

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 Eogr    ambient    77  
## 4 Eogr    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$p_scaled)
shapiro.test(herb_kbs$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

```
# 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 Eogr        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
```

```
# 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 ***
## statearmed     -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
## statearmed      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 ***
## statearmed       -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 **
## statearmed:growth_habit 0.09784    0.57356   0.171  0.86456
## statearmed: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 **
## statearmed        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 ***
## statearmed:growth_habit 0.2041    0.4952   0.412  0.68028
## statearmed: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 ***
## statearmed      -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 ***
## statearmed:growth_habit 0.79064    1.93084   0.409 0.682186
## statearmed:growth_habitGraminoid -2.76514    1.36096  -2.032 0.042179 *
## statearmed: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 *
## statearmed:growth_habit:year -0.17471    0.44274  -0.395 0.693128
## statearmed: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 ***
## statearmed      -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 ***
## statearmed:growth_habit 2.3181     2.0202   1.147 0.251180
## statearmed:growth_habitGraminoid -0.4083     1.1837  -0.345 0.730171
```

```

## statearmed: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
## statearmed:growth_habit:year   -0.4303    0.4575   -0.941 0.346929
## statearmed: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 ***
## statearmed    -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 **
## statearmed     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 ***
## statearmed:originBoth      0.3577      0.4303    0.831 0.405808
## statearmed: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 ***
## statearmed     -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 **

```



```
## statearmed:originBoth      0.94606    1.94507    0.486    0.62669
## statearmed:originExotic    -0.13014    0.73234   -0.178    0.85896
## statearmed: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
## statearmed:originBoth:year -0.23616    0.44593   -0.530    0.59640
## statearmed: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 ***
## statearmed     -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 ***
## statearmed:originBoth 2.5088    2.0208    1.241 0.214428
## statearmed:originExotic 1.2284    1.0258    1.198 0.231110
## statearmed: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
## statearmed:originBoth:year -0.4697    0.4579   -1.026 0.305052
## statearmed: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
```

```
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
```

```
# 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

# 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 .
## statearmed     -0.22879    0.08973  -2.550  0.0108 *
## speciesEugr     0.30066    0.17100   1.758  0.0787 .
## speciesHispr   -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
## statearmed      0.1933    0.1357   1.425  0.1542
## speciesEugr     0.5715    0.3900   1.465  0.1429
## speciesHispr    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 .
## statearmed          -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 *
## statearmed:speciesEugr 0.28197    0.32875    0.858    0.3910
## statearmed:speciesHisp 0.15699    0.45694    0.344    0.7312
## statearmed:speciesPhpr -0.76163    0.46758   -1.629    0.1033
## statearmed:speciesPopr -0.04837    0.45134   -0.107    0.9147
## statearmed: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
## statearmed     -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
## statearmed:speciesEugr 0.8375    0.9352    0.895 0.370542
## statearmed:speciesHisp 0.7449    0.8458    0.881 0.378501
## statearmed:speciesPhpr -0.1405    0.8682   -0.162 0.871399
## statearmed:speciesPopr 0.4300    0.8348    0.515 0.606460
## statearmed: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
sum(E^2) / (N - p) # a little overdispersed - is that okay?

## [1] 1.302343

# 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

```
### 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

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
## statearmed        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 ***
## statearmed: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
## statearmed       -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
## statearmed: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 work - 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 native is reference
```

```
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 ***
## statearmed    -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 .
## statearmed    -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  17 -4240.7  0 43.623  < 2.2e-16 ***
```

```

## 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 *
## statearmed -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
## statearmed 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
## statearmed     -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
## statearmed      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 ***
## statearmed:speciesCest -0.09171    0.54453  -0.168 0.866259
## statearmed:speciesDasp -0.38308    0.57492  -0.666 0.505211
## statearmed:speciesHype  0.79783    0.77615   1.028 0.303981
## statearmed:speciesPoco  0.45497    0.77816   0.585 0.558771
## statearmed:speciesPopr -0.20828    1.36477  -0.153 0.878705
## statearmed:speciesPosp -0.67450    0.64178  -1.051 0.293267
## statearmed:speciesPtaq -0.63943    0.60653  -1.054 0.291767
## statearmed: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
## statearmed     -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
## statearmed:speciesCest 2.04479    0.71433    2.863 0.004203 **
## statearmed:speciesDasp 1.68122    0.73296    2.294 0.021805 *
## statearmed:speciesHype 2.47526    0.88283    2.804 0.005051 **
## statearmed:speciesPoco 2.24483    2.35794    0.952 0.341083
## statearmed:speciesPopr -0.04895    1.26292   -0.039 0.969080
## statearmed:speciesPosp 3.67473    0.80065    4.590 4.44e-06 ***
## statearmed:speciesPtaq 2.83563    0.80840    3.508 0.000452 ***
## statearmed: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
emmmeans(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							