Friday, May 2

Moose and Winter Tick Data

This is part of an ongoing research project in collaboration with researchers in the College of Natural Resources.

Setup

The following packages are being used.

```
library(dplyr)      # data manipulation
library(tidyr)      # data manipulation
library(lubridate)  # working with dates
library(forcats)    # working with factors
library(whereami)   # find current directory
library(ggplot2)    # graphics
library(mgcv)       # GAMs
library(trtools)    # inference tools
library(emmeans)    # inference tools
options(digits = 4) # control number of digits displayed
```

Import and Process Tick Count Data

Here I can use `dirname(thisfile())` to find the directory containing this Rmarkdown file, so I do not have to specify the full path to the data file. Note that `thisfile()` is from the **whereami** package. I have the data stored in a sub-directory ("tickdata") of the directory containing this Rmarkdown file.

```
ticks <- read.csv(paste(dirname(thisfile()),
  "/tickdata/tick_data_Robenstein.csv", sep = ""))
names(ticks) <- c("moose","mortality","ticks","size","date","gmu","sex","note")
head(ticks)
```

```
     moose mortality ticks size       date gmu  sex note
1 21005370         H     0  100  9/16/2020   1 MALE    1
2 21005396         H    21  100 10/14/2020   1 MALE    1
3 21005452         H     0  100  10/5/2020   1 MALE    1
4 21005506         H     9  100 11/11/2020   1 MALE    1
5 21005526         H    34  100 11/22/2020   1 MALE    1
6 21005538         H     1  100  11/5/2020   1 MALE    0
```

Here I am going to process the data to get it ready for plotting and modeling.

```
ticks <- ticks |>
  mutate(note = factor(note, levels = 0:3,
    labels = c("exclude", "include", "deterioration", "nodate"))) |>
  mutate(date = mdy(date)) |>
  mutate(month = month(date, label = TRUE), year = year(date), day = yday(date)) |>
  filter(!is.na(date), month %in% c("Aug","Sep","Oct","Nov")) |>
  mutate(year = factor(year)) |> mutate(sex = tolower(sex)) |>
```

```r
  mutate(day = ifelse(year == "2020", day - 1, day))
head(ticks)
```

```
     moose mortality ticks size       date gmu  sex    note month year day
1 21005370         H     0  100 2020-09-16   1 male include   Sep 2020 259
2 21005396         H    21  100 2020-10-14   1 male include   Oct 2020 287
3 21005452         H     0  100 2020-10-05   1 male include   Oct 2020 278
4 21005506         H     9  100 2020-11-11   1 male include   Nov 2020 315
5 21005526         H    34  100 2020-11-22   1 male include   Nov 2020 326
6 21005538         H     1  100 2020-11-05   1 male exclude   Nov 2020 309
```

Import and Process Game Management Unit Data

Here I am going to use `rename` to rename the imported variables.

```r
gmu <- read.csv(paste(dirname(thisfile()), "/tickdata/tick_study_areas.csv", sep = "")) |>
  rename(gmu = GMU, area = study.Area, samples = hh_samples)
head(gmu, 10)
```

```
   gmu          area samples
1    1         North      27
2    2         North      36
3    3         North      19
4    4         North      24
5   4A         North       6
6    5 North Central      18
7    6 North Central      22
8    7 North Central       7
9    8 North Central       9
10  8A North Central       8
```

Merging Data Frames and Filtering

```r
ticks <- left_join(ticks, gmu) |>
  mutate(area = factor(area)) |>
  mutate(area = fct_relevel(area, c("North", "North Central",
    "Central", "Southeast", "Island Park")))
head(ticks)
```

```
     moose mortality ticks size       date gmu  sex    note month year day  area samples
1 21005370         H     0  100 2020-09-16   1 male include   Sep 2020 259 North      27
2 21005396         H    21  100 2020-10-14   1 male include   Oct 2020 287 North      27
3 21005452         H     0  100 2020-10-05   1 male include   Oct 2020 278 North      27
4 21005506         H     9  100 2020-11-11   1 male include   Nov 2020 315 North      27
5 21005526         H    34  100 2020-11-22   1 male include   Nov 2020 326 North      27
6 21005538         H     1  100 2020-11-05   1 male exclude   Nov 2020 309 North      27
```

Some variables we do not need. Also we are going to discard some questionable observations and focus only on the males.

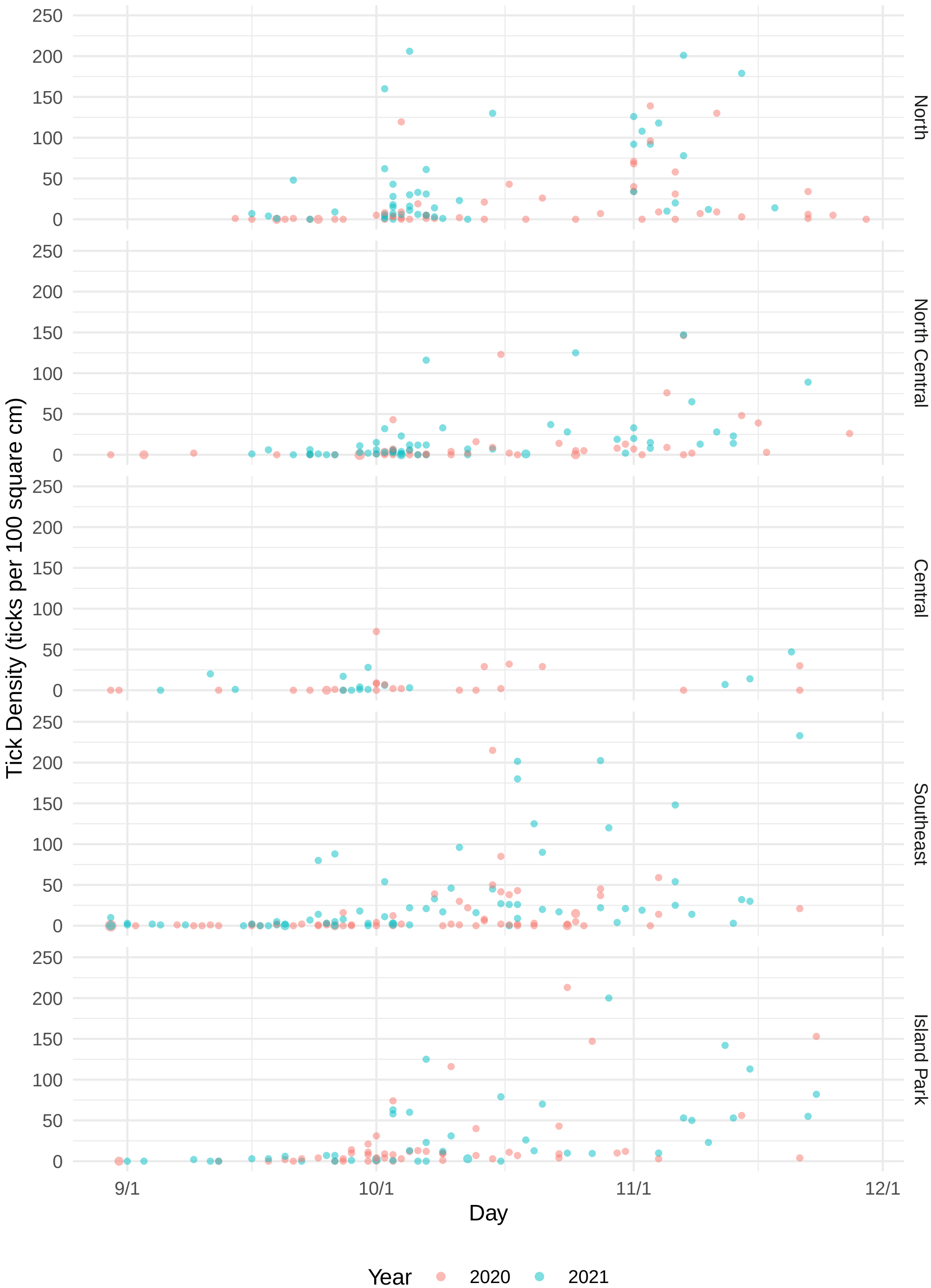
```r
ticks <- ticks |> select(-mortality, -samples) |>
  filter(note == "include") |> filter(sex == "male")
head(ticks)
```

```
     moose ticks size       date gmu  sex    note month year day  area
1 21005370     0  100 2020-09-16   1 male include   Sep 2020 259 North
```

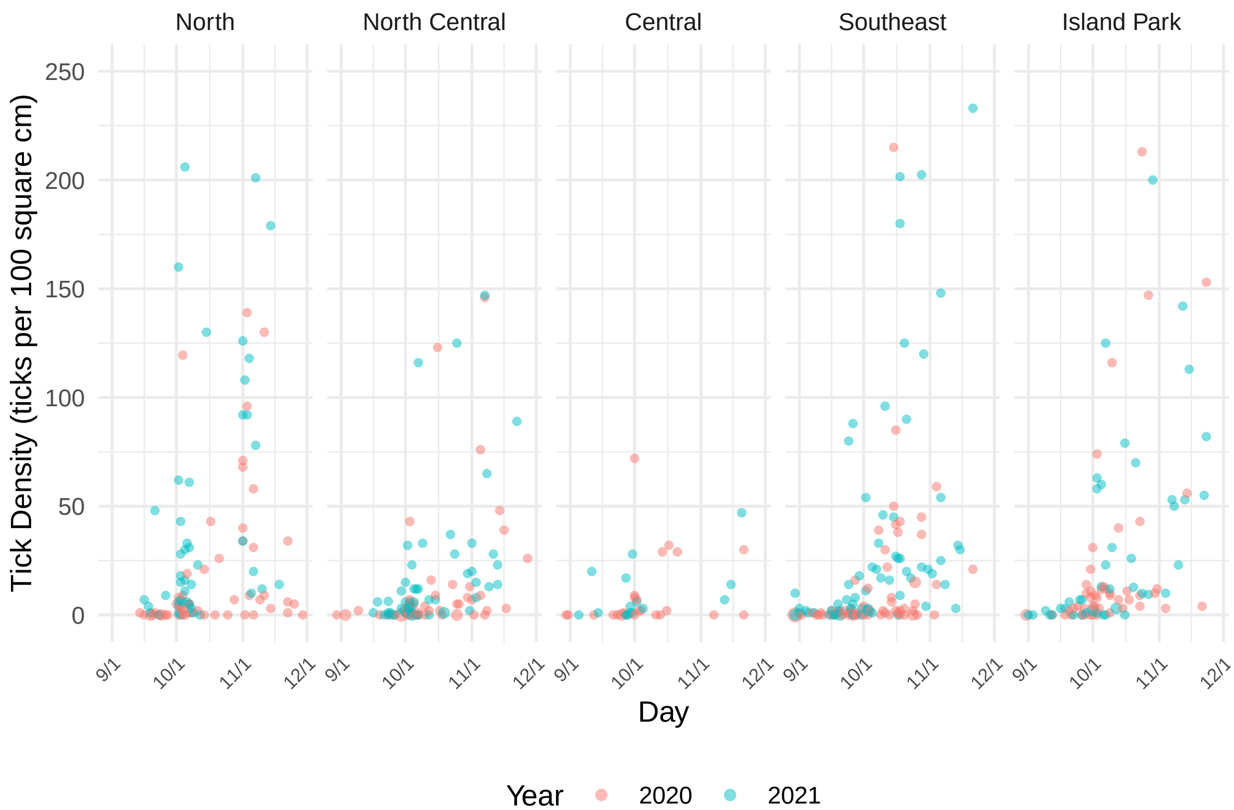
```
2 21005396    21   100 2020-10-14   1 male include   Oct 2020 287 North
3 21005452     0   100 2020-10-05   1 male include   Oct 2020 278 North
4 21005506     9   100 2020-11-11   1 male include   Nov 2020 315 North
5 21005526    34   100 2020-11-22   1 male include   Nov 2020 326 North
6 21005546     1   100 2020-11-22   1 male include   Nov 2020 326 North
```

Raw Data Visualization

```
d09 <- yday(mdy("09/1/2021"))
d10 <- yday(mdy("10/1/2021"))
d11 <- yday(mdy("11/1/2021"))
d12 <- yday(mdy("12/1/2021"))

pv <- ggplot(ticks, aes(x = day, y = ticks/size*100, color = year)) +
  geom_count(alpha = 0.5) + scale_size_area(max_size = 2) +
  theme_minimal() + facet_grid(area ~ .) +
  labs(x = "Day", y = "Tick Density (ticks per 100 square cm)", color = "Year") +
  guides(size = "none") +
  scale_x_continuous(breaks = c(d09, d10, d11, d12),
    labels = c("9/1", "10/1", "11/1", "12/1")) + ylim(c(0,250)) +
  theme(legend.position = "bottom")

plot(pv)
```


Tick Density (ticks per 100 square cm)
North
North Central
Central
Southeast
Island Park
0
50
100
150
200
250
9/1
10/1
11/1
12/1
Day
Year
2020
2021

```r
ph <- ggplot(ticks, aes(x = day, y = ticks/size*100, color = year)) +
  geom_count(alpha = 0.5) + scale_size_area(max_size = 2) + theme_minimal() +
  facet_wrap(~ area, ncol = 5) +
  labs(x = "Day", y = "Tick Density (ticks per 100 square cm)", color = "Year") +
  guides(size = "none") +
  scale_x_continuous(breaks = c(d09, d10, d11, d12),
    labels = c("9/1", "10/1", "11/1", "12/1")) + ylim(c(0,250)) +
  theme(legend.position = "bottom",
    axis.text.x = element_text(angle = 45, size = 7, hjust = 1))

plot(ph)
```



Modeling

I used a generalized additive model with a log link function estimated using (penalized) quasi-likelihood to deal with considerable over-dispersion.

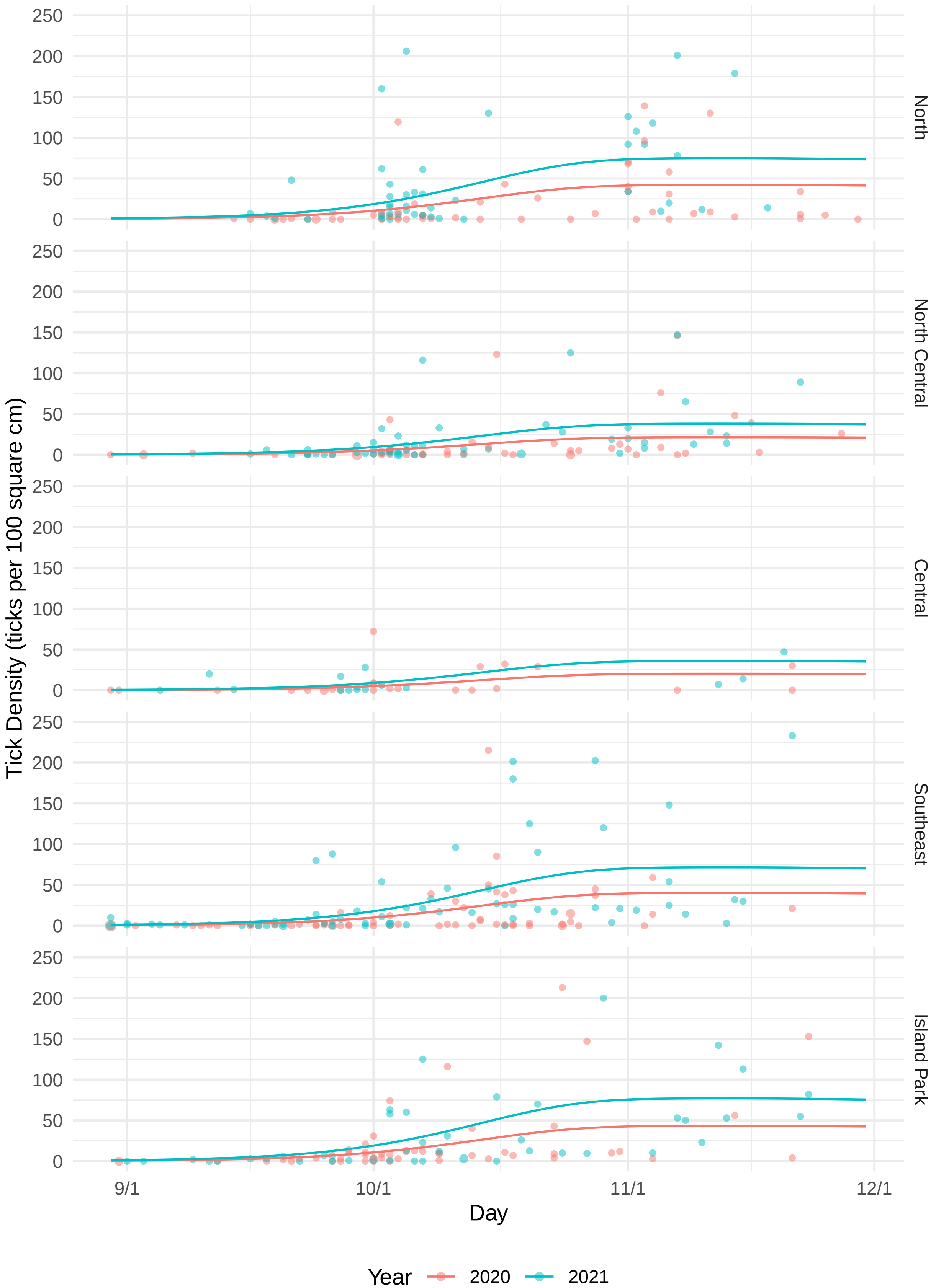
```r
m <- gam(ticks ~ offset(log(size)) + s(day) + year + area,
  family = quasipoisson(link = log), data = ticks)
summary(m)
```

```
Family: quasipoisson
Link function: log

Formula:
ticks ~ offset(log(size)) + s(day) + year + area

Parametric coefficients:
```

```
                  Estimate Std. Error t value Pr(>|t|)
(Intercept)        -1.9941     0.1849  -10.78  < 2e-16 ***
year2021            0.5734     0.1493    3.84  0.00014 ***
areaNorth Central  -0.6751     0.2304   -2.93  0.00355 **
areaCentral        -0.7342     0.4097   -1.79  0.07376 .
areaSoutheast      -0.0457     0.1923   -0.24  0.81228
areaIsland Park     0.0282     0.2019    0.14  0.88909
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
        edf Ref.df    F p-value
s(day) 2.99   3.78 20.2  <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) =  0.196   Deviance explained = 33.9%
GCV = 34.395  Scale est. = 54.637    n = 471
```

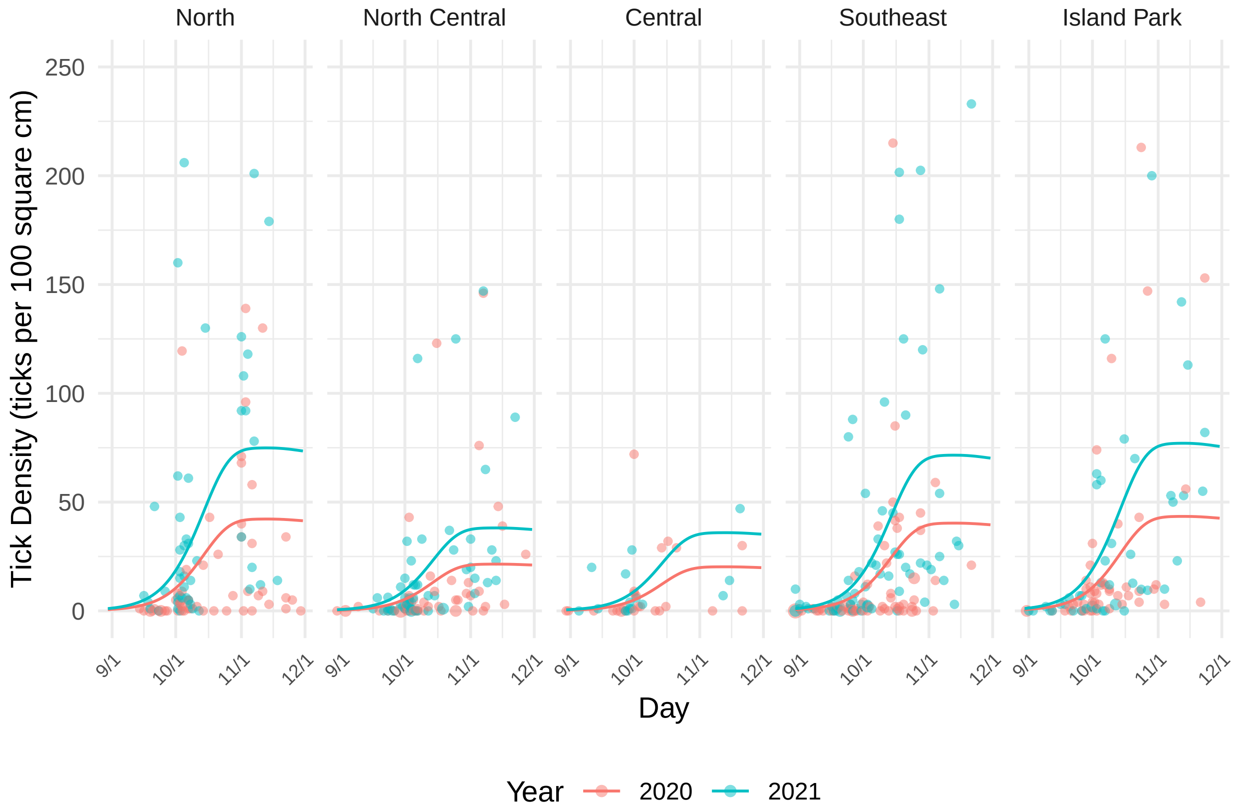
Here we can visualize this model.

```r
d <- expand.grid(year = c("2020","2021"), day = 242:334,
  area = unique(ticks$area), size = 100)
d$yhat <- predict(m, newdata = d, type = "response")

pv <- pv + geom_line(aes(y = yhat), data = d)
plot(pv)
```



North
North Central
Central
Southeast
Island Park
Tick Density (ticks per 100 square cm)
0
50
100
150
200
250
9/1
10/1
11/1
12/1
Day
Year
2020
2021

```r
ph <- ph + geom_line(aes(y = yhat), data = d)
plot(ph)
```



Model-Based Inferences

How much higher is the expected tick density in 2021 than in 2020?

```r
emmeans(m, ~year | area, at = list(day = d10),
  type = "response", offset = log(100), data = ticks)
```

```
area = North:
 year  rate    SE  df lower.CL upper.CL
 2020 10.49 2.14 462     7.02    15.68
 2021 18.61 3.61 462    12.71    27.25

area = North Central:
 year  rate    SE  df lower.CL upper.CL
 2020  5.34 1.31 462     3.30     8.64
 2021  9.48 2.16 462     6.05    14.83

area = Central:
 year  rate    SE  df lower.CL upper.CL
 2020  5.03 2.04 462     2.27    11.16
 2021  8.93 3.61 462     4.03    19.78

area = Southeast:
 year  rate    SE  df lower.CL upper.CL
 2020 10.02 2.12 462     6.62    15.17
 2021 17.78 3.39 462    12.22    25.86
```

```
area = Island Park:
 year  rate   SE  df lower.CL upper.CL
 2020 10.79 2.32 462     7.07    16.47
 2021 19.14 3.77 462    13.00    28.19

Confidence level used: 0.95
Intervals are back-transformed from the log scale
```

```
pairs(emmeans(m, ~year | area, at = list(day = d10),
  type = "response", offset = log(100), data = ticks), reverse = TRUE, infer = TRUE)
```

```
area = North:
 contrast            ratio    SE  df lower.CL upper.CL null t.ratio p.value
 year2021 / year2020  1.77 0.265 462     1.32     2.38    1   3.841  0.0001

area = North Central:
 contrast            ratio    SE  df lower.CL upper.CL null t.ratio p.value
 year2021 / year2020  1.77 0.265 462     1.32     2.38    1   3.841  0.0001

area = Central:
 contrast            ratio    SE  df lower.CL upper.CL null t.ratio p.value
 year2021 / year2020  1.77 0.265 462     1.32     2.38    1   3.841  0.0001

area = Southeast:
 contrast            ratio    SE  df lower.CL upper.CL null t.ratio p.value
 year2021 / year2020  1.77 0.265 462     1.32     2.38    1   3.841  0.0001

area = Island Park:
 contrast            ratio    SE  df lower.CL upper.CL null t.ratio p.value
 year2021 / year2020  1.77 0.265 462     1.32     2.38    1   3.841  0.0001

Confidence level used: 0.95
Intervals are back-transformed from the log scale
Tests are performed on the log scale
```

Note: Here `emmeans` needs a bit more information that is not contained in the model object, so we pass it the data with `data = ticks`.

How about the *difference* in the expected density for each area and the first of October? This is a *discrete marginal effect*, and both area and day matter.

```
margeff(m,
  a = list(year = "2021", area = unique(ticks$area), day = d10, size = 100),
  b = list(year = "2020", area = unique(ticks$area), day = d10, size = 100),
  cnames = unique(ticks$area), df = m$df.residual)
```

```
              estimate    se  lower  upper tvalue  df   pvalue
North            8.122 2.546 3.1197 13.125  3.191 462 0.001517
North Central    4.135 1.356 1.4702  6.800  3.049 462 0.002426
Central          3.898 1.865 0.2326  7.563  2.090 462 0.037182
Southeast        7.760 2.351 3.1405 12.379  3.301 462 0.001037
Island Park      8.354 2.574 3.2971 13.412  3.246 462 0.001254
```

This can also be done using the **emmeans** package through use of the `regrid` function.

```r
tmp <- emmeans(m, ~year | area, at = list(day = d10),
  type = "response", offset = log(100), data = ticks)
pairs(regrid(tmp, type = "response"), reverse = TRUE, infer = TRUE)
```

```
area = North:
 contrast            estimate   SE  df lower.CL upper.CL t.ratio p.value
 year2021 - year2020     8.12 2.55 462    3.120    13.12   3.191  0.0015

area = North Central:
 contrast            estimate   SE  df lower.CL upper.CL t.ratio p.value
 year2021 - year2020     4.13 1.36 462    1.470     6.80   3.049  0.0024

area = Central:
 contrast            estimate   SE  df lower.CL upper.CL t.ratio p.value
 year2021 - year2020     3.90 1.87 462    0.233     7.56   2.090  0.0372

area = Southeast:
 contrast            estimate   SE  df lower.CL upper.CL t.ratio p.value
 year2021 - year2020     7.76 2.35 462    3.141    12.38   3.301  0.0010

area = Island Park:
 contrast            estimate   SE  df lower.CL upper.CL t.ratio p.value
 year2021 - year2020     8.35 2.57 462    3.297    13.41   3.246  0.0013

Confidence level used: 0.95
```

How about inferences for the *average* difference across areas?

```r
emmeans(regrid(pairs(regrid(tmp, type = "response"), reverse = TRUE)), ~1)
```

```
 1       estimate   SE  df lower.CL upper.CL
 overall     6.45 1.85 462     2.82     10.1

Results are averaged over the levels of: area
Confidence level used: 0.95
```

Tricky!

How much does the expected tick density increase between, say, the first day of October and November?

```r
emmeans(m, ~ day | year * area, at = list(day = c(d11,d10)),
  data = ticks, type = "response")
```

```
year = 2020, area = North:
 day   rate     SE  df lower.CL upper.CL
 305 0.4144 0.0741 462   0.2917   0.5889
 274 0.1049 0.0214 462   0.0702   0.1568

year = 2021, area = North:
 day   rate     SE  df lower.CL upper.CL
 305 0.7353 0.1260 462   0.5253   1.0292
 274 0.1861 0.0361 462   0.1271   0.2725

year = 2020, area = North Central:
 day   rate     SE  df lower.CL upper.CL
 305 0.2110 0.0474 462   0.1358   0.3279
 274 0.0534 0.0131 462   0.0330   0.0864
```

```
year = 2021, area = North Central:
 day   rate     SE  df lower.CL upper.CL
 305 0.3743 0.0783 462   0.2481   0.5647
 274 0.0948 0.0216 462   0.0605   0.1483

year = 2020, area = Central:
 day   rate     SE  df lower.CL upper.CL
 305 0.1989 0.0818 462   0.0886   0.4463
 274 0.0503 0.0204 462   0.0227   0.1116

year = 2021, area = Central:
 day   rate     SE  df lower.CL upper.CL
 305 0.3529 0.1460 462   0.1569   0.7936
 274 0.0893 0.0361 462   0.0403   0.1978

year = 2020, area = Southeast:
 day   rate     SE  df lower.CL upper.CL
 305 0.3959 0.0725 462   0.2762   0.5675
 274 0.1002 0.0212 462   0.0662   0.1517

year = 2021, area = Southeast:
 day   rate     SE  df lower.CL upper.CL
 305 0.7025 0.1150 462   0.5091   0.9693
 274 0.1778 0.0339 462   0.1222   0.2587

year = 2020, area = Island Park:
 day   rate     SE  df lower.CL upper.CL
 305 0.4263 0.0858 462   0.2870   0.6331
 274 0.1079 0.0232 462   0.0707   0.1647

year = 2021, area = Island Park:
 day   rate     SE  df lower.CL upper.CL
 305 0.7563 0.1400 462   0.5254   1.0887
 274 0.1915 0.0377 462   0.1300   0.2819

Confidence level used: 0.95
Intervals are back-transformed from the log scale
```

```r
pairs(emmeans(m, ~ day | year * area, at = list(day = c(d11,d10)),
  data = ticks, type = "response"), infer = TRUE)
```

```
year = 2020, area = North:
 contrast        ratio    SE  df lower.CL upper.CL null t.ratio p.value
 day305 / day274  3.95 0.739 462     2.74     5.71    1   7.343  <.0001

year = 2021, area = North:
 contrast        ratio    SE  df lower.CL upper.CL null t.ratio p.value
 day305 / day274  3.95 0.739 462     2.74     5.71    1   7.343  <.0001

year = 2020, area = North Central:
 contrast        ratio    SE  df lower.CL upper.CL null t.ratio p.value
 day305 / day274  3.95 0.739 462     2.74     5.71    1   7.343  <.0001

year = 2021, area = North Central:
```

```
 contrast        ratio    SE  df lower.CL upper.CL null t.ratio p.value
 day305 / day274  3.95 0.739 462     2.74     5.71    1   7.343  <.0001

year = 2020, area = Central:
 contrast        ratio    SE  df lower.CL upper.CL null t.ratio p.value
 day305 / day274  3.95 0.739 462     2.74     5.71    1   7.343  <.0001

year = 2021, area = Central:
 contrast        ratio    SE  df lower.CL upper.CL null t.ratio p.value
 day305 / day274  3.95 0.739 462     2.74     5.71    1   7.343  <.0001

year = 2020, area = Southeast:
 contrast        ratio    SE  df lower.CL upper.CL null t.ratio p.value
 day305 / day274  3.95 0.739 462     2.74     5.71    1   7.343  <.0001

year = 2021, area = Southeast:
 contrast        ratio    SE  df lower.CL upper.CL null t.ratio p.value
 day305 / day274  3.95 0.739 462     2.74     5.71    1   7.343  <.0001

year = 2020, area = Island Park:
 contrast        ratio    SE  df lower.CL upper.CL null t.ratio p.value
 day305 / day274  3.95 0.739 462     2.74     5.71    1   7.343  <.0001

year = 2021, area = Island Park:
 contrast        ratio    SE  df lower.CL upper.CL null t.ratio p.value
 day305 / day274  3.95 0.739 462     2.74     5.71    1   7.343  <.0001

Confidence level used: 0.95
Intervals are back-transformed from the log scale
Tests are performed on the log scale
```

What about the *difference* in the expected densities (i.e., marginal effects)?

```r
tmp <- emmeans(m, ~ day | year * area, at = list(day = c(d11,d10)),
  data = ticks, type = "response")
pairs(regrid(tmp, type = "response"), infer = TRUE)
```

```
year = 2020, area = North:
 contrast        estimate     SE  df lower.CL upper.CL t.ratio p.value
 day305 - day274    0.309 0.0653 462   0.1812    0.438   4.739  <.0001

year = 2021, area = North:
 contrast        estimate     SE  df lower.CL upper.CL t.ratio p.value
 day305 - day274    0.549 0.1130 462   0.3271    0.771   4.860  <.0001

year = 2020, area = North Central:
 contrast        estimate     SE  df lower.CL upper.CL t.ratio p.value
 day305 - day274    0.158 0.0396 462   0.0799    0.235   3.985  0.0001

year = 2021, area = North Central:
 contrast        estimate     SE  df lower.CL upper.CL t.ratio p.value
 day305 - day274    0.280 0.0667 462   0.1485    0.411   4.193  <.0001

year = 2020, area = Central:
 contrast        estimate     SE  df lower.CL upper.CL t.ratio p.value
```

```
 day305 - day274    0.148 0.0642 462   0.0224    0.275   2.314  0.0211

year = 2021, area = Central:
 contrast        estimate     SE  df lower.CL upper.CL t.ratio p.value
 day305 - day274    0.264 0.1140 462   0.0389    0.488   2.305  0.0216

year = 2020, area = Southeast:
 contrast        estimate     SE  df lower.CL upper.CL t.ratio p.value
 day305 - day274    0.296 0.0632 462   0.1714    0.420   4.676  <.0001

year = 2021, area = Southeast:
 contrast        estimate     SE  df lower.CL upper.CL t.ratio p.value
 day305 - day274    0.525 0.1040 462   0.3197    0.730   5.032  <.0001

year = 2020, area = Island Park:
 contrast        estimate     SE  df lower.CL upper.CL t.ratio p.value
 day305 - day274    0.318 0.0743 462   0.1724    0.464   4.287  <.0001

year = 2021, area = Island Park:
 contrast        estimate     SE  df lower.CL upper.CL t.ratio p.value
 day305 - day274    0.565 0.1250 462   0.3198    0.810   4.529  <.0001

Confidence level used: 0.95
```

Here is the average marginal effect for each year (i.e., averaging across areas).

```r
emmeans(regrid(pairs(regrid(tmp, type = "response"))), ~year)
```

```
 year estimate     SE  df lower.CL upper.CL
 2020    0.246 0.0467 462    0.154    0.338
 2021    0.436 0.0780 462    0.283    0.590

Results are averaged over the levels of: area
Confidence level used: 0.95
```

Finally consider a comparison of areas.

```r
pairs(emmeans(m, ~area | year, at = list(day = d10), type = "response",
  data = ticks), adjust = "none")
```

```
year = 2020:
 contrast                    ratio    SE  df null t.ratio p.value
 North / North Central       1.964 0.452 462    1   2.930  0.0036
 North / Central             2.084 0.854 462    1   1.792  0.0738
 North / Southeast           1.047 0.201 462    1   0.238  0.8123
 North / Island Park         0.972 0.196 462    1  -0.140  0.8891
 North Central / Central     1.061 0.457 462    1   0.137  0.8908
 North Central / Southeast   0.533 0.122 462    1  -2.758  0.0060
 North Central / Island Park 0.495 0.118 462    1  -2.951  0.0033
 Central / Southeast         0.502 0.207 462    1  -1.672  0.0952
 Central / Island Park       0.467 0.193 462    1  -1.842  0.0661
 Southeast / Island Park     0.929 0.186 462    1  -0.370  0.7119

year = 2021:
 contrast                    ratio    SE  df null t.ratio p.value
 North / North Central       1.964 0.452 462    1   2.930  0.0036
```

```
 North / Central              2.084 0.854 462    1   1.792  0.0738
 North / Southeast            1.047 0.201 462    1   0.238  0.8123
 North / Island Park          0.972 0.196 462    1  -0.140  0.8891
 North Central / Central      1.061 0.457 462    1   0.137  0.8908
 North Central / Southeast    0.533 0.122 462    1  -2.758  0.0060
 North Central / Island Park 0.495 0.118 462    1  -2.951  0.0033
 Central / Southeast          0.502 0.207 462    1  -1.672  0.0952
 Central / Island Park        0.467 0.193 462    1  -1.842  0.0661
 Southeast / Island Park      0.929 0.186 462    1  -0.370  0.7119

Tests are performed on the log scale
```

Due to an absence of interactions involving area, neither year or day matter.

```r
pairs(emmeans(m, ~area, type = "response", data = ticks), adjust = "none")
```

```
 contrast                     ratio    SE  df null t.ratio p.value
 North / North Central        1.964 0.452 462    1   2.930  0.0036
 North / Central              2.084 0.854 462    1   1.792  0.0738
 North / Southeast            1.047 0.201 462    1   0.238  0.8123
 North / Island Park          0.972 0.196 462    1  -0.140  0.8891
 North Central / Central      1.061 0.457 462    1   0.137  0.8908
 North Central / Southeast    0.533 0.122 462    1  -2.758  0.0060
 North Central / Island Park 0.495 0.118 462    1  -2.951  0.0033
 Central / Southeast          0.502 0.207 462    1  -1.672  0.0952
 Central / Island Park        0.467 0.193 462    1  -1.842  0.0661
 Southeast / Island Park      0.929 0.186 462    1  -0.370  0.7119

Results are averaged over the levels of: year
Tests are performed on the log scale
```

A Mixed Effects Generalized Additive Model

More recently we have been incorporating a random effect for GMU. A Poisson GLMM still shows over-dispersion, but unfortunately the **mgcv** package cannot handle a mixed effects negative binomial model. So instead we have been accounting for the over-dispersion by including a per-observation random effect which is effectively what the negative binomial distribution does.

```r
ticks <- ticks |> mutate(obs = 1:n())
m <- gamm(ticks ~ offset(log(size)) + s(day) + year + area,
  family = poisson, random = list(gmu = ~1, obs = ~1), data = ticks)
```

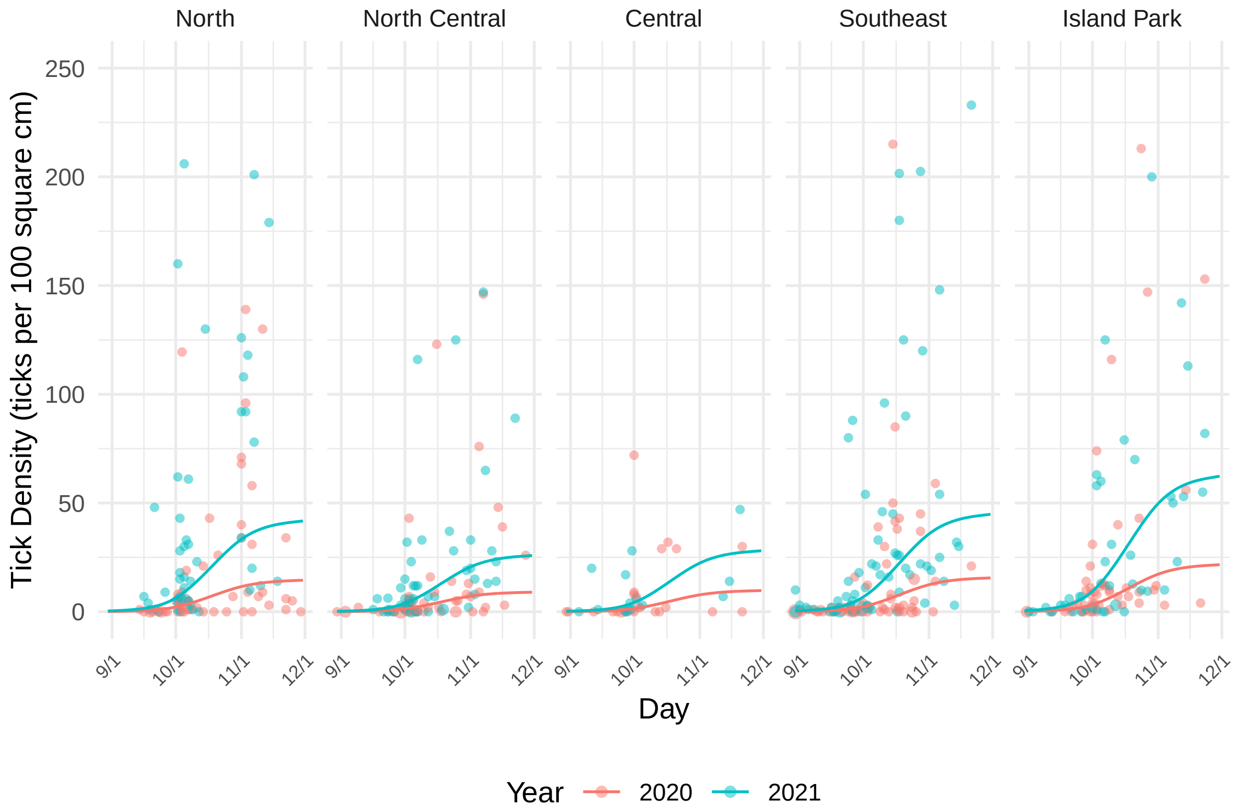
```
 Maximum number of PQL iterations:  20
```

Note the use of `m[["gam"]]` in `predict` below. This is a bit of a hack to get it to work with `predict`.

```r
d$yhat <- predict(m[["gam"]], newdata = d, type = "response")
p <- ggplot(ticks, aes(x = day, y = ticks/size*100, color = year)) +
  geom_count(alpha = 0.5) + scale_size_area(max_size = 2) + theme_minimal() +
  facet_wrap(~ area, ncol = 5) +
  labs(x = "Day", y = "Tick Density (ticks per 100 square cm)", color = "Year") +
  guides(size = "none") +
  scale_x_continuous(breaks = c(d09, d10, d11, d12),
    labels = c("9/1", "10/1", "11/1", "12/1")) + ylim(c(0,250)) +
  theme(legend.position = "bottom",
    axis.text.x = element_text(angle = 45, size = 7, hjust = 1)) +
```

```
  geom_line(aes(y = yhat), data = d)
plot(p)
```

```
Warning: Removed 1 row containing non-finite outside the scale range (`stat_sum()`).
```



Inferences using this model can be done the same way. For example, we can look at the rate ratios for the effect of year.

```
emmeans(m, ~year | area, at = list(day = d10),
  type = "response", offset = log(100), data = ticks)
```

```
area = North:
 year rate    SE  df lower.CL upper.CL
 2020 2.20 0.686 462    1.190     4.06
 2021 6.33 1.960 462    3.448    11.61

area = North Central:
 year rate    SE  df lower.CL upper.CL
 2020 1.36 0.365 462    0.803     2.31
 2021 3.92 1.020 462    2.353     6.53

area = Central:
 year rate    SE  df lower.CL upper.CL
 2020 1.48 0.488 462    0.770     2.83
 2021 4.25 1.420 462    2.203     8.20

area = Southeast:
 year rate    SE  df lower.CL upper.CL
 2020 2.36 0.570 462    1.467     3.79
```

```
 2021 6.79 1.600 462    4.276    10.79

area = Island Park:
 year rate    SE  df lower.CL upper.CL
 2020 3.28 0.877 462    1.940     5.54
 2021 9.45 2.520 462    5.587    15.97

Confidence level used: 0.95
Intervals are back-transformed from the log scale
```

```r
pairs(emmeans(m, ~year | area, at = list(day = d10),
  type = "response", offset = log(100), data = ticks), reverse = TRUE, infer = TRUE)
```

```
area = North:
 contrast            ratio    SE  df lower.CL upper.CL null t.ratio p.value
 year2021 / year2020  2.88 0.427 462     2.15     3.85    1   7.130  <.0001

area = North Central:
 contrast            ratio    SE  df lower.CL upper.CL null t.ratio p.value
 year2021 / year2020  2.88 0.427 462     2.15     3.85    1   7.130  <.0001

area = Central:
 contrast            ratio    SE  df lower.CL upper.CL null t.ratio p.value
 year2021 / year2020  2.88 0.427 462     2.15     3.85    1   7.130  <.0001

area = Southeast:
 contrast            ratio    SE  df lower.CL upper.CL null t.ratio p.value
 year2021 / year2020  2.88 0.427 462     2.15     3.85    1   7.130  <.0001

area = Island Park:
 contrast            ratio    SE  df lower.CL upper.CL null t.ratio p.value
 year2021 / year2020  2.88 0.427 462     2.15     3.85    1   7.130  <.0001

Confidence level used: 0.95
Intervals are back-transformed from the log scale
Tests are performed on the log scale
```

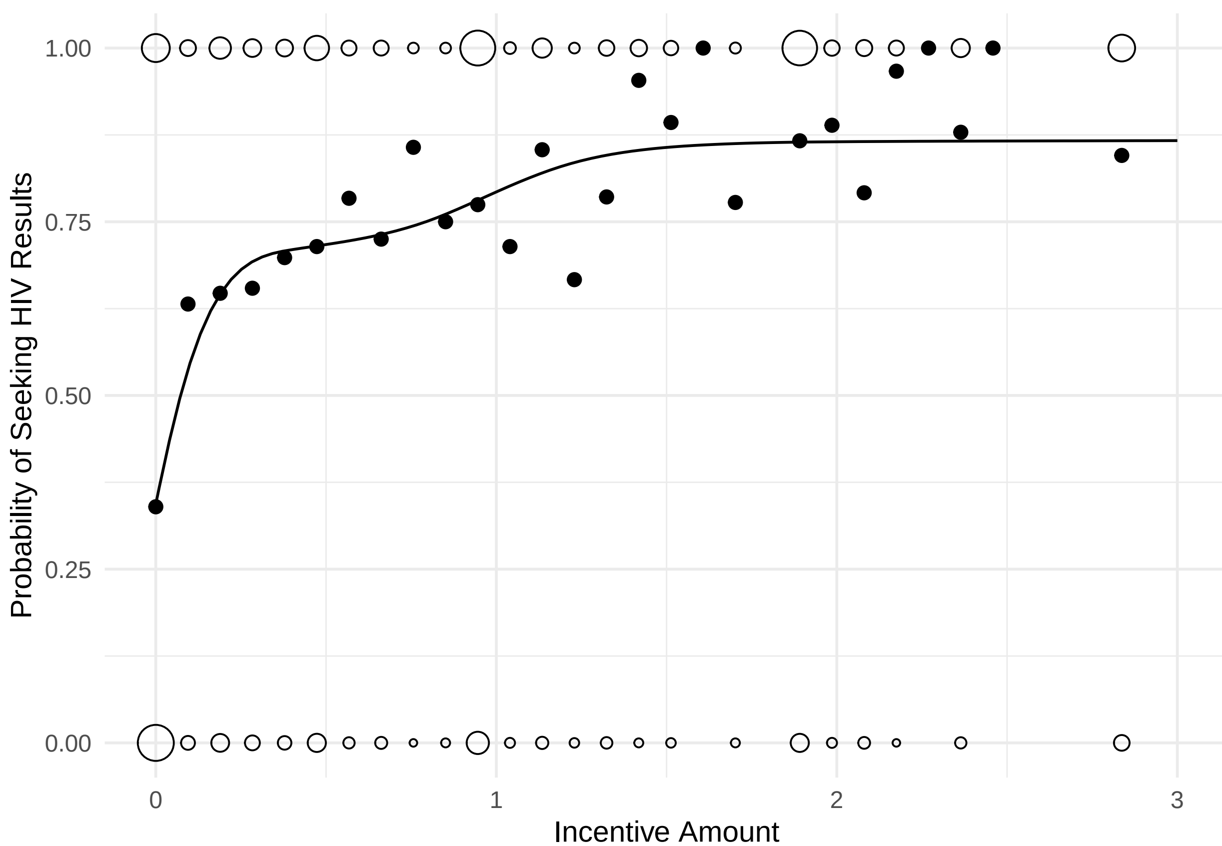
Demand for Learning HIV Status – A Field Experiment in Malawi

```r
library(dplyr)
library(causaldata)
library(ggplot2)
library(mgcv)
library(scam)

hiv <- thornton_hiv[complete.cases(thornton_hiv),] |>
  mutate(z = ifelse(tinc == 0, 1, 0))

m <- scam(got ~ s(tinc, bs = "mpi"), family = binomial, data = hiv)
summary(m)
```

```
Family: binomial
Link function: logit
```

```
Formula:
got ~ s(tinc, bs = "mpi")

Parametric coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)   0.9398     0.0469    20.1   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
         edf Ref.df Chi.sq p-value
s(tinc) 3.61   4.08    449  <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) =  0.1836   Deviance explained = 14.6%
UBRE score = 0.058452  Scale est. = 1         n = 2825
```

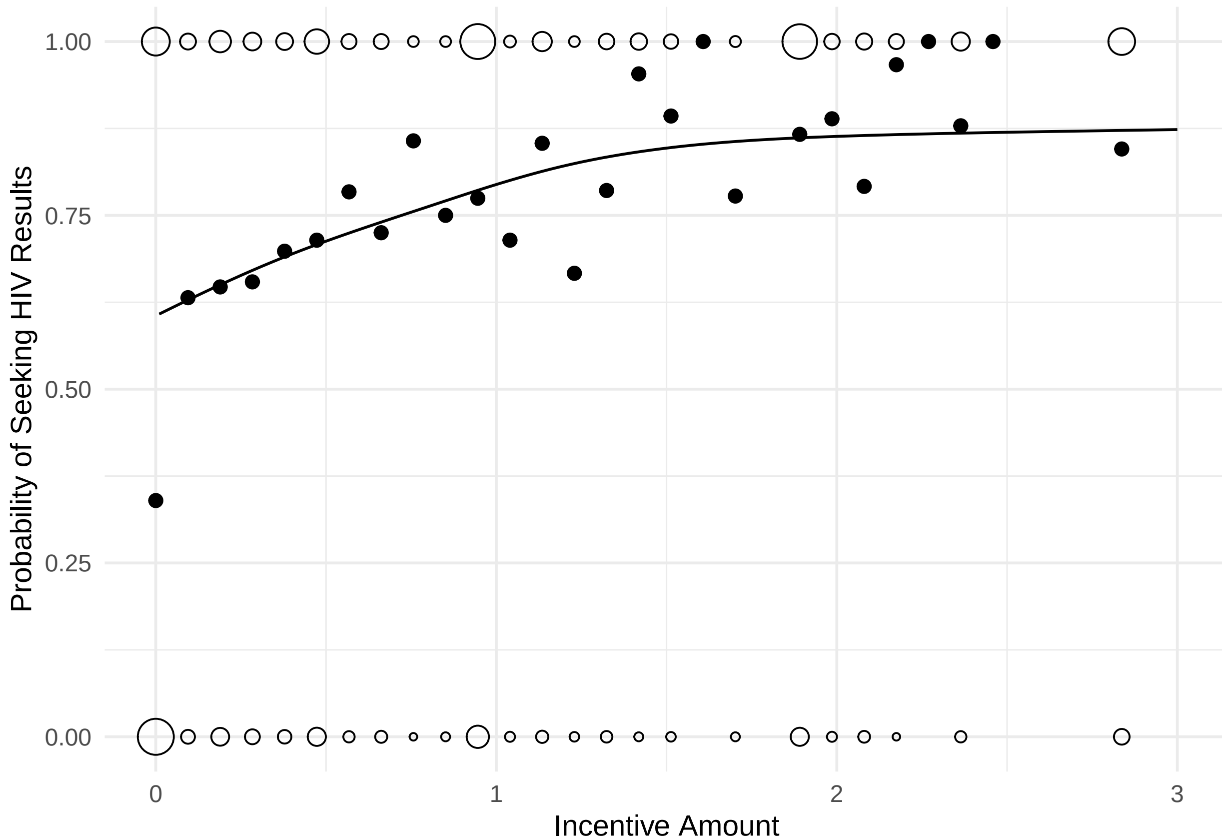
```r
d <- expand.grid(tinc = c(0, seq(0.01, 3, length = 100)))
d$yhat <- predict(m, d, type = "response")

p <- ggplot(hiv, aes(x = tinc, y = got)) + theme_minimal() +
  geom_count(shape = 21) + guides(size = "none") +
  stat_summary(fun = "mean", size = 2, geom = "point") +
  geom_line(aes(y = yhat), data = d) +
  labs(y = "Probability of Seeking HIV Results", x = "Incentive Amount")
plot(p)
```



```r
m <- scam(got ~ I(tinc == 0) + s(tinc, bs = "mpi"), family = binomial, data = hiv)
summary(m)
```

```

Family: binomial
Link function: logit

Formula:
got ~ I(tinc == 0) + s(tinc, bs = "mpi")

Parametric coefficients:
                 Estimate Std. Error z value Pr(>|z|)
(Intercept)        1.1784     0.0715   16.48   <2e-16 ***
I(tinc == 0)TRUE  -1.0931     0.2479   -4.41    1e-05 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
         edf Ref.df Chi.sq p-value
s(tinc) 2.66   3.17     76 6.1e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) =  0.1843   Deviance explained = 14.6%
UBRE score = 0.058083  Scale est. = 1         n = 2825
```

```r
d <- expand.grid(tinc = c(0, seq(0.01, 3, length = 100)))
d$yhat <- predict(m, d, type = "response")

p <- ggplot(hiv, aes(x = tinc, y = got)) + theme_minimal() +
  geom_count(shape = 21) + guides(size = "none") +
  stat_summary(fun = "mean", size = 2, geom = "point") +
  geom_line(aes(y = yhat), data = subset(d, tinc > 0)) +
  geom_point(aes(y = yhat), data = subset(d, tinc == 0)) +
  labs(y = "Probability of Seeking HIV Results", x = "Incentive Amount")
plot(p)
```


1.00
0.75
0.50
0.25
0.00
Probability of Seeking HIV Results
0
1
2
3
Incentive Amount