warmXtrophic Project: Herbivory Analyses

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Load in and prepare data for analyses

```
# Clear all existing data
rm(list=ls())

#Load packages
library(tidyverse)
library(lmerTest)
library(olsrr)
library(predictmeans)
library(car)
library(fitdistrplus)
library(MASS)
library(pscl)
library(lmtest)
library(emmeans)
library(bbmle)

# Get data
#Sys.getenv("L1DIR")
L1_dir<-Sys.getenv("L1DIR")
#list.files(L1_dir)
herb <- read.csv(file.path(L1_dir, "herbivory/final_herbivory_L1.csv"))

# changing scale of years
herb$year1<-herb$year
herb$year[herb$year == 2015] <- 1
herb$year[herb$year == 2016] <- 2
herb$year[herb$year == 2017] <- 3
herb$year[herb$year == 2018] <- 4
herb$year[herb$year == 2019] <- 5
herb$year[herb$year == 2020] <- 6

# Remove NAs
herb <- herb[complete.cases(herb),]

# create dataframes for kbs and umbs only for plots with no insecticide
herb_kbs <- subset(herb, site == "kbs" & insecticide == "insects")
herb_umbs <- subset(herb, site == "umbs" & insecticide == "insects")

# only keep species that were recorded in both warmed and ambient plots
```

```
herb_kbs <- herb_kbs %>%
        group_by(species) %>%
        filter(all(c('warmed', 'ambient') %in% state))
herb_umbs <- herb_umbs %>%
        group_by(species) %>%
        filter(all(c('warmed', 'ambient') %in% state))

# checking to see if any species/state combos are all zeros
with(herb_kbs,table(species,state,p_eaten==0))
```

```
## , ,  = FALSE
##
##        state
## species ambient warmed
##    Cest      78     39
##    Eugr      33     65
##    Hisp      27     11
##    Hype       0      5
##    Phpr      13     21
##    Popr      19     14
##    Soca     192    173
##
## , ,  = TRUE
##
##        state
## species ambient warmed
##    Cest      64     42
##    Eugr      44    103
##    Hisp     165    117
##    Hype       8     11
##    Phpr      27     51
##    Popr     183    176
##    Soca     217    244
```

```
with(herb_umbs,table(species,state,p_eaten==0))
```

```
## , ,  = FALSE
##
##        state
## species ambient warmed
##    Cape      10     14
##    Cest     142    175
##    Dasp      49     65
##    Hype       9      8
##    Poco       6     43
##    Popr       1     11
##    Posp      25     17
##    Ptaq      27     39
##    Ruac      80     98
##
## , ,  = TRUE
##
##        state
## species ambient warmed
```

```
##    Cape      70     10
##    Cest     182    153
##    Dasp     131     87
##    Hype      55     40
##    Poco       6     21
##    Popr     107     85
##    Posp      23     47
##    Ptaq      29     65
##    Ruac      64    102
```

```
# number of observation per species/state combo (to find rare species)
herb_kbs %>% count(state, species)
```

```
## # A tibble: 14 x 3
## # Groups:   species [7]
##    species state       n
##    <chr>   <chr>   <int>
##  1 Cest    ambient   142
##  2 Cest    warmed     81
##  3 Eugr    ambient    77
##  4 Eugr    warmed    168
##  5 Hisp    ambient   192
##  6 Hisp    warmed    128
##  7 Hype    ambient     8
##  8 Hype    warmed     16
##  9 Phpr    ambient    40
## 10 Phpr    warmed     72
## 11 Popr    ambient   202
## 12 Popr    warmed    190
## 13 Soca    ambient   409
## 14 Soca    warmed    417
```

```
herb_umbs %>% count(state, species)
```

```
## # A tibble: 18 x 3
## # Groups:   species [9]
##    species state       n
##    <chr>   <chr>   <int>
##  1 Cape    ambient    80
##  2 Cape    warmed     24
##  3 Cest    ambient   324
##  4 Cest    warmed    328
##  5 Dasp    ambient   180
##  6 Dasp    warmed    152
##  7 Hype    ambient    64
##  8 Hype    warmed     48
##  9 Poco    ambient    12
## 10 Poco    warmed     64
## 11 Popr    ambient   108
## 12 Popr    warmed     96
## 13 Posp    ambient    48
## 14 Posp    warmed     64
## 15 Ptaq    ambient    56
## 16 Ptaq    warmed    104
## 17 Ruac    ambient   144
```

```
## 18 Ruac    warmed    200
```

```
# removing rare species from KBS
herb_kbs <- herb_kbs[!grepl("Hype",herb_kbs$species),]
herb_kbs %>% count(state, species)
```

```
## # A tibble: 12 x 3
## # Groups:   species [6]
##    species state       n
##    <chr>   <chr>   <int>
##  1 Cest    ambient   142
##  2 Cest    warmed     81
##  3 Eugr    ambient    77
##  4 Eugr    warmed    168
##  5 Hisp    ambient   192
##  6 Hisp    warmed    128
##  7 Phpr    ambient    40
##  8 Phpr    warmed     72
##  9 Popr    ambient   202
## 10 Popr    warmed    190
## 11 Soca    ambient   409
## 12 Soca    warmed    417
```

```
# How much of the data is zeros?
100*sum(herb_kbs$p_eaten == 0)/nrow(herb_kbs) #68% - thats a lot! probably have to use a zero-inflated
```

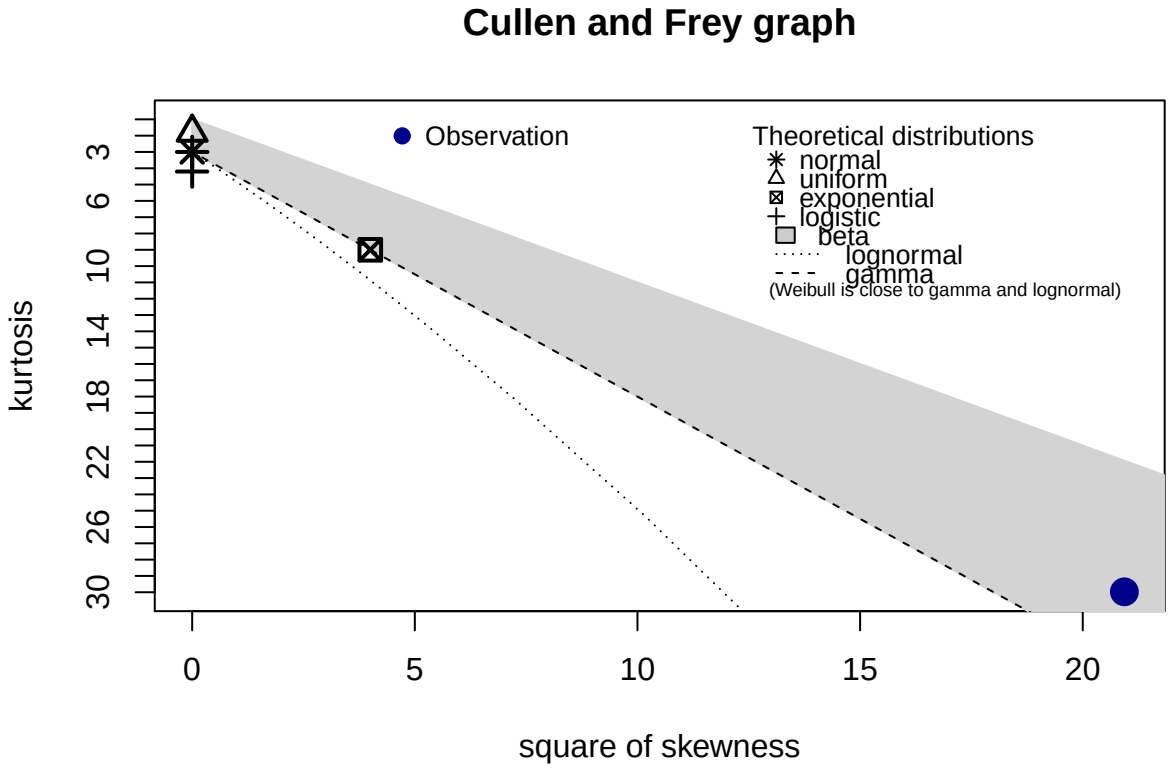
```
## [1] 67.65817
```

```
# but I'll still check for normality & try some transformations below
100*sum(herb_umbs$p_eaten == 0)/nrow(herb_umbs) #61%
```

```
## [1] 60.92557
```

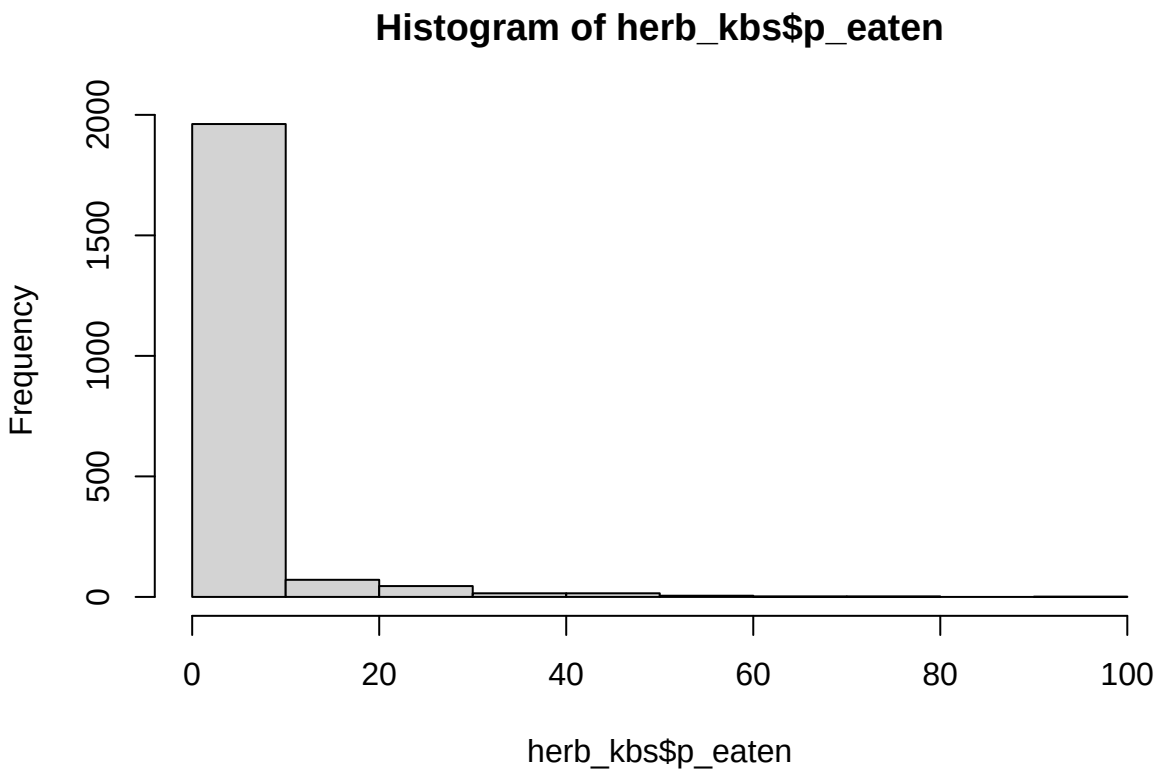
KBS Data Exploration

```
descdist(herb_kbs$p_eaten, discrete = FALSE)
```

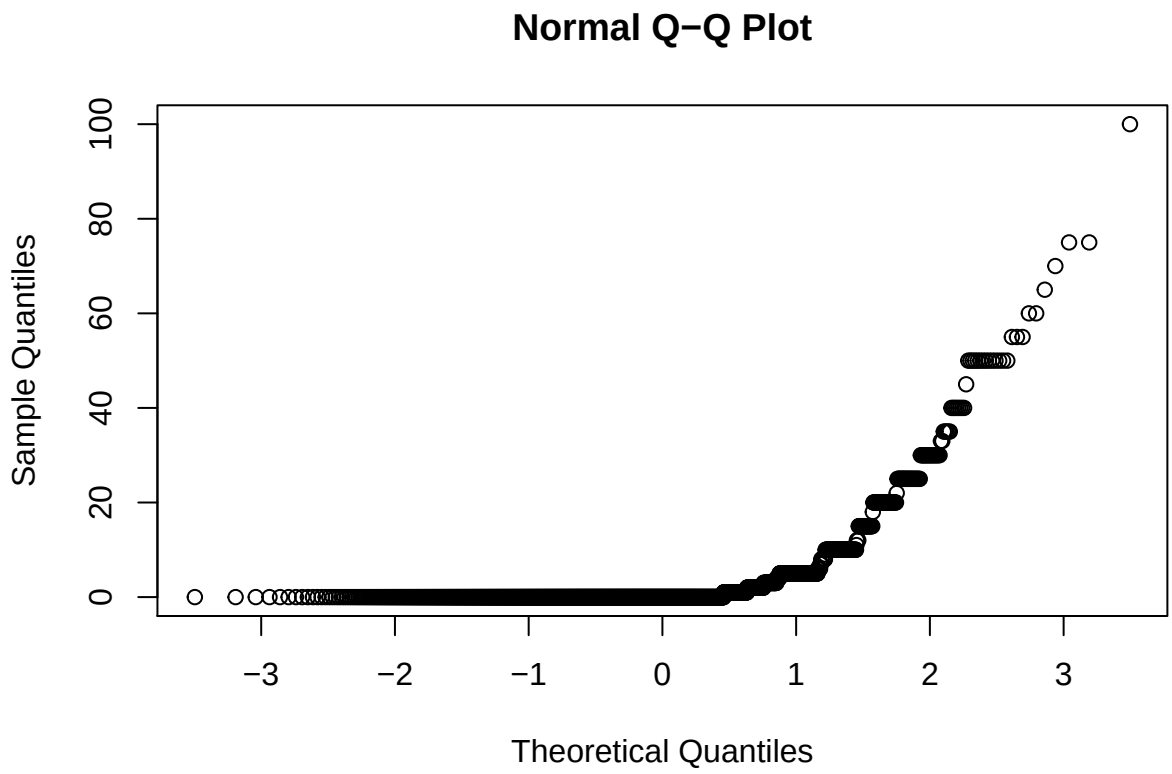



```
## summary statistics
## ------
## min:  0   max:  100
## median:  0
## mean:  3.1322
## estimated sd:  8.497325
## estimated skewness:  4.575498
## estimated kurtosis:  29.97498
```

```
# normal distribution?
hist(herb_kbs$p_eaten)
```




```
qqnorm(herb_kbs$p_eaten)
```

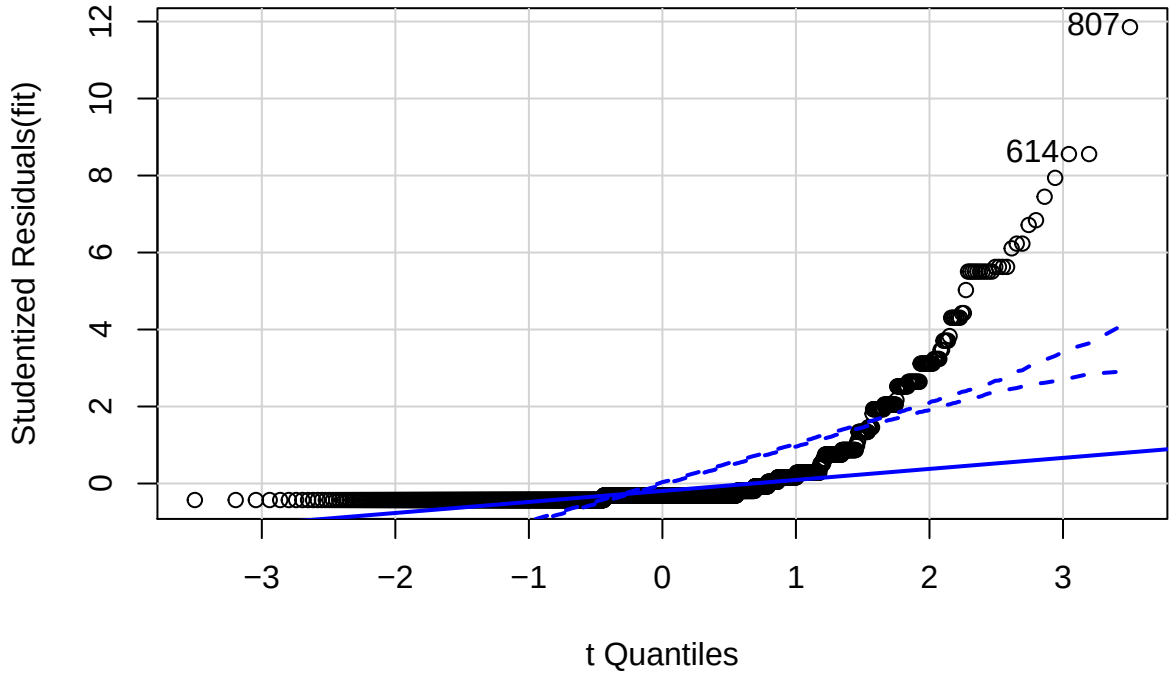



```
shapiro.test(herb_kbs$p_eaten)
```

```
##
```

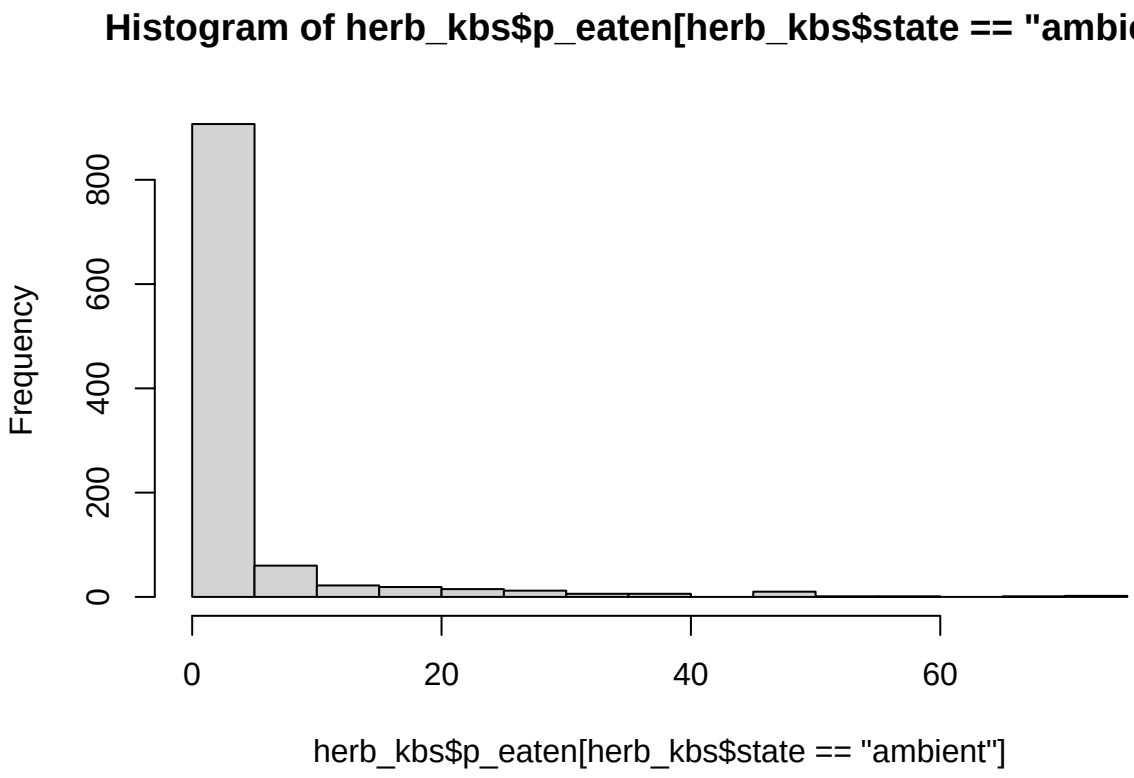
```
##  Shapiro-Wilk normality test
##
## data:  herb_kbs$p_eaten
## W = 0.41878, p-value < 2.2e-16
```

```
fit <- lm(p_eaten~state, data = herb_kbs)
qqPlot(fit)
```

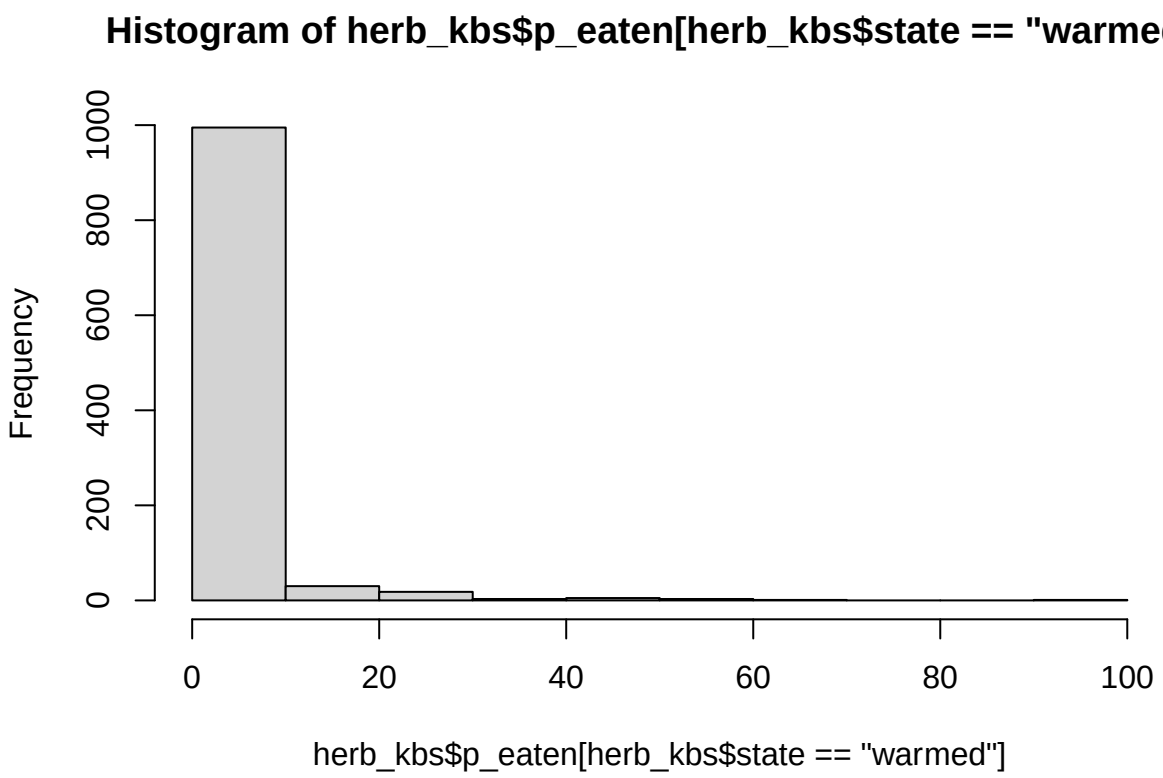



```
## [1] 614 807
```

```
# looking at each treatment separately
hist(herb_kbs$p_eaten[herb_kbs$state == "ambient"])
```



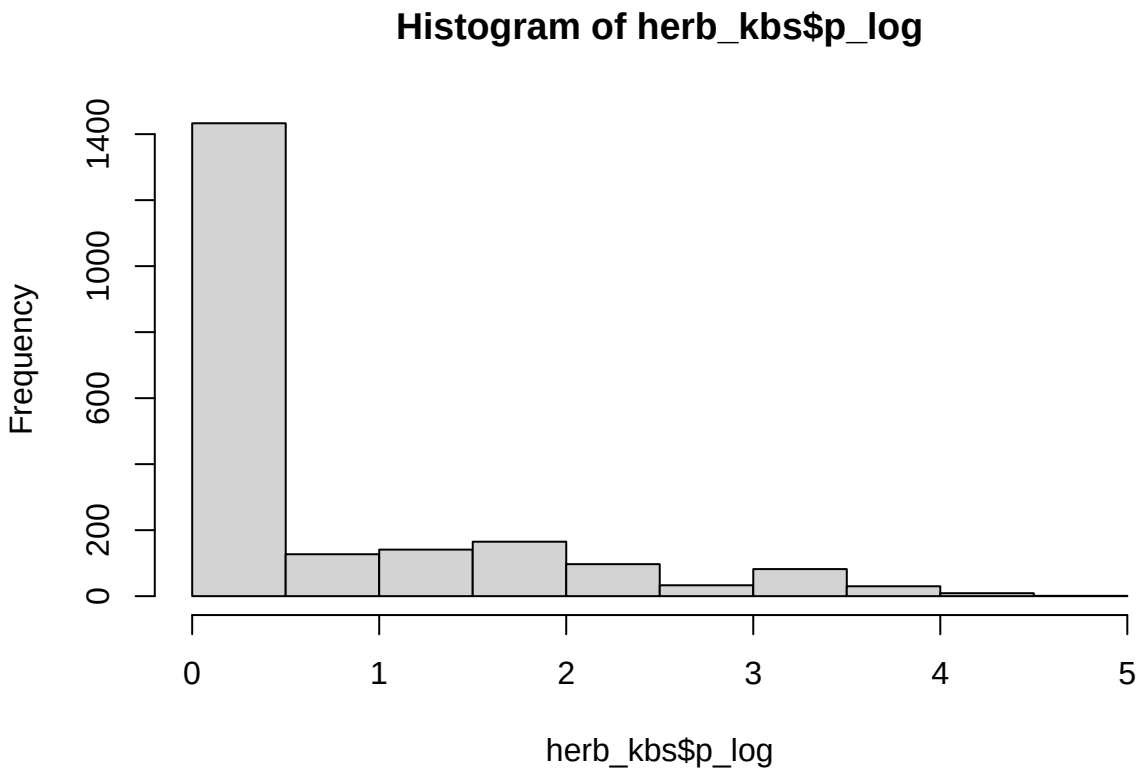

```r
hist(herb_kbs$p_eaten[herb_kbs$state == "warmed"])
```



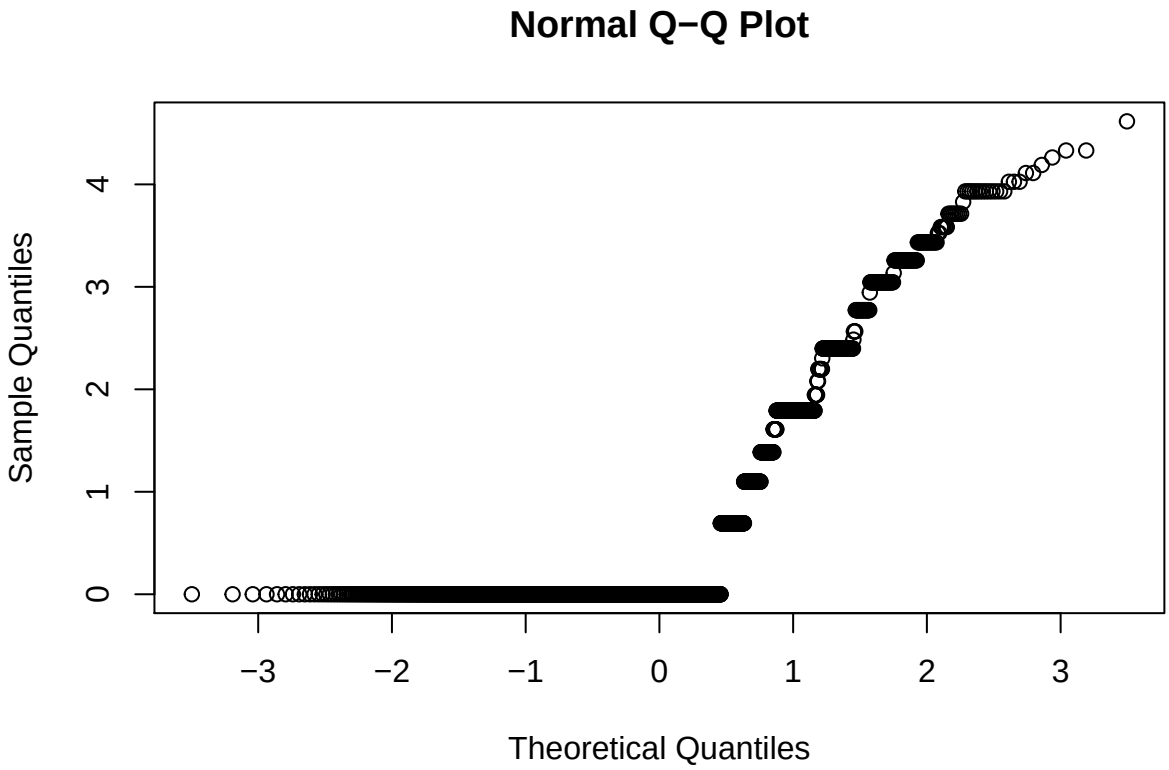

```r
# gamma distribution? - error message "the function mle failed to estimate the parameters"
#fit.gamma <- fitdist(herb_kbs$p_eaten, "gamma")
#plot(fit.gamma)
```

```
# lognormal distribution? - error message "values must be positive to fit a lognormal"
#fit.ln <- fitdist(herb_kbs$p_eaten, "lnorm")
#plot(fit.ln)

# log transform
herb_kbs$p_log <- log(herb_kbs$p_eaten+1)
hist(herb_kbs$p_log)
```



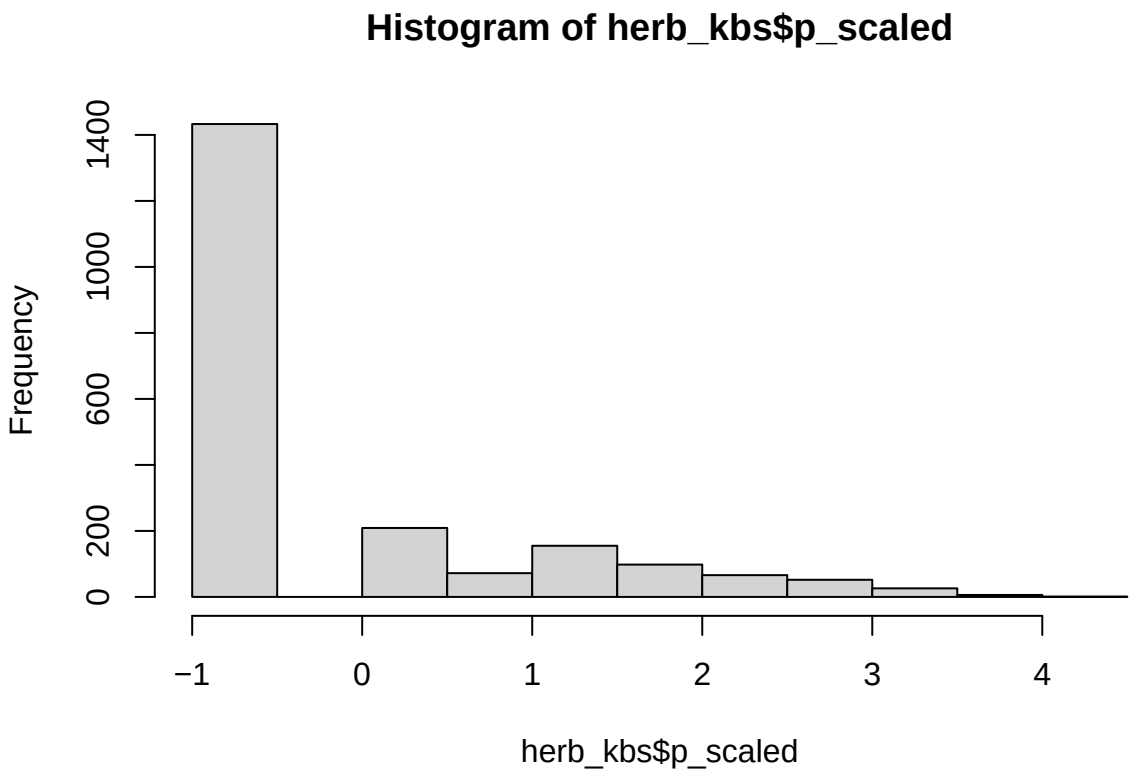

```
qqnorm(herb_kbs$p_log)
```



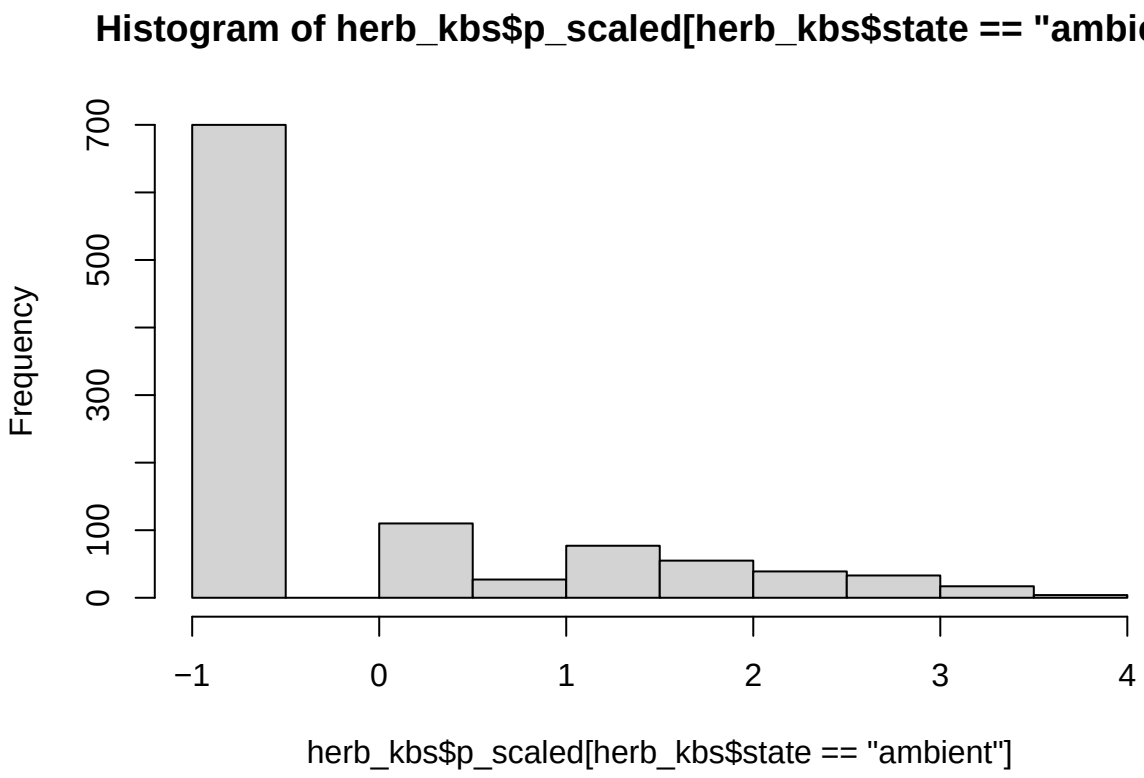

```
shapiro.test(herb_kbs$p_log) # NAs - data contains 0s
```

```
##
##  Shapiro-Wilk normality test
##
## data:  herb_kbs$p_log
## W = 0.65296, p-value < 2.2e-16
```

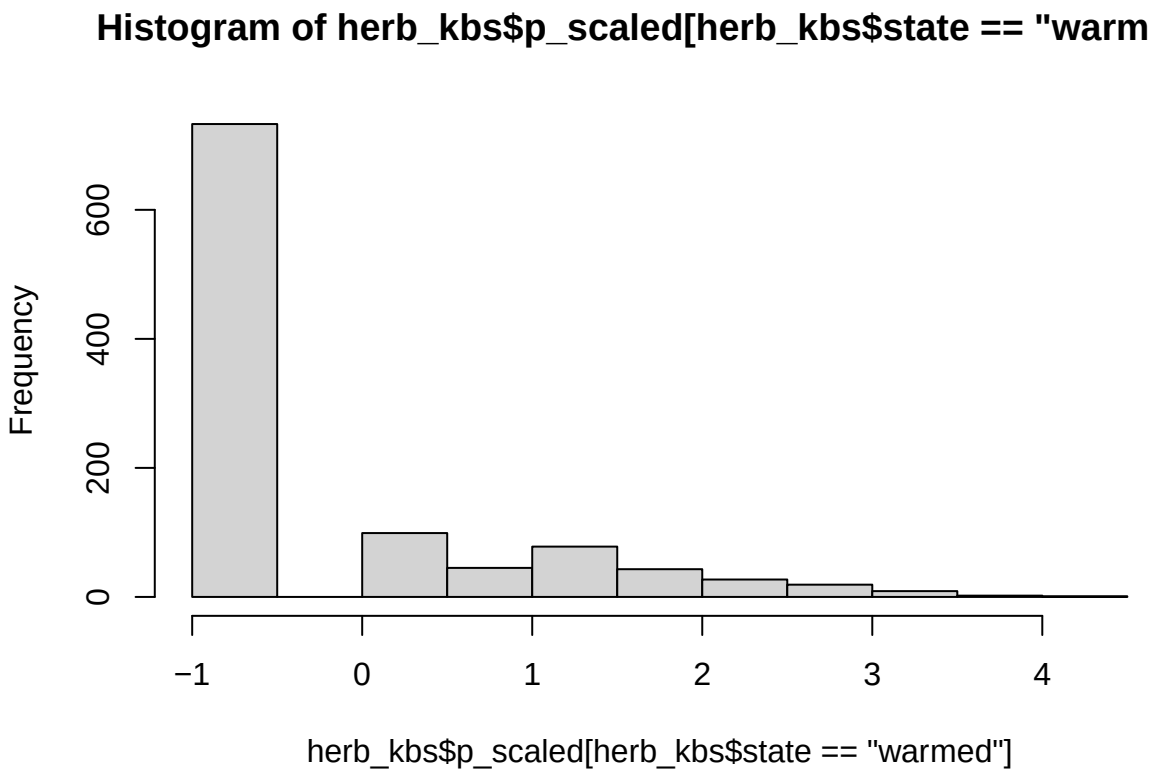
```
# mean centering p_eaten
herb_kbs$p_scaled <- herb_kbs$p_log - mean(herb_kbs$p_log)
hist(herb_kbs$p_scaled)
```



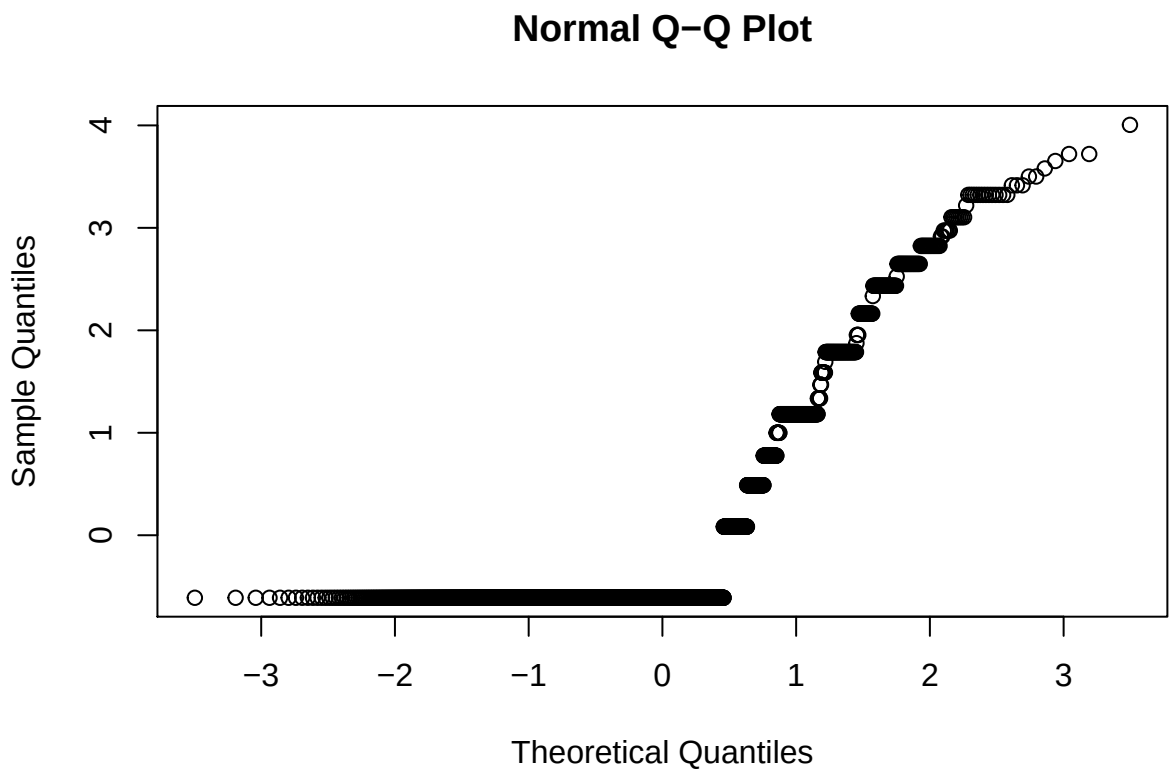

```
hist(herb_kbs$p_scaled[herb_kbs$state == "ambient"])
```




```
hist(herb_kbs$p_scaled[herb_kbs$state == "warmed"])
```




```
qqnorm(herb_kbs$p_scaled)
```

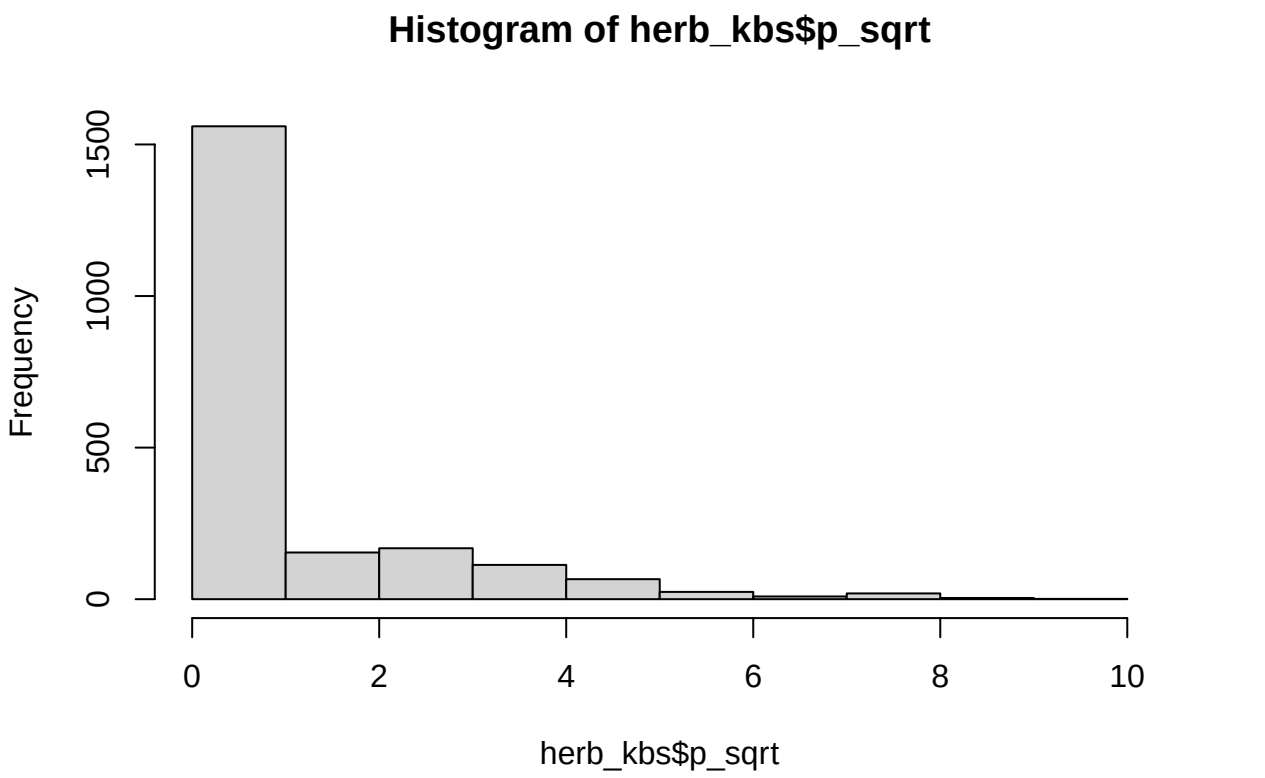



```
shapiro.test(herb_kbs$p_scaled)
```

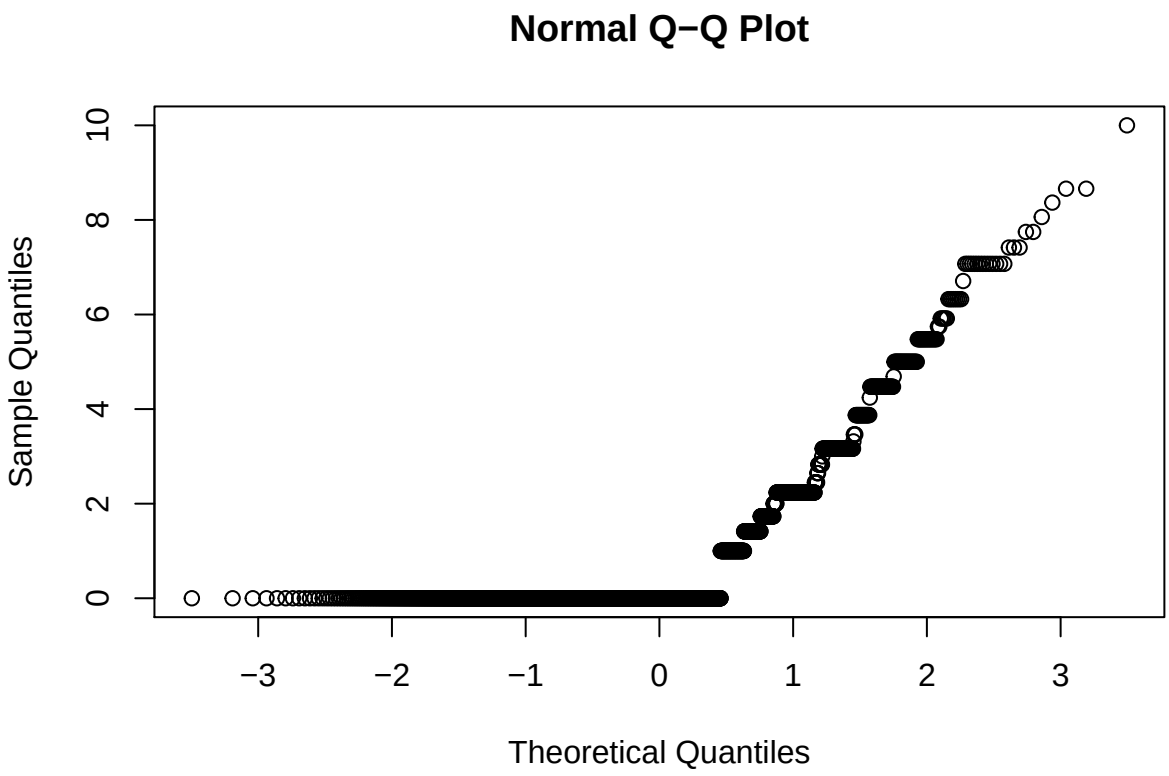
```
##
```

```
##  Shapiro-Wilk normality test
##
## data:  herb_kbs$p_scaled
## W = 0.65296, p-value < 2.2e-16
```

```
# square root?
herb_kbs$p_sqrt <- sqrt(herb_kbs$p_eaten)
hist(herb_kbs$p_sqrt)
```




```
qqnorm(herb_kbs$p_sqrt)
```




```
shapiro.test(herb_kbs$p_sqrt)
```

```
##
##  Shapiro-Wilk normality test
##
## data:  herb_kbs$p_sqrt
## W = 0.62798, p-value < 2.2e-16
```

Transformations are a no-go

Going to try a zero-inflated model due to the excess number of zeros in the data

```
# mean and var of non-zero counts
herb_kbs %>%
  dplyr::filter(p_eaten != "0") %>%
  dplyr::summarize(mean_eaten = mean(p_eaten, na.rm=T), var_eaten = var(p_eaten, na.rm=T))
```

```
## `summarise()` ungrouping output (override with `.groups` argument)
```

```
## # A tibble: 6 x 3
##   species mean_eaten var_eaten
##   <chr>        <dbl>     <dbl>
## 1 Cest          9.41     156.
## 2 Eugr          6.60      66.3
## 3 Hisp         10.9      210.
## 4 Phpr         14.3      445.
## 5 Popr         17.8      455.
## 6 Soca          9.31     120.
```

```
# variance is also > mean, so can't be poisson
# I'll try zero-inflated negative binomial due to an excess of zeros
```

```r
# zero-inflated negative binomial
# state as a fixed effect
k.m1 <- zeroinfl(p_eaten ~ state,
                 dist = 'negbin',
                 data = herb_kbs)
summary(k.m1)
```

```
##
## Call:
## zeroinfl(formula = p_eaten ~ state, data = herb_kbs, dist = "negbin")
##
## Pearson residuals:
##     Min      1Q  Median      3Q     Max
## -0.3791 -0.3791 -0.3650 -0.1706 13.5408
##
## Count model coefficients (negbin with log link):
##             Estimate Std. Error z value Pr(>|z|)
## (Intercept)   1.8793     0.1236  15.208  < 2e-16 ***
## statewarmed  -0.2704     0.1225  -2.208   0.0273 *
## Log(theta)   -1.1840     0.1778  -6.657 2.79e-11 ***
##
## Zero-inflation model coefficients (binomial with logit link):
##             Estimate Std. Error z value Pr(>|z|)
## (Intercept)  -0.2221     0.2274  -0.977    0.329
## statewarmed   0.1209     0.1466   0.825    0.410
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Theta = 0.3061
## Number of iterations in BFGS optimization: 14
## Log-likelihood: -3478 on 5 Df
```

```r
# state and year as fixed effects
k.m2 <- zeroinfl(p_eaten ~ state + as.factor(year),
                 dist = 'negbin',
                 data = herb_kbs)
summary(k.m2)
```

```
##
## Call:
## zeroinfl(formula = p_eaten ~ state + as.factor(year), data = herb_kbs,
##     dist = "negbin")
##
## Pearson residuals:
##      Min       1Q   Median       3Q      Max
## -0.71839 -0.44651 -0.41647 -0.03154 24.51222
##
## Count model coefficients (negbin with log link):
##                   Estimate Std. Error z value Pr(>|z|)
## (Intercept)        0.44518    0.11989   3.713 0.000205 ***
## statewarmed       -0.16251    0.09187  -1.769 0.076902 .
## as.factor(year)2   1.42300    0.14034  10.140  < 2e-16 ***
## as.factor(year)3   2.21892    0.17820  12.452  < 2e-16 ***
## as.factor(year)4   2.19989    0.16157  13.616  < 2e-16 ***
```

```
## as.factor(year)5  2.18813    0.14669  14.917  < 2e-16 ***
## as.factor(year)6 -0.51223    0.23018  -2.225 0.026058 *
## Log(theta)       -0.25988    0.09587  -2.711 0.006716 **
##
## Zero-inflation model coefficients (binomial with logit link):
##                  Estimate Std. Error z value Pr(>|z|)
## (Intercept)       -9.6472    70.3916  -0.137    0.891
## statewarmed        0.1375     0.1138   1.208    0.227
## as.factor(year)2   9.9493    70.3907   0.141    0.888
## as.factor(year)3  10.0800    70.3911   0.143    0.886
## as.factor(year)4  10.5992    70.3912   0.151    0.880
## as.factor(year)5  10.0197    70.3910   0.142    0.887
## as.factor(year)6   9.4078    70.3904   0.134    0.894
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Theta = 0.7711
## Number of iterations in BFGS optimization: 32
## Log-likelihood: -3324 on 15 Df
```

```
lrtest(k.m1, k.m2) # model 2
```

```
## Likelihood ratio test
##
## Model 1: p_eaten ~ state
## Model 2: p_eaten ~ state + as.factor(year)
##   #Df  LogLik Df  Chisq Pr(>Chisq)
## 1   5 -3478.4
## 2  15 -3324.2 10 308.54  < 2.2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
# state and growth habit as fixed effects
herb_kbs <- within(herb_kbs, growth_habit <- relevel(factor(growth_habit), ref = "Forb")) # releveling
k.m3 <- zeroinfl(p_eaten ~ state + growth_habit,
                 dist = 'negbin',
                 data = herb_kbs)
summary(k.m3)
```

```
##
## Call:
## zeroinfl(formula = p_eaten ~ state + growth_habit, data = herb_kbs, dist = "negbin")
##
## Pearson residuals:
##     Min      1Q  Median      3Q     Max
## -0.4727 -0.4510 -0.2344 -0.1775 12.4665
##
## Count model coefficients (negbin with log link):
##                       Estimate Std. Error z value Pr(>|z|)
## (Intercept)             1.8335     0.1138  16.115  < 2e-16 ***
## statewarmed            -0.2884     0.1177  -2.451 0.014252 *
## growth_habit            0.1991     0.2617   0.761 0.446673
## growth_habitGraminoid   0.7194     0.2029   3.546 0.000391 ***
## Log(theta)             -1.0808     0.1624  -6.654 2.85e-11 ***
##
```

```
## Zero-inflation model coefficients (binomial with logit link):
##                       Estimate Std. Error z value Pr(>|z|)
## (Intercept)            -1.0996     0.3332  -3.301 0.000965 ***
## statewarmed             0.2366     0.1699   1.393 0.163696
## growth_habit            2.4997     0.3064   8.158 3.42e-16 ***
## growth_habitGraminoid   2.4265     0.2801   8.663  < 2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Theta = 0.3393
## Number of iterations in BFGS optimization: 18
## Log-likelihood: -3340 on 9 Df
```

```
lrtest(k.m2, k.m3) # model 2
```

```
## Likelihood ratio test
##
## Model 1: p_eaten ~ state + as.factor(year)
## Model 2: p_eaten ~ state + growth_habit
##   #Df  LogLik Df  Chisq Pr(>Chisq)
## 1  15 -3324.2
## 2   9 -3340.4 -6 32.431  1.349e-05 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
# state, growth habit, and year as fixed effects
k.m4 <- zeroinfl(p_eaten ~ state + growth_habit + as.factor(year),
                 dist = 'negbin',
                 data = herb_kbs)
summary(k.m4)
```

```
##
## Call:
## zeroinfl(formula = p_eaten ~ state + growth_habit + as.factor(year),
##     data = herb_kbs, dist = "negbin")
##
## Pearson residuals:
##     Min      1Q  Median      3Q     Max
## -0.7411 -0.4548 -0.2839 -0.1254 25.0060
##
## Count model coefficients (negbin with log link):
##                       Estimate Std. Error z value Pr(>|z|)
## (Intercept)            0.49467    0.14961   3.306 0.000945 ***
## statewarmed           -0.21211    0.08821  -2.405 0.016189 *
## growth_habit          -0.32882    0.19555  -1.682 0.092664 .
## growth_habitGraminoid  1.00010    0.15612   6.406 1.49e-10 ***
## as.factor(year)2       1.04559    0.16519   6.330 2.45e-10 ***
## as.factor(year)3       2.03927    0.19241  10.599  < 2e-16 ***
## as.factor(year)4       2.21073    0.17883  12.362  < 2e-16 ***
## as.factor(year)5       2.21518    0.17006  13.026  < 2e-16 ***
## as.factor(year)6      -0.47038    0.23756  -1.980 0.047694 *
## Log(theta)            -0.13935    0.10226  -1.363 0.172982
##
## Zero-inflation model coefficients (binomial with logit link):
##                       Estimate Std. Error z value Pr(>|z|)
```

```
## (Intercept)            -3.8052     4.0358  -0.943    0.346
## statewarmed             0.1768     0.1297   1.363    0.173
## growth_habit            2.2262     0.2111  10.544   <2e-16 ***
## growth_habitGraminoid   2.3299     0.1794  12.990   <2e-16 ***
## as.factor(year)2        2.8667     4.0061   0.716    0.474
## as.factor(year)3        4.1000     4.0258   1.018    0.308
## as.factor(year)4        3.7975     4.0235   0.944    0.345
## as.factor(year)5        3.2467     4.0205   0.808    0.419
## as.factor(year)6        3.6621     4.0145   0.912    0.362
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Theta = 0.8699
## Number of iterations in BFGS optimization: 32
## Log-likelihood: -3155 on 19 Df
```

```
lrtest(k.m2, k.m4) # model 4
```

```
## Likelihood ratio test
##
## Model 1: p_eaten ~ state + as.factor(year)
## Model 2: p_eaten ~ state + growth_habit + as.factor(year)
##   #Df  LogLik Df  Chisq Pr(>Chisq)
## 1  15 -3324.2
## 2  19 -3155.4  4 337.52  < 2.2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
# interaction between state and growth habit as fixed effects
k.m5 <- zeroinfl(p_eaten ~ state * growth_habit,
                 dist = 'negbin',
                 data = herb_kbs)
summary(k.m5)
```

```
##
## Call:
## zeroinfl(formula = p_eaten ~ state * growth_habit, data = herb_kbs, dist = "negbin")
##
## Pearson residuals:
##     Min      1Q  Median      3Q     Max
## -0.4762 -0.4463 -0.2255 -0.1741 12.0804
##
## Count model coefficients (negbin with log link):
##                                 Estimate Std. Error z value Pr(>|z|)
## (Intercept)                      1.81793    0.12149  14.964  < 2e-16 ***
## statewarmed                     -0.26877    0.12954  -2.075  0.03801 *
## growth_habit                     0.17585    0.31430   0.560  0.57582
## growth_habitGraminoid            0.76152    0.29406   2.590  0.00961 **
## statewarmed:growth_habit         0.09784    0.57356   0.171  0.86456
## statewarmed:growth_habitGraminoid -0.08490    0.40707  -0.209  0.83479
## Log(theta)                      -1.09260    0.16784  -6.510 7.52e-11 ***
##
## Zero-inflation model coefficients (binomial with logit link):
##                                 Estimate Std. Error z value Pr(>|z|)
## (Intercept)                      -1.1861     0.3989  -2.973  0.00295 **
```

```
## statewarmed                          0.3549     0.2611   1.360  0.17393
## growth_habit                         2.4733     0.3930   6.293 3.11e-10 ***
## growth_habitGraminoid                2.6617     0.3847   6.919 4.55e-12 ***
## statewarmed:growth_habit             0.2041     0.4952   0.412  0.68028
## statewarmed:growth_habitGraminoid   -0.4306     0.3916  -1.100  0.27141
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Theta = 0.3353
## Number of iterations in BFGS optimization: 22
## Log-likelihood: -3339 on 13 Df
```

```
lrtest(k.m4, k.m5) # model 4
```

```
## Likelihood ratio test
##
## Model 1: p_eaten ~ state + growth_habit + as.factor(year)
## Model 2: p_eaten ~ state * growth_habit
##   #Df  LogLik Df  Chisq Pr(>Chisq)
## 1  19 -3155.4
## 2  13 -3339.4 -6 367.97  < 2.2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
# interaction between state and growth habit as fixed effects, plus year
k.m6 <- zeroinfl(p_eaten ~ state * growth_habit + as.factor(year),
                 dist = 'negbin',
                 data = herb_kbs)
summary(k.m6)
```

```
##
## Call:
## zeroinfl(formula = p_eaten ~ state * growth_habit + as.factor(year),
##     data = herb_kbs, dist = "negbin")
##
## Pearson residuals:
##     Min      1Q  Median      3Q     Max
## -0.7380 -0.4559 -0.2932 -0.1375 24.8209
##
## Count model coefficients (negbin with log link):
##                                   Estimate Std. Error z value Pr(>|z|)
## (Intercept)                        0.470803   0.149260   3.154  0.00161 **
## statewarmed                       -0.155999   0.095415  -1.635  0.10206
## growth_habit                      -0.312403   0.228490  -1.367  0.17155
## growth_habitGraminoid              1.234010   0.214060   5.765 8.18e-09 ***
## as.factor(year)2                   1.041649   0.164115   6.347 2.19e-10 ***
## as.factor(year)3                   2.069581   0.192776  10.736  < 2e-16 ***
## as.factor(year)4                   2.216598   0.177989  12.454  < 2e-16 ***
## as.factor(year)5                   2.207352   0.169315  13.037  < 2e-16 ***
## as.factor(year)6                  -0.487341   0.237227  -2.054  0.03994 *
## statewarmed:growth_habit          -0.001963   0.407694  -0.005  0.99616
## statewarmed:growth_habitGraminoid -0.504858   0.287675  -1.755  0.07927 .
## Log(theta)                        -0.129596   0.101683  -1.275  0.20248
##
## Zero-inflation model coefficients (binomial with logit link):
```

```
##                                  Estimate Std. Error z value Pr(>|z|)
## (Intercept)                       -3.6332     3.3116  -1.097    0.273
## statewarmed                        0.2195     0.1603   1.369    0.171
## growth_habit                       2.1203     0.2563   8.272   <2e-16 ***
## growth_habitGraminoid              2.4782     0.2395  10.346   <2e-16 ***
## as.factor(year)2                   2.6837     3.2845   0.817    0.414
## as.factor(year)3                   3.9208     3.3036   1.187    0.235
## as.factor(year)4                   3.6122     3.3012   1.094    0.274
## as.factor(year)5                   3.0516     3.2986   0.925    0.355
## as.factor(year)6                   3.4608     3.2955   1.050    0.294
## statewarmed:growth_habit           0.3307     0.4308   0.767    0.443
## statewarmed:growth_habitGraminoid -0.3176     0.3139  -1.012    0.312
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Theta = 0.8785
## Number of iterations in BFGS optimization: 34
## Log-likelihood: -3153 on 23 Df
```

```
lrtest(k.m4, k.m6) # virtually the same, keeping model 4 because its simpler
```

```
## Likelihood ratio test
##
## Model 1: p_eaten ~ state + growth_habit + as.factor(year)
## Model 2: p_eaten ~ state * growth_habit + as.factor(year)
##   #Df  LogLik Df  Chisq Pr(>Chisq)
## 1  19 -3155.4
## 2  23 -3153.0  4 4.7846     0.3101
```

```
# calculating effect size of graminoids vs forb herbivory - accounting for log link
exp(0.470803 + 1.234010*0) # 1.60128
```

```
## [1] 1.60128
```

```
exp(0.470803 + 1.234010*1) # 5.500357
```

```
## [1] 5.500357
```

```
# effect of herbivory:
5.500357 - 1.60128 # 3.899077
```

```
## [1] 3.899077
```

```
# interaction between state, growth habit, and year (year as a factor wouldn't work - non-finite value)
k.m7 <- zeroinfl(p_eaten ~ state * growth_habit * year,
                 dist = 'negbin',
                 data = herb_kbs)
summary(k.m7)
```

```
##
## Call:
## zeroinfl(formula = p_eaten ~ state * growth_habit * year, data = herb_kbs,
##     dist = "negbin")
##
## Pearson residuals:
##      Min       1Q   Median       3Q      Max
## -0.56843 -0.40006 -0.26576 -0.08172 11.76507
##
```

```
## Count model coefficients (negbin with log link):
##                                       Estimate Std. Error z value Pr(>|z|)
## (Intercept)                            0.77601    0.22791   3.405 0.000662 ***
## statewarmed                           -0.45569    0.30759  -1.482 0.138468
## growth_habit                          -1.65557    1.02935  -1.608 0.107756
## growth_habitGraminoid                  2.20228    0.65545   3.360 0.000780 ***
## year                                   0.33931    0.06416   5.288 1.24e-07 ***
## statewarmed:growth_habit               0.79064    1.93084   0.409 0.682186
## statewarmed:growth_habitGraminoid     -2.76514    1.36096  -2.032 0.042179 *
## statewarmed:year                       0.02585    0.08696   0.297 0.766234
## growth_habit:year                      0.35538    0.25021   1.420 0.155512
## growth_habitGraminoid:year            -0.45555    0.22861  -1.993 0.046298 *
## statewarmed:growth_habit:year         -0.17471    0.44274  -0.395 0.693128
## statewarmed:growth_habitGraminoid:year  1.12621    0.54740   2.057 0.039650 *
## Log(theta)                            -0.80962    0.14393  -5.625 1.86e-08 ***
##
## Zero-inflation model coefficients (binomial with logit link):
##                                       Estimate Std. Error z value Pr(>|z|)
## (Intercept)                            -2.3035     0.6130  -3.758 0.000171 ***
## statewarmed                            -0.6725     0.8506  -0.791 0.429165
## growth_habit                            4.4783     1.0629   4.213 2.52e-05 ***
## growth_habitGraminoid                   2.0373     0.7860   2.592 0.009542 **
## year                                    0.4131     0.1112   3.716 0.000202 ***
## statewarmed:growth_habit                2.3181     2.0202   1.147 0.251180
## statewarmed:growth_habitGraminoid      -0.4083     1.1837  -0.345 0.730171
## statewarmed:year                        0.1739     0.1680   1.035 0.300601
## growth_habit:year                      -0.6463     0.2452  -2.636 0.008396 **
## growth_habitGraminoid:year              0.2075     0.2163   0.959 0.337456
## statewarmed:growth_habit:year          -0.4303     0.4575  -0.941 0.346929
## statewarmed:growth_habitGraminoid:year  0.2377     0.3445   0.690 0.490296
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Theta = 0.445
## Number of iterations in BFGS optimization: 34
## Log-likelihood: -3266 on 25 Df
```

```
lrtest(k.m4, k.m7) # model 4
```

```
## Likelihood ratio test
##
## Model 1: p_eaten ~ state + growth_habit + as.factor(year)
## Model 2: p_eaten ~ state * growth_habit * year
##   #Df  LogLik Df Chisq Pr(>Chisq)
## 1  19 -3155.4
## 2  25 -3266.0  6 221.1  < 2.2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
# state and origin as fixed effects
herb_kbs <- within(herb_kbs, origin <- relevel(factor(origin), ref = "Native")) # releveling so native
k.m8 <- zeroinfl(p_eaten ~ state + origin,
                 dist = 'negbin',
                 data = herb_kbs)
summary(k.m8)
```

```
##
## Call:
## zeroinfl(formula = p_eaten ~ state + origin, data = herb_kbs, dist = "negbin")
##
## Pearson residuals:
##     Min      1Q  Median      3Q     Max
## -0.4643 -0.4335 -0.2957 -0.1633 12.6798
##
## Count model coefficients (negbin with log link):
##              Estimate Std. Error z value Pr(>|z|)
## (Intercept)    1.7525     0.1307  13.411  < 2e-16 ***
## statewarmed   -0.2265     0.1206  -1.878   0.0604 .
## originBoth     0.2241     0.2702   0.830   0.4068
## originExotic   0.3493     0.1395   2.503   0.0123 *
## Log(theta)    -1.1607     0.1757  -6.606 3.94e-11 ***
##
## Zero-inflation model coefficients (binomial with logit link):
##              Estimate Std. Error z value Pr(>|z|)
## (Intercept)   -1.2312     0.4108  -2.997  0.00273 **
## statewarmed    0.3956     0.1704   2.322  0.02024 *
## originBoth     2.5301     0.3507   7.215 5.39e-13 ***
## originExotic   1.4576     0.2757   5.287 1.25e-07 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Theta = 0.3133
## Number of iterations in BFGS optimization: 18
## Log-likelihood: -3399 on 9 Df
```

```
lrtest(k.m4, k.m8) # model 4
```

```
## Likelihood ratio test
##
## Model 1: p_eaten ~ state + growth_habit + as.factor(year)
## Model 2: p_eaten ~ state + origin
##   #Df  LogLik  Df  Chisq Pr(>Chisq)
## 1  19 -3155.4
## 2   9 -3398.8 -10 486.71  < 2.2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
# state, origin, and year as fixed effects
k.m9 <- zeroinfl(p_eaten ~ state + origin + as.factor(year),
                 dist = 'negbin',
                 data = herb_kbs)
summary(k.m9)
```

```
##
## Call:
## zeroinfl(formula = p_eaten ~ state + origin + as.factor(year), data = herb_kbs,
##     dist = "negbin")
##
## Pearson residuals:
##     Min      1Q  Median      3Q     Max
## -0.7219 -0.4221 -0.3205 -0.1137 24.9342
```

```
##
## Count model coefficients (negbin with log link):
##                   Estimate Std. Error z value Pr(>|z|)
## (Intercept)        0.45619    0.13519   3.375 0.000739 ***
## statewarmed       -0.15828    0.08981  -1.762 0.078000 .
## originBoth        -0.31058    0.19804  -1.568 0.116816
## originExotic       0.30246    0.10637   2.843 0.004462 **
## as.factor(year)2   1.30567    0.15286   8.542  < 2e-16 ***
## as.factor(year)3   2.06704    0.18635  11.092  < 2e-16 ***
## as.factor(year)4   2.12925    0.16958  12.556  < 2e-16 ***
## as.factor(year)5   2.22129    0.15866  14.000  < 2e-16 ***
## as.factor(year)6  -0.48355    0.23247  -2.080 0.037519 *
## Log(theta)        -0.15767    0.09422  -1.673 0.094258 .
##
## Zero-inflation model coefficients (binomial with logit link):
##                   Estimate Std. Error z value Pr(>|z|)
## (Intercept)       -3.1976     0.8412  -3.801 0.000144 ***
## statewarmed        0.2822     0.1211   2.331 0.019764 *
## originBoth         2.1256     0.2095  10.146  < 2e-16 ***
## originExotic       1.4067     0.1408   9.989  < 2e-16 ***
## as.factor(year)2   2.4214     0.8309   2.914 0.003565 **
## as.factor(year)3   3.2969     0.8462   3.896 9.77e-05 ***
## as.factor(year)4   3.1316     0.8380   3.737 0.000186 ***
## as.factor(year)5   2.7791     0.8364   3.323 0.000892 ***
## as.factor(year)6   2.9608     0.8787   3.370 0.000753 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Theta = 0.8541
## Number of iterations in BFGS optimization: 27
## Log-likelihood: -3229 on 19 Df
```

```
lrtest(k.m4, k.m9) # model 4
```

```
## Likelihood ratio test
##
## Model 1: p_eaten ~ state + growth_habit + as.factor(year)
## Model 2: p_eaten ~ state + origin + as.factor(year)
##   #Df  LogLik Df  Chisq Pr(>Chisq)
## 1  19 -3155.4
## 2  19 -3229.1  0 147.37  < 2.2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
# interaction between state and origin as fixed effects
k.m10 <- zeroinfl(p_eaten ~ state * origin,
                  dist = 'negbin',
                  data = herb_kbs)
summary(k.m10)
```

```
##
## Call:
## zeroinfl(formula = p_eaten ~ state * origin, data = herb_kbs, dist = "negbin")
##
## Pearson residuals:
```

```
##     Min      1Q  Median      3Q     Max
## -0.4616 -0.4373 -0.2958 -0.1653 12.6601
##
## Count model coefficients (negbin with log link):
##                          Estimate Std. Error z value Pr(>|z|)
## (Intercept)               1.77245    0.13716  12.922  < 2e-16 ***
## statewarmed              -0.24684    0.14692  -1.680   0.0929 .
## originBoth                0.19652    0.32341   0.608   0.5434
## originExotic              0.33345    0.18498   1.803   0.0715 .
## statewarmed:originBoth    0.07524    0.58560   0.128   0.8978
## statewarmed:originExotic  0.03024    0.28042   0.108   0.9141
## Log(theta)               -1.14401    0.17332  -6.601 4.09e-11 ***
##
## Zero-inflation model coefficients (binomial with logit link):
##                          Estimate Std. Error z value Pr(>|z|)
## (Intercept)               -1.1359     0.4211  -2.697  0.00699 **
## statewarmed                0.2919     0.2891   1.010  0.31259
## originBoth                 2.3914     0.4097   5.837 5.32e-09 ***
## originExotic               1.3719     0.3391   4.046 5.21e-05 ***
## statewarmed:originBoth     0.2693     0.5133   0.525  0.59983
## statewarmed:originExotic   0.1128     0.3633   0.310  0.75624
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Theta = 0.3185
## Number of iterations in BFGS optimization: 21
## Log-likelihood: -3399 on 13 Df
```

```
lrtest(k.m4, k.m10) # model 4
```

```
## Likelihood ratio test
##
## Model 1: p_eaten ~ state + growth_habit + as.factor(year)
## Model 2: p_eaten ~ state * origin
##   #Df  LogLik Df  Chisq Pr(>Chisq)
## 1  19 -3155.4
## 2  13 -3398.6 -6 486.43  < 2.2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
# interaction between state and origin as fixed effects, plus year
k.m11 <- zeroinfl(p_eaten ~ state * origin + as.factor(year),
                  dist = 'negbin',
                  data = herb_kbs)
summary(k.m11)
```

```
##
## Call:
## zeroinfl(formula = p_eaten ~ state * origin + as.factor(year), data = herb_kbs,
##     dist = "negbin")
##
## Pearson residuals:
##     Min      1Q  Median      3Q     Max
## -0.7179 -0.4281 -0.3252 -0.1216 24.4702
##
```

```
## Count model coefficients (negbin with log link):
##                            Estimate Std. Error z value Pr(>|z|)
## (Intercept)                 0.43056    0.13973   3.081  0.00206 **
## statewarmed                -0.11188    0.10810  -1.035  0.30070
## originBoth                 -0.28071    0.23332  -1.203  0.22893
## originExotic                0.37613    0.13409   2.805  0.00503 **
## as.factor(year)2            1.30898    0.15326   8.541  < 2e-16 ***
## as.factor(year)3            2.08185    0.18733  11.113  < 2e-16 ***
## as.factor(year)4            2.12297    0.16979  12.504  < 2e-16 ***
## as.factor(year)5            2.22721    0.15904  14.004  < 2e-16 ***
## as.factor(year)6           -0.49356    0.23250  -2.123  0.03377 *
## statewarmed:originBoth     -0.07068    0.41642  -0.170  0.86521
## statewarmed:originExotic   -0.17972    0.20005  -0.898  0.36899
## Log(theta)                 -0.15837    0.09430  -1.679  0.09307 .
##
## Zero-inflation model coefficients (binomial with logit link):
##                            Estimate Std. Error z value Pr(>|z|)
## (Intercept)                 -3.1704     0.8721  -3.635 0.000277 ***
## statewarmed                  0.1815     0.1675   1.084 0.278495
## originBoth                   1.9865     0.2571   7.727 1.10e-14 ***
## originExotic                 1.3201     0.1846   7.149 8.73e-13 ***
## as.factor(year)2             2.4473     0.8574   2.854 0.004312 **
## as.factor(year)3             3.3156     0.8726   3.800 0.000145 ***
## as.factor(year)4             3.1585     0.8639   3.656 0.000256 ***
## as.factor(year)5             2.8081     0.8626   3.255 0.001132 **
## as.factor(year)6             2.9887     0.9019   3.314 0.000920 ***
## statewarmed:originBoth       0.3577     0.4303   0.831 0.405808
## statewarmed:originExotic     0.1720     0.2586   0.665 0.505956
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Theta = 0.8535
## Number of iterations in BFGS optimization: 31
## Log-likelihood: -3228 on 23 Df
```

```
lrtest(k.m4, k.m11) # model 4
```

```
## Likelihood ratio test
##
## Model 1: p_eaten ~ state + growth_habit + as.factor(year)
## Model 2: p_eaten ~ state * origin + as.factor(year)
##   #Df  LogLik Df  Chisq Pr(>Chisq)
## 1  19 -3155.4
## 2  23 -3228.1  4 145.36  < 2.2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
exp(0.43056 + 0.37613*0) # 1.538119
```

```
## [1] 1.538119
```

```
exp(0.43056 + 0.37613*1) # 2.24048
```

```
## [1] 2.24048
```

```
# effect of herbivory:
2.24048 - 1.538119 # 0.702361
```

```
## [1] 0.702361
```

```
# interaction between state, origin, and year
k.m12 <- zeroinfl(p_eaten ~ state * origin * year,
                  dist = 'negbin',
                  data = herb_kbs)
summary(k.m12)
```

```
##
## Call:
## zeroinfl(formula = p_eaten ~ state * origin * year, data = herb_kbs,
##     dist = "negbin")
##
## Pearson residuals:
##     Min      1Q  Median      3Q     Max
## -0.5746 -0.4153 -0.2949 -0.1208 11.7653
##
## Count model coefficients (negbin with log link):
##                               Estimate Std. Error z value Pr(>|z|)
## (Intercept)                    1.19507    0.25961   4.603 4.16e-06 ***
## statewarmed                   -0.60988    0.35131  -1.736  0.08256 .
## originBoth                    -2.08427    1.04165  -2.001  0.04540 *
## originExotic                  -0.23923    0.47813  -0.500  0.61683
## year                           0.20242    0.06980   2.900  0.00373 **
## statewarmed:originBoth         0.94606    1.94507   0.486  0.62669
## statewarmed:originExotic      -0.13014    0.73234  -0.178  0.85896
## statewarmed:year               0.08694    0.09460   0.919  0.35812
## originBoth:year                0.49312    0.25274   1.951  0.05104 .
## originExotic:year              0.25884    0.16320   1.586  0.11274
## statewarmed:originBoth:year   -0.23616    0.44593  -0.530  0.59640
## statewarmed:originExotic:year  0.10152    0.25784   0.394  0.69379
## Log(theta)                    -0.82485    0.13153  -6.271 3.58e-10 ***
##
## Zero-inflation model coefficients (binomial with logit link):
##                               Estimate Std. Error z value Pr(>|z|)
## (Intercept)                    -2.1576     0.5704  -3.783 0.000155 ***
## statewarmed                    -0.8619     0.8477  -1.017 0.309283
## originBoth                      4.3214     1.0533   4.103 4.08e-05 ***
## originExotic                    1.0546     0.6285   1.678 0.093338 .
## year                            0.3894     0.1070   3.640 0.000273 ***
## statewarmed:originBoth          2.5088     2.0208   1.241 0.214428
## statewarmed:originExotic        1.2284     1.0258   1.198 0.231110
## statewarmed:year                0.2130     0.1676   1.270 0.203956
## originBoth:year                -0.6218     0.2445  -2.543 0.010991 *
## originExotic:year               0.1357     0.1522   0.892 0.372526
## statewarmed:originBoth:year    -0.4697     0.4579  -1.026 0.305052
## statewarmed:originExotic:year  -0.1957     0.2434  -0.804 0.421432
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Theta = 0.4383
## Number of iterations in BFGS optimization: 33
## Log-likelihood: -3333 on 25 Df
```

```r
lrtest(k.m4,k.m12) # model 4
```

```
## Likelihood ratio test
##
## Model 1: p_eaten ~ state + growth_habit + as.factor(year)
## Model 2: p_eaten ~ state * origin * year
##   #Df  LogLik Df  Chisq Pr(>Chisq)
## 1  19 -3155.4
## 2  25 -3332.6  6 354.47  < 2.2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```r
# just origin - testing to see w/o state
k.m12.2 <- zeroinfl(p_eaten ~ origin,
                    dist = 'negbin',
                    data = herb_kbs)
summary(k.m12.2)
```

```
##
## Call:
## zeroinfl(formula = p_eaten ~ origin, data = herb_kbs, dist = "negbin")
##
## Pearson residuals:
##     Min      1Q  Median      3Q     Max
## -0.4466 -0.4466 -0.3184 -0.2101 12.2255
##
## Count model coefficients (negbin with log link):
##              Estimate Std. Error z value Pr(>|z|)
## (Intercept)    1.6412     0.1177  13.945  < 2e-16 ***
## originBoth     0.2700     0.2694   1.002  0.31611
## originExotic   0.3721     0.1392   2.672  0.00754 **
## Log(theta)    -1.1657     0.1758  -6.632  3.3e-11 ***
##
## Zero-inflation model coefficients (binomial with logit link):
##              Estimate Std. Error z value Pr(>|z|)
## (Intercept)   -1.0043     0.3703  -2.712  0.00668 **
## originBoth     2.4485     0.3366   7.273 3.51e-13 ***
## originExotic   1.4116     0.2677   5.273 1.34e-07 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Theta = 0.3117
## Number of iterations in BFGS optimization: 16
## Log-likelihood: -3406 on 7 Df
```

```r
# state and species as fixed effects
k.m13 <- zeroinfl(p_eaten ~ state + species,
                    dist = 'negbin',
                    data = herb_kbs)
summary(k.m13)
```

```
##
## Call:
## zeroinfl(formula = p_eaten ~ state + species, data = herb_kbs, dist = "negbin")
##
```

```
## Pearson residuals:
##     Min      1Q  Median      3Q     Max
## -0.5130 -0.4423 -0.2280 -0.1620 11.0764
##
## Count model coefficients (negbin with log link):
##             Estimate Std. Error z value Pr(>|z|)
## (Intercept)  1.85217    0.16652  11.123  < 2e-16 ***
## statewarmed -0.23848    0.11937  -1.998   0.0457 *
## speciesEugr -0.37812    0.21503  -1.758   0.0787 .
## speciesHisp  0.17181    0.28973   0.593   0.5532
## speciesPhpr  0.57539    0.30652   1.877   0.0605 .
## speciesPopr  0.77610    0.30867   2.514   0.0119 *
## speciesSoca  0.02802    0.16609   0.169   0.8660
## Log(theta)  -1.06876    0.16412  -6.512 7.41e-11 ***
##
## Zero-inflation model coefficients (binomial with logit link):
##             Estimate Std. Error z value Pr(>|z|)
## (Intercept)  -1.7171     0.6409  -2.679  0.00738 **
## statewarmed   0.2975     0.1799   1.653  0.09823 .
## speciesEugr   0.6616     0.5383   1.229  0.21905
## speciesHisp   3.1040     0.5945   5.221 1.78e-07 ***
## speciesPhpr   1.7594     0.5973   2.945  0.00323 **
## speciesPopr   3.5900     0.6027   5.956 2.58e-09 ***
## speciesSoca   0.7035     0.4821   1.459  0.14447
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Theta = 0.3434
## Number of iterations in BFGS optimization: 24
## Log-likelihood: -3318 on 15 Df
```

```
lrtest(k.m4, k.m13) # model 4
```

```
## Likelihood ratio test
##
## Model 1: p_eaten ~ state + growth_habit + as.factor(year)
## Model 2: p_eaten ~ state + species
##   #Df  LogLik Df  Chisq Pr(>Chisq)
## 1  19 -3155.4
## 2  15 -3318.4 -4 326.01  < 2.2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
# state. species and year as fixed effects
k.m14 <- zeroinfl(p_eaten ~ state + species + as.factor(year),
                  dist = 'negbin',
                  data = herb_kbs)
summary(k.m14)
```

```
##
## Call:
## zeroinfl(formula = p_eaten ~ state + species + as.factor(year), data = herb_kbs,
##     dist = "negbin")
##
## Pearson residuals:
```

```
##     Min      1Q  Median      3Q     Max
## -0.7568 -0.4595 -0.2437 -0.1264 24.5632
##
## Count model coefficients (negbin with log link):
##                   Estimate Std. Error z value Pr(>|z|)
## (Intercept)        0.27490    0.14310   1.921   0.0547 .
## statewarmed       -0.22879    0.08973  -2.550   0.0108 *
## speciesEugr        0.30066    0.17100   1.758   0.0787 .
## speciesHisp       -0.08568    0.21913  -0.391   0.6958
## speciesPhpr        0.96249    0.23019   4.181 2.90e-05 ***
## speciesPopr        1.45768    0.23949   6.087 1.15e-09 ***
## speciesSoca        0.27379    0.12256   2.234   0.0255 *
## as.factor(year)2   1.00539    0.14799   6.794 1.09e-11 ***
## as.factor(year)3   2.11838    0.17565  12.060  < 2e-16 ***
## as.factor(year)4   2.25866    0.15781  14.313  < 2e-16 ***
## as.factor(year)5   2.18186    0.14707  14.835  < 2e-16 ***
## as.factor(year)6  -0.53881    0.23597  -2.283   0.0224 *
## Log(theta)        -0.16853    0.09807  -1.718   0.0857 .
##
## Zero-inflation model coefficients (binomial with logit link):
##                    Estimate Std. Error z value Pr(>|z|)
## (Intercept)       -16.0545  1638.7804  -0.010   0.9922
## statewarmed         0.1933     0.1357   1.425   0.1542
## speciesEugr         0.5715     0.3900   1.465   0.1429
## speciesHisp         2.8006     0.3579   7.825 5.09e-15 ***
## speciesPhpr         1.7573     0.4182   4.202 2.64e-05 ***
## speciesPopr         3.4030     0.3744   9.090  < 2e-16 ***
## speciesSoca         0.6532     0.3048   2.143   0.0321 *
## as.factor(year)2   14.6235  1638.7802   0.009   0.9929
## as.factor(year)3   15.8370  1638.7802   0.010   0.9923
## as.factor(year)4   15.4532  1638.7802   0.009   0.9925
## as.factor(year)5   14.7907  1638.7803   0.009   0.9928
## as.factor(year)6   15.2518  1638.7804   0.009   0.9926
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Theta = 0.8449
## Number of iterations in BFGS optimization: 50
## Log-likelihood: -3135 on 25 Df
```

```
lrtest(k.m4, k.m14) # model 14
```

```
## Likelihood ratio test
##
## Model 1: p_eaten ~ state + growth_habit + as.factor(year)
## Model 2: p_eaten ~ state + species + as.factor(year)
##   #Df  LogLik Df  Chisq Pr(>Chisq)
## 1  19 -3155.4
## 2  25 -3135.2  6 40.308  3.962e-07 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
# calculating effect size - accounting for log link
exp(0.27490 + -0.22879*0) # 1.316399
```

```
## [1] 1.316399
```

```
exp(0.27490 + -0.22879*1) # 1.04719
```

```
## [1] 1.04719
```

```
# effect of herbivory:
1.04719 - 1.316399 # -0.269209
```

```
## [1] -0.269209
```

```
# interaction between state and species as fixed effects, plus year
k.m15 <- zeroinfl(p_eaten ~ state * species + as.factor(year),
                  dist = 'negbin',
                  data = herb_kbs)
summary(k.m15)
```

```
##
## Call:
## zeroinfl(formula = p_eaten ~ state * species + as.factor(year), data = herb_kbs,
##     dist = "negbin")
##
## Pearson residuals:
##     Min      1Q  Median      3Q     Max
## -0.7484 -0.4512 -0.2436 -0.1453 24.4209
##
## Count model coefficients (negbin with log link):
##                          Estimate Std. Error z value Pr(>|z|)
## (Intercept)               0.28180    0.16239   1.735   0.0827 .
## statewarmed              -0.30056    0.21826  -1.377   0.1685
## speciesEugr               0.18694    0.23344   0.801   0.4232
## speciesHisp              -0.11739    0.26062  -0.450   0.6524
## speciesPhpr               1.38715    0.35200   3.941 8.12e-05 ***
## speciesPopr               1.52144    0.30340   5.015 5.32e-07 ***
## speciesSoca               0.24827    0.15802   1.571   0.1162
## as.factor(year)2          0.98047    0.15108   6.490 8.61e-11 ***
## as.factor(year)3          2.18486    0.18141  12.044  < 2e-16 ***
## as.factor(year)4          2.25850    0.15994  14.121  < 2e-16 ***
## as.factor(year)5          2.18045    0.14810  14.723  < 2e-16 ***
## as.factor(year)6         -0.63192    0.25350  -2.493   0.0127 *
## statewarmed:speciesEugr   0.28197    0.32875   0.858   0.3910
## statewarmed:speciesHisp   0.15699    0.45694   0.344   0.7312
## statewarmed:speciesPhpr  -0.76163    0.46758  -1.629   0.1033
## statewarmed:speciesPopr  -0.04837    0.45134  -0.107   0.9147
## statewarmed:speciesSoca   0.11182    0.24880   0.449   0.6531
## Log(theta)               -0.17952    0.10189  -1.762   0.0781 .
##
## Zero-inflation model coefficients (binomial with logit link):
##                          Estimate Std. Error z value Pr(>|z|)
## (Intercept)               -16.0304  1675.9445  -0.010 0.992368
## statewarmed                -0.1854     0.7459  -0.249 0.803662
## speciesEugr                 0.2039     0.5995   0.340 0.733823
## speciesHisp                 2.6398     0.4045   6.526 6.75e-11 ***
## speciesPhpr                 2.0039     0.5328   3.761 0.000169 ***
## speciesPopr                 3.3475     0.4313   7.761 8.45e-15 ***
## speciesSoca                 0.6303     0.3477   1.812 0.069910 .
```

```
## as.factor(year)2          14.6149  1675.9445   0.009 0.993042
## as.factor(year)3          15.8883  1675.9445   0.009 0.992436
## as.factor(year)4          15.4714  1675.9445   0.009 0.992634
## as.factor(year)5          14.8115  1675.9446   0.009 0.992949
## as.factor(year)6          15.1591  1675.9447   0.009 0.992783
## statewarmed:speciesEugr    0.8375     0.9352   0.895 0.370542
## statewarmed:speciesHisp    0.7449     0.8458   0.881 0.378501
## statewarmed:speciesPhpr   -0.1405     0.8682  -0.162 0.871399
## statewarmed:speciesPopr    0.4300     0.8348   0.515 0.606460
## statewarmed:speciesSoca    0.3230     0.7660   0.422 0.673285
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Theta = 0.8357
## Number of iterations in BFGS optimization: 59
## Log-likelihood: -3131 on 35 Df
```

```
lrtest(k.m14, k.m15) # model 15 slightly better, going with 14 because its simpler
```

```
## Likelihood ratio test
##
## Model 1: p_eaten ~ state + species + as.factor(year)
## Model 2: p_eaten ~ state * species + as.factor(year)
##   #Df  LogLik Df  Chisq Pr(>Chisq)
## 1  25 -3135.2
## 2  35 -3131.5 10 7.5151     0.6761
```

```
# checking models again
lrtest(k.m2, k.m4, k.m9, k.m14) # model 14 best - with species
```

```
## Likelihood ratio test
##
## Model 1: p_eaten ~ state + as.factor(year)
## Model 2: p_eaten ~ state + growth_habit + as.factor(year)
## Model 3: p_eaten ~ state + origin + as.factor(year)
## Model 4: p_eaten ~ state + species + as.factor(year)
##   #Df  LogLik Df  Chisq Pr(>Chisq)
## 1  15 -3324.2
## 2  19 -3155.4  4 337.52  < 2.2e-16 ***
## 3  19 -3229.1  0 147.37  < 2.2e-16 ***
## 4  25 -3135.2  6 187.68  < 2.2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
res.k <- AIC(k.m1, k.m2, k.m3, k.m4, k.m5, k.m6, k.m7, k.m8, k.m9, k.m10, k.m11,k.m12,k.m13,k.m14,k.m15)

## interaction between state, species, and year - doesn't run
#m8 <- zeroinfl(p_eaten ~ state * species * as.factor(year),
#                      dist = 'negbin',
#                      data = herb_kbs)
#summary(m8)

# check dispersion
E <- resid(k.m14, type = "pearson")
N  <- nrow(herb_kbs)
p  <- length(coef(k.m14)) + 1 # '+1' is due to theta
```

```r
sum(E^2) / (N - p) # a little overdispersed - is that okay?
```

```
## [1] 1.302343
```

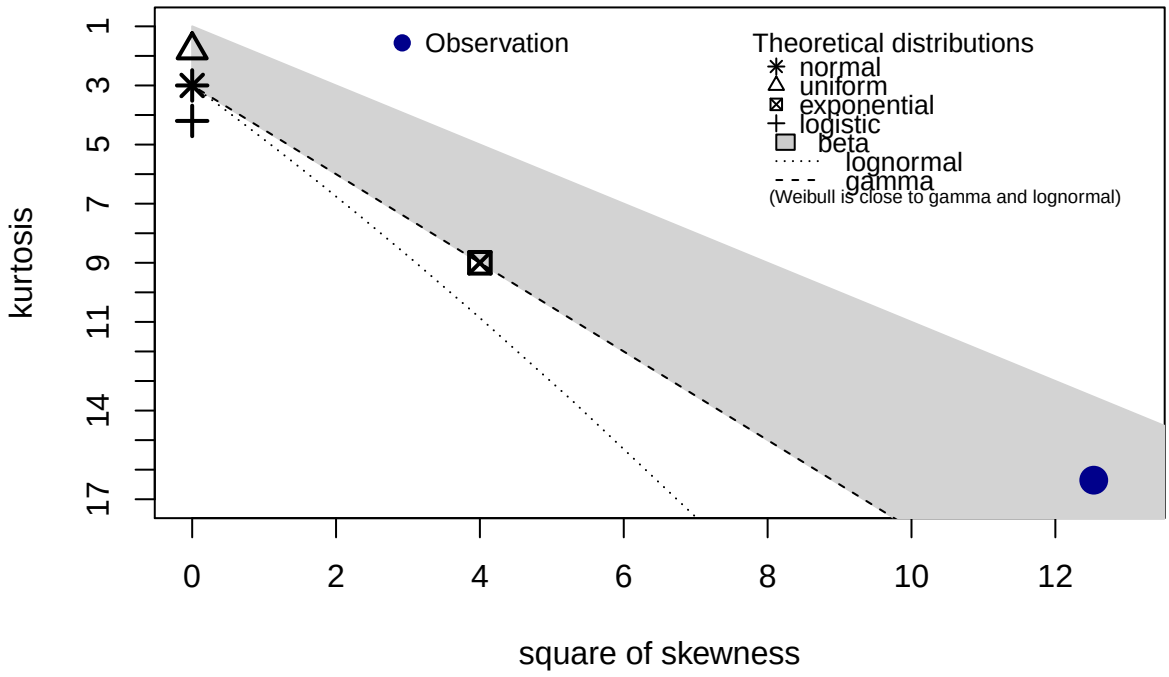
```r
# pairwise comparisons
emmeans(k.m14, ~ state + species + as.factor(year))
```

```
##  state   species year  emmean     SE  df asymp.LCL asymp.UCL
##  ambient Cest       1  1.3164 0.1884 Inf    0.9472    1.6856
##  warmed  Cest       1  1.0472 0.1557 Inf    0.7420    1.3524
##  ambient Eugr       1  1.7781 0.2968 Inf    1.1964    2.3598
##  warmed  Eugr       1  1.4145 0.2252 Inf    0.9731    1.8559
##  ambient Hisp       1  1.2083 0.2732 Inf    0.6728    1.7438
##  warmed  Hisp       1  0.9612 0.2238 Inf    0.5226    1.3998
##  ambient Phpr       1  3.4466 0.8260 Inf    1.8277    5.0655
##  warmed  Phpr       1  2.7417 0.6480 Inf    1.4716    4.0118
##  ambient Popr       1  5.6552 1.3852 Inf    2.9403    8.3701
##  warmed  Popr       1  4.4987 1.0871 Inf    2.3681    6.6292
##  ambient Soca       1  1.7310 0.2164 Inf    1.3069    2.1551
##  warmed  Soca       1  1.3770 0.1689 Inf    1.0459    1.7081
##  ambient Cest       2  2.9035 0.3731 Inf    2.1722    3.6348
##  warmed  Cest       2  2.2184 0.3164 Inf    1.5983    2.8386
##  ambient Eugr       2  3.4141 0.5006 Inf    2.4328    4.3953
##  warmed  Eugr       2  2.5539 0.3823 Inf    1.8046    3.3032
##  ambient Hisp       2  0.6693 0.1600 Inf    0.3557    0.9829
##  warmed  Hisp       2  0.4550 0.1163 Inf    0.2271    0.6830
##  ambient Phpr       2  3.9480 0.8915 Inf    2.2007    5.6953
##  warmed  Phpr       2  2.7945 0.6450 Inf    1.5303    4.0586
##  ambient Popr       2  1.8882 0.5015 Inf    0.9053    2.8711
##  warmed  Popr       2  1.2652 0.3471 Inf    0.5850    1.9455
##  ambient Soca       2  3.2414 0.3388 Inf    2.5775    3.9054
##  warmed  Soca       2  2.4163 0.2771 Inf    1.8732    2.9595
##  ambient Cest       3  6.0676 1.1547 Inf    3.8043    8.3308
##  warmed  Cest       3  4.4077 0.8975 Inf    2.6487    6.1666
##  ambient Eugr       3  6.0994 1.4558 Inf    3.2460    8.9527
##  warmed  Eugr       3  4.3118 1.0325 Inf    2.2882    6.3354
##  ambient Hisp       3  0.7058 0.2249 Inf    0.2649    1.1467
##  warmed  Hisp       3  0.4686 0.1546 Inf    0.1655    0.7717
##  ambient Phpr       3  5.0615 1.6185 Inf    1.8893    8.2337
##  warmed  Phpr       3  3.4250 1.0997 Inf    1.2697    5.5803
##  ambient Popr       3  1.8680 0.6456 Inf    0.6027    3.1334
##  warmed  Popr       3  1.2335 0.4317 Inf    0.3874    2.0795
##  ambient Soca       3  5.6547 0.9788 Inf    3.7362    7.5732
##  warmed  Soca       3  3.9826 0.7048 Inf    2.6012    5.3640
##  ambient Cest       4  8.1379 1.2603 Inf    5.6679   10.6080
##  warmed  Cest       4  6.0193 1.0445 Inf    3.9721    8.0665
##  ambient Eugr       4  8.6354 1.7680 Inf    5.1703   12.1006
##  warmed  Eugr       4  6.2166 1.3059 Inf    3.6571    8.7760
##  ambient Hisp       4  1.1542 0.3137 Inf    0.5393    1.7691
##  warmed  Hisp       4  0.7703 0.2217 Inf    0.3358    1.2048
##  ambient Phpr       4  7.8965 2.4273 Inf    3.1390   12.6540
##  warmed  Phpr       4  5.4050 1.6927 Inf    2.0873    8.7227
##  ambient Popr       4  3.0976 0.9735 Inf    1.1895    5.0056
##  warmed  Popr       4  2.0517 0.6605 Inf    0.7571    3.3462
```

```
##  ambient Soca       4  8.0681 1.1531 Inf    5.8080   10.3281
##  warmed  Soca       4  5.7853 0.8888 Inf    4.0432    7.5274
##  ambient Cest       5  9.0964 1.3647 Inf    6.4216   11.7712
##  warmed  Cest       5  6.9115 1.0704 Inf    4.8135    9.0094
##  ambient Eugr       5 10.5031 1.7037 Inf    7.1638   13.8424
##  warmed  Eugr       5  7.8004 1.2141 Inf    5.4209   10.1800
##  ambient Hisp       5  1.8954 0.4566 Inf    1.0005    2.7903
##  warmed  Hisp       5  1.2827 0.3231 Inf    0.6494    1.9160
##  ambient Phpr       5 11.5792 3.1964 Inf    5.3144   17.8439
##  warmed  Phpr       5  8.1342 2.2605 Inf    3.7037   12.5647
##  ambient Popr       5  5.2800 1.5475 Inf    2.2469    8.3130
##  warmed  Popr       5  3.5273 1.0419 Inf    1.4853    5.5693
##  ambient Soca       5  9.9422 1.2088 Inf    7.5731   12.3114
##  warmed  Soca       5  7.3569 0.8802 Inf    5.6317    9.0821
##  ambient Cest       6  0.5304 0.1100 Inf    0.3147    0.7461
##  warmed  Cest       6  0.3958 0.0820 Inf    0.2350    0.5565
##  ambient Eugr       6  0.5784 0.1050 Inf    0.3726    0.7843
##  warmed  Eugr       6  0.4204 0.0725 Inf    0.2783    0.5626
##  ambient Hisp       6  0.0842 0.0275 Inf    0.0302    0.1381
##  warmed  Hisp       6  0.0564 0.0190 Inf    0.0191    0.0936
##  ambient Phpr       6  0.5589 0.1820 Inf    0.2022    0.9157
##  warmed  Phpr       6  0.3853 0.1264 Inf    0.1375    0.6331
##  ambient Popr       6  0.2280 0.0826 Inf    0.0661    0.3900
##  warmed  Popr       6  0.1514 0.0553 Inf    0.0431    0.2597
##  ambient Soca       6  0.5426 0.0936 Inf    0.3592    0.7260
##  warmed  Soca       6  0.3929 0.0661 Inf    0.2633    0.5225
##
## Confidence level used: 0.95
```

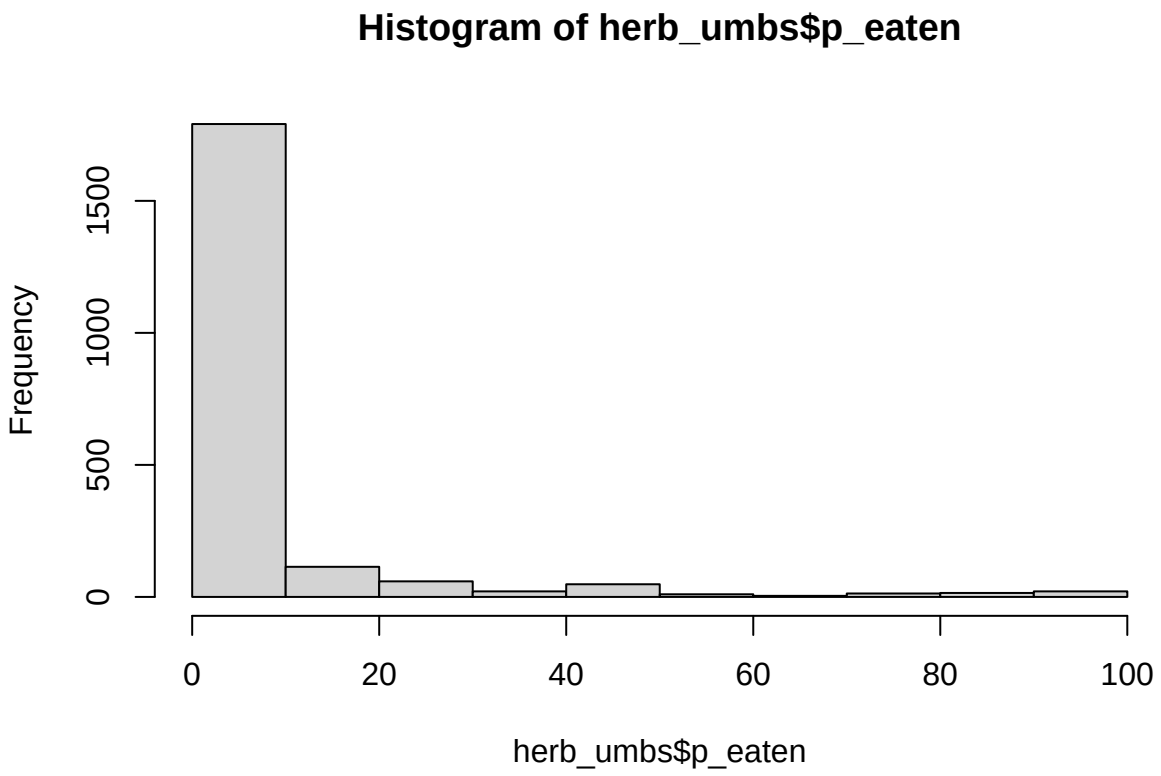
UMBS - Data Exploration

```
descdist(herb_umbs$p_eaten, discrete = FALSE)
```

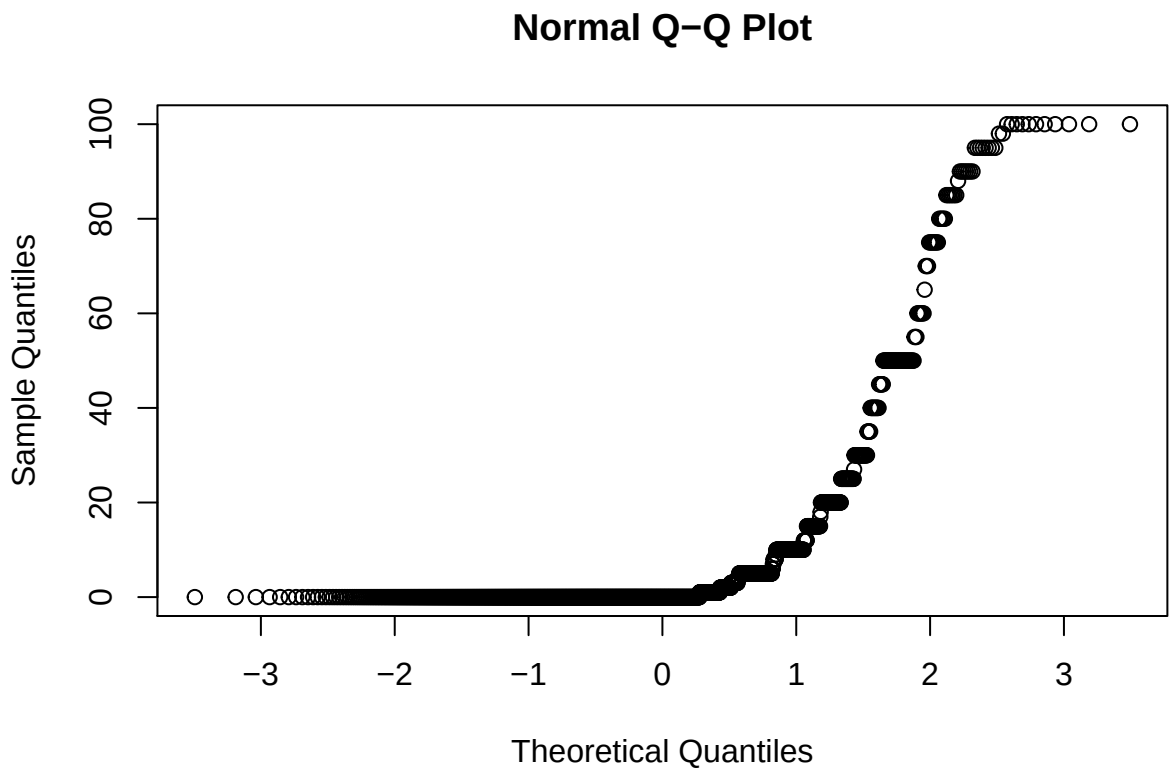



```
## summary statistics
## ------
## min:  0   max:  100
## median:  0
## mean:  6.87166
## estimated sd:  16.80741
## estimated skewness:  3.540296
## estimated kurtosis:  16.35555
```

```
# normal distribution?
hist(herb_umbs$p_eaten)
```




```
qqnorm(herb_umbs$p_eaten)
```

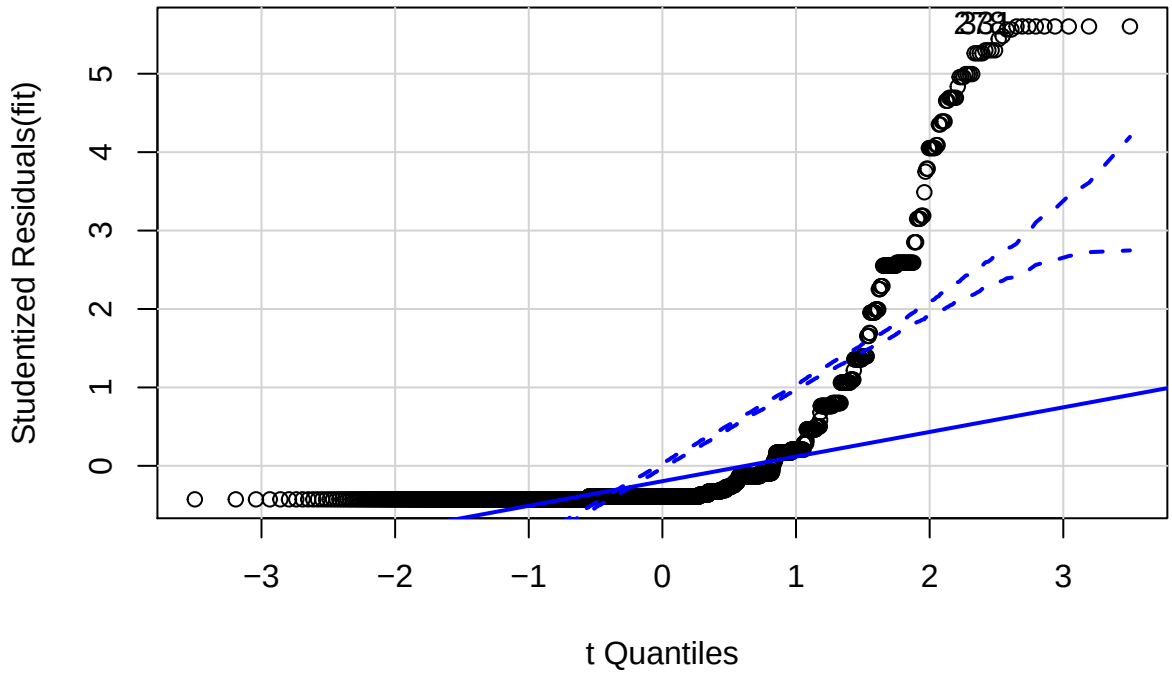



```
shapiro.test(herb_umbs$p_eaten)
```

```
##
```

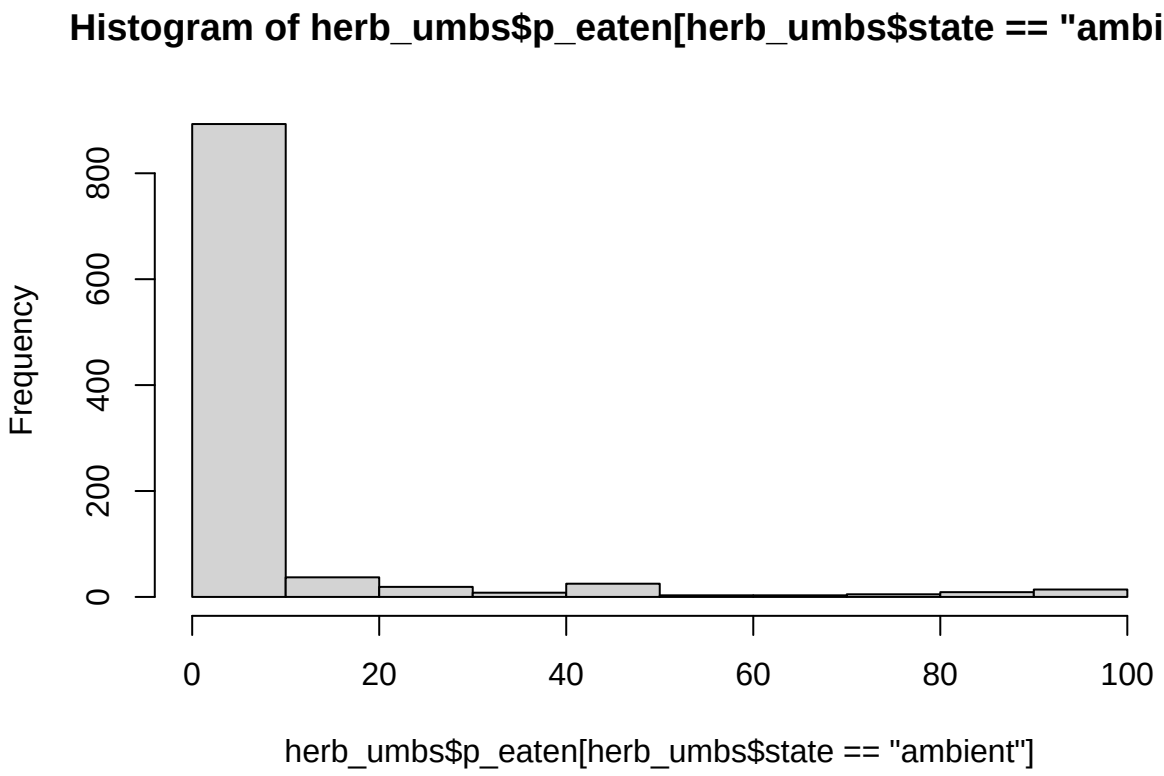
```
##  Shapiro-Wilk normality test
##
## data:  herb_umbs$p_eaten
## W = 0.46641, p-value < 2.2e-16
```

```
fit <- lm(p_eaten~state, data = herb_umbs)
qqPlot(fit)
```

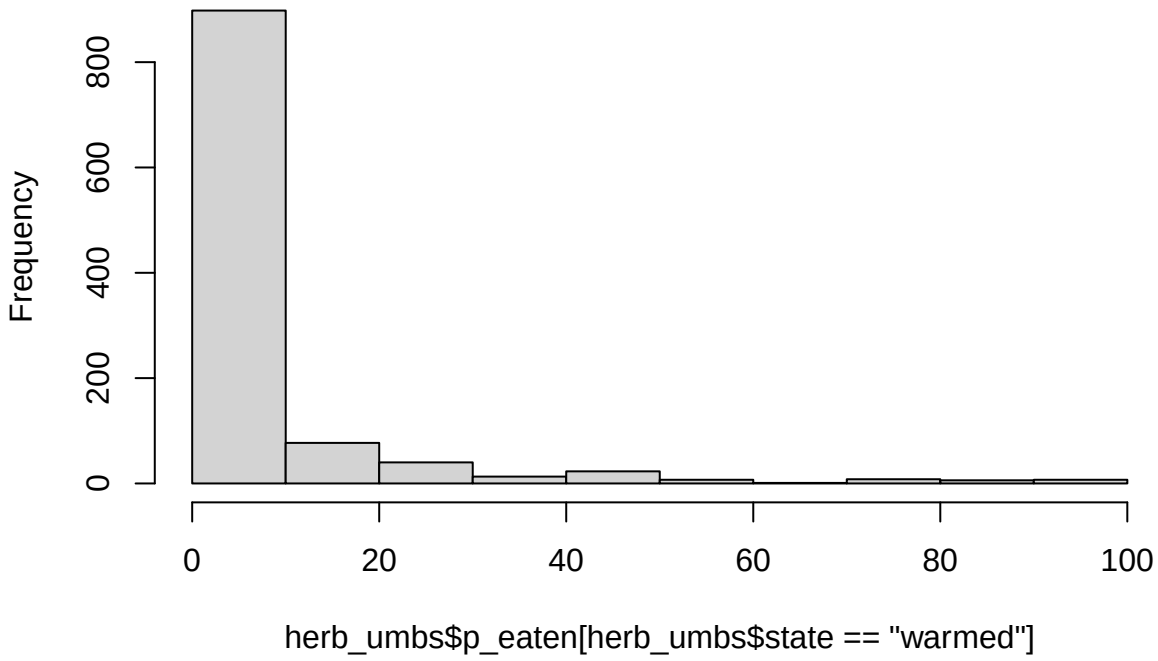



```
## [1] 278 331
```

```
# looking at each treatment separately
hist(herb_umbs$p_eaten[herb_umbs$state == "ambient"])
```



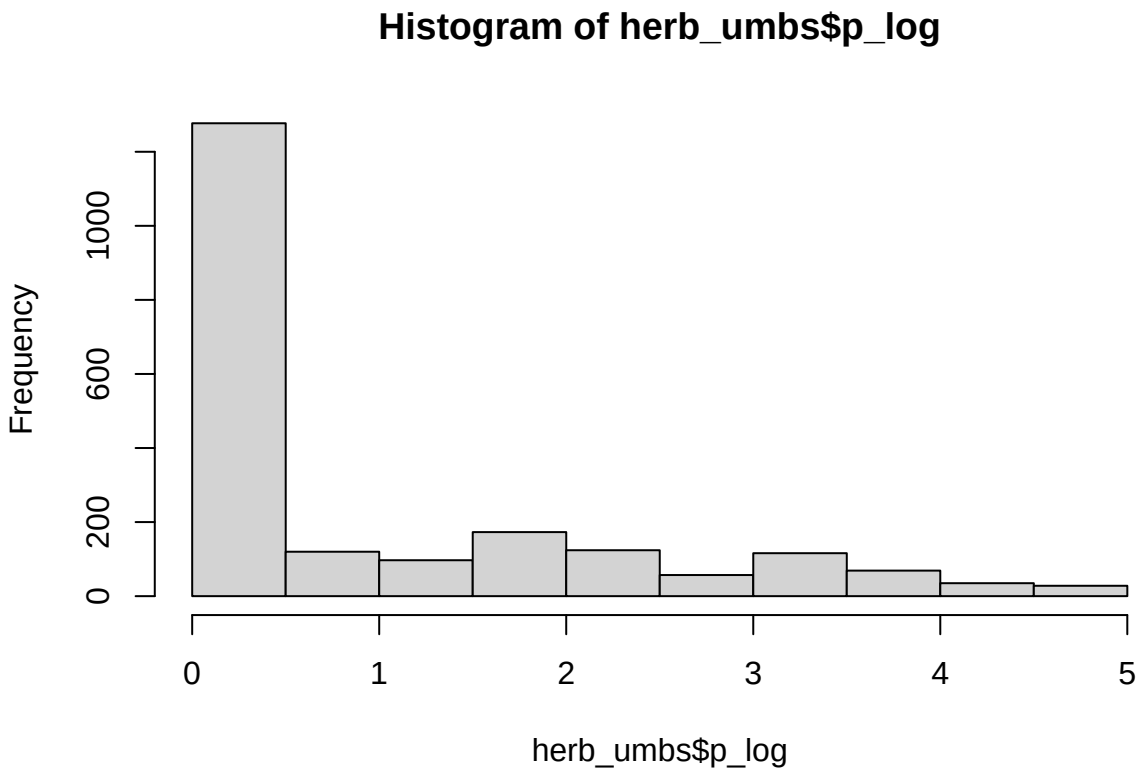

```
hist(herb_umbs$p_eaten[herb_umbs$state == "warmed"])
```



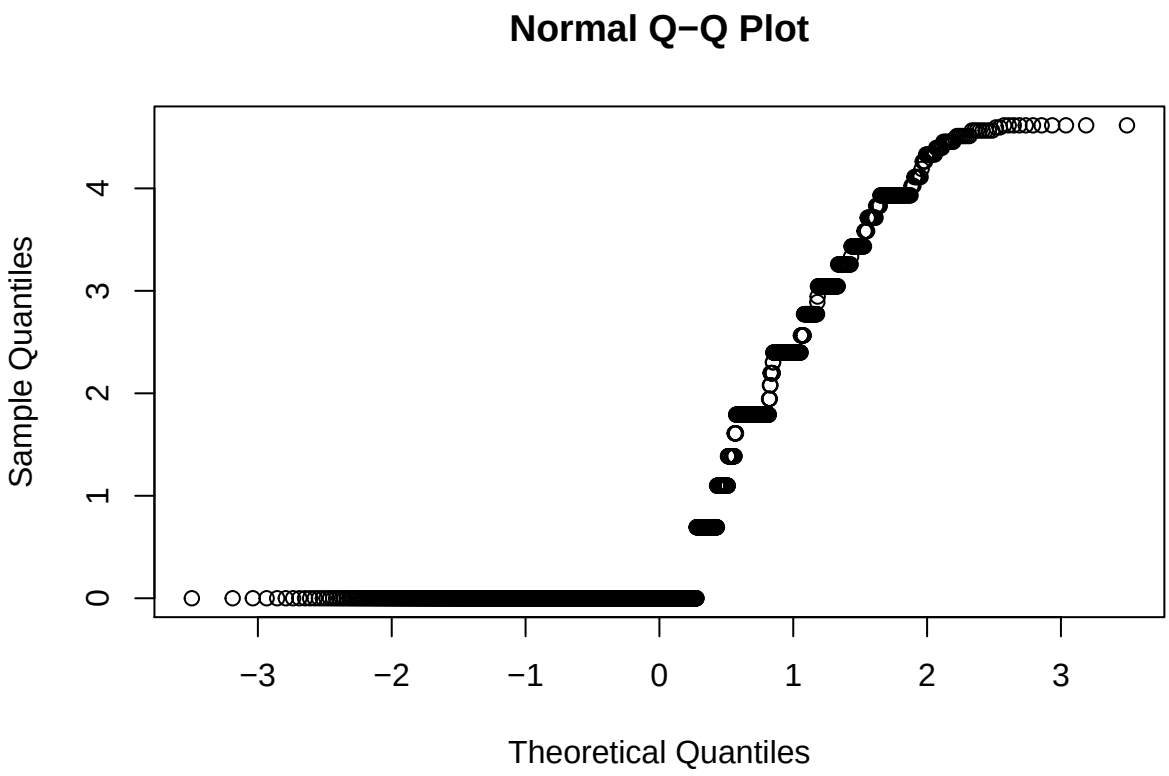

```
# gamma distribution? - error message "the function mle failed to estimate the parameters"
#fit.gamma <- fitdist(herb_umbs$p_eaten, "gamma")
#plot(fit.gamma)
```

```r
# lognormal distribution? - error message "values must be positive to fit a lognormal"
#fit.ln <- fitdist(herb_umbs$p_eaten, "lnorm")
#plot(fit.ln)

# log transform
herb_umbs$p_log <- log(herb_umbs$p_eaten+1)
hist(herb_umbs$p_log)
```



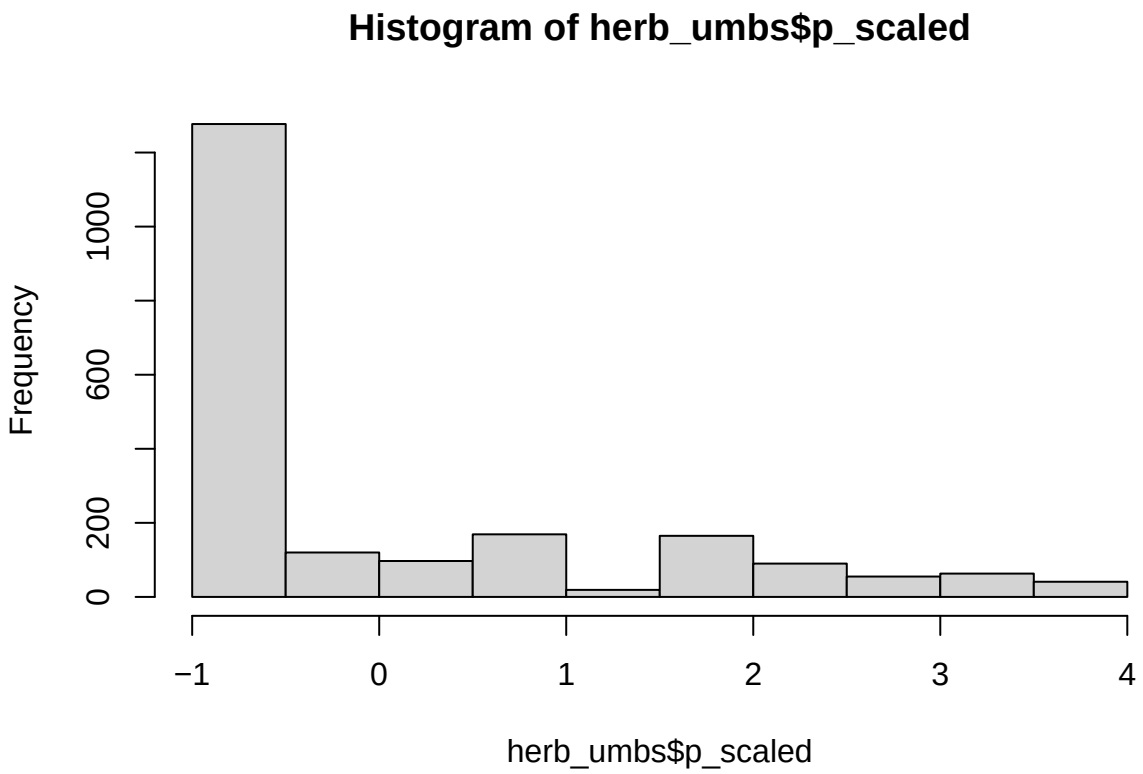

```r
qqnorm(herb_umbs$p_log)
```



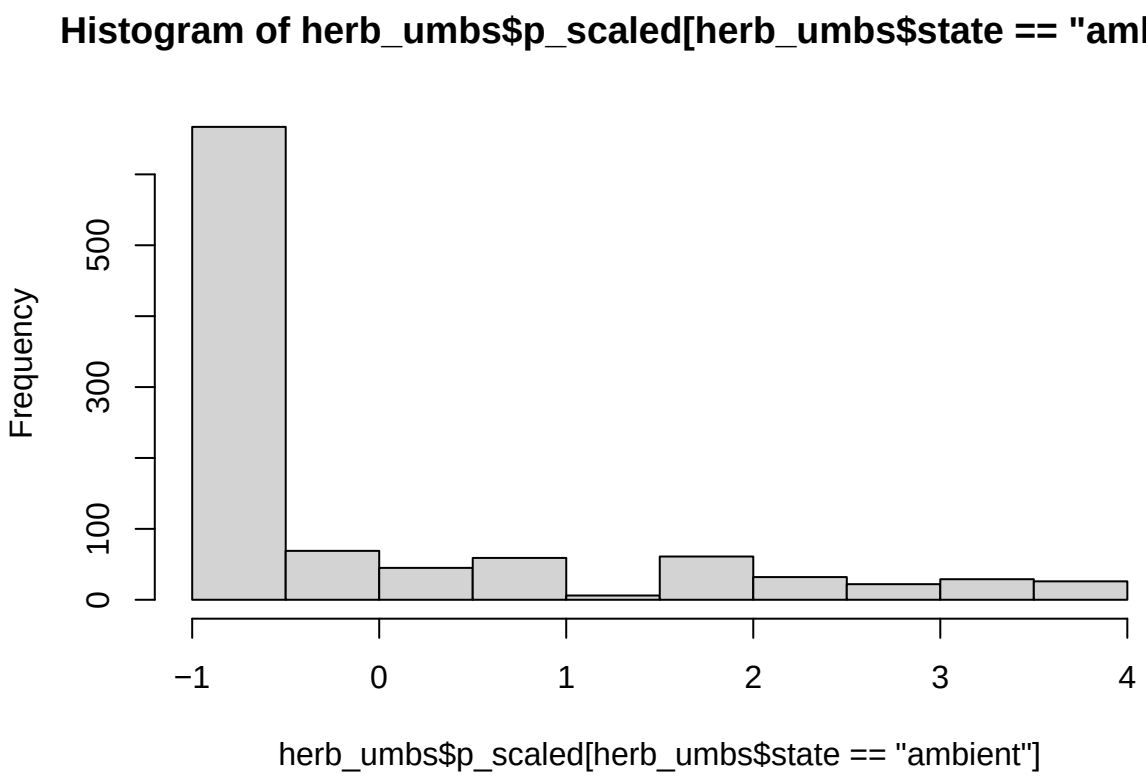

```
shapiro.test(herb_umbs$p_log) # NAs - data contains 0s
```

```
##
##  Shapiro-Wilk normality test
##
## data:  herb_umbs$p_log
## W = 0.71293, p-value < 2.2e-16
```

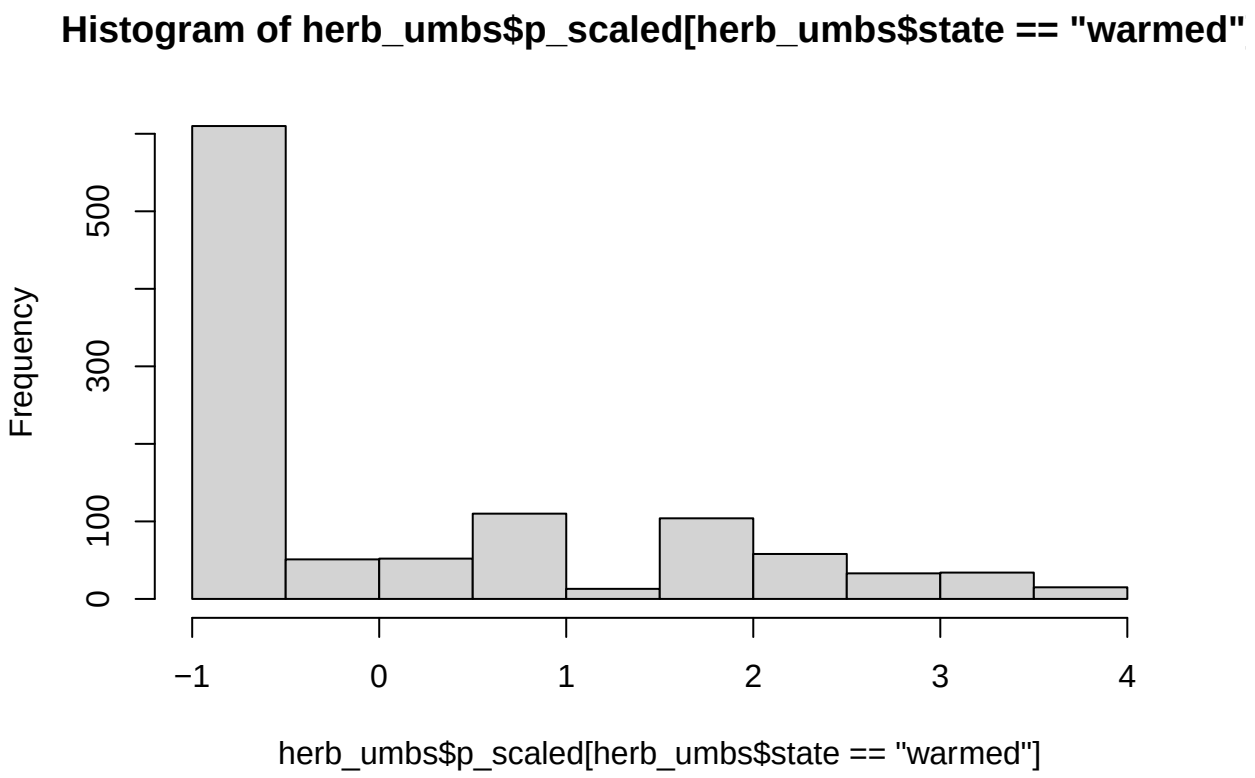
```
# mean centering p_eaten
herb_umbs$p_scaled <- herb_umbs$p_log - mean(herb_umbs$p_log)
hist(herb_umbs$p_scaled)
```



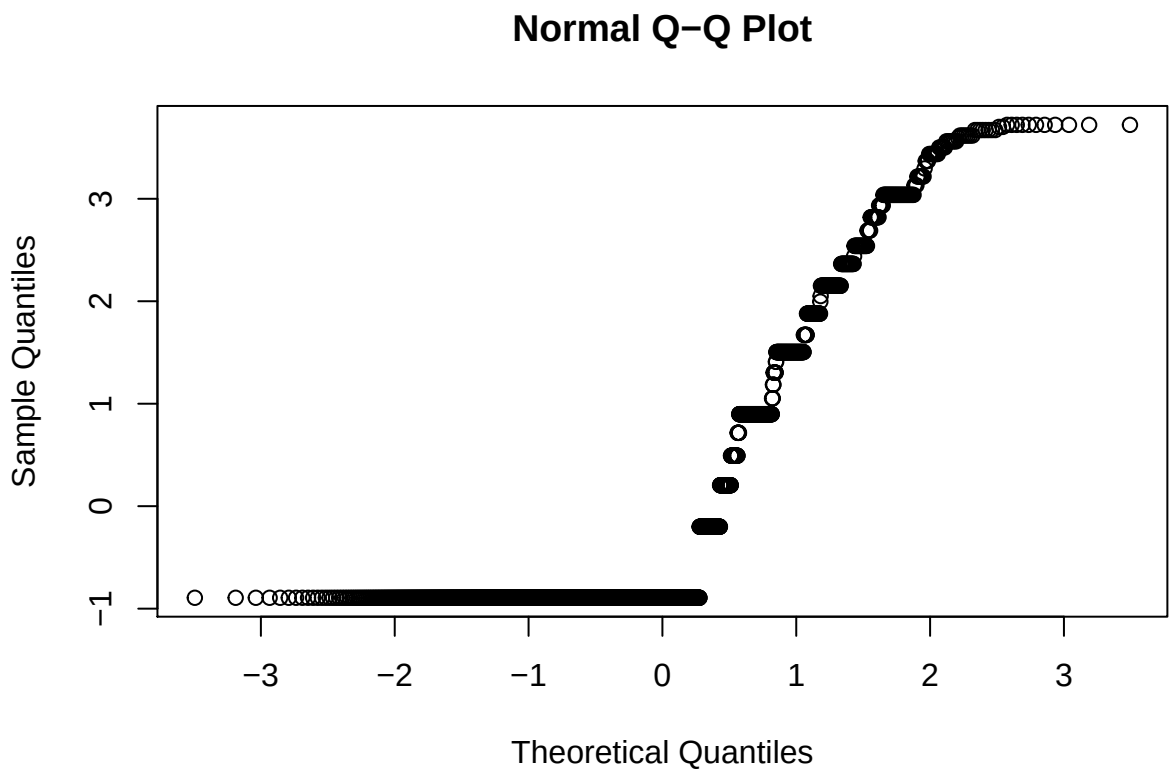

```
hist(herb_umbs$p_scaled[herb_umbs$state == "ambient"])
```




```
hist(herb_umbs$p_scaled[herb_umbs$state == "warmed"])
```




```
qqnorm(herb_umbs$p_scaled)
```

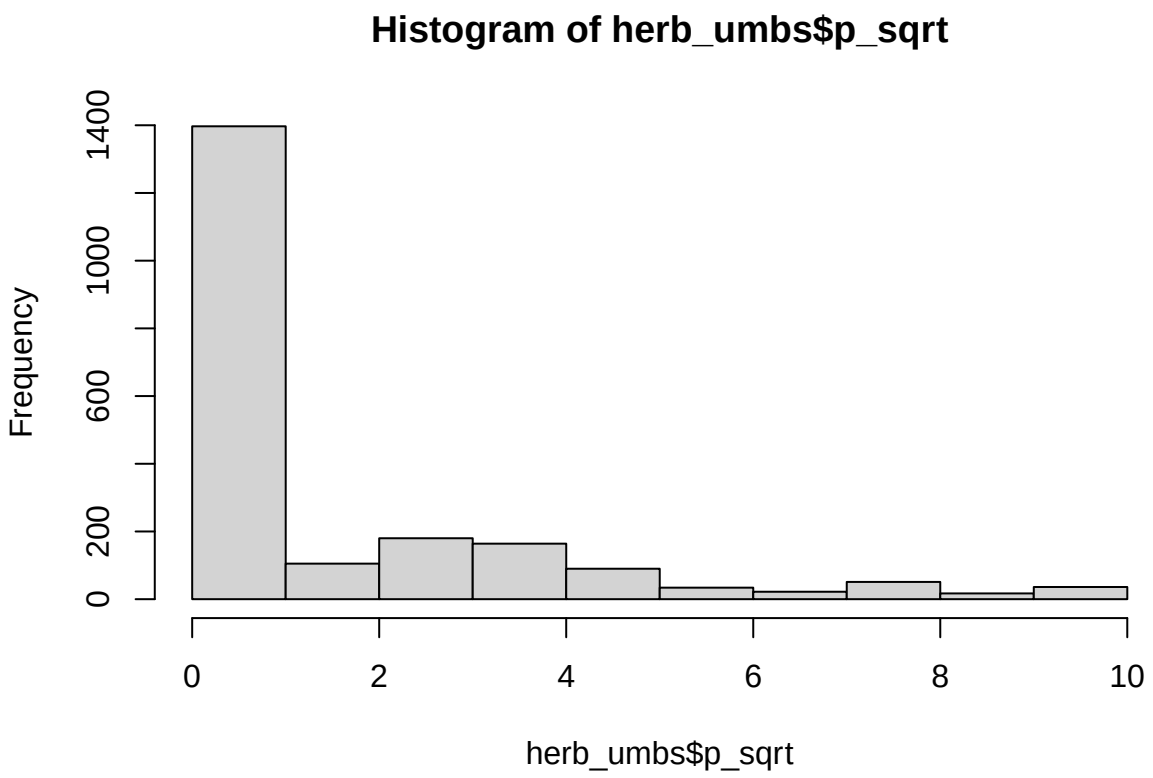



```
shapiro.test(herb_umbs$p_scaled)
```

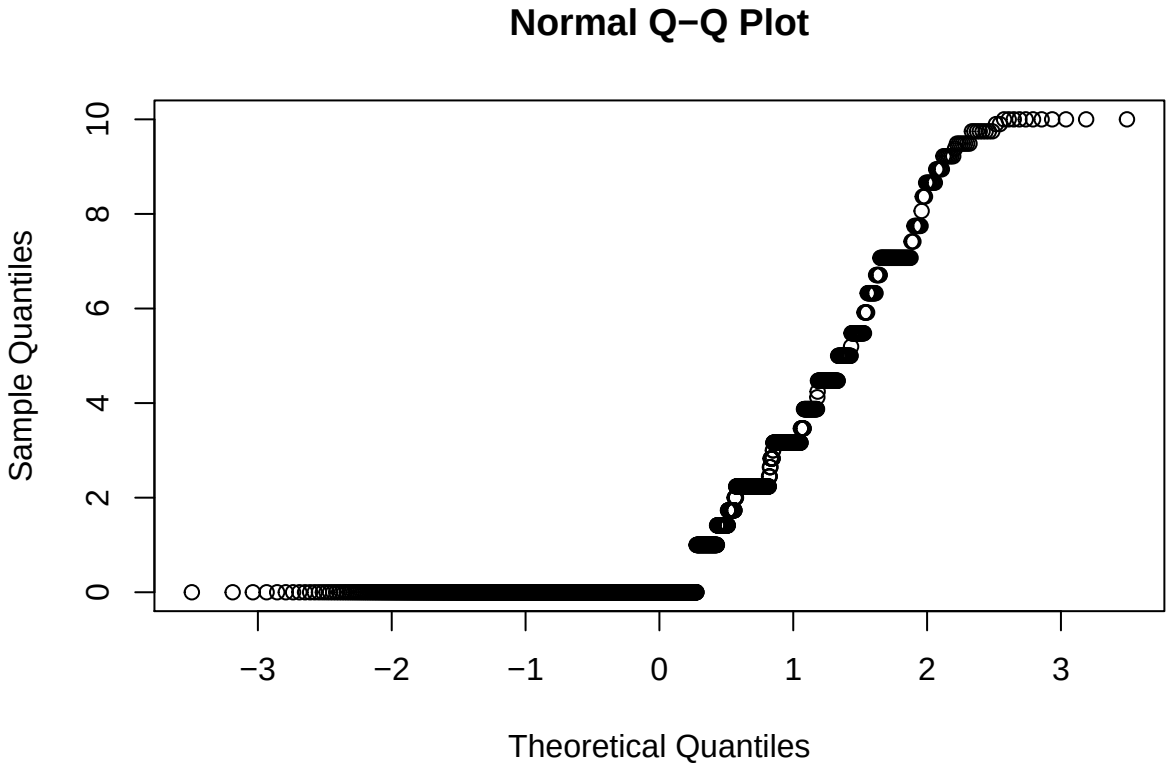
```
##
```

```
##  Shapiro-Wilk normality test
##
## data:  herb_umbs$p_scaled
## W = 0.71293, p-value < 2.2e-16
```

```r
# square root?
herb_umbs$p_sqrt <- sqrt(herb_umbs$p_eaten)
hist(herb_umbs$p_sqrt)
```




```r
qqnorm(herb_umbs$p_sqrt)
```




```
shapiro.test(herb_umbs$p_sqrt)
```

```
##
##  Shapiro-Wilk normality test
##
## data:  herb_umbs$p_sqrt
## W = 0.67356, p-value < 2.2e-16
```

Transformations are a no-go

Going to try a zero-inflated model due to the excess number of zeros in the data

```
# mean and var of non-zero counts
herb_umbs %>%
        dplyr::filter(p_eaten != "0") %>%
        dplyr::summarize(mean_eaten = mean(p_eaten, na.rm=T), var_eaten = var(p_eaten, na.rm=T))
```

```
## `summarise()` ungrouping output (override with `.groups` argument)
```

```
## # A tibble: 9 x 3
##   species mean_eaten var_eaten
##   <chr>        <dbl>     <dbl>
## 1 Cape          5.62      96.2
## 2 Cest         16.9      562.
## 3 Dasp         16.4      578.
## 4 Hype         27.5      622.
## 5 Poco          5.65      40.3
## 6 Popr         20.6      445.
## 7 Posp         37.1      654.
## 8 Ptaq          8.27      52.3
```

```
## 9 Ruac         22.3      606.
```

```
# variance is also > mean, so can't be poisson
# I'll try zero-inflated negative binomial due to an excess of zeros

# zero-inflated negative binomial
# state as a fixed effect
u.m1 <- zeroinfl(p_eaten ~ state,
                 dist = 'negbin',
                 data = herb_umbs)
summary(u.m1)
```

```
##
## Call:
## zeroinfl(formula = p_eaten ~ state, data = herb_umbs, dist = "negbin")
##
## Pearson residuals:
##     Min      1Q  Median      3Q     Max
## -0.4225 -0.4225 -0.3644 -0.1282  5.4643
##
## Count model coefficients (negbin with log link):
##             Estimate Std. Error z value Pr(>|z|)
## (Intercept)   2.5920     0.1030  25.172   <2e-16 ***
## statewarmed  -0.1678     0.1132  -1.482    0.138
## Log(theta)   -1.1336     0.1290  -8.785   <2e-16 ***
##
## Zero-inflation model coefficients (binomial with logit link):
##             Estimate Std. Error z value Pr(>|z|)
## (Intercept)  0.03949    0.14194   0.278    0.781
## statewarmed -0.59583    0.14157  -4.209 2.57e-05 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Theta = 0.3219
## Number of iterations in BFGS optimization: 11
## Log-likelihood: -4445 on 5 Df
```

```
# state and year as fixed effects
u.m2 <- zeroinfl(p_eaten ~ state + as.factor(year),
                 dist = 'negbin',
                 data = herb_umbs)
summary(u.m2)
```

```
##
## Call:
## zeroinfl(formula = p_eaten ~ state + as.factor(year), data = herb_umbs,
##     dist = "negbin")
##
## Pearson residuals:
##       Min        1Q    Median        3Q       Max
## -0.647684 -0.465711 -0.381948  0.004589 10.296157
##
## Count model coefficients (negbin with log link):
##                   Estimate Std. Error z value Pr(>|z|)
## (Intercept)      -0.25914    0.21082  -1.229  0.21899
```

```
## statewarmed       0.27295    0.09317   2.930  0.00339 **
## as.factor(year)2  1.34767    0.22722   5.931 3.01e-09 ***
## as.factor(year)3  3.38400    0.22206  15.239  < 2e-16 ***
## as.factor(year)4  2.35628    0.23443  10.051  < 2e-16 ***
## as.factor(year)5  3.16140    0.23452  13.480  < 2e-16 ***
## as.factor(year)6  3.32342    0.23381  14.214  < 2e-16 ***
## Log(theta)       -0.33468    0.08254  -4.055 5.01e-05 ***
##
## Zero-inflation model coefficients (binomial with logit link):
##                  Estimate Std. Error z value Pr(>|z|)
## (Intercept)      -10.8508    98.3571  -0.110 0.912155
## statewarmed       -0.4088     0.1082  -3.777 0.000159 ***
## as.factor(year)2  10.3579    98.3571   0.105 0.916131
## as.factor(year)3  11.1118    98.3571   0.113 0.910051
## as.factor(year)4  11.9030    98.3571   0.121 0.903677
## as.factor(year)5  11.6406    98.3571   0.118 0.905790
## as.factor(year)6  11.2062    98.3571   0.114 0.909290
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Theta = 0.7156
## Number of iterations in BFGS optimization: 32
## Log-likelihood: -4260 on 15 Df
```

```
lrtest(u.m1, u.m2) # model 2
```

```
## Likelihood ratio test
##
## Model 1: p_eaten ~ state
## Model 2: p_eaten ~ state + as.factor(year)
##   #Df  LogLik Df  Chisq Pr(>Chisq)
## 1   5 -4445.5
## 2  15 -4260.0 10 370.95  < 2.2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
# state and growth habit as fixed effects
herb_umbs <- within(herb_umbs, growth_habit <- relevel(factor(growth_habit), ref = "Forb")) # relevelin
u.m3 <- zeroinfl(p_eaten ~ state + growth_habit,
                 dist = 'negbin',
                 data = herb_umbs)
summary(u.m3)
```

```
##
## Call:
## zeroinfl(formula = p_eaten ~ state + growth_habit, data = herb_umbs,
##     dist = "negbin")
##
## Pearson residuals:
##     Min      1Q  Median      3Q     Max
## -0.4518 -0.3987 -0.3004 -0.1529  6.0071
##
## Count model coefficients (negbin with log link):
##                       Estimate Std. Error z value Pr(>|z|)
## (Intercept)            2.58249    0.12350  20.911  < 2e-16 ***
```

```
## statewarmed           -0.20063    0.11663  -1.720   0.0854 .
## growth_habitGraminoid -0.06051    0.12624  -0.479   0.6317
## Log(theta)            -1.22162    0.16327  -7.482 7.31e-14 ***
##
## Zero-inflation model coefficients (binomial with logit link):
##                       Estimate Std. Error z value Pr(>|z|)
## (Intercept)            -0.4595     0.2446  -1.879 0.060302 .
## statewarmed            -0.6956     0.1909  -3.644 0.000268 ***
## growth_habitGraminoid   1.0522     0.1993   5.279  1.3e-07 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Theta = 0.2948
## Number of iterations in BFGS optimization: 14
## Log-likelihood: -4415 on 7 Df
```

```
lrtest(u.m2, u.m3) # model 2
```

```
## Likelihood ratio test
##
## Model 1: p_eaten ~ state + as.factor(year)
## Model 2: p_eaten ~ state + growth_habit
##   #Df  LogLik Df  Chisq Pr(>Chisq)
## 1  15 -4260.0
## 2   7 -4415.4 -8 310.84  < 2.2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
# state, growth habit, and year as fixed effects
u.m4 <- zeroinfl(p_eaten ~ state + growth_habit + as.factor(year),
                 dist = 'negbin',
                 data = herb_umbs)
summary(u.m4)
```

```
##
## Call:
## zeroinfl(formula = p_eaten ~ state + growth_habit + as.factor(year),
##     data = herb_umbs, dist = "negbin")
##
## Pearson residuals:
##      Min       1Q   Median       3Q      Max
## -0.66222 -0.48107 -0.33430 -0.01702 11.87829
##
## Count model coefficients (negbin with log link):
##                       Estimate Std. Error z value Pr(>|z|)
## (Intercept)           -0.27115    0.22055  -1.229  0.21893
## statewarmed            0.29903    0.09776   3.059  0.00222 **
## growth_habitGraminoid  0.26020    0.10883   2.391  0.01680 *
## as.factor(year)2       1.03870    0.24609   4.221 2.43e-05 ***
## as.factor(year)3       3.21873    0.23991  13.417  < 2e-16 ***
## as.factor(year)4       2.28114    0.24752   9.216  < 2e-16 ***
## as.factor(year)5       3.12171    0.24711  12.633  < 2e-16 ***
## as.factor(year)6       3.29536    0.24648  13.370  < 2e-16 ***
## Log(theta)            -0.49276    0.10365  -4.754 2.00e-06 ***
##
```

```
## Zero-inflation model coefficients (binomial with logit link):
##                       Estimate Std. Error z value Pr(>|z|)
## (Intercept)           -11.4470   117.6274  -0.097  0.92248
## statewarmed            -0.3613     0.1206  -2.996  0.00274 **
## growth_habitGraminoid   1.2685     0.1648   7.697 1.39e-14 ***
## as.factor(year)2        9.5099   117.6279   0.081  0.93556
## as.factor(year)3       11.0962   117.6274   0.094  0.92484
## as.factor(year)4       11.9345   117.6274   0.101  0.91918
## as.factor(year)5       11.5427   117.6274   0.098  0.92183
## as.factor(year)6       11.7235   117.6274   0.100  0.92061
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Theta = 0.6109
## Number of iterations in BFGS optimization: 36
## Log-likelihood: -4219 on 17 Df
```

```
lrtest(u.m2, u.m4) # model 4
```

```
## Likelihood ratio test
##
## Model 1: p_eaten ~ state + as.factor(year)
## Model 2: p_eaten ~ state + growth_habit + as.factor(year)
##   #Df  LogLik Df  Chisq Pr(>Chisq)
## 1  15 -4260.0
## 2  17 -4218.9  2 82.184  < 2.2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
# interaction between state and growth habit as fixed effects
u.m5 <- zeroinfl(p_eaten ~ state * growth_habit,
                 dist = 'negbin',
                 data = herb_umbs)
summary(u.m5)
```

```
##
## Call:
## zeroinfl(formula = p_eaten ~ state * growth_habit, data = herb_umbs,
##     dist = "negbin")
##
## Pearson residuals:
##     Min      1Q  Median      3Q     Max
## -0.4419 -0.4251 -0.3161 -0.1483  6.9637
##
## Count model coefficients (negbin with log link):
##                                  Estimate Std. Error z value Pr(>|z|)
## (Intercept)                       2.50845    0.11297  22.204  < 2e-16 ***
## statewarmed                       0.04183    0.13261   0.315  0.75242
## growth_habitGraminoid             0.33677    0.19420   1.734  0.08290 .
## statewarmed:growth_habitGraminoid -0.73025    0.24921  -2.930  0.00339 **
## Log(theta)                        -1.09911    0.12628  -8.704  < 2e-16 ***
##
## Zero-inflation model coefficients (binomial with logit link):
##                                  Estimate Std. Error z value Pr(>|z|)
## (Intercept)                       -0.5108     0.1959  -2.608 0.009110 **
```

```
## statewarmed                          -0.1816     0.1823  -0.996 0.319271
## growth_habitGraminoid                 1.4059     0.2005   7.013 2.33e-12 ***
## statewarmed:growth_habitGraminoid    -0.9663     0.2772  -3.486 0.000491 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Theta = 0.3332
## Number of iterations in BFGS optimization: 15
## Log-likelihood: -4407 on 9 Df
```

```
lrtest(u.m4, u.m5) # model 4
```

```
## Likelihood ratio test
##
## Model 1: p_eaten ~ state + growth_habit + as.factor(year)
## Model 2: p_eaten ~ state * growth_habit
##   #Df  LogLik Df  Chisq Pr(>Chisq)
## 1  17 -4218.9
## 2   9 -4407.2 -8 376.53  < 2.2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
# interaction between state and growth habit as fixed effects, plus year
u.m6 <- zeroinfl(p_eaten ~ state * growth_habit + as.factor(year),
                 dist = 'negbin',
                 data = herb_umbs)
summary(u.m6)
```

```
##
## Call:
## zeroinfl(formula = p_eaten ~ state * growth_habit + as.factor(year),
##     data = herb_umbs, dist = "negbin")
##
## Pearson residuals:
##      Min       1Q   Median       3Q      Max
## -0.65834 -0.47972 -0.32606 -0.01636 11.83813
##
## Count model coefficients (negbin with log link):
##                                   Estimate Std. Error z value Pr(>|z|)
## (Intercept)                       -0.270199   0.220072  -1.228  0.21953
## statewarmed                        0.296797   0.106514   2.786  0.00533 **
## growth_habitGraminoid              0.254834   0.164301   1.551  0.12090
## as.factor(year)2                   1.061158   0.245930   4.315 1.60e-05 ***
## as.factor(year)3                   3.226367   0.239076  13.495  < 2e-16 ***
## as.factor(year)4                   2.289732   0.245551   9.325  < 2e-16 ***
## as.factor(year)5                   3.125807   0.245176  12.749  < 2e-16 ***
## as.factor(year)6                   3.300644   0.244568  13.496  < 2e-16 ***
## statewarmed:growth_habitGraminoid  0.003845   0.204963   0.019  0.98503
## Log(theta)                        -0.469147   0.102137  -4.593 4.36e-06 ***
##
## Zero-inflation model coefficients (binomial with logit link):
##                                  Estimate Std. Error z value Pr(>|z|)
## (Intercept)                      -13.5562   323.7932  -0.042    0.967
## statewarmed                       -0.1634     0.1515  -1.079    0.281
## growth_habitGraminoid              1.5102     0.2045   7.384 1.53e-13 ***
```

```
## as.factor(year)2                   11.6530   323.7933   0.036    0.971
## as.factor(year)3                   13.1255   323.7932   0.041    0.968
## as.factor(year)4                   13.9538   323.7932   0.043    0.966
## as.factor(year)5                   13.5468   323.7932   0.042    0.967
## as.factor(year)6                   13.7481   323.7932   0.042    0.966
## statewarmed:growth_habitGraminoid  -0.5139     0.2450  -2.097    0.036 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Theta = 0.6255
## Number of iterations in BFGS optimization: 40
## Log-likelihood: -4217 on 19 Df
```

```
lrtest(u.m4, u.m6) # almost the same, going with model 4 because its simpler
```

```
## Likelihood ratio test
##
## Model 1: p_eaten ~ state + growth_habit + as.factor(year)
## Model 2: p_eaten ~ state * growth_habit + as.factor(year)
##   #Df  LogLik Df  Chisq Pr(>Chisq)
## 1  17 -4218.9
## 2  19 -4216.7  2 4.5081      0.105
```

```
# interaction between state, growth habit, and year (year as a factor wouldn't woru - non-finite value)
u.m7 <- zeroinfl(p_eaten ~ state * growth_habit * year,
                 dist = 'negbin',
                 data = herb_umbs)
summary(u.m7)
```

```
##
## Call:
## zeroinfl(formula = p_eaten ~ state * growth_habit * year, data = herb_umbs,
##     dist = "negbin")
##
## Pearson residuals:
##     Min      1Q  Median      3Q     Max
## -0.5691 -0.4850 -0.3393 -0.0292  7.7954
##
## Count model coefficients (negbin with log link):
##                                     Estimate Std. Error z value Pr(>|z|)
## (Intercept)                          1.21385    0.26728   4.541 5.59e-06 ***
## statewarmed                         -0.07678    0.35475  -0.216    0.829
## growth_habitGraminoid               -7.85836    0.74484 -10.550  < 2e-16 ***
## year                                 0.35226    0.06562   5.368 7.94e-08 ***
## statewarmed:growth_habitGraminoid    7.56913    0.87143   8.686  < 2e-16 ***
## statewarmed:year                     0.02195    0.08737   0.251    0.802
## growth_habitGraminoid:year           2.98042    0.27345  10.899  < 2e-16 ***
## statewarmed:growth_habitGraminoid:year -2.85337    0.30972  -9.213  < 2e-16 ***
## Log(theta)                          -0.66484    0.08994  -7.392 1.45e-13 ***
##
## Zero-inflation model coefficients (binomial with logit link):
##                                     Estimate Std. Error z value Pr(>|z|)
## (Intercept)                         -0.56841    0.31439  -1.808   0.0706 .
## statewarmed                          0.11578    0.42010   0.276   0.7828
## growth_habitGraminoid               -8.71764    1.46012  -5.970 2.37e-09 ***
```

```
## year                                     0.10017    0.06852   1.462   0.1438
## statewarmed:growth_habitGraminoid        6.14174    1.56877   3.915 9.04e-05 ***
## statewarmed:year                        -0.06972    0.09630  -0.724   0.4691
## growth_habitGraminoid:year               2.95415    0.44600   6.624 3.50e-11 ***
## statewarmed:growth_habitGraminoid:year -2.02729    0.47087  -4.305 1.67e-05 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Theta = 0.5144
## Number of iterations in BFGS optimization: 23
## Log-likelihood: -4241 on 17 Df
```

```
lrtest(u.m4, u.m7) # model 4
```

```
## Likelihood ratio test
##
## Model 1: p_eaten ~ state + growth_habit + as.factor(year)
## Model 2: p_eaten ~ state * growth_habit * year
##   #Df  LogLik Df  Chisq Pr(>Chisq)
## 1  17 -4218.9
## 2  17 -4240.7  0 43.623  < 2.2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
# state and origin as fixed effects
herb_umbs <- within(herb_umbs, origin <- relevel(factor(origin), ref = "Native")) # releveling so nativ
u.m8 <- zeroinfl(p_eaten ~ state + origin,
                 dist = 'negbin',
                 data = herb_umbs)
summary(u.m8)
```

```
##
## Call:
## zeroinfl(formula = p_eaten ~ state + origin, data = herb_umbs, dist = "negbin")
##
## Pearson residuals:
##     Min      1Q  Median      3Q     Max
## -0.4406 -0.4120 -0.3839 -0.1137  8.0557
##
## Count model coefficients (negbin with log link):
##              Estimate Std. Error z value Pr(>|z|)
## (Intercept)    2.2218     0.1314  16.903  < 2e-16 ***
## statewarmed   -0.1406     0.1103  -1.275  0.20236
## origin         1.1898     0.2641   4.505 6.65e-06 ***
## originExotic   0.4347     0.1260   3.450  0.00056 ***
## Log(theta)    -1.0216     0.1191  -8.575  < 2e-16 ***
##
## Zero-inflation model coefficients (binomial with logit link):
##              Estimate Std. Error z value Pr(>|z|)
## (Intercept)    0.2637     0.1584   1.665   0.0959 .
## statewarmed   -0.5299     0.1293  -4.097 4.19e-05 ***
## origin         0.1052     0.2716   0.387   0.6986
## originExotic  -0.2547     0.1418  -1.797   0.0724 .
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
##
## Theta = 0.36
## Number of iterations in BFGS optimization: 15
## Log-likelihood: -4429 on 9 Df
```

```
lrtest(u.m4, u.m8) # model 4
```

```
## Likelihood ratio test
##
## Model 1: p_eaten ~ state + growth_habit + as.factor(year)
## Model 2: p_eaten ~ state + origin
##   #Df  LogLik Df  Chisq Pr(>Chisq)
## 1  17 -4218.9
## 2   9 -4428.5 -8 419.15  < 2.2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
# state, origin, and year as fixed effects
u.m9 <- zeroinfl(p_eaten ~ state + origin + as.factor(year),
                 dist = 'negbin',
                 data = herb_umbs)
summary(u.m9)
```

```
##
## Call:
## zeroinfl(formula = p_eaten ~ state + origin + as.factor(year), data = herb_umbs,
##     dist = "negbin")
##
## Pearson residuals:
##       Min        1Q    Median        3Q       Max
## -0.649042 -0.471905 -0.359323 -0.008103  9.729775
##
## Count model coefficients (negbin with log link):
##                   Estimate Std. Error z value Pr(>|z|)
## (Intercept)      -0.36965    0.23396  -1.580  0.11411
## statewarmed       0.26640    0.09299   2.865  0.00417 **
## origin            0.50601    0.21288   2.377  0.01746 *
## originExotic      0.11390    0.10611   1.073  0.28309
## as.factor(year)2  1.39294    0.23123   6.024 1.70e-09 ***
## as.factor(year)3  3.32660    0.22842  14.564  < 2e-16 ***
## as.factor(year)4  2.39332    0.23661  10.115  < 2e-16 ***
## as.factor(year)5  3.17364    0.23392  13.567  < 2e-16 ***
## as.factor(year)6  3.32423    0.23309  14.262  < 2e-16 ***
## Log(theta)       -0.32531    0.08300  -3.919 8.88e-05 ***
##
## Zero-inflation model coefficients (binomial with logit link):
##                   Estimate Std. Error z value Pr(>|z|)
## (Intercept)      -13.6325   484.4662  -0.028 0.977551
## statewarmed       -0.3969     0.1092  -3.636 0.000277 ***
## origin             0.2539     0.2486   1.021 0.307107
## originExotic      -0.3973     0.1330  -2.986 0.002823 **
## as.factor(year)2  13.3454   484.4662   0.028 0.978024
## as.factor(year)3  14.0221   484.4662   0.029 0.976910
## as.factor(year)4  14.9530   484.4662   0.031 0.975377
## as.factor(year)5  14.7034   484.4662   0.030 0.975788
```

```
## as.factor(year)6  14.3824   484.4662   0.030 0.976317
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Theta = 0.7223
## Number of iterations in BFGS optimization: 40
## Log-likelihood: -4250 on 19 Df
```

```
lrtest(u.m4, u.m9) # model 4
```

```
## Likelihood ratio test
##
## Model 1: p_eaten ~ state + growth_habit + as.factor(year)
## Model 2: p_eaten ~ state + origin + as.factor(year)
##   #Df  LogLik Df  Chisq Pr(>Chisq)
## 1  17 -4218.9
## 2  19 -4249.6  2 61.362  4.736e-14 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
# interaction between state and origin as fixed effects
u.m10 <- zeroinfl(p_eaten ~ state * origin,
                  dist = 'negbin',
                  data = herb_umbs)
summary(u.m10)
```

```
##
## Call:
## zeroinfl(formula = p_eaten ~ state * origin, data = herb_umbs, dist = "negbin")
##
## Pearson residuals:
##      Min       1Q   Median       3Q      Max
## -0.45403 -0.44045 -0.33874 -0.09427  7.31531
##
## Count model coefficients (negbin with log link):
##                          Estimate Std. Error z value Pr(>|z|)
## (Intercept)                2.4173     0.1735  13.929  < 2e-16 ***
## statewarmed               -0.5187     0.2177  -2.383  0.01718 *
## origin                     1.0417     0.3551   2.933  0.00335 **
## originExotic               0.1655     0.1939   0.853  0.39350
## statewarmed:origin         0.3297     0.5382   0.613  0.54015
## statewarmed:originExotic   0.5034     0.2540   1.982  0.04748 *
## Log(theta)                -1.0171     0.1202  -8.465  < 2e-16 ***
##
## Zero-inflation model coefficients (binomial with logit link):
##                          Estimate Std. Error z value Pr(>|z|)
## (Intercept)                0.4857     0.1736   2.798  0.00514 **
## statewarmed               -1.0623     0.2674  -3.972 7.13e-05 ***
## origin                    -1.0999     0.4317  -2.548  0.01084 *
## originExotic              -0.4842     0.1873  -2.585  0.00973 **
## statewarmed:origin         2.3545     0.5871   4.010 6.07e-05 ***
## statewarmed:originExotic   0.5533     0.3026   1.829  0.06746 .
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
```

```
## Theta = 0.3616
## Number of iterations in BFGS optimization: 20
## Log-likelihood: -4418 on 13 Df
```

```
lrtest(u.m4, u.m10) # model 4
```

```
## Likelihood ratio test
##
## Model 1: p_eaten ~ state + growth_habit + as.factor(year)
## Model 2: p_eaten ~ state * origin
##   #Df  LogLik Df  Chisq Pr(>Chisq)
## 1  17 -4218.9
## 2  13 -4417.6 -4 397.42  < 2.2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
# interaction between state and origin as fixed effects, plus year
u.m11 <- zeroinfl(p_eaten ~ state * origin + as.factor(year),
                  dist = 'negbin',
                  data = herb_umbs)
summary(u.m11)
```

```
##
## Call:
## zeroinfl(formula = p_eaten ~ state * origin + as.factor(year), data = herb_umbs,
##     dist = "negbin")
##
## Pearson residuals:
##      Min       1Q   Median       3Q      Max
## -0.65417 -0.46593 -0.36493 -0.02109  9.47634
##
## Count model coefficients (negbin with log link):
##                          Estimate Std. Error z value Pr(>|z|)
## (Intercept)              -0.26760    0.25243  -1.060 0.289103
## statewarmed               0.09681    0.17695   0.547 0.584294
## origin                    0.57712    0.27344   2.111 0.034807 *
## originExotic             -0.02525    0.15781  -0.160 0.872890
## as.factor(year)2          1.38107    0.23181   5.958 2.56e-09 ***
## as.factor(year)3          3.31051    0.22899  14.457  < 2e-16 ***
## as.factor(year)4          2.38935    0.23691  10.085  < 2e-16 ***
## as.factor(year)5          3.15962    0.23432  13.484  < 2e-16 ***
## as.factor(year)6          3.33175    0.23351  14.268  < 2e-16 ***
## statewarmed:origin       -0.27675    0.41098  -0.673 0.500709
## statewarmed:originExotic  0.24530    0.19903   1.232 0.217762
## Log(theta)               -0.32561    0.08377  -3.887 0.000102 ***
##
## Zero-inflation model coefficients (binomial with logit link):
##                           Estimate Std. Error z value Pr(>|z|)
## (Intercept)               -15.3960  1295.7168  -0.012  0.99052
## statewarmed                -0.8763     0.2186  -4.008 6.12e-05 ***
## origin                     -0.8079     0.3537  -2.284  0.02235 *
## originExotic               -0.6378     0.1835  -3.476  0.00051 ***
## as.factor(year)2           15.3288  1295.7168   0.012  0.99056
## as.factor(year)3           15.9936  1295.7168   0.012  0.99015
## as.factor(year)4           16.9728  1295.7168   0.013  0.98955
```

```
## as.factor(year)5           16.6761  1295.7168   0.013  0.98973
## as.factor(year)6           16.3750  1295.7168   0.013  0.98992
## statewarmed:origin          2.0110     0.4785   4.202 2.64e-05 ***
## statewarmed:originExotic    0.5053     0.2553   1.979  0.04779 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Theta = 0.7221
## Number of iterations in BFGS optimization: 45
## Log-likelihood: -4239 on 23 Df
```

```
lrtest(u.m4, u.m11) # model 4
```

```
## Likelihood ratio test
##
## Model 1: p_eaten ~ state + growth_habit + as.factor(year)
## Model 2: p_eaten ~ state * origin + as.factor(year)
##   #Df  LogLik Df  Chisq Pr(>Chisq)
## 1  17 -4218.9
## 2  23 -4238.8  6 39.822  4.938e-07 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
exp(-0.26760 + 0.37613*0) # 1.538119
```

```
## [1] 0.7652138
```

```
exp(-0.26760 + 0.37613*1) # 2.24048
```

```
## [1] 1.114638
```

```
# effect of herbivory:
2.24048 - 1.538119 # 0.702361
```

```
## [1] 0.702361
```

```
## interaction between state, origin, and year - doesn't work
#u.m12 <- zeroinfl(p_eaten ~ state * origin * as.factor(year),
#                  dist = 'negbin',
#                  data = herb_umbs)
#summary(u.m12)

# state and species as fixed effects
u.m13 <- zeroinfl(p_eaten ~ state + species,
                  dist = 'negbin',
                  data = herb_umbs)
summary(u.m13)
```

```
##
## Call:
## zeroinfl(formula = p_eaten ~ state + species, data = herb_umbs, dist = "negbin")
##
## Pearson residuals:
##     Min      1Q  Median      3Q     Max
## -0.6206 -0.4564 -0.3392 -0.1233 12.7533
##
## Count model coefficients (negbin with log link):
##             Estimate Std. Error z value Pr(>|z|)
```

```
## (Intercept)  1.27936    0.30754   4.160 3.18e-05 ***
## statewarmed -0.02801    0.10706  -0.262 0.793622
## speciesCest  1.30581    0.30874   4.229 2.34e-05 ***
## speciesDasp  1.26957    0.32796   3.871 0.000108 ***
## speciesHype  1.85424    0.46366   3.999 6.36e-05 ***
## speciesPoco  0.03985    0.35454   0.112 0.910497
## speciesPopr  1.54323    0.51765   2.981 0.002871 **
## speciesPosp  2.16189    0.37543   5.759 8.49e-09 ***
## speciesPtaq  0.44828    0.34711   1.291 0.196542
## speciesRuac  1.60773    0.31775   5.060 4.20e-07 ***
## Log(theta)  -0.84553    0.09832  -8.600  < 2e-16 ***
##
## Zero-inflation model coefficients (binomial with logit link):
##              Estimate Std. Error z value Pr(>|z|)
## (Intercept)    0.6326     0.3132   2.020  0.04340 *
## statewarmed   -0.3529     0.1314  -2.686  0.00723 **
## speciesCest   -0.9841     0.3242  -3.036  0.00240 **
## speciesDasp   -0.2477     0.3346  -0.740  0.45904
## speciesHype    1.0087     0.4127   2.444  0.01453 *
## speciesPoco  -15.7204  1244.4038  -0.013  0.98992
## speciesPopr    2.0744     0.4333   4.788 1.69e-06 ***
## speciesPosp   -0.2279     0.3789  -0.601  0.54762
## speciesPtaq   -0.8805     0.4048  -2.175  0.02961 *
## speciesRuac   -1.0566     0.3416  -3.093  0.00198 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Theta = 0.4293
## Number of iterations in BFGS optimization: 42
## Log-likelihood: -4292 on 21 Df
```

```
lrtest(u.m4, u.m13) # model 4
```

```
## Likelihood ratio test
##
## Model 1: p_eaten ~ state + growth_habit + as.factor(year)
## Model 2: p_eaten ~ state + species
##   #Df  LogLik Df  Chisq Pr(>Chisq)
## 1  17 -4218.9
## 2  21 -4292.4  4 146.98  < 2.2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
# state, species and year as fixed effects
u.m14 <- zeroinfl(p_eaten ~ state + species + as.factor(year),
                  dist = 'negbin',
                  data = herb_umbs)
summary(u.m14)
```

```
##
## Call:
## zeroinfl(formula = p_eaten ~ state + species + as.factor(year), data = herb_umbs,
##     dist = "negbin")
##
## Pearson residuals:
```

```
##      Min       1Q   Median       3Q      Max
## -0.70260 -0.49987 -0.32878 -0.01447 11.66668
##
## Count model coefficients (negbin with log link):
##                   Estimate Std. Error z value Pr(>|z|)
## (Intercept)      -0.40972    0.35052  -1.169 0.242448
## statewarmed       0.26343    0.09307   2.830 0.004650 **
## speciesCest       0.15545    0.28274   0.550 0.582459
## speciesDasp       0.41035    0.29147   1.408 0.159171
## speciesHype       0.38761    0.40744   0.951 0.341443
## speciesPoco       0.43451    0.31758   1.368 0.171253
## speciesPopr       0.29092    0.44567   0.653 0.513902
## speciesPosp       0.80799    0.34166   2.365 0.018035 *
## speciesPtaq      -0.01442    0.30768  -0.047 0.962609
## speciesRuac       0.49122    0.28612   1.717 0.086013 .
## as.factor(year)2  1.17523    0.24755   4.748 2.06e-06 ***
## as.factor(year)3  3.06518    0.24034  12.754  < 2e-16 ***
## as.factor(year)4  2.28318    0.24552   9.299  < 2e-16 ***
## as.factor(year)5  2.99940    0.24663  12.161  < 2e-16 ***
## as.factor(year)6  3.28438    0.23403  14.034  < 2e-16 ***
## Log(theta)       -0.33330    0.08651  -3.853 0.000117 ***
##
## Zero-inflation model coefficients (binomial with logit link):
##                    Estimate Std. Error z value Pr(>|z|)
## (Intercept)       -14.9891  1547.7505  -0.010  0.99227
## statewarmed        -0.2966     0.1191  -2.490  0.01277 *
## speciesCest        -1.4338     0.3093  -4.635 3.57e-06 ***
## speciesDasp        -0.4142     0.2989  -1.386  0.16583
## speciesHype         0.6283     0.3917   1.604  0.10871
## speciesPoco        -1.8193     0.7522  -2.419  0.01558 *
## speciesPopr         1.3788     0.4077   3.382  0.00072 ***
## speciesPosp        -0.4734     0.3713  -1.275  0.20228
## speciesPtaq        -1.0125     0.3584  -2.825  0.00473 **
## speciesRuac        -1.4319     0.3053  -4.690 2.73e-06 ***
## as.factor(year)2   15.2197  1547.7505   0.010  0.99215
## as.factor(year)3   16.0462  1547.7505   0.010  0.99173
## as.factor(year)4   16.7231  1547.7505   0.011  0.99138
## as.factor(year)5   16.1363  1547.7505   0.010  0.99168
## as.factor(year)6   16.5355  1547.7505   0.011  0.99148
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Theta = 0.7166
## Number of iterations in BFGS optimization: 53
## Log-likelihood: -4154 on 31 Df
```

```
lrtest(u.m4, u.m14) # model 14
```

```
## Likelihood ratio test
##
## Model 1: p_eaten ~ state + growth_habit + as.factor(year)
## Model 2: p_eaten ~ state + species + as.factor(year)
##   #Df  LogLik Df  Chisq Pr(>Chisq)
## 1  17 -4218.9
## 2  31 -4153.7 14 130.54  < 2.2e-16 ***
```

```
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
# calculating effect size - accounting for log link
exp(-0.40972 + 0.26343*0) # 0.6638361
```

```
## [1] 0.6638361
```

```
exp(-0.40972 + 0.26343*1) # 0.8639071
```

```
## [1] 0.8639071
```

```
# effect of herbivory:
0.8639071 - 0.6638361 # 0.200071
```

```
## [1] 0.200071
```

```
# interaction between state and species as fixed effects, plus year
u.m15 <- zeroinfl(p_eaten ~ state * species + as.factor(year),
                  dist = 'negbin',
                  data = herb_umbs)
summary(u.m15)
```

```
##
## Call:
## zeroinfl(formula = p_eaten ~ state * species + as.factor(year), data = herb_umbs,
##     dist = "negbin")
##
## Pearson residuals:
##      Min       1Q   Median       3Q      Max
## -0.71759 -0.50964 -0.31412 -0.05114 10.77704
##
## Count model coefficients (negbin with log link):
##                          Estimate Std. Error z value Pr(>|z|)
## (Intercept)              -0.56238    0.46370  -1.213 0.225209
## statewarmed               0.49483    0.52624   0.940 0.347058
## speciesCest               0.23959    0.42534   0.563 0.573242
## speciesDasp               0.67525    0.45045   1.499 0.133859
## speciesHype              -0.02343    0.56353  -0.042 0.966841
## speciesPoco              -0.04919    0.67903  -0.072 0.942252
## speciesPopr               0.46320    1.27083   0.364 0.715497
## speciesPosp               1.17204    0.48351   2.424 0.015348 *
## speciesPtaq               0.38266    0.47107   0.812 0.416613
## speciesRuac               0.77307    0.43323   1.784 0.074354 .
## as.factor(year)2          1.19443    0.24644   4.847 1.26e-06 ***
## as.factor(year)3          3.01325    0.24087  12.510  < 2e-16 ***
## as.factor(year)4          2.27642    0.24396   9.331  < 2e-16 ***
## as.factor(year)5          2.96236    0.24562  12.061  < 2e-16 ***
## as.factor(year)6          3.30472    0.23268  14.203  < 2e-16 ***
## statewarmed:speciesCest -0.09171    0.54453  -0.168 0.866259
## statewarmed:speciesDasp -0.38308    0.57492  -0.666 0.505211
## statewarmed:speciesHype  0.79783    0.77615   1.028 0.303981
## statewarmed:speciesPoco  0.45497    0.77816   0.585 0.558771
## statewarmed:speciesPopr -0.20828    1.36477  -0.153 0.878705
## statewarmed:speciesPosp -0.67450    0.64178  -1.051 0.293267
## statewarmed:speciesPtaq -0.63943    0.60653  -1.054 0.291767
## statewarmed:speciesRuac -0.41412    0.55624  -0.744 0.456576
```

```
## Log(theta)              -0.30399    0.08523  -3.567 0.000361 ***
##
## Zero-inflation model coefficients (binomial with logit link):
##                            Estimate Std. Error z value Pr(>|z|)
## (Intercept)              -13.70447 1126.42094  -0.012 0.990293
## statewarmed               -2.54202    0.67898  -3.744 0.000181 ***
## speciesCest               -1.97446    0.40609  -4.862 1.16e-06 ***
## speciesDasp               -0.79081    0.41200  -1.919 0.054930 .
## speciesHype               -0.15737    0.54007  -0.291 0.770755
## speciesPoco               -2.58422    2.17122  -1.190 0.233961
## speciesPopr                2.48657    1.07616   2.311 0.020855 *
## speciesPosp               -1.90334    0.50200  -3.792 0.000150 ***
## speciesPtaq               -2.04852    0.51673  -3.964 7.36e-05 ***
## speciesRuac               -2.43632    0.41879  -5.818 5.97e-09 ***
## as.factor(year)2          14.64934 1126.42090   0.013 0.989624
## as.factor(year)3          15.40399 1126.42088   0.014 0.989089
## as.factor(year)4          16.12980 1126.42088   0.014 0.988575
## as.factor(year)5          15.44148 1126.42088   0.014 0.989063
## as.factor(year)6          15.89701 1126.42088   0.014 0.988740
## statewarmed:speciesCest    2.04479    0.71433   2.863 0.004203 **
## statewarmed:speciesDasp    1.68122    0.73296   2.294 0.021805 *
## statewarmed:speciesHype    2.47526    0.88283   2.804 0.005051 **
## statewarmed:speciesPoco    2.24483    2.35794   0.952 0.341083
## statewarmed:speciesPopr   -0.04895    1.26292  -0.039 0.969080
## statewarmed:speciesPosp    3.67473    0.80065   4.590 4.44e-06 ***
## statewarmed:speciesPtaq    2.83563    0.80840   3.508 0.000452 ***
## statewarmed:speciesRuac    2.90264    0.72344   4.012 6.01e-05 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Theta = 0.7379
## Number of iterations in BFGS optimization: 69
## Log-likelihood: -4123 on 47 Df
```

```
lrtest(u.m14, u.m15) # model 15 - might go with 14 because its simpler
```

```
## Likelihood ratio test
##
## Model 1: p_eaten ~ state + species + as.factor(year)
## Model 2: p_eaten ~ state * species + as.factor(year)
##   #Df  LogLik Df  Chisq Pr(>Chisq)
## 1  31 -4153.7
## 2  47 -4123.0 16 61.233  3.239e-07 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
## interaction between state, species, and year - doesn't run
#m8 <- zeroinfl(p_eaten ~ state * species * year,
#                      dist = 'negbin',
#                      data = herb_umbs)
#summary(m8)

# checking models again
lrtest(u.m2, u.m4, u.m9, u.m14) # model 14 best - with species
```

```
## Likelihood ratio test
##
## Model 1: p_eaten ~ state + as.factor(year)
## Model 2: p_eaten ~ state + growth_habit + as.factor(year)
## Model 3: p_eaten ~ state + origin + as.factor(year)
## Model 4: p_eaten ~ state + species + as.factor(year)
##   #Df  LogLik Df   Chisq Pr(>Chisq)
## 1  15 -4260.0
## 2  17 -4218.9  2  82.184  < 2.2e-16 ***
## 3  19 -4249.6  2  61.362  4.736e-14 ***
## 4  31 -4153.7 12 191.904  < 2.2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
res.u <- AIC(u.m1, u.m2, u.m3, u.m4, u.m5, u.m6, u.m7, u.m9, u.m10, u.m11,u.m13,u.m14,u.m15)

# check dispersion - chose lowest loglik model for example
E <- resid(u.m14, type = "pearson")
N  <- nrow(herb_umbs)
p  <- length(coef(u.m14)) + 1 # '+1' is due to theta
sum(E^2) / (N - p) # pretty close to one
```

```
## [1] 1.033222
```

```
# pairwise comparisons
emmeans(u.m14, ~ state + species + as.factor(year))
```

```
##  state   species year emmean    SE  df asymp.LCL asymp.UCL
##  ambient Cape       1  0.664 0.233 Inf    0.2078     1.120
##  warmed  Cape       1  0.864 0.307 Inf    0.2628     1.465
##  ambient Cest       1  0.775 0.163 Inf    0.4552     1.096
##  warmed  Cest       1  1.009 0.213 Inf    0.5917     1.427
##  ambient Dasp       1  1.001 0.256 Inf    0.4990     1.502
##  warmed  Dasp       1  1.302 0.336 Inf    0.6427     1.962
##  ambient Hype       1  0.978 0.364 Inf    0.2651     1.691
##  warmed  Hype       1  1.273 0.474 Inf    0.3438     2.202
##  ambient Poco       1  1.025 0.312 Inf    0.4139     1.636
##  warmed  Poco       1  1.334 0.403 Inf    0.5442     2.124
##  ambient Popr       1  0.888 0.371 Inf    0.1601     1.616
##  warmed  Popr       1  1.156 0.479 Inf    0.2165     2.095
##  ambient Posp       1  1.489 0.451 Inf    0.6044     2.374
##  warmed  Posp       1  1.938 0.594 Inf    0.7729     3.103
##  ambient Ptaq       1  0.654 0.178 Inf    0.3054     1.003
##  warmed  Ptaq       1  0.852 0.238 Inf    0.3845     1.319
##  ambient Ruac       1  1.085 0.262 Inf    0.5707     1.599
##  warmed  Ruac       1  1.412 0.348 Inf    0.7292     2.095
##  ambient Cape       2  0.952 0.283 Inf    0.3973     1.506
##  warmed  Cape       2  1.445 0.417 Inf    0.6288     2.262
##  ambient Cest       2  1.932 0.263 Inf    1.4167     2.447
##  warmed  Cest       2  2.672 0.311 Inf    2.0620     3.283
##  ambient Dasp       2  1.769 0.275 Inf    1.2294     2.308
##  warmed  Dasp       2  2.606 0.366 Inf    1.8892     3.322
##  ambient Hype       2  0.943 0.343 Inf    0.2710     1.614
##  warmed  Hype       2  1.497 0.524 Inf    0.4700     2.523
##  ambient Poco       2  2.757 0.518 Inf    1.7424     3.772
```

```
##  warmed  Poco       2  3.751 0.616 Inf    2.5449     4.958
##  ambient Popr       2  0.479 0.221 Inf    0.0461     0.913
##  warmed  Popr       2  0.794 0.354 Inf    0.0991     1.488
##  ambient Posp       2  2.703 0.691 Inf    1.3481     4.058
##  warmed  Posp       2  3.965 0.955 Inf    2.0933     5.837
##  ambient Ptaq       2  1.454 0.257 Inf    0.9510     1.957
##  warmed  Ptaq       2  2.058 0.346 Inf    1.3798     2.736
##  ambient Ruac       2  2.701 0.396 Inf    1.9260     3.477
##  warmed  Ruac       2  3.737 0.498 Inf    2.7606     4.714
##  ambient Cape       3  3.670 1.236 Inf    1.2473     6.093
##  warmed  Cape       3  5.900 1.997 Inf    1.9853     9.815
##  ambient Cest       3  9.860 1.299 Inf    7.3152    12.405
##  warmed  Cest       3 14.328 1.947 Inf   10.5120    18.145
##  ambient Dasp       3  7.393 1.230 Inf    4.9822     9.803
##  warmed  Dasp       3 11.566 1.948 Inf    7.7487    15.384
##  ambient Hype       3  3.280 1.244 Inf    0.8412     5.718
##  warmed  Hype       3  5.448 2.048 Inf    1.4340     9.461
##  ambient Poco       3 14.985 3.934 Inf    7.2748    22.695
##  warmed  Poco       3 21.235 5.105 Inf   11.2293    31.241
##  ambient Popr       3  1.532 0.709 Inf    0.1430     2.921
##  warmed  Popr       3  2.610 1.196 Inf    0.2652     4.954
##  ambient Posp       3 11.433 2.550 Inf    6.4349    16.431
##  warmed  Posp       3 17.814 3.921 Inf   10.1281    25.500
##  ambient Ptaq       3  6.858 1.350 Inf    4.2110     9.504
##  warmed  Ptaq       3 10.272 2.064 Inf    6.2263    14.318
##  ambient Ruac       3 13.784 1.803 Inf   10.2503    17.318
##  warmed  Ruac       3 20.033 2.768 Inf   14.6081    25.458
##  ambient Cape       4  0.977 0.344 Inf    0.3039     1.650
##  warmed  Cape       4  1.626 0.565 Inf    0.5195     2.733
##  ambient Cest       4  3.236 0.513 Inf    2.2318     4.241
##  warmed  Cest       4  4.940 0.696 Inf    3.5761     6.304
##  ambient Dasp       4  2.069 0.446 Inf    1.1955     2.943
##  warmed  Dasp       4  3.377 0.680 Inf    2.0444     4.710
##  ambient Hype       4  0.826 0.338 Inf    0.1629     1.489
##  warmed  Hype       4  1.404 0.560 Inf    0.3076     2.501
##  ambient Poco       4  5.241 1.852 Inf    1.6107     8.872
##  warmed  Poco       4  7.777 2.374 Inf    3.1242    12.429
##  ambient Popr       4  0.371 0.170 Inf    0.0376     0.704
##  warmed  Popr       4  0.640 0.287 Inf    0.0782     1.202
##  ambient Posp       4  3.226 1.004 Inf    1.2584     5.194
##  warmed  Posp       4  5.248 1.538 Inf    2.2346     8.262
##  ambient Ptaq       4  2.099 0.454 Inf    1.2091     2.989
##  warmed  Ptaq       4  3.302 0.659 Inf    2.0108     4.593
##  ambient Ruac       4  4.523 0.774 Inf    3.0059     6.040
##  warmed  Ruac       4  6.905 1.083 Inf    4.7825     9.027
##  ambient Cape       5  3.212 1.079 Inf    1.0961     5.327
##  warmed  Cape       5  5.191 1.714 Inf    1.8304     8.551
##  ambient Cest       5  8.891 1.439 Inf    6.0706    11.712
##  warmed  Cest       5 13.002 1.867 Inf    9.3427    16.661
##  ambient Dasp       5  6.519 1.379 Inf    3.8172     9.221
##  warmed  Dasp       5 10.263 2.028 Inf    6.2875    14.239
##  ambient Hype       5  2.845 1.057 Inf    0.7731     4.916
##  warmed  Hype       5  4.743 1.698 Inf    1.4139     8.072
##  ambient Poco       5 13.622 3.970 Inf    5.8416    21.403
```

```
##  warmed  Poco       5 19.412 4.988 Inf    9.6352    29.188
##  ambient Popr       5  1.320 0.581 Inf    0.1821     2.458
##  warmed  Popr       5  2.254 0.965 Inf    0.3616     4.145
##  ambient Posp       5 10.094 3.026 Inf    4.1641    16.024
##  warmed  Posp       5 15.827 4.457 Inf    7.0917    24.563
##  ambient Ptaq       5  6.126 1.440 Inf    3.3037     8.948
##  warmed  Ptaq       5  9.237 2.046 Inf    5.2271    13.247
##  ambient Ruac       5 12.429 2.002 Inf    8.5056    16.352
##  warmed  Ruac       5 18.178 2.678 Inf   12.9296    23.426
##  ambient Cape       6  3.112 1.138 Inf    0.8806     5.343
##  warmed  Cape       6  5.136 1.885 Inf    1.4421     8.831
##  ambient Cest       6  9.768 1.342 Inf    7.1370    12.399
##  warmed  Cest       6 14.705 2.017 Inf   10.7518    18.658
##  ambient Dasp       6  6.511 1.503 Inf    3.5643     9.457
##  warmed  Dasp       6 10.514 2.393 Inf    5.8234    15.204
##  ambient Hype       6  2.665 1.066 Inf    0.5751     4.754
##  warmed  Hype       6  4.506 1.783 Inf    1.0113     8.001
##  ambient Poco       6 15.537 5.141 Inf    5.4605    25.614
##  warmed  Poco       6 22.742 6.708 Inf    9.5950    35.890
##  ambient Popr       6  1.207 0.580 Inf    0.0709     2.343
##  warmed  Popr       6  2.077 0.988 Inf    0.1412     4.012
##  ambient Posp       6 10.130 3.148 Inf    3.9602    16.301
##  warmed  Posp       6 16.301 4.910 Inf    6.6784    25.924
##  ambient Ptaq       6  6.456 1.579 Inf    3.3603     9.551
##  warmed  Ptaq       6 10.023 2.404 Inf    5.3104    14.735
##  ambient Ruac       6 13.652 2.389 Inf    8.9700    18.334
##  warmed  Ruac       6 20.555 3.636 Inf   13.4285    27.681
##
## Confidence level used: 0.95
```