Training.Total.Intensity), length = 20),
  Grazing.Years = c(2, 4, 6)
))
```

```
Dist.grid$Dist <- stats::predict(Dist.res.BIC, newdata = Dist.grid)

Dist.plot <- ggplot(data = env.master2, aes(x = Military.Training.Total.Intensity, y = Dist)) +
  geom_point(alpha = 0.5) +
  geom_line(data = Dist.grid, aes(x = Military.Training.Total.Intensity, y = Dist,
                                  color = factor(Grazing.Years),
                                  linetype = factor(Grazing.Years))) +
  scale_x_continuous(name = "Military Training Intensity") +
  scale_y_continuous(name = "Bray-Curtis Distance") +
  scale_linetype(guide = guide_legend(title = "Grazing (years)")) +
  scale_colour_discrete(guide = guide_legend(title = "Grazing (years)")) +
  theme_bw() +
  theme(panel.background = element_blank(), plot.background = element_blank(),
        panel.grid.major=element_blank(), panel.grid.minor=element_blank(),
        legend.position = "top")
Dist.plot

png("Training.vs.BCDistance.png", width = 6.5, height = 4, units = 'in', res = 800)
plot(Dist.plot) # output high-resolution plot
dev.off()


#Total Cover in 2002
m0 <- aov((TotalCover.change+TotalCover) ~ 1, data = env.master2)
TotalCover.res.BIC <- stepAIC(m0, scope = list(upper = ~ factor(Group.89) * factor(Group.02) *
                                                 Military.Training.Total.Intensity *
                                                 TA.Usage * Distance.to.Road.ft *
                                                 Grazing.Years * Fire * Maintenance, lower = ~ 1),
                              direction = "both", k = log(nrow(env.master2)))
summary(TotalCover.res.BIC) # Group.02, Military.Training.Total.Intensity, Grazing.Years
coef(TotalCover.res.BIC)
qplot(data = env.master2, x = Military.Training.Total.Intensity,
      y = TotalCover.change+TotalCover, color = Grazing.Years)

TotalCover.grid <- with(env.master2, expand.grid(
  Group.02 = levels(factor(Group.02)),
  Military.Training.Total.Intensity = seq(min(Military.Training.Total.Intensity),
```

```
                                          max(Military.Training.Total.Intensity), length = 20),
  Grazing.Years = c(2, 4, 6)
))
TotalCover.grid$TotalCover.02 <- stats::predict(TotalCover.res.BIC, newdata = TotalCover.grid)

TotalCover.plot <- ggplot(data = env.master2, aes(x = Military.Training.Total.Intensity,
                                                  y = (TotalCover.change+TotalCover))) +
  geom_point(alpha = 0.5) +
  geom_line(data = TotalCover.grid, aes(x = Military.Training.Total.Intensity,
                                        y = TotalCover.02, color = factor(Grazing.Years),
                                    linetype = factor(Grazing.Years))) +
  facet_grid(. ~ Group.02, labeller = grp_labeller) +
  scale_x_continuous(name = "Military Training Intensity") +
  scale_y_continuous(name = "Total Cover (%)") +
  scale_linetype(guide = guide_legend(title = "Grazing (years)")) +
  scale_colour_discrete(guide = guide_legend(title = "Grazing (years)")) +
  theme_bw() +
  theme(panel.background = element_blank(), plot.background = element_blank(),
        panel.grid.major=element_blank(), panel.grid.minor=element_blank(),
        legend.position = "top")
TotalCover.plot

png("Training.vs.TotalCover.png", width = 6.5, height = 4, units = 'in', res = 800)
plot(TotalCover.plot) # output high-resolution plot
dev.off()


#Species Richness in 2002
m0 <- aov((SppRich.change+SppRich) ~ 1, data = env.master2)
SppRich.res.BIC <- stepAIC(m0, scope = list(upper = ~ factor(Group.89) * factor(Group.02) *
                                            Military.Training.Total.Intensity * TA.Usage *
                                            Distance.to.Road.ft * Grazing.Years * Fire *
                                            Maintenance, lower = ~ 1),
                               direction = "both", k = log(nrow(env.master2)))
summary(SppRich.res.BIC) # Group.89, Grazing.Years, Military.Training.Total.Intensity
qplot(data = env.master2, x = Military.Training.Total.Intensity, y = SppRich.change+SppRich,
      color = Grazing.Years, facets = Group.89)
```

```
SppRich.grid <- with(env.master2, expand.grid(
  Group.89 = levels(factor(Group.89)),
  Military.Training.Total.Intensity = seq(min(Military.Training.Total.Intensity),
                                          max(Military.Training.Total.Intensity), length = 20),
  Grazing.Years = c(2, 4, 6)
))
SppRich.grid$SppRich.02 <- stats::predict(SppRich.res.BIC, newdata = SppRich.grid)

SppRich.plot <- ggplot(data = env.master2, aes(x = Military.Training.Total.Intensity,
                                               y = (SppRich.change+SppRich))) +
  geom_point(alpha = 0.5) +
  geom_line(data = SppRich.grid, aes(x = Military.Training.Total.Intensity, y = SppRich.02,
                                     color = factor(Grazing.Years),
                                     linetype = factor(Grazing.Years))) +
  facet_grid(. ~ Group.89, labeller = grp_labeller) +
  scale_x_continuous(name = "Military Training Intensity") +
  scale_y_continuous(name = "Species Richness in 2002") +
  scale_linetype(guide = guide_legend(title = "Grazing (years)")) +
  scale_colour_discrete(guide = guide_legend(title = "Grazing (years)")) +
  theme_bw() +
  theme(panel.background = element_blank(), plot.background = element_blank(),
        panel.grid.major=element_blank(), panel.grid.minor=element_blank(),
        legend.position = "top")
SppRich.plot

png("Training.vs.SppRich.png", width = 6.5, height = 4, units = 'in', res = 800)
plot(SppRich.plot) # output high-resolution plot
dev.off()

#Exotic Cover in 2002
m0 <- aov((E.change+E) ~ 1, data = env.master2)
E.res.BIC <- stepAIC(m0, scope = list(upper = ~ factor(Group.89) * factor(Group.02) *
                                        Military.Training.Total.Intensity * TA.Usage *
                                        Distance.to.Road.ft * Grazing.Years * Fire *
                                        Maintenance, lower = ~ 1),
                                     direction = "both", k = log(nrow(env.master2)))
```

```
summary(E.res.BIC) # Group.02, Group.89

#Native Forb Cover in 2002
m0 <- aov((NF.change + NF) ~ 1, data = env.master2)
NF.res.BIC <- stepAIC(m0, scope = list(upper = ~ factor(Group.89) * factor(Group.02) *
                                        Military.Training.Total.Intensity * TA.Usage *
                                        Distance.to.Road.ft * Grazing.Years * Fire *
                                        Maintenance, lower = ~ 1),
                                 direction = "both", k = log(nrow(env.master2)))
summary(NF.res.BIC) # Group.02

#Native Grass Cover in 2002
m0 <- aov((NG.change + NG) ~ 1, data = env.master2)
NG.res.BIC <- stepAIC(m0, scope = list(upper = ~ factor(Group.89) * factor(Group.02) *
                                        Military.Training.Total.Intensity * TA.Usage *
                                        Distance.to.Road.ft * Grazing.Years * Fire *
                                        Maintenance, lower = ~ 1),
                                 direction = "both", k = log(nrow(env.master2)))
summary(NG.res.BIC) # Group.02, Fire, Grazing.Years

NG.grid <- with(env.master2, expand.grid(
  Group.02 = levels(factor(Group.02)),
  Fire = levels(Fire),
  Grazing.Years = c(1:7)
))
NG.grid$NG.02 <- stats::predict(NG.res.BIC, newdata = NG.grid)

NG.plot <- ggplot(data = env.master2, aes(x = Grazing.Years,
                                          y = (NG.change+NG)*100, color = Fire)) +
  geom_line(data = NG.grid, aes(x = Grazing.Years, y = NG.02*100)) +
  geom_point(alpha = 0.5) +
  facet_grid(Fire ~ Group.02, labeller = grp_labeller) +
  scale_x_continuous(name = "Grazing (Years)") +
  scale_y_continuous(name = "Native Grasses (%)") +
  theme_bw() +
  theme(panel.background = element_blank(), plot.background = element_blank(),
        panel.grid.major=element_blank(), panel.grid.minor=element_blank(),
```

```
        legend.position = "top")
NG.plot

png("Grazing.vs.NG.png", width = 6.5, height = 4, units = 'in', res = 800)
plot(NG.plot) # output high-resolution plot
dev.off()


#Shrub Cover in 2002
m0 <- aov((S.change + S) ~ 1, data = env.master2)
S.res.BIC <- stepAIC(m0, scope = list(upper = ~ factor(Group.89) * factor(Group.02) *
                                        Military.Training.Total.Intensity * TA.Usage *
                                        Distance.to.Road.ft * Grazing.Years * Fire *
                                        Maintenance, lower = ~ 1),
                     direction = "both", k = log(nrow(env.master2)))
summary(S.res.BIC) # Group.02, Fire, Grazing.Years

S.grid <- with(env.master2, expand.grid(
  Group.02 = levels(factor(Group.02)),
  Fire = levels(Fire),
  Grazing.Years = c(1:7)
))
S.grid$S.02 <- stats::predict(S.res.BIC, newdata = S.grid)

S.plot <- ggplot(data = env.master2, aes(x = Grazing.Years,
                                         y = (S.change+S)*100, color = Fire)) +
  geom_line(data = S.grid, aes(x = Grazing.Years, y = S.02*100)) +
  geom_point(alpha = 0.5) +
  facet_grid(Fire ~ Group.02, labeller = grp_labeller) + #consider 'scales = "free"'
  scale_x_continuous(name = "Grazing (Years)") +
  scale_y_continuous(name = "Shrubs (%)") +
  theme_bw() +
  theme(panel.background = element_blank(), plot.background = element_blank(),
        panel.grid.major=element_blank(), panel.grid.minor=element_blank(),
        legend.position = "top")
S.plot
```

```
png("Grazing.vs.S.png", width = 6.5, height = 4, units = 'in', res = 800)
plot(S.plot) # output high-resolution plot
dev.off()


## Indicator species relative to disturbance variables
env.master3 <- merge(x = env, by.x = "PLOTID", all.x = TRUE,
                     y = master.02, by.y = "PLOTID", all.y = TRUE)

ISA.Fire <- multipatt(x = env.master3[ , colnames(env.master3) %in% spp],
                        cluster = env.master3$Fire, control = how(nperm = 999))
summary(ISA.Fire, indvalcomp = TRUE, minstat = 0.5) # Burned = LUSE4; Unburned = ARTR2

ISA.Training <- multipatt(x = env.master3[ , colnames(env.master3) %in% spp],
                      cluster = env.master3$Training, control = how(nperm = 999))
summary(ISA.Training, indvalcomp = TRUE, minstat = 0.5) # High = ELELH

ISA.Maintenance <- multipatt(x = env.master3[ , colnames(env.master3) %in% spp],
                         cluster = env.master3$Maintenance, control = how(nperm = 999))
summary(ISA.Maintenance, indvalcomp = TRUE, minstat = 0.5) # None

# TITAN
spp2 <- spp[spp != "ASPU9"] #drop ASPU9 as taxa must have >= 3 occurrences

TITAN.Road <- titan(env = env.master3$Distance.to.Road.ft,
                    txa = env.master3[ , colnames(env.master3) %in% spp2],
                    minsplt = 5, numprm = 999, boot = TRUE, nboot = 1000, deviance = TRUE)
write.table(TITAN.Road$sppmax, file.choose())
plot.taxaz(titan.out = TITAN.Road, xlabel = expression("Distance to road (feet)"),
           boot = TRUE, pur.cut = 0.5, rel05.cut = 0.55, rel01.cut = 0.5, cex.taxa = 0.9,
           cex.axis = 1.25, cex = 1.35, leg.x = 100, leg.y = 10)

TITAN.Military <- titan(env = env.master3$Military.Training.Total.Intensity,
                        txa = env.master3[ , colnames(env.master3) %in% spp2],
                        minsplt = 5, numprm = 500, boot = TRUE, nboot = 1000, deviance = TRUE)
write.table(TITAN.Military$sppmax, file.choose())
plot.taxaz(titan.out = TITAN.Military, xlabel = expression("Military Training Intensity"),
```

```
           boot = TRUE, pur.cut = 0.9, rel05.cut = 0.75, cex.taxa = 0.9,
           cex.axis = 1.25, cex = 1.35, leg.x = 100, leg.y = 10)

TITAN.Grazing <- titan(env = env.master3$Grazing.Years,
                       txa = env.master3[ , colnames(env.master3) %in% spp2],
                       minsplt = 5, numprm = 500, boot = TRUE, nboot = 1000, deviance = TRUE)
write.table(TITAN.Grazing$sppmax, file.choose())
plot.taxaz(titan.out = TITAN.Grazing, xlabel = expression("Grazing (years)"),
           boot = TRUE, pur.cut = 0.9, rel05.cut = 0.75, cex.taxa = 0.9,
           cex.axis = 1.25, cex = 1.35, leg.x = 100, leg.y = 10)


#Military.Training.Total.Intensity
#Grazing.Years


## Plotting exotic and shrub cover for state-transition model
S.T.plot <- ggplot(data = transition.summary[transition.summary$Transition != "89B_02D", ]) +
  geom_point(aes(x = meanE, y = meanS, color = Group.02, shape = Group.89,
                 fill = factor(YEAR), size = 4)) +
  scale_x_continuous(name = "Exotic cover (%)") +
  scale_y_continuous(name = "Shrub cover (%)") +
  theme_bw() +
  theme(panel.background = element_blank(), plot.background = element_blank(),
        panel.grid.major=element_blank(), panel.grid.minor=element_blank(),
        legend.position = "top")
S.T.plot

png("State.transition.png", width = 6.5, height = 6, units = 'in', res = 800)
plot(S.T.plot) # output high-resolution plot
dev.off()


head(env.master2)
```

```
#Examine scree plots for both years together, using functional group data
cov.clust.all<-hclust(d = vegdist(Traits[, c("E", "NF", "NG", "S")], method = "bray"),
                      method = "ward.D2")
heights.all <- cbind(cov.clust.all$height, cov.clust.all$merge)
colnames(heights.all) <- c("Height", "JoinsThis", "WithThis")
plot(x = 10:1, y = heights.all[(nrow(heights.all)-9):nrow(heights.all),1],
     xlab = "Number of groups", ylab = "Height", main = "All")
#scree plot shows 5 groups
groups.all <- data.frame(G.all = cutree(cov.clust.all, k=5))
groups.all$Group.all[groups.all$G.all == 1] <- "All.A"
groups.all$Group.all[groups.all$G.all == 2] <- "All.B"
groups.all$Group.all[groups.all$G.all == 3] <- "All.C"
groups.all$Group.all[groups.all$G.all == 4] <- "All.D"
groups.all$Group.all[groups.all$G.all == 5] <- "All.E"
groups.all2 <- data.frame(cbind(plot.year, groups.all))

with(groups.all2, table(factor(Group.all[YEAR == 1989]), factor(Group.all[YEAR == 2002])))
```

```
### Explore separate disturbance models for each transition
#Native Grass Cover in 2002
m0 <- aov((NG.change + NG) ~ 1, data = env.master2[env.master2$Transition == "89A_02A", ])
summary(stepAIC(m0, scope = list(upper = ~ Military.Training.Total.Intensity *
                                   TA.Usage * Distance.to.Road.ft * Grazing.Years * Fire *
                                   Maintenance, lower = ~ 1),
                direction = "both",
                k = log(nrow(env.master2[env.master2$Transition == "89A_02A", ]))))
#Fire
qplot(data = env.master2[env.master2$Transition == "89A_02A", ], x = Fire, y = NG.change+NG)

m0 <- aov((NG.change + NG) ~ 1, data = env.master2[env.master2$Transition == "89A_02B", ])
summary(stepAIC(m0, scope = list(upper = ~ Military.Training.Total.Intensity *
```

```
                                    TA.Usage * Distance.to.Road.ft * Grazing.Years * Fire *
                                    Maintenance, lower = ~ 1),
                direction = "both",
                k = log(nrow(env.master2[env.master2$Transition == "89A_02B", ]))))
#None

m0 <- aov((NG.change + NG) ~ 1, data = env.master2[env.master2$Transition == "89A_02C", ])
summary(stepAIC(m0, scope = list(upper = ~ Military.Training.Total.Intensity *
                                    TA.Usage * Distance.to.Road.ft * Grazing.Years * Fire *
                                    Maintenance, lower = ~ 1),
                direction = "both",
                k = log(nrow(env.master2[env.master2$Transition == "89A_02C", ]))))
#didn't work

m0 <- aov((NG.change + NG) ~ 1, data = env.master2[env.master2$Transition == "89B_02B", ])
summary(stepAIC(m0, scope = list(upper = ~ Military.Training.Total.Intensity *
                                    TA.Usage * Distance.to.Road.ft * Grazing.Years * Fire *
                                    Maintenance, lower = ~ 1),
                direction = "both",
                k = log(nrow(env.master2[env.master2$Transition == "89B_02B", ]))))
#none

m0 <- aov((NG.change + NG) ~ 1, data = env.master2[env.master2$Transition == "89B_02C", ])
summary(stepAIC(m0, scope = list(upper = ~ Military.Training.Total.Intensity *
                                    TA.Usage * Distance.to.Road.ft * Grazing.Years * Fire *
                                    Maintenance, lower = ~ 1),
                direction = "both",
                k = log(nrow(env.master2[env.master2$Transition == "89B_02C", ]))))
#didn't work

m0 <- aov((NG.change + NG) ~ 1, data = env.master2[env.master2$Transition == "89C_02A", ])
summary(stepAIC(m0, scope = list(upper = ~ Military.Training.Total.Intensity *
                                    TA.Usage * Distance.to.Road.ft * Grazing.Years * Fire *
                                    Maintenance, lower = ~ 1),
                direction = "both",
                k = log(nrow(env.master2[env.master2$Transition == "89C_02A", ]))))
#grazing
```

```
qplot(data = env.master2[env.master2$Transition == "89C_02A", ], x = Grazing.Years,
      y = NG.change+NG)

m0 <- aov((NG.change + NG) ~ 1, data = env.master2[env.master2$Transition == "89C_02B", ])
summary(stepAIC(m0, scope = list(upper = ~ Military.Training.Total.Intensity *
                                   TA.Usage * Distance.to.Road.ft * Grazing.Years * Fire *
                                   Maintenance, lower = ~ 1),
                direction = "both",
                k = log(nrow(env.master2[env.master2$Transition == "89C_02B", ]))))
#fire
qplot(data = env.master2[env.master2$Transition == "89C_02B", ], x = Fire, y = NG.change+NG)

m0 <- aov((NG.change + NG) ~ 1, data = env.master2[env.master2$Transition == "89C_02C", ])
summary(stepAIC(m0, scope = list(upper = ~ Military.Training.Total.Intensity *
                                   TA.Usage * Distance.to.Road.ft * Grazing.Years * Fire *
                                   Maintenance, lower = ~ 1),
                direction = "both",
                k = log(nrow(env.master2[env.master2$Transition == "89C_02C", ]))))
#road, TA.Usage
qplot(data = env.master2[env.master2$Transition == "89C_02C", ], x = Distance.to.Road.ft,
      y = NG.change+NG, facets = . ~ TA.Usage)

m0 <- aov((NG.change + NG) ~ 1, data = env.master2[env.master2$Transition == "89C_02D", ])
summary(stepAIC(m0, scope = list(upper = ~ Military.Training.Total.Intensity *
                                   TA.Usage * Distance.to.Road.ft * Grazing.Years * Fire *
                                   Maintenance, lower = ~ 1),
                direction = "both",
                k = log(nrow(env.master2[env.master2$Transition == "89C_02D", ]))))
#Maintenance
qplot(data = env.master2[env.master2$Transition == "89C_02D", ], x = Maintenance,
      y = NG.change+NG)



#Distance
m0 <- aov(Dist ~ 1, data = env.master2[env.master2$Transition == "89A_02A", ])
summary(stepAIC(m0, scope = list(upper = ~ Military.Training.Total.Intensity *
```

```
                                    TA.Usage * Distance.to.Road.ft * Grazing.Years * Fire *
                                    Maintenance, lower = ~ 1),
                direction = "both",
                k = log(nrow(env.master2[env.master2$Transition == "89A_02A", ]))))
#Training
qplot(data = env.master2[env.master2$Transition == "89A_02A", ],
      x = Military.Training.Total.Intensity, y = Dist)

m0 <- aov(Dist ~ 1, data = env.master2[env.master2$Transition == "89A_02B", ])
summary(stepAIC(m0, scope = list(upper = ~ Military.Training.Total.Intensity *
                                    TA.Usage * Distance.to.Road.ft * Grazing.Years * Fire *
                                    Maintenance, lower = ~ 1),
                direction = "both",
                k = log(nrow(env.master2[env.master2$Transition == "89A_02B", ]))))
#None

m0 <- aov(Dist ~ 1, data = env.master2[env.master2$Transition == "89A_02C", ])
summary(stepAIC(m0, scope = list(upper = ~ Military.Training.Total.Intensity *
                                    TA.Usage * Distance.to.Road.ft * Grazing.Years * Fire *
                                    Maintenance, lower = ~ 1),
                direction = "both",
                k = log(nrow(env.master2[env.master2$Transition == "89A_02C", ]))))
#maintenance, fire
qplot(data = env.master2[env.master2$Transition == "89A_02C", ], x = Maintenance, y = Dist,
      facets = . ~ Fire)

m0 <- aov(Dist ~ 1, data = env.master2[env.master2$Transition == "89B_02B", ])
summary(stepAIC(m0, scope = list(upper = ~ Military.Training.Total.Intensity *
                                    TA.Usage * Distance.to.Road.ft * Grazing.Years * Fire *
                                    Maintenance, lower = ~ 1),
                direction = "both",
                k = log(nrow(env.master2[env.master2$Transition == "89B_02B", ]))))
#none

m0 <- aov(Dist ~ 1, data = env.master2[env.master2$Transition == "89B_02C", ])
summary(stepAIC(m0, scope = list(upper = ~ Military.Training.Total.Intensity *
                                    TA.Usage * Distance.to.Road.ft * Grazing.Years * Fire *
```

```
                                    Maintenance, lower = ~ 1),
                direction = "both",
                k = log(nrow(env.master2[env.master2$Transition == "89B_02C", ]))))
#none

m0 <- aov(Dist ~ 1, data = env.master2[env.master2$Transition == "89C_02A", ])
summary(stepAIC(m0, scope = list(upper = ~ Military.Training.Total.Intensity *
                                    TA.Usage * Distance.to.Road.ft * Grazing.Years * Fire *
                                    Maintenance, lower = ~ 1),
                direction = "both",
                k = log(nrow(env.master2[env.master2$Transition == "89C_02A", ]))))
#grazing, road
qplot(data = env.master2[env.master2$Transition == "89C_02A", ], x = Grazing.Years, y = Dist)

m0 <- aov(Dist ~ 1, data = env.master2[env.master2$Transition == "89C_02B", ])
summary(stepAIC(m0, scope = list(upper = ~ Military.Training.Total.Intensity *
                                    TA.Usage * Distance.to.Road.ft * Grazing.Years * Fire *
                                    Maintenance, lower = ~ 1),
                direction = "both",
                k = log(nrow(env.master2[env.master2$Transition == "89C_02B", ]))))
#none

m0 <- aov(Dist ~ 1, data = env.master2[env.master2$Transition == "89C_02C", ])
summary(stepAIC(m0, scope = list(upper = ~ Military.Training.Total.Intensity *
                                    TA.Usage * Distance.to.Road.ft * Grazing.Years * Fire *
                                    Maintenance, lower = ~ 1),
                direction = "both",
                k = log(nrow(env.master2[env.master2$Transition == "89C_02C", ]))))
#training
qplot(data = env.master2[env.master2$Transition == "89C_02C", ],
      x = Military.Training.Total.Intensity, y = Dist)

m0 <- aov(Dist ~ 1, data = env.master2[env.master2$Transition == "89C_02D", ])
summary(stepAIC(m0, scope = list(upper = ~ Military.Training.Total.Intensity *
                                    TA.Usage * Distance.to.Road.ft * Grazing.Years * Fire *
                                    Maintenance, lower = ~ 1),
                direction = "both",
```

```
                k = log(nrow(env.master2[env.master2$Transition == "89C_02D", ]))))
#TA.Usage
qplot(data = env.master2[env.master2$Transition == "89C_02D", ], x = TA.Usage, y = Dist)


### Classification tree relating disturbance to the various transitions
temp.tree <- rpart(factor(Transition) ~ TA.Usage + Fire + Maintenance +
                     Grazing.Years + Military.Training.Total.Intensity + Distance.to.Road.ft +
                     Elevation + Heat.Load.Index + Soil.Depth + Percent.Sand,
                   data = env.master2,
                   subset = Common.Transition.plots,
                   method = "class", dissim = "euc",
                   control = rpart.control(minsplit = 5, cp = 0.01, xval = 1000))
plotcp(temp.tree) #size 8
(Transition.tree.pruned <- prune(temp.tree,
                                 cp = temp.tree$cptable[which.min(temp.tree$cptable[,"xerror"]),
                                                        "CP"]))
plot(Transition.tree.pruned); text(Transition.tree.pruned); printcp(Transition.tree.pruned)
#Distance.to.Road.ft, Elevation, HLI, Percent.Sand

temp.tree <- rpart(factor(Group.02) ~ TA.Usage + Fire + Maintenance +
                     Grazing.Years + Military.Training.Total.Intensity + Distance.to.Road.ft +
                     Elevation + Heat.Load.Index + Soil.Depth + Percent.Sand,
                   data = env.master2,
                   method = "class", dissim = "euc",
                   control = rpart.control(minsplit = 5, cp = 0.01, xval = 1000))
plotcp(temp.tree) #size 2
(Transition.tree.pruned <- prune(temp.tree,
                                 cp = temp.tree$cptable[which.min(temp.tree$cptable[,"xerror"]),
                                                        "CP"]))
plot(Transition.tree.pruned); text(Transition.tree.pruned); printcp(Transition.tree.pruned)
#Elevation


### Classification tree relating environmental variables to the various Group.89 levels
temp.tree <- rpart(factor(Group.89) ~ Elevation + Heat.Load.Index + Soil.Depth + Percent.Sand,
                   data = env.master2, method = "class", dissim = "euc",
```

```
                    control = rpart.control(minsplit = 5, cp = 0.01, xval = 1000))
plotcp(temp.tree) #size 2
(Group.89.tree.pruned <- prune(temp.tree,
                               cp = temp.tree$cptable[which.min(temp.tree$cptable[,"xerror"]),
                                                      "CP"]))
plot(Group.89.tree.pruned); text(Group.89.tree.pruned); printcp(Group.89.tree.pruned)
#None
```

```
# focus on common transitions, analyzing each 1989 community separately

#Transitions from 1989 group 89A (Longleaf Phlox)
E89A <- env.master2[env.master2$Group.89 == "89A", ]

m0 <- aov(Dist ~ 1, data = E89A)
Dist.89A.res.BIC <- stepAIC(m0, scope = list(upper = ~ factor(Group.02) *
                                             Military.Training.Total.Intensity *
                                             TA.Usage * Distance.to.Road.ft * Grazing.Years *
                                             Fire * Maintenance, lower = ~ 1),
                            direction = "both", k = log(nrow(env.master2)))
summary(Dist.89A.res.BIC) # None

m0 <- aov((TotalCover+TotalCover.change) ~ 1, data = E89A)
TotalCover.89A.res.BIC <- stepAIC(m0, scope = list(upper = ~ factor(Group.02) *
                                                     Military.Training.Total.Intensity *
                                                     TA.Usage * Distance.to.Road.ft *
                                                     Grazing.Years * Fire * Maintenance,
                                                   lower = ~ 1),
                                  direction = "both", k = log(nrow(env.master2)))
summary(TotalCover.89A.res.BIC) # Military.Training.Total.Intensity
qplot(data = E89A, x = TotalCover, y = Dist)

m0 <- aov((SppRich+SppRich.change) ~ 1, data = E89A)
```

```
SppRich.89A.res.BIC <- stepAIC(m0, scope = list(upper = ~ factor(Group.02) *
                                                  Military.Training.Total.Intensity *
                                                  TA.Usage * Distance.to.Road.ft *
                                                  Grazing.Years * Fire * Maintenance,
                                                lower = ~ 1),
                               direction = "both", k = log(nrow(env.master2)))
summary(SppRich.89A.res.BIC) # Military.Training.Total.Intensity + Grazing.Years

m0 <- aov((E+E.change) ~ 1, data = E89A)
E.89A.res.BIC <- stepAIC(m0, scope = list(upper = ~ factor(Group.02) *
                                            Military.Training.Total.Intensity *
                                            TA.Usage * Distance.to.Road.ft * Grazing.Years *
                                            Fire * Maintenance, lower = ~ 1),
                         direction = "both", k = log(nrow(env.master2)))
summary(E.89A.res.BIC) # Group.02 + Military.Training.Total.Intensity
qplot(data = E89A, x = Military.Training.Total.Intensity, y = E+E.change)

m0 <- aov((NF+NF.change) ~ 1, data = E89A)
NF.89A.res.BIC <- stepAIC(m0, scope = list(upper = ~ factor(Group.02) *
                                             Military.Training.Total.Intensity * TA.Usage *
                                             Distance.to.Road.ft * Grazing.Years * Fire *
                                             Maintenance, lower = ~ 1),
                          direction = "both", k = log(nrow(env.master2)))
summary(NF.89A.res.BIC) # Group.02 + NF

m0 <- aov((NG+NG.change) ~ 1, data = E89A)
NG.89A.res.BIC <- stepAIC(m0, scope = list(upper = ~ factor(Group.02) *
                                             Military.Training.Total.Intensity * TA.Usage *
                                             Distance.to.Road.ft * Grazing.Years * Fire *
                                             Maintenance, lower = ~ 1),
                          direction = "both", k = log(nrow(env.master2)))
summary(NG.89A.res.BIC) # Group.02 + Fire

m0 <- aov((S+S.change) ~ 1, data = E89A)
S.89A.res.BIC <- stepAIC(m0, scope = list(upper = ~ factor(Group.02) *
                                            Military.Training.Total.Intensity * TA.Usage *
                                            Distance.to.Road.ft * Grazing.Years * Fire *
```

```
                                                Maintenance, lower = ~ 1),
                              direction = "both", k = log(nrow(env.master2)))
summary(S.89A.res.BIC) # S + Fire + Group.02 + S:Group.02 + S:Fire
qplot(data = E89A, x = Fire, y = S+S.change, facet = ~ factor(Group.02))

ddply(E89A, .(Group.02), summarize,
      meanDist = mean(Dist),
      meanTotalCover = mean(TotalCover),
      meanSppRich = mean(SppRich),
      meanE = mean(E),
      meanNF = mean(NF),
      meanNG = mean(NG),
      meanS = mean(S))

ddply(E89A, .(Military), summarize,
      meanDist = mean(Dist),
      meanTotalCover = mean(TotalCover),
      meanSppRich = mean(SppRich),
      meanE = mean(E),
      meanNF = mean(NF),
      meanNG = mean(NG),
      meanS = mean(S))

ddply(E89A, .(Grazing), summarize,
      meanDist = mean(Dist),
      meanTotalCover = mean(TotalCover),
      meanSppRich = mean(SppRich),
      meanE = mean(E),
      meanNF = mean(NF),
      meanNG = mean(NG),
      meanS = mean(S))

ddply(E89A, .(Disturbance), summarize,
      meanDist = mean(Dist),
      meanTotalCover = mean(TotalCover),
      meanSppRich = mean(SppRich),
      meanE = mean(E),
```

```
      meanNF = mean(NF),
      meanNG = mean(NG),
      meanS = mean(S))

#Transitions from 1989 group 89B (Big Sagebrush/Exotic)
E89B <- env.master2[env.master2$Group.89 == "89B" &
                      (env.master2$Transition == "89B_02B" |
                         env.master2$Transition == "89B_02E"), ]

m0 <- aov(Dist ~ 1, data = E89B)
Dist.89B.res.BIC <- stepAIC(m0, scope = list(upper = ~ factor(Group.02) * factor(Disturbance) *
                                             factor(Fire) * factor(Training.Area) *
                                             factor(Grazing) * factor(Military) *
                                             factor(Road), lower = ~ 1),
                            direction = "both", k = log(nrow(env.master2)))
summary(Dist.89B.res.BIC) # None

m0 <- aov((TotalCover+TotalCover.change) ~ 1, data = E89B)
TotalCover.89B.res.BIC <- stepAIC(m0, scope = list(upper = ~ TotalCover * factor(Group.02) *
                                                     factor(Disturbance) * factor(Fire) *
                                                     factor(Training.Area) * factor(Grazing) *
                                                     factor(Military) * factor(Road),
                                                   lower = ~ 1),
                                  direction = "both", k = log(nrow(env.master2)))
summary(TotalCover.89B.res.BIC) # None

m0 <- aov((SppRich+SppRich.change) ~ 1, data = E89B)
SppRich.89B.res.BIC <- stepAIC(m0, scope = list(upper = ~ SppRich * factor(Group.02) *
                                                  factor(Disturbance) * factor(Fire) *
                                                  factor(Training.Area) * factor(Grazing) *
                                                  factor(Military) * factor(Road),
                                                lower = ~ 1),
                               direction = "both", k = log(nrow(env.master2)))
summary(SppRich.89B.res.BIC) # None

m0 <- aov((E+E.change) ~ 1, data = E89B)
E.89B.res.BIC <- stepAIC(m0, scope = list(upper = ~ E * factor(Group.02) *
```

```
                                          factor(Disturbance) * factor(Fire) *
                                          factor(Training.Area) * factor(Grazing) *
                                          factor(Military) * factor(Road), lower = ~ 1),
                         direction = "both", k = log(nrow(env.master2)))
summary(E.89B.res.BIC) # Group.02

m0 <- aov((NF+NF.change) ~ 1, data = E89B)
NF.89B.res.BIC <- stepAIC(m0, scope = list(upper = ~ NF * factor(Group.02) *
                                           factor(Disturbance) * factor(Fire) *
                                           factor(Training.Area) * factor(Grazing) *
                                           factor(Military) * factor(Road), lower = ~ 1),
                          direction = "both", k = log(nrow(env.master2)))
summary(NF.89B.res.BIC)
# NF + Training.Area + Group.02 + Fire + NF:Training.Area + Group.02:Fire +
# Training.Area:Group.02

m0 <- aov((NG+NG.change) ~ 1, data = E89B)
NG.89B.res.BIC <- stepAIC(m0, scope = list(upper = ~ NG * factor(Group.02) *
                                           factor(Disturbance) * factor(Fire) *
                                           factor(Training.Area) * factor(Grazing) *
                                           factor(Military) * factor(Road), lower = ~ 1),
                          direction = "both", k = log(nrow(env.master2)))
summary(NG.89B.res.BIC) # None

m0 <- aov((S+S.change) ~ 1, data = E89B)
S.89B.res.BIC <- stepAIC(m0, scope = list(upper = ~ S * factor(Group.02) *
                                          factor(Disturbance) * factor(Fire) *
                                          factor(Training.Area) * factor(Grazing) *
                                          factor(Military) * factor(Road), lower = ~ 1),
                         direction = "both", k = log(nrow(env.master2)))
summary(S.89B.res.BIC) # Group.02

#Transitions from 1989 group 89C (Dwarf Shrub)
E89C <- env.master2[env.master2$Group.89 == "89C" &
                      (env.master2$Transition == "89C_02C"
                       | env.master2$Transition == "89C_02D"), ]
```

```
m0 <- aov(Dist ~ 1, data = E89C)
Dist.89C.res.BIC <- stepAIC(m0, scope = list(upper = ~ factor(Group.02) * factor(Disturbance) *
                                                factor(Fire) * factor(Training.Area) *
                                                factor(Grazing) * factor(Military) *
                                                factor(Road), lower = ~ 1),
                              direction = "both", k = log(nrow(env.master2)))
summary(Dist.89C.res.BIC) # Group.02

m0 <- aov((TotalCover+TotalCover.change) ~ 1, data = E89C)
TotalCover.89C.res.BIC <- stepAIC(m0, scope = list(upper = ~ TotalCover * factor(Group.02) *
                                                       factor(Disturbance) * factor(Fire) *
                                                       factor(Training.Area) * factor(Grazing) *
                                                       factor(Military) * factor(Road),
                                                     lower = ~ 1),
                                  direction = "both", k = log(nrow(env.master2)))
summary(TotalCover.89C.res.BIC) # None

m0 <- aov((SppRich+SppRich.change) ~ 1, data = E89C)
SppRich.89C.res.BIC <- stepAIC(m0, scope = list(upper = ~ SppRich * factor(Group.02) *
                                                    factor(Disturbance) * factor(Fire) *
                                                    factor(Training.Area) * factor(Grazing) *
                                                    factor(Military) * factor(Road),
                                                  lower = ~ 1),
                                direction = "both", k = log(nrow(env.master2)))
summary(SppRich.89C.res.BIC) # SppRich + Group.02

m0 <- aov((E+E.change) ~ 1, data = E89C)
E.89C.res.BIC <- stepAIC(m0, scope = list(upper = ~ E * factor(Group.02) *
                                             factor(Disturbance) * factor(Fire) *
                                             factor(Training.Area) * factor(Grazing) *
                                             factor(Military) * factor(Road), lower = ~ 1),
                         direction = "both", k = log(nrow(env.master2)))
summary(E.89C.res.BIC) # E

m0 <- aov((NF+NF.change) ~ 1, data = E89C)
NF.89C.res.BIC <- stepAIC(m0, scope = list(upper = ~ NF * factor(Group.02) *
                                              factor(Disturbance) * factor(Fire) *
```

```
                                          factor(Training.Area) * factor(Grazing) *
                                          factor(Military) * factor(Road), lower = ~ 1),
                          direction = "both", k = log(nrow(env.master2)))
summary(NF.89C.res.BIC) # NF + Group.02

m0 <- aov((NG+NG.change) ~ 1, data = E89C)
NG.89C.res.BIC <- stepAIC(m0, scope = list(upper = ~ NG * factor(Group.02) *
                                          factor(Disturbance) * factor(Fire) *
                                          factor(Training.Area) * factor(Grazing) *
                                          factor(Military) * factor(Road), lower = ~ 1),
                          direction = "both", k = log(nrow(env.master2)))
summary(NG.89C.res.BIC) # NG

m0 <- aov((S+S.change) ~ 1, data = E89C)
S.89C.res.BIC <- stepAIC(m0, scope = list(upper = ~ S * factor(Group.02) *
                                         factor(Disturbance) * factor(Fire) *
                                         factor(Training.Area) * factor(Grazing) *
                                         factor(Military) * factor(Road), lower = ~ 1),
                         direction = "both", k = log(nrow(env.master2)))
summary(S.89C.res.BIC) # S + Group.02




#All Common Transitions (BIC)
common.transitions <- c("89A_02A", "89A_02B", "89A_02D", "89A_02E", "89B_02B",
                        "89B_02E", "89C_02C", "89C_02D")
env.master.red <- env.master2[env.master2$Transition %in% common.transitions, ]

m0 <- aov(Dist ~ 1, data = env.master.red)
Dist.res <- stepAIC(m0, scope = list(upper = ~ factor(Group.02) * factor(Group.89) *
                                     factor(Transition) * factor(Disturbance) *
                                     factor(Fire) * factor(Training.Area) *
                                     factor(Grazing) * factor(Military) * factor(Road),
                                   lower = ~ 1),
                    direction = "both", k = log(nrow(env.master.red)))
summary(Dist.res) # Group.02 + Military
```

```
lsmeans(Dist.res, specs = pairwise ~ Group.02)
lsmeans(Dist.res, specs = pairwise ~ Military) # low has low distance

m0 <- aov((TotalCover + TotalCover.change) ~ 1, data = env.master.red)
TotalCover.res <- stepAIC(m0, scope = list(upper = ~ TotalCover * factor(Group.02) *
                                           factor(Group.89) * factor(Transition) *
                                           factor(Disturbance) * factor(Transition) *
                                           factor(Fire) * factor(Training.Area) *
                                           factor(Grazing) * factor(Military) *
                                           factor(Road), lower = ~ 1),
                          direction = "both", k = log(nrow(env.master.red)))
summary(TotalCover.res) # TotalCover + Group.02

m0 <- aov((SppRich+SppRich.change) ~ 1, data = env.master.red)
SppRich.res <- stepAIC(m0, scope = list(upper = ~ SppRich * factor(Group.89) *
                                        factor(Group.02) * factor(Transition) *
                                        factor(Disturbance) * factor(Fire) *
                                        factor(Training.Area) * factor(Grazing) *
                                        factor(Military) * factor(Road), lower = ~ 1),
                       direction = "both", k = log(nrow(env.master.red)))
summary(SppRich.res) # SppRich

m0 <- aov((E+E.change) ~ 1, data = env.master.red)
E.res <- stepAIC(m0, scope = list(upper = ~ E * factor(Group.89) * factor(Group.02) *
                                  factor(Transition) * factor(Disturbance) *
                                  factor(Fire) * factor(Training.Area) * factor(Grazing) *
                                  factor(Military) * factor(Road), lower = ~ 1),
                 direction = "both", k = log(nrow(env.master.red)))
summary(E.res) # Group.02 + E

m0 <- aov((NF+NF.change) ~ 1, data = env.master.red)
NF.res <- stepAIC(m0, scope = list(upper = ~ NF * factor(Group.89) * factor(Group.02) *
                                   factor(Transition) * factor(Disturbance) *
                                   factor(Fire) * factor(Training.Area) * factor(Grazing) *
                                   factor(Military) * factor(Road), lower = ~ 1),
                  direction = "both", k = log(nrow(env.master.red)))
summary(NF.res) # Group.02 + NF
```

```
m0 <- aov((NG+NG.change) ~ 1, data = env.master.red)
NG.res <- stepAIC(m0, scope = list(upper = ~ NG * factor(Group.89) * factor(Group.02) *
                                   factor(Transition) * factor(Disturbance) *
                                   factor(Fire) * factor(Training.Area) * factor(Grazing) *
                                   factor(Military) * factor(Road), lower = ~ 1),
                  direction = "both", k = log(nrow(env.master.red)))
summary(NG.res) # NG + Group.02 + Training.Area

m0 <- aov((S+S.change) ~ 1, data = env.master.red)
S.res <- stepAIC(m0, scope = list(upper = ~ S * factor(Group.89) * factor(Group.02) *
                                  factor(Transition) * factor(Disturbance) *
                                  factor(Fire) * factor(Training.Area) * factor(Grazing) *
                                  factor(Military) * factor(Road), lower = ~ 1),
                 direction = "both", k = log(nrow(env.master.red)))
summary(S.res) # S + Transition + Fire
lsmeans(S.res, specs = pairwise ~ Fire) # low has low distance


### ISA of disturbances
env.master3 <- merge(x = env.master2, by.x = "PLOTID", all.x = TRUE,
                     y = master[master$YEAR == "2002",], by.y = "PLOTID", all.y = TRUE)

ISA.Fire <- multipatt(x = env.master3[, colnames(env.master3) %in% spp],
                      cluster = env.master3$Fire, control = how(nperm = 999))
summary(ISA.Fire, indvalcomp = TRUE, minstat = 0.5)
ISA.89A.Fire <- multipatt(x = env.master3[env.master3$Group.89 == "89A",
                                          colnames(env.master3) %in% spp],
                         cluster = env.master3$Fire[env.master3$Group.89 == "89A"],
                         control = how(nperm = 999))
summary(ISA.89A.Fire, indvalcomp = TRUE, minstat = 0.5)
ISA.89B.Fire <- multipatt(x = env.master3[env.master3$Group.89 == "89B",
                                          colnames(env.master3) %in% spp],
                          cluster = env.master3$Fire[env.master3$Group.89 == "89B"],
                          control = how(nperm = 999))
summary(ISA.89B.Fire, indvalcomp = TRUE, minstat = 0.5)
ISA.89C.Fire <- multipatt(x = env.master3[env.master3$Group.89 == "89C",
```

```
                                        colnames(env.master3) %in% spp],
                          cluster = env.master3$Fire[env.master3$Group.89 == "89C"],
                          control = how(nperm = 999))
summary(ISA.89C.Fire, indvalcomp = TRUE, minstat = 0.5)

ISA.Maintenance <- multipatt(x = env.master3[, colnames(env.master3) %in% spp],
                          cluster = env.master3$Maintenance, control = how(nperm = 999))
summary(ISA.Maintenance, indvalcomp = TRUE, minstat = 0.5)

ISA.TA.Usage <- multipatt(x = env.master3[, colnames(env.master3) %in% spp],
                             cluster = env.master3$TA.Usage, control = how(nperm = 999))
summary(ISA.TA.Usage, indvalcomp = TRUE, minstat = 0.5)

ISA.Training <- multipatt(x = env.master3[, colnames(env.master3) %in% spp],
                          cluster = env.master3$Training, control = how(nperm = 999))
summary(ISA.Training, indvalcomp = TRUE, minstat = 0.5)

#add TITAN analyses

##### Compare our classifications with the Wildlife Habitat Types from Jones & Kunze (2003)

#1989 communities vs WHT
tab.89vWHT <- table(factor(env.master$Group.89),
                    factor(env.master$WILDLIFE_HABITAT_TYPE_1ST_YR))
tab.89vWHT <- rbind(tab.89vWHT, colSums(tab.89vWHT))
tab.89vWHT <- cbind(tab.89vWHT, rowSums(tab.89vWHT))
tab.89vWHT

#2002 communities vs WHT
tab.02vWHT <- table(factor(env.master$Group.02),
                    factor(env.master$WILDLIFE_HABITAT_TYPE_1ST_YR))
tab.02vWHT <- rbind(tab.02vWHT, colSums(tab.02vWHT))
tab.02vWHT <- cbind(tab.02vWHT, rowSums(tab.02vWHT))
tab.02vWHT
```

```
#### Appendix 2: Environmental Cluster Analysis
env.sub <- env[,c("Elevation", "Soil.Depth", "Heat.Load.Index", "Percent.Sand",
                  "X30.Year.Annual.Precip", "X30.Year.Temp..C.")]
env.sub2 <- scale(env.sub)


#Environmental data (no scaling)
env.clust <- hclust(d = vegdist(env.sub, method = "euc"), method = "ward.D2")
plot(env.clust)
heights.env <- cbind(env.clust$height, env.clust$merge)
colnames(heights.env) <- c("Height", "JoinsThis", "WithThis")
plot(x = 10:1, y = heights.env[(nrow(heights.env)-9):nrow(heights.env),1],
     xlab = "Number of groups", ylab = "Height", main = "Environmental")
#scree plot shows 3 groups

#Environmental data (scaled)
env.clust.2 <- hclust(d = vegdist(env.sub2, method = "euc"), method = "ward.D2")
plot(env.clust.2)
heights.env.2 <- cbind(env.clust.2$height, env.clust.2$merge)
colnames(heights.env.2) <- c("Height", "JoinsThis", "WithThis")
plot(x = 10:1, y = heights.env.2[(nrow(heights.env.2)-9):nrow(heights.env.2),1],
     xlab = "Number of groups", ylab = "Height", main = "Environmental (scaled)")
#scree plot shows 2, 5, or 7 groups

plot(env.clust.2)
rect.hclust(env.clust.2, k = 2, border = "red")
rect.hclust(env.clust.2, k = 5, border = "green")
rect.hclust(env.clust.2, k = 7, border = "blue")
Group.2.env <- as.factor(cutree(env.clust.2, k = 2))

#Environmental groupings
NMDS.env <- metaMDS(env.sub2, distance = "euc", k = 2, autotransform = F,
                    trymax = 1000, model = "global", engine = "monoMDS", maxit = 500)
stressplot(NMDS.env)
NMDS.env$stress

out.MDS.env <- data.frame(MDS1 = NMDS.env$points[,1], MDS2 = NMDS.env$points[,2],
```

```
                           Group = Group.2.env)
out.MDS.env <- merge(x = env[,], y = out.MDS.env, by.x = "row.names", by.y = "row.names")

find_hull <- function(out.MDS.env) out.MDS.env[chull(out.MDS.env$MDS1, out.MDS.env$MDS2), ]
hulls.env <- ddply(out.MDS.env, .(Group), find_hull)

ord.all.env <- ggplot(data = out.MDS.env, aes(MDS1, MDS2, color = Group, linetype = Group,
                                              shape = Group, fill = Group)) +
  geom_polygon(data = hulls.env, fill = "grey", alpha = 0.1) +
  geom_point(size = 2, alpha = 0.75) +
  scale_color_manual(name = "Environmental Group", values = c("black", "black"),
                     labels=c("Group A", "Group B")) +
  scale_linetype_manual(name = "Environmental Group", values=c("solid", "dotted"),
                        labels=c("Group A", "Group B")) +
  scale_shape_manual(name = "Environmental Group", values = c(24, 22),
                     labels=c("Group A", "Group B")) +
  scale_fill_manual(name = "Environmental Group", values = c("black", "grey"),
                    labels=c("Group A", "Group B")) +
  theme_bw() + #set background theme for plot
  theme(plot.background=element_blank(), panel.grid.major=element_blank(),
        panel.grid.minor=element_blank(), panel.background=element_blank(),
        axis.ticks = element_blank(), axis.text = element_blank(),
        axis.title = element_blank())
ord.all.env

png("env_NMDS.png", width = 6.5, height = 4, units = 'in', res = 800)
plot(ord.all.env) # output high-resolution plot
dev.off()

## Compare with 1989 vegetation
out.MDS.1989$Group.env <- out.MDS.env$Group
find_hull <- function(out.MDS.1989) out.MDS.1989[chull(out.MDS.1989$MDS1, out.MDS.1989$MDS2), ]
hulls.89.env <- ddply(out.MDS.1989, .(Group.env), find_hull)

ord.all.89.env <- ggplot(data = out.MDS.1989,
                         aes(MDS1, MDS2, color = Group.env, linetype = Group.env,
                             shape = Group.env, fill = Group.env)) +
```

```
  geom_polygon(data = hulls.89.env, fill = "grey", alpha = 0.1) +
  geom_point(size = 2, alpha = 0.75) +
  scale_color_manual(name = "Environmental Group", values = c("black", "black"),
                     labels=c("Group A", "Group B")) +
  scale_linetype_manual(name = "Environmental Group", values=c("solid", "dotted"),
                        labels=c("Group A", "Group B")) +
  scale_shape_manual(name = "Environmental Group", values = c(24, 22),
                     labels=c("Group A", "Group B")) +
  scale_fill_manual(name = "Environmental Group", values = c("black", "grey"),
                    labels=c("Group A", "Group B")) +
  theme_bw() + #set background theme for plot
  theme(plot.background=element_blank(), panel.grid.major=element_blank(),
        panel.grid.minor=element_blank(), panel.background=element_blank(),
        axis.ticks = element_blank(), axis.text = element_blank(),
        axis.title = element_blank())
ord.all.89.env

png("env_89_NMDS.png", width = 6.5, height = 4, units = 'in', res = 800)
plot(ord.all.89.env) # output high-resolution plot
dev.off()
```