Q1: Are lake and terrestrial primary productivity coherent?

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This document organizes for openness and reproducibility analyses of the temporal coherence of interannual variation in lake primary productivity with terrestrial primary productivity in the landscape surrounding the lake.

Data import

Data produced in 'ms1__prep.Rmd' are loaded.

```
load("/Users/jonathanwalter/Box Sync/NSF EAGER Synchrony/Data/RData files/ms1_analysis_inprogress1.RData
```

```
any(sapply(analysislakes$lakedata, function(x){any(is.infinite(x))}))
```

```
## [1] FALSE
```

```
any(sapply(analysislakes$lakedata, function(x){any(is.na(x))}))
```

```
## [1] FALSE
```

```
which(sapply(analysislakes$lakedata, function(x){any(is.na(x))}))
```

```
## named integer(0)
```

```
analysislakes$lakeinfo[which(sapply(analysislakes$lakedata, function(x){any(is.na(x))})),]
```

```
##  [1] lagoslakeid       gnis_name         nhd_lat
##  [4] nhd_long          lake_area_ha      lake_perim_meters
##  [7] nhd_ftype         nhd_fcode         hu4_zoneid
## [10] hu12_zoneid       state_zoneid      elevation_m
## [13] start             end
## <0 rows> (or 0-length row.names)
```

```
# image(accndvi)
# points(lakepts.prj[which(sapply(analysislakes$lakedata, function(x){any(is.na(x))})),])

dbuff[which(sapply(analysislakes$lakedata, function(x){any(is.na(x))}))]
```

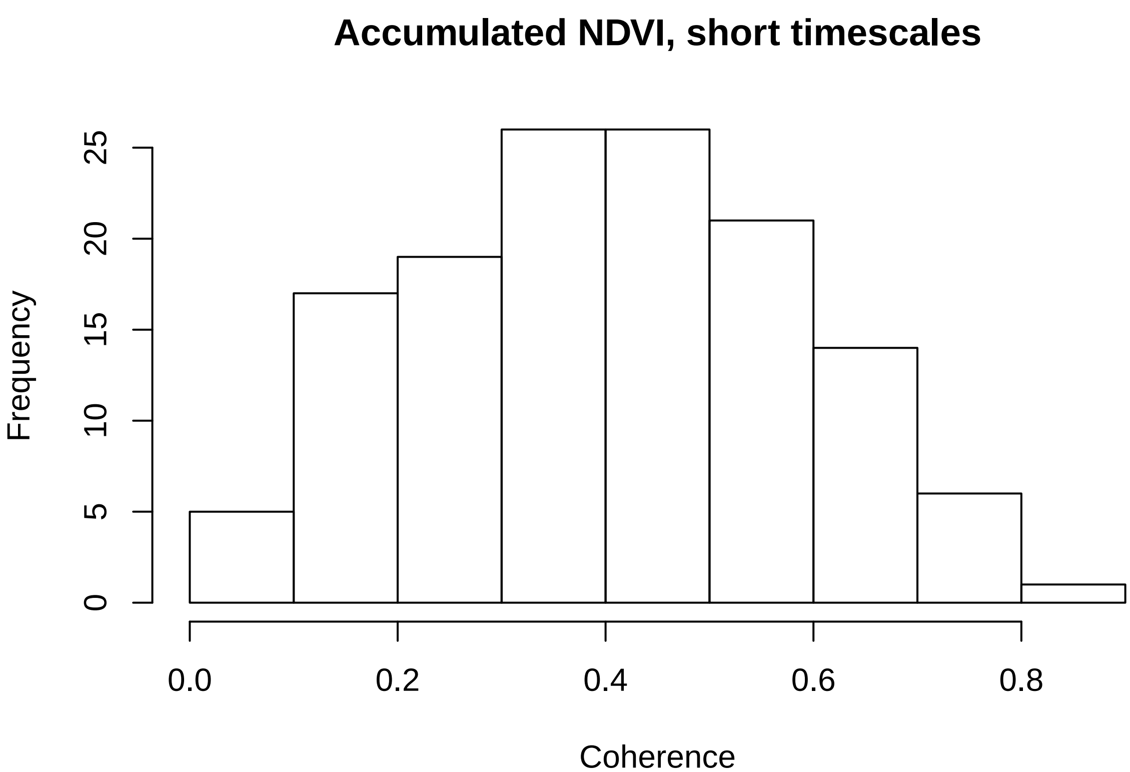
```
## numeric(0)
```

```
analysislakes$lakeinfo<-analysislakes$lakeinfo[!sapply(analysislakes$lakedata, function(x){any(is.na(x)
analysislakes$lakedata<-analysislakes$lakedata[!sapply(analysislakes$lakedata, function(x){any(is.na(x)

analysislakes$lakeinfo$tslength<-analysislakes$lakeinfo$end-analysislakes$lakeinfo$start+1
# analysislakes$lakedata<-analysislakes$lakedata[analysislakes$lakeinfo$tslength >= 20]
# analysislakes$lakeinfo<-analysislakes$lakeinfo[analysislakes$lakeinfo$tslength >= 20,]
```

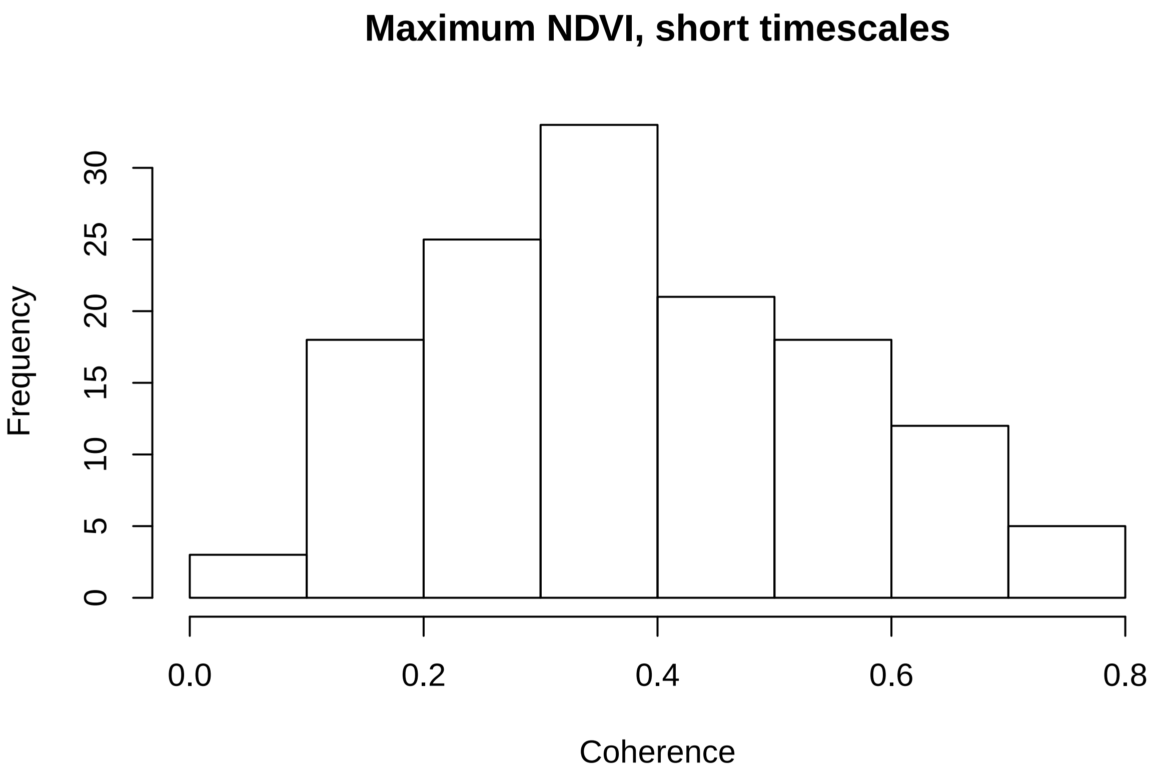
```
source("~/GitHub/AquaTerrSynch/AnalysisCode/bandtest_coh.R")

tsranges<-rbind(c(2,4),c(4,Inf),c(2,Inf))
```

```
coh.chlaXaccndvi<-NULL
coh.chlaXmaxndvi<-NULL

for(lind in 1:length(analysislakes$lakedata)){
  lakedat.ii<-cleandat(analysislakes$lakedata[[lind]], as.numeric(colnames(analysislakes$lakedata[[lind
  chlaXaccndvi<-coh(lakedat.ii[1,], lakedat.ii[2,], as.numeric(colnames(analysislakes$lakedata[[lind]])
                    norm="powall", sigmethod="fast", nrand=10000)
  chlaXmaxndvi<-coh(lakedat.ii[1,], lakedat.ii[3,], as.numeric(colnames(analysislakes$lakedata[[lind]])
                    norm="powall", sigmethod="fast", nrand=10000)
  for(rind in 1:nrow(tsranges)){
    chlaXaccndvi<-bandtest.coh(chlaXaccndvi, tsranges[rind,])
    chlaXmaxndvi<-bandtest.coh(chlaXmaxndvi, tsranges[rind,])
  }
  coh.chlaXaccndvi<-rbind(coh.chlaXaccndvi, c(t(as.matrix(chlaXaccndvi$bandp[,3:5]))))
  coh.chlaXmaxndvi<-rbind(coh.chlaXmaxndvi, c(t(as.matrix(chlaXmaxndvi$bandp[,3:5]))))

}

coh.chlaXaccndvi<-as.data.frame(coh.chlaXaccndvi)
coh.chlaXmaxndvi<-as.data.frame(coh.chlaXmaxndvi)

colnames(coh.chlaXaccndvi)<-paste0("accndvi",c("p.ts1","phi.ts1","coh.ts1","p.ts2","phi.ts2","coh.ts2",
colnames(coh.chlaXmaxndvi)<-paste0("maxndvi",c("p.ts1","phi.ts1","coh.ts1","p.ts2","phi.ts2","coh.ts2",

coh.chlaXaccndvi$lagoslakeid<-analysislakes$lakeinfo$lagoslakeid
coh.chlaXmaxndvi$lagoslakeid<-analysislakes$lakeinfo$lagoslakeid
```

```
#short timescales
hist(coh.chlaXaccndvi$accndvicoh.ts1, main="Accumulated NDVI, short timescales", xlab="Coherence", ylab
```



```r
hist(coh.chlaXmaxndvi$maxndvicoh.ts1, main="Maximum NDVI, short timescales", xlab="Coherence", ylab="Fr
```




```r
quantile(coh.chlaXaccndvi$accndvicoh.ts1)
```

```
##         0%        25%        50%        75%       100%
## 0.03540956 0.26015941 0.40373548 0.52492077 0.81625251
```

```r
quantile(coh.chlaXmaxndvi$maxndvicoh.ts1)
```

```
##         0%        25%        50%        75%       100%
## 0.04514692 0.24996954 0.35281892 0.50311715 0.77145899
```

```r
alpha=0.05
sum(coh.chlaXaccndvi$accndvip.ts1<alpha)/nrow(coh.chlaXaccndvi)
```

```
## [1] 0.06666667
```

```r
sum(coh.chlaXmaxndvi$maxndvip.ts1<alpha)/nrow(coh.chlaXmaxndvi)
```

```
## [1] 0.05925926
```

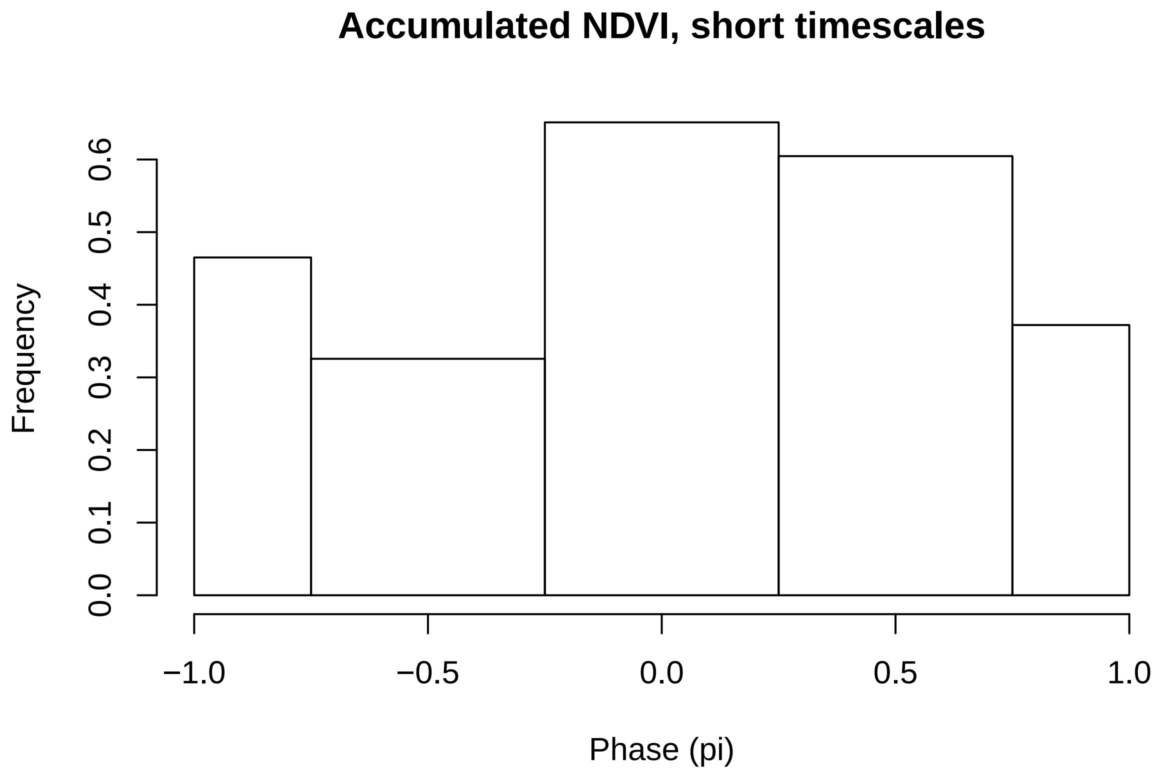
```r
print(coh.chlaXaccndvi$accndviphi.ts1[coh.chlaXaccndvi$accndvip.ts1<alpha]/pi) #only pattern is that la
```

```
## [1]  0.33224850 -0.97156054 -0.04413595  0.56356061 -0.86709075 -0.05260276
## [7]  0.12416199 -0.04172693  0.92429361
```

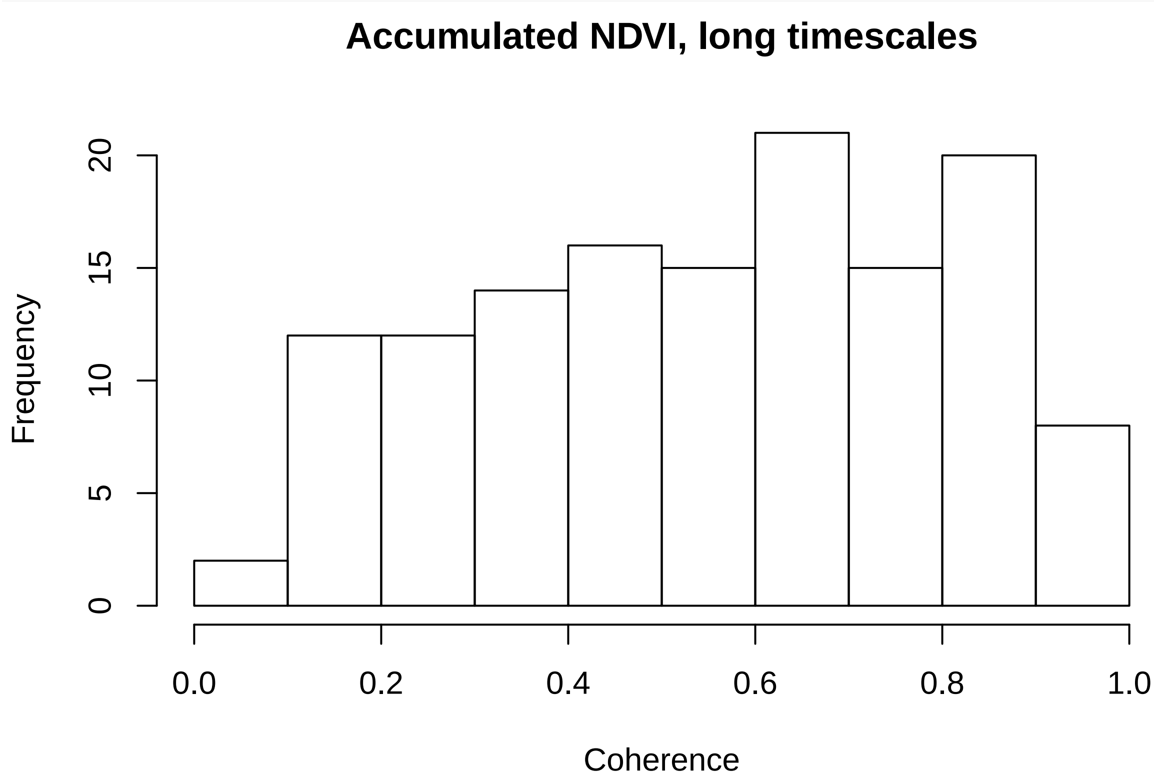
```r
print(coh.chlaXmaxndvi$maxndviphi.ts1[coh.chlaXmaxndvi$maxndvip.ts1<alpha]/pi)
```

```
## [1] -0.1573764 -0.8240104 -0.7892870 -0.7185325 -0.9310910 -0.8435071
## [7] -0.2280369  0.5324496
```

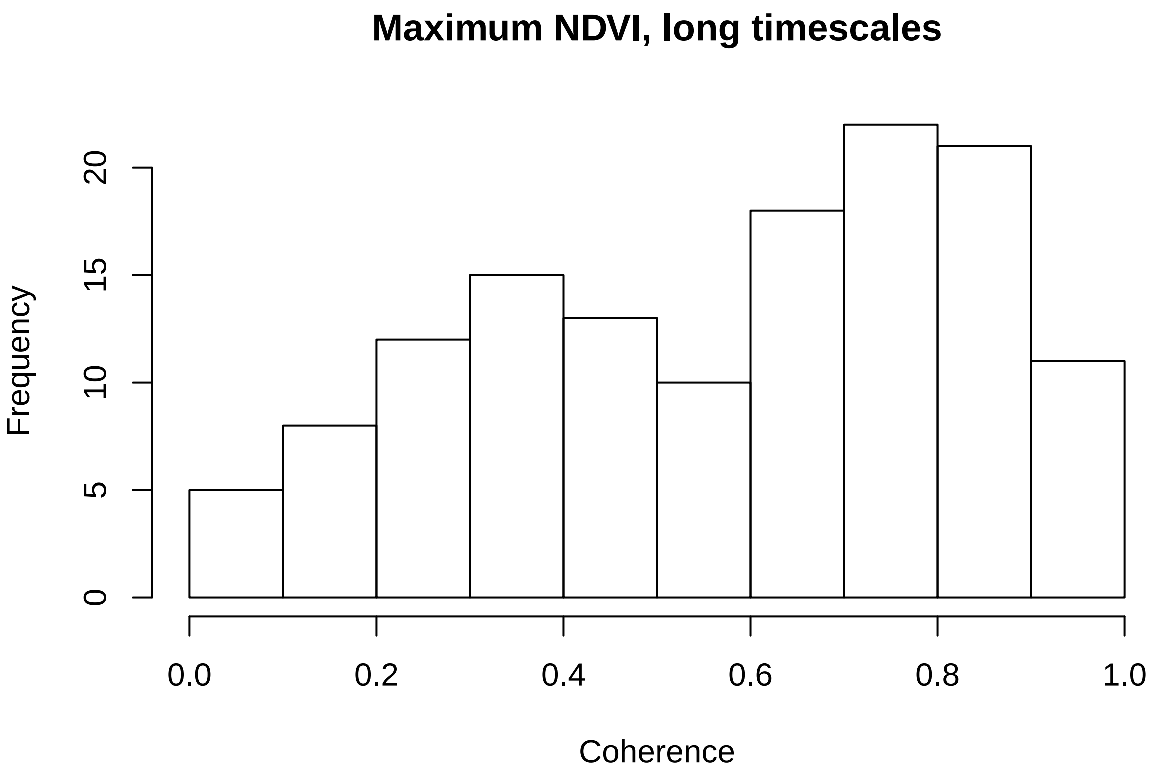
```r
phicls<-c(-1,-.75,-0.25,0.25,0.75,1)

hist(coh.chlaXaccndvi$accndviphi.ts1[coh.chlaXaccndvi$accndvip.ts1<0.3]/pi, main="Accumulated NDVI, sho
```




```
#hist(coh.chlaXmaxndvi$maxndviphi.ts1[coh.chlaXmaxndvi$maxndvip.ts1<0.2]/pi, main="Maximum NDVI, short

#long timescales
hist(coh.chlaXaccndvi$accndvicoh.ts2, main="Accumulated NDVI, long timescales", xlab="Coherence", ylab=
```



```r
hist(coh.chlaXmaxndvi$maxndvicoh.ts2, main="Maximum NDVI, long timescales", xlab="Coherence", ylab="Fre
```




```r
quantile(coh.chlaXaccndvi$accndvicoh.ts2)
```

```
##         0%        25%        50%        75%       100%
## 0.06700155 0.35635453 0.56072757 0.75753276 0.96052338
```

```r
quantile(coh.chlaXmaxndvi$maxndvicoh.ts2)
```

```
##         0%        25%        50%        75%       100%
## 0.04123391 0.35832298 0.61507443 0.78760333 0.96402244
```

```r
alpha=0.05
sum(coh.chlaXaccndvi$accndvip.ts2<alpha)/nrow(coh.chlaXaccndvi)
```

```
## [1] 0.05185185
```

```r
sum(coh.chlaXmaxndvi$maxndvip.ts2<alpha)/nrow(coh.chlaXmaxndvi)
```

```
## [1] 0.05925926
```

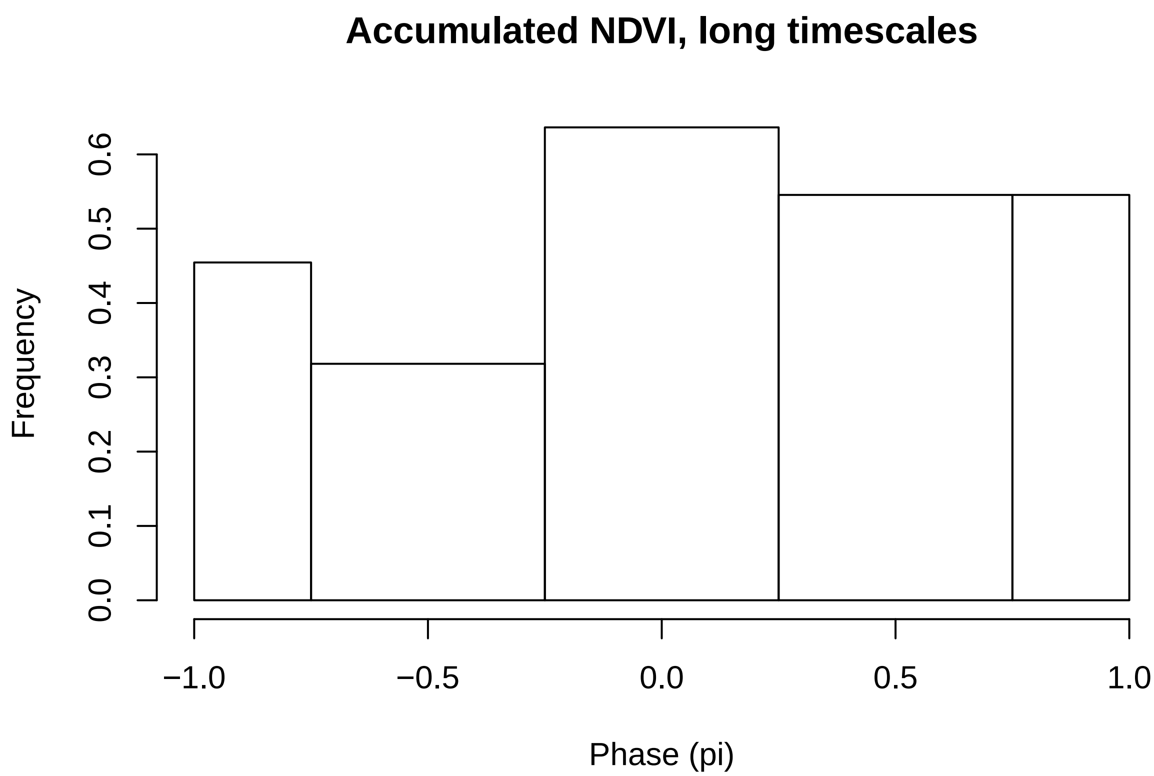
```r
print(coh.chlaXaccndvi$accndviphi.ts2[coh.chlaXaccndvi$accndvip.ts2<alpha]/pi)
```

```
## [1] -0.43893809  0.25315167 -0.40935196 -0.04386325 -0.65597599  0.36382168
## [7]  0.89471121
```

```r
print(coh.chlaXmaxndvi$maxndviphi.ts2[coh.chlaXmaxndvi$maxndvip.ts2<alpha]/pi)
```

```
## [1]  0.69982097 -0.97179292 -0.04190360  0.02097044 -0.67004320 -0.58501674
## [7] -0.31373024 -0.33804686
```

```r
hist(coh.chlaXaccndvi$accndviphi.ts1[coh.chlaXaccndvi$accndvip.ts2<0.3]/pi, main="Accumulated NDVI, lon
```

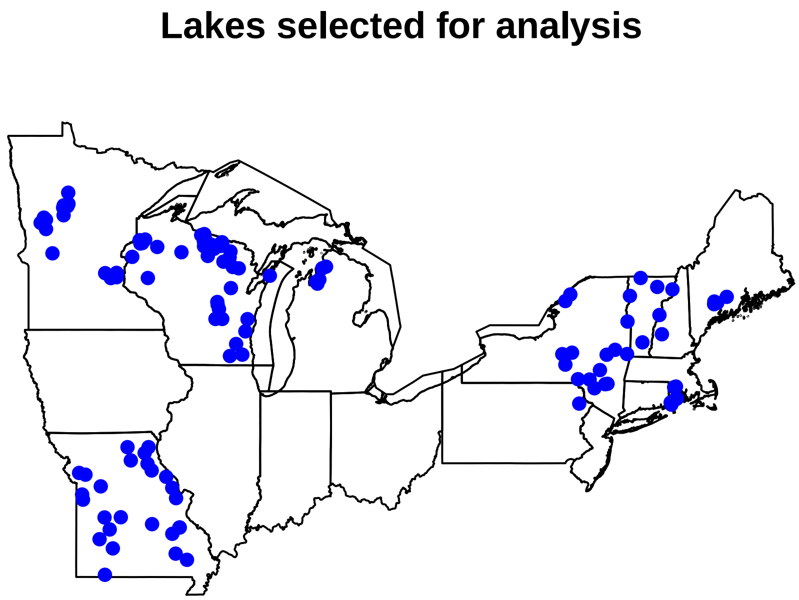



```
#hist(coh.chlaXmaxndvi$maxndviphi.ts1[coh.chlaXmaxndvi$maxndvicoh.ts2>0.6]/pi, main="Maximum NDVI, shor
```

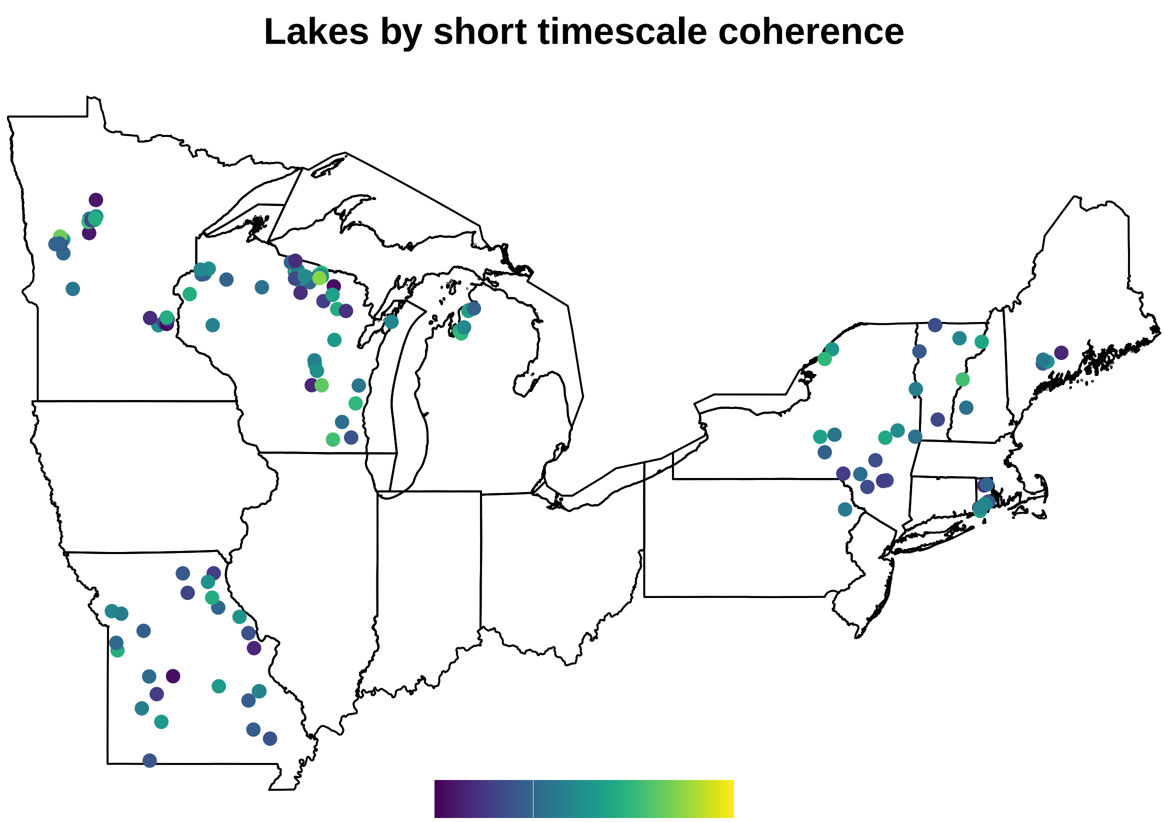
```
states<-readOGR("~/Box Sync/NSF EAGER Synchrony/Data/statesp020.shp")
```

```
## OGR data source with driver: ESRI Shapefile
## Source: "/Users/jonathanwalter/Box Sync/NSF EAGER Synchrony/Data/statesp020.shp", layer: "statesp020
## with 2895 features
## It has 9 fields
## Integer64 fields read as strings:  STATESP020 DAY_ADM YEAR_ADM
```

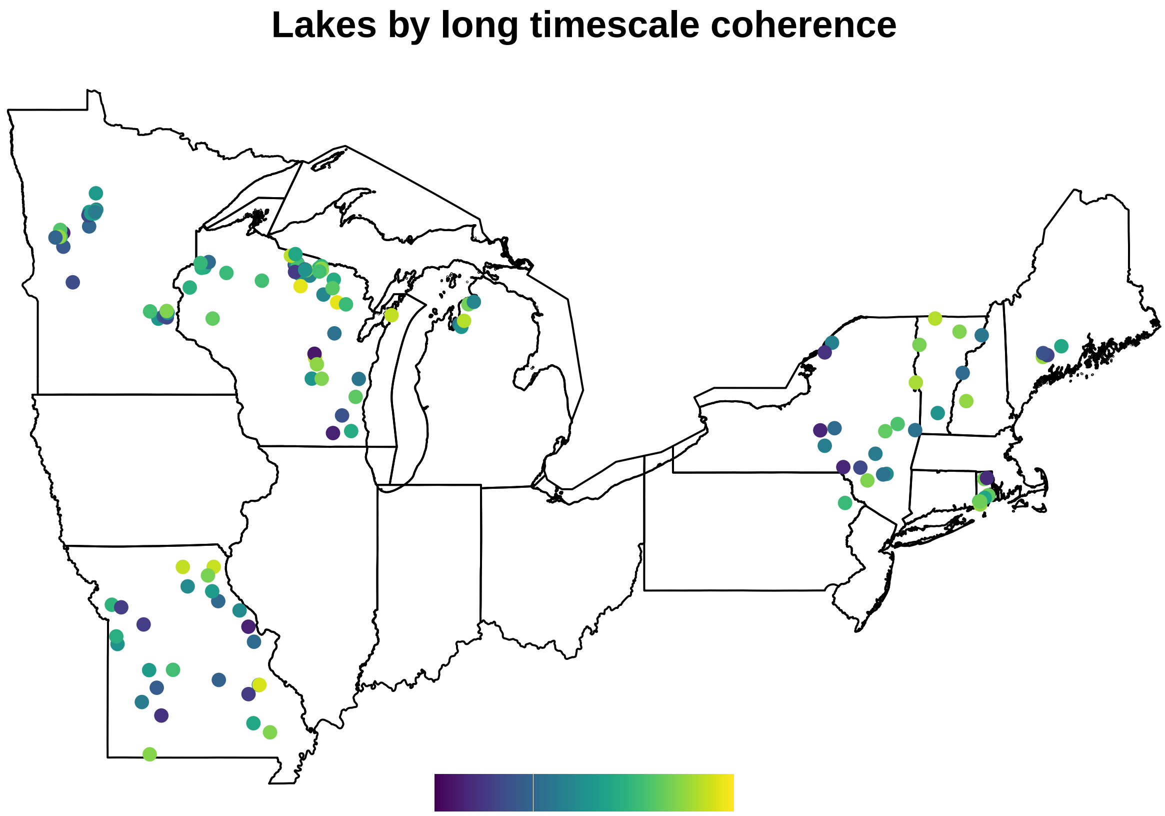
```
getstates<-c("Minnesota", "Iowa", "Wisconsin", "Illinois", "Missouri", "Michigan", "Indiana", "Ohio", "
lagosstates<-states[states@data$STATE %in% getstates,]

plot(lagosstates, main="Lakes selected for analysis")
points(analysislakes$lakeinfo$nhd_long, analysislakes$lakeinfo$nhd_lat, pch=16, cex=1, col="blue")
```




```
cohplotdata<-left_join(analysislakes$lakeinfo, coh.chlaXaccndvi, by="lagoslakeid")

pal<-viridis(100)

par(mar=c(1,0,2,0))

plot(lagosstates, main="Lakes by short timescale coherence")
points(cohplotdata$nhd_long, cohplotdata$nhd_lat, pch=16, cex=1, col=pal[round(cohplotdata$accndvicoh.t
colorbar.plot(x=mean(par("usr")[1:2]),y=par("usr")[3],strip=1:100,col=pal,horizontal = T)
```



```r
plot(lagosstates, main="Lakes by long timescale coherence")
points(cohplotdata$nhd_long, cohplotdata$nhd_lat, pch=16, cex=1, col=pal[round(cohplotdata$accndvicoh.t
colorbar.plot(x=mean(par("usr")[1:2]),y=par("usr")[3],strip=1:100,col=pal,horizontal = T)
```




```r
#Need to add: depth, average growing season Chlorophyll-a, TSI(chla) categories, pct ag

#agriculture -- is 500m buffer best? Other options include 100m buffer (probably too small) and hu12 wa
# pct.ag<-lagosne_select(table="buffer500m.lulc", vars=c("lagoslakeid","buffer500m_nlcd2001_pct_82","bu
pct.ag<-lagosne_select(table="hu12.lulc", vars=c("hu12_zoneid","hu12_nlcd2001_pct_82","hu12_nlcd2006_pc
pct.ag<-pct.ag[pct.ag$hu12_zoneid %in% analysislakes$lakeinfo$hu12_zoneid,]
pct.ag.avg<-data.frame(hu12_zoneid=pct.ag$hu12_zoneid, pct.ag=rowMeans(pct.ag[,2:4]))

#depth
depth<-lagosne_select(table="lakes_limno", vars=c("lagoslakeid","maxdepth"))
depth<-depth[depth$lagoslakeid %in% analysislakes$lakeinfo$lagoslakeid,] #use max depth because it's mo

#growing season Chlorophyll-a
chla<-lagosne_select(table="epi_nutr", vars=c("lagoslakeid","samplemonth","chla"))
chla<-chla[chla$lagoslakeid %in% analysislakes$lakeinfo$lagoslakeid,]
gs.chla<-chla[chla$samplemonth %in% 5:9,]
avg.chla<-aggregate(chla ~ lagoslakeid, data=gs.chla, FUN=mean, na.rm=T)

#Chlorophyll-a TSI class
#TSI(CHL) = 9.81 ln(CHL) + 30.6
tsi.chl<-data.frame(lagoslakeid=avg.chla$lagoslakeid, tsi=9.81 * log(avg.chla$chla) + 30.6)
tsi.chl$tsi.cat<-rep("lake",nrow(tsi.chl))

tsi.chl$tsi.cat[tsi.chl$tsi < 40]<-"oligotrophic"
```

```r
tsi.chl$tsi.cat[tsi.chl$tsi >=40 & tsi.chl$tsi < 50]<-"mesotrophic"
tsi.chl$tsi.cat[tsi.chl$tsi >=50 & tsi.chl$tsi < 70]<-"eutrophic"
tsi.chl$tsi.cat[tsi.chl$tsi >= 70] <-"hypereutrophic"

#CV of terrestrial NDVI
cv.accndvi<-NULL
for(lake in 1:length(analysislakes$lakedata)){
  tmp<-analysislakes$lakedata[[lake]][rownames(analysislakes$lakedata[[lake]])=="accndvi",]
  cv.accndvi<-c(cv.accndvi, sd(tmp)/mean(tmp))
 # rm(tmp)
}
cv.accndvi<-data.frame(lagoslakeid=as.numeric(names(analysislakes$lakedata)), cv.accndvi=cv.accndvi)

#huc2 and huc4 watershed codes
huc_codes<-read.csv("/Users/jonathanwalter/GitHub/AquaTerrSynch/AnalysisCode/match_huc_codes.csv", colCl

#state info
states<-lagosne_select(table="state", vars=c("state_zoneid","state_name"))

predictors<-analysislakes$lakeinfo
predictors<-left_join(predictors, depth, by="lagoslakeid")
predictors<-left_join(predictors, pct.ag.avg, by="hu12_zoneid")
```

```
## Warning: Column `hu12_zoneid` joining factors with different levels,
## coercing to character vector
```

```r
predictors<-left_join(predictors, avg.chla, by="lagoslakeid")
predictors<-left_join(predictors, tsi.chl, by="lagoslakeid")
predictors<-left_join(predictors, states, by="state_zoneid")
```

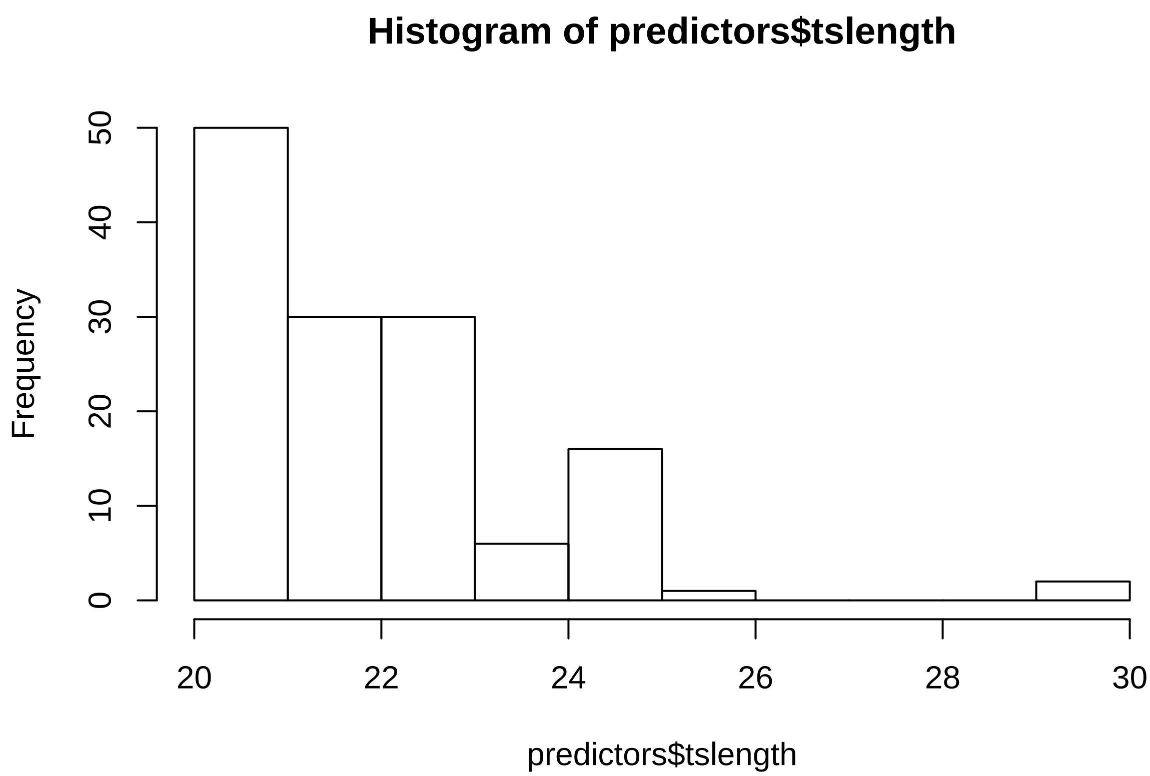
```
## Warning: Column `state_zoneid` joining factors with different levels,
## coercing to character vector
```

```r
predictors<-left_join(predictors, cv.accndvi, by="lagoslakeid")
#predictors<-left_join(predictors, huc_codes, by="hu4_zoneid")

for(nn in 1:ncol(predictors)){

  if(is.factor(predictors[,nn])){
    predictors[,nn]<-factor(predictors[,nn])
  }

}

str(predictors)
```

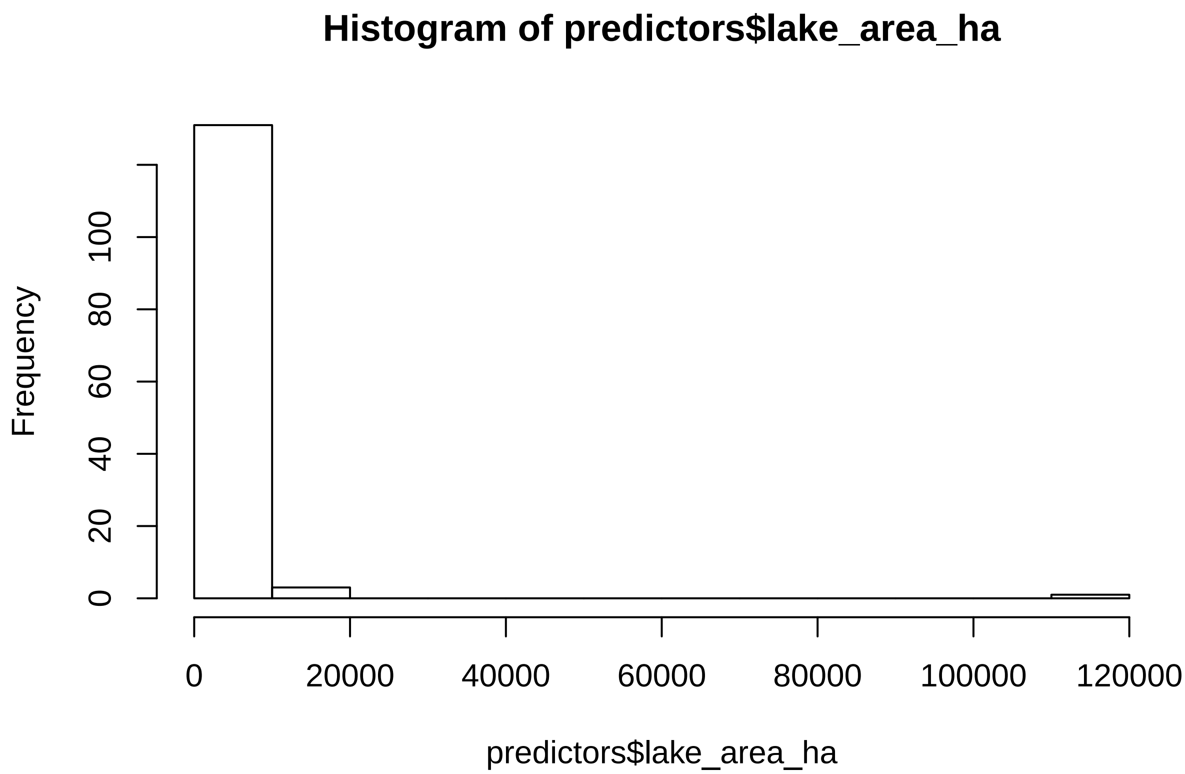
```
## 'data.frame':    135 obs. of  22 variables:
##  $ lagoslakeid      : num  211 249 618 906 969 ...
##  $ gnis_name        : chr  NA NA "Butternut Lake" "Sparkling Lake" ...
##  $ nhd_lat          : num  44.5 43.7 45.9 46 45.8 ...
##  $ nhd_long         : num  -73.3 -73.4 -89 -89.7 -89.3 ...
##  $ lake_area_ha     : num  113496.4 30 504.7 63.7 210.2 ...
##  $ lake_perim_meters: num  1042251 3494 13134 3777 9402 ...
##  $ nhd_ftype        : int  390 390 390 390 390 390 390 390 390 390 ...
##  $ nhd_fcode        : int  39004 39004 39004 39004 39004 39004 39004 39004 39004 39004 ...
```

```
##  $ hu4_zoneid      : Factor w/ 28 levels "HU4_10","HU4_12",..: 17 17 11 8 12 10 10 10 10 10 ...
##  $ hu12_zoneid     : chr  "HU12_17646" "HU12_16835" "HU12_13309" "HU12_13098" ...
##  $ state_zoneid    : chr  "State_17" "State_5" "State_9" "State_9" ...
##  $ elevation_m     : num  28.8 28.2 514.5 494.7 503.3 ...
##  $ start           : num  1989 1990 1993 1989 1994 ...
##  $ end             : num  2010 2010 2013 2011 2013 ...
##  $ tslength        : num  22 21 21 23 20 21 21 21 21 22 ...
##  $ maxdepth        : num  97 NA 12.8 20 11.6 ...
##  $ pct.ag          : num  2.5298 0.4199 0.0976 0.3029 6.6886 ...
##  $ chla            : num  5.39 7.94 2.44 1.86 2.04 ...
##  $ tsi             : num  47.1 50.9 39.4 36.7 37.6 ...
##  $ tsi.cat         : chr  "mesotrophic" "eutrophic" "oligotrophic" "oligotrophic" ...
##  $ state_name      : Factor w/ 10 levels "Maine","Michigan",..: 9 6 10 10 10 2 2 2 2 2 ...
##  $ cv.accndvi      : num  0.0572 0.0542 0.0443 0.0561 0.0417 ...
```

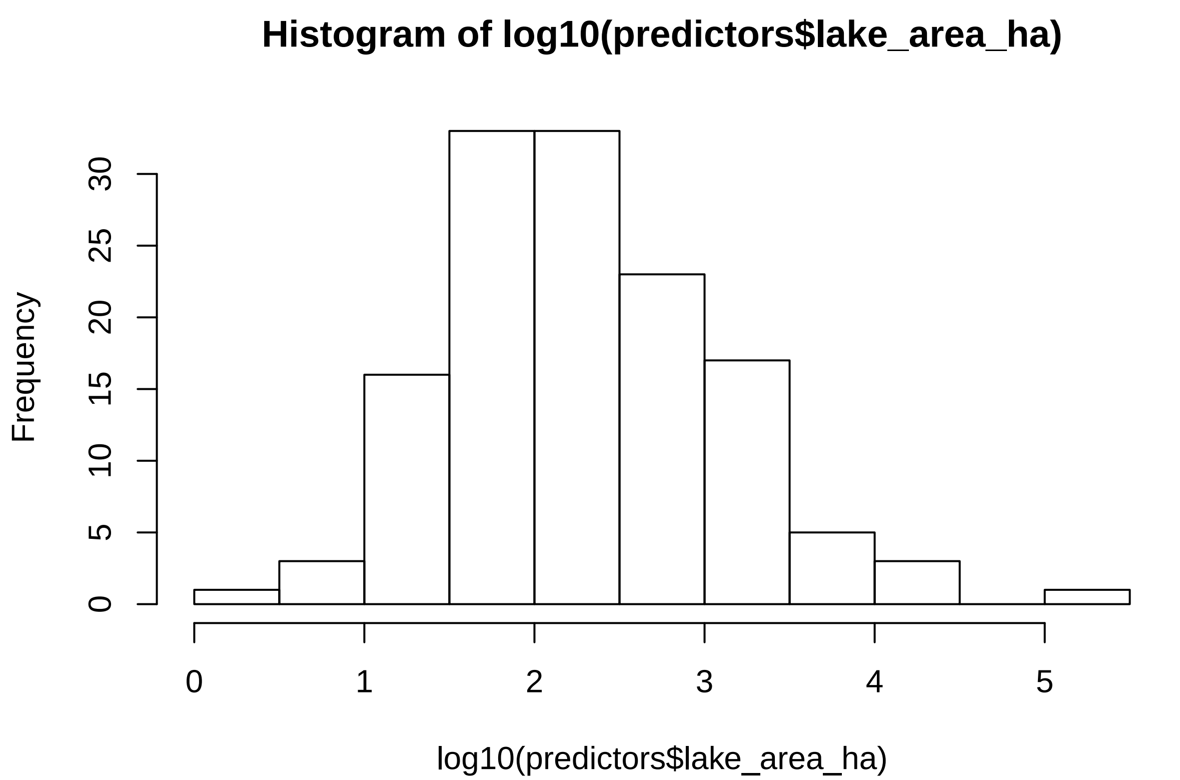
```
hist(predictors$tslength)
```



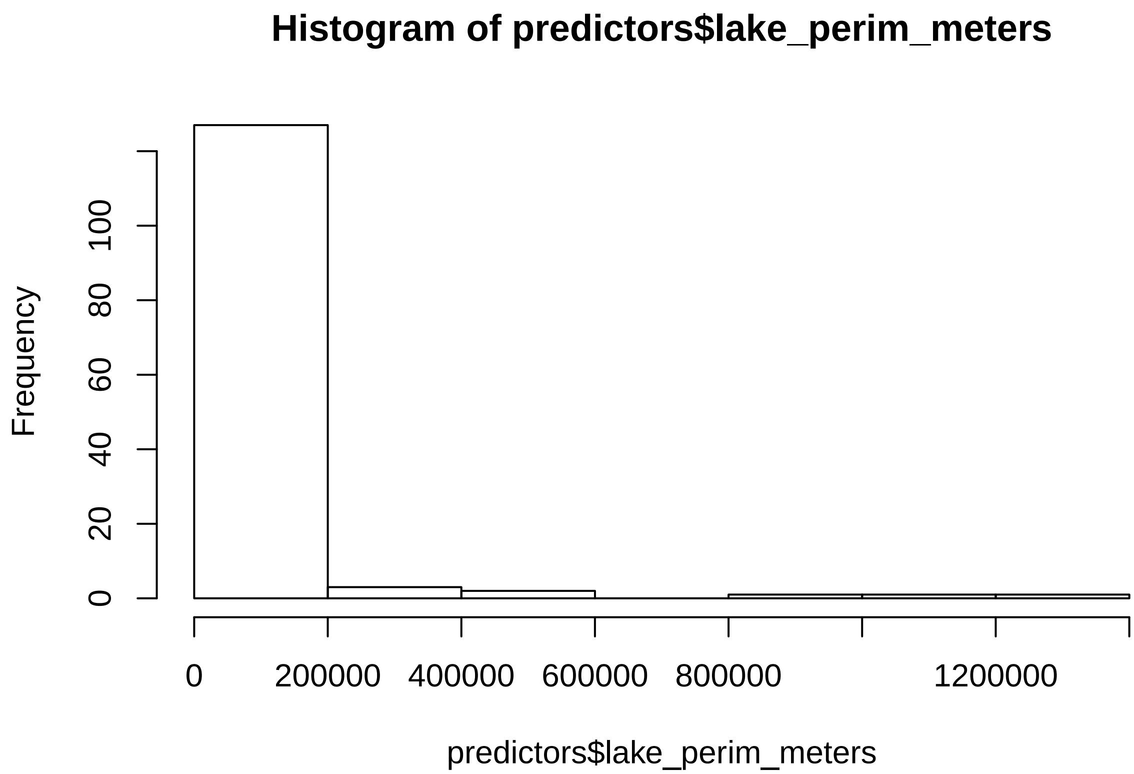

```
hist(predictors$lake_area_ha)
```



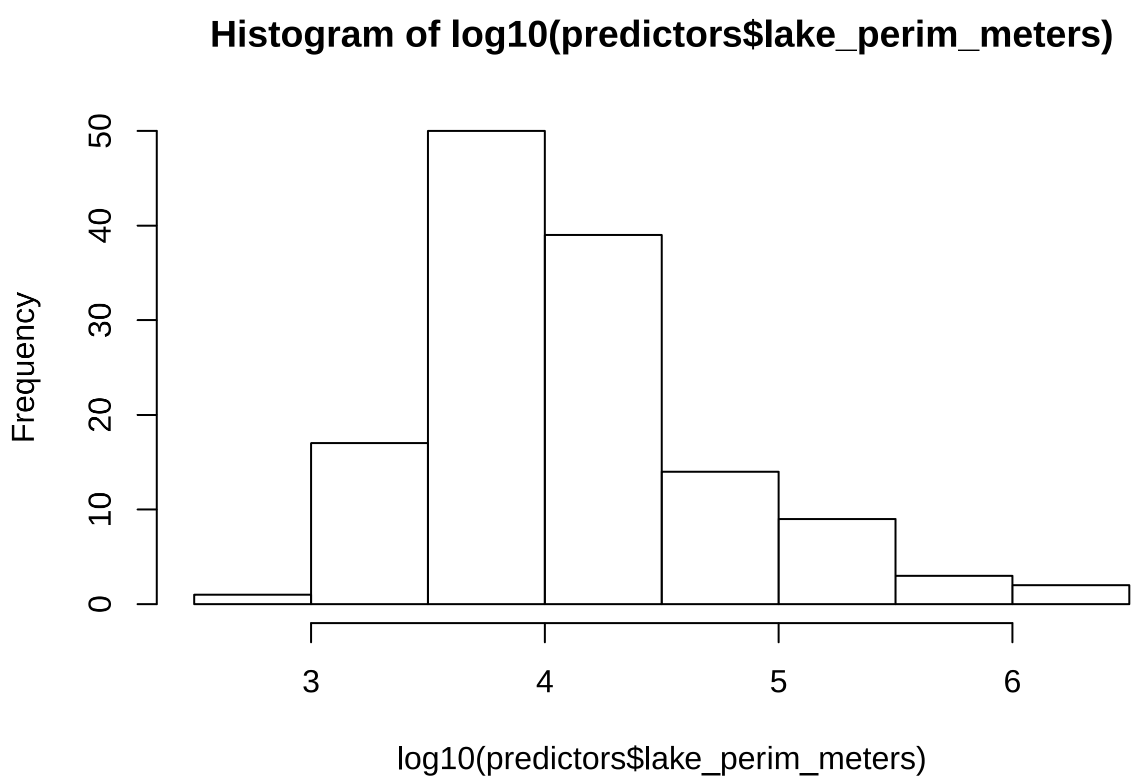

```r
hist(log10(predictors$lake_area_ha))
```




```r
hist(predictors$lake_perim_meters)
```




```
hist(log10(predictors$lake_perim_meters))
```




```
table(predictors$nhd_fcode)
```

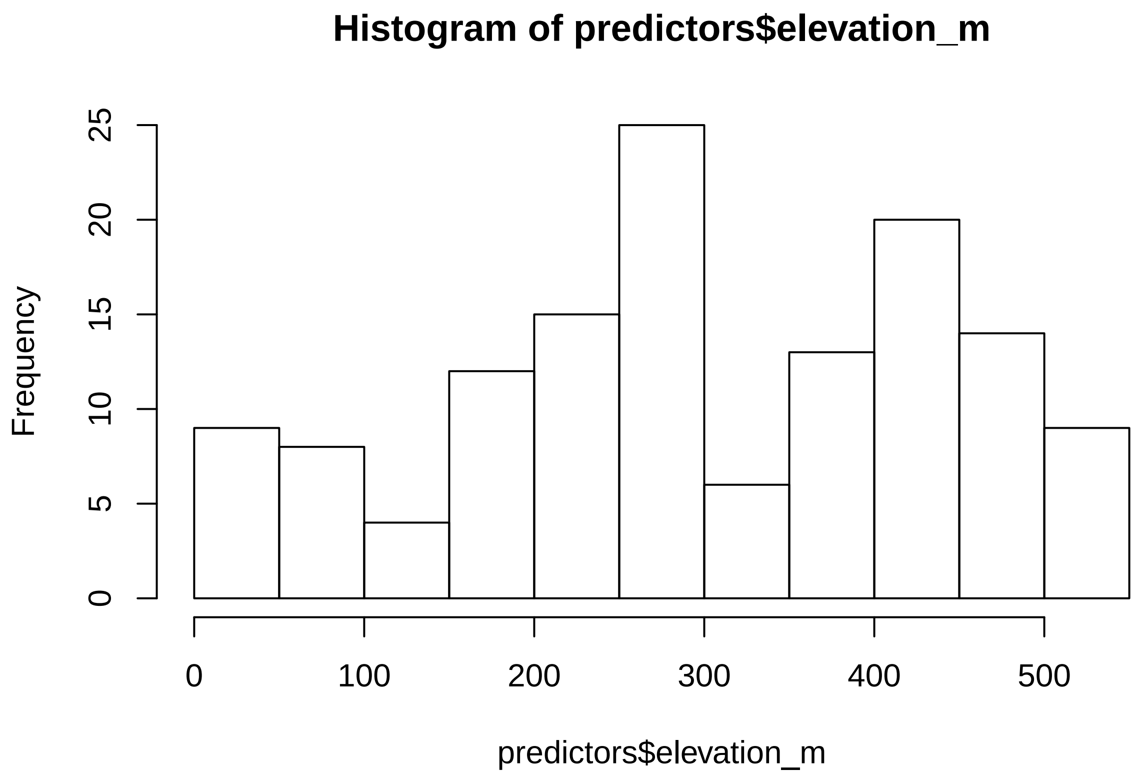
```
##
```

```
## 39000 39004 39009 39010 39012 43601
##     1   110    14     3     6     1
```

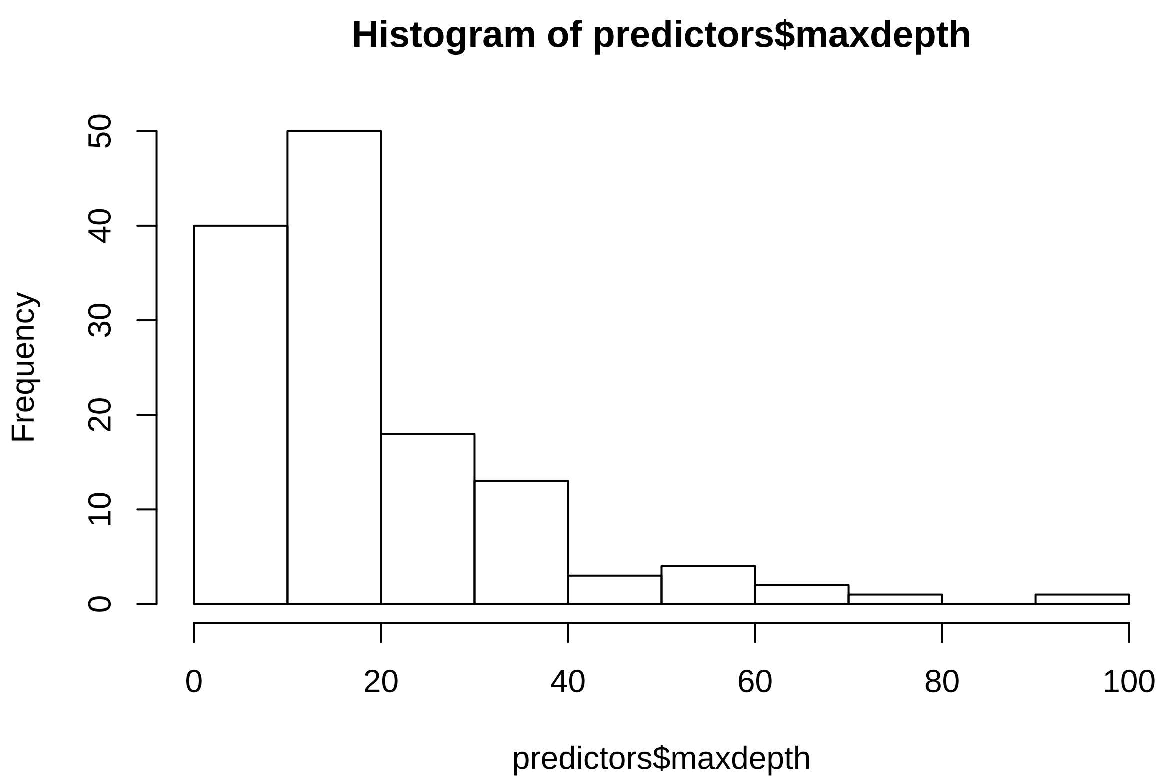
```r
table(predictors$hu12_zoneid)
```

```
##
## HU12_10463 HU12_10471 HU12_10488 HU12_10493 HU12_10499 HU12_10676
##          1          2          1          1          1          1
## HU12_10700 HU12_10785 HU12_10862 HU12_10863 HU12_10865 HU12_11197
##          1          1          1          4          1          1
## HU12_11495 HU12_11509 HU12_11514 HU12_11515 HU12_11522 HU12_11768
##          1          1          2          1          1          1
## HU12_11816 HU12_11826 HU12_11829 HU12_11889 HU12_11938 HU12_11978
##          1          1          1          1          1          1
## HU12_12113 HU12_12125 HU12_12225 HU12_13098 HU12_13100 HU12_13125
##          1          1          1          5          1          1
## HU12_13164 HU12_13192 HU12_13234 HU12_13241 HU12_13244 HU12_13261
##          1          1          1          1          1          1
## HU12_13300 HU12_13304 HU12_13309 HU12_13354 HU12_13360 HU12_13370
##          1          1          2          1          1          3
## HU12_13374 HU12_13376 HU12_13388 HU12_13413 HU12_13616 HU12_13624
##          1          1          1          1          1          1
## HU12_13628 HU12_13633 HU12_13634 HU12_14494 HU12_14495 HU12_14496
##          1          1          1          1          1          1
## HU12_14497 HU12_14533   HU12_148  HU12_1494 HU12_15183 HU12_15280
##          4          1          1          1          1          1
## HU12_15296 HU12_15315 HU12_15329  HU12_1537 HU12_15856 HU12_16122
##          1          1          1          1          1          1
## HU12_16125  HU12_1615  HU12_1621 HU12_16347 HU12_16746 HU12_16747
##          1          1          2          1          1          2
## HU12_16749 HU12_16835 HU12_16882 HU12_17143 HU12_17178 HU12_17235
##          1          1          1          1          1          2
## HU12_17401 HU12_17407 HU12_17433 HU12_17477 HU12_17488 HU12_17504
##          1          1          1          1          2          2
## HU12_17512 HU12_17513 HU12_17541 HU12_17646 HU12_17651 HU12_17655
##          1          2          1          1          1          1
##  HU12_1802 HU12_18174  HU12_1819  HU12_1828 HU12_18730  HU12_1896
##          1          1          1          1          1          1
## HU12_19726  HU12_1980 HU12_19842 HU12_20279  HU12_2173  HU12_2200
##          1          1          1          1          1          1
##  HU12_2239  HU12_2410  HU12_2412  HU12_2429  HU12_4337  HU12_4347
##          1          1          1          1          1          1
##   HU12_442   HU12_488   HU12_509   HU12_542   HU12_581   HU12_829
##          1          1          1          1          1          1
```

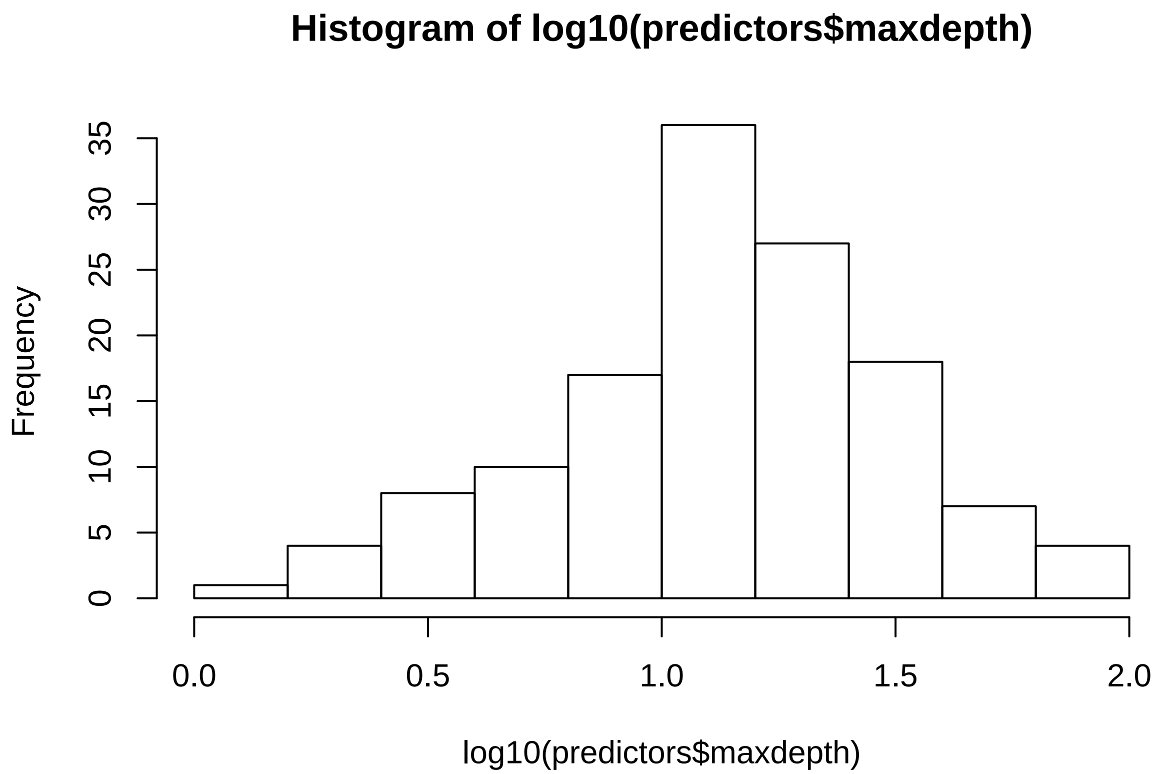
```r
hist(predictors$elevation_m)
```



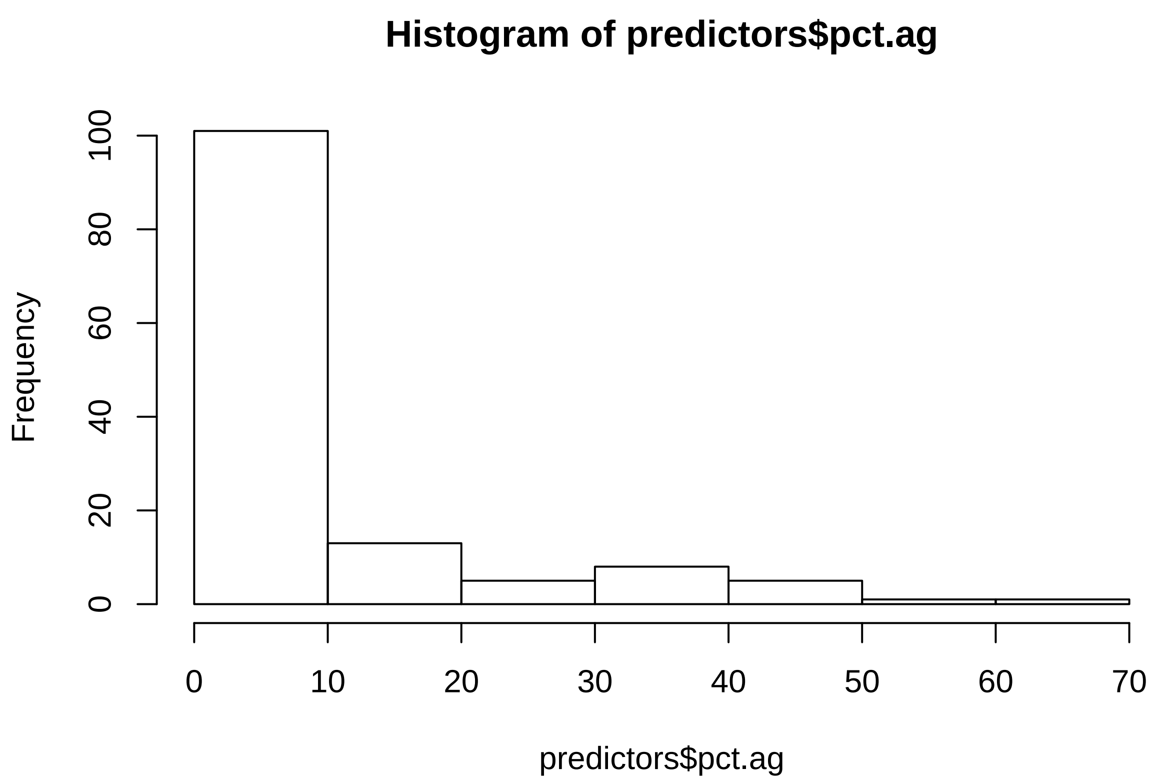

```r
hist(predictors$maxdepth)
```



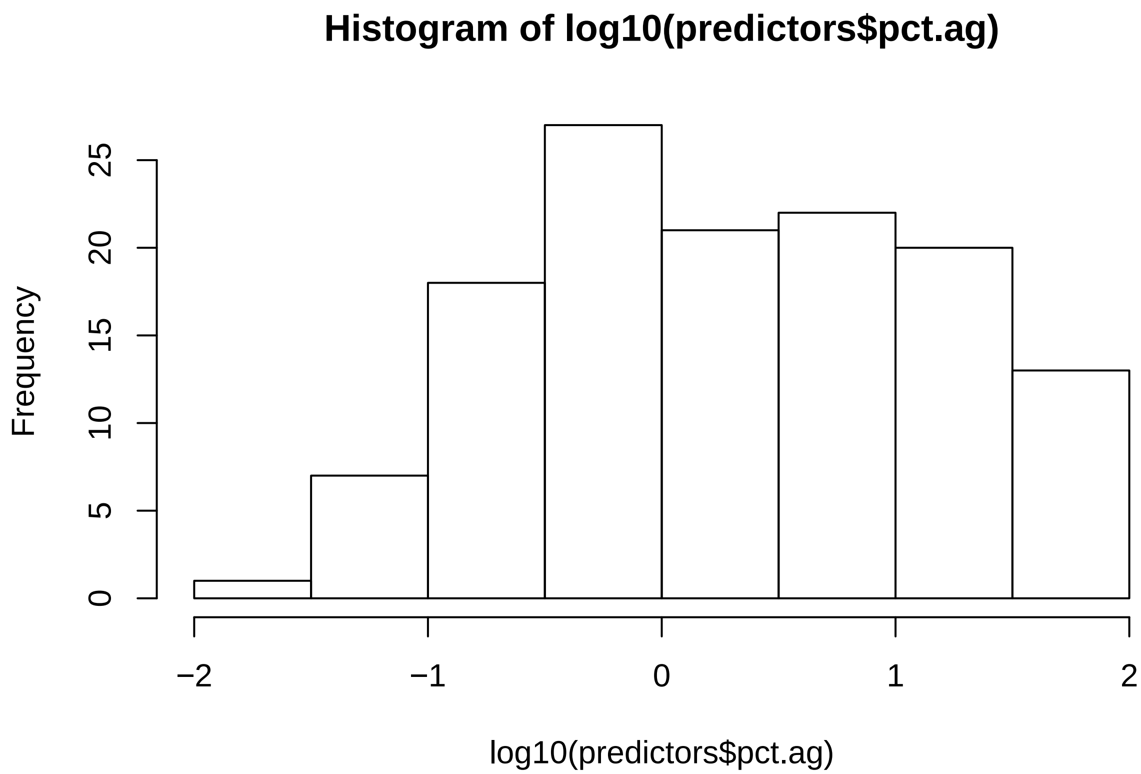

```r
hist(log10(predictors$maxdepth))
```



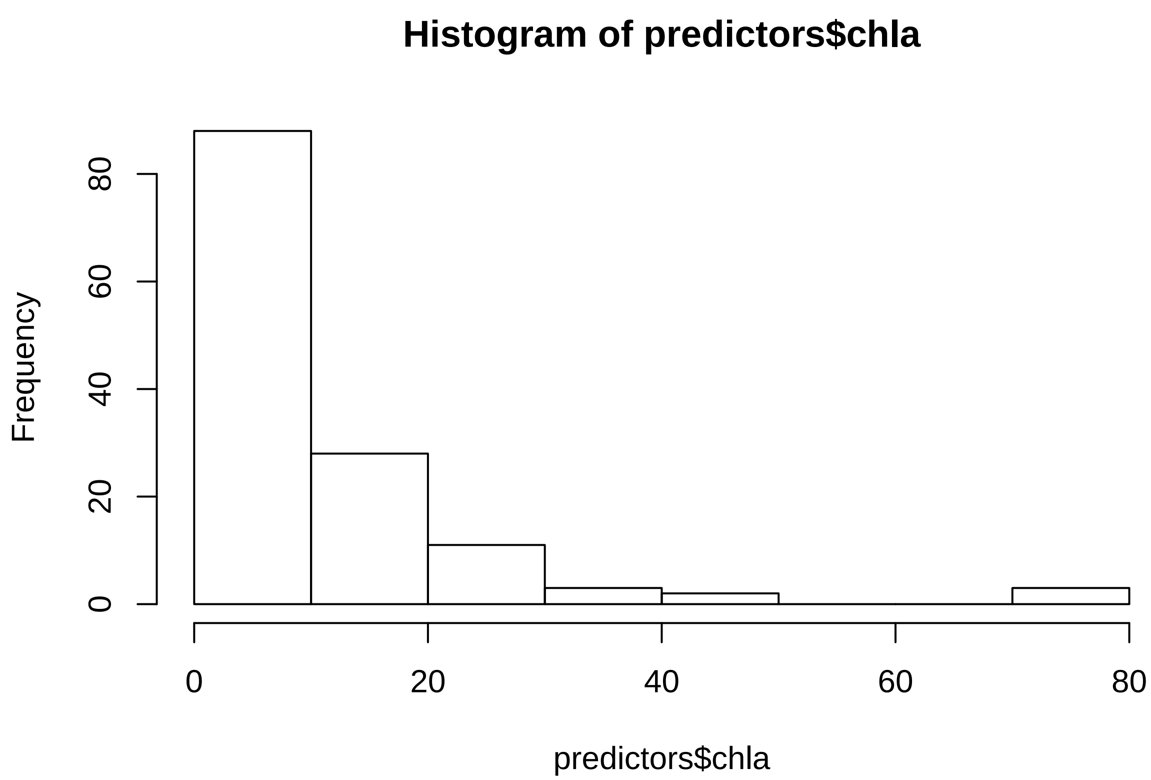

```r
hist(predictors$pct.ag)
```



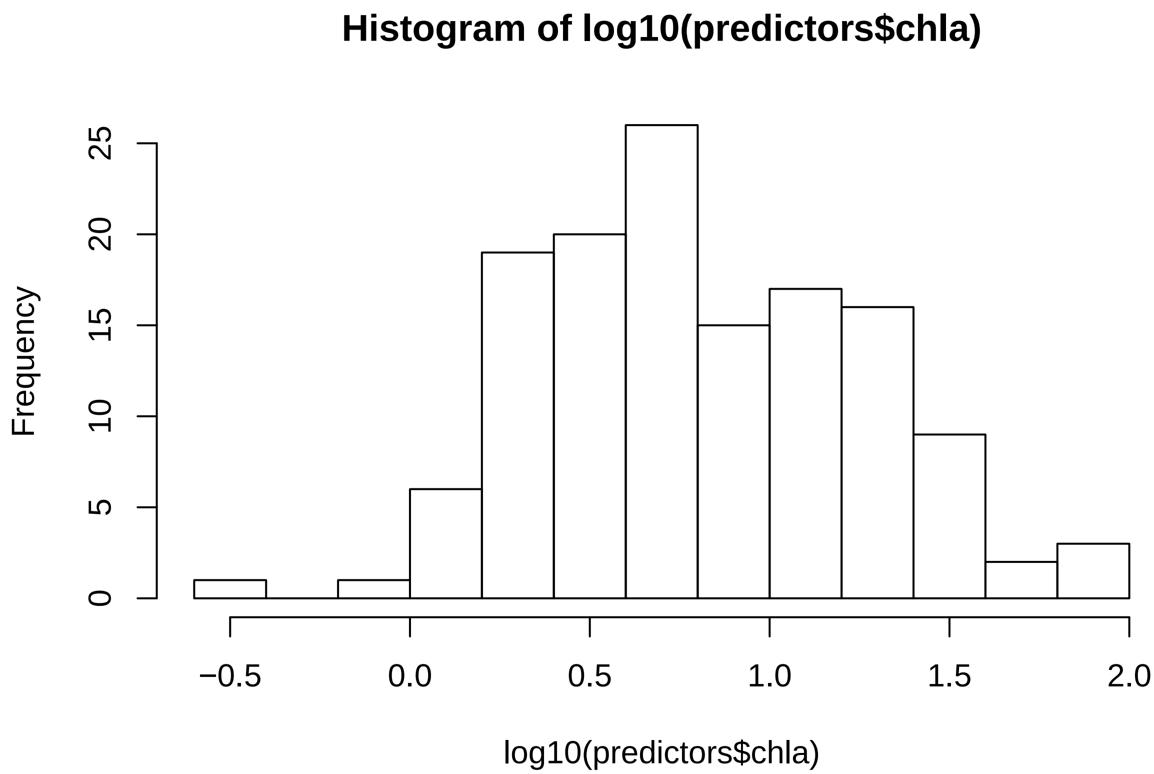

```r
hist(log10(predictors$pct.ag))
```



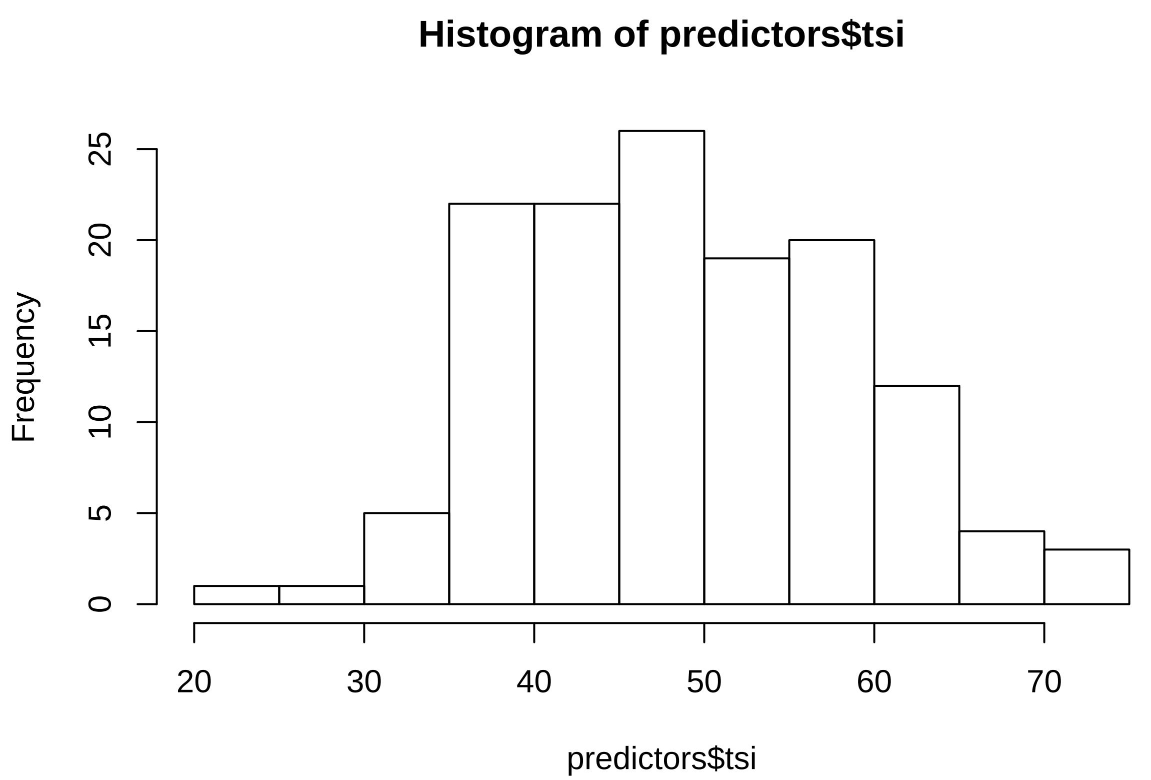

```
hist(predictors$chla)
```




```
hist(log10(predictors$chla))
```




```
hist(predictors$tsi)
```




```
table(predictors$tsi.cat)
```

```
##
```

```
##      eutrophic hypereutrophic    mesotrophic   oligotrophic 
##             55              3             48             29
```

```
predictors$log10_lake_area_ha<-log10(predictors$lake_area_ha)
predictors$log10_lake_perim_meters<-log10(predictors$lake_perim_meters)
predictors$log10_maxdepth<-log10(predictors$maxdepth)
predictors$log10_pct.ag<-log10(predictors$pct.ag+1)
predictors$log10_chla<-log10(predictors$chla)

modvars.accndvi<-left_join(predictors, coh.chlaXaccndvi, by="lagoslakeid")
modvars.accndvi$nhd_ftype<-factor(modvars.accndvi$nhd_ftype)
modvars.accndvi$tsi.cat<-factor(modvars.accndvi$tsi.cat)
modvars.accndvi$tslength<-modvars.accndvi$end-modvars.accndvi$start + 1

modvars.accndvi<-modvars.accndvi[!is.na(modvars.accndvi$maxdepth),]
modvars.accndvi<-modvars.accndvi[!is.na(modvars.accndvi$pct.ag),]

modvars.accndvi.phist<-modvars.accndvi[modvars.accndvi$accndvip.ts1<0.3,]
modvars.accndvi.philt<-modvars.accndvi[modvars.accndvi$accndvip.ts2<0.3,]

modvars.accndvi[modvars.accndvi$tslength < 20,]
```

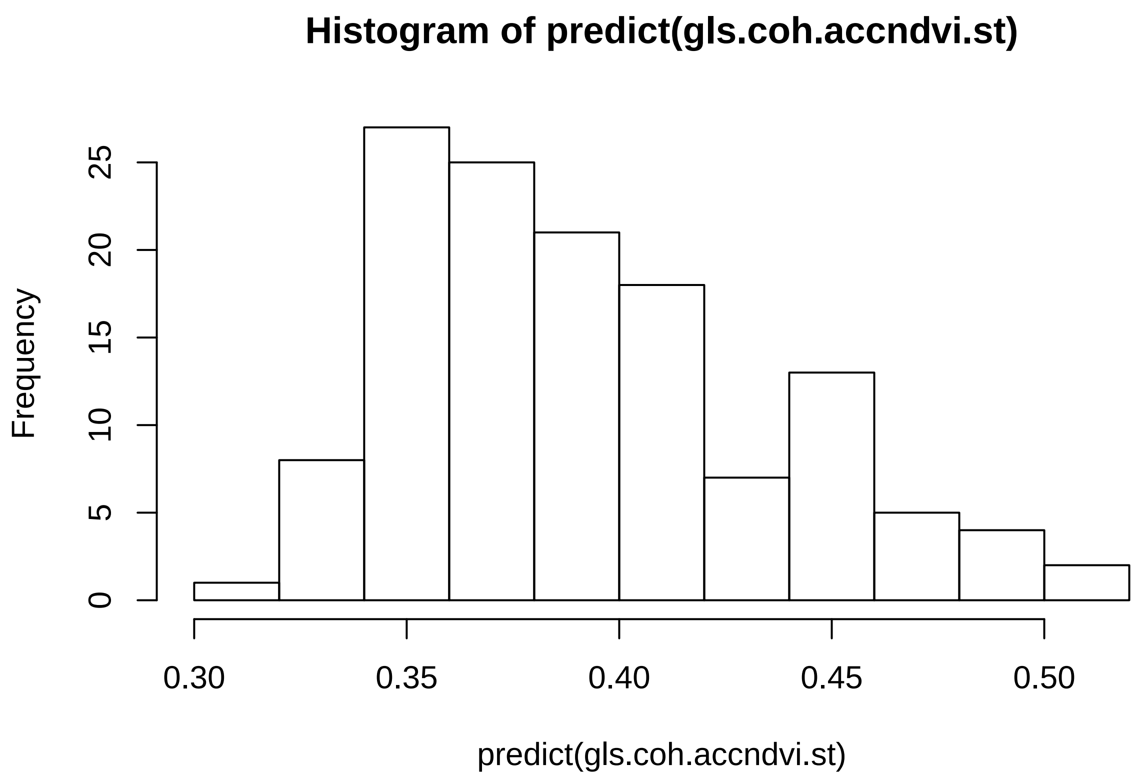
```
##  [1] lagoslakeid             gnis_name              
##  [3] nhd_lat                 nhd_long               
##  [5] lake_area_ha            lake_perim_meters      
##  [7] nhd_ftype               nhd_fcode              
##  [9] hu4_zoneid              hu12_zoneid            
## [11] state_zoneid            elevation_m            
## [13] start                   end                    
## [15] tslength                maxdepth               
## [17] pct.ag                  chla                   
## [19] tsi                     tsi.cat                
## [21] state_name              cv.accndvi             
## [23] log10_lake_area_ha      log10_lake_perim_meters
## [25] log10_maxdepth          log10_pct.ag           
## [27] log10_chla              accndvip.ts1           
## [29] accndviphi.ts1          accndvicoh.ts1         
## [31] accndvip.ts2            accndviphi.ts2         
## [33] accndvicoh.ts2          accndvip.ts3           
## [35] accndviphi.ts3          accndvicoh.ts3         
## <0 rows> (or 0-length row.names)
```

```
#short timescales
gls.coh.accndvi.st<-gls(accndvicoh.ts1 ~ log10_maxdepth + log10_lake_area_ha + log10_pct.ag + log10_chl
                        data=modvars.accndvi,
                        correlation=corExp(form = ~ nhd_lat + nhd_long))
summary(gls.coh.accndvi.st)
```

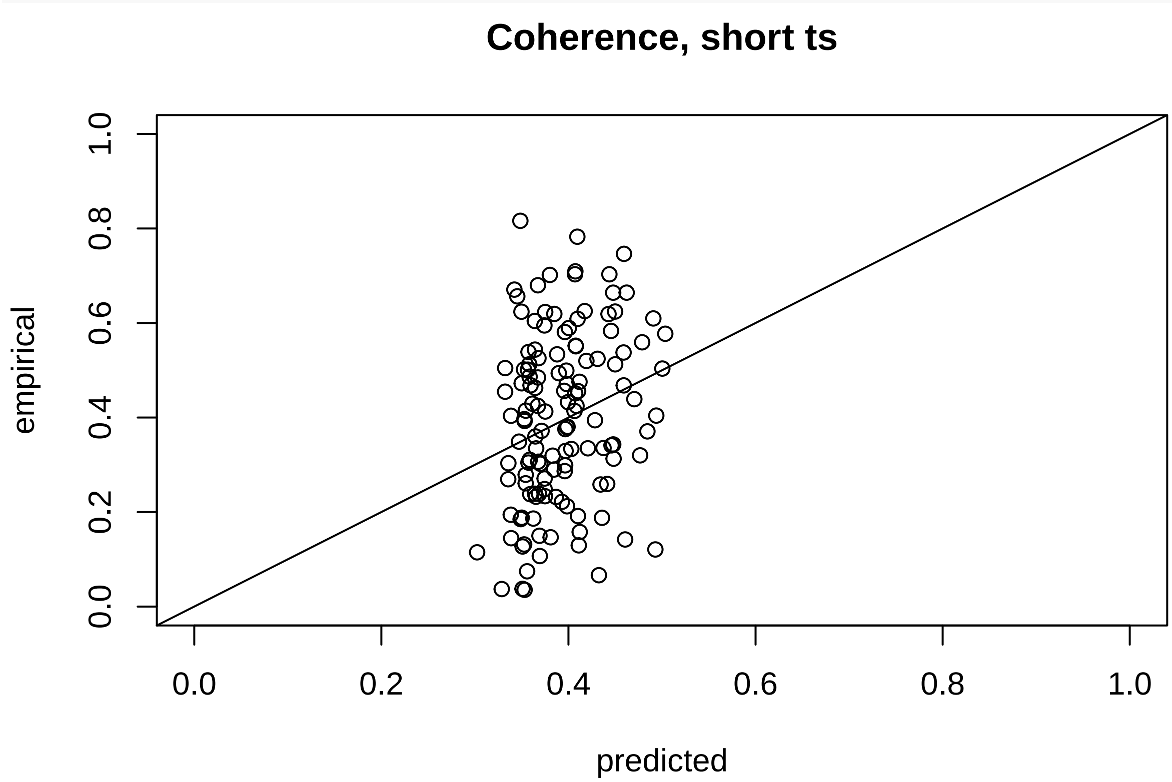
```
## Generalized least squares fit by REML
##   Model: accndvicoh.ts1 ~ log10_maxdepth + log10_lake_area_ha + log10_pct.ag +      log10_chla + tsi
##   Data: modvars.accndvi 
##         AIC        BIC   logLik
##   -31.41051 -0.5662766 26.70525
## 
## Correlation Structure: Exponential spatial correlation
```

```
##  Formula: ~nhd_lat + nhd_long
##  Parameter estimate(s):
##      range
## 0.02349765
##
## Coefficients:
##                            Value Std.Error    t-value p-value
## (Intercept)            0.3510606 0.2033533  1.7263576  0.0868
## log10_maxdepth         0.0118779 0.0635738  0.1868367  0.8521
## log10_lake_area_ha    -0.0051255 0.0265398 -0.1931265  0.8472
## log10_pct.ag           0.0676981 0.0335170  2.0198151  0.0456
## log10_chla            -0.0262859 0.0995111 -0.2641501  0.7921
## tsi.cathypereutrophic -0.0928587 0.1288598 -0.7206181  0.4725
## tsi.catmesotrophic     0.0011120 0.0651011  0.0170808  0.9864
## tsi.catoligotrophic    0.0318553 0.1017923  0.3129442  0.7549
## cv.accndvi             0.2964180 2.9461017  0.1006136  0.9200
##
##  Correlation:
##                       (Intr) lg10_m l10___ lg10_. lg10_c ts.cth ts.ctm
## log10_maxdepth        -0.092
## log10_lake_area_ha    -0.049 -0.619
## log10_pct.ag          -0.265 -0.209  0.159
## log10_chla            -0.664  0.186 -0.093 -0.089
## tsi.cathypereutrophic  0.314  0.078 -0.049 -0.183 -0.470
## tsi.catmesotrophic    -0.668  0.047  0.004  0.026  0.824 -0.347
## tsi.catoligotrophic   -0.645  0.049  0.001 -0.044  0.901 -0.399  0.853
## cv.accndvi            -0.724 -0.202 -0.015  0.318  0.076 -0.077  0.170
##                       ts.ctl
## log10_maxdepth
## log10_lake_area_ha
## log10_pct.ag
## log10_chla
## tsi.cathypereutrophic
## tsi.catmesotrophic
## tsi.catoligotrophic
## cv.accndvi             0.108
##
## Standardized residuals:
##         Min          Q1         Med          Q3         Max
## -2.03720285 -0.68836220  0.01782336  0.76851613  2.56086059
##
## Residual standard error: 0.1826308
## Degrees of freedom: 131 total; 122 residual
```

```r
hist(predict(gls.coh.accndvi.st))
```




```
plot(predict(gls.coh.accndvi.st), modvars.accndvi$accndvicoh.ts1, ylim=c(0,1), xlim=c(0,1),
     ylab="empirical", xlab="predicted", main="Coherence, short ts")
abline(a=0,b=1)
```



```r
cor.test(predict(gls.coh.accndvi.st),modvars.accndvi$accndvicoh.ts1)
```

```
##
##  Pearson's product-moment correlation
##
## data:  predict(gls.coh.accndvi.st) and modvars.accndvi$accndvicoh.ts1
## t = 2.6767, df = 129, p-value = 0.0084
## alternative hypothesis: true correlation is not equal to 0
## 95 percent confidence interval:
##  0.06023459 0.38573822
## sample estimates:
##       cor
## 0.2293901
```

```r
suppressWarnings(dredge.coh.accndvi.st<-dredge(gls.coh.accndvi.st, beta="sd")) #intercept only is best 
```

```
## Fixed term is "(Intercept)"
```

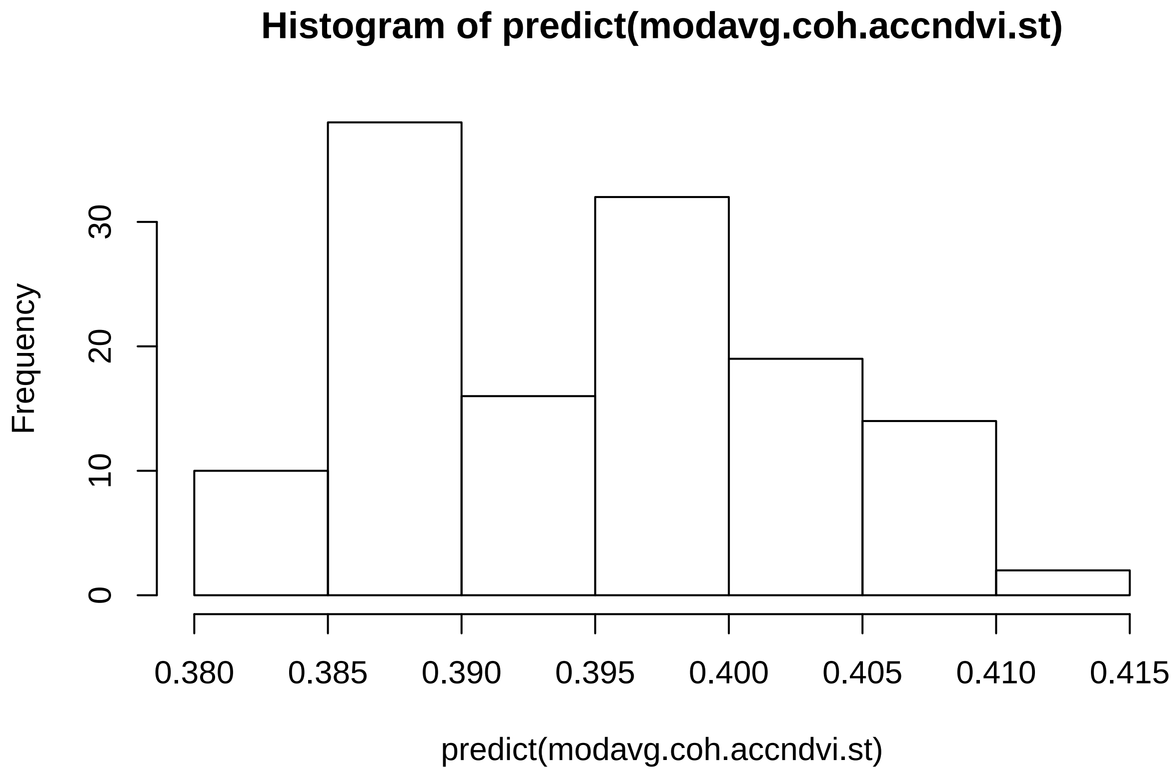
```r
print(head(dredge.coh.accndvi.st))
```

```
## Global model call: gls(model = accndvicoh.ts1 ~ log10_maxdepth + log10_lake_area_ha +
##     log10_pct.ag + log10_chla + tsi.cat + cv.accndvi, data = modvars.accndvi,
##     correlation = corExp(form = ~nhd_lat + nhd_long))
## ---
## Model selection table
##     (Int)  cv.acc  l10_chl l10_mxd l10_pct.ag df logLik  AICc delta weight
## 2  0.4592 -1.3080                              4 37.998 -67.7  0.00  0.576
## 1  0.3952                                      3 35.996 -65.8  1.88  0.225
## 18 0.3347  0.4166                      0.05951  5 37.181 -63.9  3.80  0.086
## 4  0.5092 -1.4800 -0.05006                     5 36.538 -62.6  5.08  0.045
## 17 0.3566                              0.05769  4 35.236 -62.2  5.52  0.036
## 10 0.4432 -1.8240          0.03587             5 36.149 -61.8  5.86  0.031
## Models ranked by AICc(x)
```

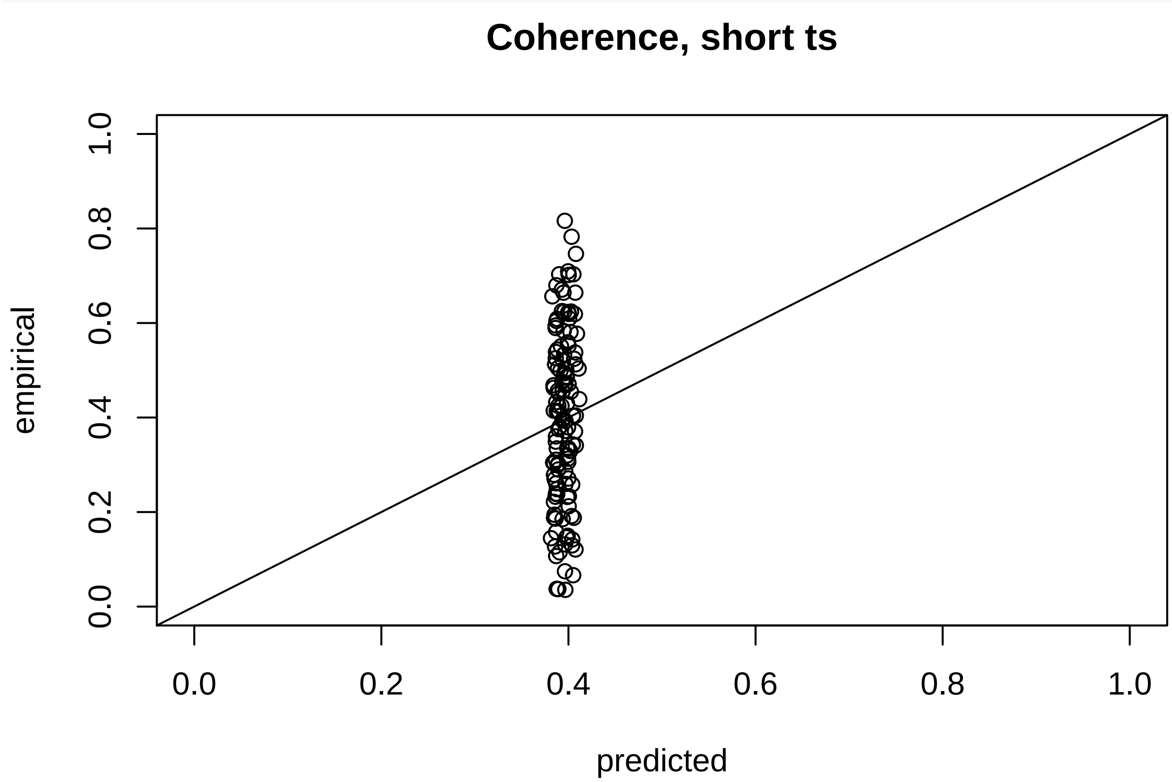
```r
modavg.coh.accndvi.st<-model.avg(dredge.coh.accndvi.st, fit=T)
modavg.coh.accndvi.st$importance
```

```
##                      cv.accndvi log10_pct.ag log10_chla log10_maxdepth
## Importance:           0.72       0.14         0.08       0.05
## N containing models:    32         32           32         32
##                      log10_lake_area_ha tsi.cat
## Importance:           0.02               <0.01
## N containing models:    32                 32
```

```r
hist(predict(modavg.coh.accndvi.st))
```




```
plot(predict(modavg.coh.accndvi.st), modvars.accndvi$accndvicoh.ts1, ylim=c(0,1), xlim=c(0,1),
     ylab="empirical", xlab="predicted", main="Coherence, short ts")
abline(a=0,b=1)
```



```r
cor.test(predict(modavg.coh.accndvi.st),modvars.accndvi$accndvicoh.ts1)
```

```
##
##  Pearson's product-moment correlation
##
## data:  predict(modavg.coh.accndvi.st) and modvars.accndvi$accndvicoh.ts1
## t = 1.8961, df = 129, p-value = 0.06018
## alternative hypothesis: true correlation is not equal to 0
## 95 percent confidence interval:
##  -0.007058904  0.326956759
## sample estimates:
##      cor
## 0.164666
```

```r
gls.phi.accndvi.st<-gls(cos(accndviphi.ts1) ~ log10_maxdepth + log10_lake_area_ha + log10_pct.ag + log1
                        data=modvars.accndvi.phist,
                        correlation=corExp(form = ~ nhd_lat + nhd_long)) #remove ftype b/c only lakes
summary(gls.phi.accndvi.st)
```

```
## Generalized least squares fit by REML
##   Model: cos(accndviphi.ts1) ~ log10_maxdepth + log10_lake_area_ha + log10_pct.ag +      log10_chla +
##   Data: modvars.accndvi.phist
##        AIC     BIC    logLik
##   98.54103 115.331 -38.27051
##
## Correlation Structure: Exponential spatial correlation
##  Formula: ~nhd_lat + nhd_long
##  Parameter estimate(s):
##        range
## 0.0009104139
##
## Coefficients:
##                           Value Std.Error    t-value p-value
## (Intercept)            -0.11260  1.247412 -0.0902704  0.9286
## log10_maxdepth          0.80731  0.362959  2.2242424  0.0329
## log10_lake_area_ha      0.29911  0.200578  1.4912562  0.1451
## log10_pct.ag            0.05680  0.221376  0.2565968  0.7990
## log10_chla              0.36366  0.619340  0.5871671  0.5610
## tsi.cathypereutrophic   0.38144  0.831404  0.4587861  0.6493
## tsi.catmesotrophic      0.07466  0.422400  0.1767531  0.8608
## tsi.catoligotrophic     0.32639  0.704787  0.4631019  0.6462
## cv.accndvi            -38.80599 19.390498 -2.0012891  0.0534
##
##  Correlation:
##                       (Intr) lg10_m l10___ lg10_. lg10_c ts.cth ts.ctm
## log10_maxdepth        -0.094
## log10_lake_area_ha    -0.082 -0.440
## log10_pct.ag          -0.129  0.000  0.209
## log10_chla            -0.750  0.247  0.013  0.046
## tsi.cathypereutrophic  0.290 -0.104 -0.145 -0.332 -0.457
## tsi.catmesotrophic    -0.709  0.085  0.137  0.072  0.822 -0.315
## tsi.catoligotrophic   -0.736  0.101  0.056  0.004  0.911 -0.358  0.851
## cv.accndvi            -0.583 -0.255 -0.292 -0.111  0.058  0.122  0.080
##                       ts.ctl
```

```
## log10_maxdepth
## log10_lake_area_ha
## log10_pct.ag
## log10_chla
## tsi.cathypereutrophic
## tsi.catmesotrophic
## tsi.catoligotrophic
## cv.accndvi             0.116
##
## Standardized residuals:
##         Min          Q1         Med          Q3         Max
## -1.75747470 -0.57912951  0.09538008  0.55371932  2.26746996
##
## Residual standard error: 0.6656146
## Degrees of freedom: 43 total; 34 residual
```

```r
suppressWarnings(dredge.phi.accndvi.st<-dredge(gls.phi.accndvi.st, beta="sd")) #intercept only is best m
```

```
## Fixed term is "(Intercept)"
```

```r
print(head(dredge.phi.accndvi.st))
```

```
## Global model call: gls(model = cos(accndviphi.ts1) ~ log10_maxdepth + log10_lake_area_ha +
##     log10_pct.ag + log10_chla + tsi.cat + cv.accndvi, data = modvars.accndvi.phist,
##     correlation = corExp(form = ~nhd_lat + nhd_long))
## ---
## Model selection table
##     (Int) cv.acc l10_chl l10_lak_are_ha l10_mxd l10_pct.ag df  logLik AICc
## 10 0.5157 -31.00                         0.9619             5 -39.454 90.5
## 14 0.4558 -40.93                0.3370  0.7019             6 -38.557 91.4
## 6  0.3309 -30.49                0.5134                      5 -40.672 93.0
## 12 0.2764 -33.40  0.2589                 1.0840             6 -39.366 93.1
## 26 0.4688 -31.05                         0.9684    0.07116  6 -40.076 94.5
## 16 0.2868 -41.82  0.1886        0.3076  0.8134             7 -38.779 94.8
##    delta weight
## 10  0.00  0.405
## 14  0.92  0.256
## 6   2.44  0.120
## 12  2.54  0.114
## 26  3.96  0.056
## 16  4.23  0.049
## Models ranked by AICc(x)
```

```r
#long timescales
gls.coh.accndvi.lt<-gls(accndvicoh.ts2 ~ log10_maxdepth + log10_lake_area_ha + log10_pct.ag + log10_chla
                        data=modvars.accndvi,
                        correlation=corExp(form = ~ nhd_lat + nhd_long))
summary(gls.coh.accndvi.lt)
```

```
## Generalized least squares fit by REML
##   Model: accndvicoh.ts2 ~ log10_maxdepth + log10_lake_area_ha + log10_pct.ag +      log10_chla + tsi
##   Data: modvars.accndvi
##        AIC      BIC   logLik
##   31.58574 62.42997 -4.79287
##
## Correlation Structure: Exponential spatial correlation
```

```
##  Formula: ~nhd_lat + nhd_long
##  Parameter estimate(s):
##       range
## 0.007786396
##
## Coefficients:
##                            Value Std.Error   t-value p-value
## (Intercept)             1.043355  0.256408  4.069125  0.0001
## log10_maxdepth         -0.131064  0.079689 -1.644684  0.1026
## log10_lake_area_ha      0.050170  0.033825  1.483218  0.1406
## log10_pct.ag           -0.037990  0.041879 -0.907153  0.3661
## log10_chla             -0.095555  0.127915 -0.747018  0.4565
## tsi.cathypereutrophic -0.049708  0.164852 -0.301531  0.7635
## tsi.catmesotrophic     -0.099118  0.084665 -1.170708  0.2440
## tsi.catoligotrophic     0.008968  0.131666  0.068108  0.9458
## cv.accndvi             -6.859698  3.607424 -1.901550  0.0596
##
##  Correlation:
##                        (Intr) lg10_m l10___ lg10_. lg10_c ts.cth ts.ctm
## log10_maxdepth         -0.104
## log10_lake_area_ha     -0.049 -0.624
## log10_pct.ag           -0.247 -0.211  0.151
## log10_chla             -0.687  0.192 -0.089 -0.085
## tsi.cathypereutrophic  0.324  0.070 -0.047 -0.184 -0.471
## tsi.catmesotrophic     -0.687  0.056  0.004  0.036  0.819 -0.342
## tsi.catoligotrophic    -0.666  0.056  0.007 -0.034  0.903 -0.401  0.847
## cv.accndvi             -0.713 -0.191 -0.020  0.306  0.088 -0.080  0.182
##                        ts.ctl
## log10_maxdepth
## log10_lake_area_ha
## log10_pct.ag
## log10_chla
## tsi.cathypereutrophic
## tsi.catmesotrophic
## tsi.catoligotrophic
## cv.accndvi              0.113
##
## Standardized residuals:
##         Min          Q1         Med          Q3         Max
## -2.01418977 -0.79855229  0.03412664  0.70465229  1.75993640
##
## Residual standard error: 0.2338056
## Degrees of freedom: 131 total; 122 residual
```

```
suppressWarnings(dredge.coh.accndvi.lt<-dredge(gls.coh.accndvi.lt, beta="sd")) #intercept only is best
```

```
## Fixed term is "(Intercept)"
```

```
print(head(dredge.coh.accndvi.lt))
```

```
## Global model call: gls(model = accndvicoh.ts2 ~ log10_maxdepth + log10_lake_area_ha +
##     log10_pct.ag + log10_chla + tsi.cat + cv.accndvi, data = modvars.accndvi,
##     correlation = corExp(form = ~nhd_lat + nhd_long))
## ---
## Model selection table
```

```
##     (Int) cv.acc  l10_chl l10_lak_are_ha  l10_mxd l10_pct.ag df  logLik
## 2  0.8041 -5.465                                               4  3.104
## 1  0.5373                                                      3 -0.331
## 4  0.8497 -5.533 -0.05122                                      5  1.543
## 18 0.8923 -6.647                                   -0.04757  5  1.506
## 10 0.8184 -4.976                          -0.03325             5  1.373
## 6  0.7860 -6.005                0.01914                        5  0.660
##    AICc delta weight
## 2   2.1  0.00  0.756
## 1   6.9  4.74  0.071
## 4   7.4  5.28  0.054
## 18  7.5  5.36  0.052
## 10  7.7  5.63  0.045
## 6   9.2  7.05  0.022
## Models ranked by AICc(x)
```

```
gls.phi.accndvi.lt<-gls(cos(accndviphi.ts2) ~ log10_maxdepth + log10_lake_area_ha + log10_pct.ag + log10
                        data=modvars.accndvi.philt,
                        correlation=corExp(form = ~ nhd_lat + nhd_long))
summary(gls.phi.accndvi.lt)
```

```
## Generalized least squares fit by REML
##   Model: cos(accndviphi.ts2) ~ log10_maxdepth + log10_lake_area_ha + log10_pct.ag +      log10_chla +
##   Data: modvars.accndvi.philt
##        AIC    BIC    logLik
##   92.06493 107.03 -36.03247
##
## Correlation Structure: Exponential spatial correlation
##  Formula: ~nhd_lat + nhd_long
##  Parameter estimate(s):
##     range
## 0.3231273
##
## Coefficients:
##                         Value Std.Error    t-value p-value
## (Intercept)         -2.575687  1.456751 -1.7681035  0.0863
## log10_maxdepth       0.061629  0.358149  0.1720754  0.8644
## log10_lake_area_ha   0.348215  0.154147  2.2589836  0.0306
## log10_pct.ag         0.034131  0.251798  0.1355499  0.8930
## log10_chla           0.813370  0.552937  1.4709987  0.1508
## tsi.catmesotrophic   0.391136  0.445030  0.8788985  0.3858
## tsi.catoligotrophic  0.885177  0.583862  1.5160722  0.1390
## cv.accndvi          16.156394 22.035031  0.7332140  0.4686
##
##  Correlation:
##                     (Intr) lg10_m l10___ lg10_. lg10_c ts.ctm ts.ctl
## log10_maxdepth      -0.152
## log10_lake_area_ha  -0.109 -0.456
## log10_pct.ag        -0.433 -0.194  0.080
## log10_chla          -0.648  0.429 -0.024  0.078
## tsi.catmesotrophic  -0.573  0.383 -0.090  0.072  0.774
## tsi.catoligotrophic -0.657  0.298  0.081  0.057  0.857  0.858
## cv.accndvi          -0.763 -0.259 -0.010  0.435  0.098  0.093  0.151
##
## Standardized residuals:
```

```
##         Min          Q1         Med          Q3         Max 
## -1.57642734 -0.93302620 -0.09045728  0.47570242  1.76525586 
## 
## Residual standard error: 0.6997279 
## Degrees of freedom: 41 total; 33 residual
```

```
suppressWarnings(dredge.phi.accndvi.lt<-dredge(gls.phi.accndvi.lt, beta="sd")) #intercept only is best 
```

```
## Fixed term is "(Intercept)"
```

```
print(head(dredge.phi.accndvi.lt))
```

```
## Global model call: gls(model = cos(accndviphi.ts2) ~ log10_maxdepth + log10_lake_area_ha + 
##     log10_pct.ag + log10_chla + tsi.cat + cv.accndvi, data = modvars.accndvi.philt, 
##     correlation = corExp(form = ~nhd_lat + nhd_long))
## ---
## Model selection table 
##      (Int) cv.acc l10_chl l10_lak_are_ha  l10_mxd l10_pct.ag df  logLik
## 2  -0.8516 18.830                                              4 -37.200
## 6  -1.0020  8.501                 0.2846                       5 -36.024
## 10 -0.8738 14.710                         0.19250              5 -37.317
## 4  -0.9446 18.980  0.1174                                      5 -37.529
## 14 -1.0020  9.431                 0.2986 -0.06732              6 -36.294
## 18 -0.9495 20.280                                   0.04255   5 -37.708
##    AICc delta weight
## 2  83.5  0.00  0.377
## 6  83.8  0.25  0.332
## 10 86.3  2.84  0.091
## 4  86.8  3.26  0.074
## 14 87.1  3.55  0.064
## 18 87.1  3.62  0.062
## Models ranked by AICc(x)
```

Early iterations of this made us wonder of things differed by region, so we tested these relationships broken down into 3 regions. The regions are: 1) Missouri; 2) Minnesota, Wisconsin, and Michigan; 3) Pennsylvania, New York, Rhode Island, Vermont, New Hampshire, Maine.

```
# #Region 1: Missouri
# 
# modvars.accndvi.r1<-modvars.accndvi[modvars.accndvi$state_name=="Missouri",]
# # modvars.accndvi.philt.r1<-modvars.accndvi.philt[modvars.accndvi.philt$state_name=="Missouri",]
# # modvars.accndvi.phist.r1<-modvars.accndvi.phist[modvars.accndvi.phist$state_name=="Missouri",]
# 
# #short timescales
# gls.coh.accndvi.st<-gls(accndvicoh.ts1 ~ log10_maxdepth + log10_lake_area_ha + log10_pct.ag + log10_c
#                         data=modvars.accndvi.r1,
#                         correlation=corExp(form = ~ nhd_lat + nhd_long))
# summary(gls.coh.accndvi.st)
# suppressWarnings(dredge.coh.accndvi.st<-dredge(gls.coh.accndvi.st, beta="sd")) #intercept only is bes
# print(head(dredge.coh.accndvi.st))
# 
# #long timescales
# gls.coh.accndvi.lt<-gls(accndvicoh.ts2 ~ log10_maxdepth + log10_lake_area_ha + log10_pct.ag + log10_c
#                         data=modvars.accndvi.r1,
#                         correlation=corExp(form = ~ nhd_lat + nhd_long))
# summary(gls.coh.accndvi.lt)
```

```
# suppressWarnings(dredge.coh.accndvi.lt<-dredge(gls.coh.accndvi.lt, beta="sd")) #intercept only is bes
# print(head(dredge.coh.accndvi.lt))
```

```
# #Region 2: Minnesota, Wisconsin, Michigan
#
# modvars.accndvi.r2<-modvars.accndvi[modvars.accndvi$state_name %in% c("Minnesota","Wisconsin","Michig
#
# #short timescales
# gls.coh.accndvi.st<-gls(accndvicoh.ts1 ~ log10_maxdepth + log10_lake_area_ha + log10_pct.ag + log10_c
#                         data=modvars.accndvi.r2,
#                         correlation=corExp(form = ~ nhd_lat + nhd_long))
# summary(gls.coh.accndvi.st)
# suppressWarnings(dredge.coh.accndvi.st<-dredge(gls.coh.accndvi.st, beta="sd")) #intercept only is bes
# print(head(dredge.coh.accndvi.st))
#
# #long timescales
# gls.coh.accndvi.lt<-gls(accndvicoh.ts2 ~ log10_maxdepth + log10_lake_area_ha + log10_pct.ag + log10_c
#                         data=modvars.accndvi.r2,
#                         correlation=corExp(form = ~ nhd_lat + nhd_long))
# summary(gls.coh.accndvi.lt)
# suppressWarnings(dredge.coh.accndvi.lt<-dredge(gls.coh.accndvi.lt, beta="sd")) #intercept only is bes
# print(head(dredge.coh.accndvi.lt))
```

```
# #Region 2: Minnesota, Wisconsin, Michigan
#
# modvars.accndvi.r3<-modvars.accndvi[modvars.accndvi$state_name %in% c("Pennsylvania","New York","Rhod
#
# #short timescales
# gls.coh.accndvi.st<-gls(accndvicoh.ts1 ~ log10_maxdepth + log10_lake_area_ha + log10_pct.ag + log10_c
#                         data=modvars.accndvi.r3,
#                         correlation=corExp(form = ~ nhd_lat + nhd_long))
# summary(gls.coh.accndvi.st)
# suppressWarnings(dredge.coh.accndvi.st<-dredge(gls.coh.accndvi.st, beta="sd")) #intercept only is bes
# print(head(dredge.coh.accndvi.st))
#
# #long timescales
# gls.coh.accndvi.lt<-gls(accndvicoh.ts2 ~ log10_maxdepth + log10_lake_area_ha + log10_pct.ag + log10_c
#                         data=modvars.accndvi.r3,
#                         correlation=corExp(form = ~ nhd_lat + nhd_long))
# summary(gls.coh.accndvi.lt)
# suppressWarnings(dredge.coh.accndvi.lt<-dredge(gls.coh.accndvi.lt, beta="sd")) #intercept only is bes
# print(head(dredge.coh.accndvi.lt))
```