Scripps's Murrelet Egg Size model

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#TODO - Calculate confidence intervals - Prediction

Introduction

This document details steps taken to model Scripps's Murrelet (*Synthliboramphus scrippsi*) egg size at Santa Barbara Island within Channel Islands National Park from 2009-2017.

Load and format data

```
egg <- read_csv(here("data", "SCMU_egg_data.csv"))
```

```
## Warning: Missing column names filled in: 'X1' [1]
```

```
##
## -- Column specification --------------------------------------------------------
## cols(
##   X1 = col_double(),
##   ID = col_character(),
##   Year = col_double(),
##   ObservationDate = col_date(format = ""),
##   Observer = col_character(),
##   Plot = col_character(),
##   NestNumber = col_character(),
##   NestContents = col_character(),
##   EggOrderKnown = col_character(),
##   TrueOrder = col_logical(),
##   EggOrder = col_character(),
##   EggState = col_character(),
##   Length = col_double(),
##   Width = col_double(),
##   Size = col_double(),
##   CommentList = col_character(),
##   AdditionalComments = col_character()
## )
```

```
covars <- read_csv(here("data", "covariates", "covars.csv"))
```

```
## Warning: Missing column names filled in: 'X1' [1]
```

```
##
## -- Column specification --------------------------------------------------------
```

```
## cols(
##   X1 = col_double(),
##   Year = col_double(),
##   ANCHL = col_double(),
##   BEUTI = col_double(),
##   NPGO = col_double(),
##   ONI = col_double(),
##   PDO = col_double(),
##   SST = col_double()
## )
```

```
## join covariate data with egg data by year
df <- left_join(egg, covars, by = "Year") %>%
  filter(TrueOrder == TRUE) %>% # egg order known only
  select(Year, Observer, Plot, Size, EggOrder, ANCHL, BEUTI, NPGO, ONI, PDO, SST)
```

Null Intercept-Only Model

This model includes observer and plot as random effects, but does not include any covariates.

```
## run model
nm <- lmer(Size ~ 1 + (1 | Observer) + (1 | Plot), data = df)

## look at model output and estimates
sumary(nm)
```

```
## Fixed Effects:
## coef.est  coef.se
##  1884.29    12.20
##
## Random Effects:
##  Groups   Name        Std.Dev.
##  Observer (Intercept)  17.22
##  Plot     (Intercept)  24.49
##  Residual             111.96
## ---
## number of obs: 753, groups: Observer, 27; Plot, 8
## AIC = 9263.1, DIC = 9268.5
## deviance = 9261.8
```

```
coef(nm) # these are the coefficients
```

```
## $Observer
##     (Intercept)
## AAY    1899.553
## AJB    1880.127
## AJD    1895.666
## AML    1886.089
## CAC    1876.699
## CEH    1880.914
## CEK    1880.307
## CLE    1879.914
## DLW    1874.348
## EWW    1891.898
## GRK    1882.978
```

```
## JAH    1902.680
## KMR    1885.299
## KWB    1880.009
## LAH    1883.315
## MEJ    1878.435
## MGB    1886.816
## NAG    1869.396
## PTL    1876.981
## RER    1893.489
## REW    1881.330
## SAA    1887.456
## SFC    1885.064
## SJK    1893.394
## SKT    1862.709
## SLA    1884.647
## SMC    1896.380
##
## $Plot
##      (Intercept)
## APNC    1905.622
## BH      1898.588
## BT      1850.797
## CC      1903.414
## DO      1885.298
## ESC     1882.827
## LC      1873.535
## WC      1874.258
##
## attr(,"class")
## [1] "coef.mer"
```

```
ranef(nm) # these are the random effects
```

```
## $Observer
##     (Intercept)
## AAY  15.2610062
## AJB  -4.1654786
## AJD  11.3739567
## AML   1.7970244
## CAC  -7.5934214
## CEH  -3.3784652
## CEK  -3.9853109
## CLE  -4.3779272
## DLW  -9.9445690
## EWW   7.6052536
## GRK  -1.3144290
## JAH  18.3876524
## KMR   1.0067101
## KWB  -4.2835217
## LAH  -0.9770916
## MEJ  -5.8572070
## MGB   2.5241208
## NAG -14.8959509
## PTL  -7.3117215
## RER   9.1963408
```

```
## REW  -2.9625711
## SAA   3.1632622
## SFC   0.7713125
## SJK   9.1015277
## SKT -21.5831481
## SLA   0.3551011
## SMC  12.0875447
##
## $Plot
##      (Intercept)
## APNC   21.329246
## BH     14.295406
## BT    -33.494909
## CC     19.121674
## DO      1.005254
## ESC    -1.464948
## LC    -10.757089
## WC    -10.034635
##
## with conditional variances for "Observer" "Plot"
```

```r
## you can store the model results to objects
obs.ranef <- ranef(nm)$Observer
plot.ranef <- ranef(nm)$Plot
## the mean of these values should be close to 0
mean(obs.ranef[[1]])
```

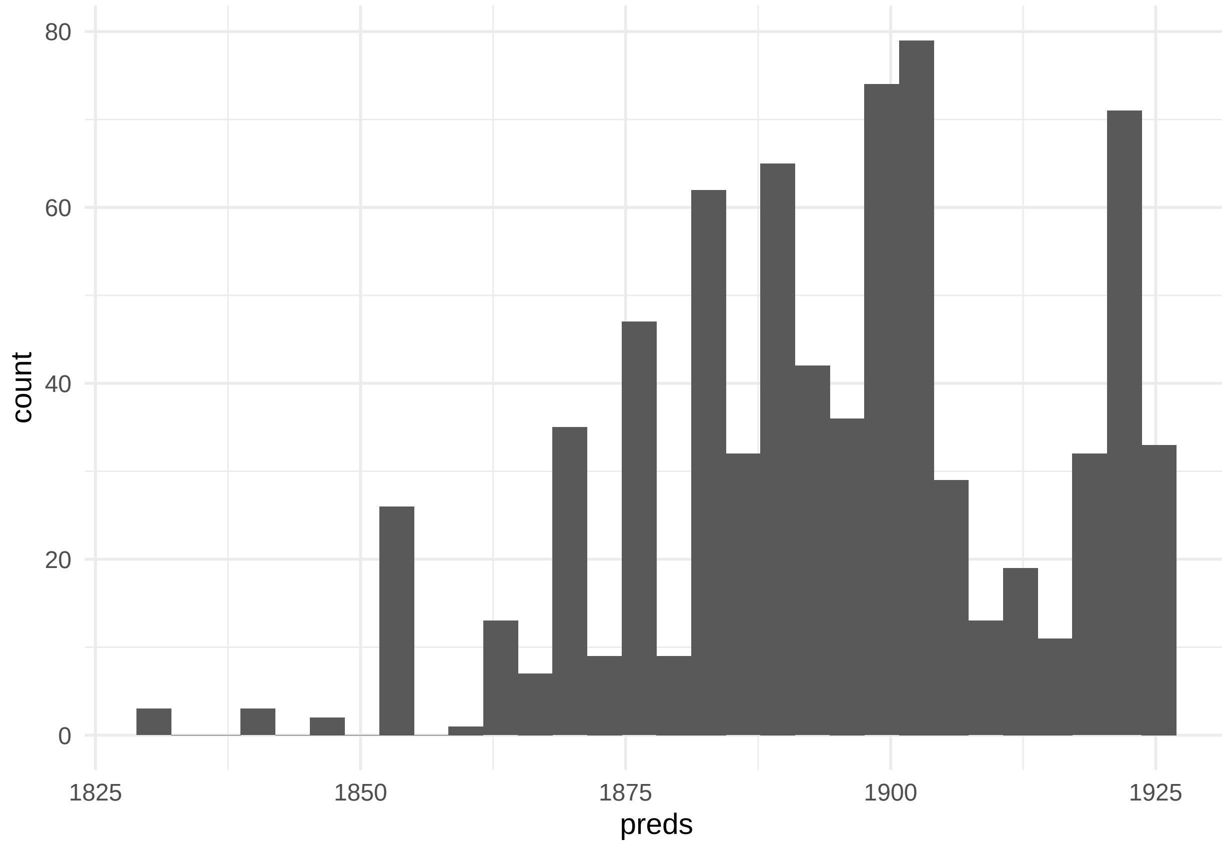
```
## [1] 3.494283e-13
```

```r
mean(plot.ranef[[1]])
```

```
## [1] -7.280149e-12
```

```r
## quick model diagnostics
## extract predicted values and plot
preds <- predict(nm)
ggplot() +
  geom_histogram(mapping = aes(preds)) +
  theme_minimal()
```

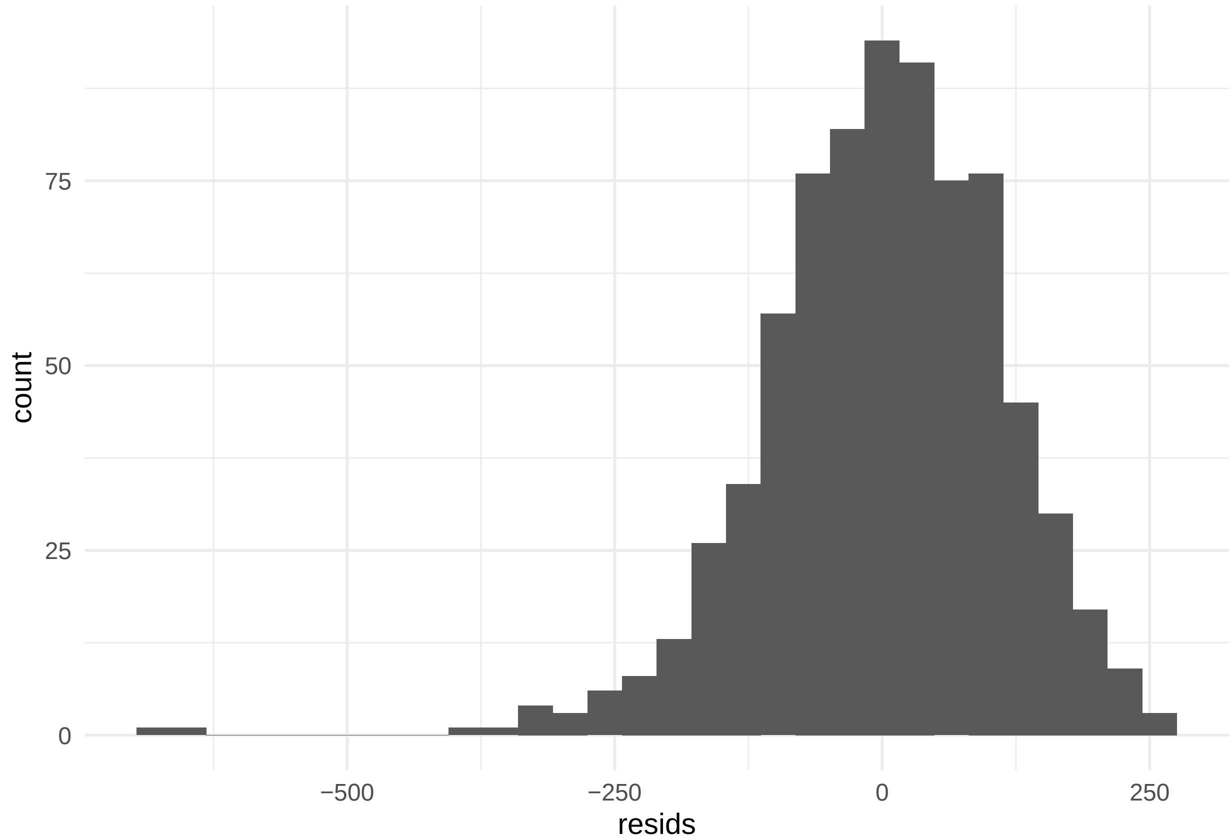
```
## `stat_bin()` using `bins = 30`. Pick better value with `binwidth`.
```




```
# we want these to look normally distributed

## extract residuals and plot
resids <- residuals(nm)
ggplot() +
  geom_histogram(mapping = aes(resids)) +
  theme_minimal()
```

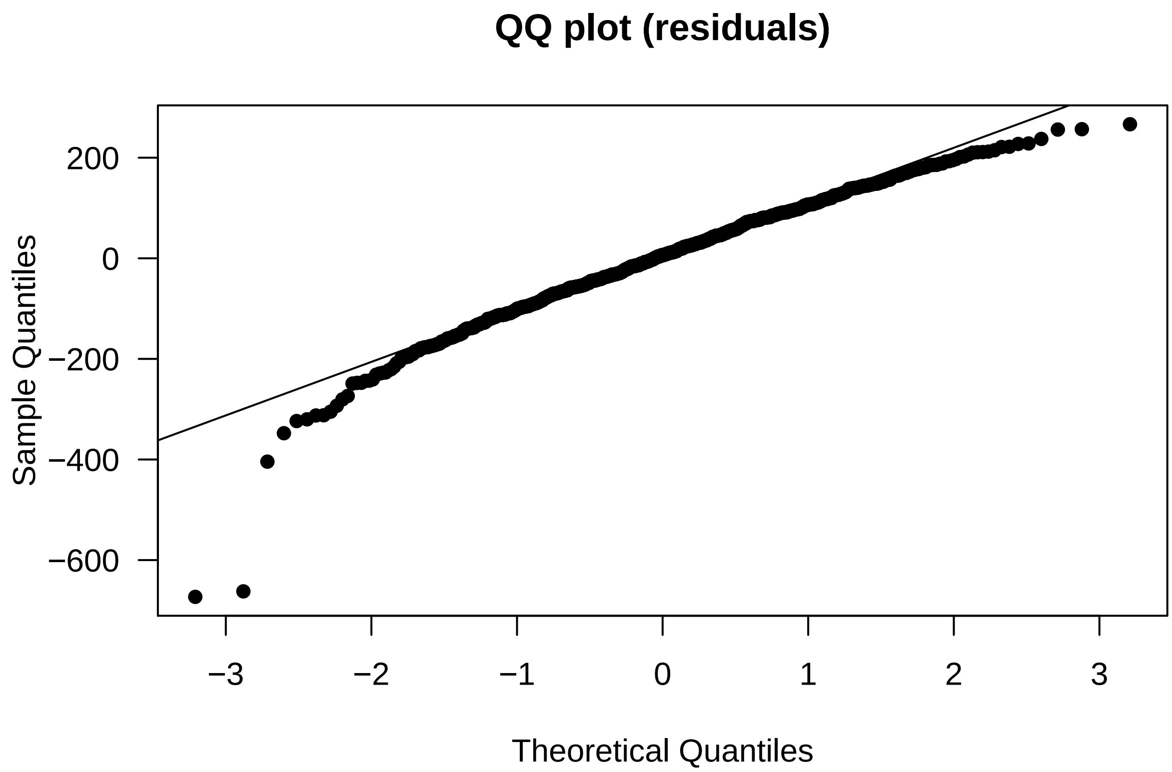
```
## `stat_bin()` using `bins = 30`. Pick better value with `binwidth`.
```



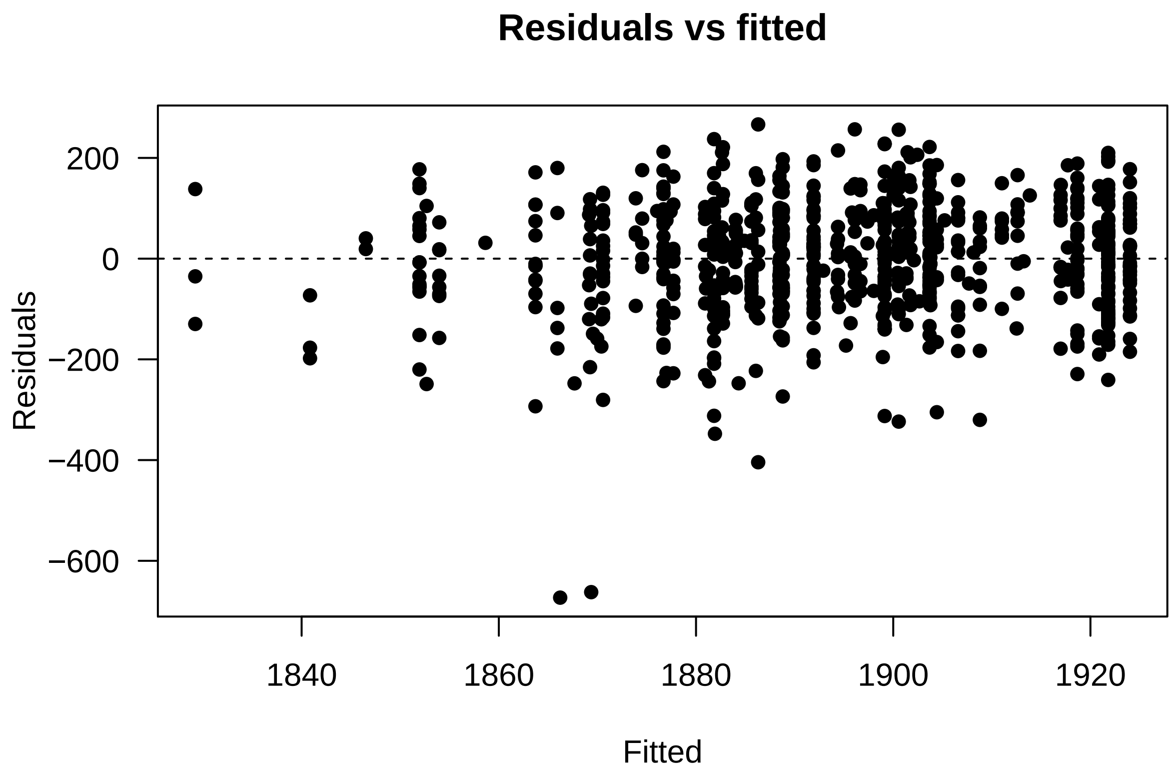

```
# we want these to look normally distributed

## Q-Q Plots
# ## set plot area
# par(mai = c(0.9, 0.9, 0.6, 0.1),
#     omi = c(0, 0, 0, 0),
#     mfrow = c(1,2), cex.lab = 1.2)

# qq resids
qqnorm(resids, main = "QQ plot (residuals)", las = 1, pch = 16)
qqline(resids)
```




```r
## plot residuals versus fitted values
yh <- fitted(nm)
plot(yh, resids, las = 1, pch = 16,
     xlab = "Fitted", ylab = "Residuals",
     main = "Residuals vs fitted")
abline(h=0, lty = "dashed")
```



Egg Order-only Model

This model includes observer and plot as random effects and egg order as a fixed effect.

```
## run the model
order.mod <- lmer(Size ~ EggOrder + (1 | Observer) + (1 | Plot), data = df)

## look at model summary and estimates
sumary(order.mod)
```

```
## Fixed Effects:
##              coef.est coef.se
## (Intercept)  1877.38    12.31
## EggOrderEgg2   31.04    10.14
##
## Random Effects:
##  Groups   Name        Std.Dev.
##  Observer (Intercept)  18.15
##  Plot     (Intercept)  24.02
##  Residual             111.29
## ---
## number of obs: 753, groups: Observer, 27; Plot, 8
## AIC = 9249.3, DIC = 9265.6
## deviance = 9252.5
```

```r
coef(summary(order.mod))
```

```
##                Estimate Std. Error    t value
## (Intercept)  1877.38022   12.31228 152.480334
## EggOrderEgg2   31.03979   10.13834   3.061624
```

```r
VarCorr(order.mod)
```

```
##  Groups   Name        Std.Dev.
##  Observer (Intercept)  18.149
##  Plot     (Intercept)  24.018
##  Residual             111.286
```

```r
ranef(order.mod)
```

```
## $Observer
##     (Intercept)
## AAY  16.3995440
## AJB  -3.8561645
## AJD  13.2643062
## AML   1.3889281
## CAC  -8.9415957
## CEH  -5.3878571
## CEK  -3.9207379
## CLE  -5.8069434
## DLW -10.7080014
## EWW   7.0226116
## GRK  -1.3811942
## JAH  20.0523198
## KMR   1.1207978
## KWB  -3.7789003
## LAH  -0.7457820
## MEJ  -6.3933777
## MGB   2.3718992
## NAG -15.5908573
## PTL  -7.8956364
## RER   8.7443717
## REW  -2.6758168
## SAA   4.2279036
## SFC   1.6627498
## SJK  10.2403593
## SKT -23.7215706
## SLA   0.7036607
## SMC  13.6049837
##
## $Plot
##      (Intercept)
## APNC   21.808429
## BH     12.045434
## BT    -32.536067
## CC     19.167373
## DO      1.045153
## ESC    -1.099696
## LC    -10.595856
## WC     -9.834771
```

```
##
## with conditional variances for "Observer" "Plot"
```

Fit Candidate Models

```r
## create data frame specifying predictors to include
predictors <- as.data.frame(matrix(c(FALSE, TRUE), 2, 7)) # 7 potential predictors (includes EggOrder)

## add column names
cov_names <- colnames(predictors) <- colnames(df[,5:11])

## create set of all possible combinations
full_set <- expand.grid(predictors) # 128 combinations

## select models with correlated predictors
ii <- which(full_set$ANCHL + full_set$NPGO == 2 |
              full_set$BEUTI + full_set$PDO == 2 |
              full_set$NPGO + full_set$SST == 2 |
              full_set$ONI + full_set$PDO == 2 |
              full_set$ONI + full_set$SST == 2 |
              full_set$PDO + full_set$SST == 2 ) # 90 models

## create reduced set of models and convert to a matrix for easier indexing
use_set <- as.matrix(full_set[-ii,]) # 38 models

## number of models in set
(n_mods <- nrow(use_set)) # 38 models out of potential 64
```

```
## [1] 38
```

```r
## create empty matrix for storing results
mod_res <- matrix(NA, n_mods, 2)
colnames(mod_res) <- c("AIC", "BIC")

## fit models and store AIC & BIC
for(i in 1:n_mods) {
  if(i == 1) {
    fmla <- "Size ~ 1 + (1 | Observer) + (1 | Plot)"
  } else {
    fmla <- paste("Size ~ (1 | Observer) + (1 | Plot) +", paste(cov_names[use_set[i,]], collapse = " +
  }
  mod_fit <- lmer(as.formula(fmla), data = df)
  mod_res[i,"AIC"] <- AIC(mod_fit)
  mod_res[i,"BIC"] <- BIC(mod_fit)
}

## create empty matrix for storing results
delta_res <- matrix(NA, n_mods, 2)
colnames(delta_res) <- c("deltaAIC", "deltaBIC")

## convert IC to deltaIC
delta_res[,"deltaAIC"] <- mod_res[,"AIC"] - min(mod_res[,"AIC"])
delta_res[,"deltaBIC"] <- mod_res[,"BIC"] - min(mod_res[,"BIC"])
(delta_res <- round(delta_res, 2)) # round results
```

```
##       deltaAIC deltaBIC
##  [1,]    34.73    17.22
##  [2,]    20.95     8.07
##  [3,]    26.11    13.22
##  [4,]    12.95     4.68
##  [5,]    31.68    18.79
##  [6,]    17.88     9.62
##  [7,]    17.06     8.80
##  [8,]     4.26     0.62
##  [9,]    23.16    10.27
## [10,]     9.80     1.54
## [11,]    16.92     8.65
## [12,]     3.64     0.00
## [13,]    30.68    17.79
## [14,]    16.54     8.28
## [15,]    19.31    11.04
## [16,]     5.78     2.13
## [17,]    27.17    18.90
## [18,]    12.96     9.32
## [19,]    13.18     9.54
## [20,]     0.10     1.08
## [21,]    19.84    11.57
## [22,]     6.26     2.62
## [23,]    13.10     9.45
## [24,]     0.00     0.98
## [25,]    31.49    18.60
## [26,]    17.68     9.41
## [27,]    19.83    11.57
## [28,]     6.54     2.90
## [29,]    19.66    11.39
## [30,]     6.19     2.55
## [31,]    30.95    18.06
## [32,]    17.35     9.09
## [33,]    21.80    13.54
## [34,]     8.55     4.91
## [35,]    27.00    18.74
## [36,]    13.50     9.86
## [37,]    13.23     9.59
## [38,]     0.37     1.36
```

```r
## create df with mod results
mp <- as.data.frame(use_set)

for (i in 1:length(mp)) {
   mp[[i]] <- str_replace(mp[[i]], "TRUE", colnames(mp)[i])
}

for (i in 1:length(mp)) {
   mp[[i]] <- str_replace(mp[[i]], "FALSE", " ")
}

mpfe <- mp %>%
  mutate(FEs = paste(EggOrder, ANCHL, BEUTI, NPGO, ONI, PDO, SST, sep = " "))
```

```r
usmr <- mpfe %>%
  mutate(k = as.vector(rowSums(use_set) + 2)) %>% #2 check this
  mutate(modelno = 1:38)

allm <- as.data.frame(delta_res) %>%
  mutate(modelno = 1:38) %>%
  arrange(deltaAIC) %>%
  left_join(usmr, by = "modelno") %>%
  dplyr::select(modelno, FEs, k, deltaAIC, deltaBIC)

## create df with top models
bestm <- allm %>%
  filter(deltaAIC <= 2)
```

There are three competitive models. All three models include EggOrder and BEUTI as a predictor.

Top Models

Here we look at the top three competitive models.

First Top Model

```r
##run model
bm1 <- lmer(Size ~ EggOrder + BEUTI + NPGO + ONI + (1 | Observer) + (1 | Plot), data = df)
## look at model output and estimates
summary(bm1)
```

```
## Linear mixed model fit by REML ['lmerMod']
## Formula: Size ~ EggOrder + BEUTI + NPGO + ONI + (1 | Observer) + (1 |
##     Plot)
##    Data: df
##
## REML criterion at convergence: 9212.3
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -6.2281 -0.5687  0.0450  0.6626  2.3189
##
## Random effects:
##  Groups   Name        Variance Std.Dev.
##  Observer (Intercept)   132.2   11.50
##  Plot     (Intercept)   349.9   18.71
##  Residual             12365.8  111.20
## Number of obs: 753, groups:  Observer, 27; Plot, 8
##
## Fixed effects:
##              Estimate Std. Error t value
## (Intercept)  1889.549     10.362 182.358
## EggOrderEgg2   29.910     10.123   2.955
## BEUTI          11.104      6.859   1.619
## NPGO          -22.759      6.732  -3.381
## ONI             2.972      5.913   0.503
##
```

```
## Correlation of Fixed Effects:
##              (Intr) EggOE2 BEUTI  NPGO
## EggOrdrEgg2 -0.218
## BEUTI        0.146 -0.042
## NPGO        -0.252  0.031 -0.597
## ONI          0.109 -0.052  0.700 -0.457
```

```
coef(bm1)
```

```
## $Observer
##     (Intercept) EggOrderEgg2   BEUTI      NPGO      ONI
## AAY    1898.226     29.90976 11.1043 -22.75851 2.971758
## AJB    1887.490     29.90976 11.1043 -22.75851 2.971758
## AJD    1893.335     29.90976 11.1043 -22.75851 2.971758
## AML    1889.849     29.90976 11.1043 -22.75851 2.971758
## CAC    1882.309     29.90976 11.1043 -22.75851 2.971758
## CEH    1886.834     29.90976 11.1043 -22.75851 2.971758
## CEK    1888.526     29.90976 11.1043 -22.75851 2.971758
## CLE    1885.842     29.90976 11.1043 -22.75851 2.971758
## DLW    1886.151     29.90976 11.1043 -22.75851 2.971758
## EWW    1890.804     29.90976 11.1043 -22.75851 2.971758
## GRK    1888.900     29.90976 11.1043 -22.75851 2.971758
## JAH    1894.719     29.90976 11.1043 -22.75851 2.971758
## KMR    1890.363     29.90976 11.1043 -22.75851 2.971758
## KWB    1893.889     29.90976 11.1043 -22.75851 2.971758
## LAH    1889.444     29.90976 11.1043 -22.75851 2.971758
## MEJ    1887.006     29.90976 11.1043 -22.75851 2.971758
## MGB    1890.467     29.90976 11.1043 -22.75851 2.971758
## NAG    1885.550     29.90976 11.1043 -22.75851 2.971758
## PTL    1885.434     29.90976 11.1043 -22.75851 2.971758
## RER    1891.692     29.90976 11.1043 -22.75851 2.971758
## REW    1887.998     29.90976 11.1043 -22.75851 2.971758
## SAA    1900.548     29.90976 11.1043 -22.75851 2.971758
## SFC    1889.011     29.90976 11.1043 -22.75851 2.971758
## SJK    1893.045     29.90976 11.1043 -22.75851 2.971758
## SKT    1879.078     29.90976 11.1043 -22.75851 2.971758
## SLA    1890.326     29.90976 11.1043 -22.75851 2.971758
## SMC    1890.980     29.90976 11.1043 -22.75851 2.971758
##
## $Plot
##      (Intercept) EggOrderEgg2   BEUTI      NPGO      ONI
## APNC    1906.937     29.90976 11.1043 -22.75851 2.971758
## BH      1899.167     29.90976 11.1043 -22.75851 2.971758
## BT      1870.282     29.90976 11.1043 -22.75851 2.971758
## CC      1904.589     29.90976 11.1043 -22.75851 2.971758
## DO      1884.902     29.90976 11.1043 -22.75851 2.971758
## ESC     1888.654     29.90976 11.1043 -22.75851 2.971758
## LC      1877.422     29.90976 11.1043 -22.75851 2.971758
## WC      1884.437     29.90976 11.1043 -22.75851 2.971758
##
## attr(,"class")
## [1] "coef.mer"
```

```
ranef(bm1)
```

```
## $Observer
```

```
##     (Intercept)
## AAY   8.6772576
## AJB  -2.0586077
## AJD   3.7860407
## AML   0.3004975
## CAC  -7.2399067
## CEH  -2.7152268
## CEK  -1.0229503
## CLE  -3.7068839
## DLW  -3.3975244
## EWW   1.2556806
## GRK  -0.6489871
## JAH   5.1701353
## KMR   0.8141630
## KWB   4.3404043
## LAH  -0.1049257
## MEJ  -2.5423008
## MGB   0.9181979
## NAG  -3.9985573
## PTL  -4.1146182
## RER   2.1428225
## REW  -1.5503674
## SAA  10.9992085
## SFC  -0.5374726
## SJK   3.4960544
## SKT -10.4707426
## SLA   0.7769067
## SMC   1.4317026
##
## $Plot
##      (Intercept)
## APNC  17.3883993
## BH     9.6185095
## BT   -19.2669360
## CC    15.0399622
## DO    -4.6469222
## ESC   -0.8947288
## LC   -12.1267777
## WC    -5.1115063
##
## with conditional variances for "Observer" "Plot"
```

```
model.matrix(bm1)
```

```
##    (Intercept) EggOrderEgg2      BEUTI      NPGO         ONI
## 1            1            0  0.6675426  0.3555739 -0.61651548
## 2            1            0  0.6675426  0.3555739 -0.61651548
## 3            1            0  0.6675426  0.3555739 -0.61651548
## 4            1            0 -0.1856417  1.5217365  0.71011823
## 5            1            0 -0.1856417  1.5217365  0.71011823
## 6            1            0 -0.1856417  1.5217365  0.71011823
## 7            1            0 -0.1856417  1.5217365  0.71011823
## 8            1            0 -0.1856417  1.5217365  0.71011823
## 9            1            0 -0.1856417  1.5217365  0.71011823
## 10           1            0 -0.1856417  1.5217365  0.71011823
```

```
## 11             1             0 -0.1856417  1.5217365  0.71011823
## 12             1             0 -0.1856417  1.5217365  0.71011823
## 13             1             0 -0.1856417  1.5217365  0.71011823
## 14             1             0 -0.1856417  1.5217365  0.71011823
## 15             1             0 -0.1856417  1.5217365  0.71011823
## 16             1             0 -0.1856417  1.5217365  0.71011823
## 17             1             0 -0.1856417  1.5217365  0.71011823
## 18             1             0 -0.1856417  1.5217365  0.71011823
## 19             1             0 -0.1856417  1.5217365  0.71011823
## 20             1             0 -0.1856417  1.5217365  0.71011823
## 21             1             0 -0.1856417  1.5217365  0.71011823
## 22             1             0 -0.1856417  1.5217365  0.71011823
## 23             1             0 -0.1856417  1.5217365  0.71011823
## 24             1             0 -0.1856417  1.5217365  0.71011823
## 25             1             0 -0.1856417  1.5217365  0.71011823
## 26             1             0 -0.1856417  1.5217365  0.71011823
## 27             1             0 -0.1856417  1.5217365  0.71011823
## 28             1             0 -0.1856417  1.5217365  0.71011823
## 29             1             0 -0.1856417  1.5217365  0.71011823
## 30             1             0 -0.1856417  1.5217365  0.71011823
## 31             1             0 -0.1856417  1.5217365  0.71011823
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## 735             1             1 -0.1902758  0.4783374 -1.35024026
## 736             1             1 -0.1902758  0.4783374 -1.35024026
## 737             1             1 -0.1902758  0.4783374 -1.35024026
## 738             1             1 -0.1902758  0.4783374 -1.35024026
## 739             1             1 -0.1902758  0.4783374 -1.35024026
## 740             1             1 -0.1902758  0.4783374 -1.35024026
## 741             1             1 -0.1902758  0.4783374 -1.35024026
## 742             1             1  0.4290217  0.5034663 -0.77215407
## 743             1             1  0.4290217  0.5034663 -0.77215407
## 744             1             1  0.4290217  0.5034663 -0.77215407
## 745             1             1  0.4290217  0.5034663 -0.77215407
## 746             1             1  0.4290217  0.5034663 -0.77215407
## 747             1             1  0.4290217  0.5034663 -0.77215407
## 748             1             1  0.4290217  0.5034663 -0.77215407
## 749             1             1  0.4290217  0.5034663 -0.77215407
## 750             1             1  0.4290217  0.5034663 -0.77215407
## 751             1             1  0.4290217  0.5034663 -0.77215407
## 752             1             1  0.4290217  0.5034663 -0.77215407
## 753             1             1  0.4290217  0.5034663 -0.77215407
## 754             1             1  0.4290217  0.5034663 -0.77215407
```

```
## 755            1             1  0.4290217  0.5034663 -0.77215407
## 756            1             1  0.4290217  0.5034663 -0.77215407
## 757            1             1  0.4290217  0.5034663 -0.77215407
## 758            1             1  0.4290217  0.5034663 -0.77215407
## 759            1             1  0.4290217  0.5034663 -0.77215407
## 760            1             1  0.4290217  0.5034663 -0.77215407
## 761            1             1  0.4290217  0.5034663 -0.77215407
## 762            1             1  0.4290217  0.5034663 -0.77215407
## 763            1             1  0.4290217  0.5034663 -0.77215407
## 764            1             1  0.4290217  0.5034663 -0.77215407
## 765            1             1  0.4290217  0.5034663 -0.77215407
## 766            1             1  0.4290217  0.5034663 -0.77215407
## 767            1             1  0.4290217  0.5034663 -0.77215407
## 768            1             1  2.1517850  0.8723367 -0.60663366
## 769            1             1  2.1517850  0.8723367 -0.60663366
## 770            1             1  2.1517850  0.8723367 -0.60663366
## 771            1             1  2.1517850  0.8723367 -0.60663366
## 772            1             1  2.1517850  0.8723367 -0.60663366
## 773            1             1  2.1517850  0.8723367 -0.60663366
## 774            1             1  2.1517850  0.8723367 -0.60663366
## 775            1             1  2.1517850  0.8723367 -0.60663366
## 776            1             1  2.1517850  0.8723367 -0.60663366
## 777            1             1  2.1517850  0.8723367 -0.60663366
## 778            1             1  2.1517850  0.8723367 -0.60663366
## 779            1             1  2.1517850  0.8723367 -0.60663366
## 780            1             1  2.1517850  0.8723367 -0.60663366
## 781            1             1  2.1517850  0.8723367 -0.60663366
## 782            1             1  2.1517850  0.8723367 -0.60663366
## 783            1             1  2.1517850  0.8723367 -0.60663366
## 784            1             1  2.1517850  0.8723367 -0.60663366
## 785            1             1  2.1517850  0.8723367 -0.60663366
## 786            1             1  2.1517850  0.8723367 -0.60663366
## 787            1             1  2.1517850  0.8723367 -0.60663366
## 788            1             1  2.1517850  0.8723367 -0.60663366
## 789            1             1 -0.3861161 -1.0216977 -0.22865423
## 790            1             1 -0.3861161 -1.0216977 -0.22865423
## 791            1             1 -0.3861161 -1.0216977 -0.22865423
## 792            1             1 -0.3861161 -1.0216977 -0.22865423
## 793            1             1 -0.3861161 -1.0216977 -0.22865423
## 794            1             1 -0.3861161 -1.0216977 -0.22865423
## 795            1             1 -0.3861161 -1.0216977 -0.22865423
## 796            1             1 -0.3861161 -1.0216977 -0.22865423
## 797            1             1 -0.3861161 -1.0216977 -0.22865423
## 798            1             1 -0.3861161 -1.0216977 -0.22865423
## 799            1             1 -0.3861161 -1.0216977 -0.22865423
## 800            1             1 -0.3861161 -1.0216977 -0.22865423
## 801            1             1 -0.3861161 -1.0216977 -0.22865423
## 802            1             1 -0.3861161 -1.0216977 -0.22865423
## 803            1             1 -0.3861161 -1.0216977 -0.22865423
## 804            1             1 -0.3861161 -1.0216977 -0.22865423
## 805            1             1 -0.3861161 -1.0216977 -0.22865423
## 831            1             1 -1.3133684 -0.1631466  1.79464745
## 832            1             1 -1.3133684 -0.1631466  1.79464745
## 833            1             1 -1.3133684 -0.1631466  1.79464745
```

```
## 834           1             1 -1.3133684 -0.1631466  1.79464745
## 835           1             1 -1.3133684 -0.1631466  1.79464745
## 836           1             1 -1.3133684 -0.1631466  1.79464745
## 837           1             1 -1.3133684 -0.1631466  1.79464745
## 838           1             1 -1.3133684 -0.1631466  1.79464745
## 839           1             1 -1.3133684 -0.1631466  1.79464745
## 840           1             1 -1.3133684 -0.1631466  1.79464745
## 841           1             1 -1.3133684 -0.1631466  1.79464745
## 842           1             1 -1.3133684 -0.1631466  1.79464745
## 843           1             1 -1.3133684 -0.1631466  1.79464745
## 844           1             1 -1.3133684 -0.1631466  1.79464745
## 845           1             1 -1.3133684 -0.1631466  1.79464745
## 846           1             1 -1.3133684 -0.1631466  1.79464745
## 847           1             1 -1.3133684 -0.1631466  1.79464745
## 848           1             1 -1.3133684 -0.1631466  1.79464745
## 849           1             1 -1.3133684 -0.1631466  1.79464745
## 850           1             1 -1.3133684 -0.1631466  1.79464745
## 851           1             1 -1.3133684 -0.1631466  1.79464745
## 852           1             1 -1.3133684 -0.1631466  1.79464745
## 853           1             1 -1.3133684 -0.1631466  1.79464745
## 854           1             1 -1.3133684 -0.1631466  1.79464745
## 855           1             1 -1.3133684 -0.1631466  1.79464745
## 856           1             1 -1.3133684 -0.1631466  1.79464745
## 857           1             1 -1.3133684 -0.1631466  1.79464745
## 858           1             1 -1.3133684 -0.1631466  1.79464745
## 859           1             1 -1.3133684 -0.1631466  1.79464745
## 860           1             1 -1.3133684 -0.1631466  1.79464745
## 861           1             1 -0.8183743 -1.2455211  0.04309569
## 862           1             1 -0.8183743 -1.2455211  0.04309569
## 863           1             1 -0.8183743 -1.2455211  0.04309569
## 864           1             1 -0.8183743 -1.2455211  0.04309569
## 865           1             1 -0.8183743 -1.2455211  0.04309569
## 866           1             1 -0.8183743 -1.2455211  0.04309569
## 867           1             1 -0.8183743 -1.2455211  0.04309569
## 868           1             1 -0.8183743 -1.2455211  0.04309569
## 869           1             1 -0.8183743 -1.2455211  0.04309569
## 870           1             1 -0.8183743 -1.2455211  0.04309569
## 871           1             1 -0.8183743 -1.2455211  0.04309569
## 872           1             1 -0.8183743 -1.2455211  0.04309569
## 873           1             1 -0.8183743 -1.2455211  0.04309569
## 874           1             1 -0.8183743 -1.2455211  0.04309569
## attr(,"assign")
## [1] 0 1 2 3 4
## attr(,"contrasts")
## attr(,"contrasts")$EggOrder
## [1] "contr.treatment"
##
## attr(,"msgScaleX")
## character(0)
```

Second Top Model

```r
##run model
bm2 <- lmer(Size ~ EggOrder + ANCHL + BEUTI + ONI + (1 | Observer) + (1 | Plot), data = df)
```

```r
## look at model output and estimates
summary(bm2)
```

```
## Linear mixed model fit by REML ['lmerMod']
## Formula: Size ~ EggOrder + ANCHL + BEUTI + ONI + (1 | Observer) + (1 |
##     Plot)
##    Data: df
##
## REML criterion at convergence: 9212.4
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -6.2131 -0.5812  0.0618  0.6658  2.3488
##
## Random effects:
##  Groups   Name        Variance Std.Dev.
##  Observer (Intercept)   109.3   10.45
##  Plot     (Intercept)   337.1   18.36
##  Residual             12380.3  111.27
## Number of obs: 753, groups:  Observer, 27; Plot, 8
##
## Fixed effects:
##              Estimate Std. Error t value
## (Intercept)  1884.733      9.882 190.716
## EggOrderEgg2   29.894     10.124   2.953
## ANCHL          22.170      6.378   3.476
## BEUTI           9.546      6.514   1.465
## ONI            -5.347      5.244  -1.020
##
## Correlation of Fixed Effects:
##             (Intr) EggOE2 ANCHL  BEUTI
## EggOrdrEgg2 -0.223
## ANCHL        0.104 -0.026
## BEUTI        0.056 -0.040  0.544
## ONI         -0.004 -0.044  0.033  0.521
```

```r
coef(bm2)
```

```
## $Observer
##     (Intercept) EggOrderEgg2    ANCHL    BEUTI       ONI
## AAY    1893.437      29.8937 22.17002 9.546142 -5.346525
## AJB    1883.313      29.8937 22.17002 9.546142 -5.346525
## AJD    1887.079      29.8937 22.17002 9.546142 -5.346525
## AML    1885.024      29.8937 22.17002 9.546142 -5.346525
## CAC    1879.133      29.8937 22.17002 9.546142 -5.346525
## CEH    1882.567      29.8937 22.17002 9.546142 -5.346525
## CEK    1883.783      29.8937 22.17002 9.546142 -5.346525
## CLE    1881.542      29.8937 22.17002 9.546142 -5.346525
## DLW    1881.590      29.8937 22.17002 9.546142 -5.346525
## EWW    1886.065      29.8937 22.17002 9.546142 -5.346525
## GRK    1884.338      29.8937 22.17002 9.546142 -5.346525
## JAH    1888.808      29.8937 22.17002 9.546142 -5.346525
## KMR    1886.197      29.8937 22.17002 9.546142 -5.346525
## KWB    1887.317      29.8937 22.17002 9.546142 -5.346525
```

```
## LAH    1884.619      29.8937 22.17002 9.546142 -5.346525
## MEJ    1882.600      29.8937 22.17002 9.546142 -5.346525
## MGB    1885.551      29.8937 22.17002 9.546142 -5.346525
## NAG    1880.707      29.8937 22.17002 9.546142 -5.346525
## PTL    1881.487      29.8937 22.17002 9.546142 -5.346525
## RER    1886.401      29.8937 22.17002 9.546142 -5.346525
## REW    1884.001      29.8937 22.17002 9.546142 -5.346525
## SAA    1893.001      29.8937 22.17002 9.546142 -5.346525
## SFC    1884.442      29.8937 22.17002 9.546142 -5.346525
## SJK    1887.579      29.8937 22.17002 9.546142 -5.346525
## SKT    1875.007      29.8937 22.17002 9.546142 -5.346525
## SLA    1885.729      29.8937 22.17002 9.546142 -5.346525
## SMC    1886.473      29.8937 22.17002 9.546142 -5.346525
##
## $Plot
##      (Intercept) EggOrderEgg2    ANCHL    BEUTI       ONI
## APNC    1901.362      29.8937 22.17002 9.546142 -5.346525
## BH      1894.141      29.8937 22.17002 9.546142 -5.346525
## BT      1864.569      29.8937 22.17002 9.546142 -5.346525
## CC      1899.300      29.8937 22.17002 9.546142 -5.346525
## DO      1880.738      29.8937 22.17002 9.546142 -5.346525
## ESC     1883.886      29.8937 22.17002 9.546142 -5.346525
## LC      1874.590      29.8937 22.17002 9.546142 -5.346525
## WC      1879.278      29.8937 22.17002 9.546142 -5.346525
##
## attr(,"class")
## [1] "coef.mer"
```

```
ranef(bm2)
```

```
## $Observer
##     (Intercept)
## AAY   8.7037184
## AJB  -1.4199693
## AJD   2.3463483
## AML   0.2909773
## CAC  -5.6002721
## CEH  -2.1655779
## CEK  -0.9502841
## CLE  -3.1904763
## DLW  -3.1426862
## EWW   1.3322116
## GRK  -0.3949463
## JAH   4.0746183
## KMR   1.4645020
## KWB   2.5836403
## LAH  -0.1143350
## MEJ  -2.1334064
## MGB   0.8175811
## NAG  -4.0257174
## PTL  -3.2458735
## RER   1.6680647
## REW  -0.7319769
## SAA   8.2680905
## SFC  -0.2911164
```

```
## SJK   2.8460718
## SKT  -9.7256778
## SLA   0.9959990
## SMC   1.7404923
##
## $Plot
##      (Intercept)
## APNC  16.6291061
## BH     9.4084040
## BT   -20.1642390
## CC    14.5669458
## DO    -3.9950551
## ESC   -0.8469532
## LC   -10.1427500
## WC    -5.4554586
##
## with conditional variances for "Observer" "Plot"
```

```
model.matrix(bm2)
```

```
##     (Intercept) EggOrderEgg2      ANCHL      BEUTI         ONI
## 1             1            0 -0.4071777  0.6675426 -0.61651548
## 2             1            0 -0.4071777  0.6675426 -0.61651548
## 3             1            0 -0.4071777  0.6675426 -0.61651548
## 4             1            0 -0.8196345 -0.1856417  0.71011823
## 5             1            0 -0.8196345 -0.1856417  0.71011823
## 6             1            0 -0.8196345 -0.1856417  0.71011823
## 7             1            0 -0.8196345 -0.1856417  0.71011823
## 8             1            0 -0.8196345 -0.1856417  0.71011823
## 9             1            0 -0.8196345 -0.1856417  0.71011823
## 10            1            0 -0.8196345 -0.1856417  0.71011823
## 11            1            0 -0.8196345 -0.1856417  0.71011823
## 12            1            0 -0.8196345 -0.1856417  0.71011823
## 13            1            0 -0.8196345 -0.1856417  0.71011823
## 14            1            0 -0.8196345 -0.1856417  0.71011823
## 15            1            0 -0.8196345 -0.1856417  0.71011823
## 16            1            0 -0.8196345 -0.1856417  0.71011823
## 17            1            0 -0.8196345 -0.1856417  0.71011823
## 18            1            0 -0.8196345 -0.1856417  0.71011823
## 19            1            0 -0.8196345 -0.1856417  0.71011823
## 20            1            0 -0.8196345 -0.1856417  0.71011823
## 21            1            0 -0.8196345 -0.1856417  0.71011823
## 22            1            0 -0.8196345 -0.1856417  0.71011823
## 23            1            0 -0.8196345 -0.1856417  0.71011823
## 24            1            0 -0.8196345 -0.1856417  0.71011823
## 25            1            0 -0.8196345 -0.1856417  0.71011823
## 26            1            0 -0.8196345 -0.1856417  0.71011823
## 27            1            0 -0.8196345 -0.1856417  0.71011823
## 28            1            0 -0.8196345 -0.1856417  0.71011823
## 29            1            0 -0.8196345 -0.1856417  0.71011823
## 30            1            0 -0.8196345 -0.1856417  0.71011823
## 31            1            0 -0.8196345 -0.1856417  0.71011823
## 32            1            0 -0.8196345 -0.1856417  0.71011823
## 33            1            0 -0.8196345 -0.1856417  0.71011823
## 34            1            0 -0.8196345 -0.1856417  0.71011823
```

```
## 35                1               0 -0.8196345 -0.1856417  0.71011823
## 36                1               0 -0.8196345 -0.1856417  0.71011823
## 37                1               0 -0.8196345 -0.1856417  0.71011823
## 38                1               0 -0.8196345 -0.1856417  0.71011823
## 39                1               0 -0.8196345 -0.1856417  0.71011823
## 40                1               0 -0.8196345 -0.1856417  0.71011823
## 41                1               0 -0.8196345 -0.1856417  0.71011823
## 42                1               0 -0.8196345 -0.1856417  0.71011823
## 43                1               0 -0.8196345 -0.1856417  0.71011823
## 44                1               0 -0.8196345 -0.1856417  0.71011823
## 45                1               0 -0.8196345 -0.1856417  0.71011823
## 46                1               0 -0.8196345 -0.1856417  0.71011823
## 47                1               0 -0.8196345 -0.1856417  0.71011823
## 48                1               0 -0.8196345 -0.1856417  0.71011823
## 49                1               0 -0.8196345 -0.1856417  0.71011823
## 50                1               0 -0.8196345 -0.1856417  0.71011823
## 51                1               0 -0.8196345 -0.1856417  0.71011823
## 52                1               0 -0.8196345 -0.1856417  0.71011823
## 53                1               0 -0.8196345 -0.1856417  0.71011823
## 54                1               0 -0.8196345 -0.1856417  0.71011823
## 55                1               0 -0.8196345 -0.1856417  0.71011823
## 56                1               0 -0.8196345 -0.1856417  0.71011823
## 57                1               0 -0.8196345 -0.1856417  0.71011823
## 58                1               0 -0.8196345 -0.1856417  0.71011823
## 59                1               0 -0.8196345 -0.1856417  0.71011823
## 60                1               0 -0.8196345 -0.1856417  0.71011823
## 61                1               0 -0.8196345 -0.1856417  0.71011823
## 62                1               0 -0.8196345 -0.1856417  0.71011823
## 63                1               0 -0.8196345 -0.1856417  0.71011823
## 64                1               0 -0.8196345 -0.1856417  0.71011823
## 65                1               0 -0.8196345 -0.1856417  0.71011823
## 66                1               0 -0.8196345 -0.1856417  0.71011823
## 67                1               0 -0.8196345 -0.1856417  0.71011823
## 68                1               0 -0.8196345 -0.1856417  0.71011823
## 69                1               0 -0.8196345 -0.1856417  0.71011823
## 70                1               0 -0.8196345 -0.1856417  0.71011823
## 71                1               0 -0.8196345 -0.1856417  0.71011823
## 72                1               0 -0.8196345 -0.1856417  0.71011823
## 73                1               0 -0.8196345 -0.1856417  0.71011823
## 74                1               0 -0.8196345 -0.1856417  0.71011823
## 75                1               0 -0.8196345 -0.1856417  0.71011823
## 76                1               0 -0.8196345 -0.1856417  0.71011823
## 77                1               0 -0.8196345 -0.1856417  0.71011823
## 78                1               0 -0.8196345 -0.1856417  0.71011823
## 79                1               0 -0.8196345 -0.1856417  0.71011823
## 80                1               0 -0.8196345 -0.1856417  0.71011823
## 81                1               0 -0.8196345 -0.1856417  0.71011823
## 82                1               0 -0.8196345 -0.1856417  0.71011823
## 83                1               0 -0.8196345 -0.1856417  0.71011823
## 84                1               0 -0.8196345 -0.1856417  0.71011823
## 85                1               0 -0.8196345 -0.1856417  0.71011823
## 86                1               0 -0.8196345 -0.1856417  0.71011823
## 87                1               0 -0.8196345 -0.1856417  0.71011823
## 88                1               0 -0.8196345 -0.1856417  0.71011823
```

```
## 89             1             0 -0.8196345 -0.1856417  0.71011823
## 90             1             0 -0.8196345 -0.1856417  0.71011823
## 91             1             0 -0.8196345 -0.1856417  0.71011823
## 92             1             0 -0.8196345 -0.1856417  0.71011823
## 93             1             0 -0.8196345 -0.1856417  0.71011823
## 94             1             0 -0.8196345 -0.1856417  0.71011823
## 95             1             0 -0.8196345 -0.1856417  0.71011823
## 96             1             0 -0.8196345 -0.1856417  0.71011823
## 97             1             0 -0.8196345 -0.1856417  0.71011823
## 98             1             0 -0.8196345 -0.1856417  0.71011823
## 99             1             0 -0.8196345 -0.1856417  0.71011823
## 100            1             0 -0.8196345 -0.1856417  0.71011823
## 101            1             0 -0.8196345 -0.1856417  0.71011823
## 102            1             0 -0.8196345 -0.1856417  0.71011823
## 103            1             0 -0.8196345 -0.1856417  0.71011823
## 104            1             0 -0.8196345 -0.1856417  0.71011823
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## 834           1             1  0.7911322 -1.3133684  1.79464745
## 835           1             1  0.7911322 -1.3133684  1.79464745
## 836           1             1  0.7911322 -1.3133684  1.79464745
## 837           1             1  0.7911322 -1.3133684  1.79464745
## 838           1             1  0.7911322 -1.3133684  1.79464745
## 839           1             1  0.7911322 -1.3133684  1.79464745
## 840           1             1  0.7911322 -1.3133684  1.79464745
## 841           1             1  0.7911322 -1.3133684  1.79464745
## 842           1             1  0.7911322 -1.3133684  1.79464745
## 843           1             1  0.7911322 -1.3133684  1.79464745
## 844           1             1  0.7911322 -1.3133684  1.79464745
## 845           1             1  0.7911322 -1.3133684  1.79464745
## 846           1             1  0.7911322 -1.3133684  1.79464745
## 847           1             1  0.7911322 -1.3133684  1.79464745
## 848           1             1  0.7911322 -1.3133684  1.79464745
## 849           1             1  0.7911322 -1.3133684  1.79464745
## 850           1             1  0.7911322 -1.3133684  1.79464745
## 851           1             1  0.7911322 -1.3133684  1.79464745
## 852           1             1  0.7911322 -1.3133684  1.79464745
## 853           1             1  0.7911322 -1.3133684  1.79464745
## 854           1             1  0.7911322 -1.3133684  1.79464745
## 855           1             1  0.7911322 -1.3133684  1.79464745
## 856           1             1  0.7911322 -1.3133684  1.79464745
## 857           1             1  0.7911322 -1.3133684  1.79464745
```

```
## 858           1            1  0.7911322 -1.3133684  1.79464745
## 859           1            1  0.7911322 -1.3133684  1.79464745
## 860           1            1  0.7911322 -1.3133684  1.79464745
## 861           1            1  1.9637172 -0.8183743  0.04309569
## 862           1            1  1.9637172 -0.8183743  0.04309569
## 863           1            1  1.9637172 -0.8183743  0.04309569
## 864           1            1  1.9637172 -0.8183743  0.04309569
## 865           1            1  1.9637172 -0.8183743  0.04309569
## 866           1            1  1.9637172 -0.8183743  0.04309569
## 867           1            1  1.9637172 -0.8183743  0.04309569
## 868           1            1  1.9637172 -0.8183743  0.04309569
## 869           1            1  1.9637172 -0.8183743  0.04309569
## 870           1            1  1.9637172 -0.8183743  0.04309569
## 871           1            1  1.9637172 -0.8183743  0.04309569
## 872           1            1  1.9637172 -0.8183743  0.04309569
## 873           1            1  1.9637172 -0.8183743  0.04309569
## 874           1            1  1.9637172 -0.8183743  0.04309569
## attr(,"assign")
## [1] 0 1 2 3 4
## attr(,"contrasts")
## attr(,"contrasts")$EggOrder
## [1] "contr.treatment"
##
## attr(,"msgScaleX")
## character(0)
```

Third Top Model

```r
##run model
bm3 <- lmer(Size ~ EggOrder + ANCHL + BEUTI + SST + (1 | Observer) + (1 | Plot), data = df)

## look at model output and estimates
summary(bm3)
```

```
## Linear mixed model fit by REML ['lmerMod']
## Formula: Size ~ EggOrder + ANCHL + BEUTI + SST + (1 | Observer) + (1 |
##     Plot)
##    Data: df
##
## REML criterion at convergence: 9212.7
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -6.2323 -0.5763  0.0686  0.6646  2.3094
##
## Random effects:
##  Groups   Name        Variance Std.Dev.
##  Observer (Intercept)   110.5   10.51
##  Plot     (Intercept)   393.7   19.84
##  Residual             12384.7  111.29
## Number of obs: 753, groups:  Observer, 27; Plot, 8
##
## Fixed effects:
##              Estimate Std. Error t value
```

```
## (Intercept)  1883.766     10.440 180.433
## EggOrderEgg2   29.471     10.117   2.913
## ANCHL          23.916      7.467   3.203
## BEUTI          12.624      5.642   2.237
## SST            -2.913      6.967  -0.418
##
## Correlation of Fixed Effects:
##             (Intr) EggOE2 ANCHL  BEUTI
## EggOrdrEgg2 -0.213
## ANCHL        0.030 -0.016
## BEUTI        0.083 -0.021  0.438
## SST          0.112 -0.009 -0.518  0.162
```

```
coef(bm3)
```

```
## $Observer
##     (Intercept) EggOrderEgg2    ANCHL    BEUTI       SST
## AAY    1891.907     29.47095 23.91574 12.62421 -2.913246
## AJB    1881.994     29.47095 23.91574 12.62421 -2.913246
## AJD    1886.099     29.47095 23.91574 12.62421 -2.913246
## AML    1884.089     29.47095 23.91574 12.62421 -2.913246
## CAC    1878.427     29.47095 23.91574 12.62421 -2.913246
## CEH    1881.634     29.47095 23.91574 12.62421 -2.913246
## CEK    1883.272     29.47095 23.91574 12.62421 -2.913246
## CLE    1880.340     29.47095 23.91574 12.62421 -2.913246
## DLW    1880.529     29.47095 23.91574 12.62421 -2.913246
## EWW    1885.244     29.47095 23.91574 12.62421 -2.913246
## GRK    1883.196     29.47095 23.91574 12.62421 -2.913246
## JAH    1887.207     29.47095 23.91574 12.62421 -2.913246
## KMR    1885.164     29.47095 23.91574 12.62421 -2.913246
## KWB    1887.102     29.47095 23.91574 12.62421 -2.913246
## LAH    1883.771     29.47095 23.91574 12.62421 -2.913246
## MEJ    1881.681     29.47095 23.91574 12.62421 -2.913246
## MGB    1884.529     29.47095 23.91574 12.62421 -2.913246
## NAG    1879.407     29.47095 23.91574 12.62421 -2.913246
## PTL    1880.153     29.47095 23.91574 12.62421 -2.913246
## RER    1885.036     29.47095 23.91574 12.62421 -2.913246
## REW    1883.064     29.47095 23.91574 12.62421 -2.913246
## SAA    1892.769     29.47095 23.91574 12.62421 -2.913246
## SFC    1883.628     29.47095 23.91574 12.62421 -2.913246
## SJK    1886.354     29.47095 23.91574 12.62421 -2.913246
## SKT    1874.150     29.47095 23.91574 12.62421 -2.913246
## SLA    1884.664     29.47095 23.91574 12.62421 -2.913246
## SMC    1886.276     29.47095 23.91574 12.62421 -2.913246
##
## $Plot
##      (Intercept) EggOrderEgg2    ANCHL    BEUTI       SST
## APNC    1901.622     29.47095 23.91574 12.62421 -2.913246
## BH      1894.684     29.47095 23.91574 12.62421 -2.913246
## BT      1860.679     29.47095 23.91574 12.62421 -2.913246
## CC      1899.619     29.47095 23.91574 12.62421 -2.913246
## DO      1880.277     29.47095 23.91574 12.62421 -2.913246
## ESC     1882.730     29.47095 23.91574 12.62421 -2.913246
## LC      1873.241     29.47095 23.91574 12.62421 -2.913246
## WC      1877.278     29.47095 23.91574 12.62421 -2.913246
```

```
##
## attr(,"class")
## [1] "coef.mer"
```

```
ranef(bm3)
```

```
## $Observer
##     (Intercept)
## AAY   8.1408130
## AJB  -1.7723671
## AJD   2.3324821
## AML   0.3233991
## CAC  -5.3388210
## CEH  -2.1322987
## CEK  -0.4945298
## CLE  -3.4259606
## DLW  -3.2368660
## EWW   1.4775362
## GRK  -0.5699635
## JAH   3.4408482
## KMR   1.3975007
## KWB   3.3356245
## LAH   0.0051516
## MEJ  -2.0850697
## MGB   0.7629937
## NAG  -4.3594131
## PTL  -3.6128646
## RER   1.2704058
## REW  -0.7020500
## SAA   9.0024622
## SFC  -0.1381779
## SJK   2.5879189
## SKT  -9.6165109
## SLA   0.8976424
## SMC   2.5101145
##
## $Plot
##      (Intercept)
## APNC   17.855839
## BH     10.917564
## BT    -23.087343
## CC     15.852792
## DO     -3.488970
## ESC    -1.036457
## LC    -10.525551
## WC     -6.487875
##
## with conditional variances for "Observer" "Plot"
```

```
model.matrix(bm3)
```

```
##     (Intercept) EggOrderEgg2      ANCHL      BEUTI        SST
## 1             1            0 -0.4071777  0.6675426 -0.3804073
## 2             1            0 -0.4071777  0.6675426 -0.3804073
## 3             1            0 -0.4071777  0.6675426 -0.3804073
## 4             1            0 -0.8196345 -0.1856417 -0.2808295
```

```
## 5             1             0 -0.8196345 -0.1856417 -0.2808295
## 6             1             0 -0.8196345 -0.1856417 -0.2808295
## 7             1             0 -0.8196345 -0.1856417 -0.2808295
## 8             1             0 -0.8196345 -0.1856417 -0.2808295
## 9             1             0 -0.8196345 -0.1856417 -0.2808295
## 10            1             0 -0.8196345 -0.1856417 -0.2808295
## 11            1             0 -0.8196345 -0.1856417 -0.2808295
## 12            1             0 -0.8196345 -0.1856417 -0.2808295
## 13            1             0 -0.8196345 -0.1856417 -0.2808295
## 14            1             0 -0.8196345 -0.1856417 -0.2808295
## 15            1             0 -0.8196345 -0.1856417 -0.2808295
## 16            1             0 -0.8196345 -0.1856417 -0.2808295
## 17            1             0 -0.8196345 -0.1856417 -0.2808295
## 18            1             0 -0.8196345 -0.1856417 -0.2808295
## 19            1             0 -0.8196345 -0.1856417 -0.2808295
## 20            1             0 -0.8196345 -0.1856417 -0.2808295
## 21            1             0 -0.8196345 -0.1856417 -0.2808295
## 22            1             0 -0.8196345 -0.1856417 -0.2808295
## 23            1             0 -0.8196345 -0.1856417 -0.2808295
## 24            1             0 -0.8196345 -0.1856417 -0.2808295
## 25            1             0 -0.8196345 -0.1856417 -0.2808295
## 26            1             0 -0.8196345 -0.1856417 -0.2808295
## 27            1             0 -0.8196345 -0.1856417 -0.2808295
## 28            1             0 -0.8196345 -0.1856417 -0.2808295
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## 32            1             0 -0.8196345 -0.1856417 -0.2808295
## 33            1             0 -0.8196345 -0.1856417 -0.2808295
## 34            1             0 -0.8196345 -0.1856417 -0.2808295
## 35            1             0 -0.8196345 -0.1856417 -0.2808295
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## 51            1             0 -0.8196345 -0.1856417 -0.2808295
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## 54            1             0 -0.8196345 -0.1856417 -0.2808295
## 55            1             0 -0.8196345 -0.1856417 -0.2808295
## 56            1             0 -0.8196345 -0.1856417 -0.2808295
## 57            1             0 -0.8196345 -0.1856417 -0.2808295
## 58            1             0 -0.8196345 -0.1856417 -0.2808295
```

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## 59            1             0 -0.8196345 -0.1856417 -0.2808295
## 60            1             0 -0.8196345 -0.1856417 -0.2808295
## 61            1             0 -0.8196345 -0.1856417 -0.2808295
## 62            1             0 -0.8196345 -0.1856417 -0.2808295
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## 80            1             0 -0.8196345 -0.1856417 -0.2808295
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## 100           1             0 -0.8196345 -0.1856417 -0.2808295
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## 112           1             0 -0.8196345 -0.1856417 -0.2808295
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## 113            1            0 -0.7266228 -0.1902758 -0.7750975
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## 166            1            0 -0.7266228 -0.1902758 -0.7750975
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## 167           1            0 -0.7266228 -0.1902758 -0.7750975
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## 181           1            0 -0.7266228 -0.1902758 -0.7750975
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## 593           1           0  0.7911322 -1.3133684  0.8742729
## 594           1           0  0.7911322 -1.3133684  0.8742729
## 595           1           0  0.7911322 -1.3133684  0.8742729
## 596           1           0  0.7911322 -1.3133684  0.8742729
## 597           1           0  0.7911322 -1.3133684  0.8742729
## 598           1           0  0.7911322 -1.3133684  0.8742729
## 599           1           0  0.7911322 -1.3133684  0.8742729
## 600           1           0  0.7911322 -1.3133684  0.8742729
## 601           1           0  0.7911322 -1.3133684  0.8742729
## 602           1           0  0.7911322 -1.3133684  0.8742729
## 603           1           0  0.7911322 -1.3133684  0.8742729
## 604           1           0  0.7911322 -1.3133684  0.8742729
## 605           1           0  0.7911322 -1.3133684  0.8742729
## 606           1           0  0.7911322 -1.3133684  0.8742729
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## 608           1           0  0.7911322 -1.3133684  0.8742729
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## 612           1           0  0.7911322 -1.3133684  0.8742729
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## 618           1           0  0.7911322 -1.3133684  0.8742729
## 619           1           0  0.7911322 -1.3133684  0.8742729
## 620           1           0  0.7911322 -1.3133684  0.8742729
## 621           1           0  0.7911322 -1.3133684  0.8742729
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## 623           1           0  0.7911322 -1.3133684  0.8742729
## 624           1           0  0.7911322 -1.3133684  0.8742729
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## 630           1           0  0.7911322 -1.3133684  0.8742729
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## 633           1           0  0.7911322 -1.3133684  0.8742729
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## 635           1           0  0.7911322 -1.3133684  0.8742729
## 636           1           0  0.7911322 -1.3133684  0.8742729
## 637           1           0  0.7911322 -1.3133684  0.8742729
## 638           1           0  0.7911322 -1.3133684  0.8742729
## 639           1           0  0.7911322 -1.3133684  0.8742729
## 640           1           0  0.7911322 -1.3133684  0.8742729
```

```
## 641            1            0  1.9637172 -0.8183743  0.2098175
## 642            1            0  1.9637172 -0.8183743  0.2098175
## 643            1            0  1.9637172 -0.8183743  0.2098175
## 644            1            0  1.9637172 -0.8183743  0.2098175
## 645            1            0  1.9637172 -0.8183743  0.2098175
## 646            1            0  1.9637172 -0.8183743  0.2098175
## 647            1            0  1.9637172 -0.8183743  0.2098175
## 648            1            0  1.9637172 -0.8183743  0.2098175
## 649            1            0  1.9637172 -0.8183743  0.2098175
## 650            1            0  1.9637172 -0.8183743  0.2098175
## 651            1            0  1.9637172 -0.8183743  0.2098175
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## 655            1            0  1.9637172 -0.8183743  0.2098175
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## 663            1            0  1.9637172 -0.8183743  0.2098175
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## 665            1            0  1.9637172 -0.8183743  0.2098175
## 666            1            0  1.9637172 -0.8183743  0.2098175
## 667            1            0  1.9637172 -0.8183743  0.2098175
## 668            1            0  1.9637172 -0.8183743  0.2098175
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## 670            1            0  1.9637172 -0.8183743  0.2098175
## 671            1            0  1.9637172 -0.8183743  0.2098175
## 672            1            0  1.9637172 -0.8183743  0.2098175
## 673            1            0  1.9637172 -0.8183743  0.2098175
## 674            1            0  1.9637172 -0.8183743  0.2098175
## 675            1            0  1.9637172 -0.8183743  0.2098175
## 676            1            0  1.9637172 -0.8183743  0.2098175
## 677            1            0  1.9637172 -0.8183743  0.2098175
## 678            1            0  1.9637172 -0.8183743  0.2098175
## 679            1            0  1.9637172 -0.8183743  0.2098175
## 680            1            0  1.9637172 -0.8183743  0.2098175
## 681            1            0  1.9637172 -0.8183743  0.2098175
## 682            1            0  1.9637172 -0.8183743  0.2098175
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## 689            1            0  1.9637172 -0.8183743  0.2098175
## 690            1            0  1.9637172 -0.8183743  0.2098175
## 691            1            0  1.9637172 -0.8183743  0.2098175
## 692            1            0  1.9637172 -0.8183743  0.2098175
## 693            1            0  1.9637172 -0.8183743  0.2098175
## 694            1            0  1.9637172 -0.8183743  0.2098175
```

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## 695           1            0  1.9637172 -0.8183743  0.2098175
## 696           1            0  1.9637172 -0.8183743  0.2098175
## 697           1            1 -0.4071777  0.6675426 -0.3804073
## 698           1            1 -0.4071777  0.6675426 -0.3804073
## 699           1            1 -0.4071777  0.6675426 -0.3804073
## 700           1            1 -0.4071777  0.6675426 -0.3804073
## 701           1            1 -0.8196345 -0.1856417 -0.2808295
## 702           1            1 -0.8196345 -0.1856417 -0.2808295
## 703           1            1 -0.8196345 -0.1856417 -0.2808295
## 704           1            1 -0.8196345 -0.1856417 -0.2808295
## 705           1            1 -0.8196345 -0.1856417 -0.2808295
## 706           1            1 -0.8196345 -0.1856417 -0.2808295
## 707           1            1 -0.8196345 -0.1856417 -0.2808295
## 708           1            1 -0.8196345 -0.1856417 -0.2808295
## 709           1            1 -0.8196345 -0.1856417 -0.2808295
## 710           1            1 -0.8196345 -0.1856417 -0.2808295
## 711           1            1 -0.8196345 -0.1856417 -0.2808295
## 712           1            1 -0.8196345 -0.1856417 -0.2808295
## 713           1            1 -0.8196345 -0.1856417 -0.2808295
## 714           1            1 -0.8196345 -0.1856417 -0.2808295
## 715           1            1 -0.8196345 -0.1856417 -0.2808295
## 716           1            1 -0.8196345 -0.1856417 -0.2808295
## 717           1            1 -0.8196345 -0.1856417 -0.2808295
## 718           1            1 -0.8196345 -0.1856417 -0.2808295
## 719           1            1 -0.8196345 -0.1856417 -0.2808295
## 720           1            1 -0.8196345 -0.1856417 -0.2808295
## 721           1            1 -0.8196345 -0.1856417 -0.2808295
## 722           1            1 -0.8196345 -0.1856417 -0.2808295
## 723           1            1 -0.8196345 -0.1856417 -0.2808295
## 724           1            1 -0.8196345 -0.1856417 -0.2808295
## 725           1            1 -0.8196345 -0.1856417 -0.2808295
## 726           1            1 -0.8196345 -0.1856417 -0.2808295
## 727           1            1 -0.7266228 -0.1902758 -0.7750975
## 728           1            1 -0.7266228 -0.1902758 -0.7750975
## 729           1            1 -0.7266228 -0.1902758 -0.7750975
## 730           1            1 -0.7266228 -0.1902758 -0.7750975
## 731           1            1 -0.7266228 -0.1902758 -0.7750975
## 732           1            1 -0.7266228 -0.1902758 -0.7750975
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## 734           1            1 -0.7266228 -0.1902758 -0.7750975
## 735           1            1 -0.7266228 -0.1902758 -0.7750975
## 736           1            1 -0.7266228 -0.1902758 -0.7750975
## 737           1            1 -0.7266228 -0.1902758 -0.7750975
## 738           1            1 -0.7266228 -0.1902758 -0.7750975
## 739           1            1 -0.7266228 -0.1902758 -0.7750975
## 740           1            1 -0.7266228 -0.1902758 -0.7750975
## 741           1            1 -0.7266228 -0.1902758 -0.7750975
## 742           1            1 -0.7848166  0.4290217 -1.7364758
## 743           1            1 -0.7848166  0.4290217 -1.7364758
## 744           1            1 -0.7848166  0.4290217 -1.7364758
## 745           1            1 -0.7848166  0.4290217 -1.7364758
## 746           1            1 -0.7848166  0.4290217 -1.7364758
## 747           1            1 -0.7848166  0.4290217 -1.7364758
## 748           1            1 -0.7848166  0.4290217 -1.7364758
```

```
## 749           1             1 -0.7848166  0.4290217 -1.7364758
## 750           1             1 -0.7848166  0.4290217 -1.7364758
## 751           1             1 -0.7848166  0.4290217 -1.7364758
## 752           1             1 -0.7848166  0.4290217 -1.7364758
## 753           1             1 -0.7848166  0.4290217 -1.7364758
## 754           1             1 -0.7848166  0.4290217 -1.7364758
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## 756           1             1 -0.7848166  0.4290217 -1.7364758
## 757           1             1 -0.7848166  0.4290217 -1.7364758
## 758           1             1 -0.7848166  0.4290217 -1.7364758
## 759           1             1 -0.7848166  0.4290217 -1.7364758
## 760           1             1 -0.7848166  0.4290217 -1.7364758
## 761           1             1 -0.7848166  0.4290217 -1.7364758
## 762           1             1 -0.7848166  0.4290217 -1.7364758
## 763           1             1 -0.7848166  0.4290217 -1.7364758
## 764           1             1 -0.7848166  0.4290217 -1.7364758
## 765           1             1 -0.7848166  0.4290217 -1.7364758
## 766           1             1 -0.7848166  0.4290217 -1.7364758
## 767           1             1 -0.7848166  0.4290217 -1.7364758
## 768           1             1 -0.7585699  2.1517850 -0.3423867
## 769           1             1 -0.7585699  2.1517850 -0.3423867
## 770           1             1 -0.7585699  2.1517850 -0.3423867
## 771           1             1 -0.7585699  2.1517850 -0.3423867
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## 773           1             1 -0.7585699  2.1517850 -0.3423867
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## 776           1             1 -0.7585699  2.1517850 -0.3423867
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## 778           1             1 -0.7585699  2.1517850 -0.3423867
## 779           1             1 -0.7585699  2.1517850 -0.3423867
## 780           1             1 -0.7585699  2.1517850 -0.3423867
## 781           1             1 -0.7585699  2.1517850 -0.3423867
## 782           1             1 -0.7585699  2.1517850 -0.3423867
## 783           1             1 -0.7585699  2.1517850 -0.3423867
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## 785           1             1 -0.7585699  2.1517850 -0.3423867
## 786           1             1 -0.7585699  2.1517850 -0.3423867
## 787           1             1 -0.7585699  2.1517850 -0.3423867
## 788           1             1 -0.7585699  2.1517850 -0.3423867
## 789           1             1  0.9565296 -0.3861161  0.8416838
## 790           1             1  0.9565296 -0.3861161  0.8416838
## 791           1             1  0.9565296 -0.3861161  0.8416838
## 792           1             1  0.9565296 -0.3861161  0.8416838
## 793           1             1  0.9565296 -0.3861161  0.8416838
## 794           1             1  0.9565296 -0.3861161  0.8416838
## 795           1             1  0.9565296 -0.3861161  0.8416838
## 796           1             1  0.9565296 -0.3861161  0.8416838
## 797           1             1  0.9565296 -0.3861161  0.8416838
## 798           1             1  0.9565296 -0.3861161  0.8416838
## 799           1             1  0.9565296 -0.3861161  0.8416838
## 800           1             1  0.9565296 -0.3861161  0.8416838
## 801           1             1  0.9565296 -0.3861161  0.8416838
## 802           1             1  0.9565296 -0.3861161  0.8416838
```

```
## 803           1             1  0.9565296 -0.3861161  0.8416838
## 804           1             1  0.9565296 -0.3861161  0.8416838
## 805           1             1  0.9565296 -0.3861161  0.8416838
## 831           1             1  0.7911322 -1.3133684  0.8742729
## 832           1             1  0.7911322 -1.3133684  0.8742729
## 833           1             1  0.7911322 -1.3133684  0.8742729
## 834           1             1  0.7911322 -1.3133684  0.8742729
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## 837           1             1  0.7911322 -1.3133684  0.8742729
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## 841           1             1  0.7911322 -1.3133684  0.8742729
## 842           1             1  0.7911322 -1.3133684  0.8742729
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## 849           1             1  0.7911322 -1.3133684  0.8742729
## 850           1             1  0.7911322 -1.3133684  0.8742729
## 851           1             1  0.7911322 -1.3133684  0.8742729
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## 860           1             1  0.7911322 -1.3133684  0.8742729
## 861           1             1  1.9637172 -0.8183743  0.2098175
## 862           1             1  1.9637172 -0.8183743  0.2098175
## 863           1             1  1.9637172 -0.8183743  0.2098175
## 864           1             1  1.9637172 -0.8183743  0.2098175
## 865           1             1  1.9637172 -0.8183743  0.2098175
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## 867           1             1  1.9637172 -0.8183743  0.2098175
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## 869           1             1  1.9637172 -0.8183743  0.2098175
## 870           1             1  1.9637172 -0.8183743  0.2098175
## 871           1             1  1.9637172 -0.8183743  0.2098175
## 872           1             1  1.9637172 -0.8183743  0.2098175
## 873           1             1  1.9637172 -0.8183743  0.2098175
## 874           1             1  1.9637172 -0.8183743  0.2098175
## attr(,"assign")
## [1] 0 1 2 3 4
## attr(,"contrasts")
## attr(,"contrasts")$EggOrder
## [1] "contr.treatment"
##
## attr(,"msgScaleX")
```

```
## character(0)
```

Model Diagnostics

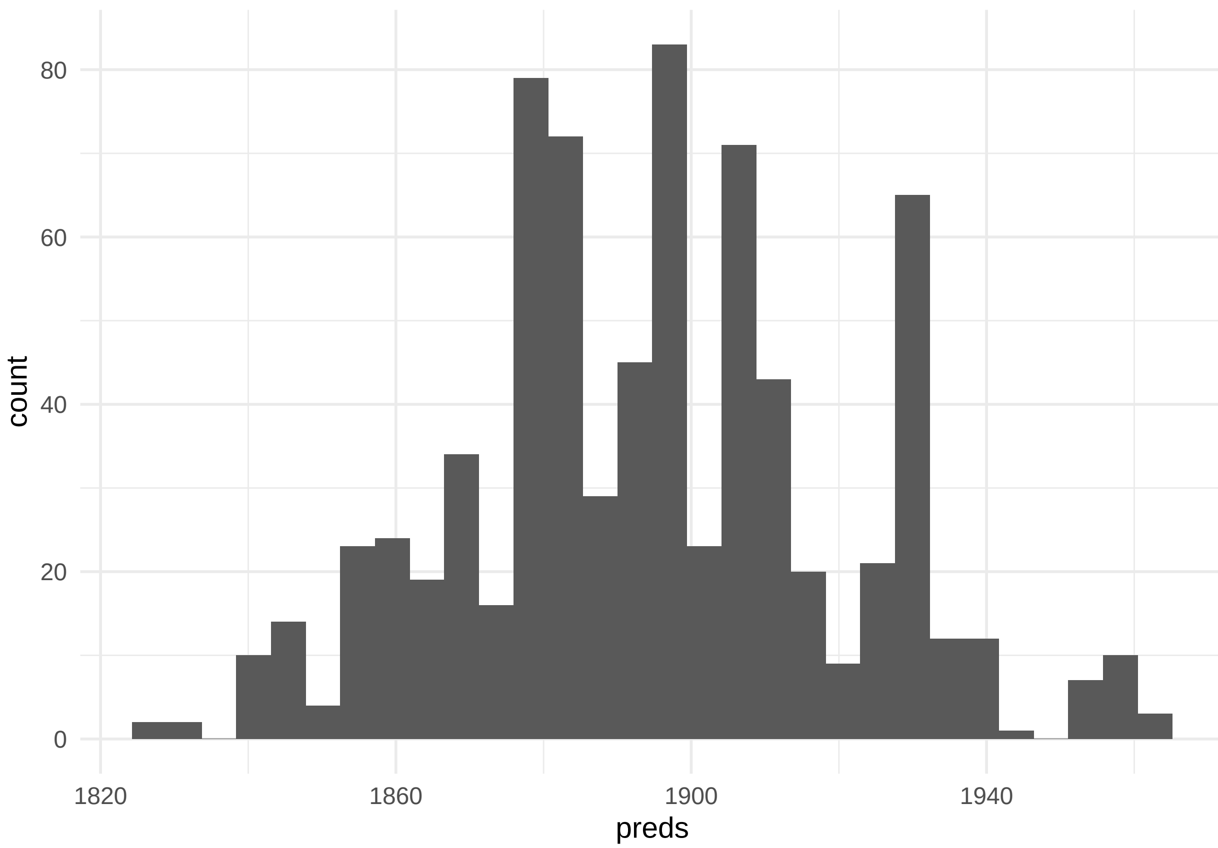
These diagnostics are done for the first top model only but can be repeated for the other 2 models.

Residuals/Fitted Plots

Histogram of Predicted Values

```
## extract predicted values and plot
preds <- predict(bm1)
ggplot() +
  geom_histogram(mapping = aes(preds)) +
  theme_minimal()
```

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



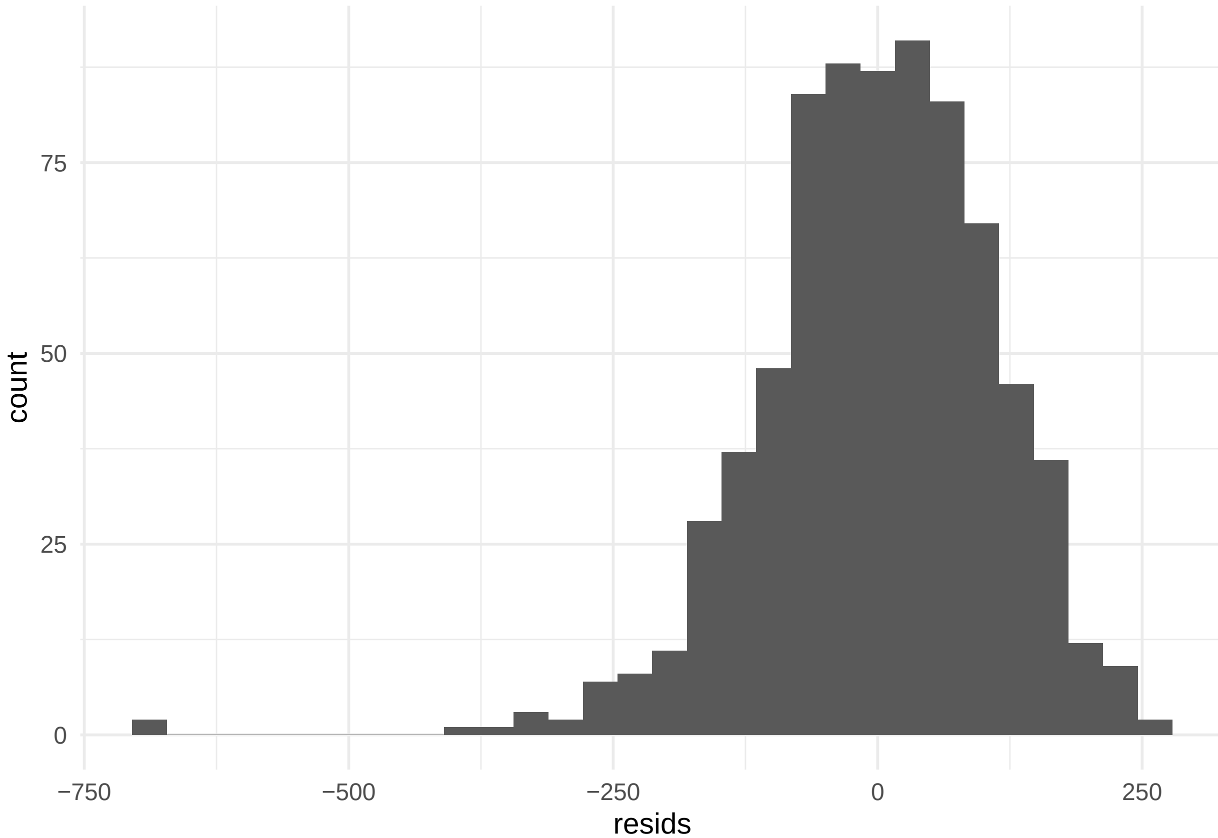
Since we assumed our data are normal, we want to see an approximately normal distribution of predicted values.

Histogram of Residuals

```
## extract residuals and plot
resids <- residuals(bm1)
ggplot() +
```

```r
  geom_histogram(mapping = aes(resids)) +
  theme_minimal()
```

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



Since we assumed our data are normal, we want to see an approximately normal distribution of residuals (differences between observed and predicted values of data).

Model Coefficients

```r
## extract coeffs and random effects
coef(bm1) # this include fixed and random effects
```

```
## $Observer
##     (Intercept) EggOrderEgg2   BEUTI      NPGO      ONI
## AAY    1898.226     29.90976 11.1043 -22.75851 2.971758
## AJB    1887.490     29.90976 11.1043 -22.75851 2.971758
## AJD    1893.335     29.90976 11.1043 -22.75851 2.971758
## AML    1889.849     29.90976 11.1043 -22.75851 2.971758
## CAC    1882.309     29.90976 11.1043 -22.75851 2.971758
## CEH    1886.834     29.90976 11.1043 -22.75851 2.971758
## CEK    1888.526     29.90976 11.1043 -22.75851 2.971758
## CLE    1885.842     29.90976 11.1043 -22.75851 2.971758
## DLW    1886.151     29.90976 11.1043 -22.75851 2.971758
## EWW    1890.804     29.90976 11.1043 -22.75851 2.971758
## GRK    1888.900     29.90976 11.1043 -22.75851 2.971758
## JAH    1894.719     29.90976 11.1043 -22.75851 2.971758
```

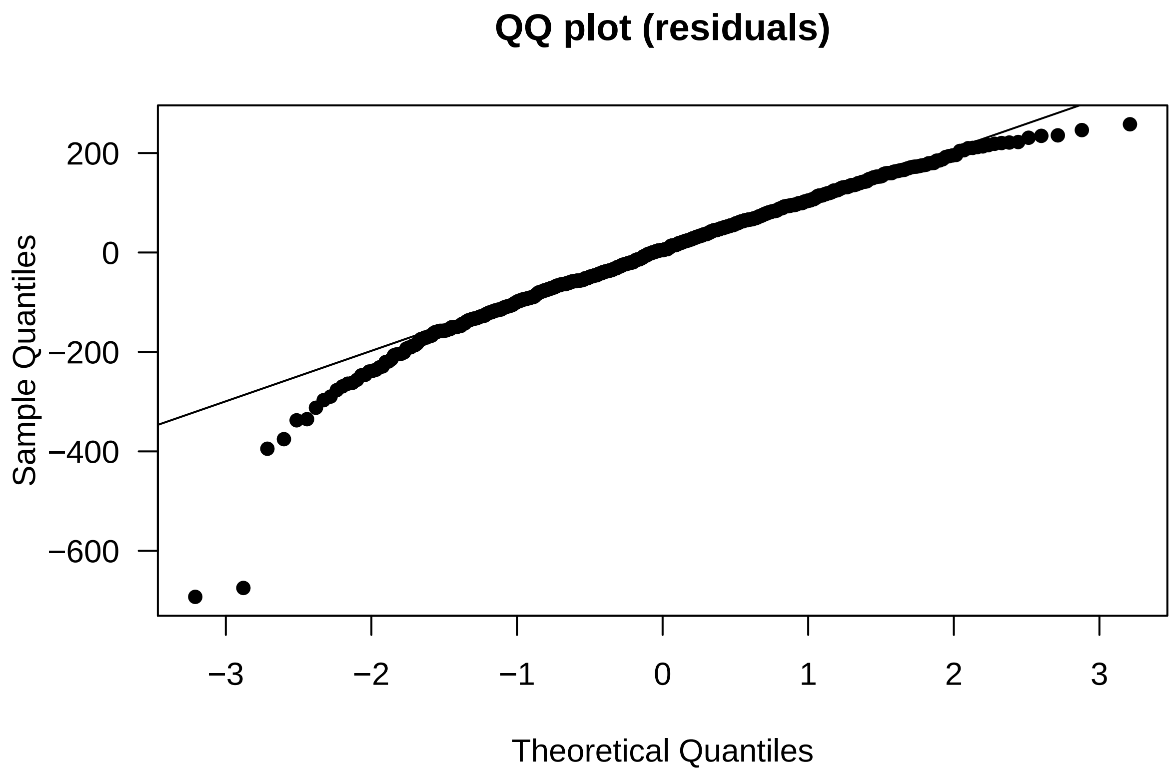
```
## KMR    1890.363     29.90976 11.1043 -22.75851 2.971758
## KWB    1893.889     29.90976 11.1043 -22.75851 2.971758
## LAH    1889.444     29.90976 11.1043 -22.75851 2.971758
## MEJ    1887.006     29.90976 11.1043 -22.75851 2.971758
## MGB    1890.467     29.90976 11.1043 -22.75851 2.971758
## NAG    1885.550     29.90976 11.1043 -22.75851 2.971758
## PTL    1885.434     29.90976 11.1043 -22.75851 2.971758
## RER    1891.692     29.90976 11.1043 -22.75851 2.971758
## REW    1887.998     29.90976 11.1043 -22.75851 2.971758
## SAA    1900.548     29.90976 11.1043 -22.75851 2.971758
## SFC    1889.011     29.90976 11.1043 -22.75851 2.971758
## SJK    1893.045     29.90976 11.1043 -22.75851 2.971758
## SKT    1879.078     29.90976 11.1043 -22.75851 2.971758
## SLA    1890.326     29.90976 11.1043 -22.75851 2.971758
## SMC    1890.980     29.90976 11.1043 -22.75851 2.971758
##
## $Plot
##      (Intercept) EggOrderEgg2   BEUTI      NPGO      ONI
## APNC    1906.937     29.90976 11.1043 -22.75851 2.971758
## BH      1899.167     29.90976 11.1043 -22.75851 2.971758
## BT      1870.282     29.90976 11.1043 -22.75851 2.971758
## CC      1904.589     29.90976 11.1043 -22.75851 2.971758
## DO      1884.902     29.90976 11.1043 -22.75851 2.971758
## ESC     1888.654     29.90976 11.1043 -22.75851 2.971758
## LC      1877.422     29.90976 11.1043 -22.75851 2.971758
## WC      1884.437     29.90976 11.1043 -22.75851 2.971758
##
## attr(,"class")
## [1] "coef.mer"
```

```
ranef_obs <- ranef(bm1)$Observer # observer random effect only
ranef_pl <- ranef(bm1)$Plot # plot random effect only
```

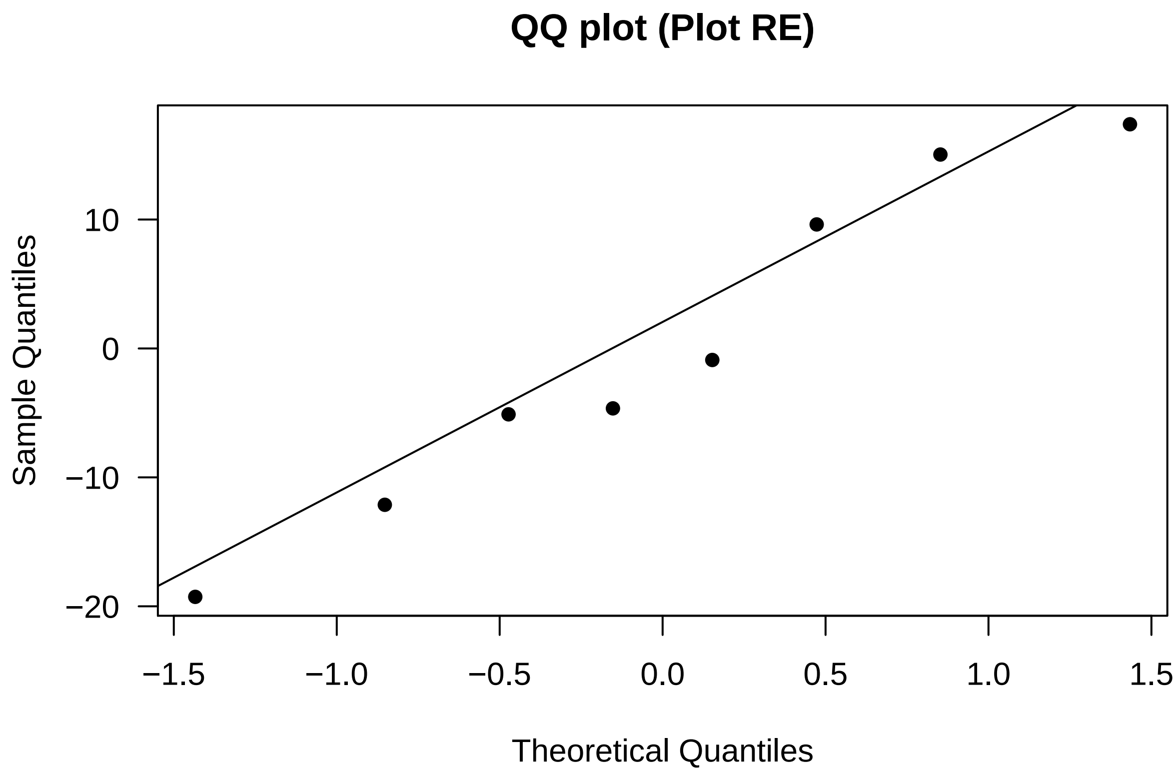
We can extract our model coefficients (for fixed and random effects) and look at them.

Q-Q Plots

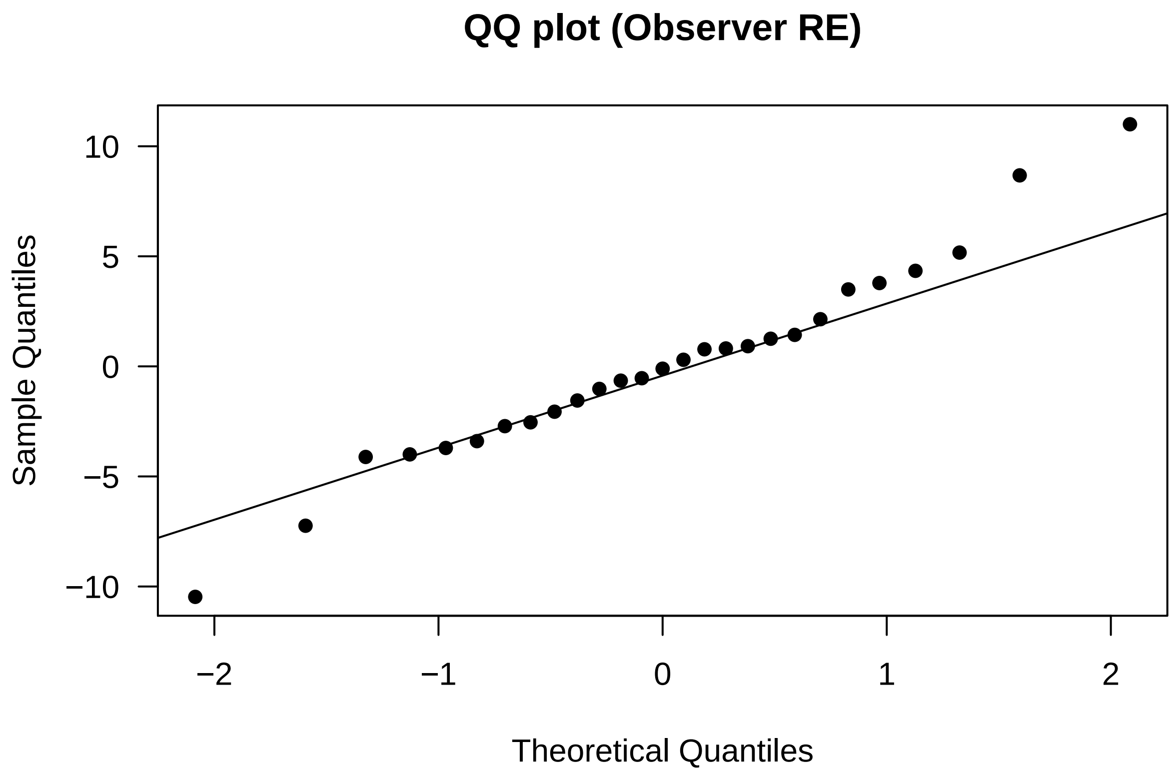
```
# qq resids
qqnorm(resids, main = "QQ plot (residuals)", las = 1, pch = 16)
qqline(resids)
```




```r
# qq Plot RE
qqnorm(unlist(ranef_pl), main = "QQ plot (Plot RE)", las = 1, pch = 16)
qqline(unlist(ranef_pl))
```



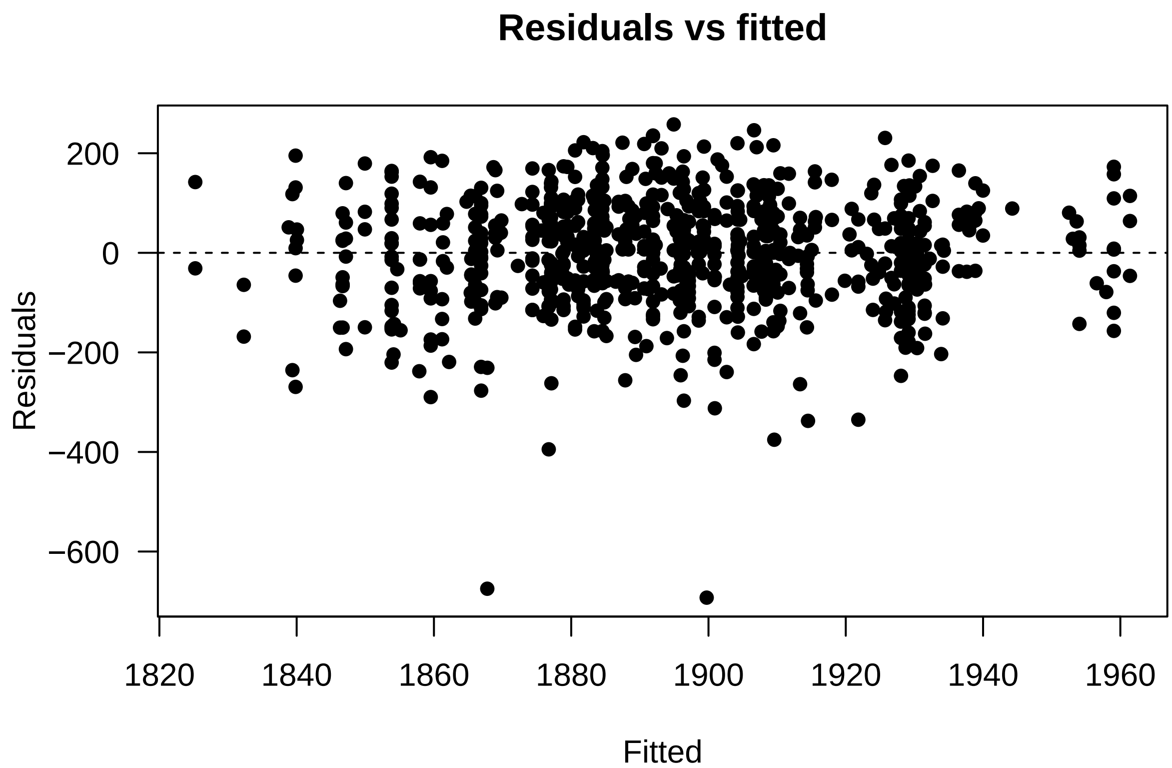

```r
# qq Observer RE
qqnorm(unlist(ranef_obs), main = "QQ plot (Observer RE)", las = 1, pch = 16)
qqline(unlist(ranef_obs))
```



We want our points to fall approximately on the diagonal lines.

Fitted v Residuals

```
## plot residuals versus fitted values
yh <- fitted(bm1)
plot(yh, resids, las = 1, pch = 16,
     xlab = "Fitted", ylab = "Residuals",
     main = "Residuals vs fitted")
abline(h=0, lty = "dashed")
```



We assume our errors are normally distributed with constant variance. We want this plot to look like a scattershot of points, without any evidence of trends.

Levene's test

We can formally test the assumption of homogenous variance via the Levene's Test, which compares the absolute values of the residuals among groups.

```r
## split residuals into 2 groups
g1 <- resids[yh <= median(yh)]
g2 <- resids[yh > median(yh)]

## Levene's test
var.test(g1, g2)
```

```
##
##  F test to compare two variances
##
## data:  g1 and g2
## F = 1.0951, num df = 378, denom df = 373, p-value = 0.3791
## alternative hypothesis: true ratio of variances is not equal to 1
## 95 percent confidence interval:
##  0.8942338 1.3409987
## sample estimates:
## ratio of variances
##            1.09514
```

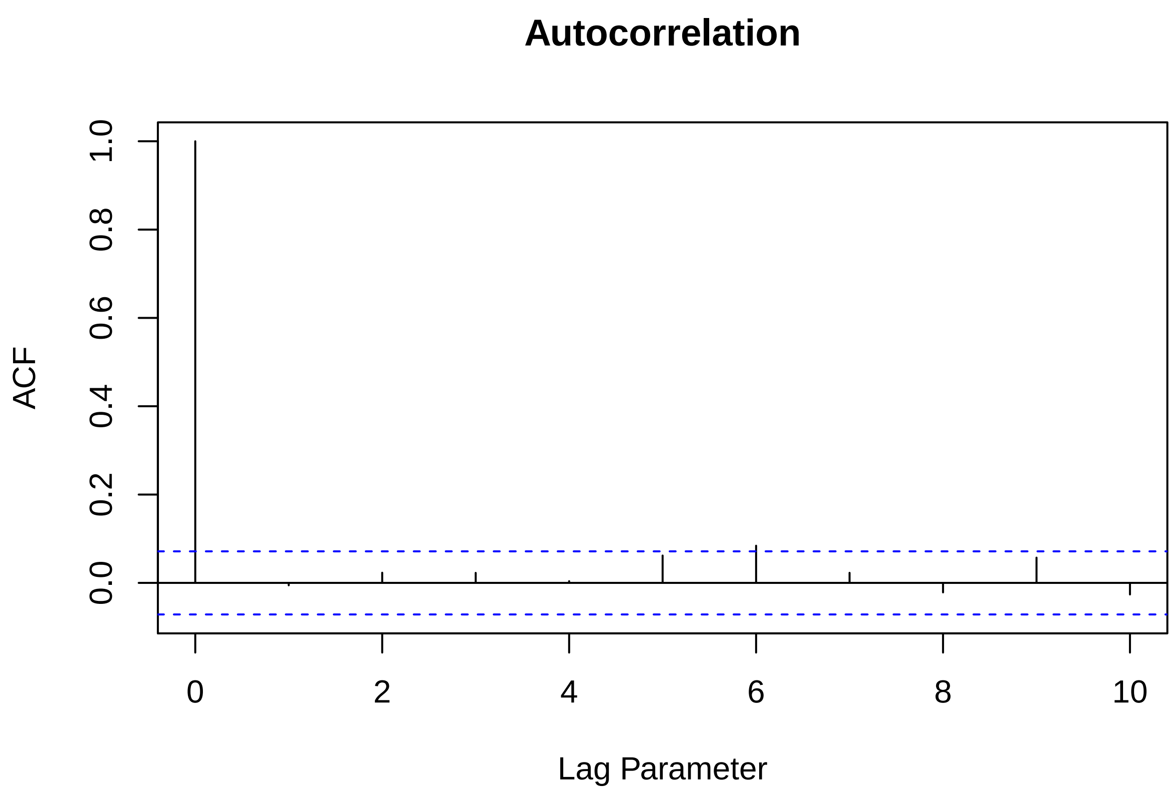
There is no justification to reject the null hypothesis that the residuals are equal. F is close to 1 and it is within the 95% confidence interval.

Autocorrelation

We also assume our errors are independent (e.g., not correlated). An ACF plot can be used to look for autocorrelation.

```
# calculate the ACF for lags between 1 and 10
autocorrelation <- acf(resids, lag.max= 10, plot = FALSE)

# Plot figure
plot(autocorrelation,
     main="Autocorrelation",
     xlab="Lag Parameter",
     ylab="ACF")
```



The first value with 0 lag will always be autocorrelated because it's stacked on itself. But after that, we want to see the values within the blue dotted lines. There does not appear to be autocorrelation in the residuals.

Goodness of Fit

Review with Sarah***

```
## Goodness of fit
## Pearson's X^2 statistic
true <- df$Size # 'true' egg size values
nn <- nrow(df) # number of observations
X2 <- sum((true - yh)^2/yh)
```

```
## Warning in true - yh: longer object length is not a multiple of shorter object
## length

## Warning in (true - yh)^2/yh: longer object length is not a multiple of shorter
## object length
```

```r
degf <- nn-6 # 4 fixed effects, 2 random effects

## likelihood ratio test
pchisq(X2, df = degf, lower.tail = FALSE)
```

```
## [1] 0
```

Likelihood Ratio Tests

Review with Sarah***

```r
## Likelihood ratio tests
## run model with plot RE only
bm_plot <- lmer(Size ~ EggOrder + BEUTI + NPGO + ONI +  (1 | Plot), data = df)

## run model with obs RE only
bm_obs <- lmer(Size ~ EggOrder + BEUTI + NPGO + ONI + (1 | Observer), data = df)

## conduct an LRT to see if the variance of the Obs RE is contributing useful info
test_1 <- 2 * (logLik(bm1) - logLik(bm_obs))
pchisq(as.numeric(test_1), df = 1, lower.tail = FALSE)
```

```
## [1] 0.01460999
```

```r
# There is support for inclusion of Obs as an RE

## check for contribution of Plot RE
test_2 <- 2 * (logLik(bm1) - logLik(bm_plot))
pchisq(as.numeric(test_2), df = 1, lower.tail = FALSE)
```

```
## [1] 1.504475e-316
```

```r
# There is support for inclusion of Plot as an RE

## Bootstrapping  to test for evidence against including multiple random effects in the same model
## set random seed
set.seed(514)

## fit null model with no RE's
nbm <- lm(Size ~ EggOrder + BEUTI + NPGO + ONI, data = df)

## calculate likelihood ratio (difference in log-likelihood)
lambda <- 2 * (logLik(bm1) - logLik(nbm))

## number of bootstrapped samples
nb <- 1000

## empty vector for storing LRT statistics
LRT_boot <- rep(NA, nb)

## bootstrapping
```

```r
for(i in 1:nb) { # repeat nb times
  sim_data <- unlist(simulate(nbm)) # simulate data from null model
  m_null <- lm(sim_data ~ EggOrder + BEUTI + NPGO + ONI, data = df) # fit null model to sim data
  m_alt <- lmer(sim_data ~ EggOrder + BEUTI + NPGO + ONI + (1 | Observer) + (1 | Plot), data = df) # fi
  LRT_boot[i] <- as.numeric(2*(logLik(m_alt) - logLik(m_null))) # calculate likelihood ratio
} # boundary (singular) fit: see ?isSingular
```

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```r
## calculate approximate p-value
mean(LRT_boot > lambda)
```

```
## [1] 0.972
```

Identifying Outliers

https://qerm514.github.io/website/labs/week_03/diagnostics_and_errors.html#unusual_observations https://qerm514.github.io/website/homework/week_03/hw_03_diagnostics_key.pdf Calculate the studentized residuals to look for outliers

```r
## get studentized residuals
(stud_e <- rstudent(bm1))
```

```
##            1            2            3            4            5
##  1.1448036145 -1.5640157363 -0.5789843706  0.2366916785 -0.8749296749
##            6            7            8            9           10
##  0.4642884660 -0.5805845565 -1.1973921638  0.0362230507 -0.2851080407
##           11           12           13           14           15
##  1.7687502093  1.0340000625  0.4625459557 -0.8889883601 -0.7339670068
##           16           17           18           19           20
##  1.0470496740 -1.0393254067 -0.6501854445 -0.1026745676  1.5330707384
##           21           22           23           24           25
## -1.0393254067 -0.4148915139 -0.9228444376  1.5103359358  0.2755537463
##           26           27           28           29           30
```

```
##  0.3551437585 -1.5403699714 -0.5885114457  0.8153896299  1.4665264884
##            31            32            33            34            35
##  0.1687745550 -1.3912408354  0.1687745550 -0.9481060288 -0.0708799832
##            36            37            38            39            40
##  0.5360277306  0.0602410298 -1.4282916484  0.2202149109  0.5563556709
##            41            42            43            44            45
## -0.6310727947  0.9634740020 -0.7871348216  1.0584682792 -1.3654440878
##            46            47            48            49            50
##  0.7074548586 -0.0272718500  0.2176370529  0.2352590647 -0.5753017044
##            51            52            53            54            55
## -0.6090370795 -0.1522387619  0.1893995080  0.7067871469 -0.2687997030
##            56            57            58            59            60
##  1.4867840796 -1.0530114116  0.6043127649 -1.9931806869 -1.3347185386
##            61            62            63            64            65
##  1.0738547884  1.3834161033  0.2637320135 -0.6890086565 -0.8287036453
##            66            67            68            69            70
## -2.6235533886 -0.1305675286 -2.1618253418  1.0815143418  1.2975826306
##            71            72            73            74            75
##  1.1892347098  0.0847655391 -0.4490219895 -0.1428555311  0.8922599534
##            76            77            78            79            80
## -1.3594074778 -2.4407582948  1.1884087017 -1.6871533435 -0.2989073874
##            81            82            83            84            85
##  0.5081846753 -1.3128295185 -0.6351985940  0.8765101744 -0.5150915641
##            86            87            88            89            90
## -1.5765199822  1.7382257253  0.9719389746  0.4408703904 -0.2591251290
##            91            92            93            94            95
## -0.5991540245  0.5508260812  1.2680995322  0.2573960331  0.7230543531
##            96            97            98            99           100
## -0.1333082712  0.4473190294  0.2871893759  1.1059217567  0.5339345518
##           101           102           103           104           105
##  0.4270450036  0.2334373726 -0.9706817062 -1.7517847131 -0.0686373538
##           106           107           108           109           110
## -1.8608465037 -0.4155356115 -1.3692683159  0.5000223669 -0.0611071312
##           111           112           113           114           115
## -0.6636422612  0.5088555026  0.0247367098  0.5805587709 -0.3816289632
##           116           117           118           119           120
##  0.1903970310  1.5734068997  0.9658067535 -1.1217594471 -1.1521757684
##           121           122           123           124           125
##  1.4777973464 -0.3328805242 -1.8751082823  0.8675144978 -0.9737666966
##           126           127           128           129           130
##  1.0567060734 -0.7615045217 -0.2254772665 -0.8863950564  0.6183840689
##           131           132           133           134           135
## -0.4380034085 -0.1263491241  1.6301934286 -0.5499485513  0.7747900693
##           136           137           138           139           140
##  1.5323038372  0.6670099221 -0.6056777582 -0.0173573062  0.5709578640
##           141           142           143           144           145
##  2.1233044583  1.0580769097  1.6265546069 -1.3569354518  0.4270689954
##           146           147           148           149           150
##  0.7470330915  0.2926009414  0.5016480856  0.1306506856  0.9005395278
##           151           152           153           154           155
##  0.9314557755  0.0409406429 -1.2315433994  1.0848037505 -0.4374624077
##           156           157           158           159           160
##  1.3771486023 -0.0755600232 -0.4686357286 -2.0844493710  0.4923659715
##           161           162           163           164           165
```

```
## -0.4686357286  0.7405341206 -1.2146185700 -0.5287917965  0.2021896823
##           166           167           168           169           170
##  0.7581283851 -1.2076674497  0.8362686027  2.1326058780 -2.1027926539
##           171           172           173           174           175
##  2.0104672717  0.2397330282 -2.8333164210 -0.2379614533  1.3573320429
##           176           177           178           179           180
##  1.4483705865  0.7438564988 -0.8505616573  0.0236505703 -0.2014704023
##           181           182           183           184           185
##  1.9116751758 -2.1653065296  1.2920588901  0.5948141383  0.3106458384
##           186           187           188           189           190
## -1.0408047327  0.4758855383  0.6976212523  0.3048590407  0.8391263767
##           191           192           193           194           195
## -0.4989159632  0.9252738128  0.3343548305  0.2910515081  0.1258255679
##           196           197           198           199           200
## -1.0177404038 -0.7121679789  0.4814719089  1.5595393948  0.8609587946
##           201           202           203           204           205
##  0.1931048960 -0.2476501352 -1.6576293776 -0.3474355629  1.7752536202
##           206           207           208           209           210
## -0.1399709920  0.8376720881  0.9955671715 -0.9075840483 -0.3751176961
##           211           212           213           214           215
## -0.1872894669 -2.3696057053  0.2077195390  1.2950794946  0.9034146782
##           216           217           218           219           220
##  0.0987439307  1.1320315214 -1.1597334578  0.1377973200 -1.4471193940
##           221           222           223           224           225
## -0.7041648601 -0.9873629922  1.5052516617 -1.4269578299 -2.6887431129
##           226           227           228           229           230
##  0.5923331906  0.2768189686 -0.2634029431 -0.3128350134  1.1550982992
##           231           232           233           234           235
##  1.7548016583  0.9036741515 -0.0949038262  1.1817459790  0.6576057069
##           236           237           238           239           240
## -2.5063383695  0.4172386410  0.3297819012  0.6007570515  0.2115634572
##           241           242           243           244           245
## -3.5760077230 -1.7089617087 -0.8069082112  0.4738672160  1.1279843201
##           246           247           248           249           250
## -0.7706511838  0.0898071669 -0.0260620930 -0.0260620930  1.5574235940
##           251           252           253           254           255
##  1.6738678957 -0.8443624214 -1.5731307008 -0.5498716917  1.2904972034
##           256           257           258           259           260
##  0.0615289747 -0.8859895737 -0.6460049661 -1.5100225614 -1.2043296464
##           261           262           263           264           265
##  0.4611620653 -0.4125199475 -0.3949706339 -0.1217485295  0.5344537654
##           266           267           268           269           270
## -0.5160486958  0.0444866872 -0.5115927771 -0.8419316427  0.7954539735
##           271           272           273           274           275
##  0.0169948484  0.3575796491 -1.0226850696 -0.6754008337  0.1766948985
##           276           277           278           279           280
## -0.9558717834  0.2608905031  0.8599920232 -0.2334191758 -0.3719345253
##           281           282           283           284           285
## -0.1102918196  0.3265553768  0.0453128437 -0.1226528877 -0.5101150336
##           286           287           288           289           290
##  1.0430421693 -0.4266761085 -0.2594829236 -0.3329040968  0.1243426157
##           291           292           293           294           295
##  1.9864053407 -0.6509413571  0.3867687893  0.7060595404  0.0618255771
##           296           297           298           299           300
```

```
##  0.4713023625 -0.8668435726  0.4525165904 -0.9024462946 -1.1833314577
##           301           302           303           304           305
## -0.5133259896  1.2854219956  0.5696431586  0.4628619950  1.4845470735
##           306           307           308           309           310
##  0.3351083997 -1.3623361557  0.9494361175 -0.1646495501 -0.8682909929
##           311           312           313           314           315
##  0.1737161770  0.0417074323 -1.1602526014  2.0152154829  0.2864906578
##           316           317           318           319           320
## -0.5208947845 -0.9348850950  0.1423836827  1.4491702136  1.6306683429
##           321           322           323           324           325
##  1.4491702136  0.4061737285  0.8758638794  0.8617854239  0.4453356276
##           326           327           328           329           330
##  1.0937739100  0.8490286543 -0.5254695626 -0.5245626024  0.0610616131
##           331           332           333           334           335
##  0.4071155687 -0.9843316695 -0.2507985420 -1.0052897589 -0.5969242227
##           336           337           338           339           340
## -0.3564969980  0.3175498833 -0.3386638953  0.2579431835 -0.2882644213
##           341           342           343           344           345
##  0.7802040825 -1.2410082496  1.9109134944  0.3066141985 -0.0221864670
##           346           347           348           349           350
##  0.2233755547  0.7289700921 -0.8217849455 -0.8283007760 -0.5411327156
##           351           352           353           354           355
## -1.1540945845 -0.2914586780 -0.5823340400 -0.2065672828 -0.1263830890
##           356           357           358           359           360
## -0.6672873043 -1.7309828127 -1.2472697578  0.0300329486 -0.4669361929
##           361           362           363           364           365
## -0.2083372698 -1.9410042686 -0.2172143520 -0.0539443235  0.0113636879
##           366           367           368           369           370
## -2.2308780368 -0.6888833232  0.6007307907 -0.7634530904 -0.8694325972
##           371           372           373           374           375
##  0.6509891366  0.6183827696 -0.8146202205 -0.1853433675 -0.8485863556
##           376           377           378           379           380
## -0.1836269937 -0.3871527976 -0.7238782454  0.6834766267  0.1274256927
##           381           382           383           384           385
## -0.4586846218  1.6030021783  0.1194161359  0.1758684997  0.0718421499
##           386           387           388           389           390
## -1.5445395004  0.8953840857 -0.3247583087  0.4366567794  0.5314724628
##           391           392           393           394           395
## -2.2311856495  0.2246027609 -0.8282117853 -0.3496597188  0.8662975773
##           396           397           398           399           400
##  0.8510709206  0.8671132910  0.8459953684  0.5642115853 -0.5091770743
##           401           402           403           404           405
##  1.3890101524 -2.1745481539  0.5873003479  0.9174108077 -1.1758618467
##           406           407           408           409           410
##  1.2399333328  0.6033129654  0.5661149174 -0.4172733252 -0.9717774052
##           411           412           413           414           415
## -0.7181810639  0.1781070772 -0.3218631934  0.1330068600 -1.4709611656
##           416           417           418           419           420
## -0.5759545090 -0.0464872125 -0.0023937435 -1.8449954370 -0.3021651114
##           421           422           423           424           425
##  0.6696324586 -1.8150479796  0.2096930261  0.6020307905 -0.0325044590
##           426           427           428           429           430
## -0.9825076309  0.3055395522 -0.3284347450  0.1729009387 -0.1795548621
##           431           432           433           434           435
```

```
##  0.9654573908 -0.4958501186  0.1619416915 -0.6048874876 -0.0049999860
##           436           437           438           439           536
## -1.0695580769  0.1230886038  0.0335394655 -0.1852536187  0.4055787275
##           537           538           539           540           541
## -6.1271357675  0.0129474782 -0.5164817969 -1.3945874354 -0.4294338576
##           542           543           544           545           546
##  0.6629104363 -0.7233581477 -0.0131377273 -0.4734440309 -1.3456025776
##           547           548           549           550           551
##  0.8099122532  0.9510719449  0.4923708555  0.0041625011  1.1655813495
##           552           553           554           555           556
## -0.3747095561 -0.4800507256  0.8548395360 -0.3139608458 -0.0010325460
##           557           558           559           560           561
##  0.8892977494 -1.3028675852 -0.8179567512  0.5895647168 -1.4333867489
##           562           563           564           565           566
## -0.0931650890 -0.1895161597  0.5858436786 -1.4225048257  1.2609894744
##           567           568           569           570           571
## -0.3413339938 -0.1558687452  0.2968916025  0.3610683782 -0.8494321562
##           572           573           574           575           576
##  0.2146368619  0.8654436008 -0.5321638710  0.0354152276 -0.5029905884
##           577           578           579           580           581
##  0.1343558324 -0.4946882539  0.6046557293 -0.1755706100 -1.3387013716
##           582           583           584           585           586
##  1.3826347021  0.4256759188 -0.5523376262  0.1488430362  1.8619548819
##           587           588           589           590           591
##  1.3809797167  2.3413123093 -0.7450425113  0.4942389945  0.0467030181
##           592           593           594           595           596
##  1.3538095137  1.2442378092 -0.5959999893  0.8468108875  0.0154766191
##           597           598           599           600           601
##  0.6564786503 -0.2253279748 -0.4413027666 -0.5316540301  0.7991956611
##           602           603           604           605           606
##  0.9258140483  0.8990686157 -0.2205901447  0.3276241430 -0.4385200125
##           607           608           609           610           611
##  0.4017437994  0.9972319655  0.4082518667  0.5238604527  1.1870505976
##           612           613           614           615           616
##  0.6376612422 -0.6650369135  0.0517720539 -0.1773138842  0.2642300581
##           617           618           619           620           621
##  1.9890167309 -0.6250933018 -0.7043470958 -0.9995832930  1.1256293332
##           622           623           624           625           626
## -0.8008614082  0.3368869000 -0.4603502386  0.8474729160  0.8379790506
##           627           628           629           630           631
##  0.3860704600  1.9400177063  0.4796346330  0.1282916160  0.7625094067
##           632           633           634           635           636
##  0.2402230999  0.9385755893 -0.5518225303  1.5457919370  1.1935214955
##           637           638           639           640           641
## -0.4275556275  0.4712540382  1.8469628151  1.3375951318 -0.5242314527
##           642           643           644           645           646
##  1.2134398836 -0.5103757210  1.2322615281  0.9436853383  1.5830899400
##           647           648           649           650           651
## -0.2239857372  1.9517252170 -0.5716410334 -1.1069830147  1.6729384173
##           652           653           654           655           656
## -0.5631032857 -0.1259565457 -0.3998958147 -1.6111716268  1.0727648455
##           657           658           659           660           661
## -1.2615816337 -1.4230647840  0.6142254364  0.4896763970 -0.2120862760
##           662           663           664           665           666
```

```
##  0.3922971721 -1.2006691612 -0.6822484067  0.0024509945  0.7210374586
##           667           668           669           670           671
##  0.4064751496  0.1406956300  0.3780266794 -1.4473319188  0.4109933240
##           672           673           674           675           676
##  0.2149095281 -0.2113085434  0.4420632576  0.0004908585  0.6277603025
##           677           678           679           680           681
##  1.1827740871  1.5874601777  0.5554723041 -1.0877058094  0.7538899871
##           682           683           684           685           686
## -0.2003100147  1.1300842007 -0.5099300229 -0.6927593208  0.3568644895
##           687           688           689           690           691
## -0.5906507558  0.0498928826 -0.4689346725 -0.4942881646 -1.1212782553
##           692           693           694           695           696
## -1.0562481618  1.0877588427 -0.1872883688 -0.9897729550 -0.9613631873
##           697           698           699           700           701
## -3.4120958385  1.2293396682 -0.1801503222  1.0422070708 -2.0115471479
##           702           703           704           705           706
##  0.7371898265 -1.0950234020 -0.2925093043 -0.5174692223  0.0327991205
##           707           708           709           710           711
## -0.4329359488  0.6737116923  1.1012377552 -1.4241671193  0.3648175016
##           712           713           714           715           716
##  0.3479965702 -1.8596079839 -0.3147686074 -0.0593664653  1.2318057301
##           717           718           719           720           721
##  0.6055076185 -0.3898136937 -0.3594600446 -0.6632214786  0.7541069218
##           722           723           724           725           726
## -1.0540405513 -0.1305441460  0.7640613608  0.6300139514  0.0566939567
##           727           728           729           730           731
##  0.6085202762  1.2167892246  1.0423921303  1.0264173209 -0.6157312236
##           732           733           734           735           736
##  0.5302157673  1.7031786964  0.1032419248 -1.5418320845  1.9260340005
##           737           738           739           740           741
## -0.5272212716  0.3923872597  1.2307542180 -3.0430826141 -0.0192267982
##           742           743           744           745           746
## -3.0621913082  2.2357789861  0.9491989701 -0.2903401578  0.0455452665
##           747           748           749           750           751
##  0.2428787474  0.8061739351  0.7869302594 -1.1692884822 -0.2087548335
##           752           753           754           755           756
## -0.3615318537 -0.8433204485  0.3880294206 -0.3735784825  1.3720301452
##           757           758           759           760           761
##  0.6826012946  0.9444189476  0.1994916520 -2.3209151935 -1.0411329889
##           762           763           764           765           766
## -0.5718077206 -0.4709031003  0.4987717661 -0.4152659945 -0.6402511647
##           767           768           769           770           771
##  0.0509287887  0.3365572073  2.0992619543  0.6394267085 -1.1056301695
##           772           773           774           775           776
##  1.2704737734  0.5904844289  0.4436514312 -1.2312431658  0.9006359351
##           777           778           779           780           781
## -0.6429258814  1.4446148682  0.7411987907  0.8113417151  0.4214768311
##           782           783           784           785           786
## -2.4045822818 -0.0545025384 -0.1965434406 -0.3117783166  0.2873903366
##           787           788           789           790           791
## -0.3292736271 -0.1133124290  1.3972296046 -0.5566771584 -0.7130131929
##           792           793           794           795           796
## -1.2982606785  0.1368084677  0.2808884276  0.0398455654 -0.9254208162
##           797           798           799           800           801
```

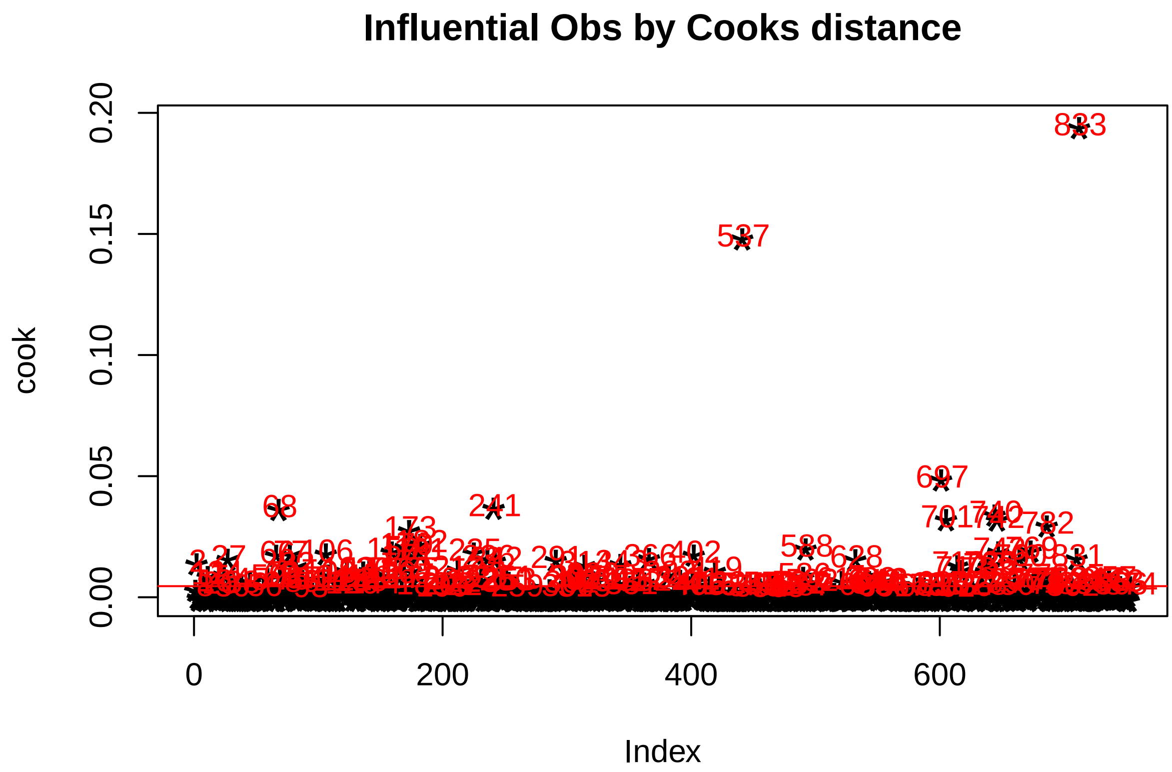
```
##  0.6295058598  0.0390828546  0.2560076156  0.5410502608  0.7587435076
##           802           803           804           805           831
## -1.0772602484 -0.8376204897  0.7341167967 -0.5746014452 -1.7380516215
##           832           833           834           835           836
## -0.8190891837 -6.3041472261 -1.1924702416 -0.3352234409  1.1370713934
##           837           838           839           840           841
##  0.3057558645 -0.1088475083  0.1896800965 -0.5725335310 -0.2638435336
##           842           843           844           845           846
##  1.1765353152 -0.2522155539  0.1473858939 -0.0636867764  0.3351703104
##           847           848           849           850           851
##  1.4487195518 -1.0583772528  0.7493371254  0.6330729757 -0.3457785894
##           852           853           854           855           856
##  0.3154172503  1.3321780050 -0.3931883711  0.4363600946 -0.3572130976
##           857           858           859           860           861
##  1.4991958049  0.5112012304  0.6926103564 -0.6828803771  0.5790872336
##           862           863           864           865           866
##  1.0378652553  1.5642963686  0.9894503799 -0.4198780848  1.4284631954
##           867           868           869           870           871
## -1.0912421661  0.4116838519  0.5747837771  0.0751120138 -0.3362813899
##           872           873           874
##  0.8098663254  0.0592648103 -1.4200490005
```

```r
## get sample size
n <- nrow(df)

## Bonferroni correction: alpha/n
alpha <- 0.05/n

## critical t value
degf <- n - length(coef(bm1))-1 # should be more due to REs?
t_crit <- qt(1 - alpha/2, degf)

## compare t_stud to t_crit
sum(stud_e > t_crit, na.rm = TRUE)
```

```
## [1] 0
```

Cook's Distance

```r
## Cook's D
cook <- cooks.distance(bm1)

# Plot the Cook's Distance using the traditional 4/n criterion
sample_size <- nrow(df)
plot(cook, pch="*", cex=2, main="Influential Obs by Cooks distance")  # plot cook's distance
abline(h = 4/sample_size, col="red")  # add cutoff line
text(x=1:length(cook)+1, y=cook, labels=ifelse(cook>4/sample_size, names(cook),""), col="red")  # add l
```



Confidence Intervals

```
# predict values
pred <- predict(bm1,re.form = NA)

# Bootstrap CI
boot <- bootMer(bm1, predict, nsim = 100, re.form = NA)
std.err <- apply(boot$t, 2, sd)
CI.lo <- pred - std.err*1.96
CI.hi <- pred + std.err*1.96

# Plot?
```

Prediction