

Spectra-trait PLSR example using NEON AOP pixel spectra and field-sampled leaf nitrogen content from CONUS NEON sites

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Overview

This is an R Markdown Notebook to illustrate how to develop pixel-scale spectra-trait PLSR models. This example uses image data from NEON AOP and associated field measurements of leaf nitrogen content collected across a range of CONUS NEON sites. For more information refer to the dataset EcoSIS page: <https://ecosis.org/package/canopy-spectra-to-map-foliar-functional-traits-over-neon-domains-in-eastern-united-states>

Getting Started

Load libraries

```
list.of.packages <- c("pls", "dplyr", "here", "plotrix", "ggplot2", "gridExtra", "spectratrait")
invisible(lapply(list.of.packages, library, character.only = TRUE))
```

```
##
## Attaching package: 'pls'
## The following object is masked from 'package:stats':
##
##   loadings
##
## Attaching package: 'dplyr'
## The following objects are masked from 'package:stats':
##
##   filter, lag
## The following objects are masked from 'package:base':
##
##   intersect, setdiff, setequal, union
## here() starts at /Users/sserbin/Data/Github/spectratrait
##
## Attaching package: 'gridExtra'
## The following object is masked from 'package:dplyr':
##
##   combine
```

Setup other functions and options

```
### Setup options

# Script options
pls::pls.options(plsralg = "oscorespls")
pls::pls.options("plsralg")

## $plsralg
## [1] "oscorespls"

# Default par options
opar <- par(no.readonly = T)

# What is the target variable? What is the variable name in the input dataset?
inVar <- "Nitrogen"

# What is the source dataset from EcoSIS?
ecosys_id <- "b9dbf3db-5b9c-4ab2-88c2-26c8b39d0903"

# Specify output directory, output_dir
# Options:
# tempdir - use a OS-specified temporary directory
# user defined PATH - e.g. "~/scratch/PLSR"
output_dir <- "tempdir"
```

Set working directory (scratch space)

```
## [1] "/private/var/folders/tq/tydmhlwn1bdf_0pmpcq70r2c0000gn/T/Rtmp0xKFW3"
```

Grab data from EcoSIS

```
print(paste0("Output directory: ",getwd())) # check wd

## [1] "Output directory: /Users/sserbin/Data/Github/spectratrait/vignettes"
dat_raw <- spectratrait::get_ecosis_data(ecosis_id = ecosys_id)

## [1] "**** Downloading Ecosis data ****"
## Downloading data...
## Rows: 674 Columns: 459
## -- Column specification -----
## Delimiter: ","
## chr   (4): Affiliation, PI, Plot_ID, Project
## dbl (455): Boron, Calcium, Carbon, Carotenoids_area, Carotenoids_mass, Cellu...
##
## i Use `spec()` to retrieve the full column specification for this data.
## i Specify the column types or set `show_col_types = FALSE` to quiet this message.
## Download complete!
head(dat_raw)

## # A tibble: 6 x 459
##   Affiliation Boron Calcium Carbon Carotenoids_area Carotenoids_mass Cellulose
##   <chr>      <dbl>  <dbl>  <dbl>          <dbl>          <dbl>      <dbl>
```

```
## 1 University ~ 0.0420 24.2 463. 9.19 1.18 221.
## 2 University ~ 0.0361 6.90 558. 10.8 1.17 183.
## 3 University ~ 0.0407 16.7 532. 12.2 1.52 133.
## 4 University ~ 0.0461 13.9 461. 9.16 1.50 220.
## 5 University ~ 0.0401 13.7 510. 11.0 1.53 101.
## 6 University ~ 0.0456 14.5 557. 8.90 1.24 214.
## # i 452 more variables: Chlorophylls_area <dbl>, Chlorophylls_mass <dbl>,
## # Copper <dbl>, EWT <dbl>, Fiber <dbl>, Flavonoids <dbl>, LMA <dbl>,
## # Lignin <dbl>, Magnesium <dbl>, Manganese <dbl>, NSC <dbl>, Nitrogen <dbl>,
## # PI <chr>, Phenolics <dbl>, Phosphorus <dbl>, Plot_ID <chr>,
## # Potassium <dbl>, Project <chr>, SLA <dbl>, Sample_Year <dbl>, Starch <dbl>,
## # Sugar <dbl>, Sulfur <dbl>, Water <dbl>, d13C <dbl>, d15N <dbl>,
## # `384` <dbl>, `389` <dbl>, `394` <dbl>, `399` <dbl>, `404` <dbl>, ...
```

```
names(dat_raw)[1:40]
```

```
## [1] "Affiliation"      "Boron"            "Calcium"
## [4] "Carbon"           "Carotenoids_area" "Carotenoids_mass"
## [7] "Cellulose"        "Chlorophylls_area" "Chlorophylls_mass"
## [10] "Copper"           "EWT"              "Fiber"
## [13] "Flavonoids"       "LMA"              "Lignin"
## [16] "Magnesium"        "Manganese"        "NSC"
## [19] "Nitrogen"         "PI"               "Phenolics"
## [22] "Phosphorus"       "Plot_ID"          "Potassium"
## [25] "Project"          "SLA"              "Sample_Year"
## [28] "Starch"           "Sugar"            "Sulfur"
## [31] "Water"           "d13C"             "d15N"
## [34] "384"              "389"              "394"
## [37] "399"              "404"              "409"
## [40] "414"
```

Create full pls dataset

```
# identify the trait data and other metadata
sample_info <- dat_raw[,names(dat_raw) %notin% seq(300,2600,1)]
head(sample_info)
```

```
## # A tibble: 6 x 33
##   Affiliation Boron Calcium Carbon Carotenoids_area Carotenoids_mass Cellulose
##   <chr>      <dbl> <dbl> <dbl> <dbl> <dbl> <dbl>
## 1 University ~ 0.0420 24.2 463. 9.19 1.18 221.
## 2 University ~ 0.0361 6.90 558. 10.8 1.17 183.
## 3 University ~ 0.0407 16.7 532. 12.2 1.52 133.
## 4 University ~ 0.0461 13.9 461. 9.16 1.50 220.
## 5 University ~ 0.0401 13.7 510. 11.0 1.53 101.
## 6 University ~ 0.0456 14.5 557. 8.90 1.24 214.
## # i 26 more variables: Chlorophylls_area <dbl>, Chlorophylls_mass <dbl>,
## # Copper <dbl>, EWT <dbl>, Fiber <dbl>, Flavonoids <dbl>, LMA <dbl>,
## # Lignin <dbl>, Magnesium <dbl>, Manganese <dbl>, NSC <dbl>, Nitrogen <dbl>,
## # PI <chr>, Phenolics <dbl>, Phosphorus <dbl>, Plot_ID <chr>,
## # Potassium <dbl>, Project <chr>, SLA <dbl>, Sample_Year <dbl>, Starch <dbl>,
## # Sugar <dbl>, Sulfur <dbl>, Water <dbl>, d13C <dbl>, d15N <dbl>
```

```
# spectra matrix
```

```
Spectra <- as.matrix(dat_raw[,names(dat_raw) %notin% names(sample_info)])
```

```

# set the desired spectra wavelength range to include
Start.wave <- 500
End.wave <- 2400
wv <- seq(Start.wave,End.wave,1)
final_spec <- Spectra[,round(as.numeric(colnames(Spectra))) %in% wv]
colnames(final_spec) <- c(paste0("Wave_",colnames(final_spec)))

## Drop bad spectra data - for canopy-scale reflectance, often the "water band" wavelengths
## are too noisy to use for trait estimation. Its possible to remove these wavelengths
## prior to model fitting. Its best to first identify which wavelengths to drop
## before attempting PLSR, as these ranges may need to be considered on a case-by-case
## basis or generalized for multiple datasets
dropwaves <- c(1350:1440, 1826:1946)
final_spec <- final_spec[,colnames(final_spec) %notin% paste0("Wave_",dropwaves)]
wv <- as.numeric(gsub(pattern = "Wave_",replacement = "", x = colnames(final_spec)))

## Drop bad spectra data - for canopy-scale reflectance, often the "water band" wavelengths
## are too noisy to use for trait estimation. Its possible to remove these wavelengths
## prior to model fitting. Its best to first identify which wavelengths to drop
## before attempting PLSR, as these ranges may need to be considered on a case-by-case
## basis or generalized for multiple datasets
dropwaves <- c(1350:1440, 1826:1946)
final_spec <- final_spec[,colnames(final_spec) %notin% paste0("Wave_",dropwaves)]
wv <- as.numeric(gsub(pattern = "Wave_",replacement = "", x = colnames(final_spec)))

# assemble example dataset
sample_info2 <- sample_info %>%
  select(Plot_ID,Sample_Year,SLA,Nitrogen)
site_plot <- data.frame(matrix(unlist(strsplit(sample_info2$Plot_ID, "_")),
                                ncol=2, byrow=TRUE))
colnames(site_plot) <- c("Plot_Num","SampleID")
sample_info3 <- data.frame(site_plot,sample_info2)

plsr_data <- data.frame(sample_info3,final_spec*0.01)
rm(sample_info,sample_info2,sample_info3,Spectra, site_plot)

# Example data cleaning. End user needs to do what's appropriate for their
# data. This may be an iterative process.
# Keep only complete rows of inVar and spec data before fitting
#
plsr_data <- plsr_data %>% # remove erroneously high values, or "bad spectra"
  filter(Nitrogen<50) %>%
  filter(Wave_859<80) %>%
  filter(Wave_859>15)
plsr_data <- plsr_data[complete.cases(plsr_data[,names(plsr_data) %in%
  c(inVar,paste0("Wave_",wv))]),]

```

Example data cleaning.

Create cal/val datasets

```
## Make a stratified random sampling in the strata USDA_Species_Code and Domain

method <- "base" #base/dplyr
# base R - a bit slow
# dplyr - much faster
split_data <- spectratrait::create_data_split(dataset=plsr_data, approach=method, split_seed=2356326,
                                              prop=0.8, group_variables="Plot_Num")

## D02    Cal: 80.46%
## D03    Cal: 80.328%
## D05    Cal: 80%
## D06    Cal: 79.73%
## D07    Cal: 79.245%
## D08    Cal: 79.817%
## D09    Cal: 79.63%

names(split_data)

## [1] "cal_data" "val_data"

cal.plsr.data <- split_data$cal_data
head(cal.plsr.data)[1:8]

##   Plot_Num SampleID Plot_ID Sample_Year      SLA Nitrogen Wave_504 Wave_509
## 2      D02      0002 D02_0002      2017 10.77861 27.70598 1.2909576 1.4075910
## 3      D02      0003 D02_0003      2017 12.46154 34.63999 1.2976806 1.4257559
## 5      D02      0005 D02_0005      2017 17.27620 26.64623 1.7735714 1.9423405
## 6      D02      0006 D02_0006      2017 12.92806 20.69437 1.7786337 1.9621929
## 7      D02      0007 D02_0007      2017 10.21521 28.87526 1.7981043 1.9359032
## 8      D02      0008 D02_0008      2017 20.87397 33.63137 0.8780127 0.9454703

val.plsr.data <- split_data$val_data
head(val.plsr.data)[1:8]

##   Plot_Num SampleID Plot_ID Sample_Year      SLA Nitrogen Wave_504 Wave_509
## 1      D02      0001 D02_0001      2017 13.66366 31.18030 1.467240 1.654816
## 4      D02      0004 D02_0004      2017 16.63205 34.54034 1.551933 1.764580
## 16     D02      0016 D02_0016      2017 14.44765 22.87740 2.198174 2.403996
## 18     D02      0019 D02_0019      2017 14.47103 17.73126 1.961911 2.175771
## 19     D02      0020 D02_0020      2017 18.98522 21.32929 1.546430 1.873175
## 20     D02      0021 D02_0021      2017 12.12731 29.50256 1.936263 2.065204

rm(split_data)

# Datasets:
print(paste("Cal observations: ",dim(cal.plsr.data)[1],sep=""))

## [1] "Cal observations: 517"

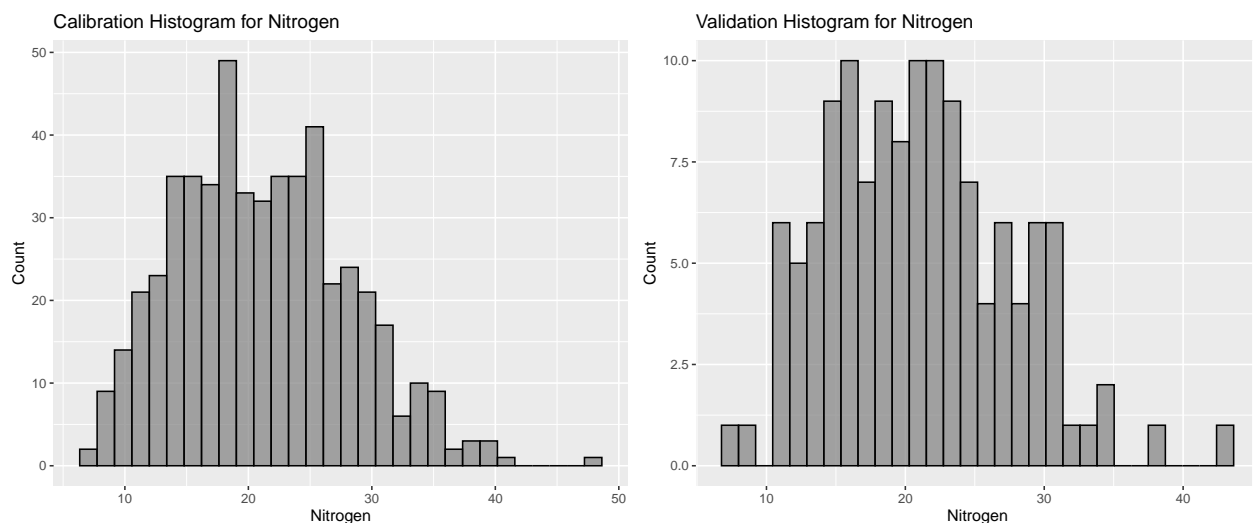
print(paste("Val observations: ",dim(val.plsr.data)[1],sep=""))

## [1] "Val observations: 130"
```

```
cal_hist_plot <- ggplot(data = cal.plsr.data,
                        aes(x = cal.plsr.data[,paste0(inVar)])) +
  geom_histogram(fill=I("grey50"),col=I("black"),alpha=I(.7)) +
  labs(title=paste0("Calibration Histogram for ",inVar), x = paste0(inVar),
       y = "Count")
val_hist_plot <- ggplot(data = val.plsr.data,
                        aes(x = val.plsr.data[,paste0(inVar)])) +
  geom_histogram(fill=I("grey50"),col=I("black"),alpha=I(.7)) +
  labs(title=paste0("Validation Histogram for ",inVar), x = paste0(inVar),
       y = "Count")
histograms <- grid.arrange(cal_hist_plot, val_hist_plot, ncol=2)
```

```
## `stat_bin()` using `bins = 30`. Pick better value with `binwidth`.
```

```
## `stat_bin()` using `bins = 30`. Pick better value with `binwidth`.
```



```
ggsave(filename = file.path(outdir,paste0(inVar,"_Cal_Val_Histograms.png")), plot = histograms,
        device="png", width = 30,
        height = 12, units = "cm",
        dpi = 300)
# output cal/val data
write.csv(cal.plsr.data,file=file.path(outdir,paste0(inVar,'_Cal_PLSR_Dataset.csv')),
          row.names=FALSE)
write.csv(val.plsr.data,file=file.path(outdir,paste0(inVar,'_Val_PLSR_Dataset.csv')),
          row.names=FALSE)
```

Create calibration and validation PLSR datasets

```
cal_spec <- as.matrix(cal.plsr.data[, which(names(cal.plsr.data) %in% paste0("Wave_",wv))])
cal.plsr.data <- data.frame(cal.plsr.data[, which(names(cal.plsr.data) %notin% paste0("Wave_",wv))],
                           Spectra=I(cal_spec))
head(cal.plsr.data)[1:5]
```

```
##   Plot_Num SampleID Plot_ID Sample_Year      SLA
## 2      D02      0002 D02_0002      2017 10.77861
## 3      D02      0003 D02_0003      2017 12.46154
## 5      D02      0005 D02_0005      2017 17.27620
## 6      D02      0006 D02_0006      2017 12.92806
```

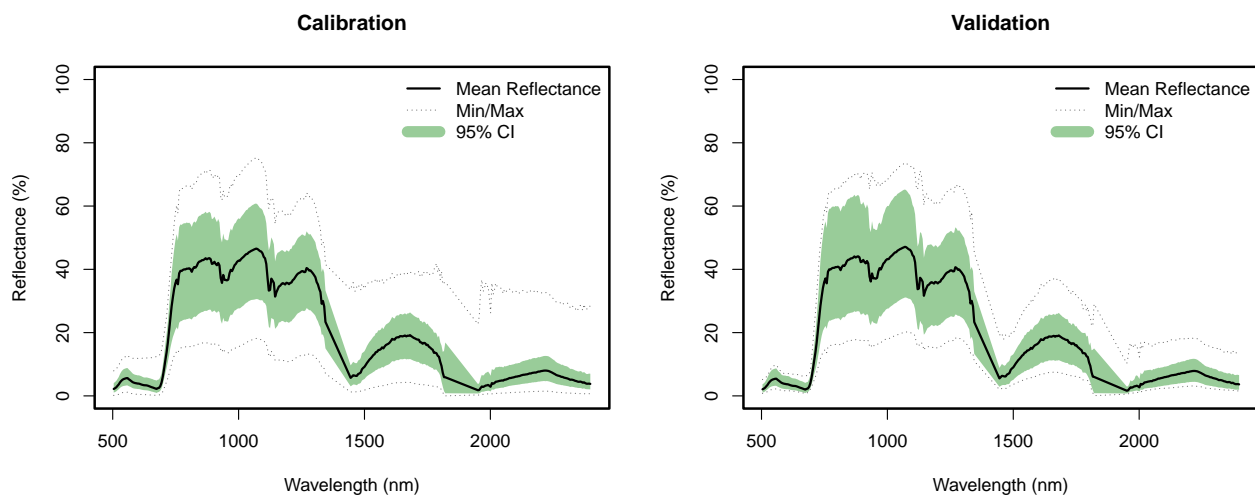
```
## 7      D02      0007 D02_0007      2017 10.21521
## 8      D02      0008 D02_0008      2017 20.87397

val_spec <- as.matrix(val.plsr.data[, which(names(val.plsr.data) %in% paste0("Wave_",wv))])
val.plsr.data <- data.frame(val.plsr.data[, which(names(val.plsr.data) %notin% paste0("Wave_",wv))],
                           Spectra=I(val_spec))
head(val.plsr.data)[1:5]
```

```
##      Plot_Num SampleID Plot_ID Sample_Year      SLA
## 1          D02      0001 D02_0001      2017 13.66366
## 4          D02      0004 D02_0004      2017 16.63205
## 16         D02      0016 D02_0016      2017 14.44765
## 18         D02      0019 D02_0019      2017 14.47103
## 19         D02      0020 D02_0020      2017 18.98522
## 20         D02      0021 D02_0021      2017 12.12731
```

plot cal and val spectra

```
par(mfrow=c(1,2)) # B, L, T, R
spectratrait::f.plot.spec(Z=cal.plsr.data$Spectra,wv=wv,plot_label="Calibration")
spectratrait::f.plot.spec(Z=val.plsr.data$Spectra,wv=wv,plot_label="Validation")
```



```
dev.copy(png,file.path(outdir,paste0(inVar,'_Cal_Val_Spectra.png')),
         height=2500,width=4900, res=340)
```

```
## quartz_off_screen
##                      3
```

```
dev.off();
```

```
## pdf
##    2
```

```
par(mfrow=c(1,1))
```

Use permutation to determine optimal number of components

```
if(grepl("Windows", sessionInfo()$running)){
  pls.options(parallel = NULL)
} else {
```

```

pls.options(parallel = parallel::detectCores()-1)
}

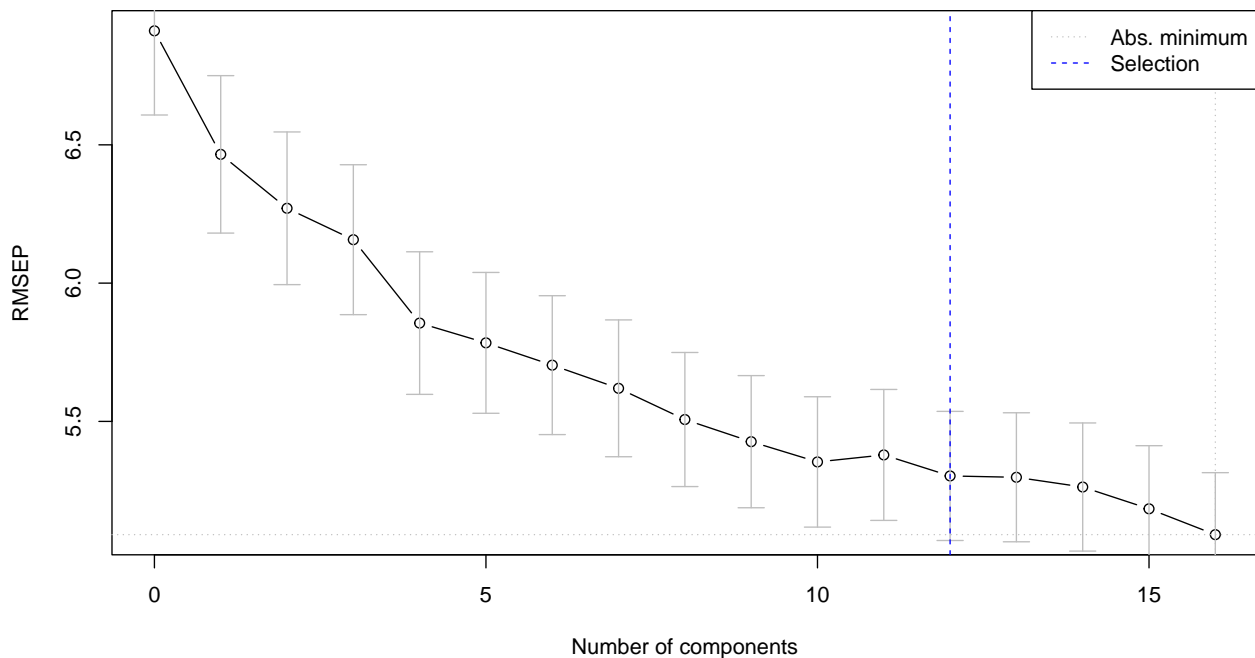
method <- "pls" #pls, firstPlateau, firstMin
random_seed <- 1245565
seg <- 50
maxComps <- 16
iterations <- 80
prop <- 0.70
if (method=="pls") {
  # pls package approach - faster but estimates more components....
  nComps <- spectratrait::find_optimal_components(dataset=cal.plsr.data, targetVariable=inVar,
                                                  method=method,
                                                  maxComps=maxComps, seg=seg,
                                                  random_seed=random_seed)

  print(paste0("*** Optimal number of components: ", nComps))
} else {
  nComps <- spectratrait::find_optimal_components(dataset=cal.plsr.data, targetVariable=inVar,
                                                  method=method,
                                                  maxComps=maxComps, iterations=iterations,
                                                  seg=seg, prop=prop,
                                                  random_seed=random_seed)
}

```

```
## [1] "*** Identifying optimal number of PLSR components ***"
```

```
## [1] "*** Running PLS permutation test ***"
```



```
## [1] "*** Optimal number of components: 12"
```

```

dev.copy(png,file.path(outdir,paste0(paste0(inVar,"_PLSR_Component_Selection.png"))),
         height=2800, width=3400, res=340)

```

```
## quartz_off_screen
```

```
## 3
```



```
dev.off();
```

```
## pdf
## 2
```

Fit final model

```
plsr.out <- plsr(as.formula(paste(inVar,"~","Spectra")),scale=FALSE,ncomp=nComps,validation="LOO",
                trace=FALSE,data=cal.plsr.data)
fit <- plsr.out$fitted.values[,1,nComps]
pls.options(parallel = NULL)

# External validation fit stats
par(mfrow=c(1,2)) # B, L, T, R
pls::RMSEP(plsr.out, newdata = val.plsr.data)
```

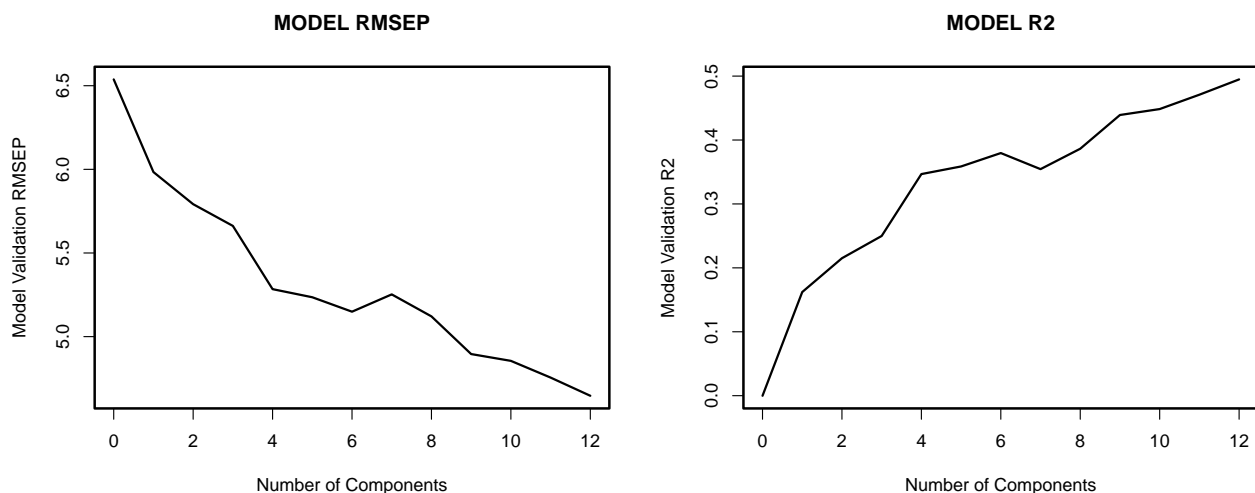
```
## (Intercept)      1 comps      2 comps      3 comps      4 comps      5 comps
##      6.538      5.984      5.792      5.662      5.284      5.235
##      6 comps      7 comps      8 comps      9 comps     10 comps     11 comps
##      5.149      5.252      5.121      4.896      4.855      4.755
##     12 comps
##      4.646
```

```
plot(pls::RMSEP(plsr.out,estimate=c("test"),newdata = val.plsr.data), main="MODEL RMSEP",
     xlab="Number of Components",ylab="Model Validation RMSEP",lty=1,col="black",cex=1.5,lwd=2)
box(lwd=2.2)
```

```
R2(plsr.out, newdata = val.plsr.data)
```

```
## (Intercept)      1 comps      2 comps      3 comps      4 comps      5 comps
## -0.0001616      0.1621284      0.2150431      0.2498762      0.3467097      0.3586424
##      6 comps      7 comps      8 comps      9 comps     10 comps     11 comps
##      0.3796062      0.3544358      0.3863604      0.4391471      0.4484252      0.4708911
##     12 comps
##      0.4948347
```

```
plot(pls::R2(plsr.out,estimate=c("test"),newdata = val.plsr.data), main="MODEL R2",
     xlab="Number of Components",ylab="Model Validation R2",lty=1,col="black",cex=1.5,lwd=2)
box(lwd=2.2)
```



```
dev.copy(png,file.path(outdir,paste0(paste0(inVar,"_Validation_RMSEP_R2_by_Component.png"))),
         height=2800, width=4800, res=340)
```

```
## quartz_off_screen
##           3
```

```
dev.off();
```

```
## pdf
##    2
par(opar)
```

PLSR fit observed vs. predicted plot data

```
#calibration
cal.plsr.output <- data.frame(cal.plsr.data[, which(names(cal.plsr.data) %notin% "Spectra")],
                             PLSR_Predicted=fit,
                             PLSR_CV_Predicted=as.vector(plsr.out$validation$pred[,nComps]))
cal.plsr.output <- cal.plsr.output %>%
  mutate(PLSR_CV_Residuals = PLSR_CV_Predicted-get(inVar))
head(cal.plsr.output)
```

##	Plot_Num	SampleID	Plot_ID	Sample_Year	SLA	Nitrogen	PLSR_Predicted
## 2	D02	0002	D02_0002	2017	10.77861	27.70598	24.65561
## 3	D02	0003	D02_0003	2017	12.46154	34.63999	27.85223
## 5	D02	0005	D02_0005	2017	17.27620	26.64623	29.36467
## 6	D02	0006	D02_0006	2017	12.92806	20.69437	21.66448
## 7	D02	0007	D02_0007	2017	10.21521	28.87526	23.04393
## 8	D02	0008	D02_0008	2017	20.87397	33.63137	25.56637
##	PLSR_CV_Predicted	PLSR_CV_Residuals					
## 2	24.59452	-3.1114612					
## 3	27.64033	-6.9996606					
## 5	29.54595	2.8997194					
## 6	21.68116	0.9867955					
## 7	22.78554	-6.0897138					
## 8	25.29798	-8.3333884					

```
cal.R2 <- round(pls::R2(plsr.out,intercept=F)[[1]][nComps],2)
cal.RMSEP <- round(sqrt(mean(cal.plsr.output$PLSR_CV_Residuals^2)),2)

val.plsr.output <- data.frame(val.plsr.data[, which(names(val.plsr.data) %notin% "Spectra")],
                             PLSR_Predicted=as.vector(predict(plsr.out,
                                                                newdata = val.plsr.data,
                                                                ncomp=nComps, type="response")[,1]))
val.plsr.output <- val.plsr.output %>%
  mutate(PLSR_Residuals = PLSR_Predicted-get(inVar))
head(val.plsr.output)
```

##	Plot_Num	SampleID	Plot_ID	Sample_Year	SLA	Nitrogen	PLSR_Predicted
## 1	D02	0001	D02_0001	2017	13.66366	31.18030	22.55166
## 4	D02	0004	D02_0004	2017	16.63205	34.54034	30.79494
## 16	D02	0016	D02_0016	2017	14.44765	22.87740	29.14446
## 18	D02	0019	D02_0019	2017	14.47103	17.73126	23.47518
## 19	D02	0020	D02_0020	2017	18.98522	21.32929	23.00736
## 20	D02	0021	D02_0021	2017	12.12731	29.50256	31.93483

```

##      PLSR_Residuals
## 1      -8.628643
## 4      -3.745399
## 16      6.267060
## 18      5.743923
## 19      1.678070
## 20      2.432274

val.R2 <- round(pls::R2(plsr.out,newdata=val.plsr.data,intercept=F)[[1]][nComps],2)
val.RMSEP <- round(sqrt(mean(val.plsr.output$PLSR_Residuals^2)),2)

rng_quant <- quantile(cal.plsr.output[,inVar], probs = c(0.001, 0.999))
cal_scatter_plot <- ggplot(cal.plsr.output, aes(x=PLSR_CV_Predicted, y=get(inVar))) +
  theme_bw() + geom_point() + geom_abline(intercept = 0, slope = 1, color="dark grey",
                                          linetype="dashed", linewidth=1.5) +

  xlim(rng_quant[1], rng_quant[2]) +
  ylim(rng_quant[1], rng_quant[2]) +
  labs(x=paste0("Predicted ", paste(inVar), " (units)"),
       y=paste0("Observed ", paste(inVar), " (units)"),
       title=paste0("Calibration: ", paste0("Rsqr = ", cal.R2), "; ", paste0("RMSEP = ",
                                                                           cal.RMSEP))) +

  theme(axis.text=element_text(size=18), legend.position="none",
        axis.title=element_text(size=20, face="bold"),
        axis.text.x = element_text(angle = 0,vjust = 0.5),
        panel.border = element_rect(linetype = "solid", fill = NA, linewidth=1.5))

cal_resid_histogram <- ggplot(cal.plsr.output, aes(x=PLSR_CV_Residuals)) +
  geom_histogram(alpha=.5, position="identity") +
  geom_vline(xintercept = 0, color="black",
            linetype="dashed", linewidth=1) + theme_bw() +
  theme(axis.text=element_text(size=18), legend.position="none",
        axis.title=element_text(size=20, face="bold"),
        axis.text.x = element_text(angle = 0,vjust = 0.5),
        panel.border = element_rect(linetype = "solid", fill = NA, linewidth=1.5))

rng_quant <- quantile(val.plsr.output[,inVar], probs = c(0.001, 0.999))
val_scatter_plot <- ggplot(val.plsr.output, aes(x=PLSR_Predicted, y=get(inVar))) +
  theme_bw() + geom_point() + geom_abline(intercept = 0, slope = 1, color="dark grey",
                                          linetype="dashed", linewidth=1.5) +

  xlim(rng_quant[1], rng_quant[2]) +
  ylim(rng_quant[1], rng_quant[2]) +
  labs(x=paste0("Predicted ", paste(inVar), " (units)"),
       y=paste0("Observed ", paste(inVar), " (units)"),
       title=paste0("Validation: ", paste0("Rsqr = ", val.R2), "; ", paste0("RMSEP = ",
                                                                           val.RMSEP))) +

  theme(axis.text=element_text(size=18), legend.position="none",
        axis.title=element_text(size=20, face="bold"),
        axis.text.x = element_text(angle = 0,vjust = 0.5),
        panel.border = element_rect(linetype = "solid", fill = NA, linewidth=1.5))

val_resid_histogram <- ggplot(val.plsr.output, aes(x=PLSR_Residuals)) +
  geom_histogram(alpha=.5, position="identity") +
  geom_vline(xintercept = 0, color="black",
            linetype="dashed", linewidth=1) + theme_bw() +

```

```

theme(axis.text=element_text(size=18), legend.position="none",
      axis.title=element_text(size=20, face="bold"),
      axis.text.x = element_text(angle = 0,vjust = 0.5),
      panel.border = element_rect(linetype = "solid", fill = NA, linewidth=1.5))

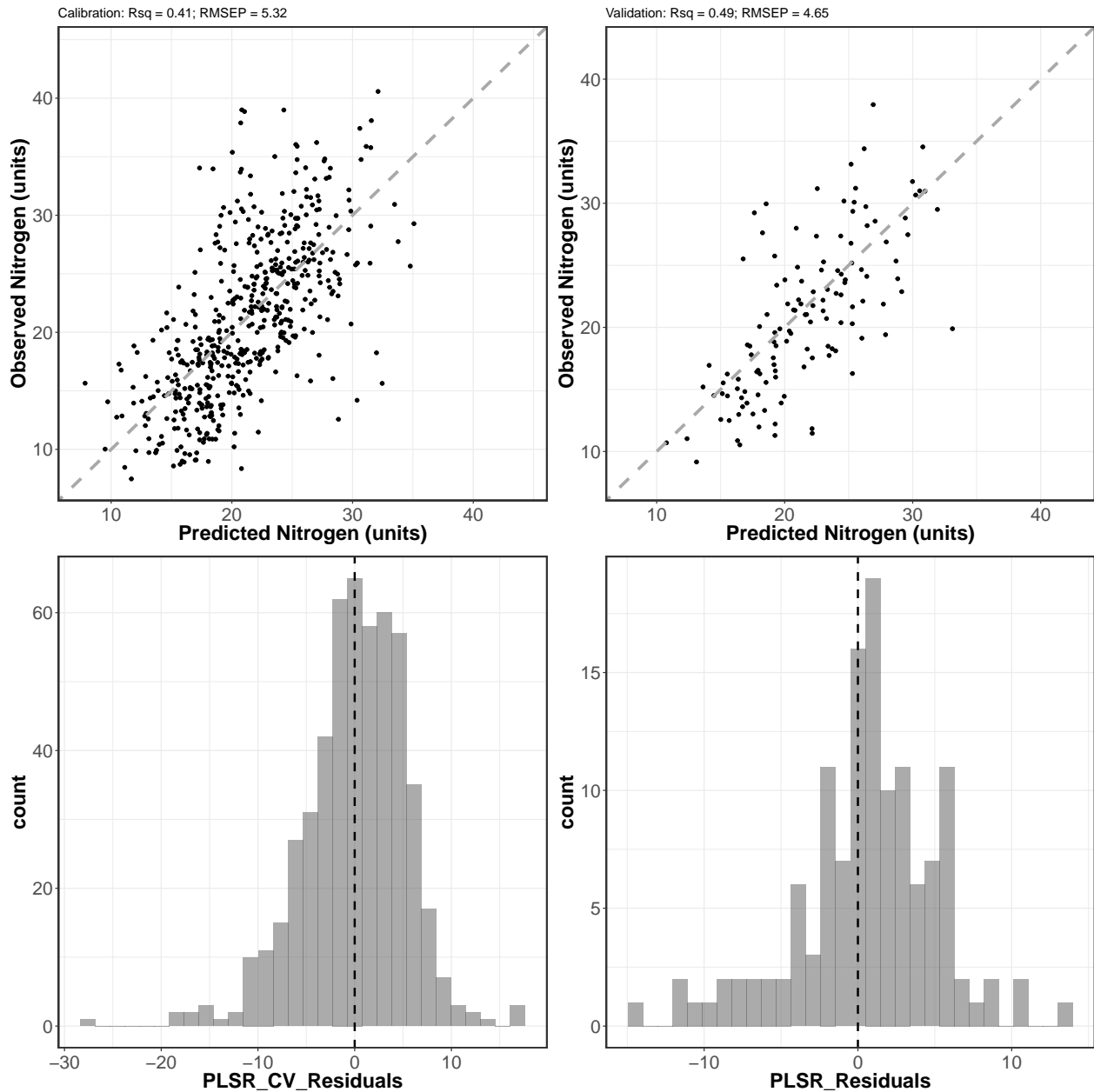
# plot cal/val side-by-side
scatterplots <- grid.arrange(cal_scatter_plot, val_scatter_plot, cal_resid_histogram,
                             val_resid_histogram, nrow=2,ncol=2)

## Warning: Removed 5 rows containing missing values or values outside the scale range
## (`geom_point()`).

## Warning: Removed 2 rows containing missing values or values outside the scale range
## (`geom_point()`).

## `stat_bin()` using `bins = 30`. Pick better value with `binwidth`.
## `stat_bin()` using `bins = 30`. Pick better value with `binwidth`.

```



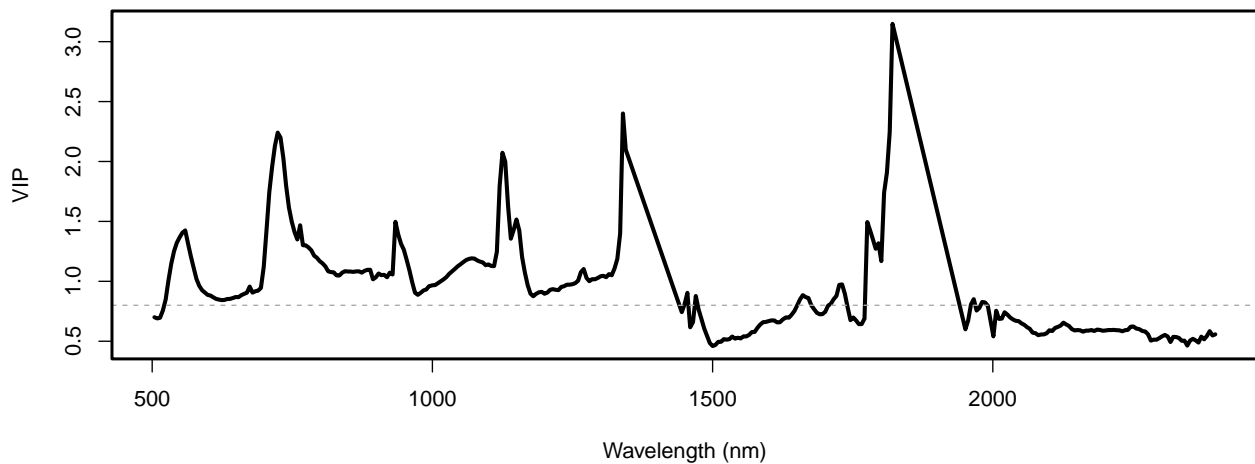
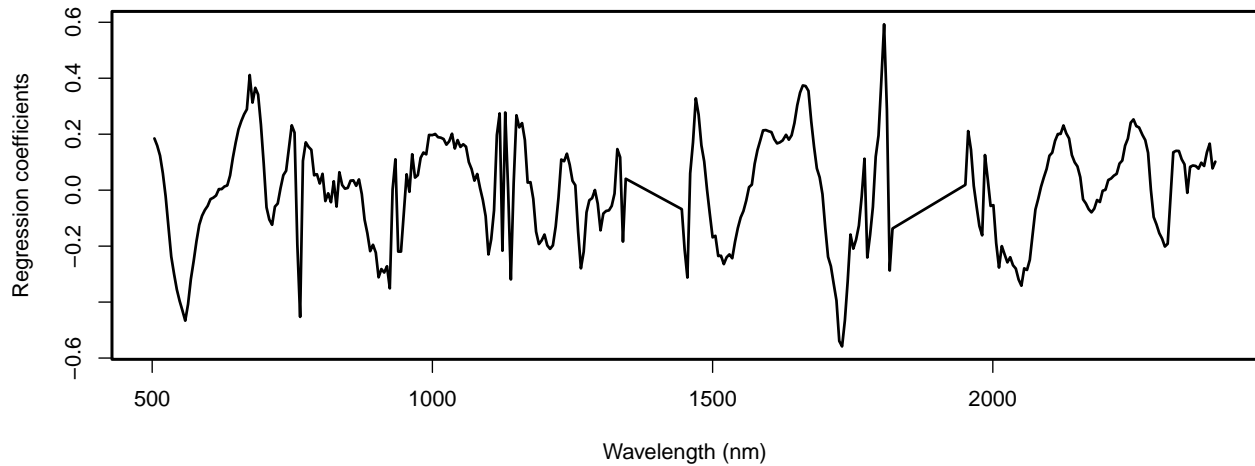
```
ggsave(filename = file.path(outdir,paste0(inVar,"_Cal_Val_Scatterplots.png")),
  plot = scatterplots, device="png", width = 32, height = 30, units = "cm",
  dpi = 300)
```

Generate Coefficient and VIP plots

```
vips <- spectratrait::VIP(plsr.out)[nComps,]

par(mfrow=c(2,1))
plot(plsr.out$coefficients[,nComps], x=wv,xlab="Wavelength (nm)",
  ylab="Regression coefficients",lwd=2,type='l')
box(lwd=2.2)
plot(wv, vips, xlab="Wavelength (nm)",ylab="VIP",cex=0.01)
lines(wv, vips, lwd=3)
```

```
abline(h=0.8, lty=2, col="dark grey")
box(lwd=2.2)
```



```
dev.copy(png, file.path(outdir, paste0(inVar, '_Coefficient_VIP_plot.png')),
         height=3100, width=4100, res=340)
```

```
## quartz_off_screen
## 3
```

```
dev.off();
```

```
## pdf
## 2
```

```
par(opar)
```

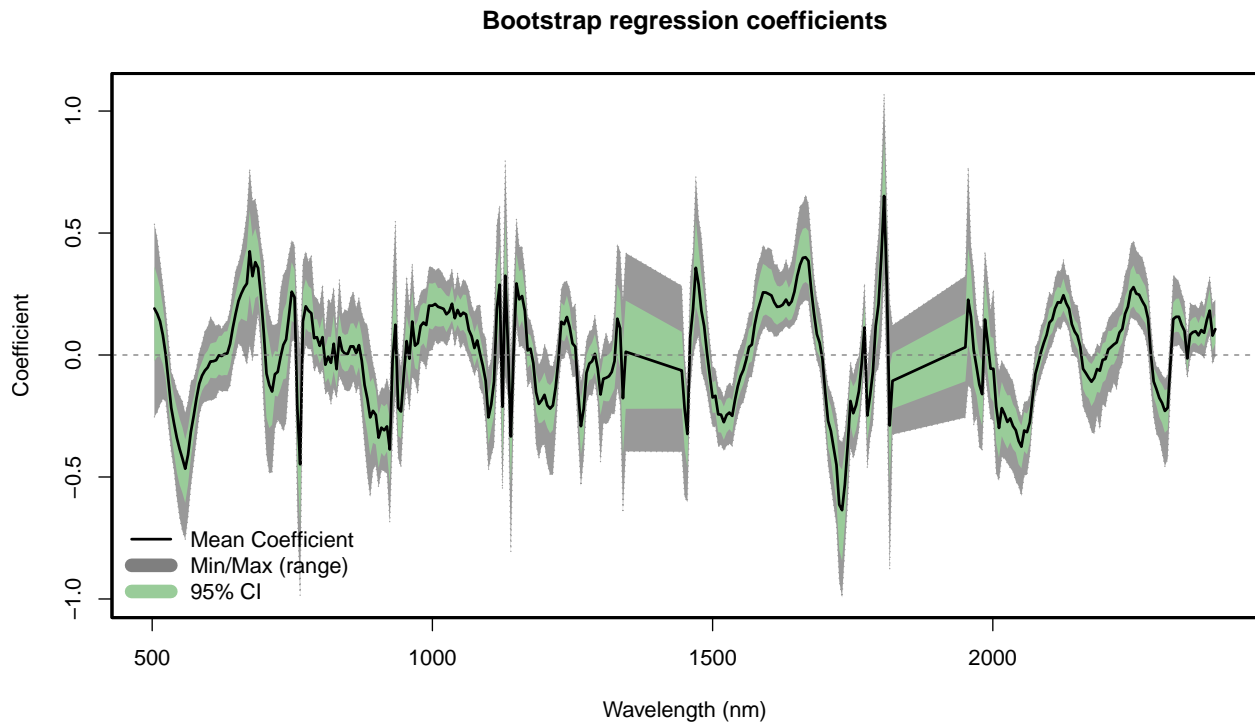
Bootstrap validation

```
## [1] "*** Running permutation test. Please hang tight, this can take awhile ***"
## [1] "Options:"
## [1] "Max Components: 12 Iterations: 500 Data Proportion (percent): 70"
## [1] "*** Providing PRESS and coefficient array output ***"
```

	Plot_Num	SampleID	Plot_ID	Sample_Year	SLA	Nitrogen	PLSR_Predicted
##	1	D02	0001	D02_0001	2017	13.66366	31.18030
##	4	D02	0004	D02_0004	2017	16.63205	34.54034
##	16	D02	0016	D02_0016	2017	14.44765	22.87740
##	18	D02	0019	D02_0019	2017	14.47103	17.73126
##	19	D02	0020	D02_0020	2017	18.98522	21.32929
##	20	D02	0021	D02_0021	2017	12.12731	29.50256
##							
	PLSR_Residuals	LCI	UCI	LPI	UPI		
##	1	-8.628643	21.75139	23.67919	13.44246	31.66086	
##	4	-3.745399	29.24737	32.37867	21.60577	39.98412	
##	16	6.267060	27.57462	30.82609	19.93270	38.35621	
##	18	5.743923	21.73808	24.49326	14.31158	32.63878	
##	19	1.678070	20.70321	24.57934	13.73687	32.27785	
##	20	2.432274	30.75996	34.32739	22.69357	41.17610	

Jackknife coefficient plot

```
spectratrait::f.plot.coef(Z = t(bootstrap_coef), wv = wv,
  plot_label="Bootstrap regression coefficients",
  position = 'bottomleft')
abline(h=0,lty=2,col="grey50")
box(lwd=2.2)
```



```
dev.copy(png,file.path(outdir,paste0(inVar,'_Bootstrap_Regression_Coefficients.png')),
  height=2100, width=3800, res=340)
```

```
## quartz_off_screen
## 3
```

```
dev.off();
```

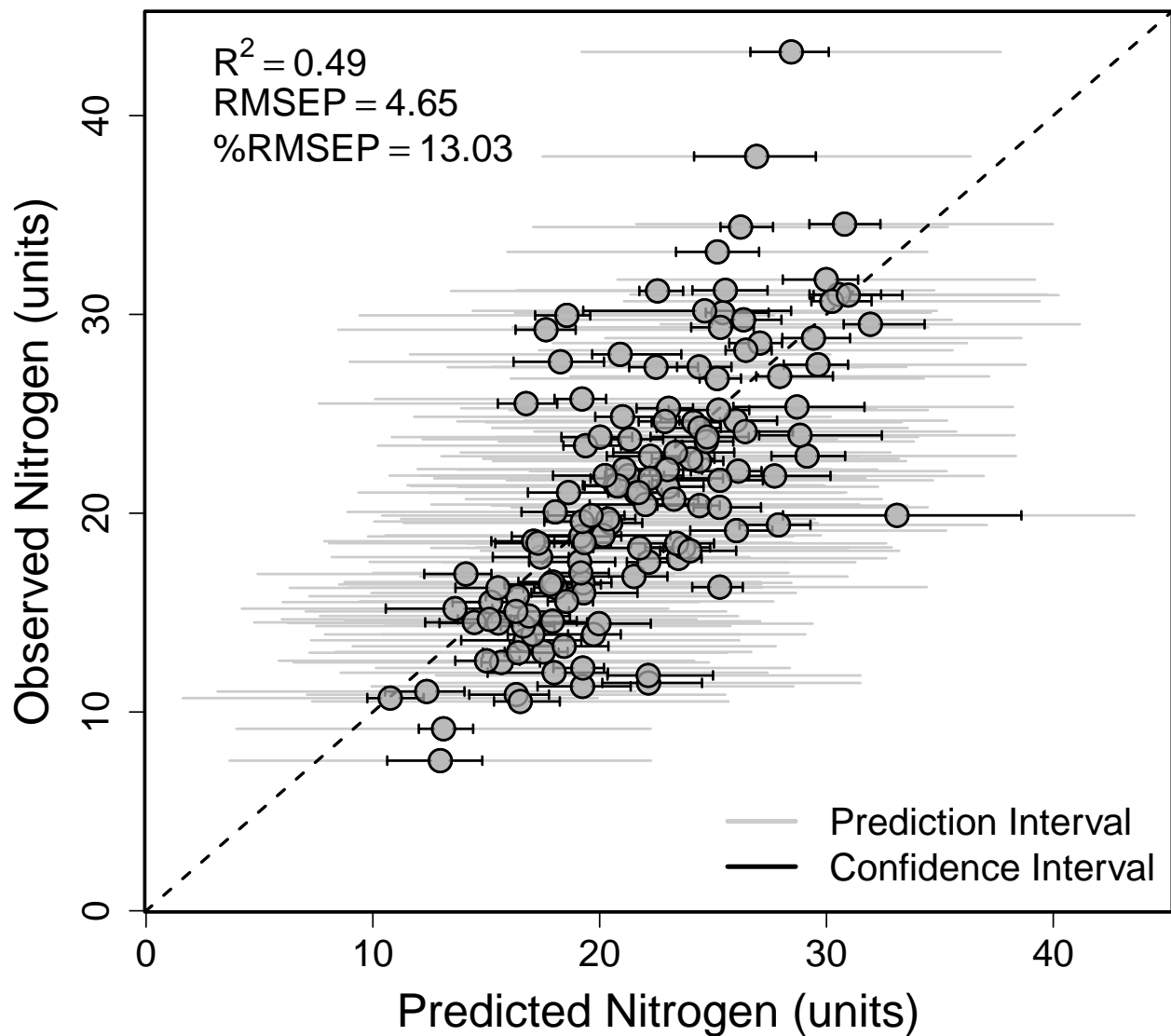
```
## pdf
```

```
## 2
```

Bootstrap validation plot

```
rmsep_percrmsep <- spectratrait::percent_rmse(plsr_dataset = val.plsr.output,
                                              inVar = inVar,
                                              residuals = val.plsr.output$PLSR_Residuals,
                                              range="full")

RMSEP <- rmsep_percrmsep$rmse
perc_RMSEP <- rmsep_percrmsep$perc_rmse
r2 <- round(pls::R2(plsr.out, newdata = val.plsr.data, intercept=F)$val[nComps],2)
expr <- vector("expression", 3)
expr[[1]] <- bquote(R^2==.(r2))
expr[[2]] <- bquote(RMSEP==.(round(RMSEP,2)))
expr[[3]] <- bquote("%RMSEP"==.(round(perc_RMSEP,2)))
rng_vals <- c(min(val.plsr.output$LPI), max(val.plsr.output$UPI))
par(mfrow=c(1,1), mar=c(4.2,5.3,1,0.4), oma=c(0, 0.1, 0, 0.2))
plotrix::plotCI(val.plsr.output$PLSR_Predicted, val.plsr.output[,inVar],
                li=val.plsr.output$LPI, ui=val.plsr.output$UPI, gap=0.009, sfrac=0.000,
                lwd=1.6, xlim=c(rng_vals[1], rng_vals[2]), ylim=c(rng_vals[1], rng_vals[2]),
                err="x", pch=21, col="black", pt.bg=scales::alpha("grey70",0.7), scol="grey80",
                cex=2, xlab=paste0("Predicted ", paste(inVar), " (units)"),
                ylab=paste0("Observed ", paste(inVar), " (units)"),
                cex.axis=1.5, cex.lab=1.8)
abline(0,1,lty=2,lw=2)
plotrix::plotCI(val.plsr.output$PLSR_Predicted, val.plsr.output[,inVar],
                li=val.plsr.output$LPI, ui=val.plsr.output$UPI, gap=0.009, sfrac=0.004,
                lwd=1.6, xlim=c(rng_vals[1], rng_vals[2]), ylim=c(rng_vals[1], rng_vals[2]),
                err="x", pch=21, col="black", pt.bg=scales::alpha("grey70",0.7), scol="black",
                cex=2, xlab=paste0("Predicted ", paste(inVar), " (units)"),
                ylab=paste0("Observed ", paste(inVar), " (units)"),
                cex.axis=1.5, cex.lab=1.8, add=T)
legend("topleft", legend=expr, bty="n", cex=1.5)
legend("bottomright", legend=c("Prediction Interval", "Confidence Interval"),
      lty=c(1,1), col = c("grey80", "black"), lwd=3, bty="n", cex=1.5)
box(lwd=2.2)
```

```
dev.copy(png,file.path(outdir,paste0(inVar,"_PLSR_Validation_Scatterplot.png")),
         height=2800, width=3200, res=340)
```

```
## quartz_off_screen
## 3
```

```
dev.off();
```

```
## pdf
## 2
```

Output bootstrap results

```
out.jk.coefs <- data.frame(Iteration=seq(1,length(bootstrap_intercept),1),
                          Intercept=bootstrap_intercept,t(bootstrap_coef))
names(out.jk.coefs) <- c("Iteration","Intercept",paste0("Wave_",wv))
head(out.jk.coefs)[1:6]
```

```
##   Iteration Intercept   Wave_504   Wave_509   Wave_514   Wave_519
## 1         1  13.57171  0.2253380  0.1886856  0.1539993  0.09577521
```

```
## 2      2  15.24466  0.1921689  0.1596680  0.1200761  0.05273115
## 3      3  14.36148  0.2138642  0.1821139  0.1216748  0.06134136
## 4      4  12.28467  0.2444603  0.2089635  0.1558502  0.10461395
## 5      5  12.94807 -0.1358811 -0.1290176 -0.1109839 -0.09476558
## 6      6  14.56747  0.2983242  0.2627539  0.2313171  0.16354535

write.csv(out.jk.coefs,file=file.path(outdir,paste0(inVar,'_Bootstrap_PLSR_Coefficients.csv')),
          row.names=FALSE)
```

Create core PLSR outputs

```
print(paste("Output directory: ", getwd()))

## [1] "Output directory: /Users/sserbin/Data/Github/spectratrait/vignettes"

# Observed versus predicted
write.csv(cal.plsr.output,file=file.path(outdir,
                                         paste0(inVar,'_Observed_PLSR_CV_Pred_',nComps,
                                                  'comp.csv')),row.names=FALSE)

# Validation data
write.csv(val.plsr.output,file=file.path(outdir,
                                         paste0(inVar,'_Validation_PLSR_Pred_',nComps,
                                                  'comp.csv')),row.names=FALSE)

# Model coefficients
coefs <- coef(plsr.out,ncomp=nComps,intercept=TRUE)
write.csv(coefs,file=file.path(outdir,paste0(inVar,'_PLSR_Coefficients_',
                                             nComps,'comp.csv')),
          row.names=TRUE)

# PLSR VIP
write.csv(vips,file=file.path(outdir,paste0(inVar,
                                             '_PLSR_VIPs_',nComps,
                                             'comp.csv')))
```

Confirm files were written to temp space

```
print("**** PLSR output files: ")

## [1] "**** PLSR output files: "

print(list.files(outdir)[grep(pattern = inVar,
                              list.files(outdir))])

## [1] "Nitrogen_Bootstrap_PLSR_Coefficients.csv"
## [2] "Nitrogen_Bootstrap_Regression_Coefficients.png"
## [3] "Nitrogen_Cal_PLSR_Dataset.csv"
## [4] "Nitrogen_Cal_Val_Histograms.png"
## [5] "Nitrogen_Cal_Val_Scatterplots.png"
## [6] "Nitrogen_Cal_Val_Spectra.png"
## [7] "Nitrogen_Coefficient_VIP_plot.png"
## [8] "Nitrogen_Observed_PLSR_CV_Pred_12comp.csv"
## [9] "Nitrogen_PLSR_Coefficients_12comp.csv"
## [10] "Nitrogen_PLSR_Component_Selection.png"
## [11] "Nitrogen_PLSR_Validation_Scatterplot.png"
```

```
## [12] "Nitrogen_PLSR_VIPs_12comp.csv"  
## [13] "Nitrogen_Val_PLSR_Dataset.csv"  
## [14] "Nitrogen_Validation_PLSR_Pred_12comp.csv"  
## [15] "Nitrogen_Validation_RMSEP_R2_by_Component.png"
```