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)

# 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

```
### determining distribution ###
# first, checking for normality
hist(herb_kbs$p_eaten)
#qqnorm(herb_kbs$p_eaten)
shapiro.test(herb_kbs$p_eaten)
#fit <- lm(p_eaten~state, data = herb_kbs)
#qqPlot(fit)
hist(herb_kbs$p_eaten[herb_kbs$state == "ambient"])
hist(herb_kbs$p_eaten[herb_kbs$state == "warmed"])
# not normal, attempting to transform data below
# log transform
herb_kbs$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
# 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)
```

```r
shapiro.test(herb_kbs$p_scaled)
# square root?
herb_kbs$p_sqrt <- sqrt(herb_kbs$p_eaten)
hist(herb_kbs$p_sqrt)
```

Transformations are a no-go

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

```r
# 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.
```

```r
# 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
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
```

```
# 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
```

```
# state and growth habit as fixed effects
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 -0.1774 12.4666
##
## Count model coefficients (negbin with log link):
##                       Estimate Std. Error z value Pr(>|z|)
## (Intercept)             2.0326     0.2656   7.653 1.96e-14 ***
## statewarmed            -0.2884     0.1177  -2.451   0.0143 *
## growth_habitForb       -0.1991     0.2617  -0.761   0.4467
## growth_habitGraminoid   0.5203     0.3186   1.633   0.1025
## 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)            1.40009    0.22518   6.218 5.05e-10 ***
## statewarmed            0.23661    0.16988   1.393    0.164
## growth_habitForb      -2.49970    0.30642  -8.158 3.42e-16 ***
## growth_habitGraminoid -0.07318    0.24395  -0.300    0.764
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Theta = 0.3393
## Number of iterations in BFGS optimization: 16
## Log-likelihood: -3340 on 9 Df
```

```
# 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)            0.16585    0.24482   0.677   0.4981
## statewarmed           -0.21211    0.08821  -2.405   0.0162 *
## growth_habitForb       0.32882    0.19555   1.682   0.0927 .
## growth_habitGraminoid  1.32892    0.24771   5.365 8.10e-08 ***
## as.factor(year)2       1.04559    0.16519   6.330 2.46e-10 ***
## as.factor(year)3       2.03927    0.19241  10.598  < 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   0.0477 *
## Log(theta)            -0.13936    0.10227  -1.363   0.1730
##
```

```
## Zero-inflation model coefficients (binomial with logit link):
##                       Estimate Std. Error z value Pr(>|z|)
## (Intercept)            -1.5792     4.0319  -0.392    0.695
## statewarmed             0.1768     0.1297   1.363    0.173
## growth_habitForb       -2.2263     0.2111 -10.544   <2e-16 ***
## growth_habitGraminoid   0.1036     0.2330   0.445    0.656
## as.factor(year)2        2.8669     4.0071   0.715    0.474
## as.factor(year)3        4.1002     4.0268   1.018    0.309
## as.factor(year)4        3.7977     4.0245   0.944    0.345
## as.factor(year)5        3.2469     4.0215   0.807    0.419
## as.factor(year)6        3.6623     4.0155   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: 30
## Log-likelihood: -3155 on 19 Df
```

```
# 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)                        1.99378    0.31158   6.399 1.56e-10 ***
## statewarmed                       -0.17091    0.55875  -0.306    0.760
## growth_habitForb                  -0.17585    0.31430  -0.559    0.576
## growth_habitGraminoid              0.58567    0.41126   1.424    0.154
## statewarmed:growth_habitForb      -0.09785    0.57356  -0.171    0.865
## statewarmed:growth_habitGraminoid -0.18276    0.67908  -0.269    0.788
## Log(theta)                        -1.09259    0.16783  -6.510 7.51e-11 ***
##
## Zero-inflation model coefficients (binomial with logit link):
##                                   Estimate Std. Error z value Pr(>|z|)
## (Intercept)                         1.2872     0.2580   4.989 6.06e-07 ***
## statewarmed                         0.5590     0.4219   1.325    0.185
## growth_habitForb                   -2.4733     0.3930  -6.293 3.11e-10 ***
## growth_habitGraminoid               0.1884     0.3153   0.597    0.550
## statewarmed:growth_habitForb       -0.2041     0.4952  -0.412    0.680
## statewarmed:growth_habitGraminoid  -0.6347     0.5122  -1.239    0.215
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Theta = 0.3353
## Number of iterations in BFGS optimization: 19
```

```
## Log-likelihood: -3339 on 13 Df
```

```
# 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 24.8208
##
## Count model coefficients (negbin with log link):
##                                  Estimate Std. Error z value Pr(>|z|)
## (Intercept)                       0.158396   0.267077   0.593   0.5531
## statewarmed                      -0.157970   0.397350  -0.398   0.6910
## growth_habitForb                  0.312405   0.228490   1.367   0.1715
## growth_habitGraminoid             1.546411   0.305612   5.060 4.19e-07 ***
## as.factor(year)2                  1.041654   0.164111   6.347 2.19e-10 ***
## as.factor(year)3                  2.069583   0.192773  10.736  < 2e-16 ***
## as.factor(year)4                  2.216604   0.177985  12.454  < 2e-16 ***
## as.factor(year)5                  2.207357   0.169311  13.037  < 2e-16 ***
## as.factor(year)6                 -0.487322   0.237224  -2.054   0.0399 *
## statewarmed:growth_habitForb      0.001971   0.407693   0.005   0.9961
## statewarmed:growth_habitGraminoid -0.502881   0.481793  -1.044   0.2966
## Log(theta)                       -0.129593   0.101681  -1.275   0.2025
##
## Zero-inflation model coefficients (binomial with logit link):
##                                  Estimate Std. Error z value Pr(>|z|)
## (Intercept)                       -1.5129     3.3120  -0.457    0.648
## statewarmed                        0.5501     0.4002   1.375    0.169
## growth_habitForb                  -2.1203     0.2563  -8.272   <2e-16 ***
## growth_habitGraminoid              0.3579     0.2981   1.201    0.230
## as.factor(year)2                   2.6836     3.2840   0.817    0.414
## as.factor(year)3                   3.9207     3.3032   1.187    0.235
## as.factor(year)4                   3.6121     3.3007   1.094    0.274
## as.factor(year)5                   3.0515     3.2981   0.925    0.355
## as.factor(year)6                   3.4608     3.2951   1.050    0.294
## statewarmed:growth_habitForb      -0.3307     0.4308  -0.767    0.443
## statewarmed:growth_habitGraminoid  -0.6483     0.4826  -1.343    0.179
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Theta = 0.8785
## Number of iterations in BFGS optimization: 33
## Log-likelihood: -3153 on 23 Df
```

```
# 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 -0.40005 -0.26576 -0.08172 11.76600
##
## Count model coefficients (negbin with log link):
##                                      Estimate Std. Error z value Pr(>|z|)
## (Intercept)                           -0.8797     1.0092  -0.872  0.38339
## statewarmed                            0.3356     1.9062   0.176  0.86027
## growth_habitForb                       1.6557     1.0293   1.609  0.10771
## growth_habitGraminoid                  3.8580     1.1805   3.268  0.00108 **
## year                                   0.6947     0.2419   2.872  0.00408 **
## statewarmed:growth_habitForb          -0.7913     1.9309  -0.410  0.68197
## statewarmed:growth_habitGraminoid     -3.5563     2.3229  -1.531  0.12577
## statewarmed:year                      -0.1490     0.4341  -0.343  0.73144
## growth_habitForb:year                 -0.3554     0.2502  -1.421  0.15546
## growth_habitGraminoid:year            -0.8110     0.3266  -2.483  0.01303 *
## statewarmed:growth_habitForb:year      0.1748     0.4428   0.395  0.69291
## statewarmed:growth_habitGraminoid:year  1.3010     0.6935   1.876  0.06065 .
## Log(theta)                            -0.8096     0.1439  -5.625 1.86e-08 ***
##
## Zero-inflation model coefficients (binomial with logit link):
##                                      Estimate Std. Error z value Pr(>|z|)
## (Intercept)                            2.1748     0.9173   2.371  0.01774 *
## statewarmed                            1.6455     1.8303   0.899  0.36863
## growth_habitForb                      -4.4783     1.0629  -4.213 2.52e-05 ***
## growth_habitGraminoid                 -2.4410     1.0628  -2.297  0.02164 *
## year                                  -0.2332     0.2205  -1.058  0.29018
## statewarmed:growth_habitForb          -2.3182     2.0202  -1.148  0.25117
## statewarmed:growth_habitGraminoid     -2.7263     2.0179  -1.351  0.17669
## statewarmed:year                      -0.2565     0.4253  -0.603  0.54650
## growth_habitForb:year                  0.6463     0.2452   2.636  0.00840 **
## growth_habitGraminoid:year             0.8538     0.2888   2.956  0.00311 **
## statewarmed:growth_habitForb:year      0.4303     0.4575   0.941  0.34693
## statewarmed:growth_habitGraminoid:year  0.6680     0.5235   1.276  0.20193
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Theta = 0.445
## Number of iterations in BFGS optimization: 38
## Log-likelihood: -3266 on 25 Df
```

```
# state and origin as fixed effects
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)    1.9766     0.2748   7.194 6.30e-13 ***
## statewarmed   -0.2265     0.1206  -1.878   0.0604 .
## originExotic   0.1252     0.2845   0.440   0.6599
## originNative  -0.2241     0.2702  -0.830   0.4068
## Log(theta)    -1.1606     0.1757  -6.606 3.94e-11 ***
##
## Zero-inflation model coefficients (binomial with logit link):
##              Estimate Std. Error z value Pr(>|z|)
## (Intercept)    1.2988     0.2396   5.420 5.95e-08 ***
## statewarmed    0.3956     0.1704   2.322   0.0202 *
## originExotic  -1.0725     0.2320  -4.623 3.79e-06 ***
## originNative  -2.5301     0.3507  -7.215 5.39e-13 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Theta = 0.3133
## Number of iterations in BFGS optimization: 17
## Log-likelihood: -3399 on 9 Df
```

```
# 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)        0.14561    0.23573   0.618  0.53677
## statewarmed       -0.15828    0.08981  -1.762  0.07800 .
## originExotic       0.61304    0.21480   2.854  0.00432 **
## originNative       0.31058    0.19804   1.568  0.11682
## 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  0.03752 *
```

```
## Log(theta)       -0.15767    0.09422  -1.673  0.09426 .
##
## Zero-inflation model coefficients (binomial with logit link):
##                   Estimate Std. Error z value Pr(>|z|)
## (Intercept)       -1.0720     0.8557  -1.253 0.210267
## statewarmed        0.2822     0.1211   2.331 0.019764 *
## originExotic      -0.7190     0.2086  -3.446 0.000568 ***
## originNative      -2.1256     0.2095 -10.146  < 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 0.000891 ***
## 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
```

```
# 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)                1.96897    0.31730   6.205 5.46e-10 ***
## statewarmed               -0.17160    0.56688  -0.303    0.762
## originExotic               0.13693    0.34136   0.401    0.688
## originNative              -0.19651    0.32341  -0.608    0.543
## statewarmed:originExotic  -0.04501    0.61515  -0.073    0.942
## statewarmed:originNative  -0.07525    0.58560  -0.129    0.898
## Log(theta)                -1.14400    0.17332  -6.601 4.09e-11 ***
##
## Zero-inflation model coefficients (binomial with logit link):
##                           Estimate Std. Error z value Pr(>|z|)
## (Intercept)                 1.2554     0.2632   4.770 1.84e-06 ***
## statewarmed                 0.5612     0.4252   1.320 0.186883
## originExotic               -1.0195     0.2859  -3.567 0.000362 ***
## originNative               -2.3913     0.4097  -5.837 5.31e-09 ***
## statewarmed:originExotic   -0.1565     0.4806  -0.326 0.744684
## statewarmed:originNative   -0.2694     0.5133  -0.525 0.599748
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
```

```
## Theta = 0.3185
## Number of iterations in BFGS optimization: 18
## Log-likelihood: -3399 on 13 Df
```

```
# 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)                0.14984    0.26059   0.575  0.56528
## statewarmed               -0.18256    0.40246  -0.454  0.65012
## originExotic               0.65684    0.25133   2.613  0.00896 **
## originNative               0.28071    0.23332   1.203  0.22892
## 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:originExotic -0.10904    0.43508  -0.251  0.80210
## statewarmed:originNative  0.07068    0.41642   0.170  0.86522
## 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)                -1.1839     0.8900  -1.330 0.183454
## statewarmed                 0.5392     0.3964   1.360 0.173802
## originExotic               -0.6664     0.2556  -2.607 0.009139 **
## originNative               -1.9865     0.2571  -7.727  1.1e-14 ***
## 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:originExotic  -0.1857     0.4425  -0.420 0.674792
## statewarmed:originNative  -0.3577     0.4303  -0.831 0.405805
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Theta = 0.8535
## Number of iterations in BFGS optimization: 30
## Log-likelihood: -3228 on 23 Df
```

```r
# 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 11.7652
##
## Count model coefficients (negbin with log link):
##                               Estimate Std. Error z value Pr(>|z|)
## (Intercept)                    -0.8893     1.0124  -0.878  0.37972
## statewarmed                     0.3362     1.9130   0.176  0.86048
## originExotic                    1.8451     1.0866   1.698  0.08949 .
## originNative                    2.0844     1.0416   2.001  0.04539 *
## year                            0.6956     0.2428   2.864  0.00418 **
## statewarmed:originExotic       -1.0762     2.0182  -0.533  0.59384
## statewarmed:originNative       -0.9461     1.9451  -0.486  0.62666
## statewarmed:year               -0.1492     0.4358  -0.342  0.73200
## originExotic:year              -0.2343     0.2839  -0.825  0.40922
## originNative:year              -0.4931     0.2527  -1.951  0.05103 .
## statewarmed:originExotic:year   0.3377     0.4974   0.679  0.49724
## statewarmed:originNative:year   0.2362     0.4459   0.530  0.59637
## Log(theta)                     -0.8249     0.1315  -6.271 3.58e-10 ***
##
## Zero-inflation model coefficients (binomial with logit link):
##                               Estimate Std. Error z value Pr(>|z|)
## (Intercept)                    2.1637     0.9187   2.355 0.018505 *
## statewarmed                    1.6470     1.8330   0.898 0.368920
## originExotic                  -3.2668     0.9923  -3.292 0.000994 ***
## originNative                  -4.3214     1.0533  -4.103 4.08e-05 ***
## year                          -0.2324     0.2210  -1.052 0.292899
## statewarmed:originExotic      -1.2805     1.9195  -0.667 0.504727
## statewarmed:originNative      -2.5090     2.0209  -1.242 0.214402
## statewarmed:year              -0.2567     0.4259  -0.603 0.546676
## originExotic:year              0.7575     0.2491   3.041 0.002358 **
## originNative:year              0.6218     0.2445   2.543 0.010992 *
## statewarmed:originExotic:year  0.2740     0.4607   0.595 0.552075
## statewarmed:originNative:year  0.4697     0.4579   1.026 0.305024
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Theta = 0.4383
## Number of iterations in BFGS optimization: 38
## Log-likelihood: -3333 on 25 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
```

```
# 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
```

```
# 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
```

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

# likelihood ratio test
lrtest(k.m1, k.m2, k.m3, k.m4, k.m5, k.m6, k.m7, k.m8, k.m8, k.m10, k.m11, k.m12, k.m13, k.m14, k.m15)
```

```
## Likelihood ratio test
##
```

```
## Model  1: p_eaten ~ state
## Model  2: p_eaten ~ state + as.factor(year)
## Model  3: p_eaten ~ state + growth_habit
## Model  4: p_eaten ~ state + growth_habit + as.factor(year)
## Model  5: p_eaten ~ state * growth_habit
## Model  6: p_eaten ~ state * growth_habit + as.factor(year)
## Model  7: p_eaten ~ state * growth_habit * year
## Model  8: p_eaten ~ state + origin
## Model  9: p_eaten ~ state + origin
## Model 10: p_eaten ~ state * origin
## Model 11: p_eaten ~ state * origin + as.factor(year)
## Model 12: p_eaten ~ state * origin * year
## Model 13: p_eaten ~ state + species
## Model 14: p_eaten ~ state + species + as.factor(year)
## Model 15: p_eaten ~ state * species + as.factor(year)
##    #Df  LogLik  Df    Chisq Pr(>Chisq)
## 1    5 -3478.4
## 2   15 -3324.2  10 308.5357  < 2.2e-16 ***
## 3    9 -3340.4  -6  32.4309  1.349e-05 ***
## 4   19 -3155.4  10 369.9465  < 2.2e-16 ***
## 5   13 -3339.4  -6 367.9652  < 2.2e-16 ***
## 6   23 -3153.0  10 372.7498  < 2.2e-16 ***
## 7   25 -3266.0   2 225.8882  < 2.2e-16 ***
## 8    9 -3398.8 -16 265.6043  < 2.2e-16 ***
## 9    9 -3398.8   0   0.0000   1.000000
## 10  13 -3398.6   4   0.2785   0.991159
## 11  23 -3228.1  10 341.0731  < 2.2e-16 ***
## 12  25 -3332.6   2 209.1141  < 2.2e-16 ***
## 13  15 -3318.4 -10  28.4633   0.001521 **
## 14  25 -3135.2  10 366.3154  < 2.2e-16 ***
## 15  35 -3131.5  10   7.5151   0.676085
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
# check dispersion - chose lowest loglik model for example
E <- resid(k.m13, type = "pearson")
N  <- nrow(herb_kbs)
p  <- length(coef(k.m13)) + 1 # '+1' is due to theta
sum(E^2) / (N - p) # pretty close to one
```

```
## [1] 0.9637512
```

```
# pairwise comparisons
emmeans(k.m13, ~ state + species)
```

```
##  state   species emmean    SE  df asymp.LCL asymp.UCL
##  ambient Cest     5.403 0.739 Inf     3.954      6.85
##  warmed  Cest     4.044 0.623 Inf     2.822      5.27
##  ambient Eugr     3.239 0.514 Inf     2.233      4.25
##  warmed  Eugr     2.343 0.349 Inf     1.658      3.03
##  ambient Hisp     1.513 0.396 Inf     0.737      2.29
##  warmed  Hisp     0.933 0.262 Inf     0.420      1.45
##  ambient Phpr     5.546 1.537 Inf     2.534      8.56
##  warmed  Phpr     3.712 1.021 Inf     1.712      5.71
##  ambient Popr     1.845 0.546 Inf     0.775      2.92
##  warmed  Popr     1.118 0.343 Inf     0.446      1.79
```

```
##  ambient Soca     4.809 0.454 Inf     3.919      5.70
##  warmed  Soca     3.469 0.333 Inf     2.816      4.12
##
## Confidence level used: 0.95
```

UMBS

```
### determining distribution ###
# first, checking for normality
hist(herb_umbs$p_eaten)
qqnorm(herb_umbs$p_eaten)
shapiro.test(herb_umbs$p_eaten)
fit <- lm(p_eaten~state, data = herb_umbs)
qqPlot(fit)
hist(herb_umbs$p_eaten[herb_umbs$state == "ambient"])
hist(herb_umbs$p_eaten[herb_umbs$state == "warmed"])
# not normal- attempting to transform data below
# log transform
herb_umbs$p_log <- log(herb_umbs$p_eaten)
hist(herb_umbs$p_log)
qqnorm(herb_umbs$p_log)
shapiro.test(herb_umbs$p_log)
```

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
```

```
# state and growth habit as fixed effects
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
```

```
# 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
```

```
# 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
```

```
# 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
```

```r
# 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
```

```r
# state and origin as fixed effects
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)    3.4116     0.2482  13.747  < 2e-16 ***
## statewarmed   -0.1406     0.1103  -1.275  0.20236
## originExotic  -0.7551     0.2509  -3.010  0.00261 **
## originNative  -1.1898     0.2641  -4.505 6.65e-06 ***
## 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)    0.3688     0.2618   1.409    0.159
## statewarmed   -0.5299     0.1293  -4.097 4.19e-05 ***
## originExotic  -0.3599     0.2568  -1.401    0.161
## originNative  -0.1052     0.2716  -0.387    0.699
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Theta = 0.36
## Number of iterations in BFGS optimization: 16
## Log-likelihood: -4429 on 9 Df
```

```r
# 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)        0.13637    0.29436   0.463  0.64318
## statewarmed        0.26640    0.09299   2.865  0.00417 **
## originExotic      -0.39211    0.20693  -1.895  0.05811 .
```

```
## originNative     -0.50601    0.21288  -2.377  0.01746 *
## 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 8.87e-05 ***
##
## Zero-inflation model coefficients (binomial with logit link):
##                  Estimate Std. Error z value Pr(>|z|)
## (Intercept)      -13.3067   467.3575  -0.028 0.977286
## statewarmed       -0.3969     0.1092  -3.636 0.000277 ***
## originExotic      -0.6512     0.2400  -2.713 0.006672 **
## originNative      -0.2539     0.2486  -1.021 0.307107
## as.factor(year)2  13.2735   467.3575   0.028 0.977342
## as.factor(year)3  13.9502   467.3575   0.030 0.976187
## as.factor(year)4  14.8811   467.3575   0.032 0.974599
## as.factor(year)5  14.6315   467.3575   0.031 0.975025
## as.factor(year)6  14.3105   467.3575   0.031 0.975573
## ---
## 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
```

```
# 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
## -0.45402 -0.44045 -0.33874 -0.09427  7.31532
##
## Count model coefficients (negbin with log link):
##                          Estimate Std. Error z value Pr(>|z|)
## (Intercept)                3.4590     0.3164  10.931  < 2e-16 ***
## statewarmed               -0.1890     0.4922  -0.384  0.70098
## originExotic              -0.8762     0.3294  -2.660  0.00782 **
## originNative              -1.0417     0.3551  -2.933  0.00335 **
## statewarmed:originExotic   0.1737     0.5093   0.341  0.73300
## statewarmed:originNative  -0.3297     0.5382  -0.613  0.54013
## 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)               -0.6142     0.4187  -1.467  0.14237
## statewarmed                1.2921     0.5153   2.507  0.01216 *
## originExotic               0.6157     0.4163   1.479  0.13922
```

```
## originNative               1.0999     0.4317   2.548  0.01085 *
## statewarmed:originExotic  -1.8012     0.5420  -3.323  0.00089 ***
## statewarmed:originNative  -2.3544     0.5871  -4.010 6.07e-05 ***
## ---
## 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
```

```
# 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)                0.30953    0.32843   0.942 0.345968
## statewarmed               -0.17994    0.37092  -0.485 0.627602
## originExotic              -0.60237    0.25997  -2.317 0.020499 *
## originNative              -0.57712    0.27344  -2.111 0.034807 *
## 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           2.38934    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:originExotic   0.52205    0.38622   1.352 0.176470
## statewarmed:originNative   0.27675    0.41098   0.673 0.500704
## 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)               -16.2399  1319.2882  -0.012 0.990179
## statewarmed                 1.1347     0.4253   2.668 0.007630 **
## originExotic                0.1701     0.3413   0.498 0.618237
## originNative                0.8079     0.3537   2.284 0.022355 *
## as.factor(year)2           15.3649  1319.2882   0.012 0.990708
## as.factor(year)3           16.0297  1319.2882   0.012 0.990306
## as.factor(year)4           17.0089  1319.2882   0.013 0.989714
## as.factor(year)5           16.7121  1319.2882   0.013 0.989893
## as.factor(year)6           16.4110  1319.2882   0.012 0.990075
## statewarmed:originExotic   -1.5057     0.4458  -3.378 0.000731 ***
## statewarmed:originNative   -2.0110     0.4785  -4.202 2.64e-05 ***
## ---
## 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
```

```
## 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
```

```
# 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
```

```
# 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
```

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

# likelihood ratio test
lrtest(u.m1, u.m2, u.m3, u.m4, u.m5, u.m6, u.m7, u.m8, u.m8, u.m10, u.m11, u.m13, u.m14, u.m15)
```

```
## Likelihood ratio test
##
## Model  1: p_eaten ~ state
## Model  2: p_eaten ~ state + as.factor(year)
## Model  3: p_eaten ~ state + growth_habit
## Model  4: p_eaten ~ state + growth_habit + as.factor(year)
## Model  5: p_eaten ~ state * growth_habit
## Model  6: p_eaten ~ state * growth_habit + as.factor(year)
## Model  7: p_eaten ~ state * growth_habit * year
## Model  8: p_eaten ~ state + origin
## Model  9: p_eaten ~ state + origin
## Model 10: p_eaten ~ state * origin
## Model 11: p_eaten ~ state * origin + as.factor(year)
## Model 12: p_eaten ~ state + species
## Model 13: p_eaten ~ state + species + as.factor(year)
## Model 14: p_eaten ~ state * species + as.factor(year)
##    #Df  LogLik Df   Chisq Pr(>Chisq)
## 1    5 -4445.5
## 2   15 -4260.0 10 370.954  < 2.2e-16 ***
## 3    7 -4415.4 -8 310.842  < 2.2e-16 ***
## 4   17 -4218.9 10 393.026  < 2.2e-16 ***
```

```
## 5    9 -4407.2 -8 376.532  < 2.2e-16 ***
## 6   19 -4216.7 10 381.040  < 2.2e-16 ***
## 7   17 -4240.7 -2  48.131  3.536e-11 ***
## 8    9 -4428.5 -8 375.526  < 2.2e-16 ***
## 9    9 -4428.5  0   0.000  1.0000000
## 10  13 -4417.6  4  21.726  0.0002272 ***
## 11  23 -4238.8 10 357.601  < 2.2e-16 ***
## 12  21 -4292.4 -2 107.162  < 2.2e-16 ***
## 13  31 -4153.7 10 277.526  < 2.2e-16 ***
## 14  47 -4123.0 16  61.233  3.239e-07 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
# check dispersion - chose lowest loglik model for example
E <- resid(u.m6, type = "pearson")
N  <- nrow(herb_umbs)
p  <- length(coef(u.m6)) + 1 # '+1' is due to theta
sum(E^2) / (N - p) # pretty close to one
```

```
## [1] 1.037604
```

```
# pairwise comparisons
emmeans(u.m13, ~ state + species)
```

```
##  state   species emmean    SE  df asymp.LCL asymp.UCL
##  ambient Cape      1.25 0.372 Inf    0.5174      1.98
##  warmed  Cape      1.50 0.443 Inf    0.6357      2.37
##  ambient Cest      7.79 0.825 Inf    6.1707      9.40
##  warmed  Cest      8.63 0.789 Inf    7.0864     10.18
##  ambient Dasp      5.18 0.794 Inf    3.6255      6.74
##  warmed  Dasp      6.12 0.934 Inf    4.2910      7.95
##  ambient Hype      3.73 1.504 Inf    0.7777      6.67
##  warmed  Hype      4.82 1.892 Inf    1.1164      8.53
##  ambient Poco      3.74 0.786 Inf    2.2009      5.28
##  warmed  Poco      3.64 0.674 Inf    2.3166      4.96
##  ambient Popr      1.05 0.508 Inf    0.0561      2.05
##  warmed  Popr      1.42 0.667 Inf    0.1110      2.73
##  ambient Posp     12.50 3.131 Inf    6.3591     18.63
##  warmed  Posp     14.79 3.649 Inf    7.6359     21.94
##  ambient Ptaq      3.16 0.590 Inf    2.0035      4.32
##  warmed  Ptaq      3.53 0.620 Inf    2.3197      4.75
##  ambient Ruac     10.84 1.350 Inf    8.1980     13.49
##  warmed  Ruac     11.95 1.458 Inf    9.0938     14.81
##
## Confidence level used: 0.95
```