Commercial Fish Harvest ~ Water Quality

Shallow, natural lakes of northwest Iowa

Overall Objective

Our aim is to quantify relationships between commercial harvest of "rough fish" (common carp and bigmouth buffalo) against a suite of water quality variables. The term *water quality* itself can be subjective, but here we have identified multiple potential response variables that are often associated with "clean" or "impaired" water body designations. They fall into three broad categories:

- **Nutrients:** Total Phosphorous ($\mu g/L$); Total Nitrogen (mg/L)
- **Physical:** Secchi depth ($m, meters$); Total Suspended Solids ($\mu g/L$); Dissolved Oxygen (mg/L)
- **Biological:** Total Zooplankton Biomass; Total Phytoplankton Biomass; Phytoplankton Biomass of *Cyanophyta*; Phytoplankton Biomass of *Chlorophyta*

Study Area

Marty's dissertation research is focused on shallow, natural lakes of Iowa. Commercial Harvest of bigmouth buffalo occurs in some 20 lakes and rivers in Iowa, and over half of them fall into the shallow natural lake category. Since 1) Common carp are known to disturb ecosystems and force shallow lakes into a turbid, algal-dominated state and 2) Bigmouth Buffalo may regulate zooplankton that graze on algae, the Iowa DNR is interested to see if managing these populations of fish can restore elusive water quality in Iowa and shift these lakes into a clear-water macrophyte and sportfish dominated lake systems.

Commercial harvest of these species is complex and variable, with weather conditions, equipment, staffing, invasive species control, permitting, supply chain management, and market fluctuations affecting how much effort commercial anglers can put into catching fish, and where they focus that effort. Fishing is restricted to times of year when water temperatures are below $70°F$, or basically between Memorial Day and and October-ish. That being said, *there might be some overlap between harvest dates and ambient lake monitoring samples (described below)*.

One final note on the study area: We can incorporate other lakes that fit our selection criteria but do not have commercial harvest of rough fish species. Not that they are a perfect control, but it could help explain any year-to-year variation in response variables across our study region.

Introducing the Data

Harvest Data

We do not have abundance data for carp and buffalo for more than a couple of years in a subset of lakes. However, based on available data from the Spirit Lake District Fisheries Office, we have total pounds removed at multiple time points spanning 25 years in about a dozen lakes. We have identified a subset of these lakes based on similarity in geographic location, lake morphometry, fish communities, and regular harvest periods. Data is provided in total pounds removed, however due to differences in lake size and capacity to hold fish, we will standardize data by pounds removed per acre (and also kilograms removed per hectare, for publication). The lakes are summarized here:

Lake	Center Lake	Five Island Lake	High Lake	Ingham Lake	Lost Island Lake	Silver Lake (Dickinson County)
Area (acres)	220	964	467	370	1,162	1,032
Area (ft^2)	9,583,200	41,991,840	20,342,520	16,117,200	50,616,720	44,953,920
Watershed Area (acres)	731	8,689		320	4,541	17,025
Wathershed:Lake Ratio	3.3:1	9.2:1		0.9:1	3.9:1	16.5:1
Mean Depth (ft)	9.5	5		6.2	10.2	6.7
Max Depth (ft)	15.5	20	8	12	14	9.8
Row Crop Usage (acres)		6,565		135		14,521
Percent Row Crop		75.6		42.2		85.3
Shoreline (ft)	13,200	74,976		22,400	38,544	50,730
Shoreline Complexity	1.20	3.26		1.57	1.53	2.13

- *Note that High Lake is considered a wetland, and not all the same TMDL and shoreline data are available for that lake.*
- *For publication, these will need to be converted to metric units.*

Water Quality Data

Water quality data (summarized above) is available from ISU and Iowa DNR through an online data base and the Limnology Laboratory, headed at ISU by Dr. Grace Wilkonson, EEOB. This is part of the Ambient Lake Monitoring Program that collects a suite of variables in 130 lakes in Iowa that are designated as "Significant Publicly Owned Lakes" and data is available from 2000 to 2015, except in 2008. Further data (2016-2018) may also be available. These lakes are visited 2-3 (almost always 3) times per year from spring to fall and in-situ measurements are taken as well as samples removed for laboratory analysis of biological and chemical components.

Lakes fluctuate over time in cycles of stratification, turnover, zooplankton and algal blooms, etc. so these snapshots in time can be problematic. Still, we have identified a suite of variables that we expect to respond to the biomanipulation (harvest) of carp and buffalo. Also, of course, these variables are common metrics used to designate water bodies as "degraded" or "healthy" and could provide insight into food web processes in the lake. The variables are summarized here:

Variable	Form of Variable	Units	Hypothesized Response (short-term)
Secchi Depth	Mean, Maximum	meters	Increase from carp removal, no difference from buffalo
Total Suspened Solids	Mean	$\mu g/L$	Decrease from carp removal, no difference from buffalo

Variable	Form of Variable	Units	Hypothesized Response (short-term)
Dissolved Oxygen	Mean	mg/L	Decrease if large buffalo removal caused enough increase in zooplankton to reduce O2 production
Total Phosphorous	Mean, Maximum	$\mu g/L$	Decrease with carp removal (resuspension)
Total Nitrogen	Mean, Maximum	mg/L	Decrease with carp removal (resuspension)
Zooplankton Biomass	Mean	$\mu g/L$	Increase with buffalo removal (trophic release)
Chlorophyll a	Mean, Maximum	$\mu g/L$	Decrease with carp and buffalo removal
Phytoplankton Biomass	Mean	mg/L	Decrease with both carp and buffalo removal (bottom up and top down pathways)
Cyanophyta	Mean	mg/L	Decrease with carp and buffalo removal (nutrient shift and zoop shift)
Chlorophyta	Mean	mg/L	Decrease with both carp and buffalo removal

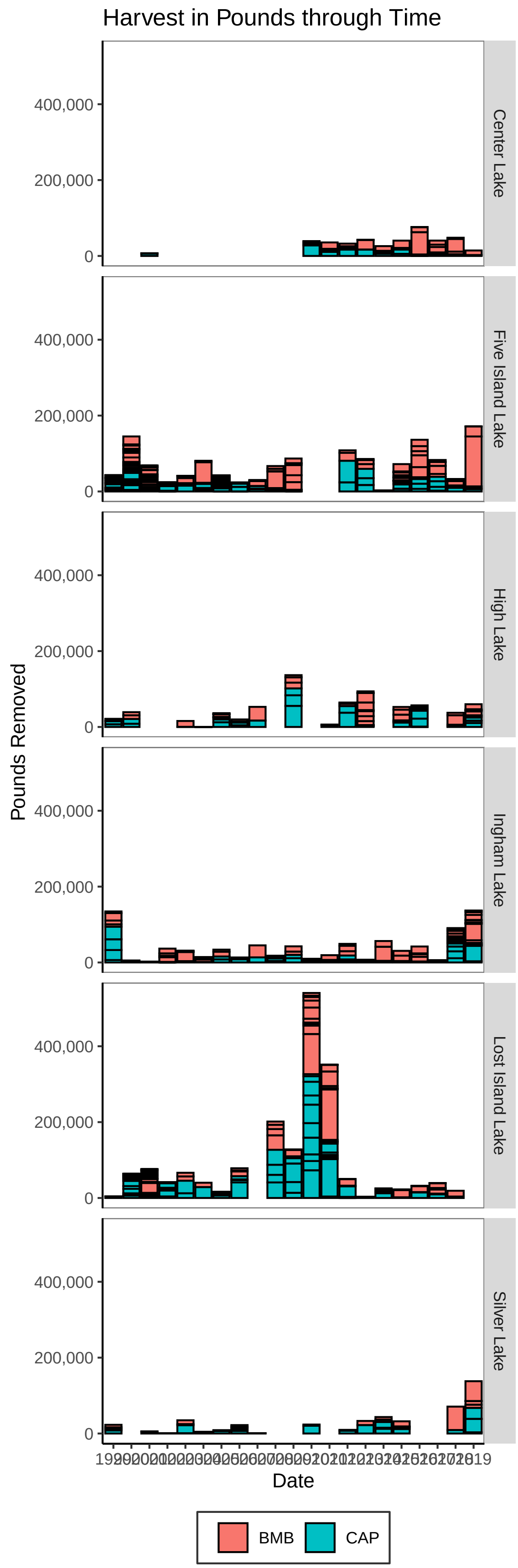
- *A Trophic State Index (TSI) can also be calculated for Secchi Depth, Chlorophyll a, and Total Phosphorus.* We may choose to pick these response variables as well, however, we do not expect the overall Trophic State of these lakes to change. Still, a directional shift in each of those three components may be indicative of the desired change in water quality from biomanipulation of rough fish.

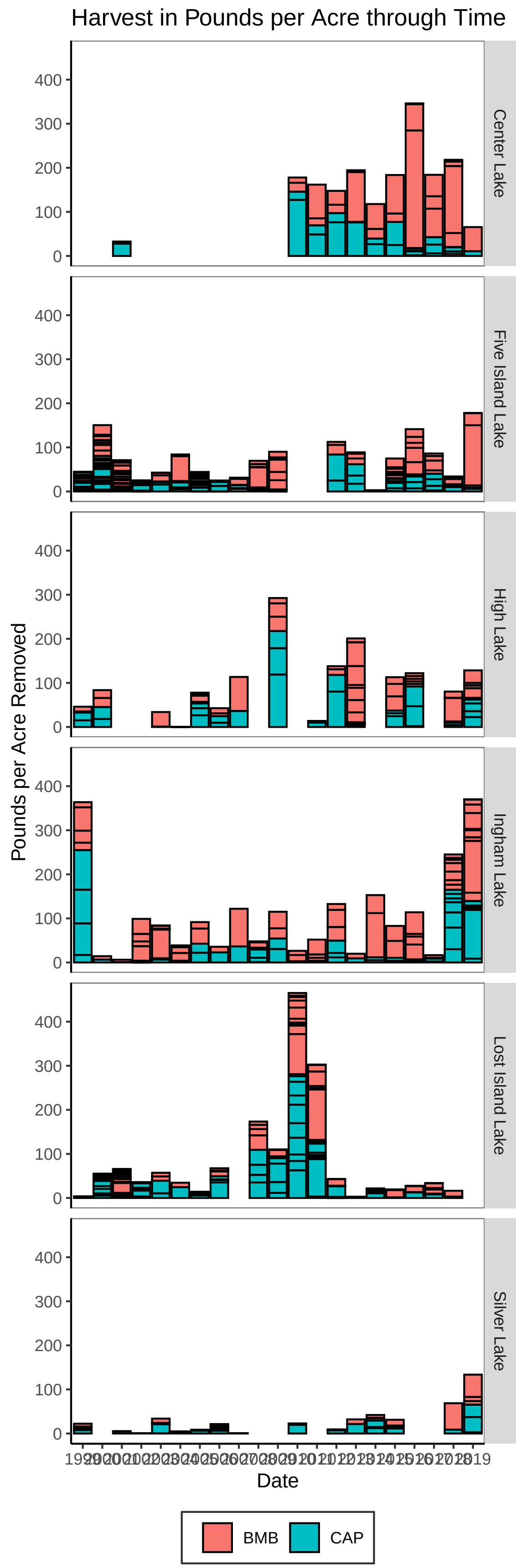
Data Analysis

Loading in Harvest Data

- Data set for Commercial Harvest from 1997 to 2019 of Iowa Lakes
- First we will correct the data set by correcting the date and year columns as well as removing blank cells and renaming cells

Harvest through time

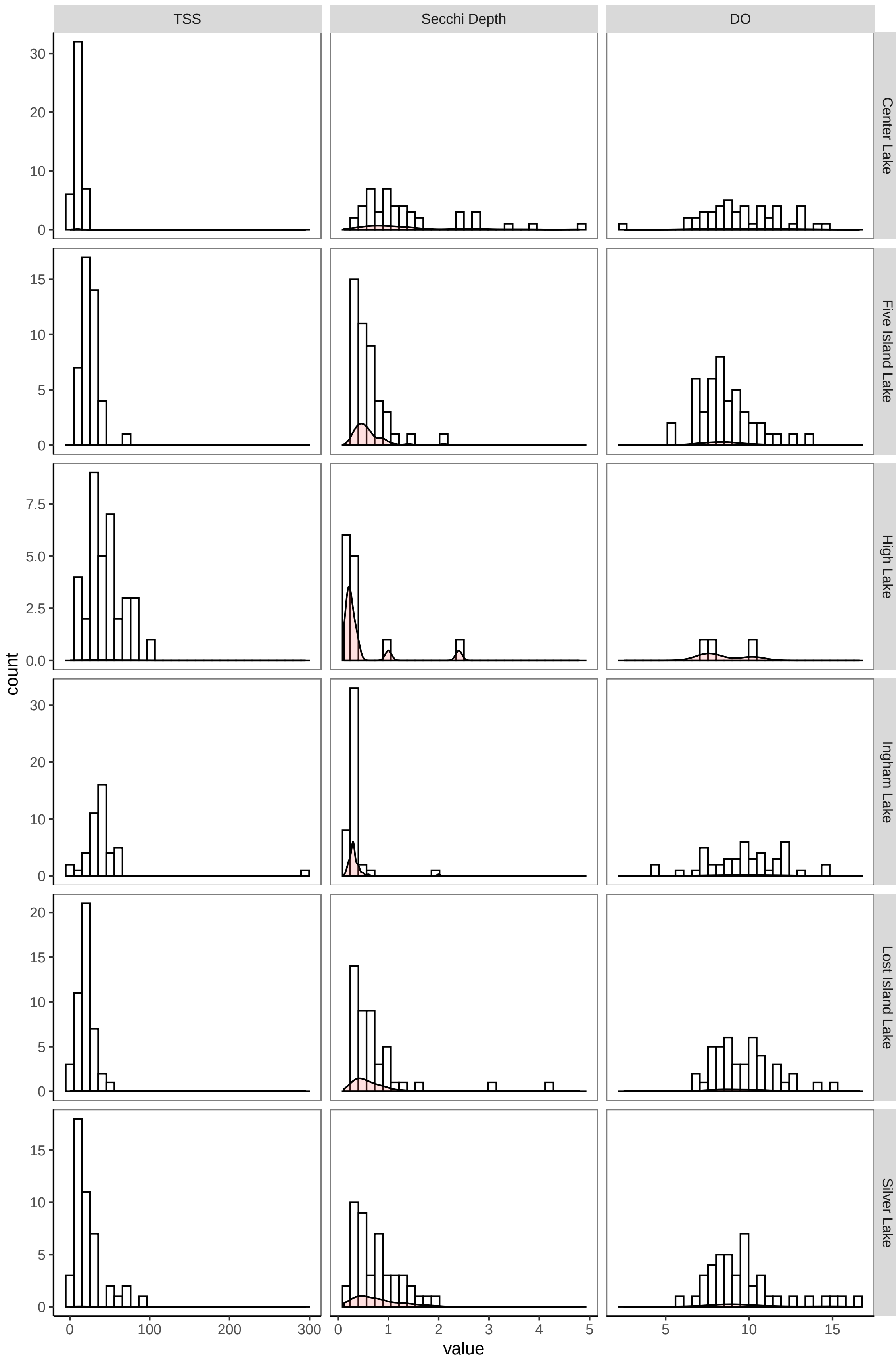




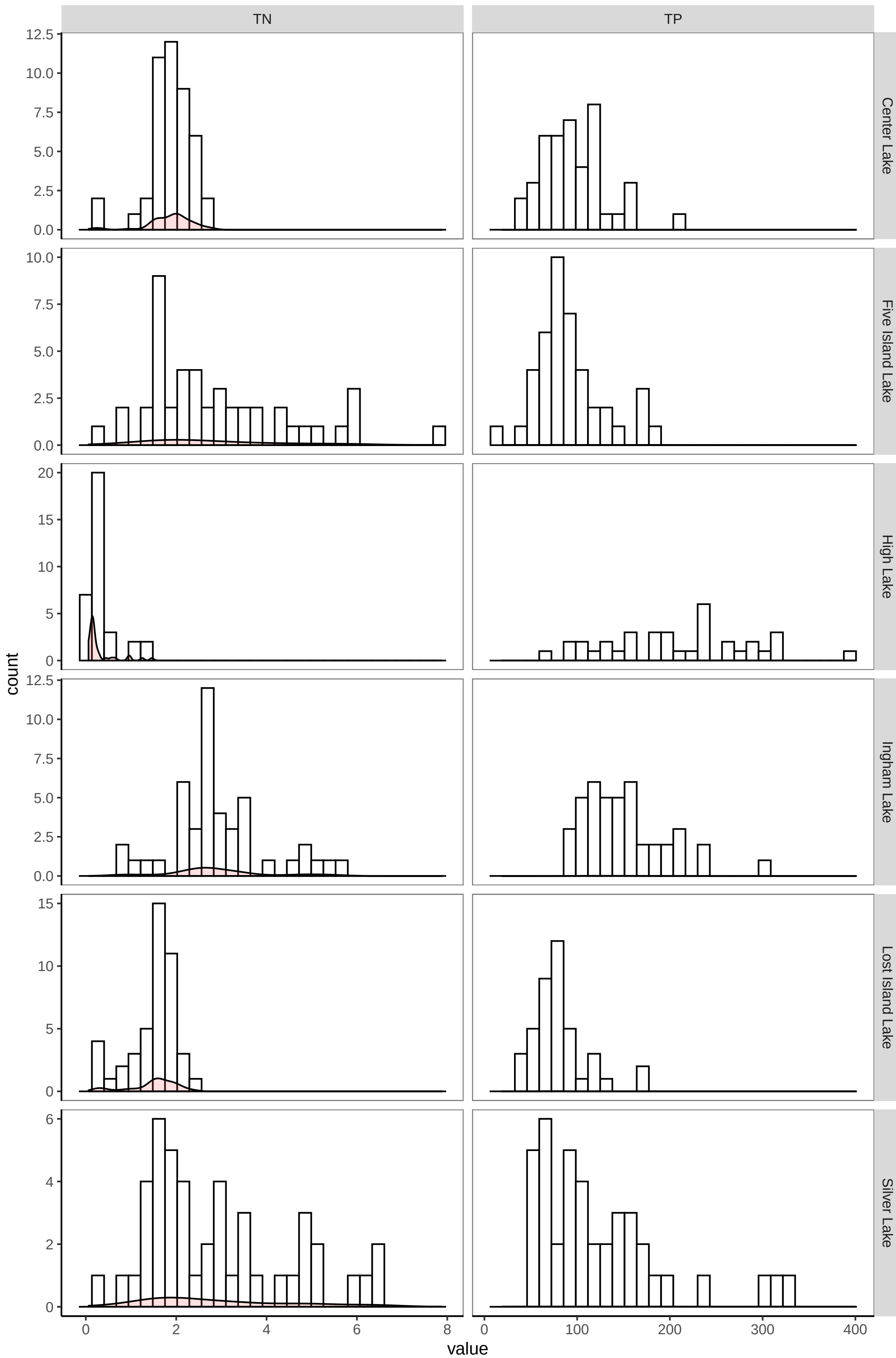
Loading in Water Quality Data

Distribution of water quality variables, for each Lake

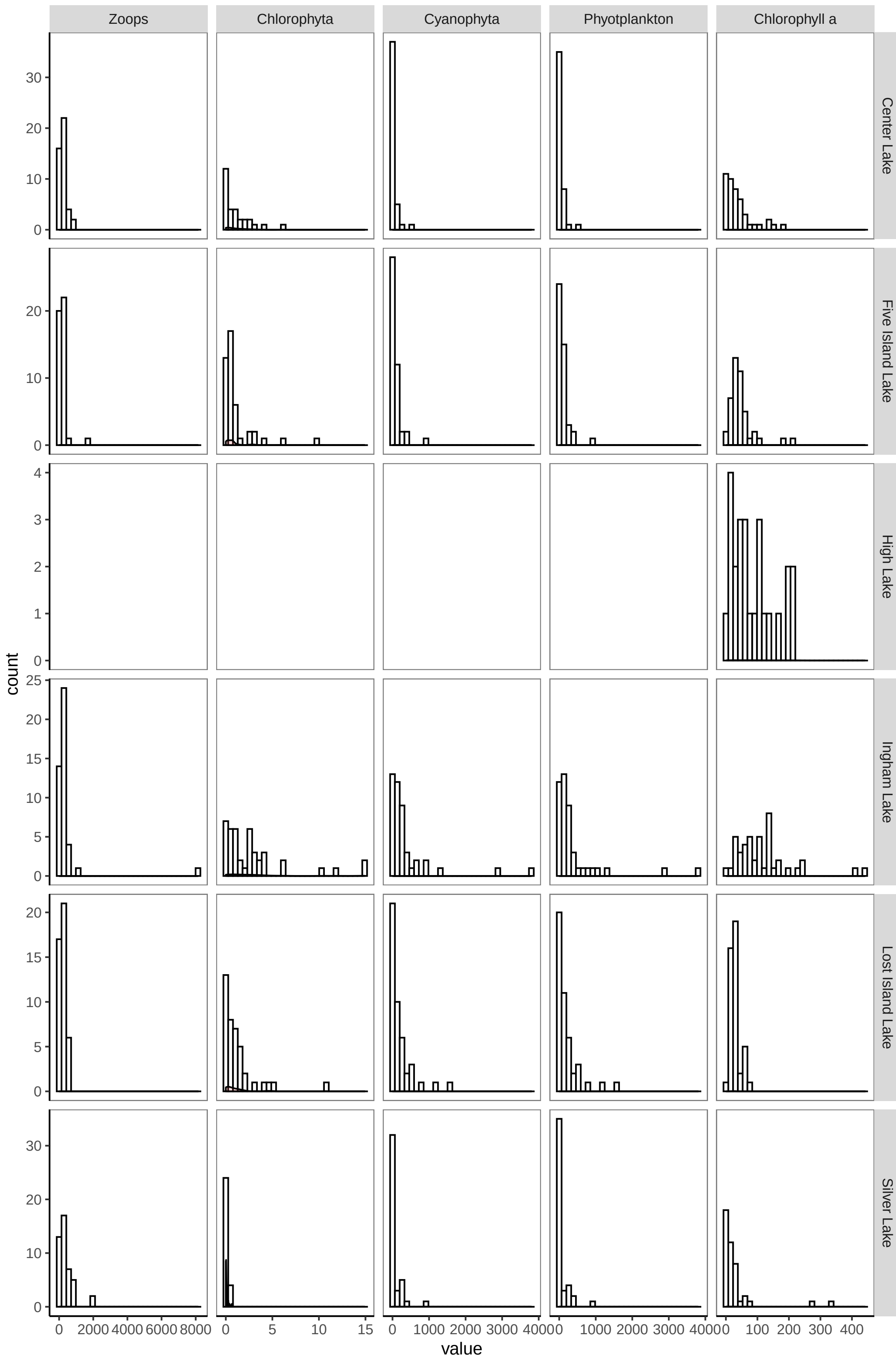
```
## Using Lake as id variables

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


TSS
Secchi Depth
DO
Center Lake
Five Island Lake
High Lake
Ingham Lake
Lost Island Lake
Silver Lake
count
value

```
## Using Lake as id variables
## `stat_bin()` using `bins = 30`. Pick better value with `binwidth`.
```


TN
TP
Center Lake
Five Island Lake
High Lake
Ingham Lake
Lost Island Lake
Silver Lake
count
value

```
## Using Lake as id variables
## `stat_bin()` using `bins = 30`. Pick better value with `binwidth`.
```


Zoops
Chlorophyta
Cyanophyta
Phyotplankton
Chlorophyll a
Center Lake
Five Island Lake
High Lake
Ingham Lake
Lost Island Lake
Silver Lake
count
value

Update 2/24/2020

After meeting with Audrey and Phil, we have a new format for how to arrange the data. The general model format is:

$$TSI \approx \beta_0 + L_i + (\beta_c * C_{li} * H_i) + (\beta_b * (1 - C_{li}) * H_i)$$

where i is indexed on year, l is indexed on lake, L is a fixed lake effect, C is the proportion of harvest made up by carp, 1-C is the proportion of harvest made up by buffalo, H is the total harvest.

Action Items:

- Calculate Mean TSI (average of TSI for TP, Secchi, Chla) taken from the June measurements. When a measurement from June is not available, we took the next closest measurement to one full year after the previous year's measurement date.
- From those mean TSI values, calculate the chanage in TSI from year a to year b.
- Apply same change in variable between year a and year b for other WQ variables.

New data frame

- Lake
- Year*: Year B for water quality stuff (represents the change in Y between year A and B)
- Year*: Total and proportional harvests between years a and b (September A to April B)
- Include the amount (pounds) of carp harvested and buffalo harvested between years A and B
- Create a new variable of the proportion of total harvest (lbs of species / lbs of both species) for carp and buffalo between years A and B
- TSI and other response variables, as the change in Y from year A to year B

———— So the overall data frame will look like: Lake| Year* | Pounds Carp | Pounds Buff | Prop. harvested carp | Prop. harvested buff | TSI | Y variables

Loading in Yearly Change Dataset

```
yearchange.dat <- read.csv("Changesdata.csv", TRUE)
colnames(yearchange.dat)[1] <- c("Lake")


#Setting Year as factor
yearchange.dat$Year <- as.factor(yearchange.dat$Year)


#Subsetting each lake for future use
center.yc <- droplevels(subset(yearchange.dat, yearchange.dat$Lake == "Center Lake"))
fiveisland.yc <- droplevels(subset(yearchange.dat, yearchange.dat$Lake == "Five Island Lake"))
ingham.yc <- droplevels(subset(yearchange.dat, yearchange.dat$Lake == "Ingham Lake"))
lostisland.yc <- droplevels(subset(yearchange.dat, yearchange.dat$Lake == "Lost Island Lake"))
silver.yc <- droplevels(subset(yearchange.dat, yearchange.dat$Lake == "Silver Lake"))
high.yc <- droplevels(subset(yearchange.dat, yearchange.dat$Lake == "High Lake"))
```

Distribution of response variables: TSS, Secchi Depth, Dissolved Oxygen

These represent the count(frequency) for each response variable along it's range. geom_density from ggplot2 is a smoothed version of the histogram, useful for continuous random variables.

```
#Plotting TSS, Secchi, DO
head(yearchange.dat)
```

```
##          Lake Year Carp..lbs.acre.yr. Buffalo..lbs.per.acre.per.year
## 1 Center Lake 1999                  0                              0
## 2 Center Lake 2000                  0                              0
## 3 Center Lake 2001                  0                              0
## 4 Center Lake 2002                  0                              0
## 5 Center Lake 2003                  0                              0
## 6 Center Lake 2004                  0                              0
##   Total.Removed..h. Proportion.of.Carp Proportion.of.Buffalo Delta.TSI..Chla.
## 1                 0                 NA                    NA               NA
## 2                 0                 NA                    NA               NA
## 3                 0                 NA                    NA         5.424935
## 4                 0                 NA                    NA       -16.791941
## 5                 0                 NA                    NA         6.964652
## 6                 0                 NA                    NA        -3.696505
##   Delta.Chla Delta.TSS    Delta.TN   Delta.TP Delta.SD    Delta.DO
## 1         NA        NA          NA         NA       NA          NA
## 2         NA        NA          NA         NA       NA          NA
## 3  -1.333333  7.666667 -0.20666667 -113.33333    -1.40 -1.03333333
## 4  20.900000 -5.333333  0.05666667   23.33333     1.45  0.90000000
## 5  16.533333  0.000000 -0.06000000   18.66667    -1.45 -1.60000000
## 6  -8.700000  4.666667 -0.11333333  -41.00000     0.65 -0.03333333
##   Delta.Turbidity Delta.Phytoplankton.Total.Biomass
## 1              NA                                NA
## 2              NA                                NA
## 3       -9.666667                         15.132023
## 4       13.666667                       -223.739203
## 5       -3.000000                        211.039690
## 6     -144.333333                          9.865767
##   Delta.Zooplankton.Total.Biomass Delta.Chlorophyta Delta.Cyanophyta
## 1                              NA                NA               NA
## 2                              NA                NA               NA
## 3                       -242.1539         0.1178167         15.06982
## 4                       -112.5690        -0.4828333       -221.77081
## 5                        148.8327         0.4780333        208.87787
## 6                       -284.0051        -0.6472967         10.47520
```

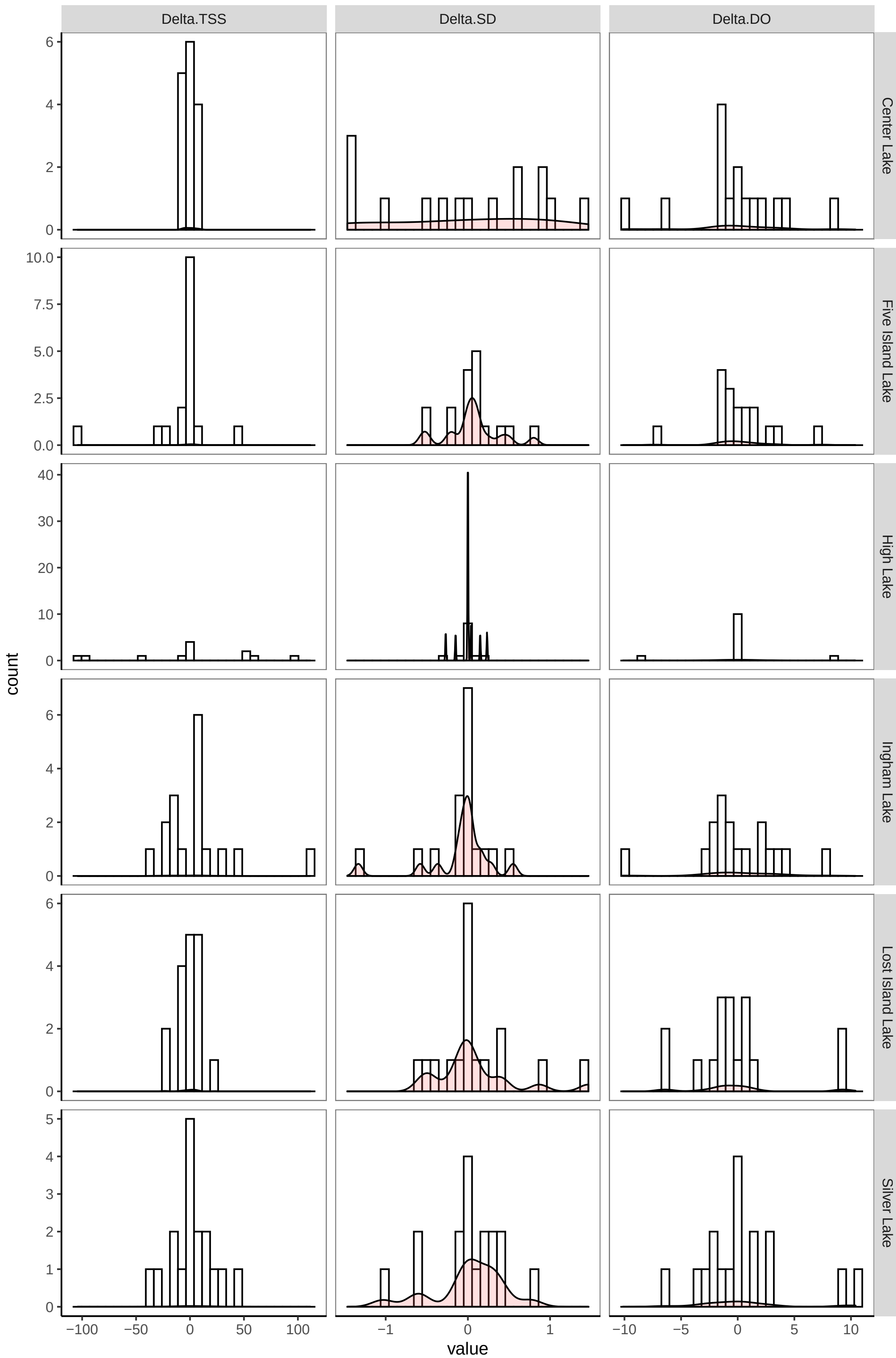
```
change.dat.m.a<-melt(yearchange.dat[,c(1,10,13,14)]) # TSS col 10, Secchi col 13,
```

```
## Using Lake as id variables
```

```
a<-ggplot(change.dat.m.a, aes(x=value))+
      geom_histogram(colour = "black", fill = "white")+
      geom_density(alpha=.2, fill = "#FF6666")+
            facet_grid(Lake~variable, scales = "free")+
```

```r
            theme(panel.grid.major = element_blank(),
                                  panel.grid.minor = element_blank(),
                                  panel.background = element_rect(fill="white",colour="grey50"),
                                  axis.line = element_line(colour = "black"),
                                  legend.position = "bottom",
                                  legend.title = element_blank(),
                                  legend.background = element_rect(colour="grey20"))
a
```

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

## Warning: Removed 21 rows containing non-finite values (stat_bin).

## Warning: Removed 21 rows containing non-finite values (stat_density).
```

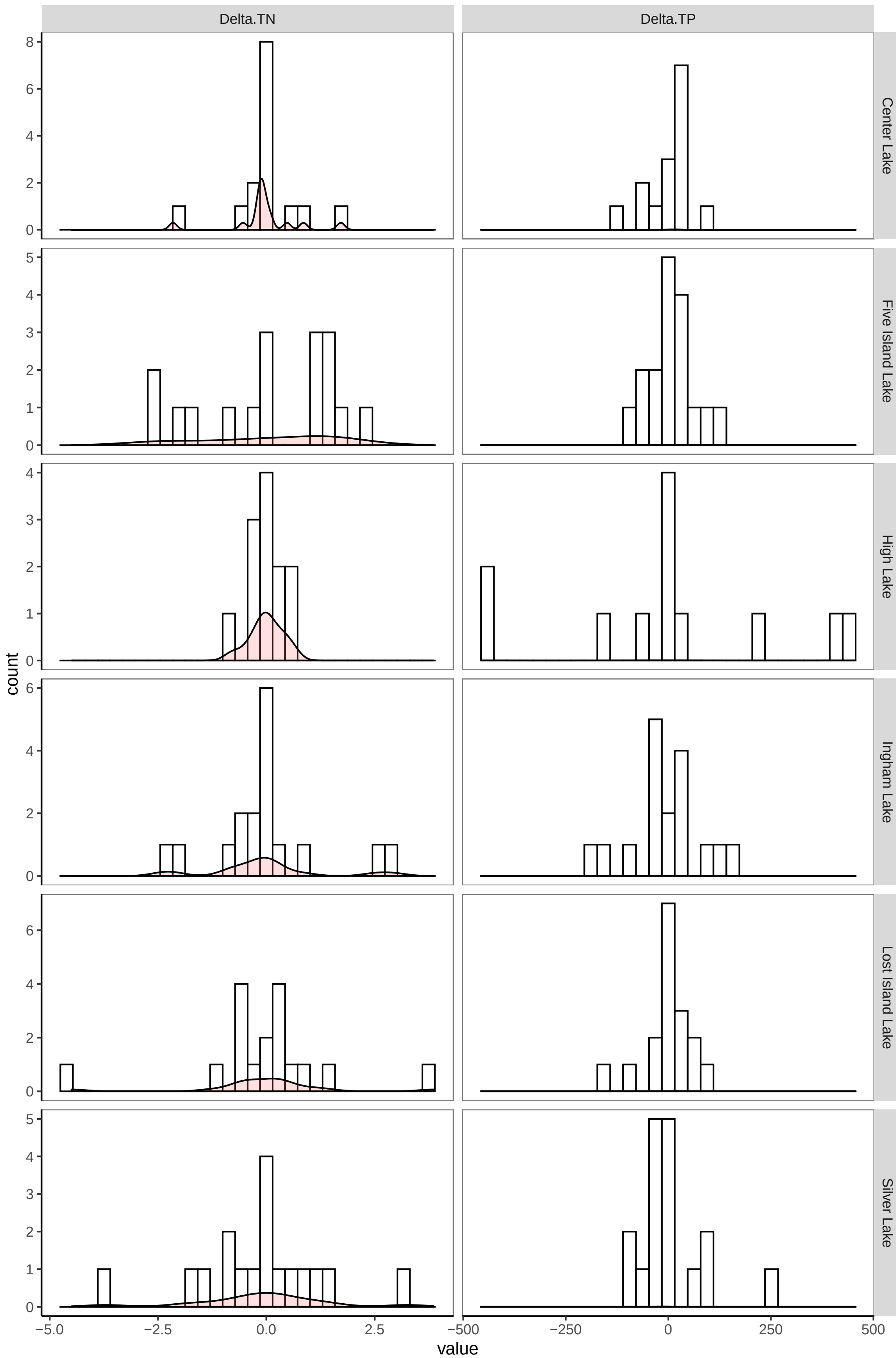

Delta.TSS
Delta.SD
Delta.DO
Center Lake
Five Island Lake
High Lake
Ingham Lake
Lost Island Lake
Silver Lake
count
value

```r
#Plotting TN and TP

change.dat.m.b<-melt(yearchange.dat[,c(1,11,12)]) # TN and TP
```

```
## Using Lake as id variables
```

```r
b<-ggplot(change.dat.m.b, aes(x=value))+
      geom_histogram(colour = "black", fill = "white")+
      geom_density(alpha=.2, fill = "#FF6666")+
            facet_grid(Lake~variable, scales = "free")+
            theme(panel.grid.major = element_blank(),
                              panel.grid.minor = element_blank(),
                              panel.background = element_rect(fill="white",colour="grey50"),
                              axis.line = element_line(colour = "black"),
                              legend.position = "bottom",
                              legend.title = element_blank(),
                              legend.background = element_rect(colour="grey20"))
b
```

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

## Warning: Removed 14 rows containing non-finite values (stat_bin).

## Warning: Removed 14 rows containing non-finite values (stat_density).
```


Delta.TN
Delta.TP
Center Lake
Five Island Lake
High Lake
Ingham Lake
Lost Island Lake
Silver Lake
count
value
−5.0
−2.5
0.0
2.5
−500
−250
0
250
500

```r
#Plotting TSI, Cholorophyll, Phytoplankton, Zoops, chlorophyta, and cyanophyta

change.dat.m.c<-melt(yearchange.dat[,c(1,8,9,16,17,18,19)])
```

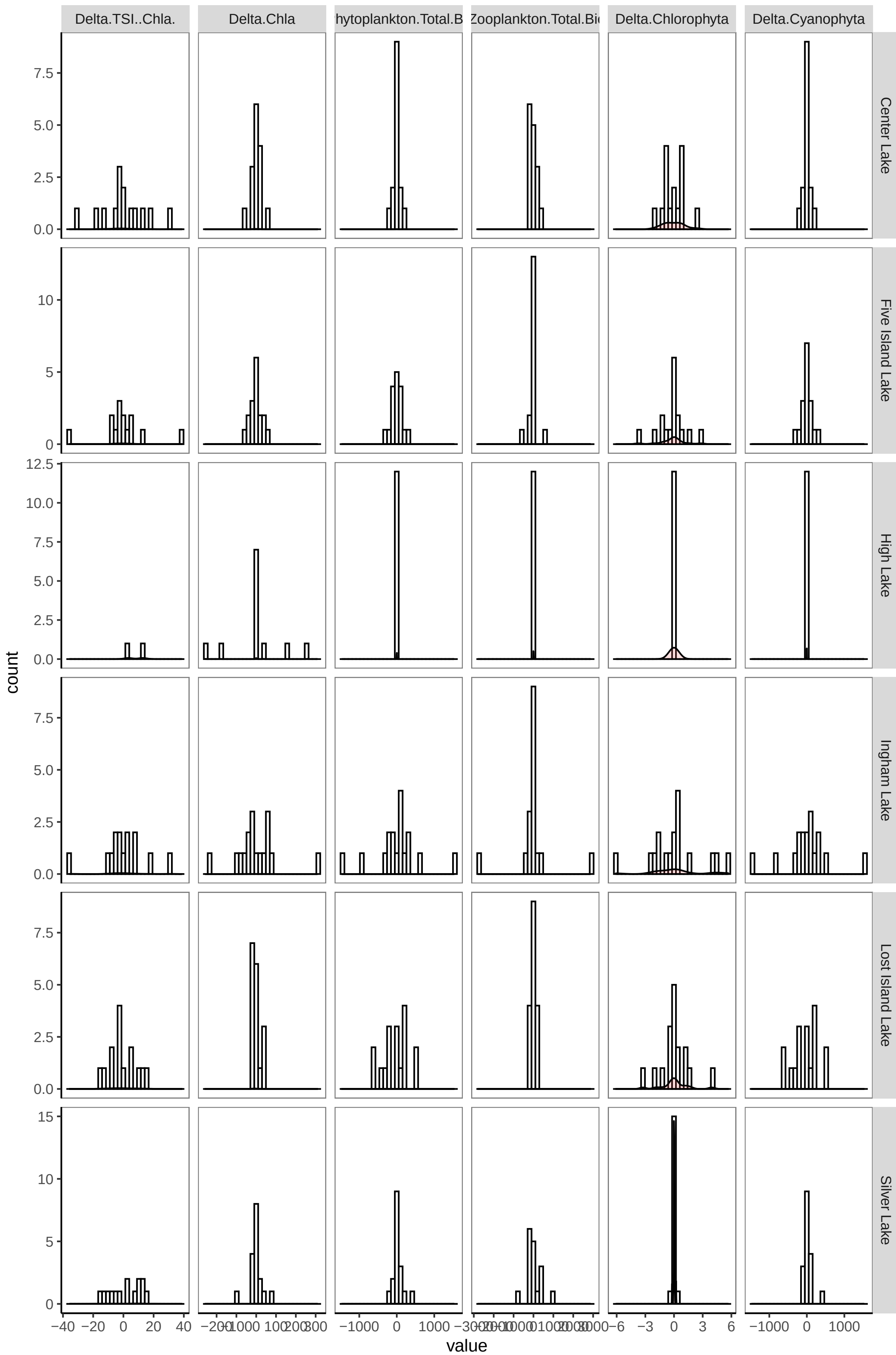
```
## Using Lake as id variables
```

```r
c<-ggplot(change.dat.m.c, aes(x=value))+
      geom_histogram(colour = "black", fill = "white")+
      geom_density(alpha=.2, fill = "#FF6666")+
            facet_grid(Lake~variable, scales = "free")+
            theme(panel.grid.major = element_blank(),
                              panel.grid.minor = element_blank(),
                              panel.background = element_rect(fill="white",colour="grey50"),
                              axis.line = element_line(colour = "black"),
                              legend.position = "bottom",
                              legend.title = element_blank(),
                              legend.background = element_rect(colour="grey20"))
c
```

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

## Warning: Removed 65 rows containing non-finite values (stat_bin).

## Warning: Removed 65 rows containing non-finite values (stat_density).
```



Delta.TSI..Chla.
Delta.Chla
hytoplankton.Total.B
Zooplankton.Total.Bi
Delta.Chlorophyta
Delta.Cyanophyta
Center Lake
Five Island Lake
High Lake
Ingham Lake
Lost Island Lake
Silver Lake
count
value

pairs plot from GGally

```
ggpairs(yearchange.dat[,8:19])
```

```
## Warning: Removed 30 rows containing non-finite values (stat_density).

## Warning in (function (data, mapping, alignPercent = 0.6, method = "pearson", :
## Removed 32 rows containing missing values

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## Warning: Removed 32 rows containing missing values (geom_point).

## Warning: Removed 7 rows containing non-finite values (stat_density).

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