Question 1 - BIOS14 (HT2021)

Read and explore data

```
#Question 1

rm(list=ls())

library(ppcor)

## Loading required package: MASS

library(lmodel2)
library(lmtest)

## Warning: package 'lmtest' was built under R version 4.1.2

## Loading required package: zoo

##
## Attaching package: 'zoo'

## The following objects are masked from 'package:base':
##
##     as.Date, as.Date.numeric

library(car)

## Loading required package: carData
```

```
#read data and explore
plankton<-read.csv('plankton.csv')
str(plankton)

## 'data.frame':    40 obs. of  3 variables:
##  $ treat: chr  "Control" "Control" "Control" "Control" ...
##  $ p    : num  18.66 9.74 10.83 1.29 16.42 ...
##  $ plank: num  311.1 211.2 269.5 58.3 264.4 ...

plankton$treat <- factor(plankton$treat)
str(plankton)

## 'data.frame':    40 obs. of  3 variables:
##  $ treat: Factor w/ 2 levels "Control","Removal_of_some_fish": 1 1 1 1 1 1
## 1 1 1 1 ...
##  $ p    : num  18.66 9.74 10.83 1.29 16.42 ...
##  $ plank: num  311.1 211.2 269.5 58.3 264.4 ...

plot(p~treat, data=plankton, main='Phosphorus data')
```
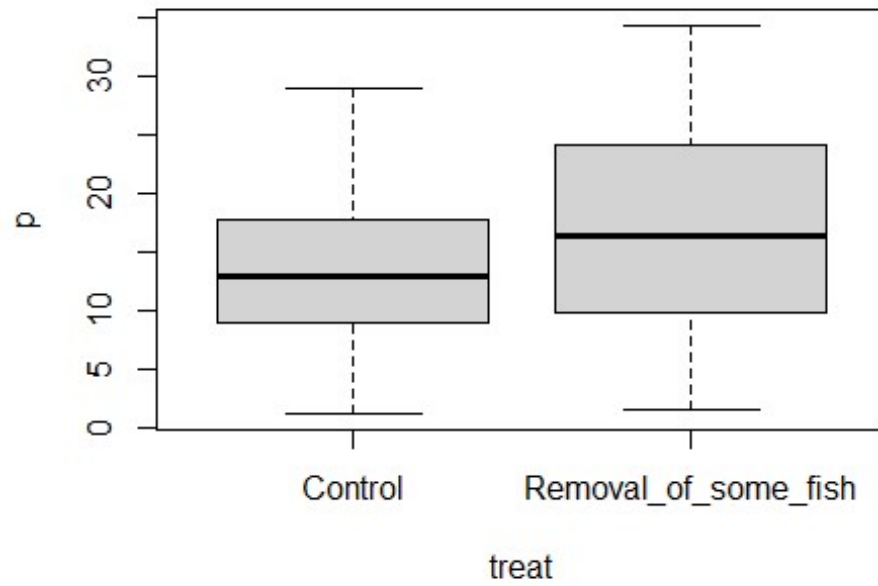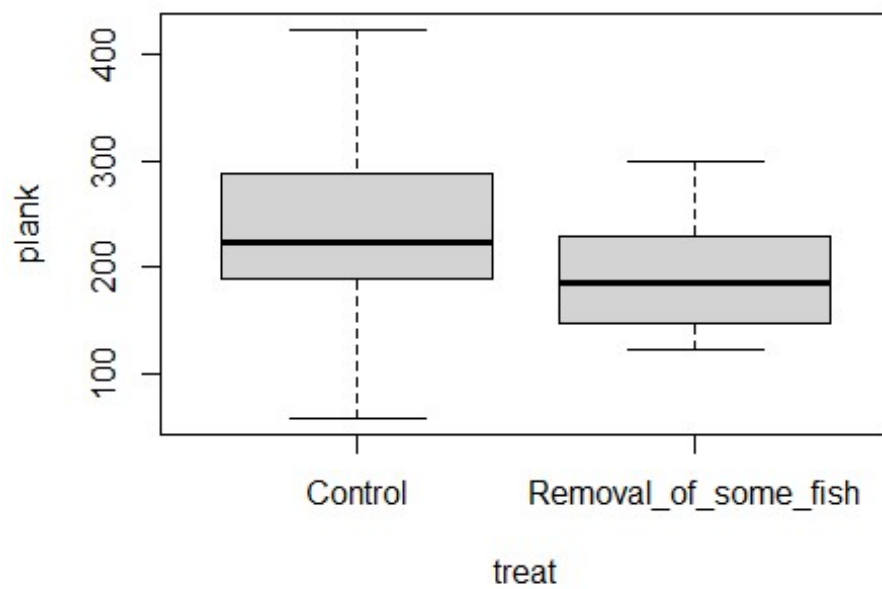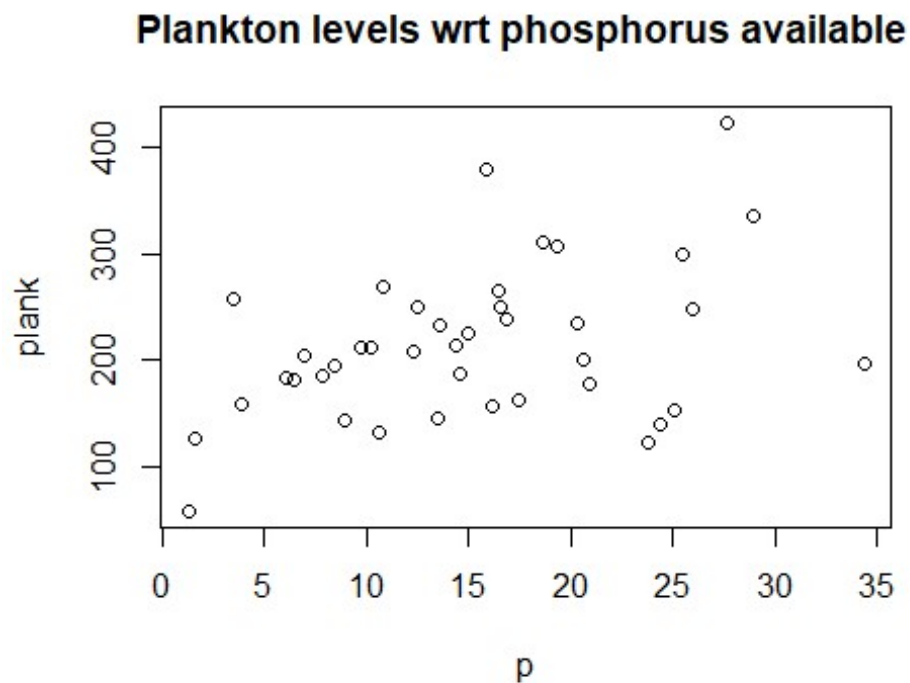
Phosphorus data


```
plot(plank~treat, data=plankton, main='Algal growth data')
```

Algal growth data

```
plot(plank~p, data=plankton, main='Plankton levels wrt phosphorus available
')
```

Plankton levels wrt phosphorus available


```
#may be linear
```

Part (a)

Here, I have used **Partial correlation** to understand if the relationship between phosphorus concentration and plankton density vary with removal of fish from the pond
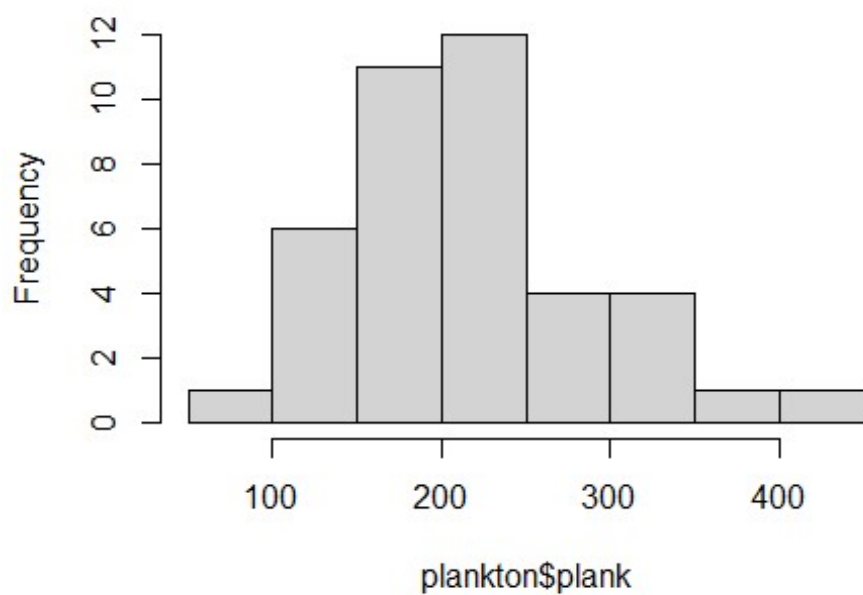
```
#Partial correlation

#plankton - dependent variable
#p level - predictor variable

#check assumptions

hist(plankton$plank)
```

Histogram of plankton$plank


```
qqnorm(plankton$plank)
qqline(plankton$plank)
```

Normal Q-Q Plot

```
shapiro.test(plankton$plank)

##
##   Shapiro-Wilk normality test
##
## data:  plankton$plank
## W = 0.96273, p-value = 0.2075
```

#not significant - normal distribution
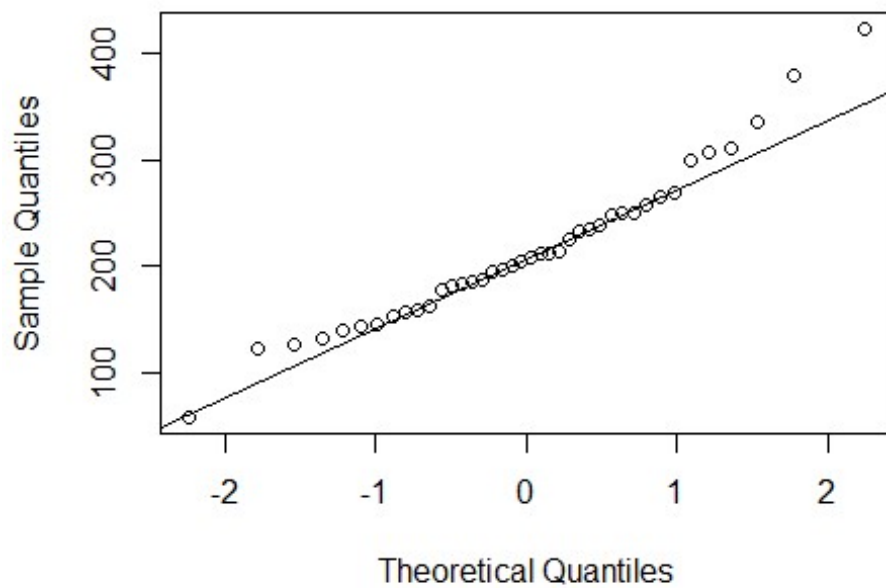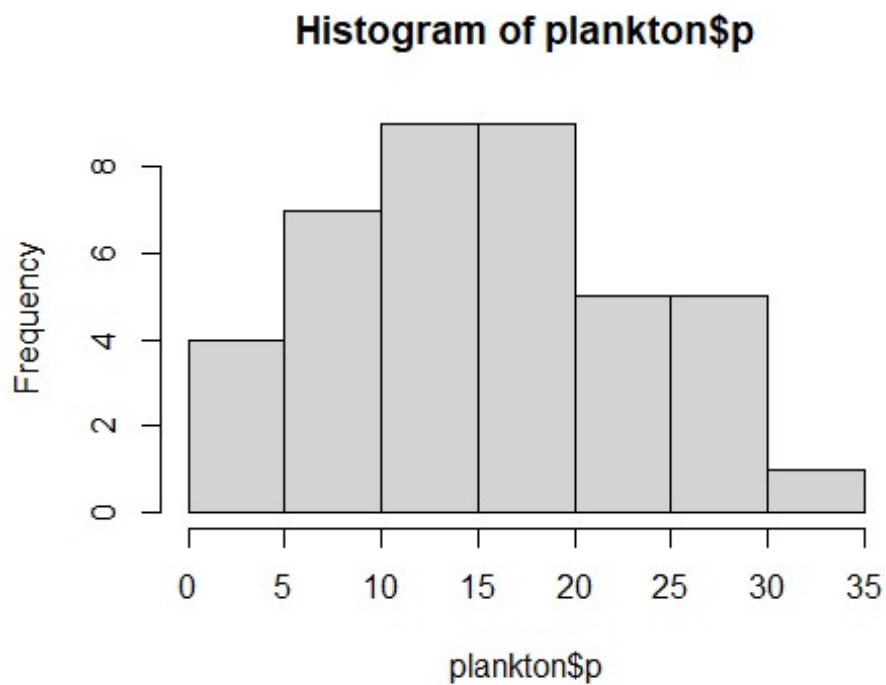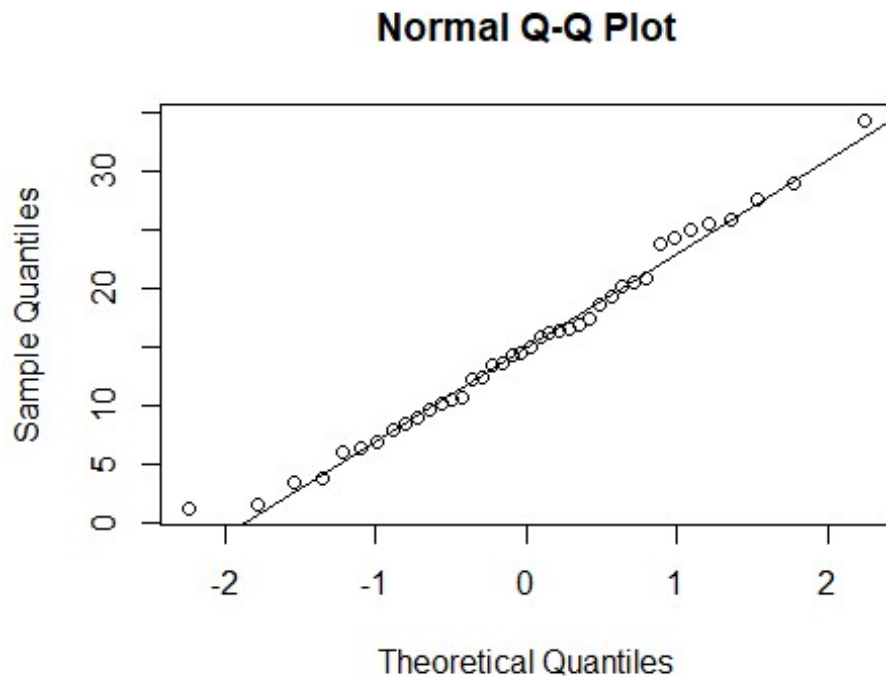
```
hist(plankton$p)
```

Histogram of plankton$p


```
qqnorm(plankton$p)
qqline(plankton$p)
```

Normal Q-Q Plot


```
shapiro.test(plankton$p)

##
##  Shapiro-Wilk normality test
##
## data:  plankton$p
## W = 0.98362, p-value = 0.8198
```

#not significant - normal distribution

#linear relationship and homoscedasticity
#scatterplot shows sort of linear relationship, but no deviations or data
grouping at any point - both assumptions fulfilled

```
pcor.test(plankton$plank, plankton$p, as.numeric(plankton$treat),
method='pearson')

##    estimate     p.value statistic  n gp  Method
## 1 0.499641 0.001201947  3.508524 40  1 pearson
```

#significant p-value, correlation value is not zero, and zero does not lie
within CI, so significant relationship between the presence of plankton in
the lakes and the levels of phosphorus, independent of treatment (fish
removal)

It is already understood from the partial correlation that fish removal does not significantly affect the relationship between plankton density and phosphorus concentration. So, we

could use a linear model including only plankton density and phosphorus concentration to analyze the linear relationship.

Here, I have however chosen to use **ANCOVA** to further support the results from the partial correlation analysis

```
#ancova to test with multiple predictors - continuous and categorical at the
same time

#full model
fit.fullplank <- lm(plank~p*treat, data=plankton)
AIC(fit.fullplank)

## [1] 432.5379

#model with only main effects (w/o phosphorus and treatment aka fish removal
interaction effect) - interaction effect not necessary as it is not relevant
- fish removal and phosphorus availability interaction is not what we want to
study here
fit.plank <- lm(plank~treat+p, data=plankton)
AIC(fit.plank)

## [1] 446.7461

#model with lower AIC - full model - further analysis

#ancova assumptions

#assumption 1: independent observations
dwtest(fit.fullplank)

##
##  Durbin-Watson test
##
## data:  fit.fullplank
## DW = 2.2295, p-value = 0.7214
## alternative hypothesis: true autocorrelation is greater than 0

#not significant - assumption true

#assumption 2 and 3: normality of residuals and homoscedasticity of variances
qqnorm(resid(fit.fullplank))
qqline(resid(fit.fullplank))
```

Normal Q-Q Plot
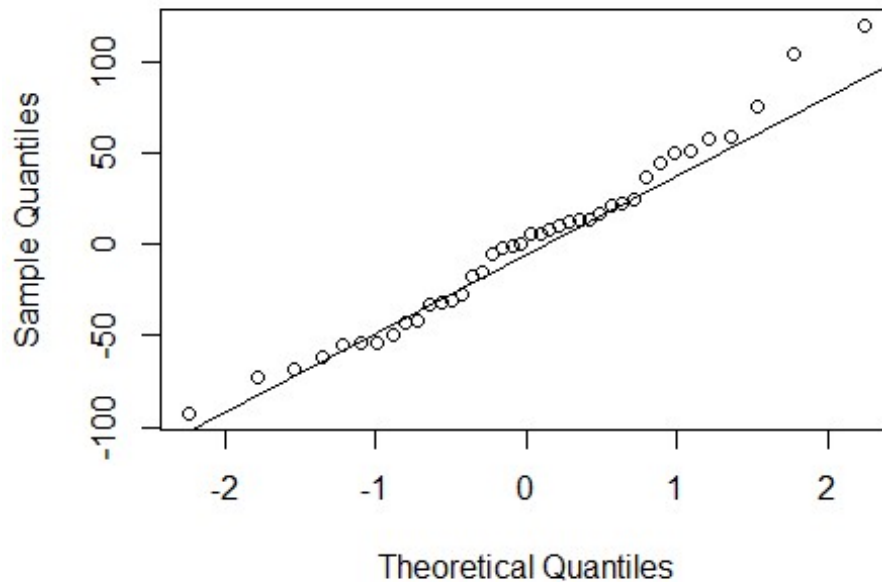

```
shapiro.test(resid(fit.fullplank))

##
##   Shapiro-Wilk normality test
##
## data:  resid(fit.fullplank)
## W = 0.9799, p-value = 0.6859
```

#not significant - normality of residues true

```
leveneTest(plank~treat, data=plankton)

## Levene's Test for Homogeneity of Variance (center = median)
##       Df F value Pr(>F)
## group  1  2.4535 0.1256
##       38
```

#not significant - homoscedasticity proved

```
par(mfrow=c(2,2))
plot(fit.fullplank)
```
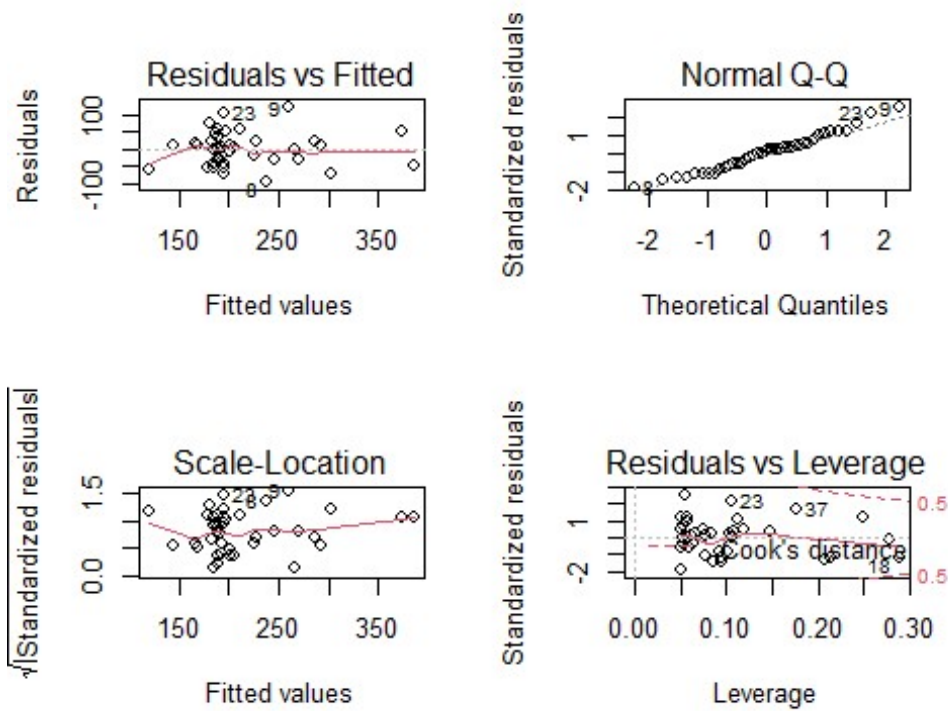
```
par(mfrow=c(1,1))

#assumption 4: linear relationship between covariate and dependent variable
#can see from scatterplot above - true

#assumption 5: covariate independent from categorical predictor
plot(p~treat, data=plankton)
```
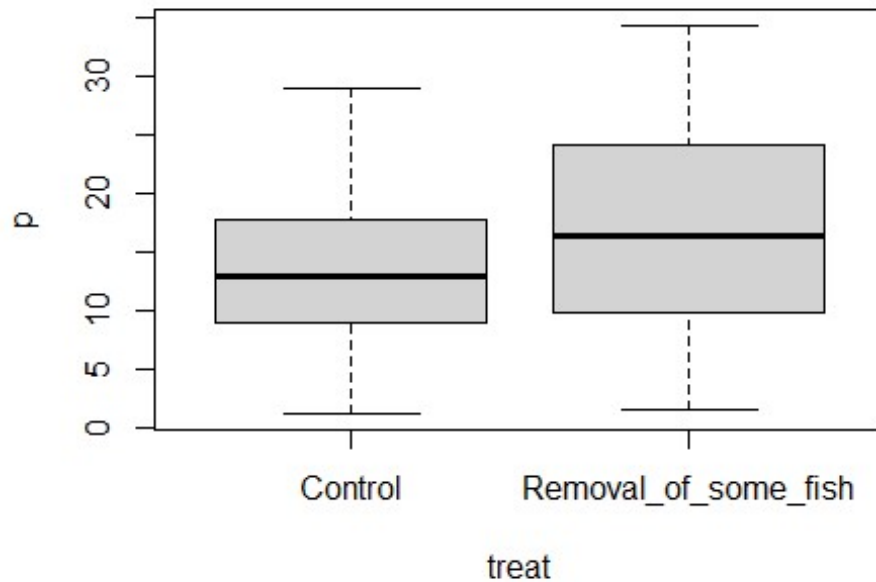
```
#has an effect
#verify w/ anova
anova(lm(p~treat, data=plankton))

## Analysis of Variance Table
##
## Response: p
##            Df  Sum Sq Mean Sq F value Pr(>F)
## treat       1   89.43  89.426  1.4439 0.2369
## Residuals 38 2353.53  61.935

#MS and SS values not equal to zero - has an effect

#get results
anova(fit.fullplank)

## Analysis of Variance Table
##
## Response: plank
##            Df Sum Sq Mean Sq F value     Pr(>F)
## p           1  32049   32049  12.732 0.0010402 **
## treat       1  37232   37232  14.790 0.0004716 ***
## p:treat     1  45276   45276  17.986 0.0001483 ***
## Residuals 36  90622    2517
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
summary(fit.fullplank)

##
## Call:
## lm(formula = plank ~ p * treat, data = plankton)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -92.571 -35.042   3.438  23.236 120.015
##
## Coefficients:
##                            Estimate Std. Error t value Pr(>|t|)
## (Intercept)                 108.029     24.659   4.381 9.78e-05 ***
## p                             9.580      1.604   5.974 7.52e-07 ***
## treatRemoval_of_some_fish    70.758     35.265   2.006 0.052367 .
## p:treatRemoval_of_some_fish  -8.899      2.098  -4.241 0.000148 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 50.17 on 36 degrees of freedom
## Multiple R-squared:  0.5583, Adjusted R-squared:  0.5215
## F-statistic: 15.17 on 3 and 36 DF,  p-value: 1.524e-06
```

Part (b)

```
#illustrate results
plot(plank~p, data=plankton, type='n',main='Data illustration:\n Variation of
plankton density wrt to\n phosphorus levels in lakes', xlab='Phsophorus
concentration', ylab='Plankton density')

points(plankton$p[plankton$treat=='Control'],
plankton$plank[plankton$treat=='Control'], col='lightseagreen')

points(plankton$p[plankton$treat=='Removal_of_some_fish'],
plankton$plank[plankton$treat=='Removal_of_some_fish'], col='lightcoral')

#add predicted lines

abline(fit.fullplank$coefficients[1:2], col='lightseagreen')
abline(fit.fullplank$coefficients[1]+fit.fullplank$coefficients[3],
fit.fullplank$coefficients[2]+fit.fullplank$coefficients[4],
col='lightcoral')

legend('topleft', fill=c('lightseagreen', 'lightcoral'), legend=c('Control',
'With fish removal'))
```

Data illustration:
Variation of plankton density wrt to
phosphorus levels in lakes
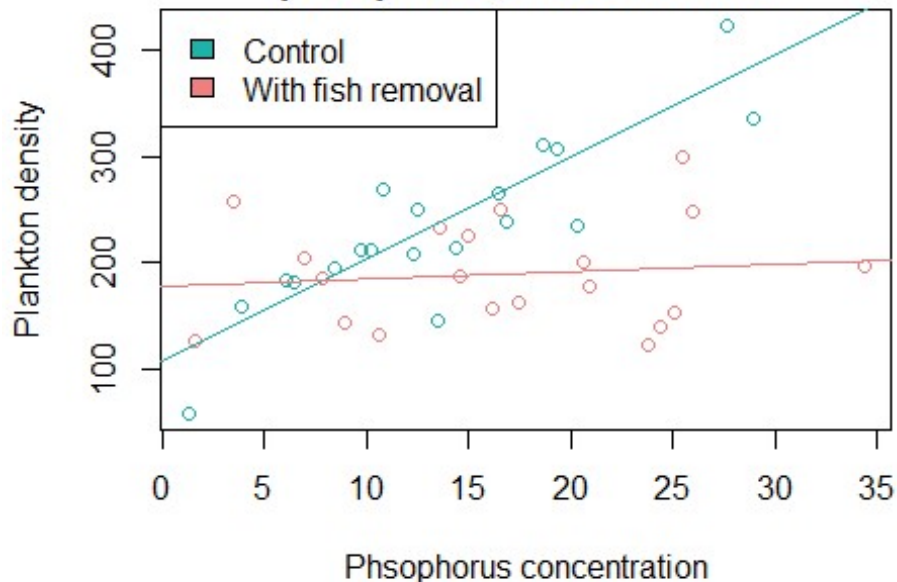
This method of graphical illustration of scatter plot and line i helpful to show actual points and the model fitting together.

The graph shows that the second factor, or fish removal is not significant in the effect of plankton density over phosphorus concentration - the intersection of the two lines in the manner as seen on the graph indicates that the difference in plankton density seen due to the treatment averages over different values or levels of phosphorus treatment

This further supports our findings from partial correlation analysis that fish removal is not a significant effect here.

Part (c)

Linear equations:

(a) For control data

plank = 108.029 + 9.580p

(b) For data with fish removal

plank = 178.787 + 0.681p

Conclusions: A linear relationship between phosphorus concentration and plankton density exists, and there is a significant relationship between phosphorus concentration and treatment. The latter relationship does not however affect the increase in plankton density with increase in phosphorus concentration.

Model parameters can be pulled up using the summary() function that displays coefficients under the table column 'estimate'. The intercept value gives the intercept of the control and the p estimate value gives the slope of the control data, i.e, how phosphorus concentration influences plankton density in control lakes. The next estimate value provides the difference between the intercept for the control data and the data with fish removal. The final estimate gives a measure of how phosphorus concentration influences plankton density in the presence of fish removal.

The 95% confidence intervals of a model over a given data set can be found using the predict() function that utilizes the model to predict plank values for a given set of p values, and then calculate the 95% CI.

For normally distributed data, the 95% CI can be roughly defined as mean +/- 2*standard error. This can be calculated from the output of summary(), which provides the standard error values for the different groups.

```r
#create dataset for confidence interval

new.x <- rep(seq(min(plankton$p), max(plankton$p), len=100), 2)
new.s <- rep(c('Control', 'Removal_of_some_fish'), each=100)

pred.data <- predict(fit.fullplank, new=data.frame(p=new.x, treat=new.s),
interval='conf', level=0.95)
pred.data

##            fit       lwr      upr
## 1     120.3930  74.08126 166.7047
## 2     123.5935  78.22498 168.9621
## 3     126.7941  82.36215 171.2260
## 4     129.9946  86.49235 173.4969
## 5     133.1952  90.61513 175.7752
## 6     136.3957  94.72998 178.0615
## 7     139.5963  98.83639 180.3562
## 8     142.7968 102.93376 182.6599
## 9     145.9974 107.02149 184.9733
## 10    149.1979 111.09888 187.2970
## 11    152.3985 115.16523 189.6317
## 12    155.5990 119.21973 191.9783
## 13    158.7996 123.26152 194.3376
## 14    162.0001 127.28970 196.7105
## 15    165.2007 131.30326 199.0981
## 16    168.4012 135.30112 201.5013
## 17    171.6018 139.28213 203.9214
## 18    174.8023 143.24502 206.3596
## 19    178.0029 147.18846 208.8172
## 20    181.2034 151.11101 211.2958
## 21    184.4039 155.01112 213.7968
## 22    187.6045 158.88716 216.3218
## 23    190.8050 162.73738 218.8727
## 24    194.0056 166.55997 221.4512
```

```
## 25   197.2061 170.35298 224.0593
## 26   200.4067 174.11443 226.6989
## 27   203.6072 177.84226 229.3722
## 28   206.8078 181.53435 232.0812
## 29   210.0083 185.18859 234.8281
## 30   213.2089 188.80287 237.6149
## 31   216.4094 192.37511 240.4437
## 32   219.6100 195.90335 243.3166
## 33   222.8105 199.38574 246.2353
## 34   226.0111 202.82060 249.2015
## 35   229.2116 206.20648 252.2167
## 36   232.4122 209.54220 255.2821
## 37   235.6127 212.82686 258.3986
## 38   238.8133 216.05989 261.5666
## 39   242.0138 219.24107 264.7865
## 40   245.2144 222.37053 268.0582
## 41   248.4149 225.44876 271.3810
## 42   251.6155 228.47657 274.7543
## 43   254.8160 231.45507 278.1769
## 44   258.0165 234.38565 281.6474
## 45   261.2171 237.26995 285.1642
## 46   264.4176 240.10975 288.7255
## 47   267.6182 242.90701 292.3294
## 48   270.8187 245.66379 295.9737
## 49   274.0193 248.38217 299.6564
## 50   277.2198 251.06428 303.3754
## 51   280.4204 253.71224 307.1285
## 52   283.6209 256.32811 310.9137
## 53   286.8215 258.91392 314.7290
## 54   290.0220 261.47161 318.5724
## 55   293.2226 264.00303 322.4421
## 56   296.4231 266.50995 326.3363
## 57   299.6237 268.99403 330.2533
## 58   302.8242 271.45683 334.1916
## 59   306.0248 273.89982 338.1497
## 60   309.2253 276.32438 342.1262
## 61   312.4259 278.73176 346.1200
## 62   315.6264 281.12317 350.1296
## 63   318.8270 283.49969 354.1542
## 64   322.0275 285.86234 358.1927
## 65   325.2281 288.21207 362.2440
## 66   328.4286 290.54974 366.3075
## 67   331.6291 292.87617 370.3821
## 68   334.8297 295.19209 374.4673
## 69   338.0302 297.49819 378.5623
## 70   341.2308 299.79511 382.6665
## 71   344.4313 302.08344 386.7792
## 72   347.6319 304.36371 390.9001
## 73   350.8324 306.63644 395.0284
## 74   354.0330 308.90209 399.1639
```

```
## 75   357.2335 311.16109 403.3060
## 76   360.4341 313.41383 407.4543
## 77   363.6346 315.66070 411.6085
## 78   366.8352 317.90203 415.7683
## 79   370.0357 320.13814 419.9333
## 80   373.2363 322.36933 424.1032
## 81   376.4368 324.59587 428.2778
## 82   379.6374 326.81803 432.4567
## 83   382.8379 329.03604 436.6398
## 84   386.0385 331.25013 440.8268
## 85   389.2390 333.46049 445.0175
## 86   392.4396 335.66734 449.2118
## 87   395.6401 337.87084 453.4094
## 88   398.8406 340.07118 457.6101
## 89   402.0412 342.26850 461.8139
## 90   405.2417 344.46296 466.0205
## 91   408.4423 346.65469 470.2299
## 92   411.6428 348.84384 474.4418
## 93   414.8434 351.03052 478.6563
## 94   418.0439 353.21484 482.8730
## 95   421.2445 355.39692 487.0920
## 96   424.4450 357.57687 491.3132
## 97   427.6456 359.75476 495.5364
## 98   430.8461 361.93071 499.7616
## 99   434.0467 364.10478 503.9886
## 100 437.2472 366.27707 508.2174
## 101 179.6667 131.68168 227.6516
## 102 179.8944 132.71464 227.0741
## 103 180.1221 133.74344 226.5007
## 104 180.3498 134.76789 225.9317
## 105 180.5775 135.78774 225.3672
## 106 180.8052 136.80274 224.8077
## 107 181.0329 137.81263 224.2532
## 108 181.2606 138.81713 223.7041
## 109 181.4883 139.81594 223.1607
## 110 181.7160 140.80873 222.6233
## 111 181.9438 141.79517 222.0923
## 112 182.1715 142.77487 221.5680
## 113 182.3992 143.74746 221.0509
## 114 182.6269 144.71251 220.5413
## 115 182.8546 145.66956 220.0396
## 116 183.0823 146.61816 219.5464
## 117 183.3100 147.55777 219.0622
## 118 183.5377 148.48786 218.5876
## 119 183.7654 149.40783 218.1230
## 120 183.9931 150.31707 217.6692
## 121 184.2208 151.21492 217.2268
## 122 184.4486 152.10065 216.7965
## 123 184.6763 152.97352 216.3790
## 124 184.9040 153.83274 215.9752
```

```
## 125 185.1317 154.67743 215.5859
## 126 185.3594 155.50672 215.2121
## 127 185.5871 156.31964 214.8546
## 128 185.8148 157.11520 214.5144
## 129 186.0425 157.89235 214.1927
## 130 186.2702 158.64998 213.8905
## 131 186.4979 159.38695 213.6089
## 132 186.7257 160.10208 213.3492
## 133 186.9534 160.79415 213.1126
## 134 187.1811 161.46190 212.9002
## 135 187.4088 162.10407 212.7135
## 136 187.6365 162.71938 212.5536
## 137 187.8642 163.30657 212.4218
## 138 188.0919 163.86436 212.3195
## 139 188.3196 164.39156 212.2477
## 140 188.5473 164.88700 212.2077
## 141 188.7750 165.34959 212.2005
## 142 189.0028 165.77834 212.2272
## 143 189.2305 166.17235 212.2886
## 144 189.4582 166.53087 212.3855
## 145 189.6859 166.85330 212.5185
## 146 189.9136 167.13918 212.6880
## 147 190.1413 167.38823 212.8944
## 148 190.3690 167.60035 213.1377
## 149 190.5967 167.77561 213.4178
## 150 190.8244 167.91427 213.7346
## 151 191.0521 168.01675 214.0875
## 152 191.2798 168.08364 214.4761
## 153 191.5076 168.11567 214.8994
## 154 191.7353 168.11371 215.3568
## 155 191.9630 168.07874 215.8472
## 156 192.1907 168.01183 216.3695
## 157 192.4184 167.91414 216.9227
## 158 192.6461 167.78688 217.5053
## 159 192.8738 167.63128 218.1164
## 160 193.1015 167.44863 218.7544
## 161 193.3292 167.24020 219.4183
## 162 193.5569 167.00726 220.1066
## 163 193.7847 166.75106 220.8183
## 164 194.0124 166.47283 221.5519
## 165 194.2401 166.17376 222.3064
## 166 194.4678 165.85500 223.0806
## 167 194.6955 165.51766 223.8733
## 168 194.9232 165.16279 224.6836
## 169 195.1509 164.79141 225.5104
## 170 195.3786 164.40447 226.3528
## 171 195.6063 164.00288 227.2098
## 172 195.8340 163.58750 228.0806
## 173 196.0618 163.15914 228.9644
## 174 196.2895 162.71855 229.8604
```

```
## 175 196.5172 162.26646 230.7679
## 176 196.7449 161.80354 231.6862
## 177 196.9726 161.33040 232.6148
## 178 197.2003 160.84766 233.5529
## 179 197.4280 160.35585 234.5002
## 180 197.6557 159.85550 235.4559
## 181 197.8834 159.34708 236.4198
## 182 198.1111 158.83106 237.3912
## 183 198.3388 158.30786 238.3698
## 184 198.5666 157.77787 239.3552
## 185 198.7943 157.24146 240.3471
## 186 199.0220 156.69899 241.3450
## 187 199.2497 156.15078 242.3486
## 188 199.4774 155.59712 243.3577
## 189 199.7051 155.03832 244.3719
## 190 199.9328 154.47463 245.3910
## 191 200.1605 153.90630 246.4148
## 192 200.3882 153.33358 247.4429
## 193 200.6159 152.75667 248.4752
## 194 200.8437 152.17580 249.5115
## 195 201.0714 151.59115 250.5516
## 196 201.2991 151.00291 251.5952
## 197 201.5268 150.41124 252.6423
## 198 201.7545 149.81632 253.6927
## 199 201.9822 149.21829 254.7461
## 200 202.2099 148.61729 255.8025
```

```r
pred.data <- data.frame(pred.data, p=new.x, treat=new.s)
pred.data
```

```
##            fit        lwr      upr          p           treat
## 1    120.3930  74.08126 166.7047   1.290529         Control
## 2    123.5935  78.22498 168.9621   1.624604         Control
## 3    126.7941  82.36215 171.2260   1.958679         Control
## 4    129.9946  86.49235 173.4969   2.292753         Control
## 5    133.1952  90.61513 175.7752   2.626828         Control
## 6    136.3957  94.72998 178.0615   2.960903         Control
## 7    139.5963  98.83639 180.3562   3.294977         Control
## 8    142.7968 102.93376 182.6599   3.629052         Control
## 9    145.9974 107.02149 184.9733   3.963127         Control
## 10   149.1979 111.09888 187.2970   4.297201         Control
## 11   152.3985 115.16523 189.6317   4.631276         Control
## 12   155.5990 119.21973 191.9783   4.965351         Control
## 13   158.7996 123.26152 194.3376   5.299425         Control
## 14   162.0001 127.28970 196.7105   5.633500         Control
## 15   165.2007 131.30326 199.0981   5.967575         Control
## 16   168.4012 135.30112 201.5013   6.301649         Control
## 17   171.6018 139.28213 203.9214   6.635724         Control
## 18   174.8023 143.24502 206.3596   6.969799         Control
## 19   178.0029 147.18846 208.8172   7.303873         Control
```

```
## 20   181.2034 151.11101 211.2958  7.637948              Control
## 21   184.4039 155.01112 213.7968  7.972023              Control
## 22   187.6045 158.88716 216.3218  8.306097              Control
## 23   190.8050 162.73738 218.8727  8.640172              Control
## 24   194.0056 166.55997 221.4512  8.974247              Control
## 25   197.2061 170.35298 224.0593  9.308321              Control
## 26   200.4067 174.11443 226.6989  9.642396              Control
## 27   203.6072 177.84226 229.3722  9.976471              Control
## 28   206.8078 181.53435 232.0812 10.310545              Control
## 29   210.0083 185.18859 234.8281 10.644620              Control
## 30   213.2089 188.80287 237.6149 10.978695              Control
## 31   216.4094 192.37511 240.4437 11.312770              Control
## 32   219.6100 195.90335 243.3166 11.646844              Control
## 33   222.8105 199.38574 246.2353 11.980919              Control
## 34   226.0111 202.82060 249.2015 12.314994              Control
## 35   229.2116 206.20648 252.2167 12.649068              Control
## 36   232.4122 209.54220 255.2821 12.983143              Control
## 37   235.6127 212.82686 258.3986 13.317218              Control
## 38   238.8133 216.05989 261.5666 13.651292              Control
## 39   242.0138 219.24107 264.7865 13.985367              Control
## 40   245.2144 222.37053 268.0582 14.319442              Control
## 41   248.4149 225.44876 271.3810 14.653516              Control
## 42   251.6155 228.47657 274.7543 14.987591              Control
## 43   254.8160 231.45507 278.1769 15.321666              Control
## 44   258.0165 234.38565 281.6474 15.655740              Control
## 45   261.2171 237.26995 285.1642 15.989815              Control
## 46   264.4176 240.10975 288.7255 16.323890              Control
## 47   267.6182 242.90701 292.3294 16.657964              Control
## 48   270.8187 245.66379 295.9737 16.992039              Control
## 49   274.0193 248.38217 299.6564 17.326114              Control
## 50   277.2198 251.06428 303.3754 17.660188              Control
## 51   280.4204 253.71224 307.1285 17.994263              Control
## 52   283.6209 256.32811 310.9137 18.328338              Control
## 53   286.8215 258.91392 314.7290 18.662412              Control
## 54   290.0220 261.47161 318.5724 18.996487              Control
## 55   293.2226 264.00303 322.4421 19.330562              Control
## 56   296.4231 266.50995 326.3363 19.664636              Control
## 57   299.6237 268.99403 330.2533 19.998711              Control
## 58   302.8242 271.45683 334.1916 20.332786              Control
## 59   306.0248 273.89982 338.1497 20.666860              Control
## 60   309.2253 276.32438 342.1262 21.000935              Control
## 61   312.4259 278.73176 346.1200 21.335010              Control
## 62   315.6264 281.12317 350.1296 21.669084              Control
## 63   318.8270 283.49969 354.1542 22.003159              Control
## 64   322.0275 285.86234 358.1927 22.337234              Control
## 65   325.2281 288.21207 362.2440 22.671308              Control
## 66   328.4286 290.54974 366.3075 23.005383              Control
## 67   331.6291 292.87617 370.3821 23.339458              Control
## 68   334.8297 295.19209 374.4673 23.673533              Control
## 69   338.0302 297.49819 378.5623 24.007607              Control
```

```
## 70   341.2308 299.79511 382.6665 24.341682                 Control
## 71   344.4313 302.08344 386.7792 24.675757                 Control
## 72   347.6319 304.36371 390.9001 25.009831                 Control
## 73   350.8324 306.63644 395.0284 25.343906                 Control
## 74   354.0330 308.90209 399.1639 25.677981                 Control
## 75   357.2335 311.16109 403.3060 26.012055                 Control
## 76   360.4341 313.41383 407.4543 26.346130                 Control
## 77   363.6346 315.66070 411.6085 26.680205                 Control
## 78   366.8352 317.90203 415.7683 27.014279                 Control
## 79   370.0357 320.13814 419.9333 27.348354                 Control
## 80   373.2363 322.36933 424.1032 27.682429                 Control
## 81   376.4368 324.59587 428.2778 28.016503                 Control
## 82   379.6374 326.81803 432.4567 28.350578                 Control
## 83   382.8379 329.03604 436.6398 28.684653                 Control
## 84   386.0385 331.25013 440.8268 29.018727                 Control
## 85   389.2390 333.46049 445.0175 29.352802                 Control
## 86   392.4396 335.66734 449.2118 29.686877                 Control
## 87   395.6401 337.87084 453.4094 30.020951                 Control
## 88   398.8406 340.07118 457.6101 30.355026                 Control
## 89   402.0412 342.26850 461.8139 30.689101                 Control
## 90   405.2417 344.46296 466.0205 31.023175                 Control
## 91   408.4423 346.65469 470.2299 31.357250                 Control
## 92   411.6428 348.84384 474.4418 31.691325                 Control
## 93   414.8434 351.03052 478.6563 32.025399                 Control
## 94   418.0439 353.21484 482.8730 32.359474                 Control
## 95   421.2445 355.39692 487.0920 32.693549                 Control
## 96   424.4450 357.57687 491.3132 33.027623                 Control
## 97   427.6456 359.75476 495.5364 33.361698                 Control
## 98   430.8461 361.93071 499.7616 33.695773                 Control
## 99   434.0467 364.10478 503.9886 34.029847                 Control
## 100 437.2472 366.27707 508.2174 34.363922                 Control
## 101 179.6667 131.68168 227.6516  1.290529 Removal_of_some_fish
## 102 179.8944 132.71464 227.0741  1.624604 Removal_of_some_fish
## 103 180.1221 133.74344 226.5007  1.958679 Removal_of_some_fish
## 104 180.3498 134.76789 225.9317  2.292753 Removal_of_some_fish
## 105 180.5775 135.78774 225.3672  2.626828 Removal_of_some_fish
## 106 180.8052 136.80274 224.8077  2.960903 Removal_of_some_fish
## 107 181.0329 137.81263 224.2532  3.294977 Removal_of_some_fish
## 108 181.2606 138.81713 223.7041  3.629052 Removal_of_some_fish
## 109 181.4883 139.81594 223.1607  3.963127 Removal_of_some_fish
## 110 181.7160 140.80873 222.6233  4.297201 Removal_of_some_fish
## 111 181.9438 141.79517 222.0923  4.631276 Removal_of_some_fish
## 112 182.1715 142.77487 221.5680  4.965351 Removal_of_some_fish
## 113 182.3992 143.74746 221.0509  5.299425 Removal_of_some_fish
## 114 182.6269 144.71251 220.5413  5.633500 Removal_of_some_fish
## 115 182.8546 145.66956 220.0396  5.967575 Removal_of_some_fish
## 116 183.0823 146.61816 219.5464  6.301649 Removal_of_some_fish
## 117 183.3100 147.55777 219.0622  6.635724 Removal_of_some_fish
## 118 183.5377 148.48786 218.5876  6.969799 Removal_of_some_fish
## 119 183.7654 149.40783 218.1230  7.303873 Removal_of_some_fish
```

```
## 120 183.9931 150.31707 217.6692  7.637948 Removal_of_some_fish
## 121 184.2208 151.21492 217.2268  7.972023 Removal_of_some_fish
## 122 184.4486 152.10065 216.7965  8.306097 Removal_of_some_fish
## 123 184.6763 152.97352 216.3790  8.640172 Removal_of_some_fish
## 124 184.9040 153.83274 215.9752  8.974247 Removal_of_some_fish
## 125 185.1317 154.67743 215.5859  9.308321 Removal_of_some_fish
## 126 185.3594 155.50672 215.2121  9.642396 Removal_of_some_fish
## 127 185.5871 156.31964 214.8546  9.976471 Removal_of_some_fish
## 128 185.8148 157.11520 214.5144 10.310545 Removal_of_some_fish
## 129 186.0425 157.89235 214.1927 10.644620 Removal_of_some_fish
## 130 186.2702 158.64998 213.8905 10.978695 Removal_of_some_fish
## 131 186.4979 159.38695 213.6089 11.312770 Removal_of_some_fish
## 132 186.7257 160.10208 213.3492 11.646844 Removal_of_some_fish
## 133 186.9534 160.79415 213.1126 11.980919 Removal_of_some_fish
## 134 187.1811 161.46190 212.9002 12.314994 Removal_of_some_fish
## 135 187.4088 162.10407 212.7135 12.649068 Removal_of_some_fish
## 136 187.6365 162.71938 212.5536 12.983143 Removal_of_some_fish
## 137 187.8642 163.30657 212.4218 13.317218 Removal_of_some_fish
## 138 188.0919 163.86436 212.3195 13.651292 Removal_of_some_fish
## 139 188.3196 164.39156 212.2477 13.985367 Removal_of_some_fish
## 140 188.5473 164.88700 212.2077 14.319442 Removal_of_some_fish
## 141 188.7750 165.34959 212.2005 14.653516 Removal_of_some_fish
## 142 189.0028 165.77834 212.2272 14.987591 Removal_of_some_fish
## 143 189.2305 166.17235 212.2886 15.321666 Removal_of_some_fish
## 144 189.4582 166.53087 212.3855 15.655740 Removal_of_some_fish
## 145 189.6859 166.85330 212.5185 15.989815 Removal_of_some_fish
## 146 189.9136 167.13918 212.6880 16.323890 Removal_of_some_fish
## 147 190.1413 167.38823 212.8944 16.657964 Removal_of_some_fish
## 148 190.3690 167.60035 213.1377 16.992039 Removal_of_some_fish
## 149 190.5967 167.77561 213.4178 17.326114 Removal_of_some_fish
## 150 190.8244 167.91427 213.7346 17.660188 Removal_of_some_fish
## 151 191.0521 168.01675 214.0875 17.994263 Removal_of_some_fish
## 152 191.2798 168.08364 214.4761 18.328338 Removal_of_some_fish
## 153 191.5076 168.11567 214.8994 18.662412 Removal_of_some_fish
## 154 191.7353 168.11371 215.3568 18.996487 Removal_of_some_fish
## 155 191.9630 168.07874 215.8472 19.330562 Removal_of_some_fish
## 156 192.1907 168.01183 216.3695 19.664636 Removal_of_some_fish
## 157 192.4184 167.91414 216.9227 19.998711 Removal_of_some_fish
## 158 192.6461 167.78688 217.5053 20.332786 Removal_of_some_fish
## 159 192.8738 167.63128 218.1164 20.666860 Removal_of_some_fish
## 160 193.1015 167.44863 218.7544 21.000935 Removal_of_some_fish
## 161 193.3292 167.24020 219.4183 21.335010 Removal_of_some_fish
## 162 193.5569 167.00726 220.1066 21.669084 Removal_of_some_fish
## 163 193.7847 166.75106 220.8183 22.003159 Removal_of_some_fish
## 164 194.0124 166.47283 221.5519 22.337234 Removal_of_some_fish
## 165 194.2401 166.17376 222.3064 22.671308 Removal_of_some_fish
## 166 194.4678 165.85500 223.0806 23.005383 Removal_of_some_fish
## 167 194.6955 165.51766 223.8733 23.339458 Removal_of_some_fish
## 168 194.9232 165.16279 224.6836 23.673533 Removal_of_some_fish
## 169 195.1509 164.79141 225.5104 24.007607 Removal_of_some_fish
```

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## 170 195.3786 164.40447 226.3528 24.341682 Removal_of_some_fish
## 171 195.6063 164.00288 227.2098 24.675757 Removal_of_some_fish
## 172 195.8340 163.58750 228.0806 25.009831 Removal_of_some_fish
## 173 196.0618 163.15914 228.9644 25.343906 Removal_of_some_fish
## 174 196.2895 162.71855 229.8604 25.677981 Removal_of_some_fish
## 175 196.5172 162.26646 230.7679 26.012055 Removal_of_some_fish
## 176 196.7449 161.80354 231.6862 26.346130 Removal_of_some_fish
## 177 196.9726 161.33040 232.6148 26.680205 Removal_of_some_fish
## 178 197.2003 160.84766 233.5529 27.014279 Removal_of_some_fish
## 179 197.4280 160.35585 234.5002 27.348354 Removal_of_some_fish
## 180 197.6557 159.85550 235.4559 27.682429 Removal_of_some_fish
## 181 197.8834 159.34708 236.4198 28.016503 Removal_of_some_fish
## 182 198.1111 158.83106 237.3912 28.350578 Removal_of_some_fish
## 183 198.3388 158.30786 238.3698 28.684653 Removal_of_some_fish
## 184 198.5666 157.77787 239.3552 29.018727 Removal_of_some_fish
## 185 198.7943 157.24146 240.3471 29.352802 Removal_of_some_fish
## 186 199.0220 156.69899 241.3450 29.686877 Removal_of_some_fish
## 187 199.2497 156.15078 242.3486 30.020951 Removal_of_some_fish
## 188 199.4774 155.59712 243.3577 30.355026 Removal_of_some_fish
## 189 199.7051 155.03832 244.3719 30.689101 Removal_of_some_fish
## 190 199.9328 154.47463 245.3910 31.023175 Removal_of_some_fish
## 191 200.1605 153.90630 246.4148 31.357250 Removal_of_some_fish
## 192 200.3882 153.33358 247.4429 31.691325 Removal_of_some_fish
## 193 200.6159 152.75667 248.4752 32.025399 Removal_of_some_fish
## 194 200.8437 152.17580 249.5115 32.359474 Removal_of_some_fish
## 195 201.0714 151.59115 250.5516 32.693549 Removal_of_some_fish
## 196 201.2991 151.00291 251.5952 33.027623 Removal_of_some_fish
## 197 201.5268 150.41124 252.6423 33.361698 Removal_of_some_fish
## 198 201.7545 149.81632 253.6927 33.695773 Removal_of_some_fish
## 199 201.9822 149.21829 254.7461 34.029847 Removal_of_some_fish
## 200 202.2099 148.61729 255.8025 34.363922 Removal_of_some_fish
```

Part (d)

To study the effect of fish removal on plankton density excluding the effect of phosphorus levels, we use **two-sample t-test** here.

```
#effect of fish removal on plankton density - two-sample t-test

plot(plank~treat, data=plankton)
```
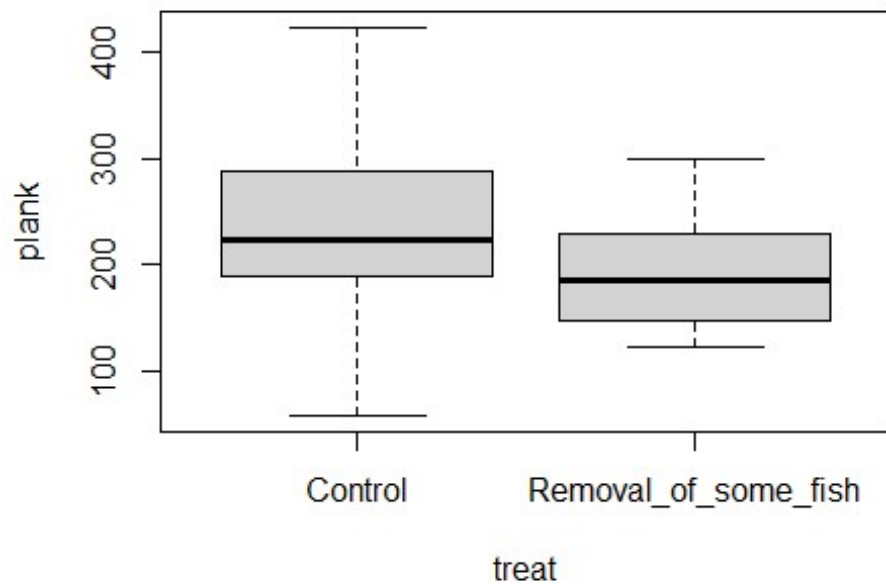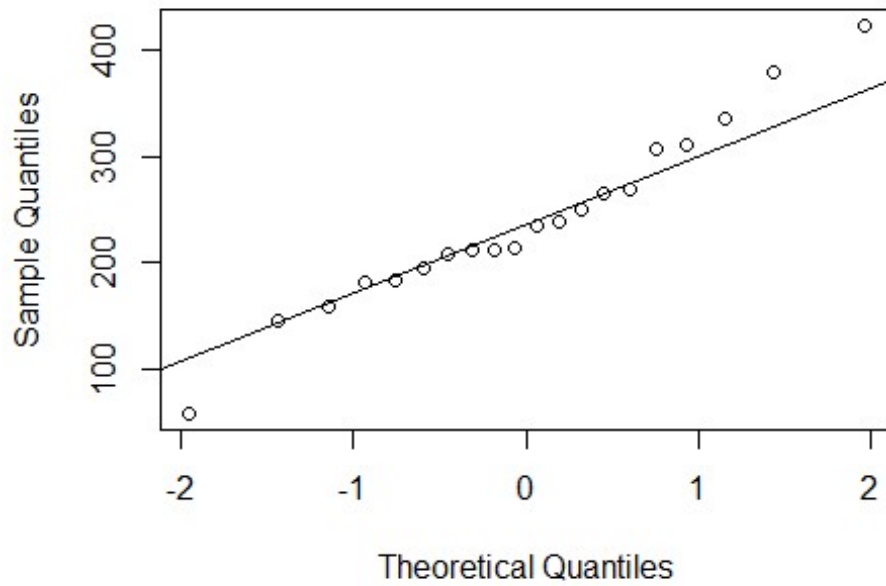
```
#t-test assumptions

#assumption 1: independent observations
#assumed to be true

#assumption 2: continuous data and normally distributed within group

control <- subset(plankton, treat=='Control')
fish_rem <- subset(plankton, treat=='Removal_of_some_fish')
qqnorm(control$plank)
qqline(control$plank)
```
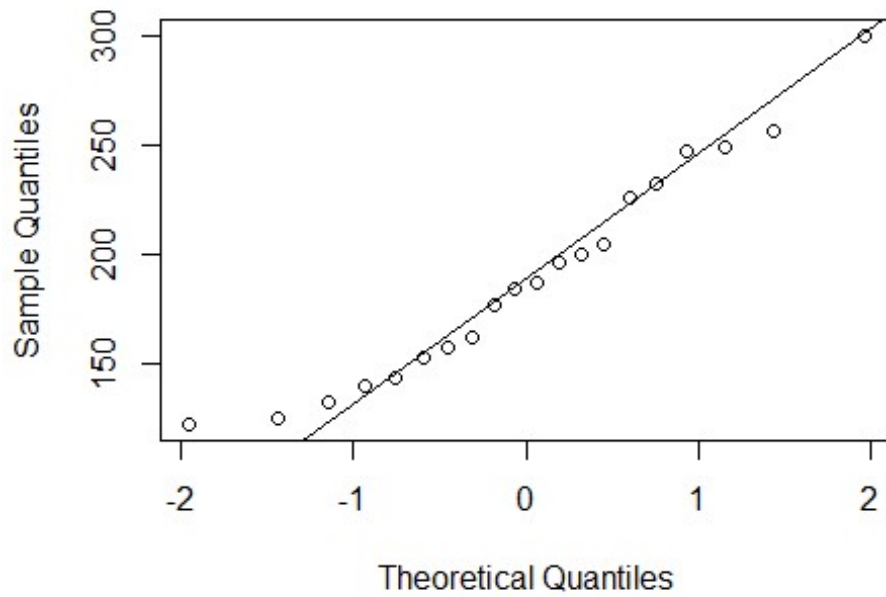
Normal Q-Q Plot


```
qqnorm(fish_rem$plank)
qqline(fish_rem$plank)
```

Normal Q-Q Plot

```
shapiro.test(control$plank)

##
##  Shapiro-Wilk normality test
##
## data:  control$plank
## W = 0.97348, p-value = 0.8259

shapiro.test(fish_rem$plank)

##
##  Shapiro-Wilk normality test
##
## data:  fish_rem$plank
## W = 0.95396, p-value = 0.4313
```

#normally distributed

```
leveneTest(plank~treat, data=plankton)

## Levene's Test for Homogeneity of Variance (center = median)
##       Df F value Pr(>F)
## group  1  2.4535 0.1256
##       38
```

#variances are not significantly different

```
t.test(plank~treat, data=plankton, var.equal=TRUE)

##
##  Two Sample t-test
##
## data:  plank by treat
## t = 2.2472, df = 38, p-value = 0.03051
## alternative hypothesis: true difference in means between group Control and
group Removal_of_some_fish is not equal to 0
## 95 percent confidence interval:
##    4.864117 93.254297
## sample estimates:
##             mean in group Control mean in group Removal_of_some_fish
##                          239.2182                           190.1590
```

There is a statistically significant difference between plankton density observed in the control lakes and the treated lakes.

Thus, the effect of fish removal on plankton density seems significant when the phosphorus levels in the different lakes are not taken into consideration.