Final\_Longitudinal\_Short

Jiseon Yang

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### New Data

# Load necessary libraries  
library(tidyr)  
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(tidyverse)

## ── Attaching core tidyverse packages ──────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────── tidyverse 2.0.0 ──  
## ✔ forcats 1.0.0 ✔ readr 2.1.5  
## ✔ ggplot2 3.5.1 ✔ stringr 1.5.1  
## ✔ lubridate 1.9.3 ✔ tibble 3.2.1  
## ✔ purrr 1.0.2

## ── Conflicts ────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────── tidyverse\_conflicts() ──  
## ✖ dplyr::filter() masks stats::filter()  
## ✖ dplyr::lag() masks stats::lag()  
## ℹ Use the conflicted package (<http://conflicted.r-lib.org/>) to force all conflicts to become errors

library(reshape2)

##   
## Attaching package: 'reshape2'  
##   
## The following object is masked from 'package:tidyr':  
##   
## smiths

# Load data: ISS\_CFU\_size\_new.csv  
ISS\_CFU\_size\_new <- read.csv("C:/Users/jyang/ASU Dropbox/Jiseon Yang/2 PROJJECT/2019\_NASA CoEvolve/10 Micro17-Ground investigation/ISS\_CFU\_size\_new.csv")  
  
# Reshape the data into long format  
data\_long <- ISS\_CFU\_size\_new %>%  
 pivot\_longer(  
 cols = c("Ral\_L", "Ral\_s", "Sph\_L", "Sph\_s"),  
 names\_to = c("Species", "Size"),  
 names\_sep = "\_",  
 values\_to = "CFU"  
 )  
  
# Column type  
data\_long <- data\_long %>%  
 mutate(  
 Days = as.numeric(Days),  
 Daysf = as.factor(Days),  
 ID = as.factor(ID),  
 trt = as.factor(trt) # 'trt' column already in your data  
 )  
# Log10\_CFU  
data\_long$log\_CFU <- log10(data\_long$CFU)  
# View the reshaped data  
head(data\_long)

## # A tibble: 6 × 11  
## ID Days trt Ral\_t Sph\_t total Species Size CFU Daysf log\_CFU  
## <fct> <dbl> <fct> <dbl> <dbl> <dbl> <chr> <chr> <dbl> <fct> <dbl>  
## 1 1 0 LS 4000000 15000000 19000000 Ral L 4000000 0 6.60  
## 2 1 0 LS 4000000 15000000 19000000 Ral s NA 0 NA   
## 3 1 0 LS 4000000 15000000 19000000 Sph L 15000000 0 7.18  
## 4 1 0 LS 4000000 15000000 19000000 Sph s NA 0 NA   
## 5 1 2 LS 2620000000 380000000 3000000000 Ral L 2620000000 2 9.42  
## 6 1 2 LS 2620000000 380000000 3000000000 Ral s NA 2 NA

# check NA  
cat("\n NA = ",sum(is.na(data\_long)))

##   
## NA = 1302

cat("\n Zero CFU = ", sum(data\_long$CFU == 0, na.rm = TRUE))

##   
## Zero CFU = 0

data\_long <- na.omit(data\_long)  
cat("\n NA = ",sum(is.na(data\_long)))

##   
## NA = 0

# Aggregate CFU for each species (L + S)  
species\_totals <- data\_long %>%  
 group\_by(ID, Days, Daysf, trt, Species) %>%  
 summarize(Species\_CFU = sum(CFU, na.rm = TRUE))

## `summarise()` has grouped output by 'ID', 'Days', 'Daysf', 'trt'. You can override using the `.groups` argument.

# Log10\_Species\_CFU  
species\_totals$log\_Species\_CFU <- log10(species\_totals$Species\_CFU)  
head(species\_totals)

## # A tibble: 6 × 7  
## # Groups: ID, Days, Daysf, trt [3]  
## ID Days Daysf trt Species Species\_CFU log\_Species\_CFU  
## <fct> <dbl> <fct> <fct> <chr> <dbl> <dbl>  
## 1 1 0 0 LS Ral 4000000 6.60  
## 2 1 0 0 LS Sph 15000000 7.18  
## 3 1 2 2 LS Ral 2620000000 9.42  
## 4 1 2 2 LS Sph 380000000 8.58  
## 5 1 4 4 LS Ral 1720000000 9.24  
## 6 1 4 4 LS Sph 150000000 8.18

cat("\n NA = ",sum(is.na(species\_totals)))

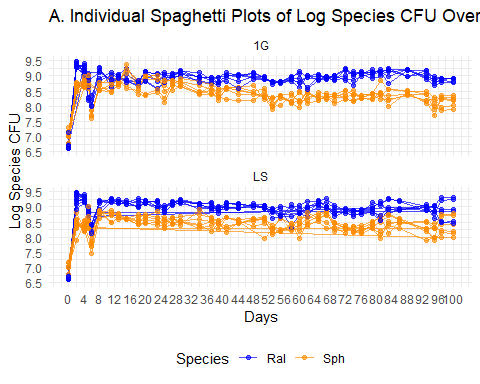
##   
## NA = 0

cat("\n Zero CFU = ", sum(species\_totals$Species\_CFU == 0, na.rm = TRUE))

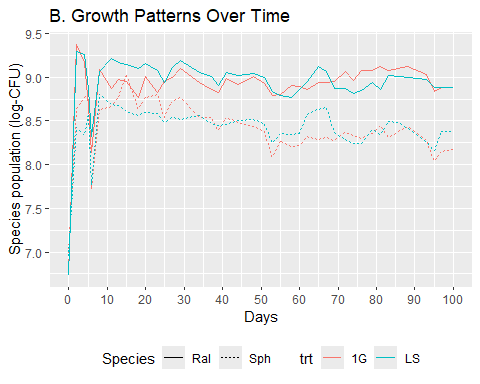
##   
## Zero CFU = 0

# spaghetti plot and profile plot

library(ggplot2)  
  
# Create spaghetti plot with modified scales  
ggplot(data = species\_totals, aes(x = Days, y = log\_Species\_CFU, color = Species, group = interaction(ID, Species))) +  
 geom\_line(alpha = 0.7) + # Lines connecting data points for each individual  
 geom\_point(alpha = 0.6, size = 1.5) + # Points for observed data  
 facet\_wrap(~ trt, ncol = 1, scales = "free\_y") + # Separate panels for each treatment group  
 labs(title = "A. Individual Spaghetti Plots of Log Species CFU Over Days",  
 x = "Days",  
 y = "Log Species CFU",  
 color = "Species") +  
 theme\_minimal() +  
 theme(legend.position = "bottom") +  
 scale\_color\_manual(values = c("Ral" = "blue", "Sph" = "darkorange")) + # Customize colors for species  
 scale\_y\_continuous(limits = c(6.5, 9.5), breaks = seq(6.5, 9.5, 0.5)) + # Set y-axis scale  
 scale\_x\_continuous(breaks = seq(0, max(species\_totals$Days), 4)) # Set x-axis scale with interval 7



library(ggplot2)  
ggplot(species\_totals, aes(x = Days, y = log\_Species\_CFU, color = trt, linetype = Species)) +  
 geom\_line(stat = "summary", fun = mean) +  
 labs(title = "B. Growth Patterns Over Time", y = "Species population (log-CFU)", x = "Days") +  
 theme(legend.position = "bottom") +  
 #scale\_y\_continuous(limits = c(6.5, 9.5), breaks = seq(6.5, 9.5)) + # Set y-axis scale  
 scale\_x\_continuous(breaks = seq(0, max(species\_totals$Days), 10)) # Set x-axis scale with interval 7



## Research Question 1:

Do treatment conditions (LS vs. 1G) significantly alter the population dynamics of Ralstonia (Ral) and Sphingomonas (Sph) over time? ### log\_Species\_CFU ∼ Days \* trt \* Species +( 1∣ID) #### Linear mixed model fit by REML

# Linear mixed model fit by REML  
  
library(lme4)

## Loading required package: Matrix

##   
## Attaching package: 'Matrix'

## The following objects are masked from 'package:tidyr':  
##   
## expand, pack, unpack

library(glmmTMB)  
  
# Using lmer (random effects)  
model\_mixed <- lmer(log\_Species\_CFU ~ Days \* trt \* Species + (1 | ID), data = species\_totals, REML = TRUE)  
summary(model\_mixed)

## Linear mixed model fit by REML ['lmerMod']  
## Formula: log\_Species\_CFU ~ Days \* trt \* Species + (1 | ID)  
## Data: species\_totals  
##   
## REML criterion at convergence: 1467.4  
##   
## Scaled residuals:   
## Min 1Q Median 3Q Max   
## -4.8029 -0.2195 0.1571 0.5103 1.9357   
##   
## Random effects:  
## Groups Name Variance Std.Dev.  
## ID (Intercept) 0.01283 0.1133   
## Residual 0.21306 0.4616   
## Number of obs: 1070, groups: ID, 26  
##   
## Fixed effects:  
## Estimate Std. Error t value  
## (Intercept) 8.5924107 0.0578070 148.640  
## Days 0.0043475 0.0009098 4.778  
## trtLS 0.1457386 0.0832779 1.750  
## SpeciesSph -0.1564976 0.0667632 -2.344  
## Days:trtLS -0.0024491 0.0012880 -1.901  
## Days:SpeciesSph -0.0068239 0.0012566 -5.430  
## trtLS:SpeciesSph -0.3150153 0.0956478 -3.293  
## Days:trtLS:SpeciesSph 0.0057783 0.0017852 3.237  
##   
## Correlation of Fixed Effects:  
## (Intr) Days trtLS SpcsSp Dys:LS Dys:SS tLS:SS  
## Days -0.592   
## trtLS -0.694 0.411   
## SpeciesSph -0.578 0.555 0.401   
## Days:trtLS 0.418 -0.706 -0.601 -0.392   
## Dys:SpcsSph 0.464 -0.691 -0.322 -0.803 0.488   
## trtLS:SpcsS 0.403 -0.387 -0.575 -0.698 0.560 0.561   
## Dys:trLS:SS -0.326 0.486 0.464 0.565 -0.694 -0.704 -0.807

cat("\n")

library(lmerTest)

## Warning: package 'lmerTest' was built under R version 4.4.2

##   
## Attaching package: 'lmerTest'

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

## The following object is masked from 'package:stats':  
##   
## step

library(car)

## Loading required package: carData

##   
## Attaching package: 'car'

## The following object is masked from 'package:purrr':  
##   
## some

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

anova(model\_mixed, type = "III")

## Warning in anova.merMod(model\_mixed, type = "III"): additional arguments ignored: 'type'

## Analysis of Variance Table  
## npar Sum Sq Mean Sq F value  
## Days 1 1.329 1.329 6.2359  
## trt 1 0.000 0.000 0.0021  
## Species 1 62.212 62.212 291.9873  
## Days:trt 1 0.048 0.048 0.2242  
## Days:Species 1 4.236 4.236 19.8817  
## trt:Species 1 0.283 0.283 1.3301  
## Days:trt:Species 1 2.232 2.232 10.4765

cat("\n \*AIC(model\_mixed) = ",AIC(model\_mixed)) # 1487.367

##   
## \*AIC(model\_mixed) = 1487.367

# Using gls (with AR(1) correlation)  
library(nlme)

##   
## Attaching package: 'nlme'

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

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

model\_ar1 <- gls(  
 log\_Species\_CFU ~ Days \* trt \* Species,  
 correlation = corAR1(form = ~ 1 | ID),  
 data = species\_totals,  
 method = "REML"  
)  
summary(model\_ar1)

## Generalized least squares fit by REML  
## Model: log\_Species\_CFU ~ Days \* trt \* Species   
## Data: species\_totals   
## AIC BIC logLik  
## 1152.575 1202.254 -566.2873  
##   
## Correlation Structure: AR(1)  
## Formula: ~1 | ID   
## Parameter estimate(s):  
## Phi   
## 0.7044421   
##   
## Coefficients:  
## Value Std.Error t-value p-value  
## (Intercept) 8.449247 0.08746925 96.59676 0.0000  
## Days 0.007571 0.00165217 4.58232 0.0000  
## trtLS 0.161536 0.12345741 1.30844 0.1910  
## SpeciesSph -0.287981 0.03451189 -8.34439 0.0000  
## Days:trtLS -0.003094 0.00225549 -1.37173 0.1704  
## Days:SpeciesSph -0.004697 0.00064747 -7.25467 0.0000  
## trtLS:SpeciesSph -0.309789 0.04944622 -6.26517 0.0000  
## Days:trtLS:SpeciesSph 0.005721 0.00092182 6.20633 0.0000  
##   
## Correlation:   
## (Intr) Days trtLS SpcsSp Dys:LS Dys:SS tLS:SS  
## Days -0.774   
## trtLS -0.708 0.548   
## SpeciesSph -0.221 0.199 0.156   
## Days:trtLS 0.567 -0.733 -0.769 -0.145   
## Days:SpeciesSph 0.145 -0.189 -0.102 -0.808 0.138   
## trtLS:SpeciesSph 0.154 -0.139 -0.224 -0.698 0.208 0.564   
## Days:trtLS:SpeciesSph -0.102 0.133 0.145 0.568 -0.196 -0.702 -0.812  
##   
## Standardized residuals:  
## Min Q1 Med Q3 Max   
## -3.5987600 -0.1594844 0.2587886 0.7152675 2.1065963   
##   
## Residual standard error: 0.5581709   
## Degrees of freedom: 1070 total; 1062 residual

anova(model\_ar1)

## Denom. DF: 1062   
## numDF F-value p-value  
## (Intercept) 1 48214.74 <.0001  
## Days 1 61.30 <.0001  
## trt 1 0.00 0.9522  
## Species 1 1303.53 <.0001  
## Days:trt 1 0.00 0.9750  
## Days:Species 1 16.80 <.0001  
## trt:Species 1 4.42 0.0358  
## Days:trt:Species 1 38.52 <.0001

cat("\n \*AIC(model\_ar1) = ",AIC(model\_ar1)) # 1152.575

##   
## \*AIC(model\_ar1) = 1152.575

AIC(model\_mixed, model\_ar1)

## Warning in AIC.default(model\_mixed, model\_ar1): models are not all fitted to the same number of observations

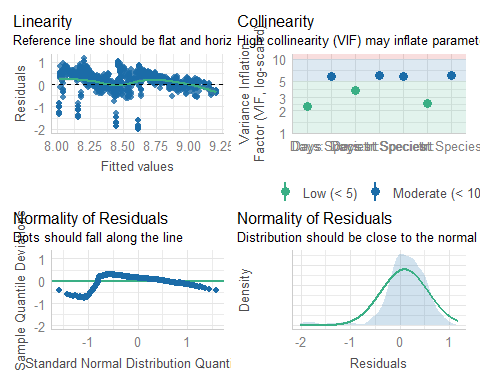
## df AIC  
## model\_mixed 10 1487.367  
## model\_ar1 10 1152.575

# Diagnostic checks  
library(performance)

## Warning: package 'performance' was built under R version 4.4.2

#check\_model(model1\_AR1)  
check\_model(model\_ar1)

## Converting missing values (`NA`) into regular values currently not possible for variables of class `NULL`.



#Research Question 2: What is the best-fit temporal autocorrelation structure?

### Days\_scaled

# Days\_scaled  
species\_totals$Days\_log <- log(species\_totals$Days+1) # natural log  
head(species\_totals)

## # A tibble: 6 × 8  
## # Groups: ID, Days, Daysf, trt [3]  
## ID Days Daysf trt Species Species\_CFU log\_Species\_CFU Days\_log  
## <fct> <dbl> <fct> <fct> <chr> <dbl> <dbl> <dbl>  
## 1 1 0 0 LS Ral 4000000 6.60 0   
## 2 1 0 0 LS Sph 15000000 7.18 0   
## 3 1 2 2 LS Ral 2620000000 9.42 1.10  
## 4 1 2 2 LS Sph 380000000 8.58 1.10  
## 5 1 4 4 LS Ral 1720000000 9.24 1.61  
## 6 1 4 4 LS Sph 150000000 8.18 1.61

###(a) Unstructured (UN) Covariance – fail to run This allows each pair of repeated measures to have its own covariance.

any(is.na(species\_totals))

## [1] FALSE

#install.packages("nlme")  
library(nlme)  
  
# model\_UN <- gls(  
# log\_Species\_CFU ~ Days\_log:Species+ trt:Species,  
# data = species\_totals,  
# correlation = corSymm(form = ~ 1 | ID),  
# method = "REML"  
# )  
# summary(model\_UN)

###b) Compound Symmetry (CS) Covariance Assumes constant variance and equal correlation between all pairs of time points.

model\_CS <- gls(  
 log\_Species\_CFU ~ Days\_log \* trt \* Species,  
 data = species\_totals,  
 correlation = corCompSymm(form = ~ Days\_log | ID),  
 method = "REML"  
)  
summary(model\_CS)

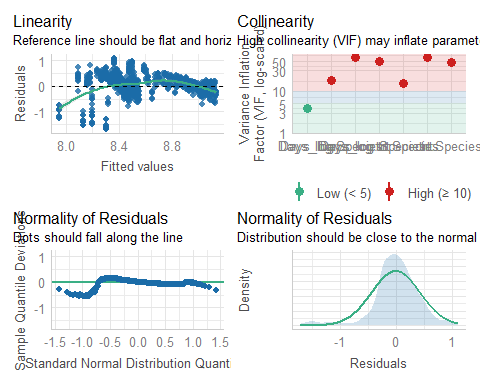
## Generalized least squares fit by REML  
## Model: log\_Species\_CFU ~ Days\_log \* trt \* Species   
## Data: species\_totals   
## AIC BIC logLik  
## 1293.588 1343.267 -636.7942  
##   
## Correlation Structure: Compound symmetry  
## Formula: ~Days\_log | ID   
## Parameter estimate(s):  
## Rho   
## -0.009640988   
##   
## Coefficients:  
## Value Std.Error t-value p-value  
## (Intercept) 8.125070 0.07231776 112.35234 0.0000  
## Days\_log 0.219322 0.02062682 10.63285 0.0000  
## trtLS 0.176320 0.10465066 1.68484 0.0923  
## SpeciesSph 0.071951 0.10357173 0.69469 0.4874  
## Days\_log:trtLS -0.040077 0.02973692 -1.34770 0.1780  
## Days\_log:SpeciesSph -0.159050 0.02956998 -5.37877 0.0000  
## trtLS:SpeciesSph -0.426654 0.14984610 -2.84728 0.0045  
## Days\_log:trtLS:SpeciesSph 0.110230 0.04254442 2.59095 0.0097  
##   
## Correlation:   
## (Intr) Dys\_lg trtLS SpcsSp Dy\_:LS Dy\_:SS tLS:SS  
## Days\_log -0.957   
## trtLS -0.691 0.661   
## SpeciesSph -0.716 0.669 0.495   
## Days\_log:trtLS 0.664 -0.694 -0.958 -0.464   
## Days\_log:SpeciesSph 0.668 -0.717 -0.462 -0.932 0.498   
## trtLS:SpeciesSph 0.495 -0.462 -0.717 -0.691 0.670 0.645   
## Days\_log:trtLS:SpeciesSph -0.464 0.499 0.670 0.648 -0.716 -0.695 -0.935  
##   
## Standardized residuals:  
## Min Q1 Med Q3 Max   
## -3.93085576 -0.46308114 0.03073344 0.55784486 2.55669319   
##   
## Residual standard error: 0.4323053   
## Degrees of freedom: 1070 total; 1062 residual

model\_cs <- gls(  
 log\_Species\_CFU ~ Days \* trt \* Species,  
 data = species\_totals,  
 correlation = corCompSymm(form = ~ Days | ID),  
 method = "REML"  
)  
summary(model\_cs)

## Generalized least squares fit by REML  
## Model: log\_Species\_CFU ~ Days \* trt \* Species   
## Data: species\_totals   
## AIC BIC logLik  
## 1484.411 1534.09 -732.2056  
##   
## Correlation Structure: Compound symmetry  
## Formula: ~Days | ID   
## Parameter estimate(s):  
## Rho   
## -0.009670691   
##   
## Coefficients:  
## Value Std.Error t-value p-value  
## (Intercept) 8.644066 0.04576767 188.86840 0.0000  
## Days 0.005092 0.00089694 5.67694 0.0000  
## trtLS 0.156406 0.06555319 2.38595 0.0172  
## SpeciesSph -0.156178 0.06790758 -2.29986 0.0216  
## Days:trtLS -0.002511 0.00127667 -1.96645 0.0495  
## Days:SpeciesSph -0.006818 0.00127818 -5.33417 0.0000  
## trtLS:SpeciesSph -0.314302 0.09728219 -3.23083 0.0013  
## Days:trtLS:SpeciesSph 0.005773 0.00181579 3.17912 0.0015  
##   
## Correlation:   
## (Intr) Days trtLS SpcsSp Dys:LS Dys:SS tLS:SS  
## Days -0.869   
## trtLS -0.698 0.606   
## SpeciesSph -0.742 0.572 0.518   
## Days:trtLS 0.610 -0.703 -0.871 -0.402   
## Days:SpeciesSph 0.596 -0.713 -0.416 -0.803 0.501   
## trtLS:SpeciesSph 0.518 -0.399 -0.744 -0.698 0.575 0.561   
## Days:trtLS:SpeciesSph -0.419 0.502 0.600 0.565 -0.712 -0.704 -0.807  
##   
## Standardized residuals:  
## Min Q1 Med Q3 Max   
## -4.7050271 -0.2762688 0.1084476 0.4844124 1.9651570   
##   
## Residual standard error: 0.4672476   
## Degrees of freedom: 1070 total; 1062 residual

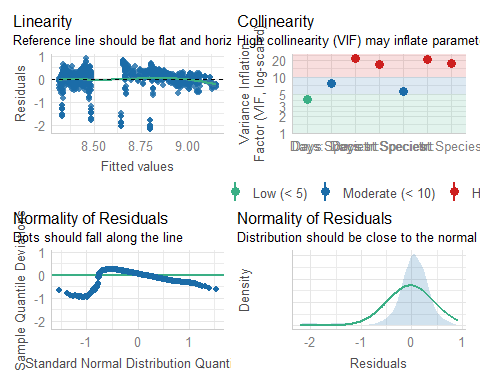
# Diagnostic checks  
library(performance)  
check\_model(model\_CS)

## Converting missing values (`NA`) into regular values currently not possible for variables of class `NULL`.



check\_model(model\_cs)

## Converting missing values (`NA`) into regular values currently not possible for variables of class `NULL`.



###(c) Autoregressive (AR(1)) Covariance Assumes that correlations decay exponentially with increasing time lag. The correlation structure is applied within each group identified by ID. The time points for correlation decay are assumed to be equally spaced and do not require an explicit time variable.

# 1. How do species, treatment, and time independently and interactively affect CFU counts? Are there specific combinations of time, species, and treatment that show unique trends? (The most comprehensive model for evaluating time, treatment, and species effects, along with all possible interactions.) {log\_Species\_CFU ~ trt \* Species \* Daysf} --------Not working Singular  
model1\_AR1 <- gls(  
 log\_Species\_CFU ~ trt \* Species \* Days\_log, #{Daysf:Species:trt} -- dont work  
 data = species\_totals,  
 correlation = corAR1(form = ~ 1 | ID),  
 method = "REML"  
)  
summary(model1\_AR1)

## Generalized least squares fit by REML  
## Model: log\_Species\_CFU ~ trt \* Species \* Days\_log   
## Data: species\_totals   
## AIC BIC logLik  
## 821.065 870.7441 -400.5325  
##   
## Correlation Structure: AR(1)  
## Formula: ~1 | ID   
## Parameter estimate(s):  
## Phi   
## 0.9838706   
##   
## Coefficients:  
## Value Std.Error t-value p-value  
## (Intercept) 4.814783 0.4632820 10.392770 0.0000  
## trtLS 1.644421 0.6706266 2.452066 0.0144  
## SpeciesSph 0.207109 0.0502063 4.125160 0.0000  
## Days\_log 1.684468 0.0795882 21.164800 0.0000  
## trtLS:SpeciesSph -0.736342 0.0703514 -10.466622 0.0000  
## trtLS:Days\_log -0.950227 0.1022244 -9.295497 0.0000  
## SpeciesSph:Days\_log -0.177245 0.0135910 -13.041410 0.0000  
## trtLS:SpeciesSph:Days\_log 0.184165 0.0190922 9.646079 0.0000  
##   
## Correlation:   
## (Intr) trtLS SpcsSp Dys\_lg trLS:SS tLS:D\_ SpS:D\_  
## trtLS -0.691   
## SpeciesSph -0.203 0.140   
## Days\_log -0.337 0.233 0.582   
## trtLS:SpeciesSph 0.145 -0.178 -0.714 -0.415   
## trtLS:Days\_log 0.263 -0.317 -0.453 -0.779 0.547   
## SpeciesSph:Days\_log 0.177 -0.122 -0.950 -0.516 0.678 0.402   
## trtLS:SpeciesSph:Days\_log -0.126 0.152 0.676 0.367 -0.950 -0.481 -0.712  
##   
## Standardized residuals:  
## Min Q1 Med Q3 Max   
## -2.2547788 -1.1638006 -0.3365838 0.1964441 1.5055064   
##   
## Residual standard error: 1.863779   
## Degrees of freedom: 1070 total; 1062 residual

model\_ar1 <- gls(  
 log\_Species\_CFU ~ trt \* Species \* Days, #{Daysf:Species:trt} -- dont work  
 data = species\_totals,  
 correlation = corAR1(form = ~ 1 | ID),  
 method = "REML"  
)  
summary(model\_ar1)

## Generalized least squares fit by REML  
## Model: log\_Species\_CFU ~ trt \* Species \* Days   
## Data: species\_totals   
## AIC BIC logLik  
## 1152.575 1202.254 -566.2873  
##   
## Correlation Structure: AR(1)  
## Formula: ~1 | ID   
## Parameter estimate(s):  
## Phi   
## 0.7044421   
##   
## Coefficients:  
## Value Std.Error t-value p-value  
## (Intercept) 8.449247 0.08746925 96.59676 0.0000  
## trtLS 0.161536 0.12345741 1.30844 0.1910  
## SpeciesSph -0.287981 0.03451189 -8.34439 0.0000  
## Days 0.007571 0.00165217 4.58232 0.0000  
## trtLS:SpeciesSph -0.309789 0.04944622 -6.26517 0.0000  
## trtLS:Days -0.003094 0.00225549 -1.37173 0.1704  
## SpeciesSph:Days -0.004697 0.00064747 -7.25467 0.0000  
## trtLS:SpeciesSph:Days 0.005721 0.00092182 6.20633 0.0000  
##   
## Correlation:   
## (Intr) trtLS SpcsSp Days trLS:SS trLS:D SpcS:D  
## trtLS -0.708   
## SpeciesSph -0.221 0.156   
## Days -0.774 0.548 0.199   
## trtLS:SpeciesSph 0.154 -0.224 -0.698 -0.139   
## trtLS:Days 0.567 -0.769 -0.145 -0.733 0.208   
## SpeciesSph:Days 0.145 -0.102 -0.808 -0.189 0.564 0.138   
## trtLS:SpeciesSph:Days -0.102 0.145 0.568 0.133 -0.812 -0.196 -0.702  
##   
## Standardized residuals:  
## Min Q1 Med Q3 Max   
## -3.5987600 -0.1594844 0.2587886 0.7152675 2.1065963   
##   
## Residual standard error: 0.5581709   
## Degrees of freedom: 1070 total; 1062 residual

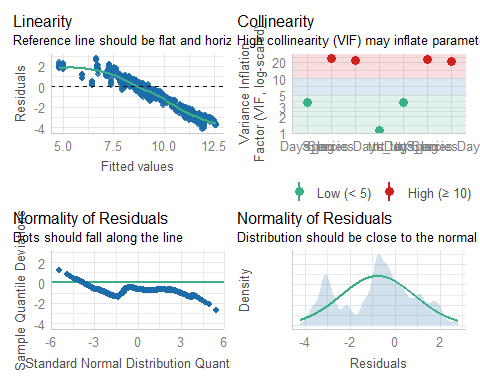
anova(model1\_AR1,model\_ar1)

## Warning in nlme::anova.lme(object = model1\_AR1, model\_ar1): fitted objects with different fixed effects. REML comparisons are not meaningful.

## Model df AIC BIC logLik  
## model1\_AR1 1 10 821.065 870.7441 -400.5325  
## model\_ar1 2 10 1152.575 1202.2538 -566.2873

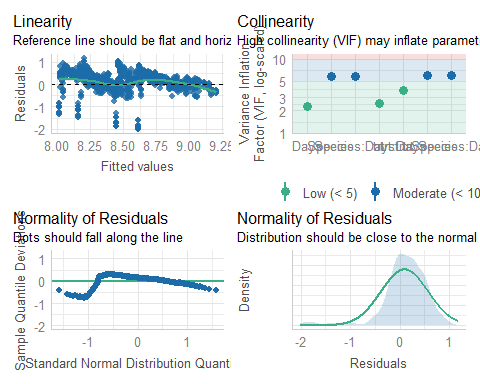
# Diagnostic checks  
library(performance)  
check\_model(model1\_AR1)

## Converting missing values (`NA`) into regular values currently not possible for variables of class `NULL`.



check\_model(model\_ar1)

## Converting missing values (`NA`) into regular values currently not possible for variables of class `NULL`.



###(d) Toeplitz (TOEP) Covariance Allows correlations to vary with time lag but remains constant for observations at the same lag.

library(glmmTMB)  
  
  
model1\_toep <- glmmTMB(  
 log\_Species\_CFU ~ Days\_log\*Species\*trt + toep(Days\_log + 0 | ID),  
 data = species\_totals,  
 #dispformula = ~ 0, # Assume Residual variance is the same across trt groups.  
 #dispformula = ~ species, # Residual variance is allowed to differ by species.  
 #Without dispformula # Residual variance is estimated freely for each group.  
 REML = TRUE)  
  
summary(model1\_toep) # 1487.2

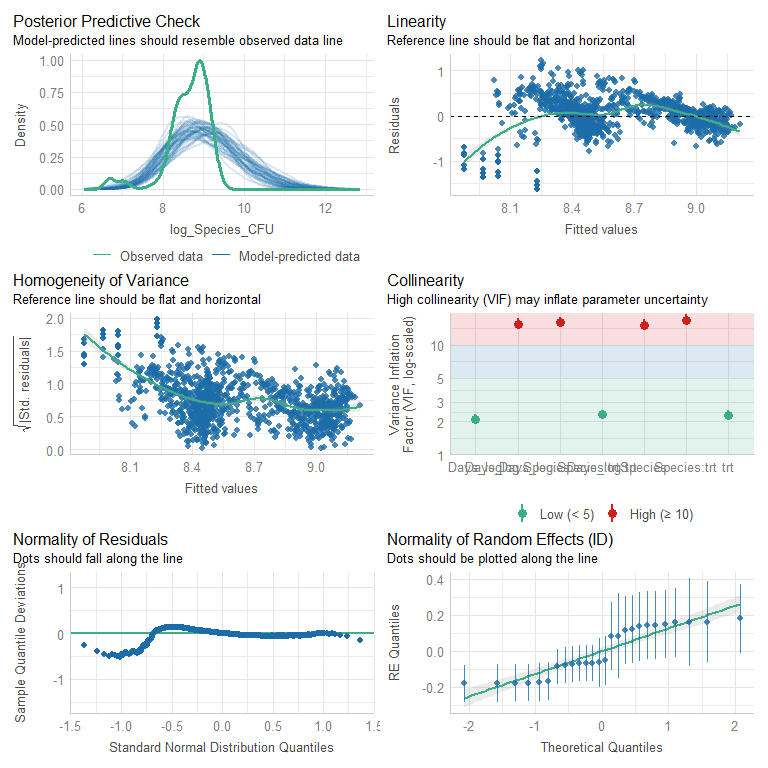
## Family: gaussian ( identity )  
## Formula: log\_Species\_CFU ~ Days\_log \* Species \* trt + toep(Days\_log + 0 | ID)  
## Data: species\_totals  
##   
## AIC BIC logLik deviance df.resid   
## 1294.3 1344.0 -637.1 1274.3 1060   
##   
## Random effects:  
##   
## Conditional model:  
## Groups Name Variance Std.Dev. Corr  
## ID Days\_log 0.02403 0.155   
## Residual 0.17472 0.418   
## Number of obs: 1070, groups: ID, 26  
##   
## Dispersion estimate for gaussian family (sigma^2): 0.175   
##   
## Conditional model:  
## Estimate Std. Error z value Pr(>|z|)   
## (Intercept) 7.96961 0.07528 105.87 < 2e-16 \*\*\*  
## Days\_log 0.43372 0.05932 7.31 2.64e-13 \*\*\*  
## SpeciesSph 0.07218 0.09966 0.72 0.46895   
## trtLS 0.26128 0.10579 2.47 0.01352 \*   
## Days\_log:SpeciesSph -0.15926 0.02845 -5.60 2.18e-08 \*\*\*  
## Days\_log:trtLS -0.16405 0.07808 -2.10 0.03562 \*   
## SpeciesSph:trtLS -0.42660 0.14419 -2.96 0.00309 \*\*   
## Days\_log:SpeciesSph:trtLS 0.11012 0.04094 2.69 0.00715 \*\*   
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1

############# select model2\_toep  
model2\_toep <- glmmTMB(  
 log\_Species\_CFU ~ Days\_log\*Species\*trt + toep(Days\_log + 0 | ID),  
 data = species\_totals,  
 #dispformula = ~ 0, # Assume Residual variance is the same across trt groups.  
 dispformula = ~ Species, # Residual variance is allowed to differ by species.  
 #none # Residual variance is estimated freely for each group.  
 REML = TRUE)  
  
summary(model2\_toep) # 1463.8

## Family: gaussian ( identity )  
## Formula: log\_Species\_CFU ~ Days\_log \* Species \* trt + toep(Days\_log + 0 | ID)  
## Dispersion: ~Species  
## Data: species\_totals  
##   
## AIC BIC logLik deviance df.resid   
## 1285.0 1339.7 -631.5 1263.0 1059   
##   
## Random effects:  
##   
## Conditional model:  
## Groups Name Variance Std.Dev. Corr  
## ID Days\_log 0.02224 0.1491   
## Residual NA NA   
## Number of obs: 1070, groups: ID, 26  
##   
## Conditional model:  
## Estimate Std. Error z value Pr(>|z|)   
## (Intercept) 7.97455 0.08002 99.66 < 2e-16 \*\*\*  
## Days\_log 0.42659 0.05871 7.27 3.71e-13 \*\*\*  
## SpeciesSph 0.07218 0.09975 0.72 0.46932   
## trtLS 0.26122 0.11276 2.32 0.02052 \*   
## Days\_log:SpeciesSph -0.15927 0.02848 -5.59 2.24e-08 \*\*\*  
## Days\_log:trtLS -0.16401 0.07688 -2.13 0.03290 \*   
## SpeciesSph:trtLS -0.42664 0.14433 -2.96 0.00312 \*\*   
## Days\_log:SpeciesSph:trtLS 0.11012 0.04098 2.69 0.00720 \*\*   
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Dispersion model:  
## Estimate Std. Error z value Pr(>|z|)   
## (Intercept) -0.80333 0.03118 -25.765 < 2e-16 \*\*\*  
## SpeciesSph -0.14700 0.04364 -3.368 0.000757 \*\*\*  
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1

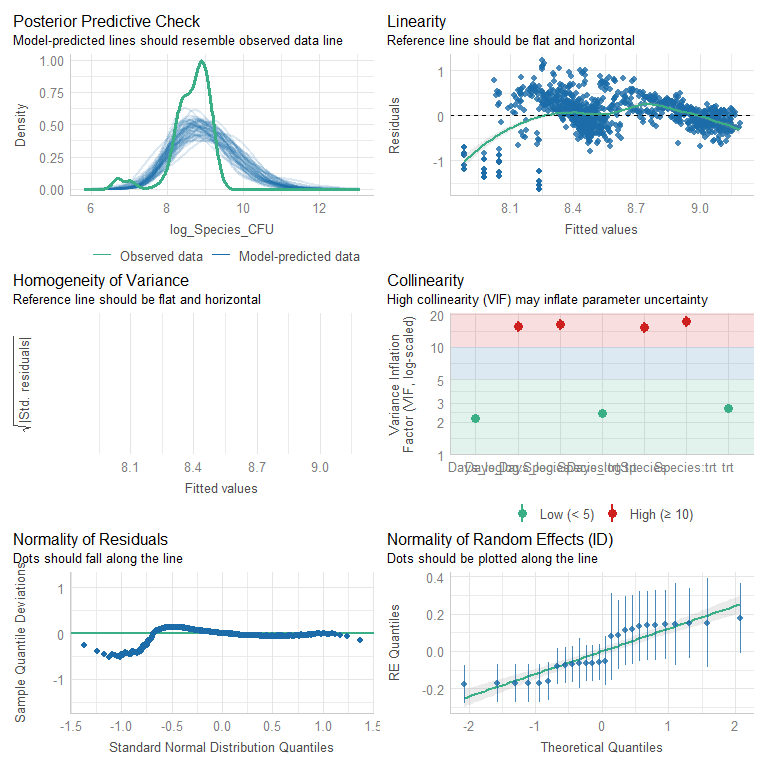
# Diagnostic checks  
library(performance)  
check\_model(model1\_toep)

## `check\_outliers()` does not yet support models of class `glmmTMB`.



check\_model(model2\_toep)

## `check\_outliers()` does not yet support models of class `glmmTMB`.



### (e) sum

# Call AIC, BIC, and logLik for each model manually  
models <- list(  
 CS = model\_CS,  
 cs = model\_cs,  
 AR1 = model1\_AR1,  
 ar1 = model\_ar1,  
 TOEP = model1\_toep,  
 TOEP\_disp\_species = model2\_toep  
 #TOEP\_scaled = model\_toep\_scaled  
)  
  
# Create an empty data frame to store the results  
results <- data.frame(  
 Model = character(),  
 AIC = numeric(),  
 BIC = numeric(),  
 logLik = numeric(),  
 stringsAsFactors = FALSE  
)  
  
# Loop through each model and extract the metrics  
for (model\_name in names(models)) {  
 model <- models[[model\_name]]  
   
 if (!is.null(model)) {  
 results <- rbind(results, data.frame(  
 Model = model\_name,  
 AIC = AIC(model),  
 BIC = BIC(model),  
 logLik = logLik(model)  
 ))  
 }  
}  
  
# Display the results  
print(results)

## Model AIC BIC logLik  
## 1 CS 1293.588 1343.2675 -636.7942  
## 2 cs 1484.411 1534.0904 -732.2056  
## 3 AR1 821.065 870.7441 -400.5325  
## 4 ar1 1152.575 1202.2538 -566.2873  
## 5 TOEP 1294.278 1344.0322 -637.1390  
## 6 TOEP\_disp\_species 1284.973 1339.7029 -631.4867

CONCLUSION: The AR(1) model, with its lowest AIC and BIC values, highest log-likelihood, and parsimonious structure, provides the best fit for modeling the CFU dynamics, effectively capturing the exponential decay in correlations over time while maintaining computational efficiency.

#Research Question 3: What are the differences in growth trajectories between Ralstonia and Sphingomonas under LS and 1G conditions over time?

#### LMM\_poly

model\_species\_REML\_poly2 <- lmer(  
 log\_Species\_CFU ~ poly(Days, 2) \* trt \* Species + (1 | ID),  
 data = species\_totals, REML = TRUE)

## boundary (singular) fit: see help('isSingular')

model\_species\_REML\_poly3 <- lmer(  
 log\_Species\_CFU ~ poly(Days, 3) \* trt \* Species + (1 | ID),  
 data = species\_totals, REML = TRUE)

## boundary (singular) fit: see help('isSingular')

model\_species\_REML\_poly4 <- lmer(  
 log\_Species\_CFU ~ poly(Days, 4) \* trt \* Species + (1 | ID),  
 data = species\_totals, REML = TRUE)

## boundary (singular) fit: see help('isSingular')

model\_species\_REML\_poly5 <- lmer(  
 log\_Species\_CFU ~ poly(Days, 5) \* trt \* Species + (1 | ID),  
 data = species\_totals, REML = TRUE)

## boundary (singular) fit: see help('isSingular')

model\_species\_REML\_poly6 <- lmer(  
 log\_Species\_CFU ~ poly(Days, 6) \* trt \* Species + (1 | ID),  
 data = species\_totals, REML = TRUE)

## boundary (singular) fit: see help('isSingular')

model\_species\_REML\_poly8 <- lmer(  
 log\_Species\_CFU ~ poly(Days, 8) \* trt \* Species + (1 | ID),  
 data = species\_totals, REML = TRUE)

## boundary (singular) fit: see help('isSingular')

model\_species\_REML\_poly10 <- lmer(  
 log\_Species\_CFU ~ poly(Days, 10) \* trt \* Species + (1 | ID),  
 data = species\_totals, REML = TRUE)

## boundary (singular) fit: see help('isSingular')

summary(model\_species\_REML\_poly10)

## Linear mixed model fit by REML. t-tests use Satterthwaite's method ['lmerModLmerTest']  
## Formula: log\_Species\_CFU ~ poly(Days, 10) \* trt \* Species + (1 | ID)  
## Data: species\_totals  
##   
## REML criterion at convergence: 182.4  
##   
## Scaled residuals:   
## Min 1Q Median 3Q Max   
## -4.4102 -0.4647 0.0283 0.5233 3.1296   
##   
## Random effects:  
## Groups Name Variance Std.Dev.  
## ID (Intercept) 0.00000 0.0000   
## Residual 0.07224 0.2688   
## Number of obs: 1070, groups: ID, 26  
##   
## Fixed effects:  
## Estimate Std. Error df t value Pr(>|t|)   
## (Intercept) 8.84920 0.01639 1026.00000 539.808 < 2e-16 \*\*\*  
## poly(Days, 10)1 4.93712 0.53553 1026.00000 9.219 < 2e-16 \*\*\*  
## poly(Days, 10)2 -3.93625 0.53701 1026.00000 -7.330 4.66e-13 \*\*\*  
## poly(Days, 10)3 3.72786 0.53671 1026.00000 6.946 6.67e-12 \*\*\*  
## poly(Days, 10)4 -6.02471 0.53713 1026.00000 -11.217 < 2e-16 \*\*\*  
## poly(Days, 10)5 4.05127 0.53354 1026.00000 7.593 7.00e-14 \*\*\*  
## poly(Days, 10)6 -4.76301 0.53396 1026.00000 -8.920 < 2e-16 \*\*\*  
## poly(Days, 10)7 5.44409 0.53723 1026.00000 10.134 < 2e-16 \*\*\*  
## poly(Days, 10)8 -4.16771 0.54049 1026.00000 -7.711 2.94e-14 \*\*\*  
## poly(Days, 10)9 4.41999 0.53391 1026.00000 8.279 3.85e-16 \*\*\*  
## poly(Days, 10)10 -3.59767 0.52828 1026.00000 -6.810 1.66e-11 \*\*\*  
## trtLS 0.03593 0.02329 1026.00000 1.542 0.12332   
## SpeciesSph -0.45140 0.02316 1026.00000 -19.489 < 2e-16 \*\*\*  
## poly(Days, 10)1:trtLS -2.23565 0.76132 1026.00000 -2.937 0.00339 \*\*   
## poly(Days, 10)2:trtLS -0.75644 0.76199 1026.00000 -0.993 0.32108   
## poly(Days, 10)3:trtLS 2.08168 0.76103 1026.00000 2.735 0.00634 \*\*   
## poly(Days, 10)4:trtLS 0.12181 0.76220 1026.00000 0.160 0.87306   
## poly(Days, 10)5:trtLS 0.99237 0.76207 1026.00000 1.302 0.19314   
## poly(Days, 10)6:trtLS -0.29314 0.76180 1026.00000 -0.385 0.70047   
## poly(Days, 10)7:trtLS -0.84840 0.76206 1026.00000 -1.113 0.26584   
## poly(Days, 10)8:trtLS -0.10442 0.76203 1026.00000 -0.137 0.89103   
## poly(Days, 10)9:trtLS -0.32866 0.76322 1026.00000 -0.431 0.66683   
## poly(Days, 10)10:trtLS 0.39319 0.76299 1026.00000 0.515 0.60643   
## poly(Days, 10)1:SpeciesSph -7.07194 0.75729 1026.00000 -9.338 < 2e-16 \*\*\*  
## poly(Days, 10)2:SpeciesSph 0.45628 0.75848 1026.00000 0.602 0.54760   
## poly(Days, 10)3:SpeciesSph 1.36020 0.75896 1026.00000 1.792 0.07340 .   
## poly(Days, 10)4:SpeciesSph -0.29622 0.75857 1026.00000 -0.390 0.69625   
## poly(Days, 10)5:SpeciesSph -0.74121 0.75441 1026.00000 -0.983 0.32608   
## poly(Days, 10)6:SpeciesSph 1.70129 0.75428 1026.00000 2.256 0.02431 \*   
## poly(Days, 10)7:SpeciesSph -1.45704 0.75957 1026.00000 -1.918 0.05536 .   
## poly(Days, 10)8:SpeciesSph 1.56867 0.76338 1026.00000 2.055 0.04014 \*   
## poly(Days, 10)9:SpeciesSph -1.52683 0.75472 1026.00000 -2.023 0.04333 \*   
## poly(Days, 10)10:SpeciesSph 1.44044 0.74626 1026.00000 1.930 0.05386 .   
## trtLS:SpeciesSph -0.06459 0.03288 1026.00000 -1.964 0.04976 \*   
## poly(Days, 10)1:trtLS:SpeciesSph 6.00787 1.07585 1026.00000 5.584 3.00e-08 \*\*\*  
## poly(Days, 10)2:trtLS:SpeciesSph -0.30652 1.07579 1026.00000 -0.285 0.77576   
## poly(Days, 10)3:trtLS:SpeciesSph -2.68792 1.07562 1026.00000 -2.499 0.01261 \*   
## poly(Days, 10)4:trtLS:SpeciesSph 1.72841 1.07559 1026.00000 1.607 0.10838   
## poly(Days, 10)5:trtLS:SpeciesSph -0.09202 1.07593 1026.00000 -0.086 0.93186   
## poly(Days, 10)6:trtLS:SpeciesSph 0.52820 1.07614 1026.00000 0.491 0.62365   
## poly(Days, 10)7:trtLS:SpeciesSph -0.45167 1.07637 1026.00000 -0.420 0.67485   
## poly(Days, 10)8:trtLS:SpeciesSph 0.94637 1.07620 1026.00000 0.879 0.37941   
## poly(Days, 10)9:trtLS:SpeciesSph -0.44348 1.07640 1026.00000 -0.412 0.68042   
## poly(Days, 10)10:trtLS:SpeciesSph 1.10932 1.07746 1026.00000 1.030 0.30346   
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1

##   
## Correlation matrix not shown by default, as p = 44 > 12.  
## Use print(x, correlation=TRUE) or  
## vcov(x) if you need it

## optimizer (nloptwrap) convergence code: 0 (OK)  
## boundary (singular) fit: see help('isSingular')

anova(model\_species\_REML\_poly10, type = "III")

## Type III Analysis of Variance Table with Satterthwaite's method  
## Sum Sq Mean Sq NumDF DenDF F value Pr(>F)   
## poly(Days, 10) 152.410 15.241 10 1026 210.9893 < 2.2e-16 \*\*\*  
## trt 0.004 0.004 1 1026 0.0488 0.82516   
## Species 62.531 62.531 1 1026 865.6545 < 2.2e-16 \*\*\*  
## poly(Days, 10):trt 1.578 0.158 10 1026 2.1845 0.01671 \*   
## poly(Days, 10):Species 8.842 0.884 10 1026 12.2398 < 2.2e-16 \*\*\*  
## trt:Species 0.279 0.279 1 1026 3.8585 0.04976 \*   
## poly(Days, 10):trt:Species 3.073 0.307 10 1026 4.2538 8.001e-06 \*\*\*  
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1

# compare  
anova(model\_mixed, model\_species\_REML\_poly2) # p < 2.2e-16

## refitting model(s) with ML (instead of REML)

## Data: species\_totals  
## Models:  
## model\_mixed: log\_Species\_CFU ~ Days \* trt \* Species + (1 | ID)  
## model\_species\_REML\_poly2: log\_Species\_CFU ~ poly(Days, 2) \* trt \* Species + (1 | ID)  
## npar AIC BIC logLik deviance Chisq Df Pr(>Chisq)   
## model\_mixed 10 1417.4 1467.1 -698.68 1397.4   
## model\_species\_REML\_poly2 14 1341.9 1411.5 -656.93 1313.9 83.506 4 < 2.2e-16 \*\*\*  
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1

anova(model\_species\_REML\_poly5, model\_species\_REML\_poly6) # p < 2.2e-16

## refitting model(s) with ML (instead of REML)

## Data: species\_totals  
## Models:  
## model\_species\_REML\_poly5: log\_Species\_CFU ~ poly(Days, 5) \* trt \* Species + (1 | ID)  
## model\_species\_REML\_poly6: log\_Species\_CFU ~ poly(Days, 6) \* trt \* Species + (1 | ID)  
## npar AIC BIC logLik deviance Chisq Df Pr(>Chisq)   
## model\_species\_REML\_poly5 26 912.30 1041.66 -430.15 860.30   
## model\_species\_REML\_poly6 30 786.29 935.55 -363.15 726.29 134.01 4 < 2.2e-16 \*\*\*  
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1

anova(model\_species\_REML\_poly6, model\_species\_REML\_poly10) # p < 2.2e-16

## refitting model(s) with ML (instead of REML)

## Data: species\_totals  
## Models:  
## model\_species\_REML\_poly6: log\_Species\_CFU ~ poly(Days, 6) \* trt \* Species + (1 | ID)  
## model\_species\_REML\_poly10: log\_Species\_CFU ~ poly(Days, 10) \* trt \* Species + (1 | ID)  
## npar AIC BIC logLik deviance Chisq Df Pr(>Chisq)   
## model\_species\_REML\_poly6 30 786.29 935.55 -363.15 726.29   
## model\_species\_REML\_poly10 46 271.83 500.70 -89.92 179.83 546.46 16 < 2.2e-16 \*\*\*  
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1

cat("\n \*AIC(model\_species\_REML) = ",AIC(model\_mixed)) # 1487.367

##   
## \*AIC(model\_species\_REML) = 1487.367

cat("\n \*AIC(model\_species\_REML\_poly2) = ",AIC(model\_species\_REML\_poly2))# 1350.321

##   
## \*AIC(model\_species\_REML\_poly2) = 1350.321

cat("\n \*AIC(model\_species\_REML\_poly3) = ",AIC(model\_species\_REML\_poly3))# 1229.857

##   
## \*AIC(model\_species\_REML\_poly3) = 1229.857

cat("\n \*AIC(model\_species\_REML\_poly4) = ",AIC(model\_species\_REML\_poly4))# 1032.717

##   
## \*AIC(model\_species\_REML\_poly4) = 1032.717

cat("\n \*AIC(model\_species\_REML\_poly5) = ",AIC(model\_species\_REML\_poly5))# 911.3526

##   
## \*AIC(model\_species\_REML\_poly5) = 911.3526

cat("\n \*AIC(model\_species\_REML\_poly6) = ",AIC(model\_species\_REML\_poly6))# 783.9919

##   
## \*AIC(model\_species\_REML\_poly6) = 783.9919

cat("\n \*AIC(model\_species\_REML\_poly8) = ",AIC(model\_species\_REML\_poly8))# 502.4344

##   
## \*AIC(model\_species\_REML\_poly8) = 502.4344

cat("\n \*AIC(model\_species\_REML\_poly10) = ",AIC(model\_species\_REML\_poly10)) #274.3817

##   
## \*AIC(model\_species\_REML\_poly10) = 274.3817

#### ar1\_poly\_nested

## 1. Polynomial Terms for AR(1) Structure with Nested Random Effects (Days\_log)

# model\_species\_REML\_poly10  
  
# LMM\_poly\_ML  
LMM\_poly\_ML <- lmer(  
 log\_Species\_CFU ~ poly (Days, 10) \* trt \* Species + (1 | ID),  
 data = species\_totals,  
 REML = FALSE  
)

## boundary (singular) fit: see help('isSingular')

############ AR(1)\_poly\_nested (Days-log)  
  
  
# Add log-polynomial terms to species\_totals  
species\_totals <- species\_totals %>%  
 mutate(  
 Days\_log\_sq = Days\_log^2,  
 Days\_log\_cub = Days\_log^3,  
 Days\_log\_4th = Days\_log^4,  
 Days\_log\_5th = Days\_log^5,  
 Days\_log\_6th = Days\_log^6,  
 Days\_log\_7th = Days\_log^7,  
 Days\_log\_8th = Days\_log^8,  
 Days\_log\_9th = Days\_log^9,  
 Days\_log\_10th = Days\_log^10  
 )  
  
  
#log-polynomial ar1\_poly\_nested  
ar1\_poly\_nested <- gls(log\_Species\_CFU ~   
 (Days\_log + Days\_log\_sq + Days\_log\_cub + Days\_log\_4th + Days\_log\_5th + Days\_log\_6th + Days\_log\_7th + Days\_log\_8th + Days\_log\_9th + Days\_log\_10th) : trt : Species,  
 data = species\_totals,   
 correlation = corAR1(form = ~ 1 | ID),   
 method = "REML")  
summary(ar1\_poly\_nested)

## Generalized least squares fit by REML  
## Model: log\_Species\_CFU ~ (Days\_log + Days\_log\_sq + Days\_log\_cub + Days\_log\_4th + Days\_log\_5th + Days\_log\_6th + Days\_log\_7th + Days\_log\_8th + Days\_log\_9th + Days\_log\_10th):trt:Species   
## Data: species\_totals   
## AIC BIC logLik  
## -140.2001 72.06263 113.1001  
##   
## Correlation Structure: AR(1)  
## Formula: ~1 | ID   
## Parameter estimate(s):  
## Phi   
## -3.830269e-15   
##   
## Coefficients:  
## Value Std.Error t-value p-value  
## (Intercept) 6.856 0.0264 259.48689 0.0000  
## Days\_log:trt1G:SpeciesRal -1014.418 167.6188 -6.05193 0.0000  
## Days\_log:trtLS:SpeciesRal -832.181 175.0622 -4.75363 0.0000  
## Days\_log:trt1G:SpeciesSph -115.035 167.4189 -0.68711 0.4922  
## Days\_log:trtLS:SpeciesSph -469.351 173.9161 -2.69872 0.0071  
## Days\_log\_sq:trt1G:SpeciesRal 3644.002 614.0734 5.93415 0.0000  
## Days\_log\_sq:trtLS:SpeciesRal 2946.291 640.6308 4.59905 0.0000  
## Days\_log\_sq:trt1G:SpeciesSph 346.272 613.3209 0.56459 0.5725  
## Days\_log\_sq:trtLS:SpeciesSph 1703.640 636.5733 2.67627 0.0076  
## Days\_log\_cub:trt1G:SpeciesRal -5575.693 965.2769 -5.77626 0.0000  
## Days\_log\_cub:trtLS:SpeciesRal -4435.516 1005.7570 -4.41013 0.0000  
## Days\_log\_cub:trt1G:SpeciesSph -408.338 964.0627 -0.42356 0.6720  
## Days\_log\_cub:trtLS:SpeciesSph -2632.600 999.6474 -2.63353 0.0086  
## Days\_log\_4th:trt1G:SpeciesRal 4802.455 857.4623 5.60078 0.0000  
## Days\_log\_4th:trtLS:SpeciesRal 3756.166 892.2079 4.20997 0.0000  
## Days\_log\_4th:trt1G:SpeciesSph 241.012 856.3581 0.28144 0.7784  
## Days\_log\_4th:trtLS:SpeciesSph 2290.291 887.0540 2.58191 0.0100  
## Days\_log\_5th:trt1G:SpeciesRal -2577.052 475.7265 -5.41709 0.0000  
## Days\_log\_5th:trtLS:SpeciesRal -1981.414 494.3061 -4.00848 0.0001  
## Days\_log\_5th:trt1G:SpeciesSph -68.519 475.1016 -0.14422 0.8854  
## Days\_log\_5th:trtLS:SpeciesSph -1241.661 491.6119 -2.52569 0.0117  
## Days\_log\_6th:trt1G:SpeciesRal 896.405 171.3792 5.23054 0.0000  
## Days\_log\_6th:trtLS:SpeciesRal 677.723 177.8201 3.81129 0.0001  
## Days\_log\_6th:trt1G:SpeciesSph 2.466 171.1506 0.01441 0.9885  
## Days\_log\_6th:trtLS:SpeciesSph 436.573 176.9116 2.46775 0.0138  
## Days\_log\_7th:trt1G:SpeciesRal -202.664 40.1770 -5.04429 0.0000  
## Days\_log\_7th:trtLS:SpeciesRal -150.762 41.6290 -3.62156 0.0003  
## Days\_log\_7th:trt1G:SpeciesSph 4.306 40.1228 0.10733 0.9146  
## Days\_log\_7th:trtLS:SpeciesSph -99.850 41.4306 -2.41005 0.0161  
## Days\_log\_8th:trt1G:SpeciesRal 28.783 5.9221 4.86018 0.0000  
## Days\_log\_8th:trtLS:SpeciesRal 21.086 6.1279 3.44090 0.0006  
## Days\_log\_8th:trt1G:SpeciesSph -1.309 5.9141 -0.22131 0.8249  
## Days\_log\_8th:trtLS:SpeciesSph 14.361 6.1008 2.35387 0.0188  
## Days\_log\_9th:trt1G:SpeciesRal -2.335 0.4989 -4.67925 0.0000  
## Days\_log\_9th:trtLS:SpeciesRal -1.686 0.5156 -3.26993 0.0011  
## Days\_log\_9th:trt1G:SpeciesSph 0.164 0.4982 0.32834 0.7427  
## Days\_log\_9th:trtLS:SpeciesSph -1.181 0.5135 -2.29997 0.0216  
## Days\_log\_10th:trt1G:SpeciesRal 0.083 0.0183 4.50205 0.0000  
## Days\_log\_10th:trtLS:SpeciesRal 0.059 0.0189 3.10870 0.0019  
## Days\_log\_10th:trt1G:SpeciesSph -0.008 0.0183 -0.42931 0.6678  
## Days\_log\_10th:trtLS:SpeciesSph 0.042 0.0189 2.24873 0.0247  
##   
## Correlation:   
## (Intr) D\_:1G:SR D\_:LS:SR D\_:1G:SS D\_:LS:SS Dys\_lg\_s:1G:SR Dys\_lg\_s:LS:SR Dys\_lg\_s:1G:SS Dys\_lg\_s:LS:SS Dys\_lg\_c:1G:SR Dys\_lg\_c:LS:SR Dys\_lg\_c:1G:SS  
## Days\_log:trt1G:SpeciesRal -0.001   
## Days\_log:trtLS:SpeciesRal -0.001 0.000   
## Days\_log:trt1G:SpeciesSph -0.001 0.000 0.000   
## Days\_log:trtLS:SpeciesSph -0.001 0.000 0.000 0.000   
## Days\_log\_sq:trt1G:SpeciesRal 0.000 -1.000 0.000 0.000 0.000   
## Days\_log\_sq:trtLS:SpeciesRal 0.000 0.000 -1.000 0.000 0.000 0.000   
## Days\_log\_sq:trt1G:SpeciesSph 0.000 0.000 0.000 -1.000 0.000 0.000 0.000   
## Days\_log\_sq:trtLS:SpeciesSph 0.000 0.000 0.000 0.000 -1.000 0.000 0.000 0.000   
## Days\_log\_cub:trt1G:SpeciesRal 0.000 0.998 0.000 0.000 0.000 -1.000 0.000 0.000 0.000   
## Days\_log\_cub:trtLS:SpeciesRal 0.000 0.000 0.998 0.000 0.000 0.000 -1.000 0.000 0.000 0.000   
## Days\_log\_cub:trt1G:SpeciesSph 0.000 0.000 0.000 0.998 0.000 0.000 0.000 -1.000 0.000 0.000 0.000   
## Days\_log\_cub:trtLS:SpeciesSph 0.000 0.000 0.000 0.000 0.998 0.000 0.000 0.000 -1.000 0.000 0.000 0.000   
## Days\_log\_4th:trt1G:SpeciesRal 0.000 -0.996 0.000 0.000 0.000 0.998 0.000 0.000 0.000 -1.000 0.000 0.000   
## Days\_log\_4th:trtLS:SpeciesRal 0.000 0.000 -0.996 0.000 0.000 0.000 0.998 0.000 0.000 0.000 -1.000 0.000   
## Days\_log\_4th:trt1G:SpeciesSph 0.000 0.000 0.000 -0.996 0.000 0.000 0.000 0.998 0.000 0.000 0.000 -1.000   
## Days\_log\_4th:trtLS:SpeciesSph 0.000 0.000 0.000 0.000 -0.996 0.000 0.000 0.000 0.998 0.000 0.000 0.000   
## Days\_log\_5th:trt1G:SpeciesRal 0.000 0.993 0.000 0.000 0.000 -0.996 0.000 0.000 0.000 0.998 0.000 0.000   
## Days\_log\_5th:trtLS:SpeciesRal 0.000 0.000 0.993 0.000 0.000 0.000 -0.996 0.000 0.000 0.000 0.998 0.000   
## Days\_log\_5th:trt1G:SpeciesSph 0.000 0.000 0.000 0.993 0.000 0.000 0.000 -0.996 0.000 0.000 0.000 0.998   
## Days\_log\_5th:trtLS:SpeciesSph 0.000 0.000 0.000 0.000 0.993 0.000 0.000 0.000 -0.996 0.000 0.000 0.000   
## Days\_log\_6th:trt1G:SpeciesRal 0.000 -0.989 0.000 0.000 0.000 0.993 0.000 0.000 0.000 -0.996 0.000 0.000   
## Days\_log\_6th:trtLS:SpeciesRal 0.000 0.000 -0.989 0.000 0.000 0.000 0.993 0.000 0.000 0.000 -0.996 0.000   
## Days\_log\_6th:trt1G:SpeciesSph 0.000 0.000 0.000 -0.989 0.000 0.000 0.000 0.993 0.000 0.000 0.000 -0.996   
## Days\_log\_6th:trtLS:SpeciesSph 0.000 0.000 0.000 0.000 -0.989 0.000 0.000 0.000 0.993 0.000 0.000 0.000   
## Days\_log\_7th:trt1G:SpeciesRal 0.000 0.984 0.000 0.000 0.000 -0.989 0.000 0.000 0.000 0.993 0.000 0.000   
## Days\_log\_7th:trtLS:SpeciesRal 0.000 0.000 0.985 0.000 0.000 0.000 -0.989 0.000 0.000 0.000 0.993 0.000   
## Days\_log\_7th:trt1G:SpeciesSph 0.000 0.000 0.000 0.984 0.000 0.000 0.000 -0.989 0.000 0.000 0.000 0.993   
## Days\_log\_7th:trtLS:SpeciesSph 0.000 0.000 0.000 0.000 0.985 0.000 0.000 0.000 -0.989 0.000 0.000 0.000   
## Days\_log\_8th:trt1G:SpeciesRal 0.000 -0.979 0.000 0.000 0.000 0.984 0.000 0.000 0.000 -0.989 0.000 0.000   
## Days\_log\_8th:trtLS:SpeciesRal 0.000 0.000 -0.980 0.000 0.000 0.000 0.985 0.000 0.000 0.000 -0.989 0.000   
## Days\_log\_8th:trt1G:SpeciesSph 0.000 0.000 0.000 -0.979 0.000 0.000 0.000 0.984 0.000 0.000 0.000 -0.989   
## Days\_log\_8th:trtLS:SpeciesSph 0.000 0.000 0.000 0.000 -0.980 0.000 0.000 0.000 0.985 0.000 0.000 0.000   
## Days\_log\_9th:trt1G:SpeciesRal 0.000 0.973 0.000 0.000 0.000 -0.979 0.000 0.000 0.000 0.984 0.000 0.000   
## Days\_log\_9th:trtLS:SpeciesRal 0.000 0.000 0.974 0.000 0.000 0.000 -0.980 0.000 0.000 0.000 0.985 0.000   
## Days\_log\_9th:trt1G:SpeciesSph 0.000 0.000 0.000 0.973 0.000 0.000 0.000 -0.979 0.000 0.000 0.000 0.984   
## Days\_log\_9th:trtLS:SpeciesSph 0.000 0.000 0.000 0.000 0.974 0.000 0.000 0.000 -0.980 0.000 0.000 0.000   
## Days\_log\_10th:trt1G:SpeciesRal 0.000 -0.967 0.000 0.000 0.000 0.973 0.000 0.000 0.000 -0.980 0.000 0.000   
## Days\_log\_10th:trtLS:SpeciesRal 0.000 0.000 -0.968 0.000 0.000 0.000 0.974 0.000 0.000 0.000 -0.980 0.000   
## Days\_log\_10th:trt1G:SpeciesSph 0.000 0.000 0.000 -0.966 0.000 0.000 0.000 0.973 0.000 0.000 0.000 -0.979   
## Days\_log\_10th:trtLS:SpeciesSph 0.000 0.000 0.000 0.000 -0.968 0.000 0.000 0.000 0.975 0.000 0.000 0.000   
## Dys\_lg\_c:LS:SS D\_\_4:1G:SR D\_\_4:LS:SR D\_\_4:1G:SS D\_\_4:LS:SS D\_\_5:1G:SR D\_\_5:LS:SR D\_\_5:1G:SS D\_\_5:LS:SS D\_\_6:1G:SR D\_\_6:LS:SR D\_\_6:1G:SS D\_\_6:LS:SS  
## Days\_log:trt1G:SpeciesRal   
## Days\_log:trtLS:SpeciesRal   
## Days\_log:trt1G:SpeciesSph   
## Days\_log:trtLS:SpeciesSph   
## Days\_log\_sq:trt1G:SpeciesRal   
## Days\_log\_sq:trtLS:SpeciesRal   
## Days\_log\_sq:trt1G:SpeciesSph   
## Days\_log\_sq:trtLS:SpeciesSph   
## Days\_log\_cub:trt1G:SpeciesRal   
## Days\_log\_cub:trtLS:SpeciesRal   
## Days\_log\_cub:trt1G:SpeciesSph   
## Days\_log\_cub:trtLS:SpeciesSph   
## Days\_log\_4th:trt1G:SpeciesRal 0.000   
## Days\_log\_4th:trtLS:SpeciesRal 0.000 0.000   
## Days\_log\_4th:trt1G:SpeciesSph 0.000 0.000 0.000   
## Days\_log\_4th:trtLS:SpeciesSph -1.000 0.000 0.000 0.000   
## Days\_log\_5th:trt1G:SpeciesRal 0.000 -1.000 0.000 0.000 0.000   
## Days\_log\_5th:trtLS:SpeciesRal 0.000 0.000 -1.000 0.000 0.000 0.000   
## Days\_log\_5th:trt1G:SpeciesSph 0.000 0.000 0.000 -1.000 0.000 0.000 0.000   
## Days\_log\_5th:trtLS:SpeciesSph 0.998 0.000 0.000 0.000 -1.000 0.000 0.000 0.000   
## Days\_log\_6th:trt1G:SpeciesRal 0.000 0.998 0.000 0.000 0.000 -1.000 0.000 0.000 0.000   
## Days\_log\_6th:trtLS:SpeciesRal 0.000 0.000 0.998 0.000 0.000 0.000 -1.000 0.000 0.000 0.000   
## Days\_log\_6th:trt1G:SpeciesSph 0.000 0.000 0.000 0.998 0.000 0.000 0.000 -1.000 0.000 0.000 0.000   
## Days\_log\_6th:trtLS:SpeciesSph -0.996 0.000 0.000 0.000 0.998 0.000 0.000 0.000 -1.000 0.000 0.000 0.000   
## Days\_log\_7th:trt1G:SpeciesRal 0.000 -0.996 0.000 0.000 0.000 0.998 0.000 0.000 0.000 -1.000 0.000 0.000 0.000   
## Days\_log\_7th:trtLS:SpeciesRal 0.000 0.000 -0.996 0.000 0.000 0.000 0.998 0.000 0.000 0.000 -1.000 0.000 0.000   
## Days\_log\_7th:trt1G:SpeciesSph 0.000 0.000 0.000 -0.996 0.000 0.000 0.000 0.998 0.000 0.000 0.000 -1.000 0.000   
## Days\_log\_7th:trtLS:SpeciesSph 0.993 0.000 0.000 0.000 -0.996 0.000 0.000 0.000 0.998 0.000 0.000 0.000 -1.000   
## Days\_log\_8th:trt1G:SpeciesRal 0.000 0.993 0.000 0.000 0.000 -0.996 0.000 0.000 0.000 0.998 0.000 0.000 0.000   
## Days\_log\_8th:trtLS:SpeciesRal 0.000 0.000 0.993 0.000 0.000 0.000 -0.996 0.000 0.000 0.000 0.998 0.000 0.000   
## Days\_log\_8th:trt1G:SpeciesSph 0.000 0.000 0.000 0.993 0.000 0.000 0.000 -0.996 0.000 0.000 0.000 0.998 0.000   
## Days\_log\_8th:trtLS:SpeciesSph -0.989 0.000 0.000 0.000 0.993 0.000 0.000 0.000 -0.996 0.000 0.000 0.000 0.998   
## Days\_log\_9th:trt1G:SpeciesRal 0.000 -0.989 0.000 0.000 0.000 0.993 0.000 0.000 0.000 -0.996 0.000 0.000 0.000   
## Days\_log\_9th:trtLS:SpeciesRal 0.000 0.000 -0.990 0.000 0.000 0.000 0.994 0.000 0.000 0.000 -0.996 0.000 0.000   
## Days\_log\_9th:trt1G:SpeciesSph 0.000 0.000 0.000 -0.989 0.000 0.000 0.000 0.993 0.000 0.000 0.000 -0.996 0.000   
## Days\_log\_9th:trtLS:SpeciesSph 0.985 0.000 0.000 0.000 -0.990 0.000 0.000 0.000 0.994 0.000 0.000 0.000 -0.996   
## Days\_log\_10th:trt1G:SpeciesRal 0.000 0.985 0.000 0.000 0.000 -0.990 0.000 0.000 0.000 0.994 0.000 0.000 0.000   
## Days\_log\_10th:trtLS:SpeciesRal 0.000 0.000 0.986 0.000 0.000 0.000 -0.990 0.000 0.000 0.000 0.994 0.000 0.000   
## Days\_log\_10th:trt1G:SpeciesSph 0.000 0.000 0.000 0.985 0.000 0.000 0.000 -0.990 0.000 0.000 0.000 0.994 0.000   
## Days\_log\_10th:trtLS:SpeciesSph -0.980 0.000 0.000 0.000 0.986 0.000 0.000 0.000 -0.990 0.000 0.000 0.000 0.994   
## D\_\_7:1G:SR D\_\_7:LS:SR D\_\_7:1G:SS D\_\_7:LS:SS D\_\_8:1G:SR D\_\_8:LS:SR D\_\_8:1G:SS D\_\_8:LS:SS D\_\_9:1G:SR D\_\_9:LS:SR D\_\_9:1G:SS D\_\_9:LS:SS D\_\_10:1G:SR  
## Days\_log:trt1G:SpeciesRal   
## Days\_log:trtLS:SpeciesRal   
## Days\_log:trt1G:SpeciesSph   
## Days\_log:trtLS:SpeciesSph   
## Days\_log\_sq:trt1G:SpeciesRal   
## Days\_log\_sq:trtLS:SpeciesRal   
## Days\_log\_sq:trt1G:SpeciesSph   
## Days\_log\_sq:trtLS:SpeciesSph   
## Days\_log\_cub:trt1G:SpeciesRal   
## Days\_log\_cub:trtLS:SpeciesRal   
## Days\_log\_cub:trt1G:SpeciesSph   
## Days\_log\_cub:trtLS:SpeciesSph   
## Days\_log\_4th:trt1G:SpeciesRal   
## Days\_log\_4th:trtLS:SpeciesRal   
## Days\_log\_4th:trt1G:SpeciesSph   
## Days\_log\_4th:trtLS:SpeciesSph   
## Days\_log\_5th:trt1G:SpeciesRal   
## Days\_log\_5th:trtLS:SpeciesRal   
## Days\_log\_5th:trt1G:SpeciesSph   
## Days\_log\_5th:trtLS:SpeciesSph   
## Days\_log\_6th:trt1G:SpeciesRal   
## Days\_log\_6th:trtLS:SpeciesRal   
## Days\_log\_6th:trt1G:SpeciesSph   
## Days\_log\_6th:trtLS:SpeciesSph   
## Days\_log\_7th:trt1G:SpeciesRal   
## Days\_log\_7th:trtLS:SpeciesRal 0.000   
## Days\_log\_7th:trt1G:SpeciesSph 0.000 0.000   
## Days\_log\_7th:trtLS:SpeciesSph 0.000 0.000 0.000   
## Days\_log\_8th:trt1G:SpeciesRal -1.000 0.000 0.000 0.000   
## Days\_log\_8th:trtLS:SpeciesRal 0.000 -1.000 0.000 0.000 0.000   
## Days\_log\_8th:trt1G:SpeciesSph 0.000 0.000 -1.000 0.000 0.000 0.000   
## Days\_log\_8th:trtLS:SpeciesSph 0.000 0.000 0.000 -1.000 0.000 0.000 0.000   
## Days\_log\_9th:trt1G:SpeciesRal 0.998 0.000 0.000 0.000 -1.000 0.000 0.000 0.000   
## Days\_log\_9th:trtLS:SpeciesRal 0.000 0.998 0.000 0.000 0.000 -1.000 0.000 0.000 0.000   
## Days\_log\_9th:trt1G:SpeciesSph 0.000 0.000 0.998 0.000 0.000 0.000 -1.000 0.000 0.000 0.000   
## Days\_log\_9th:trtLS:SpeciesSph 0.000 0.000 0.000 0.998 0.000 0.000 0.000 -1.000 0.000 0.000 0.000   
## Days\_log\_10th:trt1G:SpeciesRal -0.997 0.000 0.000 0.000 0.998 0.000 0.000 0.000 -1.000 0.000 0.000 0.000   
## Days\_log\_10th:trtLS:SpeciesRal 0.000 -0.997 0.000 0.000 0.000 0.999 0.000 0.000 0.000 -1.000 0.000 0.000 0.000   
## Days\_log\_10th:trt1G:SpeciesSph 0.000 0.000 -0.997 0.000 0.000 0.000 0.998 0.000 0.000 0.000 -1.000 0.000 0.000   
## Days\_log\_10th:trtLS:SpeciesSph 0.000 0.000 0.000 -0.997 0.000 0.000 0.000 0.999 0.000 0.000 0.000 -1.000 0.000   
## D\_\_10:LS:SR D\_\_10:1G:SS  
## Days\_log:trt1G:SpeciesRal   
## Days\_log:trtLS:SpeciesRal   
## Days\_log:trt1G:SpeciesSph   
## Days\_log:trtLS:SpeciesSph   
## Days\_log\_sq:trt1G:SpeciesRal   
## Days\_log\_sq:trtLS:SpeciesRal   
## Days\_log\_sq:trt1G:SpeciesSph   
## Days\_log\_sq:trtLS:SpeciesSph   
## Days\_log\_cub:trt1G:SpeciesRal   
## Days\_log\_cub:trtLS:SpeciesRal   
## Days\_log\_cub:trt1G:SpeciesSph   
## Days\_log\_cub:trtLS:SpeciesSph   
## Days\_log\_4th:trt1G:SpeciesRal   
## Days\_log\_4th:trtLS:SpeciesRal   
## Days\_log\_4th:trt1G:SpeciesSph   
## Days\_log\_4th:trtLS:SpeciesSph   
## Days\_log\_5th:trt1G:SpeciesRal   
## Days\_log\_5th:trtLS:SpeciesRal   
## Days\_log\_5th:trt1G:SpeciesSph   
## Days\_log\_5th:trtLS:SpeciesSph   
## Days\_log\_6th:trt1G:SpeciesRal   
## Days\_log\_6th:trtLS:SpeciesRal   
## Days\_log\_6th:trt1G:SpeciesSph   
## Days\_log\_6th:trtLS:SpeciesSph   
## Days\_log\_7th:trt1G:SpeciesRal   
## Days\_log\_7th:trtLS:SpeciesRal   
## Days\_log\_7th:trt1G:SpeciesSph   
## Days\_log\_7th:trtLS:SpeciesSph   
## Days\_log\_8th:trt1G:SpeciesRal   
## Days\_log\_8th:trtLS:SpeciesRal   
## Days\_log\_8th:trt1G:SpeciesSph   
## Days\_log\_8th:trtLS:SpeciesSph   
## Days\_log\_9th:trt1G:SpeciesRal   
## Days\_log\_9th:trtLS:SpeciesRal   
## Days\_log\_9th:trt1G:SpeciesSph   
## Days\_log\_9th:trtLS:SpeciesSph   
## Days\_log\_10th:trt1G:SpeciesRal   
## Days\_log\_10th:trtLS:SpeciesRal   
## Days\_log\_10th:trt1G:SpeciesSph 0.000   
## Days\_log\_10th:trtLS:SpeciesSph 0.000 0.000   
##   
## Standardized residuals:  
## Min Q1 Med Q3 Max   
## -4.39513803 -0.56571755 0.03283135 0.61874678 3.95681903   
##   
## Residual standard error: 0.1905138   
## Degrees of freedom: 1070 total; 1029 residual

library(car)  
  
# Type III ANOVA to test interactions  
anova\_results <- Anova(ar1\_poly\_nested, type = "III")  
print(anova\_results)

## Analysis of Deviance Table (Type III tests)  
##   
## Response: log\_Species\_CFU  
## Df Chisq Pr(>Chisq)   
## (Intercept) 1 67333.445 < 2.2e-16 \*\*\*  
## Days\_log:trt:Species 4 66.978 9.853e-14 \*\*\*  
## Days\_log\_sq:trt:Species 4 63.846 4.502e-13 \*\*\*  
## Days\_log\_cub:trt:Species 4 59.929 3.002e-12 \*\*\*  
## Days\_log\_4th:trt:Species 4 55.838 2.168e-11 \*\*\*  
## Days\_log\_5th:trt:Species 4 51.813 1.510e-10 \*\*\*  
## Days\_log\_6th:trt:Species 4 47.974 9.554e-10 \*\*\*  
## Days\_log\_7th:trt:Species 4 44.380 5.348e-09 \*\*\*  
## Days\_log\_8th:trt:Species 4 41.051 2.623e-08 \*\*\*  
## Days\_log\_9th:trt:Species 4 37.986 1.128e-07 \*\*\*  
## Days\_log\_10th:trt:Species 4 35.174 4.279e-07 \*\*\*  
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1

#log-polynomial ar1\_poly\_nested  
ar1\_poly\_nested2 <- gls(log\_Species\_CFU ~   
 (Days\_log + Days\_log\_sq + Days\_log\_cub + Days\_log\_4th + Days\_log\_5th + Days\_log\_6th + Days\_log\_7th + Days\_log\_8th + Days\_log\_9th + Days\_log\_10th) : Species : trt + trt:Species + trt + Species,  
 data = species\_totals,   
 correlation = corAR1(form = ~ 1 | ID),   
 method = "REML")  
summary(ar1\_poly\_nested2)

## Generalized least squares fit by REML  
## Model: log\_Species\_CFU ~ (Days\_log + Days\_log\_sq + Days\_log\_cub + Days\_log\_4th + Days\_log\_5th + Days\_log\_6th + Days\_log\_7th + Days\_log\_8th + Days\_log\_9th + Days\_log\_10th):Species:trt + trt:Species + trt + Species   
## Data: species\_totals   
## AIC BIC logLik  
## -253.3079 -26.37044 172.654  
##   
## Correlation Structure: AR(1)  
## Formula: ~1 | ID   
## Parameter estimate(s):  
## Phi   
## 0.3366177   
##   
## Coefficients:  
## Value Std.Error t-value p-value  
## (Intercept) 6.757 0.0508 133.02636 0.0000  
## trtLS -0.027 0.0748 -0.35488 0.7228  
## SpeciesSph 0.222 0.0584 3.79803 0.0002  
## SpeciesSph:trtLS -0.002 0.0861 -0.02724 0.9783  
## Days\_log:SpeciesRal:trt1G -1123.200 167.8027 -6.69357 0.0000  
## Days\_log:SpeciesSph:trt1G -173.377 163.4094 -1.06100 0.2889  
## Days\_log:SpeciesRal:trtLS -972.439 176.2895 -5.51615 0.0000  
## Days\_log:SpeciesSph:trtLS -496.404 171.1287 -2.90076 0.0038  
## Days\_log\_sq:SpeciesRal:trt1G 4055.396 616.2010 6.58129 0.0000  
## Days\_log\_sq:SpeciesSph:trt1G 570.703 600.4188 0.95051 0.3421  
## Days\_log\_sq:SpeciesRal:trtLS 3466.216 646.5110 5.36142 0.0000  
## Days\_log\_sq:SpeciesSph:trtLS 1810.093 628.3391 2.88076 0.0040  
## Days\_log\_cub:SpeciesRal:trt1G -6241.068 970.9360 -6.42789 0.0000  
## Days\_log\_cub:SpeciesSph:trt1G -778.444 946.7001 -0.82227 0.4111  
## Days\_log\_cub:SpeciesRal:trtLS -5259.664 1017.1781 -5.17084 0.0000  
## Days\_log\_cub:SpeciesSph:trtLS -2811.723 989.8686 -2.84050 0.0046  
## Days\_log\_4th:SpeciesRal:trt1G 5408.585 864.5035 6.25629 0.0000  
## Days\_log\_4th:SpeciesSph:trt1G 584.240 843.5469 0.69260 0.4887  
## Days\_log\_4th:SpeciesRal:trtLS 4492.163 904.2260 4.96796 0.0000  
## Days\_log\_4th:SpeciesSph:trtLS 2459.086 881.1366 2.79081 0.0054  
## Days\_log\_5th:SpeciesRal:trt1G -2920.711 480.7019 -6.07593 0.0000  
## Days\_log\_5th:SpeciesSph:trt1G -266.167 469.4233 -0.56701 0.5708  
## Days\_log\_5th:SpeciesRal:trtLS -2390.684 501.9557 -4.76274 0.0000  
## Days\_log\_5th:SpeciesSph:trtLS -1340.043 489.8093 -2.73585 0.0063  
## Days\_log\_6th:SpeciesRal:trt1G 1022.498 173.5336 5.89222 0.0000  
## Days\_log\_6th:SpeciesSph:trt1G 75.947 169.6053 0.44779 0.6544  
## Days\_log\_6th:SpeciesRal:trtLS 825.081 180.9045 4.56086 0.0000  
## Days\_log\_6th:SpeciesSph:trtLS 473.471 176.7689 2.67847 0.0075  
## Days\_log\_7th:SpeciesRal:trt1G -232.681 40.7609 -5.70843 0.0000  
## Days\_log\_7th:SpeciesSph:trt1G -13.379 39.8734 -0.33555 0.7373  
## Days\_log\_7th:SpeciesRal:trtLS -185.201 42.4228 -4.36561 0.0000  
## Days\_log\_7th:SpeciesSph:trtLS -108.784 41.5090 -2.62072 0.0089  
## Days\_log\_8th:SpeciesRal:trt1G 33.264 6.0189 5.52653 0.0000  
## Days\_log\_8th:SpeciesSph:trt1G 1.355 5.8932 0.22999 0.8181  
## Days\_log\_8th:SpeciesRal:trtLS 26.135 6.2544 4.17870 0.0000  
## Days\_log\_8th:SpeciesSph:trtLS 15.711 6.1278 2.56395 0.0105  
## Days\_log\_9th:SpeciesRal:trt1G -2.716 0.5079 -5.34765 0.0000  
## Days\_log\_9th:SpeciesSph:trt1G -0.065 0.4978 -0.13042 0.8963  
## Days\_log\_9th:SpeciesRal:trtLS -2.108 0.5270 -4.00091 0.0001  
## Days\_log\_9th:SpeciesSph:trtLS -1.297 0.5170 -2.50900 0.0123  
## Days\_log\_10th:SpeciesRal:trt1G 0.097 0.0187 5.17246 0.0000  
## Days\_log\_10th:SpeciesSph:trt1G 0.001 0.0183 0.03603 0.9713  
## Days\_log\_10th:SpeciesRal:trtLS 0.074 0.0194 3.83240 0.0001  
## Days\_log\_10th:SpeciesSph:trtLS 0.047 0.0190 2.45634 0.0142  
##   
## Correlation:   
## (Intr) trtLS SpcsSp SpS:LS D\_:SR:1 D\_:SS:1 D\_:SR:L D\_:SS:L Dys\_lg\_s:SR:1G Dys\_lg\_s:SS:1G Dys\_lg\_s:SR:LS Dys\_lg\_s:SS:LS Dys\_lg\_c:SR:1G  
## trtLS -0.679   
## SpeciesSph -0.580 0.394   
## SpeciesSph:trtLS 0.393 -0.578 -0.679   
## Days\_log:SpeciesRal:trt1G -0.006 0.004 -0.008 0.005   
## Days\_log:SpeciesSph:trt1G -0.003 0.002 -0.005 0.003 0.378   
## Days\_log:SpeciesRal:trtLS 0.000 -0.001 0.000 0.001 0.000 0.000   
## Days\_log:SpeciesSph:trtLS 0.000 0.000 0.000 -0.001 0.000 0.000 0.391   
## Days\_log\_sq:SpeciesRal:trt1G 0.006 -0.004 0.008 -0.006 -1.000 -0.378 0.000 0.000   
## Days\_log\_sq:SpeciesSph:trt1G 0.003 -0.002 0.004 -0.003 -0.385 -1.000 0.000 0.000 0.385   
## Days\_log\_sq:SpeciesRal:trtLS 0.000 0.001 0.000 0.000 0.000 0.000 -1.000 -0.391 0.000 0.000   
## Days\_log\_sq:SpeciesSph:trtLS 0.000 0.000 0.000 0.001 0.000 0.000 -0.398 -1.000 0.000 0.000 0.397   
## Days\_log\_cub:SpeciesRal:trt1G -0.005 0.004 -0.008 0.006 0.998 0.377 0.000 0.000 -1.000 -0.384 0.000 0.000   
## Days\_log\_cub:SpeciesSph:trt1G -0.003 0.002 -0.004 0.003 0.392 0.998 0.000 0.000 -0.392 -1.000 0.000 0.000 0.392   
## Days\_log\_cub:SpeciesRal:trtLS 0.000 -0.001 0.000 -0.001 0.000 0.000 0.998 0.390 0.000 0.000 -1.000 -0.397 0.000   
## Days\_log\_cub:SpeciesSph:trtLS 0.000 0.000 0.000 -0.001 0.000 0.000 0.404 0.998 0.000 0.000 -0.404 -1.000 0.000   
## Days\_log\_4th:SpeciesRal:trt1G 0.005 -0.004 0.008 -0.006 -0.996 -0.375 0.000 0.000 0.998 0.383 0.000 0.000 -1.000   
## Days\_log\_4th:SpeciesSph:trt1G 0.002 -0.002 0.004 -0.003 -0.399 -0.996 0.000 0.000 0.399 0.998 0.000 0.000 -0.399   
## Days\_log\_4th:SpeciesRal:trtLS 0.000 0.001 0.000 0.001 0.000 0.000 -0.996 -0.388 0.000 0.000 0.998 0.396 0.000   
## Days\_log\_4th:SpeciesSph:trtLS 0.000 0.000 0.000 0.001 0.000 0.000 -0.410 -0.996 0.000 0.000 0.410 0.998 0.000   
## Days\_log\_5th:SpeciesRal:trt1G -0.005 0.003 -0.008 0.006 0.993 0.373 0.000 0.000 -0.996 -0.381 0.000 0.000 0.998   
## Days\_log\_5th:SpeciesSph:trt1G -0.002 0.002 -0.004 0.003 0.404 0.992 0.000 0.000 -0.405 -0.995 0.000 0.000 0.405   
## Days\_log\_5th:SpeciesRal:trtLS 0.000 -0.001 0.000 -0.001 0.000 0.000 0.993 0.387 0.000 0.000 -0.996 -0.394 0.000   
## Days\_log\_5th:SpeciesSph:trtLS 0.000 0.000 0.000 -0.001 0.000 0.000 0.415 0.993 0.000 0.000 -0.416 -0.996 0.000   
## Days\_log\_6th:SpeciesRal:trt1G 0.005 -0.003 0.008 -0.005 -0.989 -0.370 0.000 0.000 0.993 0.379 0.000 0.000 -0.996   
## Days\_log\_6th:SpeciesSph:trt1G 0.002 -0.002 0.004 -0.003 -0.409 -0.988 0.000 0.000 0.410 0.992 0.000 0.000 -0.411   
## Days\_log\_6th:SpeciesRal:trtLS 0.000 0.001 0.000 0.001 0.000 0.000 -0.989 -0.385 0.000 0.000 0.993 0.393 0.000   
## Days\_log\_6th:SpeciesSph:trtLS 0.000 0.000 0.000 0.001 0.000 0.000 -0.419 -0.989 0.000 0.000 0.421 0.993 0.000   
## Days\_log\_7th:SpeciesRal:trt1G -0.005 0.003 -0.008 0.005 0.984 0.368 0.000 0.000 -0.988 -0.377 0.000 0.000 0.993   
## Days\_log\_7th:SpeciesSph:trt1G -0.002 0.002 -0.004 0.003 0.413 0.983 0.000 0.000 -0.415 -0.988 0.000 0.000 0.416   
## Days\_log\_7th:SpeciesRal:trtLS 0.000 -0.001 0.000 -0.001 0.000 0.000 0.985 0.382 0.000 0.000 -0.989 -0.390 0.000   
## Days\_log\_7th:SpeciesSph:trtLS 0.000 0.000 0.000 -0.001 0.000 0.000 0.423 0.984 0.000 0.000 -0.425 -0.989 0.000   
## Days\_log\_8th:SpeciesRal:trt1G 0.005 -0.003 0.007 -0.005 -0.978 -0.365 0.000 0.000 0.984 0.374 0.000 0.000 -0.989   
## Days\_log\_8th:SpeciesSph:trt1G 0.002 -0.002 0.004 -0.003 -0.417 -0.977 0.000 0.000 0.419 0.983 0.000 0.000 -0.420   
## Days\_log\_8th:SpeciesRal:trtLS 0.000 0.001 0.000 0.001 0.000 0.000 -0.980 -0.379 0.000 0.000 0.985 0.388 0.000   
## Days\_log\_8th:SpeciesSph:trtLS 0.000 0.000 0.000 0.001 0.000 0.000 -0.426 -0.979 0.000 0.000 0.428 0.984 0.000   
## Days\_log\_9th:SpeciesRal:trt1G -0.004 0.003 -0.007 0.005 0.972 0.361 0.000 0.000 -0.978 -0.371 0.000 0.000 0.984   
## Days\_log\_9th:SpeciesSph:trt1G -0.002 0.001 -0.004 0.003 0.419 0.971 0.000 0.000 -0.422 -0.977 0.000 0.000 0.424   
## Days\_log\_9th:SpeciesRal:trtLS 0.000 -0.001 0.000 -0.001 0.000 0.000 0.974 0.376 0.000 0.000 -0.980 -0.385 0.000   
## Days\_log\_9th:SpeciesSph:trtLS 0.000 0.000 0.000 -0.001 0.000 0.000 0.429 0.973 0.000 0.000 -0.431 -0.979 0.000   
## Days\_log\_10th:SpeciesRal:trt1G 0.004 -0.003 0.007 -0.005 -0.966 -0.358 0.000 0.000 0.973 0.368 0.000 0.000 -0.979   
## Days\_log\_10th:SpeciesSph:trt1G 0.002 -0.001 0.004 -0.002 -0.422 -0.964 0.000 0.000 0.424 0.971 0.000 0.000 -0.426   
## Days\_log\_10th:SpeciesRal:trtLS 0.000 0.001 0.000 0.001 0.000 0.000 -0.968 -0.373 0.000 0.000 0.974 0.382 0.000   
## Days\_log\_10th:SpeciesSph:trtLS 0.000 0.000 0.000 0.001 0.000 0.000 -0.431 -0.967 0.000 0.000 0.433 0.973 0.000   
## Dys\_lg\_c:SS:1G Dys\_lg\_c:SR:LS Dys\_lg\_c:SS:LS D\_\_4:SR:1 D\_\_4:SS:1 D\_\_4:SR:L D\_\_4:SS:L D\_\_5:SR:1 D\_\_5:SS:1 D\_\_5:SR:L D\_\_5:SS:L D\_\_6:SR:1 D\_\_6:SS:1  
## trtLS   
## SpeciesSph   
## SpeciesSph:trtLS   
## Days\_log:SpeciesRal:trt1G   
## Days\_log:SpeciesSph:trt1G   
## Days\_log:SpeciesRal:trtLS   
## Days\_log:SpeciesSph:trtLS   
## Days\_log\_sq:SpeciesRal:trt1G   
## Days\_log\_sq:SpeciesSph:trt1G   
## Days\_log\_sq:SpeciesRal:trtLS   
## Days\_log\_sq:SpeciesSph:trtLS   
## Days\_log\_cub:SpeciesRal:trt1G   
## Days\_log\_cub:SpeciesSph:trt1G   
## Days\_log\_cub:SpeciesRal:trtLS 0.000   
## Days\_log\_cub:SpeciesSph:trtLS 0.000 0.404   
## Days\_log\_4th:SpeciesRal:trt1G -0.391 0.000 0.000   
## Days\_log\_4th:SpeciesSph:trt1G -0.999 0.000 0.000 0.398   
## Days\_log\_4th:SpeciesRal:trtLS 0.000 -1.000 -0.403 0.000 0.000   
## Days\_log\_4th:SpeciesSph:trtLS 0.000 -0.410 -1.000 0.000 0.000 0.410   
## Days\_log\_5th:SpeciesRal:trt1G 0.389 0.000 0.000 -1.000 -0.397 0.000 0.000   
## Days\_log\_5th:SpeciesSph:trt1G 0.998 0.000 0.000 -0.405 -0.999 0.000 0.000 0.405   
## Days\_log\_5th:SpeciesRal:trtLS 0.000 0.998 0.402 0.000 0.000 -1.000 -0.409 0.000 0.000   
## Days\_log\_5th:SpeciesSph:trtLS 0.000 0.416 0.998 0.000 0.000 -0.416 -1.000 0.000 0.000 0.416   
## Days\_log\_6th:SpeciesRal:trt1G -0.388 0.000 0.000 0.998 0.396 0.000 0.000 -1.000 -0.404 0.000 0.000   
## Days\_log\_6th:SpeciesSph:trt1G -0.996 0.000 0.000 0.411 0.998 0.000 0.000 -0.411 -1.000 0.000 0.000 0.410   
## Days\_log\_6th:SpeciesRal:trtLS 0.000 -0.996 -0.400 0.000 0.000 0.998 0.408 0.000 0.000 -1.000 -0.415 0.000 0.000   
## Days\_log\_6th:SpeciesSph:trtLS 0.000 -0.421 -0.996 0.000 0.000 0.422 0.998 0.000 0.000 -0.422 -1.000 0.000 0.000   
## Days\_log\_7th:SpeciesRal:trt1G 0.386 0.000 0.000 -0.996 -0.394 0.000 0.000 0.998 0.402 0.000 0.000 -1.000 -0.409   
## Days\_log\_7th:SpeciesSph:trt1G 0.992 0.000 0.000 -0.417 -0.996 0.000 0.000 0.417 0.998 0.000 0.000 -0.417 -1.000   
## Days\_log\_7th:SpeciesRal:trtLS 0.000 0.993 0.399 0.000 0.000 -0.996 -0.406 0.000 0.000 0.998 0.414 0.000 0.000   
## Days\_log\_7th:SpeciesSph:trtLS 0.000 0.426 0.993 0.000 0.000 -0.427 -0.996 0.000 0.000 0.427 0.998 0.000 0.000   
## Days\_log\_8th:SpeciesRal:trt1G -0.383 0.000 0.000 0.993 0.392 0.000 0.000 -0.996 -0.400 0.000 0.000 0.998 0.408   
## Days\_log\_8th:SpeciesSph:trt1G -0.988 0.000 0.000 0.421 0.992 0.000 0.000 -0.422 -0.996 0.000 0.000 0.422 0.998   
## Days\_log\_8th:SpeciesRal:trtLS 0.000 -0.989 -0.396 0.000 0.000 0.993 0.404 0.000 0.000 -0.996 -0.412 0.000 0.000   
## Days\_log\_8th:SpeciesSph:trtLS 0.000 -0.430 -0.989 0.000 0.000 0.431 0.993 0.000 0.000 -0.432 -0.996 0.000 0.000   
## Days\_log\_9th:SpeciesRal:trt1G 0.380 0.000 0.000 -0.989 -0.389 0.000 0.000 0.993 0.398 0.000 0.000 -0.996 -0.406   
## Days\_log\_9th:SpeciesSph:trt1G 0.983 0.000 0.000 -0.425 -0.989 0.000 0.000 0.426 0.993 0.000 0.000 -0.427 -0.996   
## Days\_log\_9th:SpeciesRal:trtLS 0.000 0.985 0.394 0.000 0.000 -0.990 -0.402 0.000 0.000 0.993 0.410 0.000 0.000   
## Days\_log\_9th:SpeciesSph:trtLS 0.000 0.433 0.985 0.000 0.000 -0.434 -0.989 0.000 0.000 0.436 0.993 0.000 0.000   
## Days\_log\_10th:SpeciesRal:trt1G -0.377 0.000 0.000 0.985 0.387 0.000 0.000 -0.990 -0.396 0.000 0.000 0.993 0.404   
## Days\_log\_10th:SpeciesSph:trt1G -0.978 0.000 0.000 0.428 0.984 0.000 0.000 -0.430 -0.989 0.000 0.000 0.431 0.993   
## Days\_log\_10th:SpeciesRal:trtLS 0.000 -0.980 -0.391 0.000 0.000 0.985 0.400 0.000 0.000 -0.990 -0.408 0.000 0.000   
## Days\_log\_10th:SpeciesSph:trtLS 0.000 -0.435 -0.980 0.000 0.000 0.437 0.985 0.000 0.000 -0.439 -0.990 0.000 0.000   
## D\_\_6:SR:L D\_\_6:SS:L D\_\_7:SR:1 D\_\_7:SS:1 D\_\_7:SR:L D\_\_7:SS:L D\_\_8:SR:1 D\_\_8:SS:1 D\_\_8:SR:L D\_\_8:SS:L D\_\_9:SR:1 D\_\_9:SS:1 D\_\_9:SR:L D\_\_9:SS:L  
## trtLS   
## SpeciesSph   
## SpeciesSph:trtLS   
## Days\_log:SpeciesRal:trt1G   
## Days\_log:SpeciesSph:trt1G   
## Days\_log:SpeciesRal:trtLS   
## Days\_log:SpeciesSph:trtLS   
## Days\_log\_sq:SpeciesRal:trt1G   
## Days\_log\_sq:SpeciesSph:trt1G   
## Days\_log\_sq:SpeciesRal:trtLS   
## Days\_log\_sq:SpeciesSph:trtLS   
## Days\_log\_cub:SpeciesRal:trt1G   
## Days\_log\_cub:SpeciesSph:trt1G   
## Days\_log\_cub:SpeciesRal:trtLS   
## Days\_log\_cub:SpeciesSph:trtLS   
## Days\_log\_4th:SpeciesRal:trt1G   
## Days\_log\_4th:SpeciesSph:trt1G   
## Days\_log\_4th:SpeciesRal:trtLS   
## Days\_log\_4th:SpeciesSph:trtLS   
## Days\_log\_5th:SpeciesRal:trt1G   
## Days\_log\_5th:SpeciesSph:trt1G   
## Days\_log\_5th:SpeciesRal:trtLS   
## Days\_log\_5th:SpeciesSph:trtLS   
## Days\_log\_6th:SpeciesRal:trt1G   
## Days\_log\_6th:SpeciesSph:trt1G   
## Days\_log\_6th:SpeciesRal:trtLS   
## Days\_log\_6th:SpeciesSph:trtLS 0.421   
## Days\_log\_7th:SpeciesRal:trt1G 0.000 0.000   
## Days\_log\_7th:SpeciesSph:trt1G 0.000 0.000 0.416   
## Days\_log\_7th:SpeciesRal:trtLS -1.000 -0.421 0.000 0.000   
## Days\_log\_7th:SpeciesSph:trtLS -0.427 -1.000 0.000 0.000 0.427   
## Days\_log\_8th:SpeciesRal:trt1G 0.000 0.000 -1.000 -0.415 0.000 0.000   
## Days\_log\_8th:SpeciesSph:trt1G 0.000 0.000 -0.422 -1.000 0.000 0.000 0.421   
## Days\_log\_8th:SpeciesRal:trtLS 0.998 0.419 0.000 0.000 -1.000 -0.426 0.000 0.000   
## Days\_log\_8th:SpeciesSph:trtLS 0.432 0.998 0.000 0.000 -0.432 -1.000 0.000 0.000 0.431   
## Days\_log\_9th:SpeciesRal:trt1G 0.000 0.000 0.998 0.413 0.000 0.000 -1.000 -0.420 0.000 0.000   
## Days\_log\_9th:SpeciesSph:trt1G 0.000 0.000 0.427 0.998 0.000 0.000 -0.427 -1.000 0.000 0.000 0.426   
## Days\_log\_9th:SpeciesRal:trtLS -0.996 -0.418 0.000 0.000 0.998 0.424 0.000 0.000 -1.000 -0.430 0.000 0.000   
## Days\_log\_9th:SpeciesSph:trtLS -0.436 -0.996 0.000 0.000 0.436 0.998 0.000 0.000 -0.436 -1.000 0.000 0.000 0.436   
## Days\_log\_10th:SpeciesRal:trt1G 0.000 0.000 -0.996 -0.412 0.000 0.000 0.998 0.419 0.000 0.000 -1.000 -0.425 0.000 0.000   
## Days\_log\_10th:SpeciesSph:trt1G 0.000 0.000 -0.431 -0.996 0.000 0.000 0.431 0.998 0.000 0.000 -0.431 -1.000 0.000 0.000   
## Days\_log\_10th:SpeciesRal:trtLS 0.994 0.416 0.000 0.000 -0.997 -0.423 0.000 0.000 0.999 0.429 0.000 0.000 -1.000 -0.435   
## Days\_log\_10th:SpeciesSph:trtLS 0.440 0.994 0.000 0.000 -0.440 -0.996 0.000 0.000 0.440 0.998 0.000 0.000 -0.440 -1.000   
## D\_\_10:SR:1 D\_\_10:SS:1 D\_\_10:SR:L  
## trtLS   
## SpeciesSph   
## SpeciesSph:trtLS   
## Days\_log:SpeciesRal:trt1G   
## Days\_log:SpeciesSph:trt1G   
## Days\_log:SpeciesRal:trtLS   
## Days\_log:SpeciesSph:trtLS   
## Days\_log\_sq:SpeciesRal:trt1G   
## Days\_log\_sq:SpeciesSph:trt1G   
## Days\_log\_sq:SpeciesRal:trtLS   
## Days\_log\_sq:SpeciesSph:trtLS   
## Days\_log\_cub:SpeciesRal:trt1G   
## Days\_log\_cub:SpeciesSph:trt1G   
## Days\_log\_cub:SpeciesRal:trtLS   
## Days\_log\_cub:SpeciesSph:trtLS   
## Days\_log\_4th:SpeciesRal:trt1G   
## Days\_log\_4th:SpeciesSph:trt1G   
## Days\_log\_4th:SpeciesRal:trtLS   
## Days\_log\_4th:SpeciesSph:trtLS   
## Days\_log\_5th:SpeciesRal:trt1G   
## Days\_log\_5th:SpeciesSph:trt1G   
## Days\_log\_5th:SpeciesRal:trtLS   
## Days\_log\_5th:SpeciesSph:trtLS   
## Days\_log\_6th:SpeciesRal:trt1G   
## Days\_log\_6th:SpeciesSph:trt1G   
## Days\_log\_6th:SpeciesRal:trtLS   
## Days\_log\_6th:SpeciesSph:trtLS   
## Days\_log\_7th:SpeciesRal:trt1G   
## Days\_log\_7th:SpeciesSph:trt1G   
## Days\_log\_7th:SpeciesRal:trtLS   
## Days\_log\_7th:SpeciesSph:trtLS   
## Days\_log\_8th:SpeciesRal:trt1G   
## Days\_log\_8th:SpeciesSph:trt1G   
## Days\_log\_8th:SpeciesRal:trtLS   
## Days\_log\_8th:SpeciesSph:trtLS   
## Days\_log\_9th:SpeciesRal:trt1G   
## Days\_log\_9th:SpeciesSph:trt1G   
## Days\_log\_9th:SpeciesRal:trtLS   
## Days\_log\_9th:SpeciesSph:trtLS   
## Days\_log\_10th:SpeciesRal:trt1G   
## Days\_log\_10th:SpeciesSph:trt1G 0.430   
## Days\_log\_10th:SpeciesRal:trtLS 0.000 0.000   
## Days\_log\_10th:SpeciesSph:trtLS 0.000 0.000 0.439   
##   
## Standardized residuals:  
## Min Q1 Med Q3 Max   
## -4.50541806 -0.54531999 0.02226298 0.60421901 3.96912998   
##   
## Residual standard error: 0.1901803   
## Degrees of freedom: 1070 total; 1026 residual

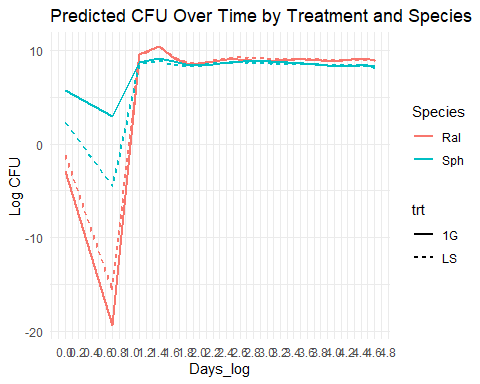
print(Anova(ar1\_poly\_nested2, type = "III"))

## Analysis of Deviance Table (Type III tests)  
##   
## Response: log\_Species\_CFU  
## Df Chisq Pr(>Chisq)   
## (Intercept) 1 17696.0128 < 2.2e-16 \*\*\*  
## trt 1 0.1259 0.7226785   
## Species 1 14.4250 0.0001459 \*\*\*  
## Species:trt 1 0.0007 0.9782706   
## Days\_log:Species:trt 4 78.4136 3.776e-16 \*\*\*  
## Days\_log\_sq:Species:trt 4 75.6700 1.438e-15 \*\*\*  
## Days\_log\_cub:Species:trt 4 72.1281 8.064e-15 \*\*\*  
## Days\_log\_4th:Species:trt 4 68.3518 5.056e-14 \*\*\*  
## Days\_log\_5th:Species:trt 4 64.5651 3.178e-13 \*\*\*  
## Days\_log\_6th:Species:trt 4 60.8858 1.889e-12 \*\*\*  
## Days\_log\_7th:Species:trt 4 57.3756 1.032e-11 \*\*\*  
## Days\_log\_8th:Species:trt 4 54.0630 5.105e-11 \*\*\*  
## Days\_log\_9th:Species:trt 4 50.9577 2.278e-10 \*\*\*  
## Days\_log\_10th:Species:trt 4 48.0586 9.176e-10 \*\*\*  
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1

##################### Visualization new\_data$predicted &2  
# Visualization  
library(ggplot2)  
  
  
# Generate new data for prediction  
new\_data <- expand.grid(  
 Days = seq(min(species\_totals$Days), max(species\_totals$Days), length.out = 100),  
 trt = unique(species\_totals$trt),  
 Species = unique(species\_totals$Species)  
)  
  
# Add transformed Days (log) and polynomial terms to the new data  
new\_data <- new\_data %>%  
 mutate(  
 Days\_log = log(Days),  
 Days\_log\_sq = Days\_log^2,  
 Days\_log\_cub = Days\_log^3,  
 Days\_log\_4th = Days\_log^4,  
 Days\_log\_5th = Days\_log^5,  
 Days\_log\_6th = Days\_log^6,  
 Days\_log\_7th = Days\_log^7,  
 Days\_log\_8th = Days\_log^8,  
 Days\_log\_9th = Days\_log^9,  
 Days\_log\_10th = Days\_log^10  
 )  
  
# Predict values using the best model (e.g., ar1\_poly\_nested or ar1\_poly\_nested2)  
new\_data$predicted <- predict(ar1\_poly\_nested, newdata = new\_data)  
  
# Plot predictions  
ggplot(new\_data, aes(x = Days\_log, y = predicted, color = Species, linetype = trt)) +  
 geom\_line(size = 1) +  
 labs(title = "Predicted CFU Over Time by Treatment and Species",  
 y = "Log CFU",  
 x = "Days\_log") +  
 scale\_x\_continuous(breaks = seq(0, max(species\_totals$Days), 0.2))+  
 theme\_minimal() +  
 theme(legend.position = "right")

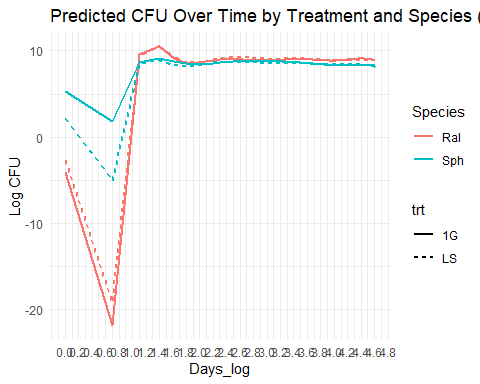
## Warning: Using `size` aesthetic for lines was deprecated in ggplot2 3.4.0.  
## ℹ Please use `linewidth` instead.  
## This warning is displayed once every 8 hours.  
## Call `lifecycle::last\_lifecycle\_warnings()` to see where this warning was generated.

## Warning: Removed 4 rows containing missing values or values outside the scale range (`geom\_line()`).



new\_data$predicted2 <- predict(ar1\_poly\_nested2, newdata = new\_data)  
  
# Plot predictions  
ggplot(new\_data, aes(x = Days\_log, y = predicted2, color = Species, linetype = trt)) +  
 geom\_line(size = 1) +  
 labs(title = "Predicted CFU Over Time by Treatment and Species (ar1\_poly\_nested2)",  
 y = "Log CFU",  
 x = "Days\_log") +  
 scale\_x\_continuous(breaks = seq(0, max(species\_totals$Days), 0.2))+  
 theme\_minimal() +  
 theme(legend.position = "right")

## Warning: Removed 4 rows containing missing values or values outside the scale range (`geom\_line()`).



###################### AR(1)\_poly\_nested  
  
# Add polynomial terms to species\_totals  
species\_totals <- species\_totals %>%  
 mutate(  
 Days\_sq = Days^2,  
 Days\_cub = Days^3,  
 Days\_4th = Days^4,  
 Days\_5th = Days^5,  
 Days\_6th = Days^6,  
 Days\_7th = Days^7,  
 Days\_8th = Days^8,  
 Days\_9th = Days^9,  
 Days\_10th = Days^10  
 )  
  
#ar1\_poly\_nested3  
ar1\_poly\_nested3 <- gls(log\_Species\_CFU ~   
 (Days + Days\_sq + Days\_cub + Days\_4th + Days\_5th + Days\_6th + Days\_7th + Days\_8th + Days\_9th + Days\_10th):trt:Species,  
 data = species\_totals,   
 correlation = corAR1(form = ~ 1 | ID),   
 method = "REML")  
summary(ar1\_poly\_nested3)

## Generalized least squares fit by REML  
## Model: log\_Species\_CFU ~ (Days + Days\_sq + Days\_cub + Days\_4th + Days\_5th + Days\_6th + Days\_7th + Days\_8th + Days\_9th + Days\_10th):trt:Species   
## Data: species\_totals   
## AIC BIC logLik  
## 1764.278 1976.541 -839.139  
##   
## Correlation Structure: AR(1)  
## Formula: ~1 | ID   
## Parameter estimate(s):  
## Phi   
## 0.5056532   
##   
## Coefficients:  
## Value Std.Error t-value p-value  
## (Intercept) 6.806793 0.04696562 144.93139 0  
## Days:trt1G:SpeciesRal 1.411146 0.05186800 27.20649 0  
## Days:trtLS:SpeciesRal 1.427976 0.05400023 26.44389 0  
## Days:trt1G:SpeciesSph 1.218558 0.05451231 22.35381 0  
## Days:trtLS:SpeciesSph 0.997206 0.05644676 17.66630 0  
## Days\_sq:trt1G:SpeciesRal -0.300145 0.01716322 -17.48767 0  
## Days\_sq:trtLS:SpeciesRal -0.301101 0.01768384 -17.02693 0  
## Days\_sq:trt1G:SpeciesSph -0.260046 0.01762747 -14.75230 0  
## Days\_sq:trtLS:SpeciesSph -0.203258 0.01809153 -11.23496 0  
## Days\_cub:trt1G:SpeciesRal 0.029559 0.00217287 13.60351 0  
## Days\_cub:trtLS:SpeciesRal 0.029814 0.00223221 13.35618 0  
## Days\_cub:trt1G:SpeciesSph 0.026088 0.00222011 11.75093 0  
## Days\_cub:trtLS:SpeciesSph 0.019935 0.00227304 8.77008 0  
## Days\_4th:trt1G:SpeciesRal -0.001602 0.00013994 -11.44935 0  
## Days\_4th:trtLS:SpeciesRal -0.001631 0.00014384 -11.33686 0  
## Days\_4th:trt1G:SpeciesSph -0.001443 0.00014298 -10.09432 0  
## Days\_4th:trtLS:SpeciesSph -0.001088 0.00014650 -7.42332 0  
## Days\_5th:trt1G:SpeciesRal 0.000052 0.00000520 10.03659 0  
## Days\_5th:trtLS:SpeciesRal 0.000054 0.00000536 10.01291 0  
## Days\_5th:trt1G:SpeciesSph 0.000048 0.00000533 8.99824 0  
## Days\_5th:trtLS:SpeciesSph 0.000036 0.00000547 6.53413 0  
## Days\_6th:trt1G:SpeciesRal -0.000001 0.00000012 -9.02059 0  
## Days\_6th:trtLS:SpeciesRal -0.000001 0.00000012 -9.06032 0  
## Days\_6th:trt1G:SpeciesSph -0.000001 0.00000012 -8.20103 0  
## Days\_6th:trtLS:SpeciesSph -0.000001 0.00000013 -5.88506 0  
## Days\_7th:trt1G:SpeciesRal 0.000000 0.00000000 8.24572 0  
## Days\_7th:trtLS:SpeciesRal 0.000000 0.00000000 8.33541 0  
## Days\_7th:trt1G:SpeciesSph 0.000000 0.00000000 7.58687 0  
## Days\_7th:trtLS:SpeciesSph 0.000000 0.00000000 5.38277 0  
## Days\_8th:trt1G:SpeciesRal 0.000000 0.00000000 -7.62937 0  
## Days\_8th:trtLS:SpeciesRal 0.000000 0.00000000 -7.76245 0  
## Days\_8th:trt1G:SpeciesSph 0.000000 0.00000000 -7.09424 0  
## Days\_8th:trtLS:SpeciesSph 0.000000 0.00000000 -4.97904 0  
## Days\_9th:trt1G:SpeciesRal 0.000000 0.00000000 7.12319 0  
## Days\_9th:trtLS:SpeciesRal 0.000000 0.00000000 7.29693 0  
## Days\_9th:trt1G:SpeciesSph 0.000000 0.00000000 6.68676 0  
## Days\_9th:trtLS:SpeciesSph 0.000000 0.00000000 4.64575 0  
## Days\_10th:trt1G:SpeciesRal 0.000000 0.00000000 -6.69702 0  
## Days\_10th:trtLS:SpeciesRal 0.000000 0.00000000 -6.91070 0  
## Days\_10th:trt1G:SpeciesSph 0.000000 0.00000000 -6.34154 0  
## Days\_10th:trtLS:SpeciesSph 0.000000 0.00000000 -4.36502 0  
##   
## Correlation:   
## (Intr) D:1G:SR D:LS:SR D:1G:SS D:LS:SS Dys\_s:1G:SR Dys\_s:LS:SR Dys\_s:1G:SS Dys\_s:LS:SS Dys\_c:1G:SR Dys\_c:LS:SR Dys\_c:1G:SS Dys\_c:LS:SS D\_4:1G:SR  
## Days:trt1G:SpeciesRal -0.294   
## Days:trtLS:SpeciesRal -0.298 0.088   
## Days:trt1G:SpeciesSph -0.373 0.698 0.111   
## Days:trtLS:SpeciesSph -0.375 0.110 0.701 0.140   
## Days\_sq:trt1G:SpeciesRal 0.110 -0.941 -0.033 -0.588 -0.041   
## Days\_sq:trtLS:SpeciesRal 0.117 -0.034 -0.942 -0.044 -0.591 0.013   
## Days\_sq:trt1G:SpeciesSph 0.189 -0.684 -0.056 -0.941 -0.071 0.668 0.022   
## Days\_sq:trtLS:SpeciesSph 0.196 -0.058 -0.686 -0.073 -0.942 0.022 0.669 0.037   
## Days\_cub:trt1G:SpeciesRal -0.055 0.873 0.016 0.512 0.021 -0.983 -0.006 -0.625 -0.011   
## Days\_cub:trtLS:SpeciesRal -0.061 0.018 0.872 0.023 0.513 -0.007 -0.982 -0.012 -0.625 0.003   
## Days\_cub:trt1G:SpeciesSph -0.126 0.652 0.037 0.871 0.047 -0.682 -0.015 -0.982 -0.025 0.665 0.008   
## Days\_cub:trtLS:SpeciesSph -0.133 0.039 0.652 0.050 0.870 -0.015 -0.682 -0.025 -0.982 0.007 0.665 0.017   
## Days\_4th:trt1G:SpeciesRal 0.031 -0.816 -0.009 -0.456 -0.012 0.951 0.004 0.583 0.006 -0.991 -0.002 -0.638 -0.004   
## Days\_4th:trtLS:SpeciesRal 0.036 -0.011 -0.813 -0.013 -0.455 0.004 0.950 0.007 0.582 -0.002 -0.991 -0.005 -0.637 0.001   
## Days\_4th:trt1G:SpeciesSph 0.095 -0.621 -0.028 -0.811 -0.036 0.676 0.011 0.949 0.019 -0.677 -0.006 -0.991 -0.013 0.664   
## Days\_4th:trtLS:SpeciesSph 0.101 -0.030 -0.620 -0.038 -0.809 0.011 0.676 0.019 0.948 -0.006 -0.677 -0.013 -0.991 0.003   
## Days\_5th:trt1G:SpeciesRal -0.018 0.767 0.005 0.412 0.007 -0.916 -0.002 -0.545 -0.004 0.972 0.001 0.609 0.002 -0.994   
## Days\_5th:trtLS:SpeciesRal -0.023 0.007 0.763 0.008 0.410 -0.002 -0.914 -0.004 -0.543 0.001 0.971 0.003 0.608 -0.001   
## Days\_5th:trt1G:SpeciesSph -0.077 0.593 0.023 0.762 0.029 -0.663 -0.009 -0.914 -0.015 0.678 0.005 0.971 0.010 -0.674   
## Days\_5th:trtLS:SpeciesSph -0.083 0.024 0.590 0.031 0.758 -0.009 -0.662 -0.016 -0.912 0.005 0.678 0.010 0.971 -0.003   
## Days\_6th:trt1G:SpeciesRal 0.011 -0.726 -0.003 -0.377 -0.004 0.883 0.001 0.511 0.002 -0.949 -0.001 -0.580 -0.001 0.982   
## Days\_6th:trtLS:SpeciesRal 0.015 -0.004 -0.720 -0.005 -0.375 0.002 0.879 0.003 0.509 -0.001 -0.948 -0.002 -0.580 0.000   
## Days\_6th:trt1G:SpeciesSph 0.066 -0.567 -0.020 -0.720 -0.025 0.648 0.008 0.880 0.013 -0.672 -0.004 -0.948 -0.009 0.676   
## Days\_6th:trtLS:SpeciesSph 0.071 -0.021 -0.564 -0.026 -0.715 0.008 0.646 0.013 0.877 -0.004 -0.672 -0.009 -0.947 0.002   
## Days\_7th:trt1G:SpeciesRal -0.006 0.690 0.002 0.348 0.002 -0.851 -0.001 -0.480 -0.001 0.925 0.000 0.554 0.001 -0.966   
## Days\_7th:trtLS:SpeciesRal -0.009 0.003 0.684 0.003 0.345 -0.001 -0.847 -0.002 -0.479 0.001 0.924 0.001 0.554 0.000   
## Days\_7th:trt1G:SpeciesSph -0.058 0.545 0.017 0.684 0.022 -0.632 -0.007 -0.848 -0.011 0.663 0.004 0.924 0.008 -0.674   
## Days\_7th:trtLS:SpeciesSph -0.062 0.018 0.541 0.023 0.678 -0.007 -0.630 -0.012 -0.844 0.003 0.663 0.008 0.923 -0.002   
## Days\_8th:trt1G:SpeciesRal 0.003 -0.660 -0.001 -0.323 -0.001 0.822 0.000 0.454 0.001 -0.902 0.000 -0.529 0.000 0.948   
## Days\_8th:trtLS:SpeciesRal 0.005 -0.002 -0.653 -0.002 -0.321 0.001 0.818 0.001 0.452 0.000 -0.900 -0.001 -0.529 0.000   
## Days\_8th:trt1G:SpeciesSph 0.052 -0.525 -0.015 -0.653 -0.019 0.616 0.006 0.819 0.010 -0.653 -0.003 -0.901 -0.007 0.669   
## Days\_8th:trtLS:SpeciesSph 0.056 -0.016 -0.521 -0.021 -0.647 0.006 0.614 0.011 0.815 -0.003 -0.653 -0.007 -0.899 0.002   
## Days\_9th:trt1G:SpeciesRal 0.000 0.633 0.000 0.302 0.000 -0.795 0.000 -0.430 0.000 0.879 0.000 0.507 0.000 -0.931   
## Days\_9th:trtLS:SpeciesRal -0.003 0.001 0.626 0.001 0.300 0.000 -0.791 -0.001 -0.429 0.000 0.877 0.000 0.507 0.000   
## Days\_9th:trt1G:SpeciesSph -0.047 0.508 0.014 0.627 0.018 -0.601 -0.005 -0.793 -0.009 0.642 0.003 0.879 0.006 -0.662   
## Days\_9th:trtLS:SpeciesSph -0.051 0.015 0.504 0.019 0.620 -0.006 -0.599 -0.010 -0.789 0.003 0.642 0.006 0.877 -0.002   
## Days\_10th:trt1G:SpeciesRal -0.002 -0.609 0.000 -0.284 0.001 0.771 0.000 0.409 0.000 -0.858 0.000 -0.486 0.000 0.913   
## Days\_10th:trtLS:SpeciesRal 0.001 0.000 -0.602 0.000 -0.282 0.000 0.767 0.000 0.408 0.000 -0.856 0.000 -0.487 0.000   
## Days\_10th:trt1G:SpeciesSph 0.043 -0.492 -0.013 -0.603 -0.016 0.587 0.005 0.769 0.008 -0.631 -0.003 -0.858 -0.006 0.654   
## Days\_10th:trtLS:SpeciesSph 0.047 -0.014 -0.488 -0.018 -0.597 0.005 0.585 0.009 0.765 -0.003 -0.631 -0.006 -0.856 0.001   
## D\_4:LS:SR D\_4:1G:SS D\_4:LS:SS D\_5:1G:SR D\_5:LS:SR D\_5:1G:SS D\_5:LS:SS D\_6:1G:SR D\_6:LS:SR D\_6:1G:SS D\_6:LS:SS D\_7:1G:SR D\_7:LS:SR D\_7:1G:SS D\_7:LS:SS  
## Days:trt1G:SpeciesRal   
## Days:trtLS:SpeciesRal   
## Days:trt1G:SpeciesSph   
## Days:trtLS:SpeciesSph   
## Days\_sq:trt1G:SpeciesRal   
## Days\_sq:trtLS:SpeciesRal   
## Days\_sq:trt1G:SpeciesSph   
## Days\_sq:trtLS:SpeciesSph   
## Days\_cub:trt1G:SpeciesRal   
## Days\_cub:trtLS:SpeciesRal   
## Days\_cub:trt1G:SpeciesSph   
## Days\_cub:trtLS:SpeciesSph   
## Days\_4th:trt1G:SpeciesRal   
## Days\_4th:trtLS:SpeciesRal   
## Days\_4th:trt1G:SpeciesSph 0.003   
## Days\_4th:trtLS:SpeciesSph 0.664 0.010   
## Days\_5th:trt1G:SpeciesRal -0.001 -0.644 -0.002   
## Days\_5th:trtLS:SpeciesRal -0.994 -0.002 -0.644 0.000   
## Days\_5th:trt1G:SpeciesSph -0.003 -0.994 -0.008 0.662 0.002   
## Days\_5th:trtLS:SpeciesSph -0.675 -0.008 -0.994 0.002 0.663 0.006   
## Days\_6th:trt1G:SpeciesRal 0.000 0.622 0.001 -0.996 0.000 -0.646 -0.001   
## Days\_6th:trtLS:SpeciesRal 0.981 0.001 0.622 0.000 -0.996 -0.001 -0.647 0.000   
## Days\_6th:trt1G:SpeciesSph 0.002 0.982 0.007 -0.671 -0.001 -0.996 -0.005 0.660 0.001   
## Days\_6th:trtLS:SpeciesSph 0.677 0.007 0.981 -0.001 -0.672 -0.005 -0.996 0.001 0.662 0.005   
## Days\_7th:trt1G:SpeciesRal 0.000 -0.600 -0.001 0.987 0.000 0.629 0.001 -0.997 0.000 -0.647 0.000   
## Days\_7th:trtLS:SpeciesRal -0.965 -0.001 -0.600 0.000 0.987 0.001 0.630 0.000 -0.997 -0.001 -0.649 0.000   
## Days\_7th:trt1G:SpeciesSph -0.002 -0.966 -0.006 0.674 0.001 0.987 0.005 -0.668 -0.001 -0.997 -0.004 0.658 0.001   
## Days\_7th:trtLS:SpeciesSph -0.675 -0.006 -0.965 0.001 0.676 0.005 0.987 -0.001 -0.670 -0.004 -0.997 0.000 0.661 0.004   
## Days\_8th:trt1G:SpeciesRal 0.000 0.578 0.000 -0.976 0.000 -0.611 0.000 0.991 0.000 0.632 0.000 -0.998 0.000 -0.646 0.000   
## Days\_8th:trtLS:SpeciesRal 0.948 0.001 0.579 0.000 -0.975 0.000 -0.613 0.000 0.991 0.000 0.635 0.000 -0.998 0.000 -0.650   
## Days\_8th:trt1G:SpeciesSph 0.002 0.948 0.005 -0.673 -0.001 -0.976 -0.004 0.671 0.001 0.991 0.004 -0.664 0.000 -0.998 -0.003   
## Days\_8th:trtLS:SpeciesSph 0.670 0.005 0.948 -0.001 -0.675 -0.004 -0.976 0.001 0.674 0.004 0.991 0.000 -0.668 -0.003 -0.998   
## Days\_9th:trt1G:SpeciesRal 0.000 -0.558 0.000 0.962 0.000 0.593 0.000 -0.982 0.000 -0.617 0.000 0.993 0.000 0.633 0.000   
## Days\_9th:trtLS:SpeciesRal -0.930 0.000 -0.559 0.000 0.962 0.000 0.595 0.000 -0.982 0.000 -0.620 0.000 0.993 0.000 0.637   
## Days\_9th:trt1G:SpeciesSph -0.002 -0.931 -0.005 0.670 0.001 0.963 0.004 -0.671 -0.001 -0.982 -0.003 0.667 0.000 0.993 0.003   
## Days\_9th:trtLS:SpeciesSph -0.663 -0.005 -0.930 0.001 0.673 0.004 0.963 -0.001 -0.674 -0.003 -0.982 0.000 0.671 0.003 0.993   
## Days\_10th:trt1G:SpeciesRal 0.000 0.538 0.000 -0.949 0.000 -0.575 0.000 0.972 0.000 0.601 0.000 -0.986 0.000 -0.620 0.000   
## Days\_10th:trtLS:SpeciesRal 0.912 0.000 0.540 0.000 -0.949 0.000 -0.578 0.000 0.972 0.000 0.605 0.000 -0.986 0.000 -0.625   
## Days\_10th:trt1G:SpeciesSph 0.002 0.913 0.004 -0.666 -0.001 -0.949 -0.004 0.669 0.001 0.972 0.003 -0.668 0.000 -0.986 -0.003   
## Days\_10th:trtLS:SpeciesSph 0.656 0.004 0.913 -0.001 -0.669 -0.004 -0.949 0.001 0.673 0.003 0.972 0.000 -0.672 -0.003 -0.987   
## D\_8:1G:SR D\_8:LS:SR D\_8:1G:SS D\_8:LS:SS D\_9:1G:SR D\_9:LS:SR D\_9:1G:SS D\_9:LS:SS D\_10:1G:SR D\_10:LS:SR D\_10:1G:SS  
## Days:trt1G:SpeciesRal   
## Days:trtLS:SpeciesRal   
## Days:trt1G:SpeciesSph   
## Days:trtLS:SpeciesSph   
## Days\_sq:trt1G:SpeciesRal   
## Days\_sq:trtLS:SpeciesRal   
## Days\_sq:trt1G:SpeciesSph   
## Days\_sq:trtLS:SpeciesSph   
## Days\_cub:trt1G:SpeciesRal   
## Days\_cub:trtLS:SpeciesRal   
## Days\_cub:trt1G:SpeciesSph   
## Days\_cub:trtLS:SpeciesSph   
## Days\_4th:trt1G:SpeciesRal   
## Days\_4th:trtLS:SpeciesRal   
## Days\_4th:trt1G:SpeciesSph   
## Days\_4th:trtLS:SpeciesSph   
## Days\_5th:trt1G:SpeciesRal   
## Days\_5th:trtLS:SpeciesRal   
## Days\_5th:trt1G:SpeciesSph   
## Days\_5th:trtLS:SpeciesSph   
## Days\_6th:trt1G:SpeciesRal   
## Days\_6th:trtLS:SpeciesRal   
## Days\_6th:trt1G:SpeciesSph   
## Days\_6th:trtLS:SpeciesSph   
## Days\_7th:trt1G:SpeciesRal   
## Days\_7th:trtLS:SpeciesRal   
## Days\_7th:trt1G:SpeciesSph   
## Days\_7th:trtLS:SpeciesSph   
## Days\_8th:trt1G:SpeciesRal   
## Days\_8th:trtLS:SpeciesRal 0.000   
## Days\_8th:trt1G:SpeciesSph 0.655 0.000   
## Days\_8th:trtLS:SpeciesSph 0.000 0.659 0.003   
## Days\_9th:trt1G:SpeciesRal -0.998 0.000 -0.645 0.000   
## Days\_9th:trtLS:SpeciesRal 0.000 -0.998 0.000 -0.649 0.000   
## Days\_9th:trt1G:SpeciesSph -0.661 0.000 -0.998 -0.003 0.652 0.000   
## Days\_9th:trtLS:SpeciesSph 0.000 -0.665 -0.003 -0.999 0.000 0.657 0.002   
## Days\_10th:trt1G:SpeciesRal 0.994 0.000 0.633 0.000 -0.999 0.000 -0.643 0.000   
## Days\_10th:trtLS:SpeciesRal 0.000 0.995 0.000 0.638 0.000 -0.999 0.000 -0.648 0.000   
## Days\_10th:trt1G:SpeciesSph 0.664 0.000 0.995 0.002 -0.657 0.000 -0.999 -0.002 0.649 0.000   
## Days\_10th:trtLS:SpeciesSph 0.000 0.669 0.002 0.995 0.000 -0.662 -0.002 -0.999 0.000 0.655 0.002   
##   
## Standardized residuals:  
## Min Q1 Med Q3 Max   
## -4.454469603 -0.459484883 0.004458307 0.574547139 2.962124566   
##   
## Residual standard error: 0.2803214   
## Degrees of freedom: 1070 total; 1029 residual

# Type III ANOVA   
library(car)  
anova\_results <- Anova(ar1\_poly\_nested3, type = "III")  
print(anova\_results)

## Analysis of Deviance Table (Type III tests)  
##   
## Response: log\_Species\_CFU  
## Df Chisq Pr(>Chisq)   
## (Intercept) 1 21005.108 < 2.2e-16 \*\*\*  
## Days:trt:Species 4 1342.418 < 2.2e-16 \*\*\*  
## Days\_sq:trt:Species 4 603.136 < 2.2e-16 \*\*\*  
## Days\_cub:trt:Species 4 374.764 < 2.2e-16 \*\*\*  
## Days\_4th:trt:Species 4 270.237 < 2.2e-16 \*\*\*  
## Days\_5th:trt:Species 4 210.669 < 2.2e-16 \*\*\*  
## Days\_6th:trt:Species 4 172.335 < 2.2e-16 \*\*\*  
## Days\_7th:trt:Species 4 145.701 < 2.2e-16 \*\*\*  
## Days\_8th:trt:Species 4 126.174 < 2.2e-16 \*\*\*  
## Days\_9th:trt:Species 4 111.271 < 2.2e-16 \*\*\*  
## Days\_10th:trt:Species 4 99.537 < 2.2e-16 \*\*\*  
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1

#ar1\_poly\_nested4  
ar1\_poly\_nested4 <- gls(log\_Species\_CFU ~   
 (Days + Days\_sq + Days\_cub + Days\_4th + Days\_5th + Days\_6th + Days\_7th + Days\_8th + Days\_9th + Days\_10th): Species : trt + trt:Species + trt + Species,  
 data = species\_totals,   
 correlation = corAR1(form = ~ 1 | ID),   
 method = "REML")  
summary(ar1\_poly\_nested4)

## Generalized least squares fit by REML  
## Model: log\_Species\_CFU ~ (Days + Days\_sq + Days\_cub + Days\_4th + Days\_5th + Days\_6th + Days\_7th + Days\_8th + Days\_9th + Days\_10th):Species:trt + trt:Species + trt + Species   
## Data: species\_totals   
## AIC BIC logLik  
## 1777.419 2004.357 -842.7096  
##   
## Correlation Structure: AR(1)  
## Formula: ~1 | ID   
## Parameter estimate(s):  
## Phi   
## 0.5079598   
##   
## Coefficients:  
## Value Std.Error t-value p-value  
## (Intercept) 6.858860 0.07432127 92.28663 0.0000  
## trtLS -0.019981 0.10960114 -0.18231 0.8554  
## SpeciesSph -0.080127 0.06929913 -1.15625 0.2478  
## SpeciesSph:trtLS -0.001905 0.10154997 -0.01876 0.9850  
## Days:SpeciesRal:trt1G 1.371256 0.06300563 21.76403 0.0000  
## Days:SpeciesSph:trt1G 1.226262 0.05837992 21.00485 0.0000  
## Days:SpeciesRal:trtLS 1.394151 0.06700257 20.80743 0.0000  
## Days:SpeciesSph:trtLS 1.014905 0.06178164 16.42729 0.0000  
## Days\_sq:SpeciesRal:trt1G -0.291324 0.01884589 -15.45821 0.0000  
## Days\_sq:SpeciesSph:trt1G -0.260529 0.01792930 -14.53092 0.0000  
## Days\_sq:SpeciesRal:trtLS -0.292927 0.01964945 -14.90766 0.0000  
## Days\_sq:SpeciesSph:trtLS -0.205450 0.01853759 -11.08288 0.0000  
## Days\_cub:SpeciesRal:trt1G 0.028671 0.00231134 12.40463 0.0000  
## Days\_cub:SpeciesSph:trt1G 0.026071 0.00223852 11.64668 0.0000  
## Days\_cub:SpeciesRal:trtLS 0.028957 0.00239460 12.09271 0.0000  
## Days\_cub:SpeciesSph:trtLS 0.020065 0.00230012 8.72353 0.0000  
## Days\_4th:SpeciesRal:trt1G -0.001553 0.00014664 -10.59238 0.0000  
## Days\_4th:SpeciesSph:trt1G -0.001440 0.00014380 -10.01448 0.0000  
## Days\_4th:SpeciesRal:trtLS -0.001582 0.00015173 -10.42836 0.0000  
## Days\_4th:SpeciesSph:trtLS -0.001092 0.00014766 -7.39307 0.0000  
## Days\_5th:SpeciesRal:trt1G 0.000051 0.00000540 9.36222 0.0000  
## Days\_5th:SpeciesSph:trt1G 0.000048 0.00000535 8.92661 0.0000  
## Days\_5th:SpeciesRal:trtLS 0.000052 0.00000560 9.29563 0.0000  
## Days\_5th:SpeciesSph:trtLS 0.000036 0.00000550 6.50623 0.0000  
## Days\_6th:SpeciesRal:trt1G -0.000001 0.00000012 -8.45872 0.0000  
## Days\_6th:SpeciesSph:trt1G -0.000001 0.00000012 -8.13350 0.0000  
## Days\_6th:SpeciesRal:trtLS -0.000001 0.00000013 -8.46165 0.0000  
## Days\_6th:SpeciesSph:trtLS -0.000001 0.00000013 -5.85691 0.0000  
## Days\_7th:SpeciesRal:trt1G 0.000000 0.00000000 7.75969 0.0000  
## Days\_7th:SpeciesSph:trt1G 0.000000 0.00000000 7.52208 0.0000  
## Days\_7th:SpeciesRal:trtLS 0.000000 0.00000000 7.81700 0.0000  
## Days\_7th:SpeciesSph:trtLS 0.000000 0.00000000 5.35400 0.0000  
## Days\_8th:SpeciesRal:trt1G 0.000000 0.00000000 -7.19777 0.0000  
## Days\_8th:SpeciesSph:trt1G 0.000000 0.00000000 -7.03160 0.0000  
## Days\_8th:SpeciesRal:trtLS 0.000000 0.00000000 -7.30169 0.0000  
## Days\_8th:SpeciesSph:trtLS 0.000000 0.00000000 -4.94979 0.0000  
## Days\_9th:SpeciesRal:trt1G 0.000000 0.00000000 6.73251 0.0000  
## Days\_9th:SpeciesSph:trt1G 0.000000 0.00000000 6.62597 0.0000  
## Days\_9th:SpeciesRal:trtLS 0.000000 0.00000000 6.87943 0.0000  
## Days\_9th:SpeciesSph:trtLS 0.000000 0.00000000 4.61618 0.0000  
## Days\_10th:SpeciesRal:trt1G 0.000000 0.00000000 -6.33821 0.0000  
## Days\_10th:SpeciesSph:trt1G 0.000000 0.00000000 -6.28238 0.0000  
## Days\_10th:SpeciesRal:trtLS 0.000000 0.00000000 -6.52677 0.0000  
## Days\_10th:SpeciesSph:trtLS 0.000000 0.00000000 -4.33529 0.0000  
##   
## Correlation:   
## (Intr) trtLS SpcsSp SpS:LS D:SR:1 D:SS:1 D:SR:L D:SS:L Dys\_s:SR:1G Dys\_s:SS:1G Dys\_s:SR:LS Dys\_s:SS:LS Dys\_c:SR:1G Dys\_c:SS:1G Dys\_c:SR:LS Dys\_c:SS:LS  
## trtLS -0.678   
## SpeciesSph -0.509 0.345   
## SpeciesSph:trtLS 0.347 -0.507 -0.682   
## Days:SpeciesRal:trt1G -0.548 0.371 0.521 -0.355   
## Days:SpeciesSph:trt1G -0.330 0.224 -0.152 0.104 0.531   
## Days:SpeciesRal:trtLS 0.000 -0.421 0.000 0.388 0.000 0.000   
## Days:SpeciesSph:trtLS 0.000 -0.263 0.000 -0.114 0.000 0.000 0.532   
## Days\_sq:SpeciesRal:trt1G 0.319 -0.216 -0.400 0.273 -0.936 -0.471 0.000 0.000   
## Days\_sq:SpeciesSph:trt1G 0.198 -0.134 0.036 -0.025 -0.575 -0.927 0.000 0.000 0.603   
## Days\_sq:SpeciesRal:trtLS 0.000 0.253 0.000 -0.305 0.000 0.000 -0.936 -0.465 0.000 0.000   
## Days\_sq:SpeciesSph:trtLS 0.000 0.164 0.000 0.029 0.000 0.000 -0.575 -0.925 0.000 0.000 0.598   
## Days\_cub:SpeciesRal:trt1G -0.229 0.155 0.333 -0.227 0.862 0.416 0.000 0.000 -0.982 -0.577 0.000 0.000   
## Days\_cub:SpeciesSph:trt1G -0.146 0.099 0.002 -0.002 0.562 0.845 0.000 0.000 -0.631 -0.980 0.000 0.000 0.630   
## Days\_cub:SpeciesRal:trtLS 0.000 -0.183 0.000 0.258 0.000 0.000 0.860 0.406 0.000 0.000 -0.981 -0.571 0.000 0.000   
## Days\_cub:SpeciesSph:trtLS 0.000 -0.123 0.000 0.001 0.000 0.000 0.560 0.840 0.000 0.000 -0.627 -0.979 0.000 0.000 0.625   
## Days\_4th:SpeciesRal:trt1G 0.182 -0.124 -0.292 0.199 -0.801 -0.372 0.000 0.000 0.949 0.544 0.000 0.000 -0.991 -0.611 0.000 0.000   
## Days\_4th:SpeciesSph:trt1G 0.119 -0.081 -0.019 0.013 -0.540 -0.780 0.000 0.000 0.631 0.945 0.000 0.000 -0.648 -0.990 0.000 0.000   
## Days\_4th:SpeciesRal:trtLS 0.000 0.147 0.000 -0.227 0.000 0.000 -0.797 -0.361 0.000 0.000 0.947 0.537 0.000 0.000 -0.991 -0.606   
## Days\_4th:SpeciesSph:trtLS 0.000 0.101 0.000 -0.014 0.000 0.000 -0.536 -0.773 0.000 0.000 0.627 0.943 0.000 0.000 -0.644 -0.990   
## Days\_5th:SpeciesRal:trt1G -0.154 0.105 0.264 -0.180 0.751 0.337 0.000 0.000 -0.913 -0.512 0.000 0.000 0.971 0.587 0.000 0.000   
## Days\_5th:SpeciesSph:trt1G -0.103 0.070 0.027 -0.018 0.518 0.728 0.000 0.000 -0.622 -0.908 0.000 0.000 0.650 0.970 0.000 0.000   
## Days\_5th:SpeciesRal:trtLS 0.000 -0.124 0.000 0.206 0.000 0.000 0.745 0.325 0.000 0.000 -0.911 -0.504 0.000 0.000 0.971 0.583   
## Days\_5th:SpeciesSph:trtLS 0.000 -0.087 0.000 0.020 0.000 0.000 0.513 0.719 0.000 0.000 -0.617 -0.905 0.000 0.000 0.647 0.969   
## Days\_6th:SpeciesRal:trt1G 0.135 -0.092 -0.243 0.166 -0.709 -0.308 0.000 0.000 0.879 0.482 0.000 0.000 -0.948 -0.563 0.000 0.000   
## Days\_6th:SpeciesSph:trt1G 0.092 -0.062 -0.031 0.021 -0.497 -0.685 0.000 0.000 0.609 0.873 0.000 0.000 -0.646 -0.947 0.000 0.000   
## Days\_6th:SpeciesRal:trtLS 0.000 0.109 0.000 -0.190 0.000 0.000 -0.703 -0.296 0.000 0.000 0.876 0.474 0.000 0.000 -0.947 -0.558   
## Days\_6th:SpeciesSph:trtLS 0.000 0.077 0.000 -0.024 0.000 0.000 -0.492 -0.674 0.000 0.000 0.604 0.868 0.000 0.000 -0.643 -0.945   
## Days\_7th:SpeciesRal:trt1G -0.121 0.082 0.227 -0.155 0.673 0.284 0.000 0.000 -0.847 -0.454 0.000 0.000 0.924 0.538 0.000 0.000   
## Days\_7th:SpeciesSph:trt1G -0.083 0.057 0.034 -0.023 0.479 0.649 0.000 0.000 -0.595 -0.841 0.000 0.000 0.638 0.922 0.000 0.000   
## Days\_7th:SpeciesRal:trtLS 0.000 -0.098 0.000 0.178 0.000 0.000 0.666 0.272 0.000 0.000 -0.843 -0.447 0.000 0.000 0.923 0.534   
## Days\_7th:SpeciesSph:trtLS 0.000 -0.070 0.000 0.026 0.000 0.000 0.473 0.638 0.000 0.000 -0.590 -0.835 0.000 0.000 0.635 0.920   
## Days\_8th:SpeciesRal:trt1G 0.111 -0.075 -0.214 0.146 -0.643 -0.264 0.000 0.000 0.818 0.430 0.000 0.000 -0.901 -0.516 0.000 0.000   
## Days\_8th:SpeciesSph:trt1G 0.077 -0.052 -0.035 0.024 -0.462 -0.619 0.000 0.000 0.580 0.811 0.000 0.000 -0.629 -0.899 0.000 0.000   
## Days\_8th:SpeciesRal:trtLS 0.000 0.090 0.000 -0.168 0.000 0.000 -0.635 -0.252 0.000 0.000 0.814 0.423 0.000 0.000 -0.899 -0.512   
## Days\_8th:SpeciesSph:trtLS 0.000 0.065 0.000 -0.027 0.000 0.000 -0.456 -0.607 0.000 0.000 0.576 0.805 0.000 0.000 -0.626 -0.896   
## Days\_9th:SpeciesRal:trt1G -0.103 0.070 0.203 -0.139 0.616 0.246 0.000 0.000 -0.791 -0.408 0.000 0.000 0.878 0.494 0.000 0.000   
## Days\_9th:SpeciesSph:trt1G -0.072 0.049 0.036 -0.024 0.447 0.593 0.000 0.000 -0.567 -0.785 0.000 0.000 0.619 0.876 0.000 0.000   
## Days\_9th:SpeciesRal:trtLS 0.000 -0.083 0.000 0.160 0.000 0.000 0.609 0.235 0.000 0.000 -0.787 -0.402 0.000 0.000 0.876 0.492   
## Days\_9th:SpeciesSph:trtLS 0.000 -0.061 0.000 0.028 0.000 0.000 0.441 0.580 0.000 0.000 -0.562 -0.779 0.000 0.000 0.616 0.874   
## Days\_10th:SpeciesRal:trt1G 0.096 -0.065 -0.194 0.133 -0.593 -0.230 0.000 0.000 0.767 0.388 0.000 0.000 -0.857 -0.475 0.000 0.000   
## Days\_10th:SpeciesSph:trt1G 0.068 -0.046 -0.036 0.025 -0.433 -0.570 0.000 0.000 0.554 0.761 0.000 0.000 -0.608 -0.855 0.000 0.000   
## Days\_10th:SpeciesRal:trtLS 0.000 0.078 0.000 -0.153 0.000 0.000 -0.586 -0.220 0.000 0.000 0.763 0.383 0.000 0.000 -0.855 -0.472   
## Days\_10th:SpeciesSph:trtLS 0.000 0.058 0.000 -0.028 0.000 0.000 -0.427 -0.557 0.000 0.000 0.549 0.755 0.000 0.000 -0.606 -0.853   
## D\_4:SR:1 D\_4:SS:1 D\_4:SR:L D\_4:SS:L D\_5:SR:1 D\_5:SS:1 D\_5:SR:L D\_5:SS:L D\_6:SR:1 D\_6:SS:1 D\_6:SR:L D\_6:SS:L D\_7:SR:1 D\_7:SS:1 D\_7:SR:L D\_7:SS:L D\_8:SR:1  
## trtLS   
## SpeciesSph   
## SpeciesSph:trtLS   
## Days:SpeciesRal:trt1G   
## Days:SpeciesSph:trt1G   
## Days:SpeciesRal:trtLS   
## Days:SpeciesSph:trtLS   
## Days\_sq:SpeciesRal:trt1G   
## Days\_sq:SpeciesSph:trt1G   
## Days\_sq:SpeciesRal:trtLS   
## Days\_sq:SpeciesSph:trtLS   
## Days\_cub:SpeciesRal:trt1G   
## Days\_cub:SpeciesSph:trt1G   
## Days\_cub:SpeciesRal:trtLS   
## Days\_cub:SpeciesSph:trtLS   
## Days\_4th:SpeciesRal:trt1G   
## Days\_4th:SpeciesSph:trt1G 0.641   
## Days\_4th:SpeciesRal:trtLS 0.000 0.000   
## Days\_4th:SpeciesSph:trtLS 0.000 0.000 0.638   
## Days\_5th:SpeciesRal:trt1G -0.994 -0.626 0.000 0.000   
## Days\_5th:SpeciesSph:trt1G -0.654 -0.994 0.000 0.000 0.647   
## Days\_5th:SpeciesRal:trtLS 0.000 0.000 -0.994 -0.623 0.000 0.000   
## Days\_5th:SpeciesSph:trtLS 0.000 0.000 -0.652 -0.994 0.000 0.000 0.645   
## Days\_6th:SpeciesRal:trt1G 0.982 0.608 0.000 0.000 -0.996 -0.634 0.000 0.000   
## Days\_6th:SpeciesSph:trt1G 0.658 0.981 0.000 0.000 -0.657 -0.996 0.000 0.000 0.649   
## Days\_6th:SpeciesRal:trtLS 0.000 0.000 0.981 0.605 0.000 0.000 -0.996 -0.633 0.000 0.000   
## Days\_6th:SpeciesSph:trtLS 0.000 0.000 0.656 0.981 0.000 0.000 -0.655 -0.996 0.000 0.000 0.648   
## Days\_7th:SpeciesRal:trt1G -0.966 -0.588 0.000 0.000 0.987 0.619 0.000 0.000 -0.997 -0.638 0.000 0.000   
## Days\_7th:SpeciesSph:trt1G -0.656 -0.965 0.000 0.000 0.660 0.987 0.000 0.000 -0.657 -0.997 0.000 0.000 0.649   
## Days\_7th:SpeciesRal:trtLS 0.000 0.000 -0.965 -0.586 0.000 0.000 0.987 0.618 0.000 0.000 -0.997 -0.638 0.000 0.000   
## Days\_7th:SpeciesSph:trtLS 0.000 0.000 -0.654 -0.964 0.000 0.000 0.660 0.987 0.000 0.000 -0.657 -0.997 0.000 0.000 0.650   
## Days\_8th:SpeciesRal:trt1G 0.948 0.568 0.000 0.000 -0.976 -0.602 0.000 0.000 0.991 0.625 0.000 0.000 -0.998 -0.639 0.000 0.000   
## Days\_8th:SpeciesSph:trt1G 0.651 0.948 0.000 0.000 -0.660 -0.976 0.000 0.000 0.661 0.991 0.000 0.000 -0.656 -0.998 0.000 0.000 0.649   
## Days\_8th:SpeciesRal:trtLS 0.000 0.000 0.947 0.567 0.000 0.000 -0.975 -0.602 0.000 0.000 0.991 0.625 0.000 0.000 -0.998 -0.641 0.000   
## Days\_8th:SpeciesSph:trtLS 0.000 0.000 0.650 0.947 0.000 0.000 -0.660 -0.975 0.000 0.000 0.661 0.991 0.000 0.000 -0.657 -0.998 0.000   
## Days\_9th:SpeciesRal:trt1G -0.930 -0.549 0.000 0.000 0.962 0.586 0.000 0.000 -0.982 -0.611 0.000 0.000 0.993 0.628 0.000 0.000 -0.998   
## Days\_9th:SpeciesSph:trt1G -0.645 -0.930 0.000 0.000 0.657 0.963 0.000 0.000 -0.661 -0.982 0.000 0.000 0.659 0.993 0.000 0.000 -0.654   
## Days\_9th:SpeciesRal:trtLS 0.000 0.000 -0.930 -0.548 0.000 0.000 0.962 0.586 0.000 0.000 -0.982 -0.612 0.000 0.000 0.993 0.630 0.000   
## Days\_9th:SpeciesSph:trtLS 0.000 0.000 -0.644 -0.929 0.000 0.000 0.658 0.962 0.000 0.000 -0.662 -0.982 0.000 0.000 0.661 0.993 0.000   
## Days\_10th:SpeciesRal:trt1G 0.913 0.531 0.000 0.000 -0.949 -0.569 0.000 0.000 0.972 0.596 0.000 0.000 -0.986 -0.615 0.000 0.000 0.995   
## Days\_10th:SpeciesSph:trt1G 0.638 0.913 0.000 0.000 -0.653 -0.949 0.000 0.000 0.659 0.972 0.000 0.000 -0.660 -0.986 0.000 0.000 0.657   
## Days\_10th:SpeciesRal:trtLS 0.000 0.000 0.912 0.531 0.000 0.000 -0.949 -0.571 0.000 0.000 0.972 0.599 0.000 0.000 -0.986 -0.618 0.000   
## Days\_10th:SpeciesSph:trtLS 0.000 0.000 0.637 0.912 0.000 0.000 -0.654 -0.949 0.000 0.000 0.661 0.972 0.000 0.000 -0.663 -0.986 0.000   
## D\_8:SS:1 D\_8:SR:L D\_8:SS:L D\_9:SR:1 D\_9:SS:1 D\_9:SR:L D\_9:SS:L D\_10:SR:1 D\_10:SS:1 D\_10:SR:L  
## trtLS   
## SpeciesSph   
## SpeciesSph:trtLS   
## Days:SpeciesRal:trt1G   
## Days:SpeciesSph:trt1G   
## Days:SpeciesRal:trtLS   
## Days:SpeciesSph:trtLS   
## Days\_sq:SpeciesRal:trt1G   
## Days\_sq:SpeciesSph:trt1G   
## Days\_sq:SpeciesRal:trtLS   
## Days\_sq:SpeciesSph:trtLS   
## Days\_cub:SpeciesRal:trt1G   
## Days\_cub:SpeciesSph:trt1G   
## Days\_cub:SpeciesRal:trtLS   
## Days\_cub:SpeciesSph:trtLS   
## Days\_4th:SpeciesRal:trt1G   
## Days\_4th:SpeciesSph:trt1G   
## Days\_4th:SpeciesRal:trtLS   
## Days\_4th:SpeciesSph:trtLS   
## Days\_5th:SpeciesRal:trt1G   
## Days\_5th:SpeciesSph:trt1G   
## Days\_5th:SpeciesRal:trtLS   
## Days\_5th:SpeciesSph:trtLS   
## Days\_6th:SpeciesRal:trt1G   
## Days\_6th:SpeciesSph:trt1G   
## Days\_6th:SpeciesRal:trtLS   
## Days\_6th:SpeciesSph:trtLS   
## Days\_7th:SpeciesRal:trt1G   
## Days\_7th:SpeciesSph:trt1G   
## Days\_7th:SpeciesRal:trtLS   
## Days\_7th:SpeciesSph:trtLS   
## Days\_8th:SpeciesRal:trt1G   
## Days\_8th:SpeciesSph:trt1G   
## Days\_8th:SpeciesRal:trtLS 0.000   
## Days\_8th:SpeciesSph:trtLS 0.000 0.651   
## Days\_9th:SpeciesRal:trt1G -0.639 0.000 0.000   
## Days\_9th:SpeciesSph:trt1G -0.998 0.000 0.000 0.647   
## Days\_9th:SpeciesRal:trtLS 0.000 -0.998 -0.642 0.000 0.000   
## Days\_9th:SpeciesSph:trtLS 0.000 -0.657 -0.999 0.000 0.000 0.650   
## Days\_10th:SpeciesRal:trt1G 0.629 0.000 0.000 -0.999 -0.638 0.000 0.000   
## Days\_10th:SpeciesSph:trt1G 0.995 0.000 0.000 -0.652 -0.999 0.000 0.000 0.644   
## Days\_10th:SpeciesRal:trtLS 0.000 0.995 0.632 0.000 0.000 -0.999 -0.642 0.000 0.000   
## Days\_10th:SpeciesSph:trtLS 0.000 0.660 0.995 0.000 0.000 -0.656 -0.999 0.000 0.000 0.649   
##   
## Standardized residuals:  
## Min Q1 Med Q3 Max   
## -4.44725947 -0.47857206 0.01045576 0.57157989 2.95259972   
##   
## Residual standard error: 0.2808171   
## Degrees of freedom: 1070 total; 1026 residual

print(Anova(ar1\_poly\_nested4, type = "III"))

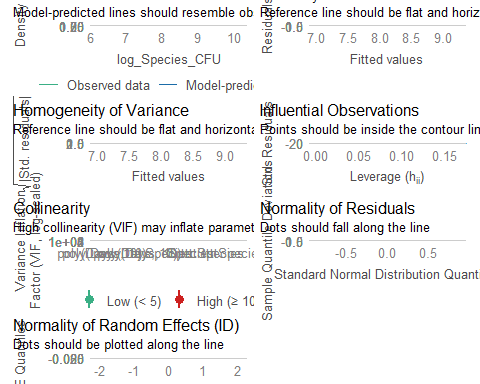
## Analysis of Deviance Table (Type III tests)  
##   
## Response: log\_Species\_CFU  
## Df Chisq Pr(>Chisq)   
## (Intercept) 1 8516.8223 <2e-16 \*\*\*  
## trt 1 0.0332 0.8553   
## Species 1 1.3369 0.2476   
## Species:trt 1 0.0004 0.9850   
## Days:Species:trt 4 1071.0241 <2e-16 \*\*\*  
## Days\_sq:Species:trt 4 511.2278 <2e-16 \*\*\*  
## Days\_cub:Species:trt 4 326.7204 <2e-16 \*\*\*  
## Days\_4th:Species:trt 4 239.4958 <2e-16 \*\*\*  
## Days\_5th:Species:trt 4 188.6781 <2e-16 \*\*\*  
## Days\_6th:Species:trt 4 155.4562 <2e-16 \*\*\*  
## Days\_7th:Species:trt 4 132.1052 <2e-16 \*\*\*  
## Days\_8th:Species:trt 4 114.8333 <2e-16 \*\*\*  
## Days\_9th:Species:trt 4 101.5588 <2e-16 \*\*\*  
## Days\_10th:Species:trt 4 91.0484 <2e-16 \*\*\*  
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1

###################### anova and diagnostics  
  
AIC( model\_species\_REML\_poly10, LMM\_poly\_ML, ar1\_poly\_nested, ar1\_poly\_nested2, ar1\_poly\_nested3, ar1\_poly\_nested4)

## Warning in AIC.default(model\_species\_REML\_poly10, LMM\_poly\_ML, ar1\_poly\_nested, : models are not all fitted to the same number of observations

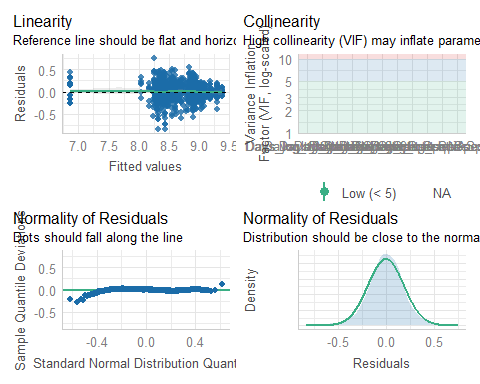
## df AIC  
## model\_species\_REML\_poly10 46 274.3817  
## LMM\_poly\_ML 46 271.8306  
## ar1\_poly\_nested 43 -140.2001  
## ar1\_poly\_nested2 46 -253.3079  
## ar1\_poly\_nested3 43 1764.2780  
## ar1\_poly\_nested4 46 1777.4191

check\_model(LMM\_poly\_ML)



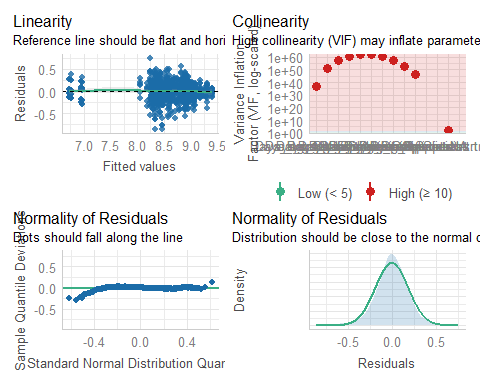
check\_model(ar1\_poly\_nested)

## Converting missing values (`NA`) into regular values currently not possible for variables of class `NULL`.



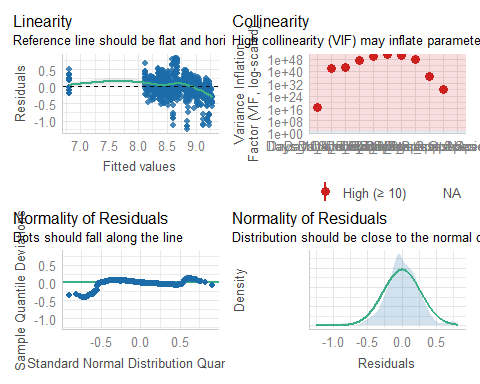
check\_model(ar1\_poly\_nested2)

## Converting missing values (`NA`) into regular values currently not possible for variables of class `NULL`.



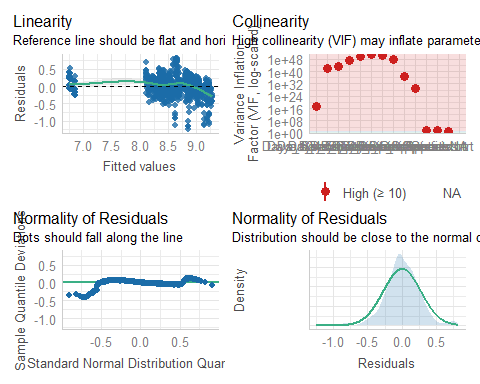
check\_model(ar1\_poly\_nested3)

## Converting missing values (`NA`) into regular values currently not possible for variables of class `NULL`.

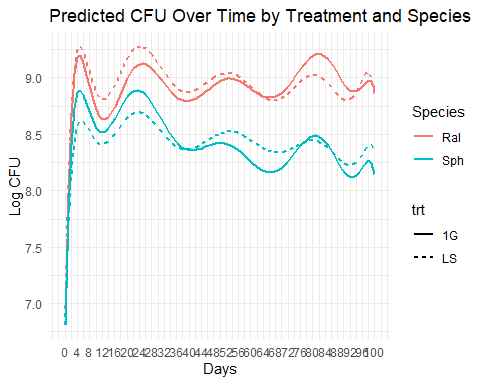


check\_model(ar1\_poly\_nested4)

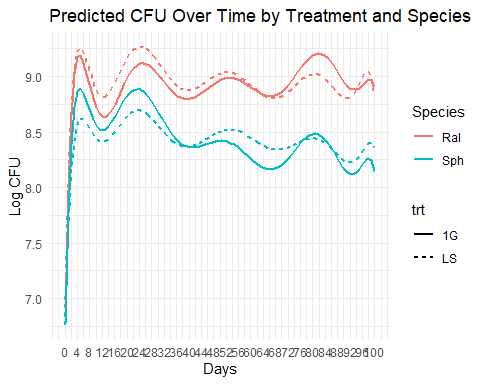
## Converting missing values (`NA`) into regular values currently not possible for variables of class `NULL`.



##################### Visualization new\_data$predicted3 &4  
# Visualization  
library(ggplot2)  
  
  
# Generate new data for prediction  
new\_data <- expand.grid(  
 Days = seq(min(species\_totals$Days), max(species\_totals$Days), length.out = 100),  
 trt = unique(species\_totals$trt),  
 Species = unique(species\_totals$Species)  
)  
  
# Add transformed Days (log) and polynomial terms to the new data  
new\_data <- new\_data %>%  
 mutate(  
 Days = Days,  
 Days\_sq = Days^2,  
 Days\_cub = Days^3,  
 Days\_4th = Days^4,  
 Days\_5th = Days^5,  
 Days\_6th = Days^6,  
 Days\_7th = Days^7,  
 Days\_8th = Days^8,  
 Days\_9th = Days^9,  
 Days\_10th = Days^10  
 )  
  
# Predict values using the best model (e.g., ar1\_poly\_nested or ar1\_poly\_nested2)  
new\_data$predicted3 <- predict(ar1\_poly\_nested3, newdata = new\_data)  
  
# Plot predictions  
ggplot(new\_data, aes(x = Days, y = predicted3, color = Species, linetype = trt)) +  
 geom\_line(size = 1) +  
 labs(title = "Predicted CFU Over Time by Treatment and Species",  
 y = "Log CFU",  
 x = "Days") +  
 scale\_x\_continuous(breaks = seq(0, max(species\_totals$Days), 4))+  
 theme\_minimal() +  
 theme(legend.position = "right")



new\_data$predicted4 <- predict(ar1\_poly\_nested4, newdata = new\_data)  
  
# Plot predictions  
ggplot(new\_data, aes(x = Days, y = predicted4, color = Species, linetype = trt)) +  
 geom\_line(size = 1) +  
 labs(title = "Predicted CFU Over Time by Treatment and Species",  
 y = "Log CFU",  
 x = "Days") +  
 scale\_x\_continuous(breaks = seq(0, max(species\_totals$Days), 4))+  
 theme\_minimal() +  
 theme(legend.position = "right")



###############  
  
anova(ar1\_poly\_nested,ar1\_poly\_nested2, ar1\_poly\_nested3,ar1\_poly\_nested4)

## Warning in nlme::anova.lme(object = ar1\_poly\_nested, ar1\_poly\_nested2, ar1\_poly\_nested3, : fitted objects with different fixed effects. REML comparisons are not meaningful.

## Model df AIC BIC logLik Test L.Ratio p-value  
## ar1\_poly\_nested 1 43 -140.2001 72.0626 113.1001   
## ar1\_poly\_nested2 2 46 -253.3079 -26.3704 172.6540 1 vs 2 119.1078 <.0001  
## ar1\_poly\_nested3 3 43 1764.2780 1976.5407 -839.1390 2 vs 3 2023.5859 <.0001  
## ar1\_poly\_nested4 4 46 1777.4191 2004.3566 -842.7096 3 vs 4 7.1411 0.0675

VarCorr(LMM\_poly\_ML)

## Groups Name Std.Dev.  
## ID (Intercept) 0.00000   
## Residual 0.26318

summary(ar1\_poly\_nested2)

## Generalized least squares fit by REML  
## Model: log\_Species\_CFU ~ (Days\_log + Days\_log\_sq + Days\_log\_cub + Days\_log\_4th + Days\_log\_5th + Days\_log\_6th + Days\_log\_7th + Days\_log\_8th + Days\_log\_9th + Days\_log\_10th):Species:trt + trt:Species + trt + Species   
## Data: species\_totals   
## AIC BIC logLik  
## -253.3079 -26.37044 172.654  
##   
## Correlation Structure: AR(1)  
## Formula: ~1 | ID   
## Parameter estimate(s):  
## Phi   
## 0.3366177   
##   
## Coefficients:  
## Value Std.Error t-value p-value  
## (Intercept) 6.757 0.0508 133.02636 0.0000  
## trtLS -0.027 0.0748 -0.35488 0.7228  
## SpeciesSph 0.222 0.0584 3.79803 0.0002  
## SpeciesSph:trtLS -0.002 0.0861 -0.02724 0.9783  
## Days\_log:SpeciesRal:trt1G -1123.200 167.8027 -6.69357 0.0000  
## Days\_log:SpeciesSph:trt1G -173.377 163.4094 -1.06100 0.2889  
## Days\_log:SpeciesRal:trtLS -972.439 176.2895 -5.51615 0.0000  
## Days\_log:SpeciesSph:trtLS -496.404 171.1287 -2.90076 0.0038  
## Days\_log\_sq:SpeciesRal:trt1G 4055.396 616.2010 6.58129 0.0000  
## Days\_log\_sq:SpeciesSph:trt1G 570.703 600.4188 0.95051 0.3421  
## Days\_log\_sq:SpeciesRal:trtLS 3466.216 646.5110 5.36142 0.0000  
## Days\_log\_sq:SpeciesSph:trtLS 1810.093 628.3391 2.88076 0.0040  
## Days\_log\_cub:SpeciesRal:trt1G -6241.068 970.9360 -6.42789 0.0000  
## Days\_log\_cub:SpeciesSph:trt1G -778.444 946.7001 -0.82227 0.4111  
## Days\_log\_cub:SpeciesRal:trtLS -5259.664 1017.1781 -5.17084 0.0000  
## Days\_log\_cub:SpeciesSph:trtLS -2811.723 989.8686 -2.84050 0.0046  
## Days\_log\_4th:SpeciesRal:trt1G 5408.585 864.5035 6.25629 0.0000  
## Days\_log\_4th:SpeciesSph:trt1G 584.240 843.5469 0.69260 0.4887  
## Days\_log\_4th:SpeciesRal:trtLS 4492.163 904.2260 4.96796 0.0000  
## Days\_log\_4th:SpeciesSph:trtLS 2459.086 881.1366 2.79081 0.0054  
## Days\_log\_5th:SpeciesRal:trt1G -2920.711 480.7019 -6.07593 0.0000  
## Days\_log\_5th:SpeciesSph:trt1G -266.167 469.4233 -0.56701 0.5708  
## Days\_log\_5th:SpeciesRal:trtLS -2390.684 501.9557 -4.76274 0.0000  
## Days\_log\_5th:SpeciesSph:trtLS -1340.043 489.8093 -2.73585 0.0063  
## Days\_log\_6th:SpeciesRal:trt1G 1022.498 173.5336 5.89222 0.0000  
## Days\_log\_6th:SpeciesSph:trt1G 75.947 169.6053 0.44779 0.6544  
## Days\_log\_6th:SpeciesRal:trtLS 825.081 180.9045 4.56086 0.0000  
## Days\_log\_6th:SpeciesSph:trtLS 473.471 176.7689 2.67847 0.0075  
## Days\_log\_7th:SpeciesRal:trt1G -232.681 40.7609 -5.70843 0.0000  
## Days\_log\_7th:SpeciesSph:trt1G -13.379 39.8734 -0.33555 0.7373  
## Days\_log\_7th:SpeciesRal:trtLS -185.201 42.4228 -4.36561 0.0000  
## Days\_log\_7th:SpeciesSph:trtLS -108.784 41.5090 -2.62072 0.0089  
## Days\_log\_8th:SpeciesRal:trt1G 33.264 6.0189 5.52653 0.0000  
## Days\_log\_8th:SpeciesSph:trt1G 1.355 5.8932 0.22999 0.8181  
## Days\_log\_8th:SpeciesRal:trtLS 26.135 6.2544 4.17870 0.0000  
## Days\_log\_8th:SpeciesSph:trtLS 15.711 6.1278 2.56395 0.0105  
## Days\_log\_9th:SpeciesRal:trt1G -2.716 0.5079 -5.34765 0.0000  
## Days\_log\_9th:SpeciesSph:trt1G -0.065 0.4978 -0.13042 0.8963  
## Days\_log\_9th:SpeciesRal:trtLS -2.108 0.5270 -4.00091 0.0001  
## Days\_log\_9th:SpeciesSph:trtLS -1.297 0.5170 -2.50900 0.0123  
## Days\_log\_10th:SpeciesRal:trt1G 0.097 0.0187 5.17246 0.0000  
## Days\_log\_10th:SpeciesSph:trt1G 0.001 0.0183 0.03603 0.9713  
## Days\_log\_10th:SpeciesRal:trtLS 0.074 0.0194 3.83240 0.0001  
## Days\_log\_10th:SpeciesSph:trtLS 0.047 0.0190 2.45634 0.0142  
##   
## Correlation:   
## (Intr) trtLS SpcsSp SpS:LS D\_:SR:1 D\_:SS:1 D\_:SR:L D\_:SS:L Dys\_lg\_s:SR:1G Dys\_lg\_s:SS:1G Dys\_lg\_s:SR:LS Dys\_lg\_s:SS:LS Dys\_lg\_c:SR:1G  
## trtLS -0.679   
## SpeciesSph -0.580 0.394   
## SpeciesSph:trtLS 0.393 -0.578 -0.679   
## Days\_log:SpeciesRal:trt1G -0.006 0.004 -0.008 0.005   
## Days\_log:SpeciesSph:trt1G -0.003 0.002 -0.005 0.003 0.378   
## Days\_log:SpeciesRal:trtLS 0.000 -0.001 0.000 0.001 0.000 0.000   
## Days\_log:SpeciesSph:trtLS 0.000 0.000 0.000 -0.001 0.000 0.000 0.391   
## Days\_log\_sq:SpeciesRal:trt1G 0.006 -0.004 0.008 -0.006 -1.000 -0.378 0.000 0.000   
## Days\_log\_sq:SpeciesSph:trt1G 0.003 -0.002 0.004 -0.003 -0.385 -1.000 0.000 0.000 0.385   
## Days\_log\_sq:SpeciesRal:trtLS 0.000 0.001 0.000 0.000 0.000 0.000 -1.000 -0.391 0.000 0.000   
## Days\_log\_sq:SpeciesSph:trtLS 0.000 0.000 0.000 0.001 0.000 0.000 -0.398 -1.000 0.000 0.000 0.397   
## Days\_log\_cub:SpeciesRal:trt1G -0.005 0.004 -0.008 0.006 0.998 0.377 0.000 0.000 -1.000 -0.384 0.000 0.000   
## Days\_log\_cub:SpeciesSph:trt1G -0.003 0.002 -0.004 0.003 0.392 0.998 0.000 0.000 -0.392 -1.000 0.000 0.000 0.392   
## Days\_log\_cub:SpeciesRal:trtLS 0.000 -0.001 0.000 -0.001 0.000 0.000 0.998 0.390 0.000 0.000 -1.000 -0.397 0.000   
## Days\_log\_cub:SpeciesSph:trtLS 0.000 0.000 0.000 -0.001 0.000 0.000 0.404 0.998 0.000 0.000 -0.404 -1.000 0.000   
## Days\_log\_4th:SpeciesRal:trt1G 0.005 -0.004 0.008 -0.006 -0.996 -0.375 0.000 0.000 0.998 0.383 0.000 0.000 -1.000   
## Days\_log\_4th:SpeciesSph:trt1G 0.002 -0.002 0.004 -0.003 -0.399 -0.996 0.000 0.000 0.399 0.998 0.000 0.000 -0.399   
## Days\_log\_4th:SpeciesRal:trtLS 0.000 0.001 0.000 0.001 0.000 0.000 -0.996 -0.388 0.000 0.000 0.998 0.396 0.000   
## Days\_log\_4th:SpeciesSph:trtLS 0.000 0.000 0.000 0.001 0.000 0.000 -0.410 -0.996 0.000 0.000 0.410 0.998 0.000   
## Days\_log\_5th:SpeciesRal:trt1G -0.005 0.003 -0.008 0.006 0.993 0.373 0.000 0.000 -0.996 -0.381 0.000 0.000 0.998   
## Days\_log\_5th:SpeciesSph:trt1G -0.002 0.002 -0.004 0.003 0.404 0.992 0.000 0.000 -0.405 -0.995 0.000 0.000 0.405   
## Days\_log\_5th:SpeciesRal:trtLS 0.000 -0.001 0.000 -0.001 0.000 0.000 0.993 0.387 0.000 0.000 -0.996 -0.394 0.000   
## Days\_log\_5th:SpeciesSph:trtLS 0.000 0.000 0.000 -0.001 0.000 0.000 0.415 0.993 0.000 0.000 -0.416 -0.996 0.000   
## Days\_log\_6th:SpeciesRal:trt1G 0.005 -0.003 0.008 -0.005 -0.989 -0.370 0.000 0.000 0.993 0.379 0.000 0.000 -0.996   
## Days\_log\_6th:SpeciesSph:trt1G 0.002 -0.002 0.004 -0.003 -0.409 -0.988 0.000 0.000 0.410 0.992 0.000 0.000 -0.411   
## Days\_log\_6th:SpeciesRal:trtLS 0.000 0.001 0.000 0.001 0.000 0.000 -0.989 -0.385 0.000 0.000 0.993 0.393 0.000   
## Days\_log\_6th:SpeciesSph:trtLS 0.000 0.000 0.000 0.001 0.000 0.000 -0.419 -0.989 0.000 0.000 0.421 0.993 0.000   
## Days\_log\_7th:SpeciesRal:trt1G -0.005 0.003 -0.008 0.005 0.984 0.368 0.000 0.000 -0.988 -0.377 0.000 0.000 0.993   
## Days\_log\_7th:SpeciesSph:trt1G -0.002 0.002 -0.004 0.003 0.413 0.983 0.000 0.000 -0.415 -0.988 0.000 0.000 0.416   
## Days\_log\_7th:SpeciesRal:trtLS 0.000 -0.001 0.000 -0.001 0.000 0.000 0.985 0.382 0.000 0.000 -0.989 -0.390 0.000   
## Days\_log\_7th:SpeciesSph:trtLS 0.000 0.000 0.000 -0.001 0.000 0.000 0.423 0.984 0.000 0.000 -0.425 -0.989 0.000   
## Days\_log\_8th:SpeciesRal:trt1G 0.005 -0.003 0.007 -0.005 -0.978 -0.365 0.000 0.000 0.984 0.374 0.000 0.000 -0.989   
## Days\_log\_8th:SpeciesSph:trt1G 0.002 -0.002 0.004 -0.003 -0.417 -0.977 0.000 0.000 0.419 0.983 0.000 0.000 -0.420   
## Days\_log\_8th:SpeciesRal:trtLS 0.000 0.001 0.000 0.001 0.000 0.000 -0.980 -0.379 0.000 0.000 0.985 0.388 0.000   
## Days\_log\_8th:SpeciesSph:trtLS 0.000 0.000 0.000 0.001 0.000 0.000 -0.426 -0.979 0.000 0.000 0.428 0.984 0.000   
## Days\_log\_9th:SpeciesRal:trt1G -0.004 0.003 -0.007 0.005 0.972 0.361 0.000 0.000 -0.978 -0.371 0.000 0.000 0.984   
## Days\_log\_9th:SpeciesSph:trt1G -0.002 0.001 -0.004 0.003 0.419 0.971 0.000 0.000 -0.422 -0.977 0.000 0.000 0.424   
## Days\_log\_9th:SpeciesRal:trtLS 0.000 -0.001 0.000 -0.001 0.000 0.000 0.974 0.376 0.000 0.000 -0.980 -0.385 0.000   
## Days\_log\_9th:SpeciesSph:trtLS 0.000 0.000 0.000 -0.001 0.000 0.000 0.429 0.973 0.000 0.000 -0.431 -0.979 0.000   
## Days\_log\_10th:SpeciesRal:trt1G 0.004 -0.003 0.007 -0.005 -0.966 -0.358 0.000 0.000 0.973 0.368 0.000 0.000 -0.979   
## Days\_log\_10th:SpeciesSph:trt1G 0.002 -0.001 0.004 -0.002 -0.422 -0.964 0.000 0.000 0.424 0.971 0.000 0.000 -0.426   
## Days\_log\_10th:SpeciesRal:trtLS 0.000 0.001 0.000 0.001 0.000 0.000 -0.968 -0.373 0.000 0.000 0.974 0.382 0.000   
## Days\_log\_10th:SpeciesSph:trtLS 0.000 0.000 0.000 0.001 0.000 0.000 -0.431 -0.967 0.000 0.000 0.433 0.973 0.000   
## Dys\_lg\_c:SS:1G Dys\_lg\_c:SR:LS Dys\_lg\_c:SS:LS D\_\_4:SR:1 D\_\_4:SS:1 D\_\_4:SR:L D\_\_4:SS:L D\_\_5:SR:1 D\_\_5:SS:1 D\_\_5:SR:L D\_\_5:SS:L D\_\_6:SR:1 D\_\_6:SS:1  
## trtLS   
## SpeciesSph   
## SpeciesSph:trtLS   
## Days\_log:SpeciesRal:trt1G   
## Days\_log:SpeciesSph:trt1G   
## Days\_log:SpeciesRal:trtLS   
## Days\_log:SpeciesSph:trtLS   
## Days\_log\_sq:SpeciesRal:trt1G   
## Days\_log\_sq:SpeciesSph:trt1G   
## Days\_log\_sq:SpeciesRal:trtLS   
## Days\_log\_sq:SpeciesSph:trtLS   
## Days\_log\_cub:SpeciesRal:trt1G   
## Days\_log\_cub:SpeciesSph:trt1G   
## Days\_log\_cub:SpeciesRal:trtLS 0.000   
## Days\_log\_cub:SpeciesSph:trtLS 0.000 0.404   
## Days\_log\_4th:SpeciesRal:trt1G -0.391 0.000 0.000   
## Days\_log\_4th:SpeciesSph:trt1G -0.999 0.000 0.000 0.398   
## Days\_log\_4th:SpeciesRal:trtLS 0.000 -1.000 -0.403 0.000 0.000   
## Days\_log\_4th:SpeciesSph:trtLS 0.000 -0.410 -1.000 0.000 0.000 0.410   
## Days\_log\_5th:SpeciesRal:trt1G 0.389 0.000 0.000 -1.000 -0.397 0.000 0.000   
## Days\_log\_5th:SpeciesSph:trt1G 0.998 0.000 0.000 -0.405 -0.999 0.000 0.000 0.405   
## Days\_log\_5th:SpeciesRal:trtLS 0.000 0.998 0.402 0.000 0.000 -1.000 -0.409 0.000 0.000   
## Days\_log\_5th:SpeciesSph:trtLS 0.000 0.416 0.998 0.000 0.000 -0.416 -1.000 0.000 0.000 0.416   
## Days\_log\_6th:SpeciesRal:trt1G -0.388 0.000 0.000 0.998 0.396 0.000 0.000 -1.000 -0.404 0.000 0.000   
## Days\_log\_6th:SpeciesSph:trt1G -0.996 0.000 0.000 0.411 0.998 0.000 0.000 -0.411 -1.000 0.000 0.000 0.410   
## Days\_log\_6th:SpeciesRal:trtLS 0.000 -0.996 -0.400 0.000 0.000 0.998 0.408 0.000 0.000 -1.000 -0.415 0.000 0.000   
## Days\_log\_6th:SpeciesSph:trtLS 0.000 -0.421 -0.996 0.000 0.000 0.422 0.998 0.000 0.000 -0.422 -1.000 0.000 0.000   
## Days\_log\_7th:SpeciesRal:trt1G 0.386 0.000 0.000 -0.996 -0.394 0.000 0.000 0.998 0.402 0.000 0.000 -1.000 -0.409   
## Days\_log\_7th:SpeciesSph:trt1G 0.992 0.000 0.000 -0.417 -0.996 0.000 0.000 0.417 0.998 0.000 0.000 -0.417 -1.000   
## Days\_log\_7th:SpeciesRal:trtLS 0.000 0.993 0.399 0.000 0.000 -0.996 -0.406 0.000 0.000 0.998 0.414 0.000 0.000   
## Days\_log\_7th:SpeciesSph:trtLS 0.000 0.426 0.993 0.000 0.000 -0.427 -0.996 0.000 0.000 0.427 0.998 0.000 0.000   
## Days\_log\_8th:SpeciesRal:trt1G -0.383 0.000 0.000 0.993 0.392 0.000 0.000 -0.996 -0.400 0.000 0.000 0.998 0.408   
## Days\_log\_8th:SpeciesSph:trt1G -0.988 0.000 0.000 0.421 0.992 0.000 0.000 -0.422 -0.996 0.000 0.000 0.422 0.998   
## Days\_log\_8th:SpeciesRal:trtLS 0.000 -0.989 -0.396 0.000 0.000 0.993 0.404 0.000 0.000 -0.996 -0.412 0.000 0.000   
## Days\_log\_8th:SpeciesSph:trtLS 0.000 -0.430 -0.989 0.000 0.000 0.431 0.993 0.000 0.000 -0.432 -0.996 0.000 0.000   
## Days\_log\_9th:SpeciesRal:trt1G 0.380 0.000 0.000 -0.989 -0.389 0.000 0.000 0.993 0.398 0.000 0.000 -0.996 -0.406   
## Days\_log\_9th:SpeciesSph:trt1G 0.983 0.000 0.000 -0.425 -0.989 0.000 0.000 0.426 0.993 0.000 0.000 -0.427 -0.996   
## Days\_log\_9th:SpeciesRal:trtLS 0.000 0.985 0.394 0.000 0.000 -0.990 -0.402 0.000 0.000 0.993 0.410 0.000 0.000   
## Days\_log\_9th:SpeciesSph:trtLS 0.000 0.433 0.985 0.000 0.000 -0.434 -0.989 0.000 0.000 0.436 0.993 0.000 0.000   
## Days\_log\_10th:SpeciesRal:trt1G -0.377 0.000 0.000 0.985 0.387 0.000 0.000 -0.990 -0.396 0.000 0.000 0.993 0.404   
## Days\_log\_10th:SpeciesSph:trt1G -0.978 0.000 0.000 0.428 0.984 0.000 0.000 -0.430 -0.989 0.000 0.000 0.431 0.993   
## Days\_log\_10th:SpeciesRal:trtLS 0.000 -0.980 -0.391 0.000 0.000 0.985 0.400 0.000 0.000 -0.990 -0.408 0.000 0.000   
## Days\_log\_10th:SpeciesSph:trtLS 0.000 -0.435 -0.980 0.000 0.000 0.437 0.985 0.000 0.000 -0.439 -0.990 0.000 0.000   
## D\_\_6:SR:L D\_\_6:SS:L D\_\_7:SR:1 D\_\_7:SS:1 D\_\_7:SR:L D\_\_7:SS:L D\_\_8:SR:1 D\_\_8:SS:1 D\_\_8:SR:L D\_\_8:SS:L D\_\_9:SR:1 D\_\_9:SS:1 D\_\_9:SR:L D\_\_9:SS:L  
## trtLS   
## SpeciesSph   
## SpeciesSph:trtLS   
## Days\_log:SpeciesRal:trt1G   
## Days\_log:SpeciesSph:trt1G   
## Days\_log:SpeciesRal:trtLS   
## Days\_log:SpeciesSph:trtLS   
## Days\_log\_sq:SpeciesRal:trt1G   
## Days\_log\_sq:SpeciesSph:trt1G   
## Days\_log\_sq:SpeciesRal:trtLS   
## Days\_log\_sq:SpeciesSph:trtLS   
## Days\_log\_cub:SpeciesRal:trt1G   
## Days\_log\_cub:SpeciesSph:trt1G   
## Days\_log\_cub:SpeciesRal:trtLS   
## Days\_log\_cub:SpeciesSph:trtLS   
## Days\_log\_4th:SpeciesRal:trt1G   
## Days\_log\_4th:SpeciesSph:trt1G   
## Days\_log\_4th:SpeciesRal:trtLS   
## Days\_log\_4th:SpeciesSph:trtLS   
## Days\_log\_5th:SpeciesRal:trt1G   
## Days\_log\_5th:SpeciesSph:trt1G   
## Days\_log\_5th:SpeciesRal:trtLS   
## Days\_log\_5th:SpeciesSph:trtLS   
## Days\_log\_6th:SpeciesRal:trt1G   
## Days\_log\_6th:SpeciesSph:trt1G   
## Days\_log\_6th:SpeciesRal:trtLS   
## Days\_log\_6th:SpeciesSph:trtLS 0.421   
## Days\_log\_7th:SpeciesRal:trt1G 0.000 0.000   
## Days\_log\_7th:SpeciesSph:trt1G 0.000 0.000 0.416   
## Days\_log\_7th:SpeciesRal:trtLS -1.000 -0.421 0.000 0.000   
## Days\_log\_7th:SpeciesSph:trtLS -0.427 -1.000 0.000 0.000 0.427   
## Days\_log\_8th:SpeciesRal:trt1G 0.000 0.000 -1.000 -0.415 0.000 0.000   
## Days\_log\_8th:SpeciesSph:trt1G 0.000 0.000 -0.422 -1.000 0.000 0.000 0.421   
## Days\_log\_8th:SpeciesRal:trtLS 0.998 0.419 0.000 0.000 -1.000 -0.426 0.000 0.000   
## Days\_log\_8th:SpeciesSph:trtLS 0.432 0.998 0.000 0.000 -0.432 -1.000 0.000 0.000 0.431   
## Days\_log\_9th:SpeciesRal:trt1G 0.000 0.000 0.998 0.413 0.000 0.000 -1.000 -0.420 0.000 0.000   
## Days\_log\_9th:SpeciesSph:trt1G 0.000 0.000 0.427 0.998 0.000 0.000 -0.427 -1.000 0.000 0.000 0.426   
## Days\_log\_9th:SpeciesRal:trtLS -0.996 -0.418 0.000 0.000 0.998 0.424 0.000 0.000 -1.000 -0.430 0.000 0.000   
## Days\_log\_9th:SpeciesSph:trtLS -0.436 -0.996 0.000 0.000 0.436 0.998 0.000 0.000 -0.436 -1.000 0.000 0.000 0.436   
## Days\_log\_10th:SpeciesRal:trt1G 0.000 0.000 -0.996 -0.412 0.000 0.000 0.998 0.419 0.000 0.000 -1.000 -0.425 0.000 0.000   
## Days\_log\_10th:SpeciesSph:trt1G 0.000 0.000 -0.431 -0.996 0.000 0.000 0.431 0.998 0.000 0.000 -0.431 -1.000 0.000 0.000   
## Days\_log\_10th:SpeciesRal:trtLS 0.994 0.416 0.000 0.000 -0.997 -0.423 0.000 0.000 0.999 0.429 0.000 0.000 -1.000 -0.435   
## Days\_log\_10th:SpeciesSph:trtLS 0.440 0.994 0.000 0.000 -0.440 -0.996 0.000 0.000 0.440 0.998 0.000 0.000 -0.440 -1.000   
## D\_\_10:SR:1 D\_\_10:SS:1 D\_\_10:SR:L  
## trtLS   
## SpeciesSph   
## SpeciesSph:trtLS   
## Days\_log:SpeciesRal:trt1G   
## Days\_log:SpeciesSph:trt1G   
## Days\_log:SpeciesRal:trtLS   
## Days\_log:SpeciesSph:trtLS   
## Days\_log\_sq:SpeciesRal:trt1G   
## Days\_log\_sq:SpeciesSph:trt1G   
## Days\_log\_sq:SpeciesRal:trtLS   
## Days\_log\_sq:SpeciesSph:trtLS   
## Days\_log\_cub:SpeciesRal:trt1G   
## Days\_log\_cub:SpeciesSph:trt1G   
## Days\_log\_cub:SpeciesRal:trtLS   
## Days\_log\_cub:SpeciesSph:trtLS   
## Days\_log\_4th:SpeciesRal:trt1G   
## Days\_log\_4th:SpeciesSph:trt1G   
## Days\_log\_4th:SpeciesRal:trtLS   
## Days\_log\_4th:SpeciesSph:trtLS   
## Days\_log\_5th:SpeciesRal:trt1G   
## Days\_log\_5th:SpeciesSph:trt1G   
## Days\_log\_5th:SpeciesRal:trtLS   
## Days\_log\_5th:SpeciesSph:trtLS   
## Days\_log\_6th:SpeciesRal:trt1G   
## Days\_log\_6th:SpeciesSph:trt1G   
## Days\_log\_6th:SpeciesRal:trtLS   
## Days\_log\_6th:SpeciesSph:trtLS   
## Days\_log\_7th:SpeciesRal:trt1G   
## Days\_log\_7th:SpeciesSph:trt1G   
## Days\_log\_7th:SpeciesRal:trtLS   
## Days\_log\_7th:SpeciesSph:trtLS   
## Days\_log\_8th:SpeciesRal:trt1G   
## Days\_log\_8th:SpeciesSph:trt1G   
## Days\_log\_8th:SpeciesRal:trtLS   
## Days\_log\_8th:SpeciesSph:trtLS   
## Days\_log\_9th:SpeciesRal:trt1G   
## Days\_log\_9th:SpeciesSph:trt1G   
## Days\_log\_9th:SpeciesRal:trtLS   
## Days\_log\_9th:SpeciesSph:trtLS   
## Days\_log\_10th:SpeciesRal:trt1G   
## Days\_log\_10th:SpeciesSph:trt1G 0.430   
## Days\_log\_10th:SpeciesRal:trtLS 0.000 0.000   
## Days\_log\_10th:SpeciesSph:trtLS 0.000 0.000 0.439   
##   
## Standardized residuals:  
## Min Q1 Med Q3 Max   
## -4.50541806 -0.54531999 0.02226298 0.60421901 3.96912998   
##   
## Residual standard error: 0.1901803   
## Degrees of freedom: 1070 total; 1026 residual

print(Anova(ar1\_poly\_nested2, type = "III"))

## Analysis of Deviance Table (Type III tests)  
##   
## Response: log\_Species\_CFU  
## Df Chisq Pr(>Chisq)   
## (Intercept) 1 17696.0128 < 2.2e-16 \*\*\*  
## trt 1 0.1259 0.7226785   
## Species 1 14.4250 0.0001459 \*\*\*  
## Species:trt 1 0.0007 0.9782706   
## Days\_log:Species:trt 4 78.4136 3.776e-16 \*\*\*  
## Days\_log\_sq:Species:trt 4 75.6700 1.438e-15 \*\*\*  
## Days\_log\_cub:Species:trt 4 72.1281 8.064e-15 \*\*\*  
## Days\_log\_4th:Species:trt 4 68.3518 5.056e-14 \*\*\*  
## Days\_log\_5th:Species:trt 4 64.5651 3.178e-13 \*\*\*  
## Days\_log\_6th:Species:trt 4 60.8858 1.889e-12 \*\*\*  
## Days\_log\_7th:Species:trt 4 57.3756 1.032e-11 \*\*\*  
## Days\_log\_8th:Species:trt 4 54.0630 5.105e-11 \*\*\*  
## Days\_log\_9th:Species:trt 4 50.9577 2.278e-10 \*\*\*  
## Days\_log\_10th:Species:trt 4 48.0586 9.176e-10 \*\*\*  
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1

## Introduce breakpoint and analyze data

### (a) Estimate breakpoint with linear regression.

#install.packages("segmented")  
library(segmented)

## Warning: package 'segmented' was built under R version 4.4.2

## Loading required package: MASS

##   
## Attaching package: 'MASS'

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

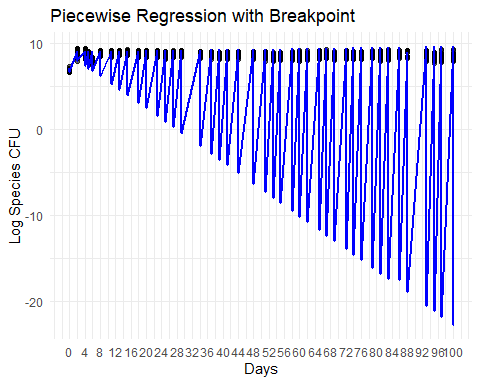
################### 1. Linear regression, find breakpoint:   
################### :estimated breakpoint is Day 2  
  
## Fit a Piecewise Regression Model  
lm\_initial <- lm(log\_Species\_CFU ~ Days \* Species \*trt, data = species\_totals)  
library(segmented)  
  
# Add a breakpoint to the initial linear model  
segmented\_model <- segmented(lm\_initial, seg.Z = ~ Days, psi = 8) # Set an initial guess for the breakpoint (e.g., psi = 8)  
  
summary(segmented\_model)

##   
## \*\*\*Regression Model with Segmented Relationship(s)\*\*\*  
##   
## Call:   
## segmented.lm(obj = lm\_initial, seg.Z = ~Days, psi = 8)  
##   
## Estimated Break-Point(s):  
## Est. St.Err  
## psi1.Days 2 0.037  
##   
## Coefficients of the linear terms:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) 6.9498382 0.0380074 182.855 < 2e-16 \*\*\*  
## Days 0.9867131 0.0232615 42.418 < 2e-16 \*\*\*  
## SpeciesSph -0.1565375 0.0336119 -4.657 3.61e-06 \*\*\*  
## trtLS 0.1235235 0.0340902 3.623 0.000305 \*\*\*  
## U1.Days -0.9861737 0.0232631 -42.392 NA   
## Days:SpeciesSph -0.3166157 0.0006327 -500.456 < 2e-16 \*\*\*  
## Days:trtLS 0.0057999 0.0006361 9.119 < 2e-16 \*\*\*  
## SpeciesSph:trtLS -0.3164660 0.0481534 -6.572 7.77e-11 \*\*\*  
## Days:SpeciesSph:trtLS 0.0057980 0.0008988 6.451 1.69e-10 \*\*\*  
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 0.2324 on 1060 degrees of freedom  
## Multiple R-Squared: 0.8113, Adjusted R-squared: 0.8097   
##   
## Boot restarting based on 6 samples. Last fit:  
## Convergence attained in 1 iterations (rel. change 0)

# Extract the estimated breakpoint  
breakpoint <- segmented\_model$psi[2]  
print(breakpoint)

## [1] 2

##Visualization: Plot the Piecewise Regression  
library(ggplot2)  
  
# Create predicted values for visualization  
species\_totals$Predicted <- predict(segmented\_model)  
  
# Plot the observed data with piecewise regression  
ggplot(species\_totals, aes(x = Days, y = log\_Species\_CFU)) +  
 geom\_point(alpha = 0.6) + # Observed data  
 geom\_line(aes(y = Predicted), color = "blue", size = 1) + # Fitted piecewise regression  
 labs(title = "Piecewise Regression with Breakpoint",  
 x = "Days",  
 y = "Log Species CFU") +  
 scale\_x\_continuous(breaks = seq(0, max(species\_totals$Days), 4))+  
 theme\_minimal()



### (b) Modeling with a Manually Set Breakpoint at Day 8.

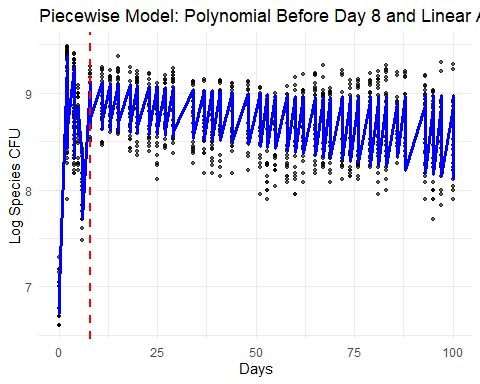
########### 2. Manually set breakpoint at day8, then polynormial before and linear after.  
  
# Define a custom variable for days before and after the breakpoint  
species\_totals$Days\_poly <- pmin(species\_totals$Days, 8) # Polynomial part (before day 8)  
species\_totals$Days\_linear <- pmax(species\_totals$Days - 8, 0) # Linear part (after day 8)  
  
  
### poly 5: Fit the combined model  
model\_piecewise5 <- lm(log\_Species\_CFU ~ poly(Days\_poly, 5)\*trt\*Species + Days\_linear\*trt\*Species, data = species\_totals)  
summary(model\_piecewise5)

##   
## Call:  
## lm(formula = log\_Species\_CFU ~ poly(Days\_poly, 5) \* trt \* Species +   
## Days\_linear \* trt \* Species, data = species\_totals)  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -0.65142 -0.10457 0.00315 0.10989 0.68517   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) 8.8266136 0.0192245 459.133 < 2e-16 \*\*\*  
## poly(Days\_poly, 5)1 9.3487989 0.4176386 22.385 < 2e-16 \*\*\*  
## poly(Days\_poly, 5)2 -8.9203619 0.3565108 -25.021 < 2e-16 \*\*\*  
## poly(Days\_poly, 5)3 9.7337028 0.3579313 27.194 < 2e-16 \*\*\*  
## poly(Days\_poly, 5)4 0.4528654 0.3657522 1.238 0.215930   
## poly(Days\_poly, 5)5 0.2915008 0.3478725 0.838 0.402249   
## trtLS 0.1633380 0.0273040 5.982 3.02e-09 \*\*\*  
## SpeciesSph -0.1906323 0.0271795 -7.014 4.17e-12 \*\*\*  
## Days\_linear 0.0005893 0.0004422 1.333 0.182885   
## poly(Days\_poly, 5)1:trtLS 2.2065432 0.6013737 3.669 0.000256 \*\*\*  
## poly(Days\_poly, 5)2:trtLS -0.2185987 0.5203961 -0.420 0.674527   
## poly(Days\_poly, 5)3:trtLS -0.8116116 0.5028778 -1.614 0.106844   
## poly(Days\_poly, 5)4:trtLS 0.2410882 0.5024883 0.480 0.631478   
## poly(Days\_poly, 5)5:trtLS 0.1540685 0.5026041 0.307 0.759254   
## poly(Days\_poly, 5)1:SpeciesSph -0.0179846 0.5905481 -0.030 0.975711   
## poly(Days\_poly, 5)2:SpeciesSph 2.5310796 0.5041647 5.020 6.06e-07 \*\*\*  
## poly(Days\_poly, 5)3:SpeciesSph -4.0726725 0.5061891 -8.046 2.32e-15 \*\*\*  
## poly(Days\_poly, 5)4:SpeciesSph 1.7404388 0.5172513 3.365 0.000794 \*\*\*  
## poly(Days\_poly, 5)5:SpeciesSph 2.2503344 0.4919659 4.574 5.36e-06 \*\*\*  
## trtLS:SpeciesSph -0.2876198 0.0385301 -7.465 1.76e-13 \*\*\*  
## trtLS:Days\_linear -0.0034290 0.0006245 -5.491 5.03e-08 \*\*\*  
## SpeciesSph:Days\_linear -0.0072930 0.0006253 -11.663 < 2e-16 \*\*\*  
## poly(Days\_poly, 5)1:trtLS:SpeciesSph -1.4276462 0.8496319 -1.680 0.093196 .   
## poly(Days\_poly, 5)2:trtLS:SpeciesSph 2.0753017 0.7357733 2.821 0.004885 \*\*   
## poly(Days\_poly, 5)3:trtLS:SpeciesSph -0.0160169 0.7111534 -0.023 0.982035   
## poly(Days\_poly, 5)4:trtLS:SpeciesSph -1.7996562 0.7106220 -2.533 0.011471 \*   
## poly(Days\_poly, 5)5:trtLS:SpeciesSph -0.0309024 0.7107893 -0.043 0.965330   
## trtLS:SpeciesSph:Days\_linear 0.0062636 0.0008819 7.102 2.27e-12 \*\*\*  
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 0.1757 on 1042 degrees of freedom  
## Multiple R-squared: 0.8939, Adjusted R-squared: 0.8912   
## F-statistic: 325.2 on 27 and 1042 DF, p-value: < 2.2e-16

### poly 3: Fit the combined model  
model\_piecewise3 <- lm(log\_Species\_CFU ~ poly(Days\_poly, 3)\*trt\*Species + Days\_linear\*trt\*Species, data = species\_totals)  
summary(model\_piecewise3)

##   
## Call:  
## lm(formula = log\_Species\_CFU ~ poly(Days\_poly, 3) \* trt \* Species +   
## Days\_linear \* trt \* Species, data = species\_totals)  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -0.77380 -0.11484 0.00455 0.11276 0.76275   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) 8.8263655 0.0204739 431.103 < 2e-16 \*\*\*  
## poly(Days\_poly, 3)1 9.3213519 0.4443479 20.978 < 2e-16 \*\*\*  
## poly(Days\_poly, 3)2 -8.9674588 0.3780820 -23.718 < 2e-16 \*\*\*  
## poly(Days\_poly, 3)3 9.6765922 0.3786014 25.559 < 2e-16 \*\*\*  
## trtLS 0.1608485 0.0290559 5.536 3.91e-08 \*\*\*  
## SpeciesSph -0.1910588 0.0289459 -6.601 6.49e-11 \*\*\*  
## Days\_linear 0.0006134 0.0004706 1.304 0.192680   
## poly(Days\_poly, 3)1:trtLS 2.2367310 0.6402009 3.494 0.000496 \*\*\*  
## poly(Days\_poly, 3)2:trtLS -0.1125893 0.5524788 -0.204 0.838558   
## poly(Days\_poly, 3)3:trtLS -0.6767306 0.5324089 -1.271 0.203984   
## poly(Days\_poly, 3)1:SpeciesSph -0.1408239 0.6283158 -0.224 0.822700   
## poly(Days\_poly, 3)2:SpeciesSph 2.2824570 0.5346702 4.269 2.14e-05 \*\*\*  
## poly(Days\_poly, 3)3:SpeciesSph -4.3957195 0.5354211 -8.210 6.45e-16 \*\*\*  
## trtLS:SpeciesSph -0.2901358 0.0410026 -7.076 2.71e-12 \*\*\*  
## trtLS:Days\_linear -0.0034066 0.0006646 -5.126 3.52e-07 \*\*\*  
## SpeciesSph:Days\_linear -0.0071909 0.0006655 -10.805 < 2e-16 \*\*\*  
## poly(Days\_poly, 3)1:trtLS:SpeciesSph -1.2888913 0.9044870 -1.425 0.154455   
## poly(Days\_poly, 3)2:trtLS:SpeciesSph 2.4534389 0.7811301 3.141 0.001731 \*\*   
## poly(Days\_poly, 3)3:trtLS:SpeciesSph 0.4953815 0.7529137 0.658 0.510713   
## trtLS:SpeciesSph:Days\_linear 0.0061935 0.0009385 6.599 6.54e-11 \*\*\*  
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 0.1872 on 1050 degrees of freedom  
## Multiple R-squared: 0.8787, Adjusted R-squared: 0.8765   
## F-statistic: 400.4 on 19 and 1050 DF, p-value: < 2.2e-16

## visualization : Generate predictions for plotting  
species\_totals$Fitted <- predict(model\_piecewise5)  
  
# Plot the combined model  
library(ggplot2)  
ggplot(species\_totals, aes(x = Days, y = log\_Species\_CFU)) +  
 geom\_point(alpha = 0.6, size = 1.2) + # Observed data points  
 geom\_line(aes(y = Fitted), color = "blue", size = 1.2) + # Fitted values  
 labs(title = "Piecewise Model: Polynomial Before Day 8 and Linear After",  
 x = "Days",  
 y = "Log Species CFU") +  
 geom\_vline(xintercept = 8, linetype = "dashed", color = "red", size = 1) + # Breakpoint  
 theme\_minimal()



###################### Compare: ar1\_poly\_nested2,model\_piecewise3, model\_piecewise5  
# compare poly 5 vs poly3  
AIC(ar1\_poly\_nested2,segmented\_model, model\_piecewise3, model\_piecewise5) # poly 5 is significantly better

## Warning in AIC.default(ar1\_poly\_nested2, segmented\_model, model\_piecewise3, : models are not all fitted to the same number of observations

## df AIC  
## ar1\_poly\_nested2 46 -253.30790  
## segmented\_model 11 -74.53509  
## model\_piecewise3 21 -527.78163  
## model\_piecewise5 29 -655.03365

anova(ar1\_poly\_nested2,segmented\_model, model\_piecewise3, model\_piecewise5) # the difference between poly-3 and poly-5 is significant

## Warning in nlme::anova.lme(object = ar1\_poly\_nested2, segmented\_model, model\_piecewise3, : fitted objects with different fixed effects. REML comparisons are not meaningful.

## Model df AIC BIC logLik Test L.Ratio p-value  
## ar1\_poly\_nested2 1 46 -253.3079 -26.3704 172.65395   
## segmented\_model 2 11 17.5415 72.1678 2.22924 1 vs 2 340.8494 <.0001  
## model\_piecewise3 3 21 -443.7085 -339.6211 242.85427 2 vs 3 481.2501 <.0001  
## model\_piecewise5 4 29 -566.3589 -422.8409 312.17947 3 vs 4 138.6504 <.0001

anova(model\_piecewise3, model\_piecewise5)

## Analysis of Variance Table  
##   
## Model 1: log\_Species\_CFU ~ poly(Days\_poly, 3) \* trt \* Species + Days\_linear \*   
## trt \* Species  
## Model 2: log\_Species\_CFU ~ poly(Days\_poly, 5) \* trt \* Species + Days\_linear \*   
## trt \* Species  
## Res.Df RSS Df Sum of Sq F Pr(>F)   
## 1 1050 36.783   
## 2 1042 32.174 8 4.6091 18.659 < 2.2e-16 \*\*\*  
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1

##result

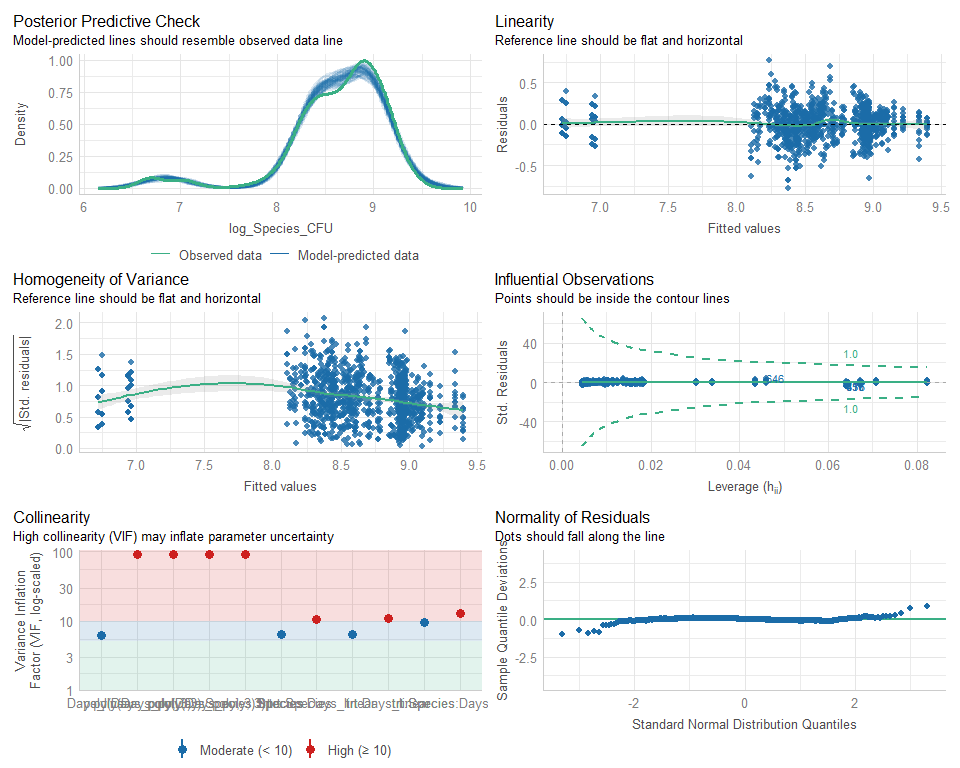
### poly 3: Fit the combined model  
model\_piecewise3 <- lm(log\_Species\_CFU ~ poly(Days\_poly, 3)\*trt\*Species + Days\_linear\*trt\*Species, data = species\_totals)  
summary(model\_piecewise3)

##   
## Call:  
## lm(formula = log\_Species\_CFU ~ poly(Days\_poly, 3) \* trt \* Species +   
## Days\_linear \* trt \* Species, data = species\_totals)  
##   
## Residuals:  
## Min 1Q Median 3Q Max   
## -0.77380 -0.11484 0.00455 0.11276 0.76275   
##   
## Coefficients:  
## Estimate Std. Error t value Pr(>|t|)   
## (Intercept) 8.8263655 0.0204739 431.103 < 2e-16 \*\*\*  
## poly(Days\_poly, 3)1 9.3213519 0.4443479 20.978 < 2e-16 \*\*\*  
## poly(Days\_poly, 3)2 -8.9674588 0.3780820 -23.718 < 2e-16 \*\*\*  
## poly(Days\_poly, 3)3 9.6765922 0.3786014 25.559 < 2e-16 \*\*\*  
## trtLS 0.1608485 0.0290559 5.536 3.91e-08 \*\*\*  
## SpeciesSph -0.1910588 0.0289459 -6.601 6.49e-11 \*\*\*  
## Days\_linear 0.0006134 0.0004706 1.304 0.192680   
## poly(Days\_poly, 3)1:trtLS 2.2367310 0.6402009 3.494 0.000496 \*\*\*  
## poly(Days\_poly, 3)2:trtLS -0.1125893 0.5524788 -0.204 0.838558   
## poly(Days\_poly, 3)3:trtLS -0.6767306 0.5324089 -1.271 0.203984   
## poly(Days\_poly, 3)1:SpeciesSph -0.1408239 0.6283158 -0.224 0.822700   
## poly(Days\_poly, 3)2:SpeciesSph 2.2824570 0.5346702 4.269 2.14e-05 \*\*\*  
## poly(Days\_poly, 3)3:SpeciesSph -4.3957195 0.5354211 -8.210 6.45e-16 \*\*\*  
## trtLS:SpeciesSph -0.2901358 0.0410026 -7.076 2.71e-12 \*\*\*  
## trtLS:Days\_linear -0.0034066 0.0006646 -5.126 3.52e-07 \*\*\*  
## SpeciesSph:Days\_linear -0.0071909 0.0006655 -10.805 < 2e-16 \*\*\*  
## poly(Days\_poly, 3)1:trtLS:SpeciesSph -1.2888913 0.9044870 -1.425 0.154455   
## poly(Days\_poly, 3)2:trtLS:SpeciesSph 2.4534389 0.7811301 3.141 0.001731 \*\*   
## poly(Days\_poly, 3)3:trtLS:SpeciesSph 0.4953815 0.7529137 0.658 0.510713   
## trtLS:SpeciesSph:Days\_linear 0.0061935 0.0009385 6.599 6.54e-11 \*\*\*  
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
##   
## Residual standard error: 0.1872 on 1050 degrees of freedom  
## Multiple R-squared: 0.8787, Adjusted R-squared: 0.8765   
## F-statistic: 400.4 on 19 and 1050 DF, p-value: < 2.2e-16

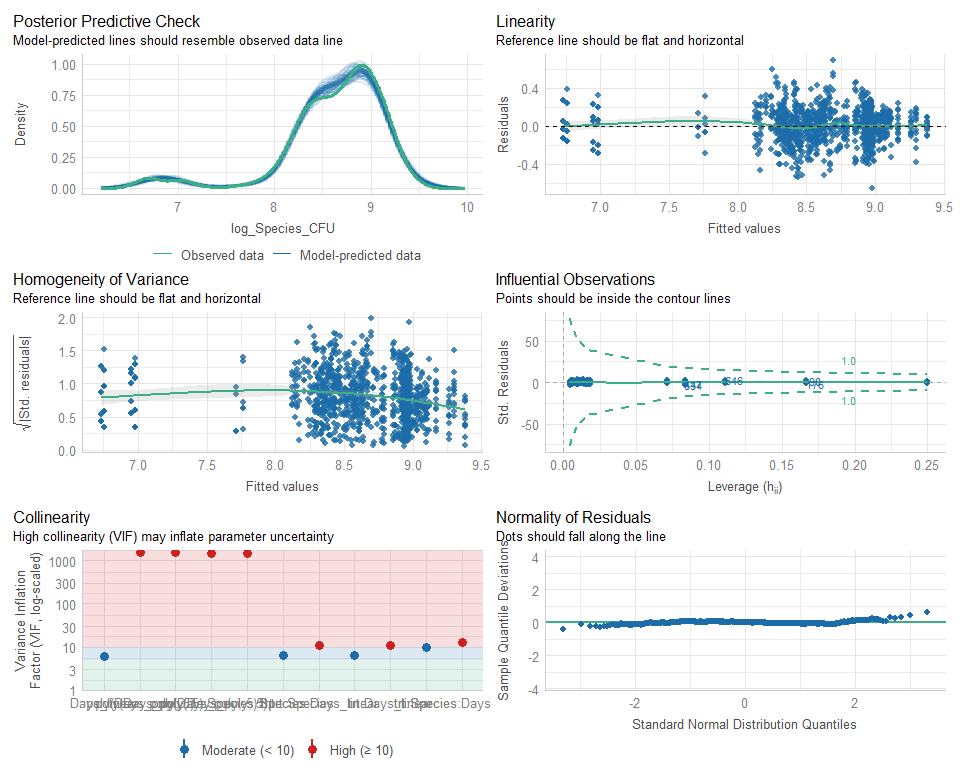
library(lmerTest)  
library(car)  
anova\_results <- Anova(model\_piecewise3, type = "III")  
print(anova\_results)

## Anova Table (Type III tests)  
##   
## Response: log\_Species\_CFU  
## Sum Sq Df F value Pr(>F)   
## (Intercept) 6510.5 1 1.8585e+05 < 2.2e-16 \*\*\*  
## poly(Days\_poly, 3) 65.4 3 6.2275e+02 < 2.2e-16 \*\*\*  
## trt 1.1 1 3.0645e+01 3.913e-08 \*\*\*  
## Species 1.5 1 4.3567e+01 6.489e-11 \*\*\*  
## Days\_linear 0.1 1 1.6992e+00 0.192680   
## poly(Days\_poly, 3):trt 0.5 3 4.9717e+00 0.001980 \*\*   
## poly(Days\_poly, 3):Species 3.1 3 2.9717e+01 < 2.2e-16 \*\*\*  
## trt:Species 1.8 1 5.0070e+01 2.707e-12 \*\*\*  
## trt:Days\_linear 0.9 1 2.6276e+01 3.522e-07 \*\*\*  
## Species:Days\_linear 4.1 1 1.1675e+02 < 2.2e-16 \*\*\*  
## poly(Days\_poly, 3):trt:Species 0.5 3 4.6856e+00 0.002946 \*\*   
## trt:Species:Days\_linear 1.5 1 4.3551e+01 6.541e-11 \*\*\*  
## Residuals 36.8 1050   
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1

check\_model(model\_piecewise3)



check\_model(model\_piecewise5)



## To test a random intercept and random slope model with a breakpoint at day 8 and a polynomial (degree 3) before the breakpoint and linear after,

breakpoint <- 8  
species\_totals$Days\_poly <- ifelse(species\_totals$Days <= breakpoint, species\_totals$Days, 0)  
species\_totals$Days\_linear <- ifelse(species\_totals$Days > breakpoint, species\_totals$Days - breakpoint, 0)  
  
# Fit Random Intercept and Random Slope Model  
library(lme4)  
model\_random\_intercept <- lmer(  
 log\_Species\_CFU ~ poly(Days\_poly, 3) \* trt \* Species + Days\_linear \* trt \* Species + (1 | ID),  
 data = species\_totals  
)

## Warning: Some predictor variables are on very different scales: consider rescaling  
## Warning: Some predictor variables are on very different scales: consider rescaling

summary(model\_random\_intercept)

## Linear mixed model fit by REML. t-tests use Satterthwaite's method ['lmerModLmerTest']  
## Formula: log\_Species\_CFU ~ poly(Days\_poly, 3) \* trt \* Species + Days\_linear \* trt \* Species + (1 | ID)  
## Data: species\_totals  
##   
## REML criterion at convergence: 1249.3  
##   
## Scaled residuals:   
## Min 1Q Median 3Q Max   
## -5.0441 -0.3177 0.1519 0.5835 2.2139   
##   
## Random effects:  
## Groups Name Variance Std.Dev.  
## ID (Intercept) 0.1065 0.3263   
## Residual 0.1720 0.4147   
## Number of obs: 1070, groups: ID, 26  
##   
## Fixed effects:  
## Estimate Std. Error df t value Pr(>|t|)   
## (Intercept) 8.296e+00 1.013e-01 3.048e+01 81.920 < 2e-16 \*\*\*  
## poly(Days\_poly, 3)1 6.428e+00 9.700e-01 1.032e+03 6.627 5.52e-11 \*\*\*  
## poly(Days\_poly, 3)2 -5.787e+00 8.803e-01 1.045e+03 -6.575 7.69e-11 \*\*\*  
## poly(Days\_poly, 3)3 6.191e+00 8.424e-01 1.026e+03 7.349 4.06e-13 \*\*\*  
## trtLS 2.190e-01 1.475e-01 2.938e+01 1.485 0.148280   
## SpeciesSph -1.210e-01 6.191e-02 1.024e+03 -1.955 0.050893 .   
## Days\_linear 7.340e-03 1.003e-03 1.030e+03 7.316 5.14e-13 \*\*\*  
## poly(Days\_poly, 3)1:trtLS -1.794e+00 1.385e+00 1.032e+03 -1.296 0.195319   
## poly(Days\_poly, 3)2:trtLS 7.457e-01 1.261e+00 1.044e+03 0.591 0.554373   
## poly(Days\_poly, 3)3:trtLS -1.367e+00 1.187e+00 1.027e+03 -1.151 0.249934   
## poly(Days\_poly, 3)1:SpeciesSph -2.471e+00 1.353e+00 1.024e+03 -1.826 0.068142 .   
## poly(Days\_poly, 3)2:SpeciesSph 1.454e+00 1.193e+00 1.024e+03 1.219 0.223135   
## poly(Days\_poly, 3)3:SpeciesSph -4.223e+00 1.188e+00 1.024e+03 -3.555 0.000395 \*\*\*  
## trtLS:SpeciesSph -2.891e-01 8.833e-02 1.024e+03 -3.274 0.001097 \*\*   
## trtLS:Days\_linear -3.330e-03 1.421e-03 1.028e+03 -2.344 0.019270 \*   
## SpeciesSph:Days\_linear -9.106e-03 1.407e-03 1.024e+03 -6.474 1.48e-10 \*\*\*  
## poly(Days\_poly, 3)1:trtLS:SpeciesSph 4.162e-01 1.929e+00 1.024e+03 0.216 0.829254   
## poly(Days\_poly, 3)2:trtLS:SpeciesSph 2.246e+00 1.709e+00 1.024e+03 1.314 0.189041   
## poly(Days\_poly, 3)3:trtLS:SpeciesSph 2.086e+00 1.672e+00 1.024e+03 1.247 0.212564   
## trtLS:SpeciesSph:Days\_linear 6.143e-03 1.995e-03 1.024e+03 3.080 0.002125 \*\*   
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1

##   
## Correlation matrix not shown by default, as p = 20 > 12.  
## Use print(x, correlation=TRUE) or  
## vcov(x) if you need it

## fit warnings:  
## Some predictor variables are on very different scales: consider rescaling

#To account for subject-specific growth trends, include random slopes:  
model\_random\_slope <- lmer(  
 log\_Species\_CFU ~ poly(Days\_poly, 3) \* trt \* Species + Days\_linear \* trt \* Species + (1 + Days\_poly + Days\_linear | ID),  
 data = species\_totals  
)

## Warning: Some predictor variables are on very different scales: consider rescaling

## boundary (singular) fit: see help('isSingular')

## Warning: Some predictor variables are on very different scales: consider rescaling

summary(model\_random\_slope)

## Linear mixed model fit by REML. t-tests use Satterthwaite's method ['lmerModLmerTest']  
## Formula: log\_Species\_CFU ~ poly(Days\_poly, 3) \* trt \* Species + Days\_linear \* trt \* Species + (1 + Days\_poly + Days\_linear | ID)  
## Data: species\_totals  
##   
## REML criterion at convergence: 949.3  
##   
## Scaled residuals:   
## Min 1Q Median 3Q Max   
## -6.2137 -0.3240 0.1439 0.5460 2.4910   
##   
## Random effects:  
## Groups Name Variance Std.Dev. Corr   
## ID (Intercept) 6.670e-01 0.81669   
## Days\_poly 4.239e-02 0.20590 -1.00   
## Days\_linear 8.373e-05 0.00915 -1.00 1.00  
## Residual 1.263e-01 0.35540   
## Number of obs: 1070, groups: ID, 26  
##   
## Fixed effects:  
## Estimate Std. Error df t value Pr(>|t|)   
## (Intercept) 7.992e+00 1.823e-01 2.633e+01 43.830 < 2e-16 \*\*\*  
## poly(Days\_poly, 3)1 1.606e+01 3.498e+00 2.599e+01 4.592 9.87e-05 \*\*\*  
## poly(Days\_poly, 3)2 -3.521e+00 7.231e-01 1.025e+03 -4.868 1.30e-06 \*\*\*  
## poly(Days\_poly, 3)3 7.903e+00 7.335e-01 1.028e+03 10.775 < 2e-16 \*\*\*  
## trtLS 2.307e-01 2.678e-01 2.608e+01 0.862 0.396711   
## SpeciesSph -1.210e-01 5.305e-02 1.025e+03 -2.282 0.022719 \*   
## Days\_linear 1.526e-02 2.618e-03 1.786e+01 5.829 1.65e-05 \*\*\*  
## poly(Days\_poly, 3)1:trtLS -2.534e+00 5.135e+00 2.571e+01 -0.493 0.625856   
## poly(Days\_poly, 3)2:trtLS 4.278e-01 1.036e+00 1.025e+03 0.413 0.679799   
## poly(Days\_poly, 3)3:trtLS -1.594e+00 1.031e+00 1.028e+03 -1.546 0.122504   
## poly(Days\_poly, 3)1:SpeciesSph -2.470e+00 1.159e+00 1.025e+03 -2.131 0.033362 \*   
## poly(Days\_poly, 3)2:SpeciesSph 1.454e+00 1.022e+00 1.025e+03 1.422 0.155227   
## poly(Days\_poly, 3)3:SpeciesSph -4.223e+00 1.018e+00 1.025e+03 -4.149 3.62e-05 \*\*\*  
## trtLS:SpeciesSph -2.898e-01 7.569e-02 1.025e+03 -3.828 0.000137 \*\*\*  
## trtLS:Days\_linear -4.267e-03 3.836e-03 1.762e+01 -1.112 0.280982   
## SpeciesSph:Days\_linear -9.106e-03 1.205e-03 1.025e+03 -7.555 9.27e-14 \*\*\*  
## poly(Days\_poly, 3)1:trtLS:SpeciesSph 4.244e-01 1.653e+00 1.025e+03 0.257 0.797436   
## poly(Days\_poly, 3)2:trtLS:SpeciesSph 2.243e+00 1.465e+00 1.025e+03 1.531 0.125975   
## poly(Days\_poly, 3)3:trtLS:SpeciesSph 2.088e+00 1.433e+00 1.025e+03 1.457 0.145479   
## trtLS:SpeciesSph:Days\_linear 6.157e-03 1.709e-03 1.025e+03 3.602 0.000331 \*\*\*  
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1

##   
## Correlation matrix not shown by default, as p = 20 > 12.  
## Use print(x, correlation=TRUE) or  
## vcov(x) if you need it

## fit warnings:  
## Some predictor variables are on very different scales: consider rescaling  
## optimizer (nloptwrap) convergence code: 0 (OK)  
## boundary (singular) fit: see help('isSingular')

# Compare models  
anova(model\_random\_intercept, model\_random\_slope)

## refitting model(s) with ML (instead of REML)

## Data: species\_totals  
## Models:  
## model\_random\_intercept: log\_Species\_CFU ~ poly(Days\_poly, 3) \* trt \* Species + Days\_linear \* trt \* Species + (1 | ID)  
## model\_random\_slope: log\_Species\_CFU ~ poly(Days\_poly, 3) \* trt \* Species + Days\_linear \* trt \* Species + (1 + Days\_poly + Days\_linear | ID)  
## npar AIC BIC logLik deviance Chisq Df Pr(>Chisq)   
## model\_random\_intercept 22 1248.03 1357.5 -602.01 1204.03   
## model\_random\_slope 27 953.35 1087.7 -449.67 899.35 304.68 5 < 2.2e-16 \*\*\*  
## ---  
## Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1

AIC(model\_random\_intercept, model\_random\_slope)

## df AIC  
## model\_random\_intercept 22 1293.309  
## model\_random\_slope 27 1003.260

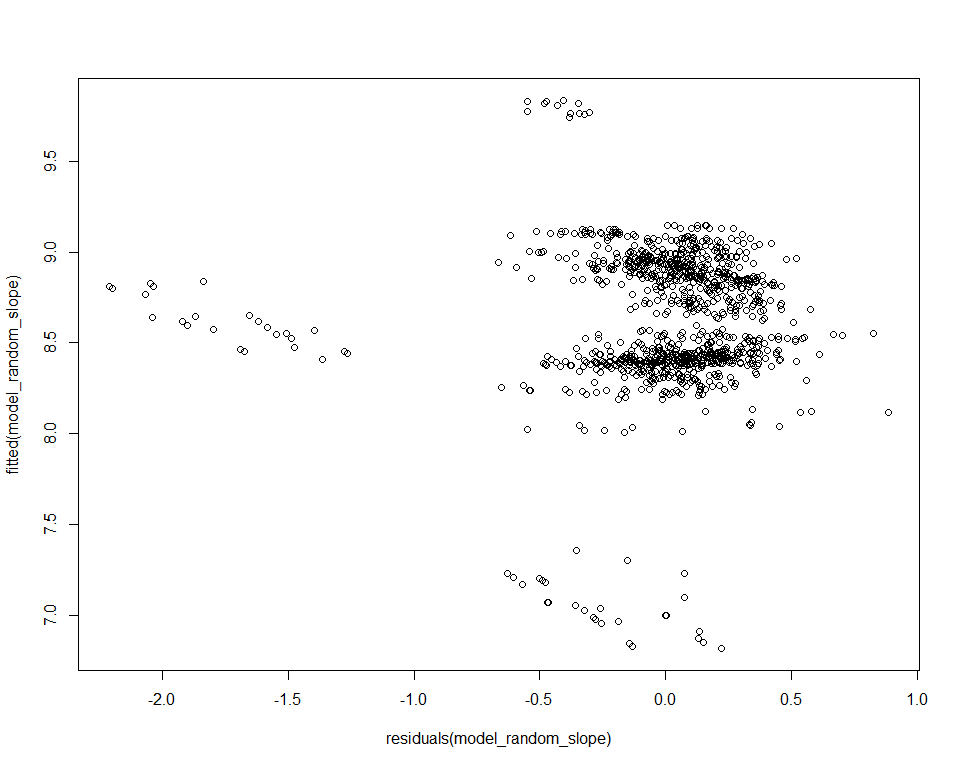
BIC(model\_random\_intercept, model\_random\_slope)

## df BIC  
## model\_random\_intercept 22 1402.768  
## model\_random\_slope 27 1137.597

summary(model\_random\_slope)$varcor

## Groups Name Std.Dev. Corr   
## ID (Intercept) 0.8166882   
## Days\_poly 0.2058987 -1.000   
## Days\_linear 0.0091502 -1.000 1.000  
## Residual 0.3554017

# Diagnostic  
library(ggplot2)  
plot(residuals(model\_random\_slope), fitted(model\_random\_slope))



check\_model(model\_random\_slope)

