

LMM_fisheries

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```
library(dplyr)

##
## Attaching package: 'dplyr'

## The following objects are masked from 'package:stats':
##       filter, lag

## The following objects are masked from 'package:base':
##       intersect, setdiff, setequal, union

library(ggplot2)
library(lme4)

## Warning: package 'lme4' was built under R version 4.0.5

## Loading required package: Matrix

library(broom.mixed)
library(knitr)
library(patchwork)
library(nlme)

##
## Attaching package: 'nlme'

## The following object is masked from 'package:lme4':
##       lmList

## The following object is masked from 'package:dplyr':
##       collapse
```

```

library(mgcv)

## This is mgcv 1.8-33. For overview type 'help("mgcv-package")'.

library(car)

## Loading required package: carData

## 
## Attaching package: 'car'

## The following object is masked from 'package:dplyr':
## 
##     recode

```

1. Input Data; Basic Data Processing

```

x<-read.csv("fullSetWithMask.csv",as.is=TRUE,
            na.strings=c("NA",".",","," "))
dim(x) ## Check the dimension (number of rows and columns) of the data matrix.

## [1] 193439      10

head(x)

##   X      uniqueid year month    cpue logcpue taxa_grouped_weight
## 1 1 00000-BCSCAM 2009      7 24.61905 3.203520          Lutjanidae
## 2 2 00000-BCSCAM 2013      8 19.33333 2.961831          Lutjanidae
## 3 3 00000-BCSCAM 2012      2 32.76190 3.489266          Lutjanidae
## 4 4 00000-BCSCAM 2010      3 10.28571 2.330756         Carangidae
## 5 5 00000-BCSCAM 2013     10  9.52381 2.253795         Carangidae
## 6 6 00000-BCSCAM 2008      8 33.33333 3.506558          Lutjanidae
##                                         agreimiacion_fed
## 1 Federacion de Sociedades Cooperativas Pesqueras Zona Centro de Baja California Sur
## 2 Federacion de Sociedades Cooperativas Pesqueras Zona Centro de Baja California Sur
## 3 Federacion de Sociedades Cooperativas Pesqueras Zona Centro de Baja California Sur
## 4 Federacion de Sociedades Cooperativas Pesqueras Zona Centro de Baja California Sur
## 5 Federacion de Sociedades Cooperativas Pesqueras Zona Centro de Baja California Sur
## 6 Federacion de Sociedades Cooperativas Pesqueras Zona Centro de Baja California Sur
##   rr coop_edad_10
## 1 3      1.4
## 2 3      1.4
## 3 3      1.4
## 4 3      1.4
## 5 3      1.4
## 6 3      1.4

```

```

## Drop Column of Row Numbers:
x<-x[,-1]
## Rename a Few Variables:
colnames(x)[colnames(x)=="taxa_grouped_weight"]<- "taxa"
colnames(x)[colnames(x)=="agremiacion_fed"]<- "fed"
colnames(x)[colnames(x)=="coop_edad_10"]<- "age"
colnames(x)[colnames(x)=="rr"]<- "region"
x$uniqueid<-as.factor(x$uniqueid)
x$fed<-as.factor(x$fed)
x$taxa<-as.factor(x$taxa)
x$region<-as.factor(x$region)
x$yearFactor<-as.factor(x$year)
x$monthFactor<-as.factor(x$month)

```

2. Basic Summaries

```
table(x$taxa,useNA="always")
```

```

##
##      Carangidae   Centropomidae       Cichlidae      Clupeidae Elasmobranchii
##          13299           11935          11541            291        12759
##      Gerreidae     Haliotidae       Lutjanidae      Mugilidae   Octopodidae
##          8294             3586          16117            5183        4555
## Ommastrephidae    Ostreidae       OTRAS       Palinuridae    Pectinidae
##          472              2568          38234            6234         860
##      Penaeidae     Portunidae      Sciaenidae      Scombridae   Serranidae
##          18103            6642          12300            3704        16002
## Stichopodidae <NA>
##          760              0

```

```
table(x$region,useNA="always")
```

```

##
##      1      2      3      4      5      6    <NA>
##  4450 10633 62428 50213 22450 43265      0

```

```
length(unique(x$uniqueid))
```

```
## [1] 182
```

```
length(unique(x$fed))
```

```
## [1] 54
```

```
table(x$year)
```

```

##
##  2008 2009 2010 2011 2012 2013 2014 2015 2016
## 19573 20485 20413 19346 21198 20111 20515 24172 27626

```

```
summary(x$age)

##      Min. 1st Qu. Median      Mean 3rd Qu.      Max.
##    0.100   1.800  2.900   3.706  5.900   8.500
```

```
summary(x$age[x$uniqueid=="00000-BCSCAM"])
```

```
##      Min. 1st Qu. Median      Mean 3rd Qu.      Max.
##    1.4     1.4     1.4     1.4     1.4     1.4
```

```
x$age2<-((10*x$age) + (x$year - 2016))
summary(x$age2)
```

```
##      Min. 1st Qu. Median      Mean 3rd Qu.      Max.
##   -6.00   15.00  27.00   33.29  53.00   85.00
```

```
table(x$age2<0)
```

```
##
##  FALSE   TRUE
## 192186 1253
```

```
tbl<-table(as.character(x$uniqueid)[x$age2<0]); tbl
```

```
##
## 00549-TAB 00685-BCS 00747-YUC 00748-YUC
##      109       226       212       706
```

```
table(x$age2[x$uniqueid %in% names(tbl)],
      as.character(x$uniqueid[x$uniqueid %in% names(tbl)]),
      useNA="always")
```

```
##
##          00549-TAB 00685-BCS 00747-YUC 00748-YUC <NA>
##  -6           0       0       3       0       0
##  -5          35       0      35       0       0
##  -4          32       0      68       0       0
##  -3          23       0      28       0       0
##  -2          17      130      35     420       0
##  -1           2       96      43     286       0
##  0            0      102      31     180       0
##  1            0      127      24     440       0
##  2            0      194      53     455       0
##  3           136     200       0     265       0
##  4            0       89       0     438       0
##  5            0      145       0     401       0
##  6            0       51       0     454       0
##  <NA>         0       0       0       0       0
```

```

## Naive Age Fix (the years associated w/ these samples may be incorrect):
x$age[(x$uniqueid=="00549-TAB")&(x$age2<0)]<- (x$age[(x$uniqueid=="00549-TAB")&(x$age2<0)] + 0.5)
x$age[(x$uniqueid=="00685-BCS")&(x$age2<0)]<- (x$age[(x$uniqueid=="00685-BCS")&(x$age2<0)] + 0.2)
x$age[(x$uniqueid=="00747-YUC")&(x$age2<0)]<- (x$age[(x$uniqueid=="00747-YUC")&(x$age2<0)] + 0.6)
x$age[(x$uniqueid=="00748-YUC")&(x$age2<0)]<- (x$age[(x$uniqueid=="00748-YUC")&(x$age2<0)] + 0.2)
x$age2<-((10*x$age) + (x$year - 2016))
summary(x$age2)

```

```

##      Min. 1st Qu. Median   Mean 3rd Qu.   Max.
##      0.00 15.00 27.00 33.31 53.00 85.00

```

2.2 Taxa by coop

```

tbl<-table(x$uniqueid,x$taxa)
dim(tbl)

```

```

## [1] 182 21

```

```

summary(coopByTaxa<-as.numeric(tbl))

```

```

##      Min. 1st Qu. Median   Mean 3rd Qu.   Max.
##      0.00 0.00 0.00 50.61 12.00 6074.00

```

```

table(coopByTaxa==0)

```

```

##
## FALSE TRUE
## 1171 2651

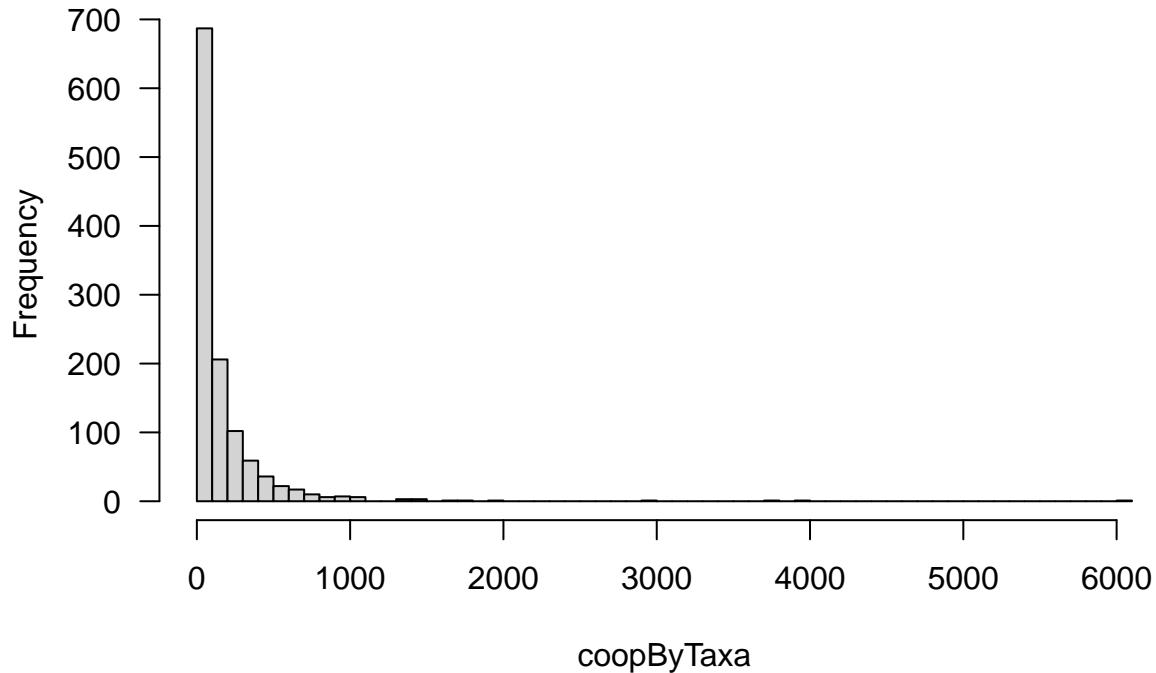
```

```

coopByTaxa<-coopByTaxa[coopByTaxa>0]
hist(coopByTaxa,nclass=50,las=1)

```

Histogram of coopByTaxa



3. Client's LME model

Note, from the `nlme::ACF` documentation: “This method function calculates the empirical autocorrelation function for the within-group residuals from an `lme` fit. The autocorrelation values are calculated using pairs of residuals within the innermost group level. The autocorrelation function is useful for investigating serial correlation models for equally spaced data.”

3.1 Full data set

```
keep<-(!is.na(x$logcpue))
lme.out<-nlme::lme(logcpue ~ age + yearFactor + monthFactor + region + taxa,
                     random = ~ 1|fed/uniqueid, data=x,subset=keep)
summary(lme.out)$tTable
```

	Value	Std.Error	DF	t-value	p-value
## (Intercept)	1.403663443	0.41978772	183217	3.34374582	8.267199e-04
## age	-0.195871810	0.05006573	183217	-3.91229336	9.145672e-05
## yearFactor2009	0.027262125	0.01630194	183217	1.67232427	9.446210e-02
## yearFactor2010	-0.109544495	0.01649317	183217	-6.64180891	3.107173e-11
## yearFactor2011	0.023352258	0.01669296	183217	1.39892864	1.618361e-01
## yearFactor2012	-0.073363190	0.01635476	183217	-4.48573939	7.270559e-06
## yearFactor2013	-0.009533991	0.01666463	183217	-0.57210948	5.672485e-01
## yearFactor2014	0.016596349	0.01664188	183217	0.99726401	3.186377e-01

```

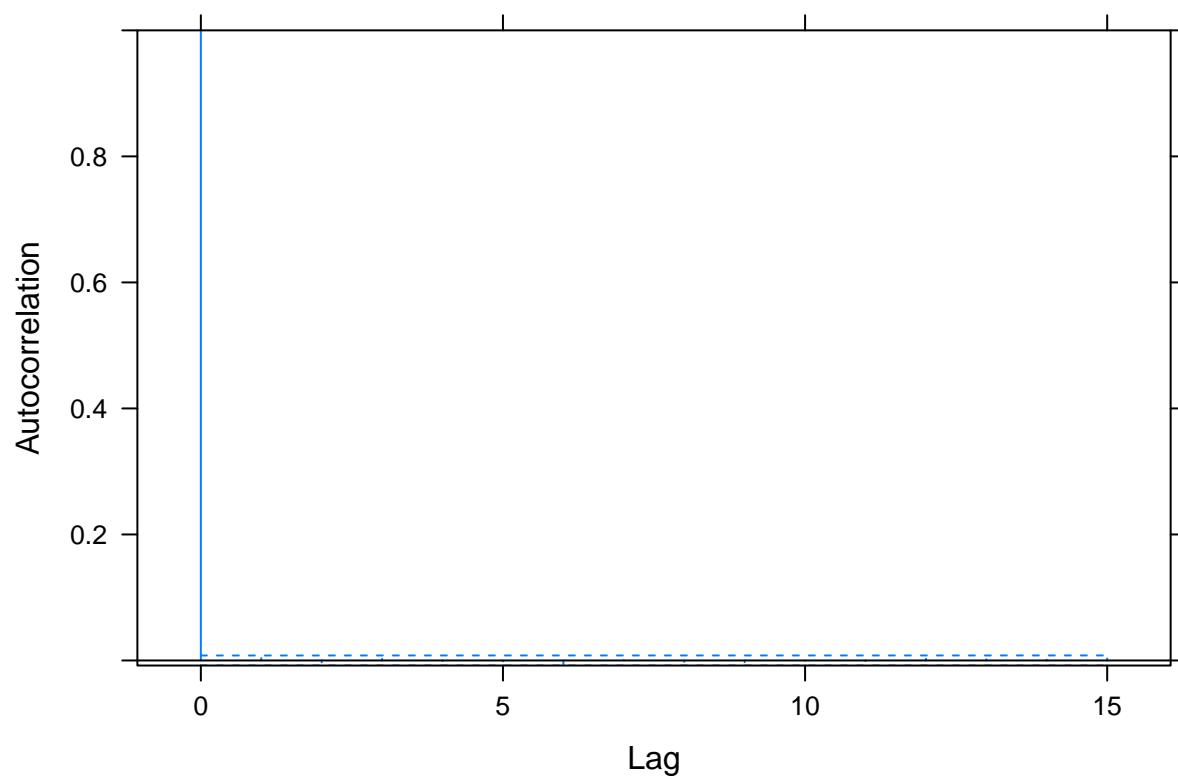
## yearFactor2015      0.005374221 0.01612237 183217    0.33333944 7.388785e-01
## yearFactor2016      0.056012774 0.01570492 183217    3.56657478 3.617698e-04
## monthFactor2        0.035024597 0.01879784 183217    1.86322403 6.243235e-02
## monthFactor3        0.128733929 0.01928850 183217    6.67412803 2.494106e-11
## monthFactor4        0.108429593 0.01939200 183217    5.59145938 2.254885e-08
## monthFactor5        0.153125799 0.01900357 183217    8.05773959 7.818014e-16
## monthFactor6        0.177137033 0.01885260 183217    9.39589312 5.735454e-21
## monthFactor7        0.234956217 0.01801286 183217   13.04380656 7.173641e-39
## monthFactor8        0.190238515 0.01790645 183217   10.62402447 2.345190e-26
## monthFactor9        0.261755659 0.01857591 183217   14.09113312 4.546237e-45
## monthFactor10       0.212403148 0.01807485 183217   11.75130642 7.139438e-32
## monthFactor11       0.167565715 0.01839680 183217   9.10841468 8.440205e-20
## monthFactor12       0.132478801 0.01870975 183217   7.08073436 1.439046e-12
## region2            0.539233765 0.61064720    124   0.88305287 3.789165e-01
## region3            2.078880747 0.46305246     52   4.48951448 3.990735e-05
## region4            1.779437804 0.43295413    124   4.10999157 7.140397e-05
## region5            -0.009984212 0.50885880    124   -0.01962079 9.843774e-01
## region6            0.679820678 0.43890199    124   1.54891226 1.239513e-01
## taxaCentropomidae -0.965678518 0.02264463 183217   -42.64491975 0.000000e+00
## taxaCichlidae      -0.239872411 0.03169818 183217   -7.56738736 3.825719e-14
## taxaClupeidae      2.519489134 0.09733478 183217   25.88477781 1.824149e-147
## taxaElasmobranchii -0.035590802 0.02147244 183217   -1.65751100 9.741792e-02
## taxaGerreidae       -0.748917162 0.02405025 183217   -31.13968742 2.518876e-212
## taxaHaliotidae      1.314033166 0.03325820 183217   39.51005498 0.000000e+00
## taxaLutjanidae      -0.426832776 0.01958706 183217   -21.79156898 3.797143e-105
## taxaMugilidae       0.003277102 0.02865295 183217   0.11437223 9.089429e-01
## taxaOctopodidae     1.240885722 0.03009656 183217   41.23015203 0.000000e+00
## taxaOmmastrephidae  2.599530248 0.08024495 183217   32.39493979 1.449267e-229
## taxaOstreidae       1.952268769 0.03814656 183217   51.17811472 0.000000e+00
## taxaOTRAS            -0.558432769 0.01741086 183217   -32.07382565 4.319535e-225
## taxaPalinuridae     0.663597312 0.02706263 183217   24.52080346 1.452410e-132
## taxaPectinidae      3.039571059 0.06591888 183217   46.11077891 0.000000e+00
## taxaPenaeidae       0.095062030 0.02406377 183217   3.95042196 7.804271e-05
## taxaPortunidae      0.907555138 0.03057724 183217   29.68074025 3.920776e-193
## taxaSciaenidae      -0.170047445 0.02124898 183217   -8.00261698 1.225070e-15
## taxaScombridae       0.047579863 0.03057967 183217   1.55593096 1.197262e-01
## taxaSerranidae       0.556641242 0.02009494 183217   27.70057070 1.534479e-168
## taxaStichopodidae   3.192020724 0.06563502 183217   48.63288706 0.000000e+00

```

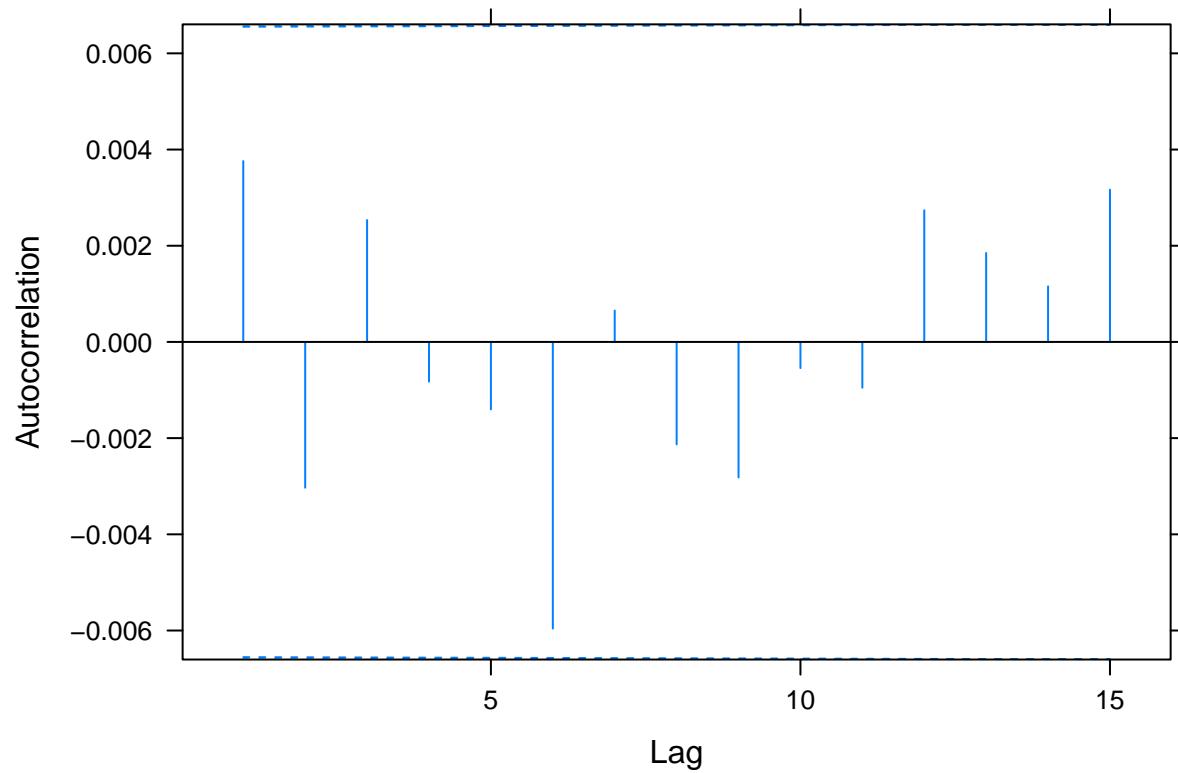
```

acf.lme<-nlme:::ACF(lme.out,maxLag=15)
plot(acf.lme,alpha=0.01/15)

```

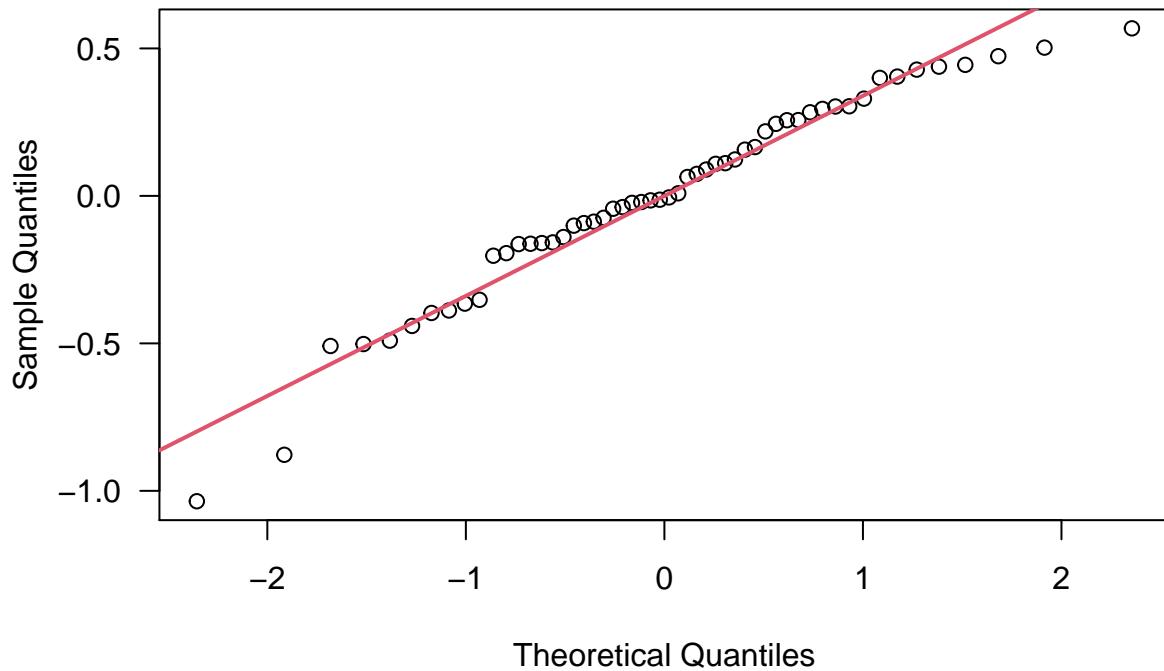


```
acf.lme<-acf.lme[-1,]  
plot(acf.lme,alpha=0.005)
```



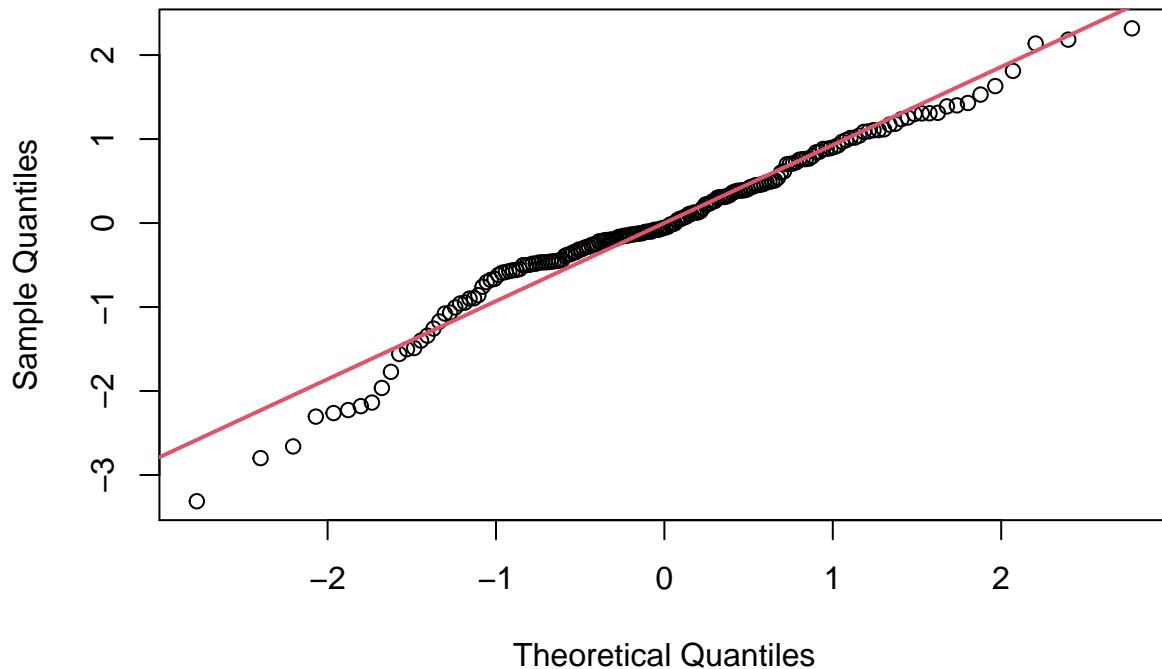
```
qqnorm(fedn.re<-unlist(nlme::ranef(lme.out)$fed), las=1)
abline(a=0, b=sd(fedn.re), lwd=2, col=2)
```

Normal Q-Q Plot



```
qqnorm(uid.re<-unlist(nlme::ranef(lme.out)$uniqueid))
abline(a=0,b=sd(uid.re),lwd=2,col=2)
```

Normal Q-Q Plot



3.2 Single taxa model

```
keep<-((x$taxa=="OTRAS")&(!is.na(x$logcpue)))
otras.out<-nlme::lme(logcpue ~ age + yearFactor + monthFactor + region,
                      random = ~ 1|fed/uniqueid, data=x,subset=keep)
summary(otras.out)$tTable
```

	Value	Std.Error	DF	t-value	p-value
## (Intercept)	1.08138634	0.84421113	36105	1.28094300	2.002219e-01
## age	-0.28365849	0.08467958	36105	-3.34978610	8.095677e-04
## yearFactor2009	0.04673876	0.03509398	36105	1.33181716	1.829287e-01
## yearFactor2010	-0.09705218	0.03579162	36105	-2.71158925	6.699319e-03
## yearFactor2011	0.13060751	0.03577393	36105	3.65091294	2.616786e-04
## yearFactor2012	0.15795034	0.03464800	36105	4.55871433	5.163641e-06
## yearFactor2013	0.08099962	0.03501745	36105	2.31312171	2.072154e-02
## yearFactor2014	0.09254657	0.03552113	36105	2.60539506	9.180602e-03
## yearFactor2015	0.19715933	0.03424718	36105	5.75695037	8.633969e-09
## yearFactor2016	0.24684516	0.03310370	36105	7.45672392	9.068682e-14
## monthFactor2	0.04320187	0.03999201	36105	1.08026257	2.800325e-01
## monthFactor3	0.03424256	0.03893670	36105	0.87944178	3.791676e-01
## monthFactor4	-0.02316908	0.03917392	36105	-0.59144151	5.542283e-01
## monthFactor5	0.08849087	0.03770718	36105	2.34679076	1.894126e-02
## monthFactor6	0.20005985	0.03774298	36105	5.30058458	1.161094e-07
## monthFactor7	0.13976807	0.03740019	36105	3.73709550	1.864450e-04

```

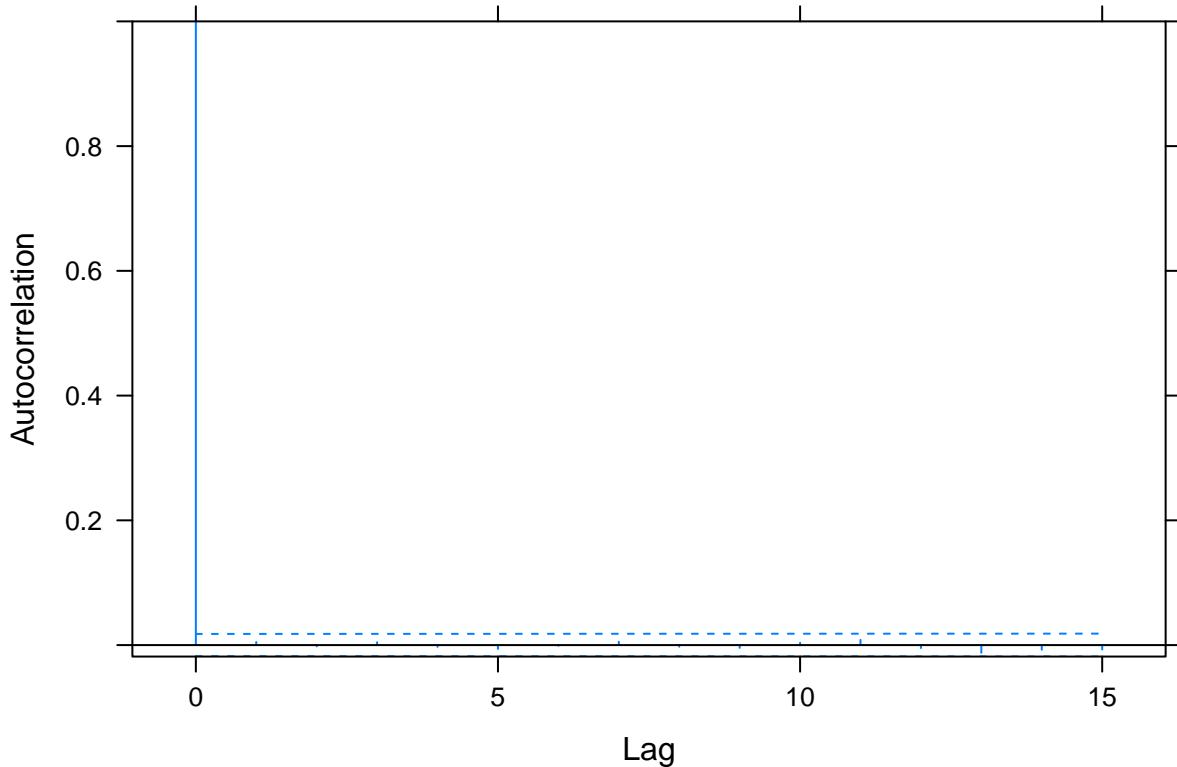
## monthFactor8 -0.04185668 0.03853893 36105 -1.08608830 2.774472e-01
## monthFactor9 -0.15388514 0.04165876 36105 -3.69394395 2.211281e-04
## monthFactor10 -0.04671011 0.04076475 36105 -1.14584556 2.518667e-01
## monthFactor11 -0.00108303 0.04102094 36105 -0.02640188 9.789369e-01
## monthFactor12 0.02164900 0.04099621 36105 0.52807330 5.974517e-01
## region2 0.50800884 1.03291245 87 0.49182178 6.240840e-01
## region3 2.51046462 0.88150159 46 2.84794111 6.557393e-03
## region4 2.13323557 0.87085476 87 2.44958822 1.630636e-02
## region5 0.29610271 0.93507039 87 0.31666355 7.522575e-01
## region6 0.50720661 0.85832077 87 0.59092897 5.561001e-01

```

```

acf.otras<-nlme:::ACF(otras.out,maxLag=15)
plot(acf.otras,alpha=0.01/15)

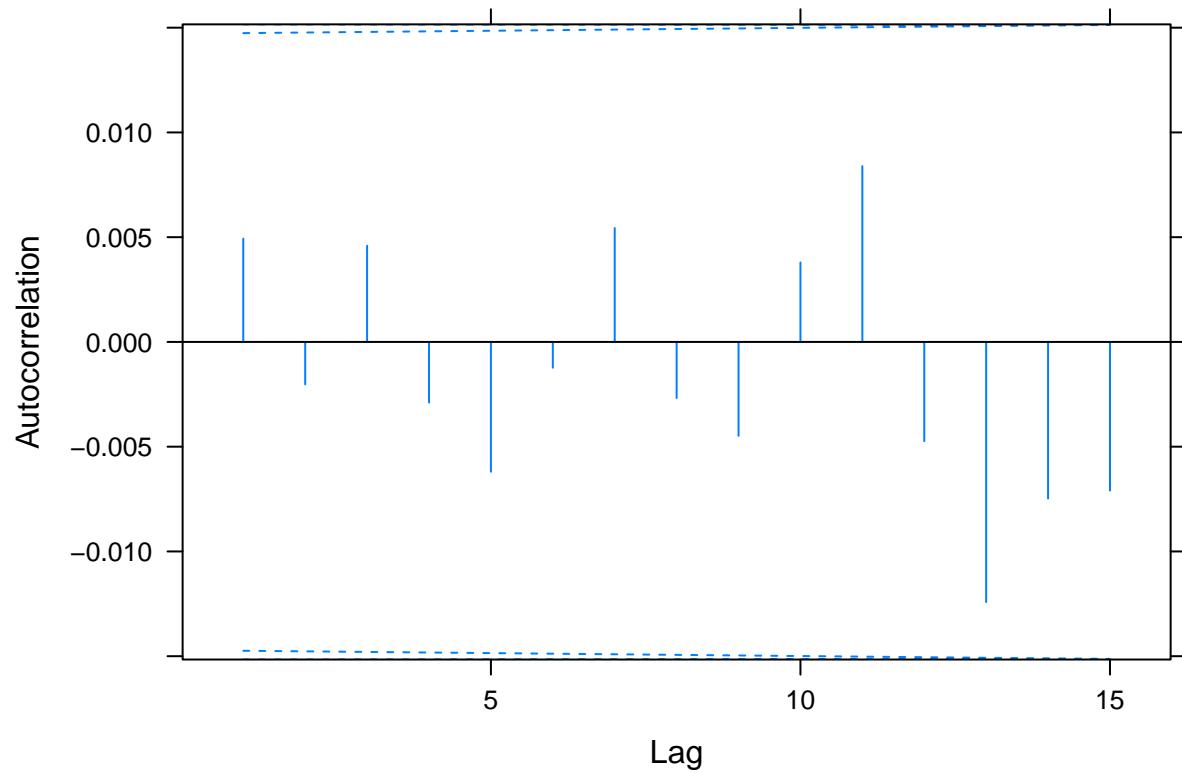
```



```

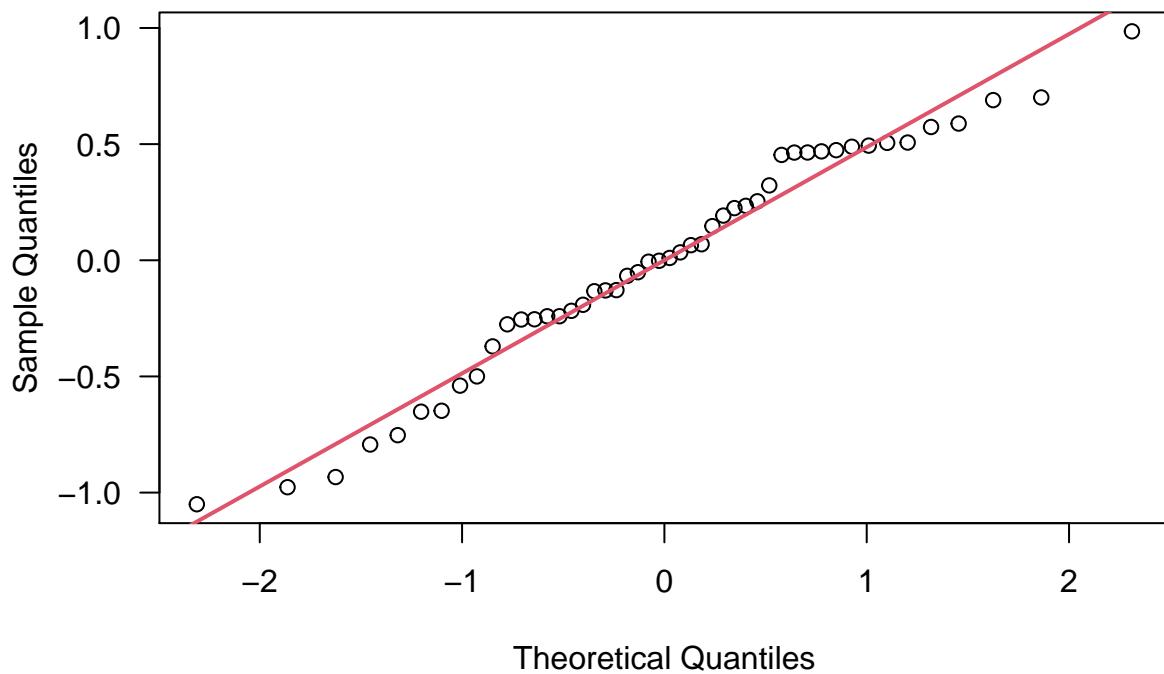
acf.otras<-acf.otras[-1,]
plot(acf.otras,alpha=0.005)

```

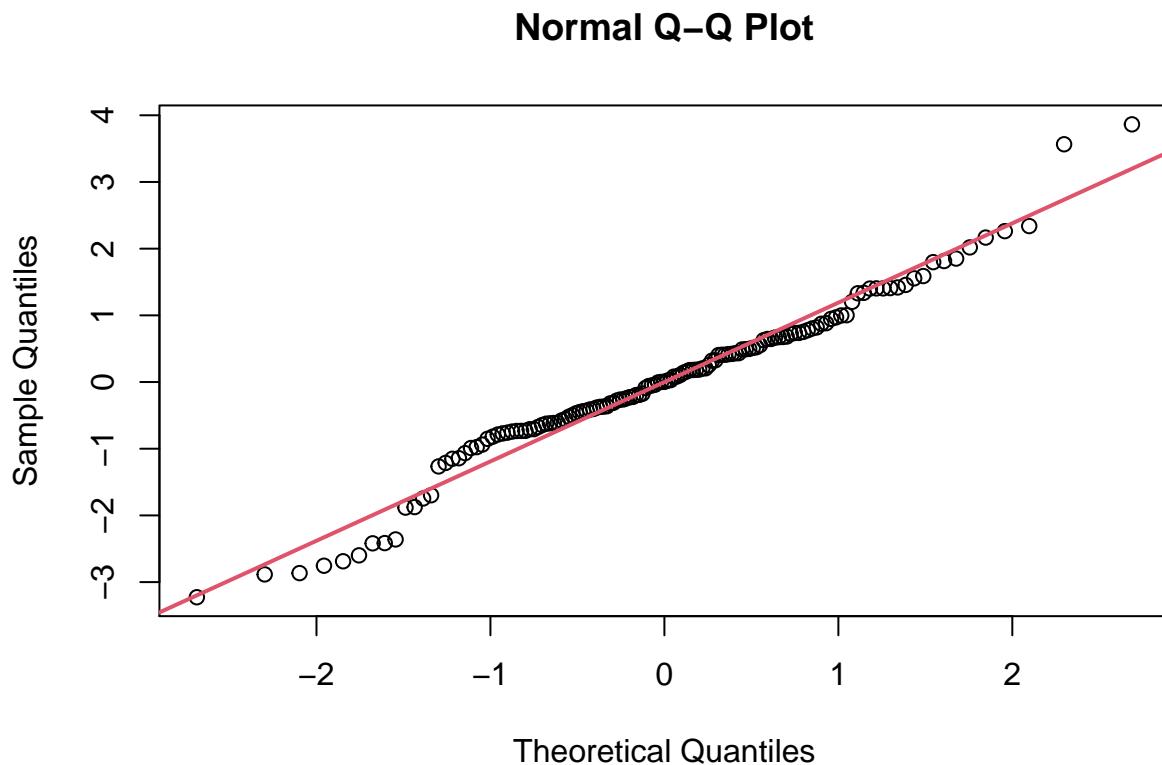


```
qqnorm(fedn.re<-unlist(nlme::ranef(otras.out)$fed),las=1)
abline(a=0,b=sd(fedn.re),lwd=2,col=2)
```

Normal Q-Q Plot



```
qqnorm(uid.re<-unlist(nlme::ranef(otras.out)$uniqueid))  
abline(a=0,b=sd(uid.re),lwd=2,col=2)
```



4. Your mgcv Models

EDA

```
response_summary <- x %>%
  summarise(mean = mean(logcpue, na.rm=TRUE),
            median = median(logcpue, na.rm=TRUE),
            variance = var(logcpue, na.rm=TRUE),
            IQR = IQR(logcpue, na.rm=TRUE),
            sd = sd(logcpue, na.rm=TRUE),
            min = min(logcpue, na.rm=TRUE),
            max = max(logcpue, na.rm=TRUE))
knitr::kable(response_summary, caption = "Summary Statistics for \n the logcpue")
```

Table 1: Summary Statistics for the logcpue

mean	median	variance	IQR	sd	min	max
1.740824	1.966113	4.71467	2.888958	2.171329	-7.863267	10.04138

```
ggplot(data = x, aes(x = logcpue)) +
  geom_histogram(fill = "darkgreen", color = "black") +
  labs(x = "logcpue", y = "Count",
```

```

    title = "Distribution of logcpue",
    caption = "Figure 1") +
theme_bw()

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

## Warning: Removed 10000 rows containing non-finite values (stat_bin).

```

Distribution of logcpue

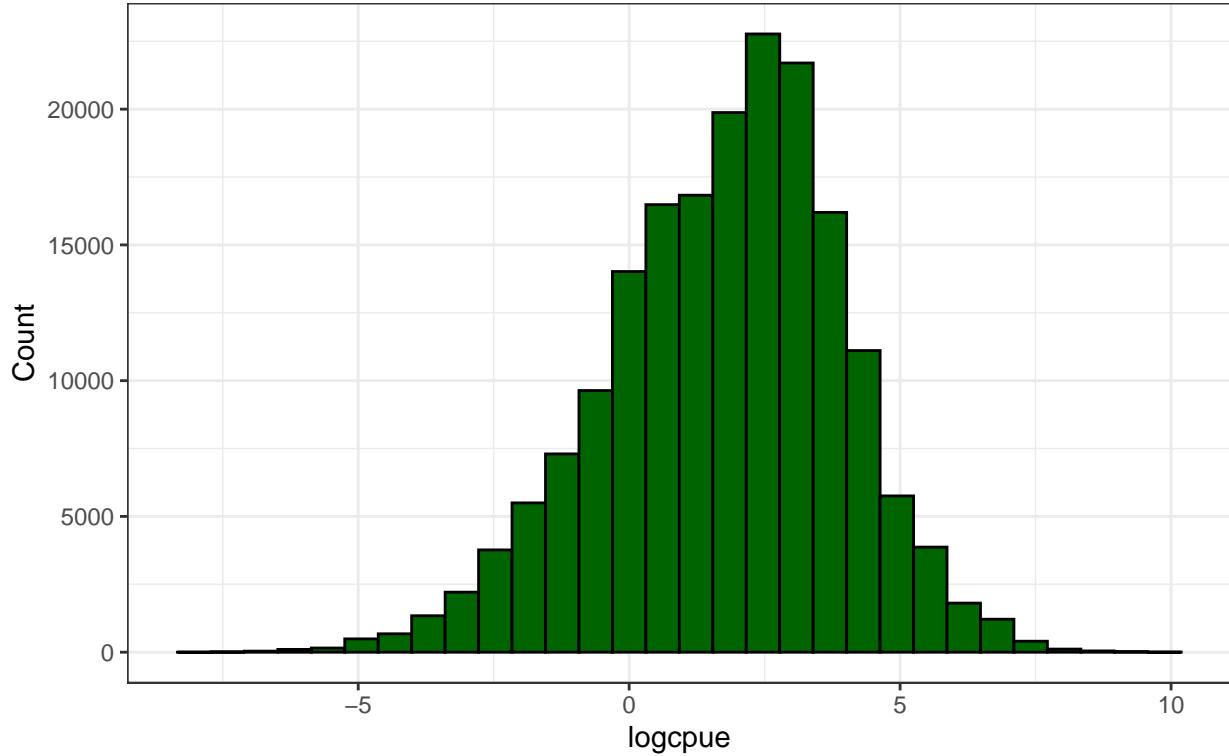


Figure 1

In this dataset, the response variable is `logcpue`, which represents catch per unit of effort, measured during different time points (Figure 1, Table 1). The distribution of this variable is unimodal and slightly skewed to the left. The center, defined by median, is 1.97. The spread, defined by the interquartile range (IQR), is 2.89. There are no evident outliers based on the histogram shown in Figure 1. To better capture the distribution of `logcpue` for individual cooperation, a random sample of 30 cooperation were selected, and their `logcpue` measured at different time points were plotted (Figure 2). Indeed, cooperation exhibit different patterns for the distribution of `logcpue`. Some shows a bimodel distribution, while some shows a unimodel distribution. This suggests that the distribution of `logcpue` differs based on cooperations, so we decided to include it as an individual level in our LMM model.

```

set.seed(031622)
# get sample of 30 cooperations

sample_org <- x %>%
  distinct(uniqueid) %>%
  sample_n(30) %>% pull()
# get data for those cooperation

```

```

sample_data <- x %>%
  filter(uniqueid %in% sample_org)
# make a histogram of the response for each lemur
ggplot(data = sample_data, aes(x = logcpue)) +
  geom_histogram(fill = "darkgreen", color = "black") +
  facet_wrap(~ uniqueid, scales = "free") +
  labs(x = "logcpue",
       title = "Distribution of logcpue by randomly sampled 30 cooperation",
       caption = "Figure 2") +
  theme_bw()

```

‘stat_bin()’ using ‘bins = 30’. Pick better value with ‘binwidth’.

Warning: Removed 1821 rows containing non-finite values (stat_bin).

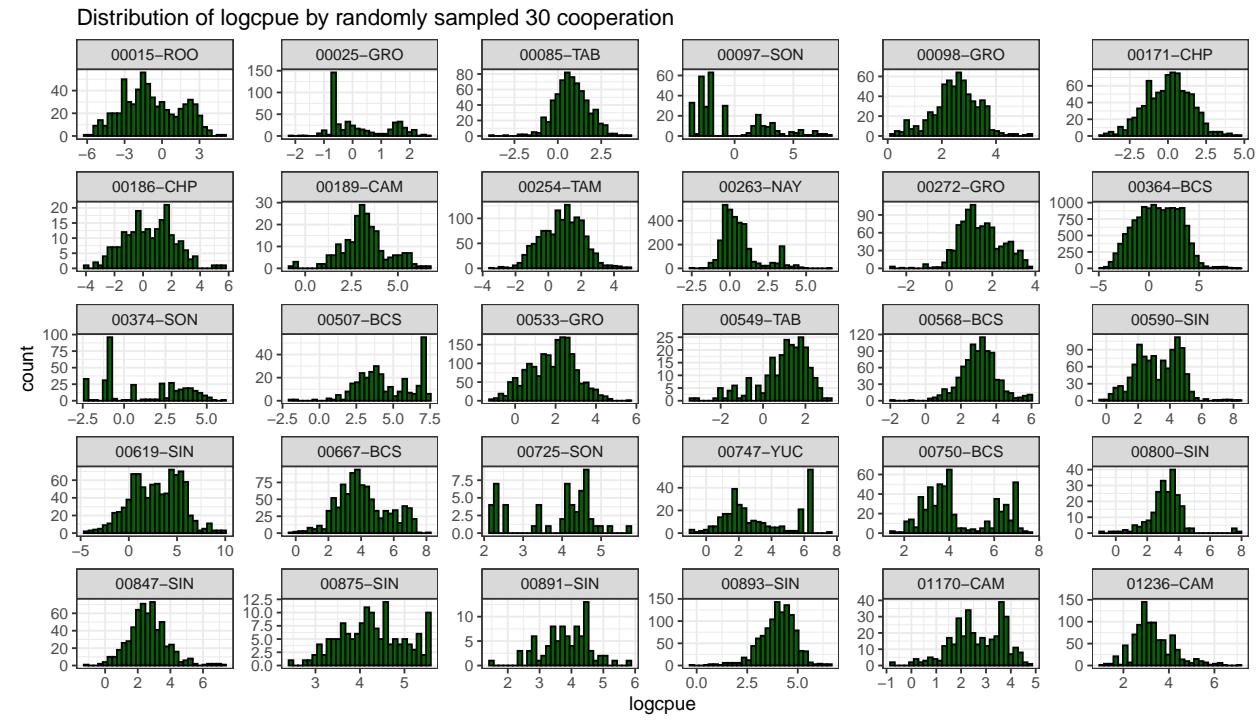


Figure 2

Other variables in the data that are of interests include year and month of each fishing event, region, taxa, and age of the federations. Figure 3 shows the relationships between year and logcpue for 30 randomly selected cooperations. Figure 4 shows the relationships between month and logcpue for 30 randomly selected cooperations. While some cooperations have a constant logcpue value across years or months, some cooperations have varying logcpue based on the year or month the fishery takes place, indicating that time alone cannot explain the distribution of logcpue observed and other factors during the year or month logcpue was collected may play a role in determining the pattern of logcpue.

```

ggplot(data = sample_data, aes(x = yearFactor, y = logcpue)) +
  geom_boxplot(fill = "darkgreen", color = "black") +
  facet_wrap(~ uniqueid, scales = "free") +
  labs(x = "Year",
       y = "logcpue",

```

```

    title = "logcpue vs year",
    caption = "Figure 3") +
theme_bw()

```

Warning: Removed 1821 rows containing non-finite values (stat_boxplot).

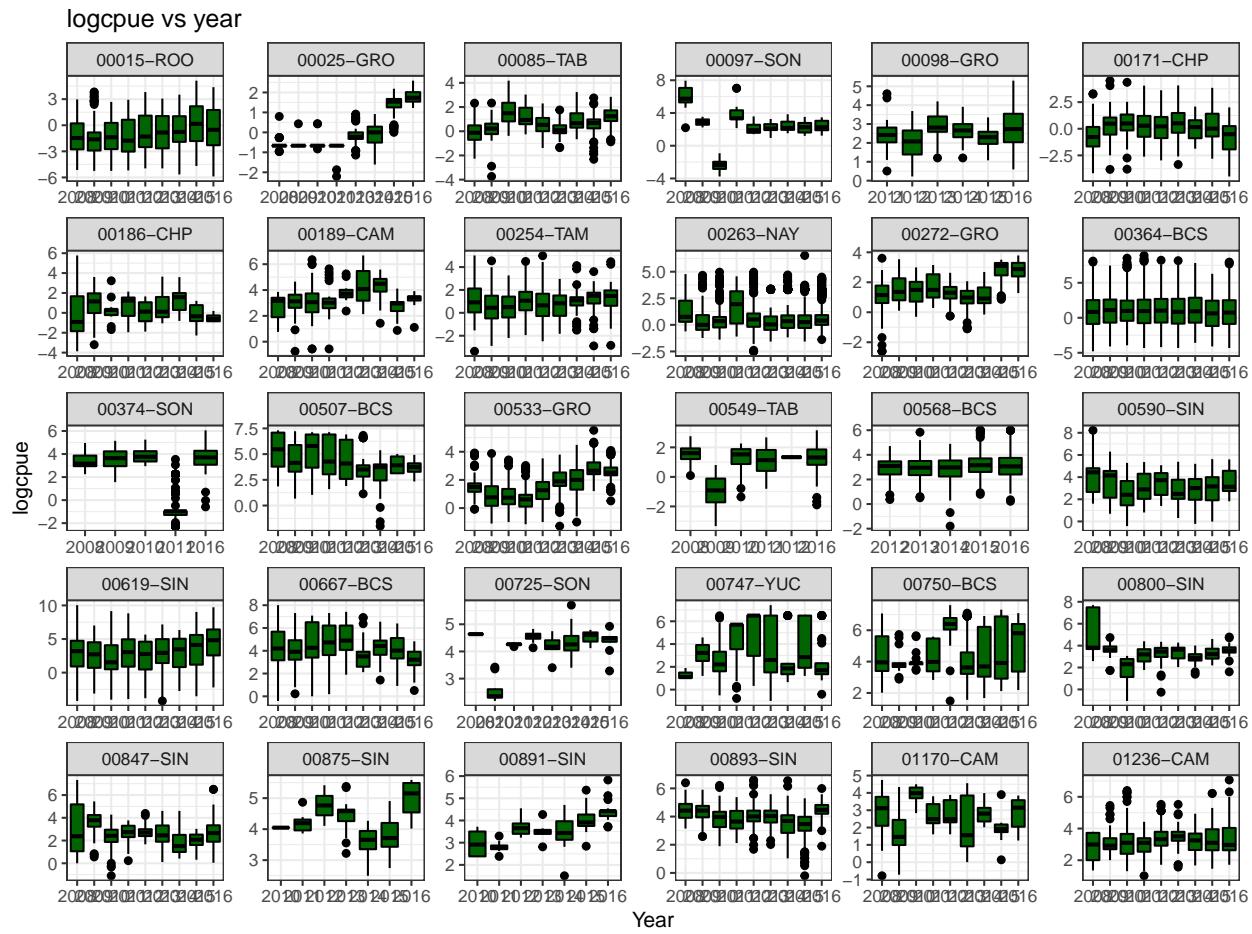


Figure 3

```

ggplot(data = sample_data, aes(x = monthFactor, y = logcpue)) +
  geom_boxplot(fill = "darkgreen", color = "black") +
  facet_wrap(~ uniqueid, scales = "free") +
  labs(x = "Month",
       y = "logcpue",
       title = "logcpue vs month",
       caption = "Figure 4") +
  theme_bw()

```

Warning: Removed 1821 rows containing non-finite values (stat_boxplot).

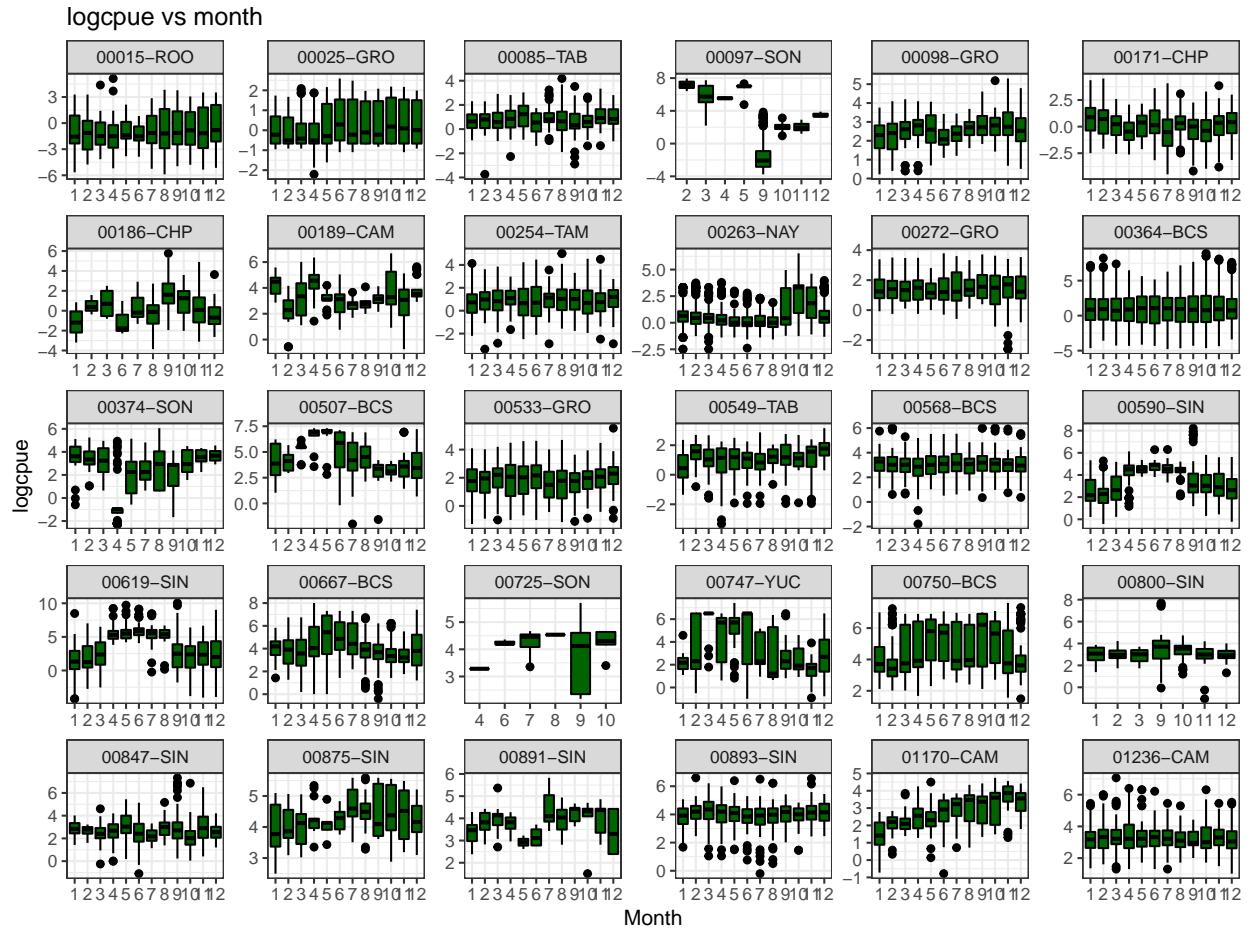


Figure 4

Therefore, a new continuous variable that incorporated both year and month is created.

```
x$yearMonth <- ((x$year - min(x$year)) *12 + x$month)
```

In addition to year and month, region and taxa also play an important role in explaining logcpue. In particular, logcpue differs based on the region where the fisheries take place and on the taxa of the fish caught (Figure 5,6). Therefore, these two variables are worth including in the final models.

```
region <- ggplot(data = x, aes(x = region, y = logcpue)) +
  geom_boxplot(fill = "darkgreen", color = "black") +
  labs(x = "Region",
       y = "logcpue",
       title = "logcpue vs. region",
       caption = "Figure 5") +
  theme_bw()
```

```
taxa<- ggplot(data = x, aes(x = taxa, y = logcpue)) +
  geom_boxplot(fill = "darkgreen", color = "black") +
  labs(x = "Taxa",
       y = "logcpue",
       title = "logcpue vs. taxa",
       caption = "Figure 6") +
  theme_bw()
```

```
region + taxa
```

```
## Warning: Removed 10000 rows containing non-finite values (stat_boxplot).  
## Warning: Removed 10000 rows containing non-finite values (stat_boxplot).
```

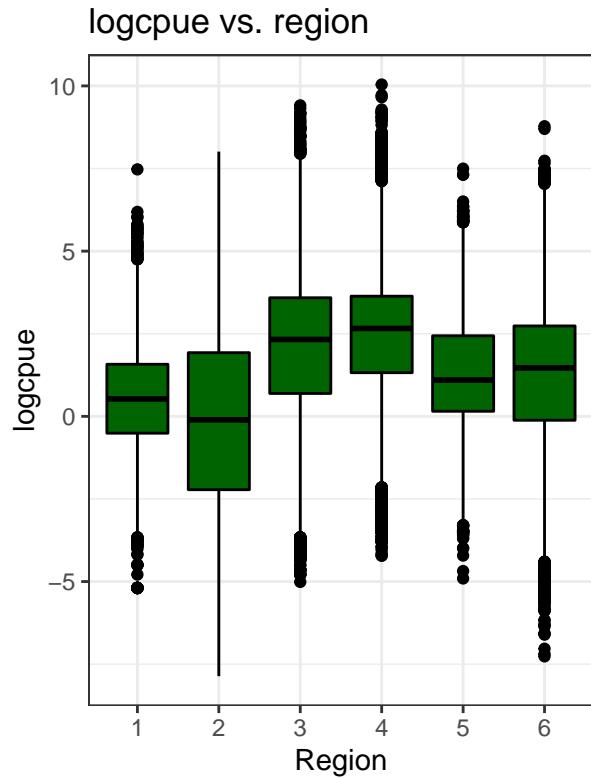


Figure 5

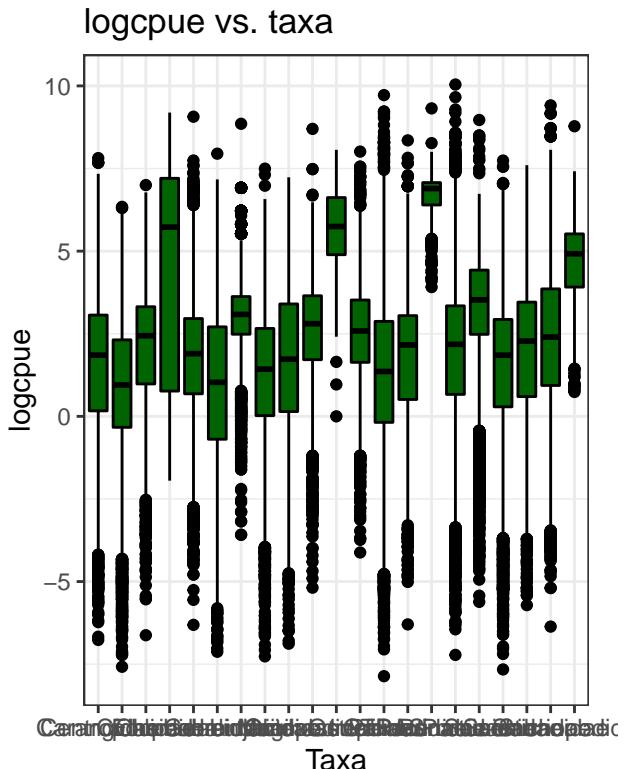


Figure 6

Methods

Both models using mgcv and lme are included in this section.

Since catch per unit of efforts (cpue) were measured at different time points for each cooperation and that cooperations from the same federations tend to have similar distribution of logcpue, a multilevel model analysis was used to model the distribution of logcpue. The multilevel analysis was done at three levels. The first level included time points when cpue were collected; the second level included individual cooperations (`uniqueid`); and the third level included federations (`fed`). To test whether a multilevel model is necessary to capture the distribution of logcpue, an unconditional means model in which there are no predictors at any level was first fitted, and intraclass correlation was calculated to estimate the relative variability between cooperations and between federations (Table 2). Indeed, the intraclass correlation for cooperations is about 0.22 and for federations is about 0.26, which means that the average correlation between any two responses from the same cooperations or from the same federations is about 0.22 and 0.26 respectively. This suggests that about 48% of the variability in the logcpue is explained by cooperation to cooperation variability and federation to federation variability. Knowing cooperation and federation, therefore, can explain almost half of the variability in the data, providing evidence that the multilevel model structure is useful in this setting.

```

unconditional_means_mgcv <- bam(logcpue ~ 1 + s(fed, bs = "re") + s(uniqueid, bs = "re"),
                                 data = x, na.action = na.omit)
summary(unconditional_means_mgcv)

## 
## Family: gaussian
## Link function: identity
##
## Formula:
## logcpue ~ 1 + s(fed, bs = "re") + s(uniqueid, bs = "re")
##
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) 2.2669    0.1898   11.94   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##          edf Ref.df      F p-value
## s(fed)     38.5     53 710455 0.00906 **
## s(uniqueid) 140.5    181 238192 0.00028 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.396 Deviance explained = 39.7%
## fREML = 3.5679e+05 Scale est. = 2.8475 n = 183439

unconditional_means <- lme(logcpue ~ 1,
                           list(fed = ~1, uniqueid = ~1),
                           data = x, na.action = na.omit)
summary(unconditional_means)

## Linear mixed-effects model fit by REML
## Data: x
##      AIC      BIC      logLik
## 713580.5 713621 -356786.2
##
## Random effects:
## Formula: ~1 | fed
##           (Intercept)
## StdDev: 1.189196
##
## Formula: ~1 | uniqueid %in% fed
##           (Intercept) Residual
## StdDev: 1.093864 1.687456
##
## Fixed effects: logcpue ~ 1
##                 Value Std.Error DF t-value p-value
## (Intercept) 2.266913 0.189815 183257 11.94275     0
##
## Standardized Within-Group Residuals:
##      Min        Q1        Med        Q3        Max

```

```

## -4.25341107 -0.59958742 -0.01052429  0.60605097  5.54494371
##
## Number of Observations: 183439
## Number of Groups:
##           fed uniqueid %in% fed
##                 54                  182

```

Next, to understand the effect of time before adding other Level One covariates, the model that only includes year and month as Level One predictors was fitted (Table 3). The Pseudo R^2 estimating the change in within-cooperation variance between the unconditional means and the Model with Time is about 0.42. Therefore, understanding changes of time (i.e. years) accounts for 42% variability in logcpue.

```

model_time <- lme(logcpue ~ yearMonth, list(fed = ~yearMonth, uniqueid = ~yearMonth),
                     data = x, na.action = na.omit)
summary(model_time)

```

```

## Linear mixed-effects model fit by REML
## Data: x
##      AIC      BIC      logLik
## 704386.3 704477.4 -352184.2
##
## Random effects:
##   Formula: ~yearMonth | fed
##   Structure: General positive-definite, Log-Cholesky parametrization
##             StdDev     Corr
## (Intercept) 1.466296838 (Intr)
## yearMonth    0.008859054 -0.69
##
##   Formula: ~yearMonth | uniqueid %in% fed
##   Structure: General positive-definite, Log-Cholesky parametrization
##             StdDev     Corr
## (Intercept) 1.27828351 (Intr)
## yearMonth    0.01280207 -0.537
## Residual     1.64283974
##
## Fixed effects: logcpue ~ yearMonth
##                 Value Std.Error DF t-value p-value
## (Intercept) 2.2279527 0.23275696 183256 9.572013 0.0000
## yearMonth   0.0004842 0.00166952 183256 0.290035 0.7718
##
## Correlation:
##             (Intr)
## yearMonth -0.632
##
## Standardized Within-Group Residuals:
##      Min       Q1       Med       Q3       Max
## -4.432812192 -0.578993635 -0.006224082  0.588661168  5.862754093
##
## Number of Observations: 183439
## Number of Groups:
##           fed uniqueid %in% fed
##                 54                  182

```

mgcv,however, cannot fit this model, which is one limitation of mgcv. We cannot encode a covariance term between two random effect in mgcv. It can only fit uncorrelated random effects.

```

# Pseudo R^2
sigm_moda <- 1.687456^2
sigm_madb <- 1.64283974
r <- (sigm_moda - sigm_madb)/sigm_moda
r

```

```
## [1] 0.4230605
```

Based on the EDA and model with only time as level one predictors, we decided to include `yearMonth`, `region`, and `taxa` as our level one predictors. `age2` was included as level three (federation) predictor since we hypothesized that the age of federation would impact the efficiency of catching fish (`logcpue`) of its subsidiary cooperation. Therefore, two models were fitted. One that includes interactions between age of federations and region and between age of federations and taxa, and one that does not include any interactions. AIC and BIC of both models were compared. Since both AIC and BIC are lower for model with additional interaction effects, providing evidence that model with interactions is a better model. One thing to note is that no random slopes were included in level two or three in both model because adding them make the model too complex and too computational heavy.

```

model_no_int_mgcv <- bam(logcpue ~ yearMonth + region + taxa + age2
                           + s(fed, bs = "re") + s(uniqueid, bs = "re"),
                           data = x, na.action = na.omit)
summary(model_no_int_mgcv)

```

```

##
## Family: gaussian
## Link function: identity
##
## Formula:
## logcpue ~ yearMonth + region + taxa + age2 + s(fed, bs = "re") +
##           s(uniqueid, bs = "re")
##
## Parametric coefficients:
##                               Estimate Std. Error t value Pr(>|t|)
## (Intercept)            1.8116502  0.3850081  4.705 2.53e-06 ***
## yearMonth             0.0039049  0.0004075  9.582 < 2e-16 ***
## region2              0.5317722  0.5973420  0.890   0.373
## region3              1.9366468  0.4422699  4.379 1.19e-05 ***
## region4              1.6569132  0.4137849  4.004 6.22e-05 ***
## region5              -0.2582846  0.4868300 -0.531   0.596
## region6              0.5435420  0.4209324  1.291   0.197
## taxaCentropomidae   -0.9627613  0.0226632 -42.481 < 2e-16 ***
## taxaCichlidae       -0.2337073  0.0317299 -7.366 1.77e-13 ***
## taxaClupeidae       2.5139063  0.0974059  25.809 < 2e-16 ***
## taxaElasmobranchii  -0.0347777  0.0214737 -1.620   0.105
## taxaGerreidae        -0.7431146  0.0240705 -30.872 < 2e-16 ***
## taxaHaliotidae      1.3255982  0.0331058  40.041 < 2e-16 ***
## taxaLutjanidae      -0.4199436  0.0196027 -21.423 < 2e-16 ***
## taxaMugilidae       0.0163083  0.0286612  0.569   0.569
## taxaOctopodidae     1.2663286  0.0300201  42.183 < 2e-16 ***
## taxaOmmastrephidae  2.5593886  0.0802817  31.880 < 2e-16 ***
## taxaOstreidae        1.9466492  0.0381693  51.000 < 2e-16 ***
## taxaOTRAS            -0.5559038  0.0174240 -31.904 < 2e-16 ***
## taxaPalinuridae     0.6478103  0.0268922  24.089 < 2e-16 ***

```

```

## taxaPectinidae      3.0447374  0.0658010  46.272 < 2e-16 ***
## taxaPenaeidae       0.0939075  0.0238604   3.936 8.30e-05 ***
## taxaPortunidae      0.9179923  0.0305922  30.007 < 2e-16 ***
## taxaSciaenidae     -0.1675650  0.0212704  -7.878 3.35e-15 ***
## taxaScombridae      0.0407509  0.0306086   1.331   0.183
## taxaSerranidae      0.5643607  0.0201107  28.063 < 2e-16 ***
## taxaStichopodidae   3.2182595  0.0655246  49.115 < 2e-16 ***
## age2                 -0.0383265  0.0047646  -8.044 8.75e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##          edf Ref.df   F p-value
## s(fed)      16.9      51 17702  0.314
## s(uniqueid) 156.2     176 10483 <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.471 Deviance explained = 47.2%
## fREML = 3.4466e+05 Scale est. = 2.4939 n = 183439

model_no_int <- lme(logcpue ~ yearMonth + region + taxa + age2,
                      list(fed = ~1, uniqueid = ~1),
                      data = x, na.action = na.omit)
summary(model_no_int)

## Linear mixed-effects model fit by REML
## Data: x
##      AIC      BIC logLik
## 689376 689689.7 -344657
##
## Random effects:
##   Formula: ~1 | fed
##             (Intercept)
## StdDev:  0.4808204
##
##   Formula: ~1 | uniqueid %in% fed
##             (Intercept) Residual
## StdDev:    1.058933 1.579194
##
## Fixed effects: logcpue ~ yearMonth + region + taxa + age2
##                  Value Std.Error DF t-value p-value
## (Intercept)      1.811649 0.3850024 183235  4.70555 0.0000
## yearMonth        0.003905 0.0004075 183235  9.58189 0.0000
## region2         0.531762 0.5973359   124  0.89022 0.3751
## region3         1.936649 0.4422630    52  4.37895 0.0001
## region4         1.656917 0.4137786   124  4.00436 0.0001
## region5        -0.258278 0.4868227   124 -0.53054 0.5967
## region6         0.543541 0.4209262   124  1.29130 0.1990
## taxaCentropomidae -0.962761 0.0226632 183235 -42.48126 0.0000
## taxaCichlidae   -0.233707 0.0317299 183235 -7.36552 0.0000
## taxaClupeidae    2.513906 0.0974059 183235 25.80855 0.0000
## taxaElasmobranchii -0.034778 0.0214737 183235 -1.61955 0.1053
## taxaGerreidae   -0.743115 0.0240705 183235 -30.87242 0.0000

```

```

## taxaHaliotidae      1.325598 0.0331058 183235  40.04131  0.0000
## taxaLutjanidae     -0.419944 0.0196027 183235 -21.42271  0.0000
## taxaMugilidae       0.016308 0.0286612 183235   0.56900  0.5694
## taxaOctopodidae    1.266329 0.0300201 183235  42.18268  0.0000
## taxaOmmastrephidae  2.559389 0.0802817 183235  31.88012  0.0000
## taxaOstreidae        1.946649 0.0381693 183235  51.00038  0.0000
## taxaOTRAS            -0.555904 0.0174240 183235 -31.90442  0.0000
## taxaPalinuridae     0.647810 0.0268922 183235  24.08919  0.0000
## taxaPectinidae       3.044737 0.0658010 183235  46.27189  0.0000
## taxaPenaeidae        0.093907 0.0238604 183235   3.93571  0.0001
## taxaPortunidae       0.917992 0.0305922 183235  30.00740  0.0000
## taxaSciaenidae       -0.167565 0.0212704 183235 -7.87784  0.0000
## taxaScombridiae     0.040751 0.0306086 183235   1.33135  0.1831
## taxaSerranidae       0.564361 0.0201107 183235  28.06273  0.0000
## taxaStichopodidae   3.218260 0.0655246 183235  49.11531  0.0000
## age2                  -0.038327 0.0047646 183235 -8.04402  0.0000
## Correlation:
##                                     (Intr) yrMnth regin2 regin3 regin4 regin5 regin6 txCntr
## yearMonth                 0.292
## region2                  -0.573  0.022
## region3                  -0.809 -0.078  0.503
## region4                  -0.864 -0.084  0.546  0.736
## region5                  -0.755 -0.131  0.460  0.631  0.679
## region6                  -0.846 -0.067  0.544  0.723  0.788  0.669
## taxaCentropomidae      -0.033  0.008 -0.001  0.006  0.001  0.003  0.003
## taxaCichlidae          -0.023 -0.003 -0.003  0.004 -0.001 -0.012  0.002  0.403
## taxaClupeidae          -0.007 -0.004  0.000  0.000  0.000  0.001  0.001  0.096
## taxaElasmobranchii     -0.028  0.011  0.001  0.000 -0.001  0.002  0.001  0.444
## taxaGerreidae          -0.029  0.004  0.001  0.005  0.002  0.003  0.003  0.488
## taxaHaliotidae         -0.014  0.020  0.000 -0.003 -0.001 -0.001  0.000  0.276
## taxaLutjanidae         -0.030 -0.007  0.000  0.001  0.000  0.001  0.001  0.485
## taxaMugilidae          -0.028  0.001  0.000  0.006  0.002  0.001  0.006  0.416
## taxaOctopodidae        -0.026 -0.022  0.000  0.003  0.002  0.002  0.001  0.317
## taxaOmmastrephidae    -0.013  0.002  0.001  0.002 -0.007  0.003  0.002  0.134
## taxaOstreidae          -0.018  0.013 -0.002  0.003  0.000 -0.001  0.003  0.313
## taxaOTRAS                -0.036  0.003  0.000  0.001  0.000  0.000  0.003  0.607
## taxaPalinuridae        -0.024 -0.016  0.000  0.000  0.001  0.002 -0.001  0.344
## taxaPectinidae          -0.012  0.017  0.002 -0.009  0.000  0.002  0.003  0.160
## taxaPenaeidae           -0.063 -0.003  0.016  0.027  0.015  0.027  0.027  0.514
## taxaPortunidae          -0.034 -0.002  0.003  0.010 -0.003  0.010  0.008  0.389
## taxaSciaenidae          -0.030  0.002  0.000  0.002  0.000  0.003  0.002  0.487
## taxaScombridiae        -0.018  0.000  0.001  0.001  0.000  0.001  0.001  0.298
## taxaSerranidae          -0.029 -0.007  0.000 -0.002 -0.001  0.002  0.001  0.459
## taxaStichopodidae      -0.008  0.005  0.000 -0.001  0.000  0.000 -0.003  0.140
## age2                   -0.311 -0.953 -0.024  0.080  0.086  0.136  0.070  0.001
##                                     txCchl txClpd txElsm txGrrd txHltd txLtjn txMgld txOctp
## yearMonth
## region2
## region3
## region4
## region5
## region6
## taxaCentropomidae
## taxaCichlidae

```

```

## taxaClupeidae      0.071
## taxaElasmobranchii 0.321  0.113
## taxaGerreidae      0.347  0.097  0.428
## taxaHaliotidae     0.204  0.076  0.361  0.270
## taxaLutjanidae     0.345  0.109  0.482  0.452  0.302
## taxaMugilidae      0.339  0.082  0.355  0.380  0.220  0.389
## taxaOctopodidae    0.221  0.070  0.328  0.298  0.210  0.371  0.245
## taxaOmmastrephidae 0.096  0.028  0.134  0.124  0.082  0.141  0.114  0.091
## taxaOstreidae       0.212  0.056  0.260  0.276  0.163  0.298  0.250  0.255
## taxaOTRAS            0.474  0.136  0.599  0.558  0.394  0.618  0.484  0.407
## taxaPalinuridae    0.249  0.087  0.421  0.333  0.295  0.397  0.271  0.287
## taxaPectinidae      0.115  0.039  0.155  0.150  0.100  0.162  0.130  0.112
## taxaPenaeidae       0.352  0.095  0.433  0.453  0.268  0.470  0.417  0.301
## taxaPortunidae     0.276  0.075  0.340  0.352  0.209  0.368  0.334  0.235
## taxaSciaenidae      0.344  0.108  0.500  0.448  0.321  0.504  0.389  0.350
## taxaScombridiae    0.207  0.069  0.301  0.279  0.185  0.342  0.244  0.216
## taxaSerranidae      0.332  0.117  0.539  0.442  0.360  0.535  0.363  0.365
## taxaStichopodidae   0.101  0.033  0.161  0.135  0.158  0.159  0.109  0.133
## age2                 0.005  0.005  0.001  0.001 -0.009  0.004  0.002  0.023
##                                         tx0mms tx0str t0TRAS txPlnr txPctn taxPnd txPrtn txScnd

## yearMonth
## region2
## region3
## region4
## region5
## region6
## taxaCentropomidae
## taxaCichlidae
## taxaClupeidae
## taxaElasmobranchii
## taxaGerreidae
## taxaHaliotidae
## taxaLutjanidae
## taxaMugilidae
## taxaOctopodidae
## taxaOmmastrephidae
## taxaOstreidae      0.080
## taxaOTRAS            0.173  0.348
## taxaPalinuridae    0.099  0.207  0.472
## taxaPectinidae      0.073  0.095  0.215  0.120
## taxaPenaeidae       0.172  0.314  0.579  0.329  0.206
## taxaPortunidae     0.139  0.241  0.454  0.258  0.145  0.533
## taxaSciaenidae      0.143  0.290  0.604  0.402  0.166  0.481  0.378
## taxaScombridiae    0.098  0.176  0.376  0.235  0.110  0.301  0.244  0.316
## taxaSerranidae      0.140  0.272  0.630  0.445  0.174  0.446  0.349  0.524
## taxaStichopodidae   0.041  0.084  0.193  0.141  0.049  0.133  0.104  0.164
## age2                 0.006 -0.005 -0.001  0.011 -0.004  0.016  0.006  0.001
##                                         txScmb txSrrn txStch

## yearMonth
## region2
## region3
## region4
## region5
## region6

```

```

## taxaCentropomidae
## taxaCichlidae
## taxaClupeidae
## taxaElasmobranchii
## taxaGerreidae
## taxaHaliotidae
## taxaLutjanidae
## taxaMugilidae
## taxaOctopodidae
## taxaOmmastrephidae
## taxaOstreidae
## taxaOTRAS
## taxaPalinuridae
## taxaPectinidae
## taxaPenaeidae
## taxaPortunidae
## taxaSciaenidae
## taxaScombridae
## taxaSerranidae      0.320
## taxaStichopodidae   0.094  0.185
## age2                  -0.001  0.004 -0.001
##
## Standardized Within-Group Residuals:
##          Min           Q1           Med           Q3           Max
## -4.774341272 -0.593715659  0.006596586  0.624830693  5.766534686
##
## Number of Observations: 183439
## Number of Groups:
##             fed uniqueid %in% fed
##                 54                182

model_int_mgcv <- bam(logcpue ~ yearMonth + region + taxa + age2
                      + age2:region + age2:taxa +
                      + s(fed, bs = "re") + s(uniqueid, bs = "re"),
                     data = x, na.action = na.omit)
summary(model_int_mgcv)

##
## Family: gaussian
## Link function: identity
##
## Formula:
## logcpue ~ yearMonth + region + taxa + age2 + age2:region + age2:taxa +
##           +s(fed, bs = "re") + s(uniqueid, bs = "re")
##
## Parametric coefficients:
##                               Estimate Std. Error t value Pr(>|t|)    
## ## (Intercept)            0.3157331  0.5528377  0.571 0.567923  
## ## yearMonth              0.0048977  0.0004825 10.150 < 2e-16 ***
## ## region2                 2.1642724  0.8325683  2.600 0.009336 ** 
## ## region3                 3.5637280  0.6358639  5.605 2.09e-08 ***
## ## region4                 3.5804158  0.6011722  5.956 2.59e-09 ***
## ## region5                -2.0326993  0.6879608 -2.955 0.003130 ** 
## ## region6                 1.6704062  0.6098052  2.739 0.006159 ** 

```

```

## taxaCentropomidae      0.0723972  0.0396744   1.825 0.068036 .
## taxaCichlidae         0.9913030  0.0648296  15.291 < 2e-16 ***
## taxaClupeidae        -4.5843851  0.2211791 -20.727 < 2e-16 ***
## taxaElasmobranchii    0.3387579  0.0426923   7.935 2.12e-15 ***
## taxaGerreidae          0.6135394  0.0411245  14.919 < 2e-16 ***
## taxaHaliotidae        2.0587052  0.2025250  10.165 < 2e-16 ***
## taxaLutjanidae         0.5148653  0.0326392  15.774 < 2e-16 ***
## taxaMugilidae          0.4760744  0.0542446   8.776 < 2e-16 ***
## taxaOctopodidae       1.1489263  0.0529767  21.687 < 2e-16 ***
## taxaOmmastrephidae    3.2917876  0.1379129  23.869 < 2e-16 ***
## taxaOstreidae          2.1141828  0.0775402  27.266 < 2e-16 ***
## taxaOTRAS               0.4942390  0.0294424  16.787 < 2e-16 ***
## taxaPalinuridae       -0.0552261  0.0870102 -0.635 0.525619
## taxaPectinidae         3.1591767  0.1215034  26.001 < 2e-16 ***
## taxaPenaeidae          0.2583453  0.0440698   5.862 4.58e-09 ***
## taxaPortunidae         1.6280125  0.0662993  24.555 < 2e-16 ***
## taxaSciaenidae         -0.1630196  0.0391340 -4.166 3.11e-05 ***
## taxaScombridae          0.5995128  0.0547695  10.946 < 2e-16 ***
## taxaSerranidae          0.7993338  0.0350406  22.812 < 2e-16 ***
## taxaStichopodidae     4.9297356  0.1378994  35.749 < 2e-16 ***
## age2                   0.0119289  0.0096274   1.239 0.215327
## region2:age2           -0.0569556  0.0105674 -5.390 7.06e-08 ***
## region3:age2           -0.0658093  0.0092623 -7.105 1.21e-12 ***
## region4:age2           -0.0811163  0.0092999 -8.722 < 2e-16 ***
## region5:age2           0.1257115  0.0099712  12.608 < 2e-16 ***
## region6:age2           -0.0415712  0.0093930 -4.426 9.62e-06 ***
## taxaCentropomidae:age2 -0.0338342  0.0010723 -31.552 < 2e-16 ***
## taxaCichlidae:age2    -0.0410582  0.0024821 -16.542 < 2e-16 ***
## taxaClupeidae:age2    0.1403458  0.0041581  33.753 < 2e-16 ***
## taxaElasmobranchii:age2 -0.0141859  0.0009016 -15.734 < 2e-16 ***
## taxaGerreidae:age2     -0.0414211  0.0010131 -40.885 < 2e-16 ***
## taxaHaliotidae:age2   -0.0213064  0.0032283 -6.600 4.13e-11 ***
## taxaLutjanidae:age2   -0.0326861  0.0009300 -35.145 < 2e-16 ***
## taxaMugilidae:age2    -0.0120442  0.0016809 -7.165 7.80e-13 ***
## taxaOctopodidae:age2  0.0021467  0.0013495   1.591 0.111686
## taxaOmmastrephidae:age2 -0.0320076  0.0067811 -4.720 2.36e-06 ***
## taxaOstreidae:age2    -0.0103979  0.0017304 -6.009 1.87e-09 ***
## taxaOTRAS:age2          -0.0315975  0.0007364 -42.908 < 2e-16 ***
## taxaPalinuridae:age2  0.0053565  0.0016281   3.290 0.001002 **
## taxaPectinidae:age2   0.0042590  0.0055991   0.761 0.446857
## taxaPenaeidae:age2    -0.0047013  0.0012636 -3.721 0.000199 ***
## taxaPortunidae:age2   -0.0237932  0.0021380 -11.129 < 2e-16 ***
## taxaSciaenidae:age2   -0.0034830  0.0009475 -3.676 0.000237 ***
## taxaScombridae:age2   -0.0187527  0.0018750 -10.001 < 2e-16 ***
## taxaSerranidae:age2   -0.0099132  0.0008264 -11.996 < 2e-16 ***
## taxaStichopodidae:age2 -0.0450482  0.0026192 -17.199 < 2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## 
## Approximate significance of smooth terms:
##          edf Ref.df   F p-value
## s(fed)      20.21     51 38482   0.359
## s(uniqueid) 153.25    176 8781 4.38e-05 ***
## ---

```

```

## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.495   Deviance explained = 49.6%
## fREML = 3.4059e+05  Scale est. = 2.3814    n = 183439

model_int <- lme(logcpue ~ yearMonth + region + taxa + age2 + age2:region + age2:taxa,
                     list(fed = ~1, uniqueid = ~1),
                     data = x, na.action = na.omit)
summary(model_int)

## Linear mixed-effects model fit by REML
## Data: x
##      AIC      BIC      logLik
## 681287.6 681854.2 -340587.8
##
## Random effects:
## Formula: ~1 | fed
##           (Intercept)
## StdDev:  0.6865054
##
## Formula: ~1 | uniqueid %in% fed
##           (Intercept) Residual
## StdDev:  1.292262 1.543179
##
## Fixed effects: logcpue ~ yearMonth + region + taxa + age2 + age2:region + age2:taxa
##                  Value Std.Error DF t-value p-value
## (Intercept)      0.315705 0.5528098 183210  0.57109 0.5679
## yearMonth        0.004898 0.0004825 183210 10.15008 0.0000
## region2          2.164223 0.8325384   124  2.59955 0.0105
## region3          3.563748 0.6358299    52  5.60488 0.0000
## region4          3.580448 0.6011414   124  5.95608 0.0000
## region5         -2.032683 0.6879243   124 -2.95481 0.0037
## region6          1.670400 0.6097753   124  2.73937 0.0071
## taxaCentropomidae 0.072397 0.0396744 183210  1.82478 0.0680
## taxaCichlidae    0.991303 0.0648296 183210 15.29090 0.0000
## taxaClupeidae    -4.584385 0.2211791 183210 -20.72703 0.0000
## taxaElasmobranchii 0.338758 0.0426923 183210  7.93486 0.0000
## taxaGerreidae     0.613539 0.0411245 183210 14.91908 0.0000
## taxaHaliotidae    2.058707 0.2025250 183210 10.16520 0.0000
## taxaLutjanidae    0.514865 0.0326392 183210 15.77445 0.0000
## taxaMugilidae     0.476074 0.0542446 183210  8.77644 0.0000
## taxaOctopodidae   1.148927 0.0529767 183210 21.68738 0.0000
## taxaOmmastrephidae 3.291788 0.1379129 183210 23.86860 0.0000
## taxaOstreidae      2.114183 0.0775402 183210 27.26563 0.0000
## taxaOTRAS           0.494239 0.0294424 183210 16.78662 0.0000
## taxaPalinuridae   -0.055226 0.0870102 183210 -0.63471 0.5256
## taxaPectinidae     3.159177 0.1215034 183210 26.00073 0.0000
## taxaPenaeidae      0.258345 0.0440698 183210  5.86219 0.0000
## taxaPortunidae     1.628012 0.0662993 183210 24.55548 0.0000
## taxaSciaenidae     -0.163020 0.0391340 183210 -4.16568 0.0000
## taxaScombridae     0.599513 0.0547695 183210 10.94610 0.0000
## taxaSerranidae     0.799334 0.0350406 183210 22.81164 0.0000
## taxaStichopodidae  4.929736 0.1378993 183210 35.74880 0.0000
## age2                0.011929 0.0096275 183210  1.23909 0.2153

```

```

## region2:age2      -0.056956  0.0105675 183210  -5.38971  0.0000
## region3:age2      -0.065809  0.0092623 183210  -7.10502  0.0000
## region4:age2      -0.081116  0.0093000 183210  -8.72221  0.0000
## region5:age2       0.125712  0.0099712 183210  12.60749  0.0000
## region6:age2      -0.041571  0.0093931 183210  -4.42571  0.0000
## taxaCentropomidae:age2 -0.033834  0.0010723 183210  -31.55235  0.0000
## taxaCichlidae:age2   -0.041058  0.0024821 183210  -16.54181  0.0000
## taxaClupeidae:age2    0.140346  0.0041581 183210  33.75257  0.0000
## taxaElasmobranchii:age2 -0.014186  0.0009016 183210  -15.73445  0.0000
## taxaGerreidae:age2     -0.041421  0.0010131 183210  -40.88486  0.0000
## taxaHaliotidae:age2    -0.021306  0.0032283 183210  -6.59983  0.0000
## taxaLutjanidae:age2     -0.032686  0.0009300 183210  -35.14506  0.0000
## taxaMugilidae:age2      -0.012044  0.0016809 183210  -7.16513  0.0000
## taxaOctopodidae:age2     0.002147  0.0013495 183210  1.59066  0.1117
## taxaOmmastrephidae:age2   -0.032008  0.0067811 183210  -4.72014  0.0000
## taxaOstreidae:age2      -0.010398  0.0017304 183210  -6.00899  0.0000
## taxaOTRAS:age2          -0.031597  0.0007364 183210  -42.90792  0.0000
## taxaPalinuridae:age2     0.005356  0.0016281 183210  3.29004  0.0010
## taxaPectinidae:age2      0.004259  0.0055991 183210  0.76067  0.4469
## taxaPenaeidae:age2       -0.004701  0.0012636 183210  -3.72065  0.0002
## taxaPortunidae:age2      -0.023793  0.0021380 183210  -11.12885  0.0000
## taxaSciaenidae:age2      -0.003483  0.0009475 183210  -3.67588  0.0002
## taxaScombridae:age2      -0.018753  0.0018750 183210  -10.00128  0.0000
## taxaSerranidae:age2      -0.009913  0.0008264 183210  -11.99595  0.0000
## taxaStichopodidae:age2   -0.045048  0.0026192 183210  -17.19929  0.0000

## Correlation:
##                                     (Intr) yrMnth regin2 regin3 regin4 regin5 regin6 txCntr
## yearMonth                         0.166
## region2                          -0.631  0.074
## region3                          -0.842  0.007  0.560
## region4                          -0.890  0.005  0.601  0.775
## region5                          -0.787 -0.045  0.519  0.677  0.721
## region6                          -0.875  0.023  0.599  0.764  0.824  0.713
## taxaCentropomidae                -0.036  0.006  0.002  0.008  0.001  0.003  0.002
## taxaCichlidae                   -0.019  0.014 -0.005  0.003 -0.013 -0.022  0.001  0.317
## taxaClupeidae                  -0.005  0.002  0.000 -0.002  0.000  0.000  0.000  0.068
## taxaElasmobranchii              -0.026  0.006  0.002  0.000  0.000  0.002 -0.002  0.372
## taxaGerreidae                  -0.032  0.003  0.002  0.004  0.000  0.001  0.002  0.473
## taxaHaliotidae                 -0.004  0.006  0.000 -0.010  0.000  0.000  0.000  0.074
## taxaLutjanidae                  -0.034 -0.008 -0.001  0.001 -0.001  0.001  0.000  0.459
## taxaMugilidae                  -0.028  0.006  0.001  0.008  0.000 -0.001  0.006  0.361
## taxaOctopodidae                -0.026 -0.027 -0.002  0.001  0.000 -0.005 -0.002  0.292
## taxaOmmastrephidae              -0.014 -0.005  0.001  0.002 -0.007  0.003  0.003  0.127
## taxaOstreidae                  -0.017 -0.001 -0.006  0.002  0.001 -0.007  0.001  0.242
## taxaOTRAS                        -0.042 -0.001  0.001  0.001 -0.001 -0.002  0.003  0.583
## taxaPalinuridae                -0.012  0.004  0.000 -0.004  0.000  0.000 -0.003  0.172
## taxaPectinidae                  -0.012  0.014  0.004 -0.005  0.002  0.003  0.004  0.144
## taxaPenaeidae                   -0.073 -0.015  0.023  0.036  0.024  0.034  0.032  0.474
## taxaPortunidae                  -0.032  0.002  0.001  0.013 -0.007  0.010  0.008  0.293
## taxaSciaenidae                  -0.031  0.001  0.000  0.002 -0.001  0.002  0.001  0.415
## taxaScombridae                  -0.021  0.002  0.001  0.002  0.000  0.002  0.001  0.268
## taxaSerranidae                  -0.033 -0.009  0.000 -0.003 -0.001  0.002  0.000  0.422
## taxaStichopodidae               -0.008  0.002  0.000 -0.001  0.000 -0.001 -0.001  0.109
## age2                            -0.478 -0.412  0.240  0.351  0.371  0.346  0.359  0.044

```

```

## region2:age2          0.345 -0.148 -0.371 -0.322 -0.341 -0.291 -0.339 -0.005
## region3:age2          0.394 -0.177 -0.294 -0.394 -0.389 -0.332 -0.387 -0.014
## region4:age2          0.392 -0.166 -0.292 -0.366 -0.418 -0.331 -0.386  0.002
## region5:age2          0.366 -0.163 -0.273 -0.343 -0.362 -0.356 -0.360 -0.007
## region6:age2          0.387 -0.176 -0.290 -0.363 -0.383 -0.327 -0.417 -0.005
## taxaCentropomidae:age2 0.029 -0.002 -0.002 -0.007 -0.003 -0.004 -0.003 -0.828
## taxaCichlidae:age2    0.009 -0.018  0.005 -0.002  0.016  0.019  0.000 -0.178
## taxaClupeidae:age2    0.005 -0.005 -0.001  0.002  0.000  0.000  0.000 -0.076
## taxaElasmobranchii:age2 0.026 -0.003 -0.001 -0.003  0.001 -0.002  0.002 -0.365
## taxaGerreidae:age2     0.029 -0.002 -0.002 -0.004 -0.002 -0.002 -0.003 -0.428
## taxaHaliotidae:age2    0.007 -0.002  0.000  0.009  0.000  0.000  0.000 -0.097
## taxaLutjanidae:age2    0.026  0.004  0.001 -0.002  0.001  0.000  0.001 -0.351
## taxaMugilidae:age2     0.023 -0.008 -0.002 -0.010 -0.002 -0.002 -0.008 -0.255
## taxaOctopodidae:age2   0.020  0.014  0.001 -0.001  0.000  0.004  0.003 -0.249
## taxaOmmastrephidae:age2 0.007  0.008  0.000  0.000  0.004 -0.002 -0.001 -0.054
## taxaOstreidae:age2      0.018  0.008  0.002 -0.003 -0.001  0.004 -0.001 -0.257
## taxaOTRAS:age2          0.036  0.002 -0.001 -0.001  0.000  0.000 -0.003 -0.492
## taxaPalinuridae:age2   0.012 -0.009 -0.001  0.004  0.000  0.000  0.003 -0.195
## taxaPectinidae:age2     0.006 -0.008 -0.002  0.000 -0.001 -0.002 -0.002 -0.069
## taxaPenaeidae:age2      0.054  0.014 -0.021 -0.026 -0.018 -0.025 -0.022 -0.379
## taxaPortunidae:age2     0.020 -0.003  0.001 -0.008  0.009 -0.006 -0.004 -0.198
## taxaSciaenidae:age2     0.026 -0.001  0.000 -0.001  0.001 -0.002  0.000 -0.355
## taxaScombridiae:age2    0.014 -0.003 -0.001 -0.003 -0.001 -0.002 -0.001 -0.169
## taxaSerranidae:age2     0.029  0.005 -0.001  0.003  0.001 -0.001  0.000 -0.380
## taxaStichopodidae:age2   0.009  0.001  0.000 -0.002  0.000  0.000  0.002 -0.121
##                                     txCchl txClpd txElsm txGrrd txHltd txLtjn txMgld txOctp
## yearMonth
## region2
## region3
## region4
## region5
## region6
## taxaCentropomidae
## taxaCichlidae          0.043
## taxaClupeidae           0.221  0.063
## taxaElasmobranchii      0.279  0.070  0.363
## taxaGerreidae           0.046  0.016  0.088  0.074
## taxaHaliotidae          0.283  0.082  0.414  0.439  0.083
## taxaLutjanidae          0.289  0.053  0.269  0.341  0.053  0.342
## taxaOctopodidae         0.179  0.047  0.259  0.282  0.061  0.344  0.209
## taxaOmmastrephidae      0.081  0.021  0.109  0.120  0.023  0.132  0.096  0.091
## taxaOstreidae           0.139  0.033  0.178  0.216  0.041  0.242  0.162  0.274
## taxaOTRAS                 0.405  0.099  0.488  0.542  0.106  0.617  0.437  0.390
## taxaPalinuridae         0.106  0.033  0.182  0.170  0.174  0.199  0.124  0.163
## taxaPectinidae          0.090  0.024  0.118  0.137  0.026  0.147  0.105  0.110
## taxaPenaeidae            0.270  0.065  0.341  0.418  0.068  0.418  0.334  0.273
## taxaPortunidae          0.192  0.043  0.225  0.273  0.045  0.280  0.248  0.177
## taxaSciaenidae          0.245  0.072  0.390  0.396  0.082  0.447  0.302  0.308
## taxaScombridiae         0.159  0.049  0.245  0.259  0.041  0.316  0.201  0.192
## taxaSerranidae          0.263  0.084  0.426  0.413  0.098  0.525  0.308  0.327
## taxaStichopodidae       0.067  0.020  0.106  0.108  0.072  0.129  0.079  0.153
## age2                     0.021  0.005  0.029  0.038  0.004  0.044  0.036  0.037
## region2:age2              0.009 -0.001 -0.004 -0.002 -0.001  0.001  0.000  0.005

```

```

## region3:age2          -0.008  0.004 -0.001 -0.006  0.023 -0.003 -0.018  0.003
## region4:age2          0.032  0.000  0.000  0.004 -0.001  0.003  0.003  0.004
## region5:age2          0.032  0.000 -0.002  0.003 -0.001 -0.001 -0.002  0.028
## region6:age2          -0.006 -0.001  0.007 -0.002 -0.001  0.004 -0.012  0.007
## taxaCentropomidae:age2 -0.257 -0.051 -0.282 -0.388 -0.057 -0.369 -0.291 -0.235
## taxaCichlidae:age2    -0.872 -0.023 -0.117 -0.153 -0.025 -0.159 -0.176 -0.101
## taxaClupeidae:age2   -0.048 -0.902 -0.072 -0.077 -0.019 -0.091 -0.058 -0.054
## taxaElasmobranchii:age2 -0.217 -0.064 -0.855 -0.355 -0.080 -0.413 -0.264 -0.259
## taxaGerreidae:age2    -0.243 -0.058 -0.304 -0.818 -0.066 -0.381 -0.291 -0.245
## taxaHaliotidae:age2   -0.060 -0.020 -0.109 -0.096 -0.983 -0.111 -0.070 -0.078
## taxaLutjanidae:age2   -0.216 -0.058 -0.305 -0.329 -0.058 -0.807 -0.255 -0.265
## taxaMugilidae:age2    -0.212 -0.033 -0.176 -0.234 -0.035 -0.236 -0.854 -0.143
## taxaOctopodidae:age2  -0.150 -0.040 -0.211 -0.235 -0.043 -0.298 -0.175 -0.830
## taxaOmmastrephidae:age2 -0.035 -0.009 -0.041 -0.052 -0.010 -0.054 -0.039 -0.042
## taxaOstreidae:age2     -0.142 -0.031 -0.165 -0.218 -0.038 -0.237 -0.167 -0.241
## taxaOTRAS:age2         -0.329 -0.082 -0.407 -0.455 -0.093 -0.521 -0.360 -0.330
## taxaPalinuridae:age2  -0.119 -0.037 -0.198 -0.191 -0.156 -0.227 -0.140 -0.176
## taxaPectinidae:age2   -0.043 -0.007 -0.053 -0.065 -0.008 -0.068 -0.049 -0.057
## taxaPenaeidae:age2    -0.212 -0.045 -0.241 -0.321 -0.048 -0.312 -0.259 -0.205
## taxaPortunidae:age2   -0.137 -0.027 -0.140 -0.179 -0.029 -0.185 -0.179 -0.116
## taxaSciaenidae:age2   -0.212 -0.061 -0.330 -0.339 -0.066 -0.392 -0.262 -0.266
## taxaScombridae:age2   -0.101 -0.027 -0.148 -0.162 -0.017 -0.200 -0.130 -0.121
## taxaSerranidae:age2   -0.234 -0.074 -0.372 -0.369 -0.081 -0.468 -0.275 -0.292
## taxaStichopodidae:age2 -0.073 -0.021 -0.114 -0.117 -0.067 -0.142 -0.086 -0.150
##                                     tx0mms tx0str txOTRAS txPlnr txPctn taxPnd txPrtn

## yearMonth
## region2
## region3
## region4
## region5
## region6
## taxaCentropomidae
## taxaCichlidae
## taxaClupeidae
## taxaElasmobranchii
## taxaGerreidae
## taxaHaliotidae
## taxaLutjanidae
## taxaMugilidae
## taxaOctopodidae
## taxaOmmastrephidae
## taxaOstreidae      0.061
## taxaOTRAS           0.172  0.281
## taxaPalinuridae    0.052  0.109  0.242
## taxaPectinidae     0.075  0.070  0.202  0.059
## taxaPenaeidae      0.168  0.212  0.538  0.157  0.194
## taxaPortunidae     0.109  0.130  0.357  0.104  0.111  0.407
## taxaSciaenidae     0.127  0.201  0.536  0.197  0.140  0.395  0.266
## taxaScombridae     0.082  0.132  0.348  0.106  0.090  0.250  0.183
## taxaSerranidae     0.135  0.213  0.604  0.232  0.154  0.397  0.262
## taxaStichopodidae  0.033  0.067  0.151  0.120  0.038  0.100  0.066
## age2                0.018  0.022  0.051  0.013  0.013  0.103  0.040
## region2:age2        -0.003  0.014 -0.003  -0.001 -0.007 -0.044  0.002
## region3:age2        -0.001 -0.004 -0.001  0.010  0.003 -0.063 -0.022

```

```

## region4:age2          0.006 -0.001  0.003   0.000 -0.006 -0.037  0.011
## region5:age2         -0.003  0.024  0.007   0.000 -0.007 -0.056 -0.016
## region6:age2         -0.004 -0.002 -0.005   0.001 -0.009 -0.051 -0.016
## taxaCentropomidae:age2 -0.099 -0.216 -0.455  -0.131 -0.113 -0.399 -0.233
## taxaCichlidae:age2    -0.047 -0.081 -0.224  -0.058 -0.050 -0.157 -0.116
## taxaClupeidae:age2    -0.023 -0.038 -0.109  -0.040 -0.026 -0.071 -0.047
## taxaElasmobranchii:age2 -0.106 -0.178 -0.482  -0.184 -0.115 -0.332 -0.220
## taxaGerreidae:age2     -0.102 -0.203 -0.462  -0.145 -0.118 -0.374 -0.230
## taxaHaliotidae:age2    -0.030 -0.053 -0.138  -0.181 -0.033 -0.089 -0.058
## taxaLutjanidae:age2    -0.097 -0.187 -0.458  -0.134 -0.108 -0.313 -0.206
## taxaMugilidae:age2     -0.065 -0.111 -0.295  -0.083 -0.071 -0.236 -0.183
## taxaOctopodidae:age2   -0.075 -0.211 -0.323  -0.116 -0.091 -0.229 -0.146
## taxaOmmastrephidae:age2 -0.818 -0.027 -0.074  -0.023 -0.037 -0.073 -0.040
## taxaOstreidae:age2      -0.058 -0.870 -0.269  -0.098 -0.068 -0.225 -0.137
## taxaOTRAS:age2          -0.142 -0.243 -0.814  -0.208 -0.165 -0.451 -0.293
## taxaPalinuridae:age2   -0.058 -0.119 -0.270  -0.943 -0.066 -0.177 -0.116
## taxaPectinidae:age2     -0.041 -0.035 -0.093  -0.026 -0.844 -0.098 -0.052
## taxaPenaeidae:age2      -0.125 -0.167 -0.396  -0.113 -0.149 -0.846 -0.297
## taxaPortunidae:age2     -0.073 -0.085 -0.231  -0.067 -0.073 -0.272 -0.891
## taxaSciaenidae:age2     -0.107 -0.173 -0.460  -0.163 -0.120 -0.336 -0.230
## taxaScombridae:age2     -0.050 -0.082 -0.214  -0.057 -0.056 -0.153 -0.119
## taxaSerranidae:age2     -0.118 -0.193 -0.534  -0.196 -0.136 -0.353 -0.231
## taxaStichopodidae:age2  -0.035 -0.071 -0.166  -0.112 -0.040 -0.109 -0.072
##                                     txScnd txScmb txSrrn txStch age2   rgn2:2 rgn3:2 rgn4:2
## yearMonth
## region2
## region3
## region4
## region5
## region6
## taxaCentropomidae
## taxaCichlidae
## taxaClupeidae
## taxaElasmobranchii
## taxaGerreidae
## taxaHaliotidae
## taxaLutjanidae
## taxaMugilidae
## taxaOctopodidae
## taxaOmmastrephidae
## taxaOstreidae
## taxaOTRAS
## taxaPalinuridae
## taxaPectinidae
## taxaPenaeidae
## taxaPortunidae
## taxaSciaenidae
## taxaScombridae          0.273
## taxaSerranidae          0.461  0.292
## taxaStichopodidae       0.136  0.073  0.157
## age2                     0.035  0.026  0.041  0.009
## region2:age2            0.003 -0.003 -0.001  0.000 -0.690
## region3:age2            0.000 -0.005  0.007  0.001 -0.786  0.806
## region4:age2            0.003 -0.002  0.001  0.000 -0.783  0.801  0.915

```

```

## region5:age2          0.001 -0.004  0.001  0.002 -0.730  0.750  0.857  0.851
## region6:age2         -0.001 -0.002  0.002 -0.009 -0.773  0.795  0.909  0.902
## taxaCentropomidae:age2 -0.308 -0.214 -0.329 -0.084 -0.057  0.005  0.019  0.005
## taxaCichlidae:age2    -0.126 -0.090 -0.144 -0.036 -0.015 -0.009  0.009 -0.039
## taxaClupeidae:age2    -0.080 -0.054 -0.092 -0.022 -0.008  0.001 -0.003  0.001
## taxaElasmobranchii:age2 -0.381 -0.245 -0.417 -0.104 -0.045  0.002  0.007 -0.001
## taxaGerreidae:age2     -0.328 -0.224 -0.353 -0.091 -0.053  0.005  0.010  0.001
## taxaHaliotidae:age2    -0.106 -0.057 -0.125 -0.079 -0.012  0.001 -0.020  0.000
## taxaLutjanidae:age2    -0.326 -0.240 -0.388 -0.092 -0.049 -0.001  0.006 -0.004
## taxaMugilidae:age2     -0.196 -0.144 -0.208 -0.052 -0.044  0.001  0.028  0.004
## taxaOctopodidae:age2   -0.251 -0.166 -0.267 -0.119 -0.038 -0.002  0.000 -0.002
## taxaOmmastrephidae:age2 -0.051 -0.033 -0.057 -0.014 -0.012  0.001  0.000 -0.005
## taxaOstreidae:age2      -0.183 -0.129 -0.202 -0.061 -0.036 -0.007  0.007  0.000
## taxaOTRAS:age2          -0.445 -0.296 -0.504 -0.127 -0.065  0.002  0.002 -0.002
## taxaPalinuridae:age2   -0.216 -0.124 -0.251 -0.119 -0.021  0.002 -0.009  0.001
## taxaPectinidae:age2     -0.063 -0.042 -0.068 -0.018 -0.009  0.005  0.002  0.003
## taxaPenaeidae:age2      -0.276 -0.188 -0.291 -0.072 -0.105  0.052  0.062  0.034
## taxaPortunidae:age2     -0.168 -0.129 -0.169 -0.043 -0.035 -0.007  0.017 -0.018
## taxaSciaenidae:age2     -0.844 -0.243 -0.395 -0.114 -0.046 -0.003  0.001 -0.003
## taxaScombridae:age2     -0.169 -0.834 -0.182 -0.044 -0.026  0.004  0.008  0.003
## taxaSerranidae:age2     -0.407 -0.265 -0.824 -0.134 -0.052  0.001 -0.007 -0.001
## taxaStichopodidae:age2  -0.143 -0.081 -0.165 -0.883 -0.016  0.000  0.006  0.000
##                                     rgn5:2 rgn6:2 txCn:2 txCc:2 txCl:2 txEl:2 txGr:2 txHl:2

## yearMonth
## region2
## region3
## region4
## region5
## region6
## taxaCentropomidae
## taxaCichlidae
## taxaClupeidae
## taxaElasmobranchii
## taxaGerreidae
## taxaHaliotidae
## taxaLutjanidae
## taxaMugilidae
## taxaOctopodidae
## taxaOmmastrephidae
## taxaOstreidae
## taxaOTRAS
## taxaPalinuridae
## taxaPectinidae
## taxaPenaeidae
## taxaPortunidae
## taxaSciaenidae
## taxaScombridae
## taxaSerranidae
## taxaStichopodidae
## age2
## region2:age2
## region3:age2
## region4:age2
## region5:age2

```

```

## region6:age2          0.844
## taxaCentropomidae:age2 0.013  0.010
## taxaCichlidae:age2    -0.029  0.005  0.222
## taxaClupeidae:age2    0.001  0.001  0.088  0.039
## taxaElasmobranchii:age2 0.003 -0.005  0.418  0.177  0.110
## taxaGerreidae:age2     0.004  0.007  0.524  0.206  0.097  0.449
## taxaHaliotidae:age2    0.001  0.001  0.114  0.050  0.034  0.149  0.126
## taxaLutjanidae:age2   -0.002 -0.005  0.436  0.187  0.100  0.465  0.439  0.122
## taxaMugilidae:age2     0.012  0.021  0.310  0.180  0.056  0.264  0.299  0.071
## taxaOctopodidae:age2   -0.018 -0.008  0.302  0.127  0.069  0.322  0.308  0.087
## taxaOmmastrephidae:age2 0.001  0.001  0.063  0.029  0.015  0.064  0.065  0.019
## taxaOstreidae:age2     -0.015  0.005  0.338  0.128  0.054  0.253  0.306  0.073
## taxaOTRAS:age2          -0.002  0.005  0.580  0.267  0.136  0.612  0.589  0.178
## taxaPalinuridae:age2   0.001 -0.001  0.227  0.099  0.064  0.296  0.246  0.192
## taxaPectinidae:age2     0.005  0.005  0.080  0.035  0.014  0.079  0.082  0.019
## taxaPenaeidae:age2      0.056  0.051  0.472  0.188  0.076  0.356  0.430  0.096
## taxaPortunidae:age2     0.013  0.013  0.237  0.123  0.044  0.209  0.227  0.056
## taxaSciaenidae:age2     0.002 -0.001  0.409  0.173  0.103  0.487  0.430  0.131
## taxaScombridae:age2     0.005  0.002  0.206  0.088  0.047  0.227  0.212  0.048
## taxaSerranidae:age2     0.000 -0.002  0.450  0.194  0.121  0.553  0.479  0.157
## taxaStichopodidae:age2  -0.002  0.004  0.140  0.060  0.035  0.169  0.149  0.095
##                                     txLt:2 txMg:2 txOc:2 txOm:2 txOs:2 tOTRAS: txPl:2
## yearMonth
## region2
## region3
## region4
## region5
## region6
## taxaCentropomidae
## taxaCichlidae
## taxaClupeidae
## taxaElasmobranchii
## taxaGerreidae
## taxaHaliotidae
## taxaLutjanidae
## taxaMugilidae
## taxaOctopodidae
## taxaOmmastrephidae
## taxaOstreidae
## taxaOTRAS
## taxaPalinuridae
## taxaPectinidae
## taxaPenaeidae
## taxaPortunidae
## taxaSciaenidae
## taxaScombridae
## taxaSerranidae
## taxaStichopodidae
## age2
## region2:age2
## region3:age2
## region4:age2
## region5:age2
## region6:age2

```

```

## taxaCentropomidae:age2
## taxaCichlidae:age2
## taxaClupeidae:age2
## taxaElasmobranchii:age2
## taxaGerreidae:age2
## taxaHaliotidae:age2
## taxaLutjanidae:age2
## taxaMugilidae:age2      0.269
## taxaOctopodidae:age2    0.355  0.181
## taxaOmmastrephidae:age2 0.062  0.040  0.049
## taxaOstreidae:age2      0.281  0.186  0.254  0.038
## taxaOTRAS:age2           0.590  0.364  0.411  0.090  0.352
## taxaPalinuridae:age2    0.248  0.143  0.193  0.038  0.156  0.346
## taxaPectinidae:age2      0.077  0.051  0.066  0.027  0.049  0.111  0.044
## taxaPenaeidae:age2       0.362  0.280  0.255  0.075  0.277  0.497  0.194
## taxaPortunidae:age2      0.210  0.193  0.143  0.038  0.147  0.283  0.113
## taxaSciaenidae:age2       0.445  0.265  0.327  0.066  0.249  0.583  0.271
## taxaScombridae:age2       0.234  0.145  0.161  0.032  0.125  0.279  0.114
## taxaSerranidae:age2       0.526  0.282  0.365  0.075  0.278  0.674  0.318
## taxaStichopodidae:age2   0.157  0.087  0.155  0.022  0.094  0.210  0.144
##                                     txPc:2 txPn:2 txPr:2 txScn:2 txScm:2 txSr:2
## yearMonth
## region2
## region3
## region4
## region5
## region6
## taxaCentropomidae
## taxaCichlidae
## taxaClupeidae
## taxaElasmobranchii
## taxaGerreidae
## taxaHaliotidae
## taxaLutjanidae
## taxaMugilidae
## taxaOctopodidae
## taxaOmmastrephidae
## taxaOstreidae
## taxaOTRAS
## taxaPalinuridae
## taxaPectinidae
## taxaPenaeidae
## taxaPortunidae
## taxaSciaenidae
## taxaScombridae
## taxaSerranidae
## taxaStichopodidae
## age2
## region2:age2
## region3:age2
## region4:age2
## region5:age2
## region6:age2
## taxaCentropomidae:age2

```

```

## taxaCichlidae:age2
## taxaClupeidae:age2
## taxaElasmobranchii:age2
## taxaGerreidae:age2
## taxaHaliotidae:age2
## taxaLutjanidae:age2
## taxaMugilidae:age2
## taxaOctopodidae:age2
## taxaOmmastrephidae:age2
## taxaOstreidae:age2
## taxaOTRAS:age2
## taxaPalinuridae:age2
## taxaPectinidae:age2
## taxaPenaeidae:age2      0.104
## taxaPortunidae:age2    0.048  0.286
## taxaSciaenidae:age2    0.081  0.361  0.222
## taxaScombridae:age2    0.041  0.179  0.127  0.231
## taxaSerranidae:age2    0.091  0.389  0.225  0.527  0.251
## taxaStichopodidae:age2 0.027  0.119  0.069  0.175  0.075  0.206
##
## Standardized Within-Group Residuals:
##          Min        Q1        Med        Q3        Max
## -5.0142858 -0.5853366  0.0114431  0.6198300  5.7579072
##
## Number of Observations: 183439
## Number of Groups:
##           fed uniqueid %in% fed
##             54            182

```

Moreover, we have also tried adding different interactions in the model, such as interactions effects between yearMonth and region and between yearMonth and taxa as shown below. However, the model selection criterion by AIC and BIC is higher than that for the previous model. Therefore, model with interactions between age2 and region and between age2 and taxa is our final model.

```

model_int2_mgcv <- bam(logcpue ~ yearMonth + region + taxa + age2
                         + yearMonth:region + yearMonth:taxa +
                         + s(fed, bs = "re") + s(uniqueid, bs = "re"),
                         data = x, na.action = na.omit)
summary(model_int2_mgcv)

##
## Family: gaussian
## Link function: identity
##
## Formula:
## logcpue ~ yearMonth + region + taxa + age2 + yearMonth:region +
##           yearMonth:taxa + +s(fed, bs = "re") + s(uniqueid, bs = "re")
##
## Parametric coefficients:
##                               Estimate Std. Error t value Pr(>|t|)
## (Intercept)                1.6078367  0.3857760   4.168 3.08e-05 ***
## yearMonth                  0.0080893  0.0011420   7.084 1.41e-12 ***
## region2                   0.6795565  0.5934569   1.145   0.2522

```

```

## region3          2.3456656  0.4418008   5.309 1.10e-07 ***
## region4          2.1257147  0.4133661   5.142 2.71e-07 ***
## region5         -0.9844932  0.4861700  -2.025  0.0429 *
## region6          0.6994770  0.4204084   1.664  0.0962 .
## taxaCentropomidae -0.8794081  0.0461313 -19.063 < 2e-16 ***
## taxaCichlidae    -0.4636168  0.0541748  -8.558 < 2e-16 ***
## taxaClupeidae     2.2876355  0.2057617  11.118 < 2e-16 ***
## taxaElasmobranchii -0.1016716  0.0418903  -2.427  0.0152 *
## taxaGerreidae     -0.5175214  0.0497962 -10.393 < 2e-16 ***
## taxaHaliotidae    0.6199439  0.0574706  10.787 < 2e-16 ***
## taxaLutjanidae    -0.5036094  0.0430314 -11.703 < 2e-16 ***
## taxaMugilidae      0.2799174  0.0589198   4.751 2.03e-06 ***
## taxaOctopodidae    1.6022557  0.0614376  26.079 < 2e-16 ***
## taxaOmmastrephidae 3.3630489  0.1558128  21.584 < 2e-16 ***
## taxaOstreidae       3.2362051  0.0772108  41.914 < 2e-16 ***
## taxaOTRAS           -0.7796508  0.0362255 -21.522 < 2e-16 ***
## taxaPalinuridae    0.5563768  0.0536722  10.366 < 2e-16 ***
## taxaPectinidae      3.3174571  0.1135869  29.206 < 2e-16 ***
## taxaPenaeidae        0.0293779  0.0451977   0.650  0.5157
## taxaPortunidae      0.9933743  0.0572811  17.342 < 2e-16 ***
## taxaSciaenidae      -0.3506816  0.0440321  -7.964 1.67e-15 ***
## taxaScombridiae     -0.0210694  0.0683614  -0.308  0.7579
## taxaSerranidae       0.8908037  0.0415239  21.453 < 2e-16 ***
## taxaStichopodidae    1.1477326  0.1191047   9.636 < 2e-16 ***
## age2                 -0.0370541  0.0047064  -7.873 3.48e-15 ***
## yearMonth:region2    -0.0044602  0.0010560  -4.224 2.40e-05 ***
## yearMonth:region3    -0.0079208  0.0009938  -7.970 1.59e-15 ***
## yearMonth:region4    -0.0086871  0.0009614  -9.036 < 2e-16 ***
## yearMonth:region5    0.0096404  0.0010378   9.289 < 2e-16 ***
## yearMonth:region6    -0.0044745  0.0009909  -4.515 6.32e-06 ***
## yearMonth:taxaCentropomidae -0.0011798  0.0006733  -1.752  0.0797 .
## yearMonth:taxaCichlidae   0.0043952  0.0007007   6.273 3.55e-10 ***
## yearMonth:taxaClupeidae   0.0040834  0.0032895   1.241  0.2145
## yearMonth:taxaElasmobranchii 0.0010424  0.0006646   1.568  0.1168
## yearMonth:taxaGerreidae   -0.0035177  0.0007367  -4.775 1.80e-06 ***
## yearMonth:taxaHaliotidae   0.0151115  0.0010125  14.925 < 2e-16 ***
## yearMonth:taxaLutjanidae   0.0013302  0.0006195   2.147  0.0318 *
## yearMonth:taxaMugilidae   -0.0042231  0.0008622  -4.898 9.69e-07 ***
## yearMonth:taxaOctopodidae  -0.0047559  0.0008995  -5.287 1.24e-07 ***
## yearMonth:taxaOmmastrephidae -0.0209073  0.0032112  -6.511 7.50e-11 ***
## yearMonth:taxaOstreidae   -0.0219299  0.0011792 -18.597 < 2e-16 ***
## yearMonth:taxaOTRAS        0.0039946  0.0005366   7.444 9.77e-14 ***
## yearMonth:taxaPalinuridae  0.0018066  0.0008133   2.221  0.0263 *
## yearMonth:taxaPectinidae   -0.0115393  0.0029278  -3.941 8.11e-05 ***
## yearMonth:taxaPenaeidae    0.0015054  0.0006585   2.286  0.0222 *
## yearMonth:taxaPortunidae   -0.0008491  0.0008058  -1.054  0.2920
## yearMonth:taxaSciaenidae   0.0034141  0.0006651   5.134 2.85e-07 ***
## yearMonth:taxaScombridiae  0.0010558  0.0009964   1.060  0.2894
## yearMonth:taxaSerranidae   -0.0056493  0.0006235  -9.061 < 2e-16 ***
## yearMonth:taxaStichopodidae 0.0402446  0.0020135  19.987 < 2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:

```

```

##          edf Ref.df      F p-value
## s(fed)     17.39      51 15087   0.161
## s(uniqueid) 155.62     176  5793 <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.481  Deviance explained = 48.2%
## fREML = 3.4308e+05  Scale est. = 2.4475    n = 183439

model_int2<- lme(logcpue ~ yearMonth + region + taxa + age2 + yearMonth:region + yearMonth:taxa,
                     list(fed = ~1, uniqueid = ~1),
                     data = x, na.action = na.omit)
summary(model_int2)

## Linear mixed-effects model fit by REML
## Data: x
##      AIC      BIC      logLik
## 686275.7 686842.4 -343081.8
##
## Random effects:
## Formula: ~1 | fed
##             (Intercept)
## StdDev: 0.4828998
##
## Formula: ~1 | uniqueid %in% fed
##             (Intercept) Residual
## StdDev: 1.039463 1.564464
##
## Fixed effects: logcpue ~ yearMonth + region + taxa + age2 + yearMonth:region + yearMonth:taxa
##                  Value Std.Error DF t-value p-value
## (Intercept) 1.607717 0.3854994 183210 4.17048 0.0000
## yearMonth 0.008089 0.0011419 183210 7.08377 0.0000
## region2 0.679122 0.5931345 124 1.14497 0.2544
## region3 2.345758 0.4414707 52 5.31351 0.0000
## region4 2.125852 0.4130595 124 5.14660 0.0000
## region5 -0.984213 0.4858159 124 -2.02590 0.0449
## region6 0.699446 0.4201089 124 1.66492 0.0985
## taxaCentropomidae -0.879407 0.0461313 183210 -19.06313 0.0000
## taxaCichlidae -0.463617 0.0541748 183210 -8.55781 0.0000
## taxaClupeidae 2.287635 0.2057617 183210 11.11788 0.0000
## taxaElasmobranchii -0.101671 0.0418903 183210 -2.42709 0.0152
## taxaGerreidae -0.517521 0.0497962 183210 -10.39278 0.0000
## taxaHaliotidae 0.619944 0.0574706 183210 10.78715 0.0000
## taxaLutjanidae -0.503609 0.0430314 183210 -11.70330 0.0000
## taxaMugilidae 0.279918 0.0589198 183210 4.75083 0.0000
## taxaOctopodidae 1.602256 0.0614376 183210 26.07941 0.0000
## taxaOmmastrephidae 3.363053 0.1558126 183210 21.58396 0.0000
## taxaOstreidae 3.236206 0.0772108 183210 41.91390 0.0000
## taxaOTRAS -0.779650 0.0362255 183210 -21.52217 0.0000
## taxaPalinuridae 0.556376 0.0536722 183210 10.36619 0.0000
## taxaPectinidae 3.317460 0.1135869 183210 29.20635 0.0000
## taxaPenaeidae 0.029380 0.0451977 183210 0.65003 0.5157
## taxaPortunidae 0.993375 0.0572811 183210 17.34211 0.0000
## taxaSciaenidae -0.350681 0.0440321 183210 -7.96422 0.0000

```

```

## taxaScombridae      -0.021069  0.0683614 183210  -0.30820  0.7579
## taxaSerranidae     0.890804  0.0415239 183210  21.45277  0.0000
## taxaStichopodidae  1.147733  0.1191048 183210  9.63633  0.0000
## age2                -0.037053  0.0047056 183210  -7.87435  0.0000
## yearMonth:region2   -0.004460  0.0010560 183210  -4.22378  0.0000
## yearMonth:region3   -0.007921  0.0009938 183210  -7.97012  0.0000
## yearMonth:region4   -0.008687  0.0009614 183210  -9.03594  0.0000
## yearMonth:region5   0.009640  0.0010378 183210  9.28911  0.0000
## yearMonth:region6   -0.004474  0.0009909 183210  -4.51544  0.0000
## yearMonth:taxaCentropomidae -0.001180  0.0006733 183210  -1.75225  0.0797
## yearMonth:taxaCichlidae  0.004395  0.0007007 183210  6.27297  0.0000
## yearMonth:taxaClupeidae 0.004083  0.0032895 183210  1.24134  0.2145
## yearMonth:taxaElasmobranchii 0.001042  0.0006646 183210  1.56832  0.1168
## yearMonth:taxaGerreidae   -0.003518  0.0007367 183210  -4.77466  0.0000
## yearMonth:taxaHaliotidae  0.015111  0.0010125 183210  14.92457  0.0000
## yearMonth:taxaLutjanidae  0.001330  0.0006195 183210  2.14730  0.0318
## yearMonth:taxaMugilidae  -0.004223  0.0008622 183210  -4.89800  0.0000
## yearMonth:taxaOctopodidae -0.004756  0.0008995 183210  -5.28730  0.0000
## yearMonth:taxaOmmastrephidae -0.020907  0.0032112 183210  -6.51076  0.0000
## yearMonth:taxaOstreidae   -0.021930  0.0011792 183210  -18.59672  0.0000
## yearMonth:taxaOTRAS       0.003995  0.0005366 183210  7.44447  0.0000
## yearMonth:taxaPalinuridae 0.001807  0.0008133 183210  2.22114  0.0263
## yearMonth:taxaPectinidae  -0.011539  0.0029278 183210  -3.94120  0.0001
## yearMonth:taxaPenaeidae   0.001505  0.0006585 183210  2.28619  0.0222
## yearMonth:taxaPortunidae -0.000849  0.0008058 183210  -1.05375  0.2920
## yearMonth:taxaSciaenidae  0.003414  0.0006651 183210  5.13362  0.0000
## yearMonth:taxaScombridae  0.001056  0.0009964 183210  1.05954  0.2894
## yearMonth:taxaSerranidae  -0.005649  0.0006235 183210  -9.06076  0.0000
## yearMonth:taxaStichopodidae 0.040245  0.0020135 183210  19.98735  0.0000

## Correlation:
##                                     (Intr) yrMnth regin2 regin3 regin4 regin5 regin6
## yearMonth                         -0.019
## region2                          -0.577  0.066
## region3                          -0.810  0.056  0.508
## region4                          -0.864  0.052  0.551  0.738
## region5                          -0.755  0.030  0.464  0.634  0.681
## region6                          -0.846  0.065  0.548  0.726  0.790  0.672
## taxaCentropomidae                 -0.064  0.288 -0.001  0.011 -0.003  0.006  0.006
## taxaCichlidae                    -0.055  0.243 -0.001  0.009 -0.007 -0.012  0.009
## taxaClupeidae                   -0.012  0.053  0.000 -0.002  0.000  0.001  0.001
## taxaElasmobranchii               -0.059  0.267  0.001 -0.004 -0.002  0.004  0.003
## taxaGerreidae                   -0.057  0.263  0.002  0.008 -0.001  0.005  0.006
## taxaHaliotidae                  -0.039  0.193  0.001 -0.008 -0.001  0.001  0.002
## taxaLutjanidae                  -0.060  0.269  0.000  0.003 -0.002  0.000  0.001
## taxaMugilidae                  -0.053  0.237 -0.001  0.010  0.001  0.001  0.010
## taxaOctopodidae                 -0.041  0.178  0.000  0.002  0.000 -0.005 -0.002
## taxaOmmastrephidae              -0.017  0.093  0.002  0.002 -0.001  0.002  0.004
## taxaOstreidae                  -0.038  0.171 -0.008  0.007  0.000 -0.003  0.007
## taxaOTRAS                        -0.071  0.329  0.000  0.000 -0.002  0.001  0.005
## taxaPalinuridae                 -0.046  0.201  0.001 -0.002  0.000  0.003 -0.002
## taxaPectinidae                  -0.021  0.106  0.002 -0.006  0.000  0.002  0.003
## taxaPenaeidae                   -0.110  0.453  0.025  0.046  0.028  0.042  0.047
## taxaPortunidae                  -0.060  0.246  0.003  0.014 -0.005  0.012  0.013
## taxaSciaenidae                  -0.060  0.271 -0.001  0.003 -0.002  0.006  0.002

```

## taxaScombridae	-0.038	0.177	0.001	0.003	-0.001	0.002	0.001	
## taxaSerranidae	-0.059	0.266	0.001	-0.004	-0.001	0.004	0.000	
## taxaStichopodidae	-0.017	0.097	0.001	-0.004	-0.001	0.000	-0.001	
## age2	-0.305	-0.347	-0.024	0.079	0.084	0.134	0.066	
## yearMonth:region2	0.094	-0.734	-0.080	-0.082	-0.085	-0.076	-0.086	
## yearMonth:region3	0.110	-0.829	-0.066	-0.103	-0.093	-0.085	-0.099	
## yearMonth:region4	0.103	-0.802	-0.066	-0.091	-0.104	-0.083	-0.095	
## yearMonth:region5	0.104	-0.794	-0.065	-0.089	-0.090	-0.102	-0.093	
## yearMonth:region6	0.104	-0.833	-0.067	-0.092	-0.092	-0.082	-0.106	
## yearMonth:taxaCentropomidae	0.056	-0.328	0.001	-0.009	0.004	-0.006	-0.005	
## yearMonth:taxaCichlidae	0.053	-0.314	-0.001	-0.009	0.008	0.004	-0.009	
## yearMonth:taxaClupeidae	0.009	-0.056	0.000	0.002	0.000	0.000	0.000	
## yearMonth:taxaElasmobranchii	0.049	-0.285	-0.001	0.004	0.002	-0.004	-0.002	
## yearMonth:taxaGerreidae	0.049	-0.299	-0.001	-0.006	0.002	-0.004	-0.005	
## yearMonth:taxaHaliotidae	0.030	-0.183	-0.001	0.007	0.001	-0.002	-0.002	
## yearMonth:taxaLutjanidae	0.054	-0.313	0.000	-0.003	0.002	0.001	-0.001	
## yearMonth:taxaMugilidae	0.046	-0.276	0.001	-0.009	0.000	-0.001	-0.009	
## yearMonth:taxaOctopodidae	0.033	-0.209	0.000	-0.001	0.001	0.005	0.003	
## yearMonth:taxaOmmastrephidae	0.008	-0.079	-0.002	-0.001	-0.004	0.000	-0.002	
## yearMonth:taxaOstreidae	0.032	-0.182	0.007	-0.005	0.001	0.002	-0.006	
## yearMonth:taxaOTRAS	0.062	-0.373	0.000	0.000	0.003	-0.001	-0.004	
## yearMonth:taxaPalinuridae	0.039	-0.228	-0.001	0.003	0.000	-0.003	0.003	
## yearMonth:taxaPectinidae	0.008	-0.067	-0.001	0.001	0.001	0.001	0.000	
## yearMonth:taxaPenaeidae	0.089	-0.519	-0.020	-0.036	-0.023	-0.032	-0.038	
## yearMonth:taxaPortunidae	0.050	-0.286	-0.001	-0.010	0.005	-0.008	-0.009	
## yearMonth:taxaSciaenidae	0.051	-0.303	0.001	-0.002	0.002	-0.005	-0.001	
## yearMonth:taxaScombridae	0.035	-0.203	-0.001	-0.003	0.001	-0.001	-0.001	
## yearMonth:taxaSerranidae	0.050	-0.301	-0.001	0.004	0.001	-0.003	0.001	
## yearMonth:taxaStichopodidae	0.013	-0.097	-0.001	0.003	0.001	0.000	0.000	
##		txCntr	txCchl	txClpd	txElsm	txGrrd	txHltd	txLtjn
## yearMonth								
## region2								
## region3								
## region4								
## region5								
## region6								
## taxaCentropomidae		0.465						
## taxaCichlidae		0.097	0.084					
## taxaClupeidae		0.491	0.419	0.122				
## taxaElasmobranchii		0.478	0.410	0.094	0.461			
## taxaGerreidae		0.345	0.298	0.094	0.444	0.329		
## taxaHaliotidae		0.507	0.435	0.107	0.527	0.462	0.379	
## taxaLutjanidae		0.410	0.387	0.079	0.386	0.367	0.276	0.396
## taxaMugilidae		0.350	0.301	0.072	0.359	0.319	0.257	0.370
## taxaOctopodidae		0.155	0.138	0.031	0.152	0.140	0.110	0.150
## taxaOmmastrephidae		0.322	0.284	0.058	0.286	0.280	0.204	0.303
## taxaOstreidae		0.607	0.539	0.136	0.654	0.556	0.485	0.625
## taxaPalinuridae		0.383	0.319	0.091	0.452	0.358	0.335	0.415
## taxaPectinidae		0.183	0.158	0.048	0.215	0.173	0.166	0.195
## taxaPenaeidae		0.558	0.481	0.104	0.515	0.492	0.366	0.518
## taxaPortunidae		0.445	0.393	0.081	0.409	0.389	0.286	0.413
## taxaSciaenidae		0.505	0.421	0.109	0.536	0.458	0.386	0.513
## taxaScombridae		0.322	0.274	0.068	0.331	0.293	0.236	0.332

## taxaSerranidae	0.496	0.418	0.120	0.583	0.465	0.433	0.537
## taxaStichopodidae	0.170	0.145	0.043	0.210	0.160	0.229	0.184
## age2	-0.004	-0.003	0.000	-0.003	-0.005	-0.012	-0.002
## yearMonth:region2	0.009	-0.002	-0.001	-0.006	-0.011	-0.005	0.001
## yearMonth:region3	-0.067	-0.056	0.013	0.028	-0.050	0.047	-0.018
## yearMonth:region4	0.016	0.037	0.000	0.007	0.003	0.001	0.009
## yearMonth:region5	-0.046	0.012	-0.006	-0.033	-0.041	-0.021	0.000
## yearMonth:region6	-0.036	-0.051	-0.004	-0.015	-0.034	-0.015	-0.007
## yearMonth:taxaCentropomidae	-0.873	-0.398	-0.086	-0.442	-0.419	-0.310	-0.457
## yearMonth:taxaCichlidae	-0.461	-0.813	-0.084	-0.425	-0.407	-0.300	-0.444
## yearMonth:taxaClupeidae	-0.080	-0.068	-0.883	-0.100	-0.076	-0.079	-0.088
## yearMonth:taxaElasmobranchii	-0.409	-0.345	-0.102	-0.858	-0.383	-0.368	-0.439
## yearMonth:taxaGerreidae	-0.412	-0.353	-0.082	-0.409	-0.878	-0.293	-0.411
## yearMonth:taxaHaliotidae	-0.258	-0.219	-0.071	-0.325	-0.245	-0.812	-0.285
## yearMonth:taxaLutjanidae	-0.465	-0.400	-0.097	-0.483	-0.423	-0.349	-0.892
## yearMonth:taxaMugilidae	-0.359	-0.330	-0.069	-0.345	-0.321	-0.246	-0.354
## yearMonth:taxaOctopodidae	-0.315	-0.271	-0.064	-0.322	-0.287	-0.232	-0.332
## yearMonth:taxaOmmastrephidae	-0.102	-0.091	-0.019	-0.096	-0.090	-0.070	-0.094
## yearMonth:taxaOstreidae	-0.268	-0.241	-0.049	-0.245	-0.235	-0.175	-0.260
## yearMonth:taxaOTRAS	-0.531	-0.458	-0.119	-0.579	-0.489	-0.429	-0.555
## yearMonth:taxaPalinuridae	-0.336	-0.276	-0.080	-0.385	-0.313	-0.290	-0.359
## yearMonth:taxaPectinidae	-0.089	-0.076	-0.025	-0.113	-0.086	-0.089	-0.099
## yearMonth:taxaPenaeidae	-0.496	-0.430	-0.092	-0.465	-0.440	-0.331	-0.468
## yearMonth:taxaPortunidae	-0.412	-0.365	-0.075	-0.382	-0.362	-0.269	-0.386
## yearMonth:taxaSciaenidae	-0.440	-0.363	-0.094	-0.464	-0.399	-0.335	-0.448
## yearMonth:taxaScombridae	-0.295	-0.252	-0.061	-0.301	-0.268	-0.216	-0.301
## yearMonth:taxaSerranidae	-0.438	-0.366	-0.107	-0.509	-0.409	-0.377	-0.469
## yearMonth:taxaStichopodidae	-0.136	-0.113	-0.034	-0.161	-0.126	-0.167	-0.143
##	txMgld	txOctp	txOmmms	tx0str	t0TRAS	txPlnr	txPctn
## yearMonth							
## region2							
## region3							
## region4							
## region5							
## region6							
## taxaCentropomidae							
## taxaCichlidae							
## taxaClupeidae							
## taxaElasmobranchii							
## taxaGerreidae							
## taxaHaliotidae							
## taxaLutjanidae							
## taxaMugilidae							
## taxaOctopodidae	0.273						
## taxaOmmastrephidae	0.122	0.100					
## taxaOstreidae	0.267	0.228	0.091				
## taxaOTRAS	0.484	0.431	0.188	0.366			
## taxaPalinuridae	0.295	0.287	0.115	0.220	0.503		
## taxaPectinidae	0.147	0.132	0.073	0.110	0.252	0.162	
## taxaPenaeidae	0.439	0.348	0.186	0.344	0.633	0.393	0.214
## taxaPortunidae	0.351	0.275	0.150	0.270	0.502	0.309	0.160
## taxaSciaenidae	0.393	0.354	0.150	0.301	0.620	0.417	0.199
## taxaScombridae	0.252	0.231	0.096	0.189	0.392	0.258	0.126
## taxaSerranidae	0.385	0.368	0.152	0.287	0.653	0.453	0.217

```

## taxaStichopodidae      0.134  0.126  0.053  0.099  0.235  0.163  0.079
## age2                   -0.002  0.001 -0.014 -0.005 -0.010  0.002 -0.014
## yearMonth:region2      0.004 -0.001 -0.008  0.070  0.000 -0.005 -0.005
## yearMonth:region3      -0.064 -0.012 -0.017 -0.040 -0.009  0.016  0.016
## yearMonth:region4      -0.012  0.002  0.008  0.000  0.009  0.001 -0.003
## yearMonth:region5      -0.020  0.029 -0.020  0.014 -0.019 -0.021 -0.015
## yearMonth:region6      -0.061  0.011 -0.022 -0.037 -0.030  0.011 -0.013
## yearMonth:taxaCentropomidae -0.357 -0.313 -0.138 -0.282 -0.540 -0.345 -0.159
## yearMonth:taxaCichlidae -0.366 -0.306 -0.140 -0.283 -0.533 -0.322 -0.155
## yearMonth:taxaClupeidae -0.064 -0.059 -0.025 -0.047 -0.111 -0.074 -0.040
## yearMonth:taxaElasmobranchii -0.317 -0.296 -0.128 -0.237 -0.543 -0.369 -0.184
## yearMonth:taxaGerreidae -0.316 -0.283 -0.123 -0.243 -0.490 -0.318 -0.150
## yearMonth:taxaHaliotidae -0.204 -0.190 -0.083 -0.152 -0.361 -0.239 -0.132
## yearMonth:taxaLutjanidae -0.361 -0.335 -0.137 -0.275 -0.572 -0.378 -0.176
## yearMonth:taxaMugilidae -0.876 -0.246 -0.107 -0.235 -0.427 -0.263 -0.126
## yearMonth:taxaOctopodidae -0.245 -0.875 -0.088 -0.195 -0.387 -0.258 -0.116
## yearMonth:taxaOmmastrephidae -0.076 -0.064 -0.858 -0.059 -0.119 -0.072 -0.043
## yearMonth:taxaOstreidae -0.224 -0.184 -0.077 -0.871 -0.311 -0.189 -0.091
## yearMonth:taxaOTRAS      -0.418 -0.381 -0.164 -0.321 -0.879 -0.443 -0.219
## yearMonth:taxaPalinuridae -0.256 -0.247 -0.100 -0.191 -0.437 -0.868 -0.145
## yearMonth:taxaPectinidae -0.071 -0.066 -0.031 -0.053 -0.125 -0.084 -0.810
## yearMonth:taxaPenaeidae -0.383 -0.312 -0.155 -0.297 -0.566 -0.354 -0.176
## yearMonth:taxaPortunidae -0.315 -0.256 -0.129 -0.243 -0.467 -0.289 -0.138
## yearMonth:taxaSciaenidae -0.336 -0.306 -0.130 -0.258 -0.540 -0.361 -0.171
## yearMonth:taxaScombridiae -0.228 -0.210 -0.084 -0.172 -0.357 -0.236 -0.112
## yearMonth:taxaSerranidae -0.337 -0.320 -0.133 -0.251 -0.572 -0.392 -0.192
## yearMonth:taxaStichopodidae -0.105 -0.094 -0.041 -0.077 -0.182 -0.124 -0.061
##                                     taxPnd txPrtn txScnd txScmb txSrrn txStch age2
## yearMonth
## region2
## region3
## region4
## region5
## region6
## taxaCentropomidae
## taxaCichlidae
## taxaClupeidae
## taxaElasmobranchii
## taxaGerreidae
## taxaHaliotidae
## taxaLutjanidae
## taxaMugilidae
## taxaOctopodidae
## taxaOmmastrephidae
## taxaOstreidae
## taxaOTRAS
## taxaPalinuridae
## taxaPectinidae
## taxaPenaeidae
## taxaPortunidae      0.528
## taxaSciaenidae      0.527  0.420
## taxaScombridiae    0.333  0.266  0.327
## taxaSerranidae     0.515  0.406  0.537  0.335
## taxaStichopodidae  0.178  0.140  0.187  0.115  0.205

```

```

## age2          -0.001 -0.002 -0.006 -0.003 -0.005 -0.012
## yearMonth:region2      -0.144 -0.001  0.012 -0.006 -0.006 -0.002  0.003
## yearMonth:region3      -0.242 -0.064 -0.017 -0.020  0.024  0.018  0.003
## yearMonth:region4      -0.155  0.027  0.005  0.002  0.004  0.000  0.006
## yearMonth:region5      -0.230 -0.055 -0.041 -0.014 -0.030 -0.011  0.006
## yearMonth:region6      -0.234 -0.055 -0.013 -0.010 -0.002 -0.001  0.019
## yearMonth:taxaCentropomidae -0.485 -0.392 -0.453 -0.291 -0.446 -0.155  0.005
## yearMonth:taxaCichlidae   -0.483 -0.396 -0.427 -0.282 -0.423 -0.147  0.007
## yearMonth:taxaClupeidae   -0.085 -0.066 -0.089 -0.055 -0.099 -0.037  0.002
## yearMonth:taxaElasmobranchii -0.429 -0.340 -0.442 -0.277 -0.482 -0.174  0.004
## yearMonth:taxaGerreidae    -0.429 -0.338 -0.406 -0.262 -0.412 -0.144  0.007
## yearMonth:taxaHaliotidae   -0.274 -0.214 -0.286 -0.179 -0.322 -0.167  0.006
## yearMonth:taxaLutjanidae   -0.473 -0.377 -0.470 -0.305 -0.489 -0.172  0.005
## yearMonth:taxaMugilidae    -0.381 -0.300 -0.347 -0.226 -0.343 -0.121  0.004
## yearMonth:taxaOctopodidae  -0.312 -0.247 -0.317 -0.209 -0.328 -0.116  0.011
## yearMonth:taxaOmmastrephidae -0.119 -0.094 -0.095 -0.061 -0.097 -0.034  0.019
## yearMonth:taxaOstreidae    -0.284 -0.224 -0.255 -0.163 -0.245 -0.086  0.002
## yearMonth:taxaOTRAS         -0.554 -0.440 -0.548 -0.350 -0.578 -0.208  0.010
## yearMonth:taxaPalinuridae  -0.345 -0.270 -0.360 -0.228 -0.387 -0.144  0.004
## yearMonth:taxaPectinidae   -0.096 -0.075 -0.099 -0.062 -0.112 -0.042  0.012
## yearMonth:taxaPenaeidae    -0.852 -0.426 -0.470 -0.301 -0.464 -0.163  0.011
## yearMonth:taxaPortunidae   -0.450 -0.848 -0.387 -0.248 -0.380 -0.132  0.006
## yearMonth:taxaSciaenidae   -0.454 -0.362 -0.878 -0.286 -0.465 -0.164  0.006
## yearMonth:taxaScombridiae  -0.302 -0.238 -0.296 -0.896 -0.304 -0.107  0.003
## yearMonth:taxaSerranidae   -0.454 -0.358 -0.470 -0.297 -0.877 -0.177  0.008
## yearMonth:taxaStichopodidae -0.141 -0.110 -0.145 -0.092 -0.157 -0.836  0.012
## yrMn:2 yrMn:3 yrMn:4 yrMn:5 yrMn:6 yrMnth:txCn

## yearMonth
## region2
## region3
## region4
## region5
## region6
## taxaCentropomidae
## taxaCichlidae
## taxaClupeidae
## taxaElasmobranchii
## taxaGerreidae
## taxaHaliotidae
## taxaLutjanidae
## taxaMugilidae
## taxaOctopodidae
## taxaOmmastrephidae
## taxaOstreidae
## taxaOTRAS
## taxaPalinuridae
## taxaPectinidae
## taxaPenaeidae
## taxaPortunidae
## taxaSciaenidae
## taxaScombridiae
## taxaSerranidae
## taxaStichopodidae
## age2

```

```

## yearMonth:region2
## yearMonth:region3          0.837
## yearMonth:region4          0.849  0.920
## yearMonth:region5          0.810  0.887  0.887
## yearMonth:region6          0.839  0.935  0.921  0.888
## yearMonth:taxaCentropomidae -0.013  0.073 -0.016  0.053  0.040
## yearMonth:taxaCichlidae    0.004  0.069 -0.045  0.000  0.062  0.524
## yearMonth:taxaClupeidae   0.001 -0.014  0.000  0.007  0.004  0.091
## yearMonth:taxaElasmobranchii 0.006 -0.031 -0.008  0.039  0.017  0.474
## yearMonth:taxaGerreidae    0.014  0.056  0.000  0.051  0.041  0.474
## yearMonth:taxaHaliotidae   0.005 -0.051  0.000  0.022  0.014  0.298
## yearMonth:taxaLutjanidae   0.000  0.022 -0.010  0.002  0.010  0.530
## yearMonth:taxaMugilidae    -0.003  0.079  0.021  0.031  0.076  0.410
## yearMonth:taxaOctopodidae  0.001  0.012 -0.003 -0.025 -0.017  0.359
## yearMonth:taxaOmmastrephidae 0.007  0.015 -0.008  0.017  0.018  0.115
## yearMonth:taxaOstreidae    -0.075  0.039 -0.002 -0.013  0.036  0.305
## yearMonth:taxaOTRAS         -0.001  0.010 -0.010  0.028  0.033  0.615
## yearMonth:taxaPalinuridae  0.005 -0.021  0.000  0.025 -0.016  0.386
## yearMonth:taxaPectinidae   0.002 -0.017  0.000  0.008  0.005  0.103
## yearMonth:taxaPenaeidae    0.168  0.270  0.173  0.262  0.265  0.563
## yearMonth:taxaPortunidae   -0.004  0.066 -0.038  0.060  0.057  0.469
## yearMonth:taxaSciaenidae   -0.015  0.018 -0.006  0.049  0.011  0.509
## yearMonth:taxaScombridiae  0.008  0.025 -0.002  0.017  0.012  0.333
## yearMonth:taxaSerranidae   0.007 -0.029 -0.005  0.036  0.001  0.503
## yearMonth:taxaStichopodidae 0.002 -0.011  0.000  0.012 -0.006  0.157
##                                     yrMnth:txCc  yrMnth:txCl  yrMn:E  yrMn:G  yrMn:H

## yearMonth
## region2
## region3
## region4
## region5
## region6
## taxaCentropomidae
## taxaCichlidae
## taxaClupeidae
## taxaElasmobranchii
## taxaGerreidae
## taxaHaliotidae
## taxaLutjanidae
## taxaMugilidae
## taxaOctopodidae
## taxaOmmastrephidae
## taxaOstreidae
## taxaOTRAS
## taxaPalinuridae
## taxaPectinidae
## taxaPenaeidae
## taxaPortunidae
## taxaSciaenidae
## taxaScombridiae
## taxaSerranidae
## taxaStichopodidae
## age2
## yearMonth:region2

```

```

## yearMonth:region3
## yearMonth:region4
## yearMonth:region5
## yearMonth:region6
## yearMonth:taxaCentropomidae
## yearMonth:taxaCichlidae
## yearMonth:taxaClupeidae      0.088
## yearMonth:taxaElasmobranchii 0.454      0.107
## yearMonth:taxaGerreidae     0.460      0.086      0.439
## yearMonth:taxaHaliotidae    0.286      0.077      0.352  0.282
## yearMonth:taxaLutjanidae   0.515      0.102      0.510  0.477  0.332
## yearMonth:taxaMugilidae    0.413      0.072      0.366  0.364  0.233
## yearMonth:taxaOctopodidae  0.347      0.067      0.341  0.325  0.221
## yearMonth:taxaOmmastrophidae 0.116      0.020      0.106  0.101  0.067
## yearMonth:taxaOstreidae    0.305      0.051      0.262  0.265  0.167
## yearMonth:taxaOTRAS         0.600      0.126      0.617  0.559  0.410
## yearMonth:taxaPalinuridae  0.359      0.084      0.410  0.357  0.278
## yearMonth:taxaPectinidae   0.099      0.026      0.122  0.097  0.089
## yearMonth:taxaPenaeidae    0.555      0.097      0.500  0.498  0.318
## yearMonth:taxaPortunidae   0.470      0.079      0.410  0.409  0.258
## yearMonth:taxaSciaenidae   0.477      0.099      0.495  0.456  0.321
## yearMonth:taxaScombridiae  0.322      0.063      0.317  0.300  0.204
## yearMonth:taxaSerranidae   0.476      0.113      0.542  0.465  0.364
## yearMonth:taxaStichopodidae 0.147      0.035      0.169  0.145  0.145
##                                     yrMn:L  yrMn:M  yrMnth:tx0c  yrMnth:tx0m  yrMnth:tx0s
## yearMonth
## region2
## region3
## region4
## region5
## region6
## taxaCentropomidae
## taxaCichlidae
## taxaClupeidae
## taxaElasmobranchii
## taxaGerreidae
## taxaHaliotidae
## taxaLutjanidae
## taxaMugilidae
## taxaOctopodidae
## taxaOmmastrophidae
## taxaOstreidae
## taxaOTRAS
## taxaPalinuridae
## taxaPectinidae
## taxaPenaeidae
## taxaPortunidae
## taxaSciaenidae
## taxaScombridiae
## taxaSerranidae
## taxaStichopodidae
## age2
## yearMonth:region2
## yearMonth:region3

```

```

## yearMonth:region4
## yearMonth:region5
## yearMonth:region6
## yearMonth:taxaCentropomidae
## yearMonth:taxaCichlidae
## yearMonth:taxaClupeidae
## yearMonth:taxaElasmobranchii
## yearMonth:taxaGerreidae
## yearMonth:taxaHaliotidae
## yearMonth:taxaLutjanidae
## yearMonth:taxaMugilidae      0.411
## yearMonth:taxaOctopodidae    0.384  0.279
## yearMonth:taxaOmmastrephidae 0.110  0.087  0.073
## yearMonth:taxaOstreidae     0.302  0.254  0.215   0.063
## yearMonth:taxaOTRAS          0.645  0.479  0.438   0.134   0.350
## yearMonth:taxaPalinuridae   0.417  0.292  0.293   0.081   0.213
## yearMonth:taxaPectinidae    0.114  0.080  0.076   0.024   0.057
## yearMonth:taxaPenaeidae     0.543  0.438  0.358   0.129   0.320
## yearMonth:taxaPortunidae   0.448  0.355  0.295   0.107   0.262
## yearMonth:taxaSciaenidae    0.521  0.384  0.356   0.107   0.283
## yearMonth:taxaScombridiae  0.348  0.257  0.239   0.069   0.187
## yearMonth:taxaSerranidae   0.545  0.384  0.371   0.109   0.275
## yearMonth:taxaStichopodidae 0.170  0.120  0.121   0.034   0.086
##                                     yM:OTR yrMnth:txPl yrMnth:txPc yrMnth:txPn

## yearMonth
## region2
## region3
## region4
## region5
## region6
## taxaCentropomidae
## taxaCichlidae
## taxaClupeidae
## taxaElasmobranchii
## taxaGerreidae
## taxaHaliotidae
## taxaLutjanidae
## taxaMugilidae
## taxaOctopodidae
## taxaOmmastrephidae
## taxaOstreidae
## taxaOTRAS
## taxaPalinuridae
## taxaPectinidae
## taxaPenaeidae
## taxaPortunidae
## taxaSciaenidae
## taxaScombridiae
## taxaSerranidae
## taxaStichopodidae
## age2
## yearMonth:region2
## yearMonth:region3
## yearMonth:region4

```

```

## yearMonth:region5
## yearMonth:region6
## yearMonth:taxaCentropomidae
## yearMonth:taxaCichlidae
## yearMonth:taxaClupeidae
## yearMonth:taxaElasmobranchii
## yearMonth:taxaGerreidae
## yearMonth:taxaHaliotidae
## yearMonth:taxaLutjanidae
## yearMonth:taxaMugilidae
## yearMonth:taxaOctopodidae
## yearMonth:taxaOmmastrephidae
## yearMonth:taxaOstreidae
## yearMonth:taxaOTRAS
## yearMonth:taxaPalinuridae      0.494
## yearMonth:taxaPectinidae       0.141  0.096
## yearMonth:taxaPenaeidae        0.642  0.397      0.110
## yearMonth:taxaPortunidae      0.530  0.323      0.088      0.504
## yearMonth:taxaSciaenidae       0.614  0.404      0.111      0.525
## yearMonth:taxaScombridiae     0.401  0.260      0.071      0.345
## yearMonth:taxaSerranidae      0.650  0.437      0.127      0.523
## yearMonth:taxaStichopodidae   0.204  0.143      0.040      0.163
##                                     yrMnth:txPr  yrMnth:txScn  yrMnth:txScm  yrMnth:txSr

## yearMonth
## region2
## region3
## region4
## region5
## region6
## taxaCentropomidae
## taxaCichlidae
## taxaClupeidae
## taxaElasmobranchii
## taxaGerreidae
## taxaHaliotidae
## taxaLutjanidae
## taxaMugilidae
## taxaOctopodidae
## taxaOmmastrephidae
## taxaOstreidae
## taxaOTRAS
## taxaPalinuridae
## taxaPectinidae
## taxaPenaeidae
## taxaPortunidae
## taxaSciaenidae
## taxaScombridiae
## taxaSerranidae
## taxaStichopodidae
## age2
## yearMonth:region2
## yearMonth:region3
## yearMonth:region4
## yearMonth:region5

```

```

## yearMonth:region6
## yearMonth:taxaCentropomidae
## yearMonth:taxaCichlidae
## yearMonth:taxaClupeidae
## yearMonth:taxaElasmobranchii
## yearMonth:taxaGerreidae
## yearMonth:taxaHaliotidae
## yearMonth:taxaLutjanidae
## yearMonth:taxaMugilidae
## yearMonth:taxaOctopodidae
## yearMonth:taxaOmmastrephidae
## yearMonth:taxaOstreidae
## yearMonth:taxaOTRAS
## yearMonth:taxaPalinuridae
## yearMonth:taxaPectinidae
## yearMonth:taxaPenaeidae
## yearMonth:taxaPortunidae
## yearMonth:taxaSciaenidae      0.433
## yearMonth:taxaScombridae     0.283      0.327
## yearMonth:taxaSerranidae     0.428      0.524      0.339
## yearMonth:taxaStichopodidae   0.133      0.166      0.106      0.178
##
## Standardized Within-Group Residuals:
##          Min        Q1        Med        Q3        Max
## -4.82701651 -0.58808663  0.01003762  0.62249212  5.84961455
##
## Number of Observations: 183439
## Number of Groups:
##           fed uniqueid %in% fed
##             54                  182

```

Final Model

Level 1 Model: Time

$$\text{Logcpue}_{ijk} = a_{ij} + b_{ij}\text{yearMonth}_{ijk} + c_{ij}\text{region}_{ijk} + d_{ij}\text{taxa}_{ijk} + \epsilon_{ijk}, \epsilon_{ijk} \sim N(0, \sigma^2)$$

Level 2 Model: Cooperations

$$a_{ij} = a_i + u_{ij}$$

$$b_{ij} = b_i$$

$$c_{ij} = c_i$$

$$d_{ij} = d_i$$

Level 3 Model: Federations

$$a_i = \alpha_0 + \alpha_1 age_i + \tilde{u}_i$$

$$b_i = \beta_0$$

$$c_i = \gamma_0 + \gamma_1 age_i$$

$$d_i = \delta_0 + \delta_1 age_i$$

Composite model

$$Logcpue_{ijk} = a_i + u_{ij} + b_i yearMonth_{ijk} + c_i region_{ijk} + d_i taxa_{ijk} + \epsilon_{ijk}, \epsilon_{ijk} \sim N(0, \sigma^2)$$

$$\begin{aligned} &= \alpha_0 + \alpha_1 age_i + \tilde{u}_i + u_{ij} + \beta_0 yearMonth_{ijk} + \gamma_0 region_{ijk} + \gamma_1 age_i region_{ijk} + \delta_0 taxa_{ijk} + \delta_1 age_i taxa_{ijk} + \epsilon_{ijk} \\ &\quad \epsilon_{ijk} \sim N(0, \sigma^2) \\ &= \alpha_0 + \alpha_1 age_i + \beta_0 yearMonth_{ijk} + \gamma_0 region_{ijk} + \gamma_1 age_i region_{ijk} + \delta_0 taxa_{ijk} + \delta_1 age_i taxa_{ijk} \\ &\quad + [\tilde{u}_i + u_{ij} + \epsilon_{ijk}] \\ &\quad \epsilon_{ijk} \sim N(0, \sigma^2), u_{ij} \sim N(0, \sigma_u^2), \tilde{u}_i \sim N(0, \sigma_{\tilde{u}}^2) \end{aligned}$$

Model Diagnostics

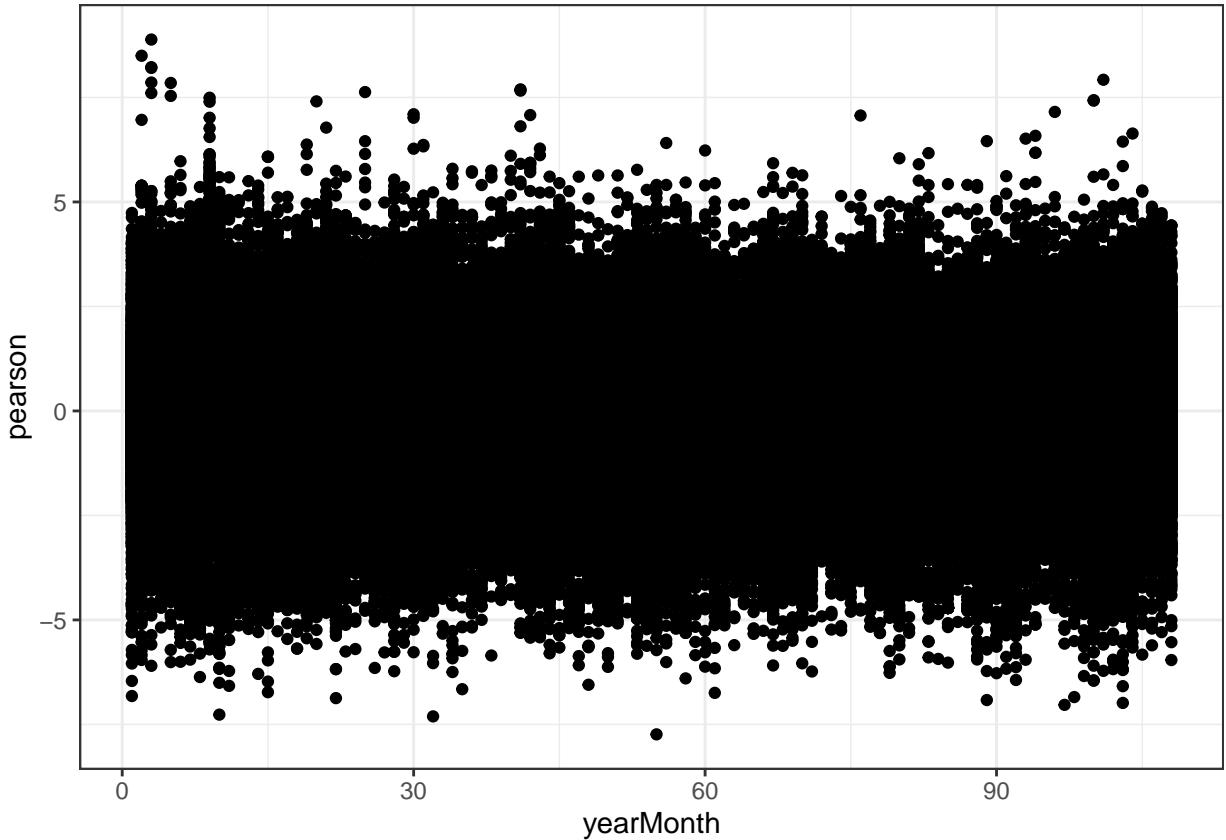
```
anova(model_int_mgcv)
```

```
## 
## Family: gaussian
## Link function: identity
##
## Formula:
## logcpue ~ yearMonth + region + taxa + age2 + age2:region + age2:taxa +
##       +s(fed, bs = "re") + s(uniqueid, bs = "re")
##
## Parametric Terms:
##                 df      F p-value
## yearMonth     1 103.026 <2e-16
## region        5   34.050 <2e-16
## taxa          20 252.349 <2e-16
## age2          1    1.535  0.215
## region:age2   5 341.288 <2e-16
## taxa:age2    20 346.760 <2e-16
##
## Approximate significance of smooth terms:
##             edf Ref.df      F p-value
## s(fed)      20.21  51.00 38482   0.359
## s(uniqueid) 153.25 176.00  8781 4.38e-05
```

Linearity

```
x_na <- na.omit(x)

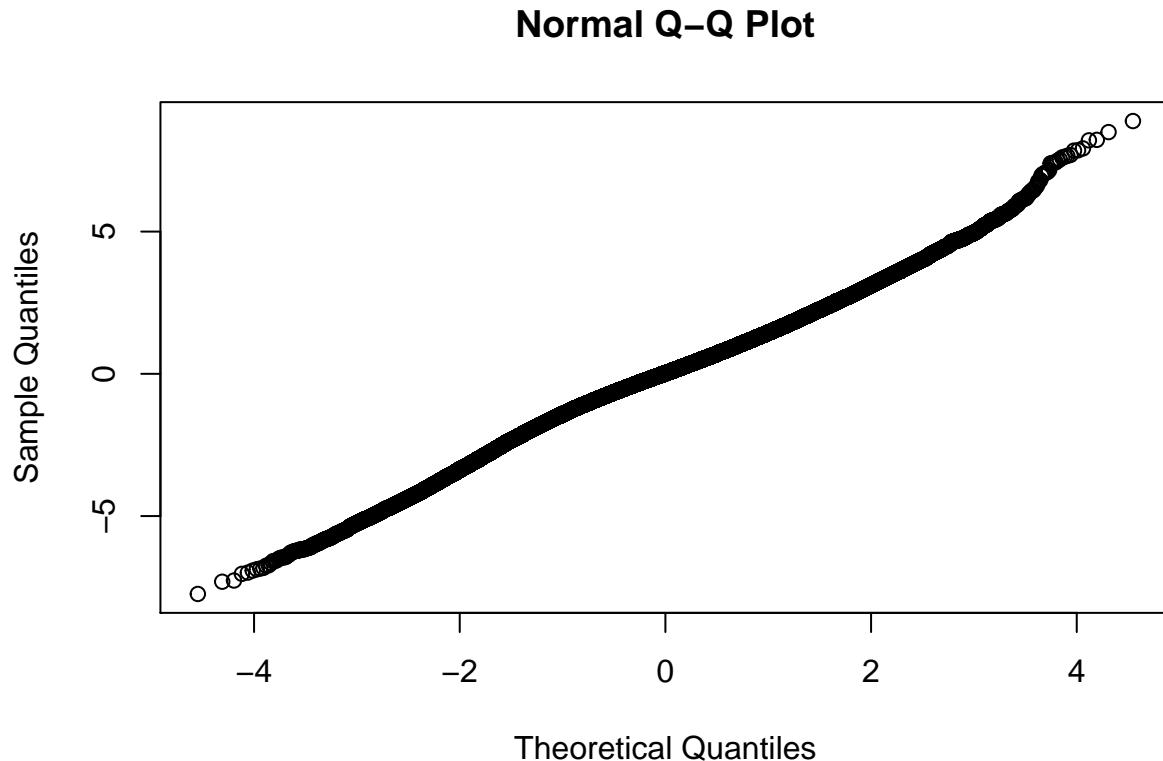
ggplot(data.frame(yearMonth=x_na$yearMonth,pearson=residuals(model_int_mgcv,type="pearson")),
       aes(x=yearMonth,y=pearson)) +
  geom_point() +
  theme_bw()
```



The residuals are randomly scattered, indicating that the data is linear and that there is a linear relationship between yearMonth and response.

Normality

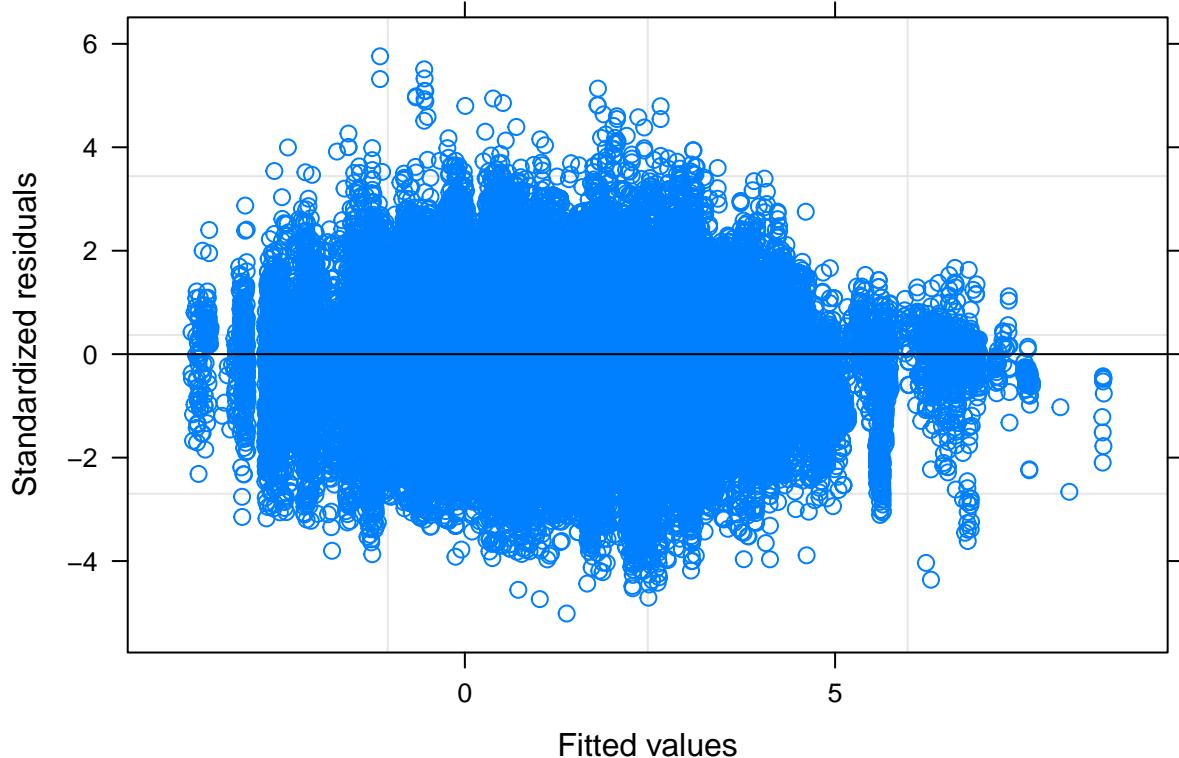
```
qqnorm(residuals(model_int))
```



Points mostly fall along a straight diagonal line on the normal quantile plot, so we can safely assume that the data is normally distributed.

Constant Variance

```
plot(model_int)
```



The vertical spread of the residuals is not constant across the residual plot, suggesting that the constant variance condition is violated for linear mixed effects model. Therefore, some transformation should be done in the future to address this problem.

Colinearity

```
vif(model_int)
```

```
##                      GVIF Df GVIF^(1/(2*Df))
## yearMonth      1.603828e+01  1        4.004782
## region        1.574637e+00  5        1.046449
## taxa          2.949230e+13 20       2.171414
## age2          4.542232e+01  1       6.739608
## region:age2   5.155707e+01  5       1.483299
## taxa:age2    3.134794e+13 20       2.174729
```

The VIF value for `age2` is over 5, which is potentially concerning. Future model thus should take colinearity into consideration in modeling `logcpue`.

Prediction

```
# generate prediction file
model <- model_int_mgcv
data <- x %>%
  filter(is.na(logcpue))
#####
df <- data %>%
  mutate(prediction = predict(model,data))%>%
  select(c('prediction'))
df <- cbind(index = rownames(df),df)
df$index <- as.numeric(as.character(df$index))
write.csv(df,'predictions.csv',row.names = FALSE) # format: index,prediction
```