

# Assignment 7: GLMs week 2 (Linear Regression and beyond)

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## OVERVIEW

This exercise accompanies the lessons in Environmental Data Analytics on generalized linear models.

## Directions

1. Change “Student Name” on line 3 (above) with your name.
2. Work through the steps, **creating code and output** that fulfill each instruction.
3. Be sure to **answer the questions** in this assignment document.
4. When you have completed the assignment, **Knit** the text and code into a single PDF file.
5. After Knitting, submit the completed exercise (PDF file) to the dropbox in Sakai. Add your last name into the file name (e.g., “Salk\_A06\_GLMs\_Week1.Rmd”) prior to submission.

The completed exercise is due on Tuesday, February 25 at 1:00 pm.

## Set up your session

1. Set up your session. Check your working directory, load the tidyverse, nlme, and piecewiseSEM packages, import the *raw* NTL-LTER raw data file for chemistry/physics, and import the processed litter dataset. You will not work with dates, so no need to format your date columns this time.
2. Build a ggplot theme and set it as your default theme.

```
#1 Load libraries, etc.
```

```
getwd() # Check working directory
```

```
## [1] "C:/Users/thoma/Thomas/2018 Grad School/Duke MEM/ENV 872/Environmental_Data_Analytics_2020"
```

```
library(tidyverse)
```

```
## -- Attaching packages ----- tidyverse 1.3.0 --
```

```
## v ggplot2 3.2.1      v purrr  0.3.3
```

```
## v tibble  2.1.3      v dplyr  0.8.3
```

```
## v tidyr   1.0.0      v stringr 1.4.0
```

```
## v readr   1.3.1      v forcats 0.4.0
```

```
## -- Conflicts ----- tidyverse_conflicts() --
```

```
## x dplyr::filter() masks stats::filter()
```

```
## x dplyr::lag()    masks stats::lag()
```

```
library(nlme)
```

```
##
```

```
## Attaching package: 'nlme'
```

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

```
##
```

```
## collapse
```

```
library(piecewiseSEM)

## Registered S3 methods overwritten by 'lme4':
##   method                      from
##   cooks.distance.influence.merMod car
##   influence.merMod             car
##   dfbeta.influence.merMod      car
##   dfbetas.influence.merMod     car

##
##   This is piecewiseSEM version 2.1.0.
##
##
##   Questions or bugs can be addressed to <LefcheckJ@si.edu>.

# Load data
Litter.Processed <- read.csv("./Data/Processed/NEON_NIWO_Litter_mass_trap_Processed.csv")
NTL.chemphys.Raw <- read.csv("./Data/Raw/NTL-LTER_Lake_ChemistryPhysics_Raw.csv")

#2 Set theme
myTheme <- theme_classic(base_size = 10) +
  theme(axis.text = element_text(color = "black"),
        legend.position = "top") # Define a theme based off of the classic theme

theme_set(myTheme) # Set defined theme to default
```

## NTL-LTER test

Research question: What is the best set of predictors for lake temperatures in July across the monitoring period at the North Temperate Lakes LTER?

3. Wrangle your NTL-LTER dataset with a pipe function so that it contains only the following criteria:
  - Only dates in July (hint: use the daynum column). No need to consider leap years.
  - Only the columns: lakename, year4, daynum, depth, temperature\_C
  - Only complete cases (i.e., remove NAs)
4. Run an AIC to determine what set of explanatory variables (year4, daynum, depth) is best suited to predict temperature. Run a multiple regression on the recommended set of variables.

```
#3 Wrangle data
NTL.chemphys.Filtered <-
  NTL.chemphys.Raw %>%
  filter(daynum > 181 & daynum < 213) %>% # Filter for days in July
  select(lakename:daynum,depth,temperature_C) %>% # Select specific columns
  na.omit() # Remove entries with any NA values

#4 Use AIC to determine best explanatory variables
NTL.AIC <- lm(data = NTL.chemphys.Filtered, temperature_C ~ year4 + daynum + depth)
step(NTL.AIC) # Compare AIC with explanatory variables removed iteratively

## Start: AIC=26016.31
## temperature_C ~ year4 + daynum + depth
##
##           Df Sum of Sq    RSS   AIC
## <none>                141118 26016
```

```
## - year4    1          80 141198 26020
## - daynum   1         1333 142450 26106
## - depth    1        403925 545042 39151

##
## Call:
## lm(formula = temperature_C ~ year4 + daynum + depth, data = NTL.chemphys.Filtered)
##
## Coefficients:
## (Intercept)      year4      daynum      depth
##    -6.45556      0.01013      0.04134     -1.94726

# The AIC was lowest for the model with all explanatory variables
NTL.model1 <- lm(data = NTL.chemphys.Filtered, temperature_C ~ year4 + daynum + depth)
summary(NTL.model1)
```

```
##
## Call:
## lm(formula = temperature_C ~ year4 + daynum + depth, data = NTL.chemphys.Filtered)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -9.6517 -2.9937  0.0855  2.9692 13.6171
##
## Coefficients:
##              Estimate Std. Error  t value Pr(>|t|)
## (Intercept) -6.455560   8.638808  -0.747   0.4549
## year4        0.010131   0.004303   2.354   0.0186 *
## daynum       0.041336   0.004315   9.580  <2e-16 ***
## depth       -1.947264   0.011676 -166.782  <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 3.811 on 9718 degrees of freedom
## Multiple R-squared:  0.7417, Adjusted R-squared:  0.7417
## F-statistic: 9303 on 3 and 9718 DF,  p-value: < 2.2e-16
```

5. What is the final set of explanatory variables that predict temperature from your multiple regression? How much of the observed variance does this model explain?

Answer: The set of explanatory variables that best explains temperature variation in the NTL-LTER region is year4, daynum, and depth (all the starting explanatory variables). This model explains 74.17% of the variance (multiple linear regression; F-statistic = 9303; df = 3, 9718; R<sup>2</sup> = 0.7417).

6. Run an interaction effects ANCOVA to predict temperature based on depth and lakenam from the same wrangled dataset.

```
#6 ANCOVA with interaction effects between lakenam and depth
NTL.interaction <- lm(data = NTL.chemphys.Filtered, temperature_C ~ lakenam * depth)
summary(NTL.interaction)
```

```
##
## Call:
## lm(formula = temperature_C ~ lakenam * depth, data = NTL.chemphys.Filtered)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
```

```
## -7.6455 -2.9133 -0.2879 2.7567 16.3606
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)      22.9455     0.5861  39.147 < 2e-16 ***
## lakenamCrampton Lake      2.2173     0.6804   3.259 0.00112 **
## lakenamEast Long Lake    -4.3884     0.6191  -7.089 1.45e-12 ***
## lakenamHummingbird Lake  -2.4126     0.8379  -2.879 0.00399 **
## lakenamPaul Lake         0.6105     0.5983   1.020 0.30754
## lakenamPeter Lake        0.2998     0.5970   0.502 0.61552
## lakenamTuesday Lake    -2.8932     0.6060  -4.774 1.83e-06 ***
## lakenamWard Lake         2.4180     0.8434   2.867 0.00415 **
## lakenamWest Long Lake   -2.4663     0.6168  -3.999 6.42e-05 ***
## depth                -2.5820     0.2411 -10.711 < 2e-16 ***
## lakenamCrampton Lake:depth  0.8058     0.2465   3.268 0.00109 **
## lakenamEast Long Lake:depth  0.9465     0.2433   3.891 0.00010 ***
## lakenamHummingbird Lake:depth -0.6026     0.2919  -2.064 0.03903 *
## lakenamPaul Lake:depth    0.4022     0.2421   1.662 0.09664 .
## lakenamPeter Lake:depth    0.5799     0.2418   2.398 0.01649 *
## lakenamTuesday Lake:depth  0.6605     0.2426   2.723 0.00648 **
## lakenamWard Lake:depth    -0.6930     0.2862  -2.421 0.01548 *
## lakenamWest Long Lake:depth  0.8154     0.2431   3.354 0.00080 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 3.471 on 9704 degrees of freedom
## Multiple R-squared:  0.7861, Adjusted R-squared:  0.7857
## F-statistic: 2097 on 17 and 9704 DF, p-value: < 2.2e-16
```

7. Is there a significant interaction between depth and lakenam? How much variance in the temperature observations does this explain?

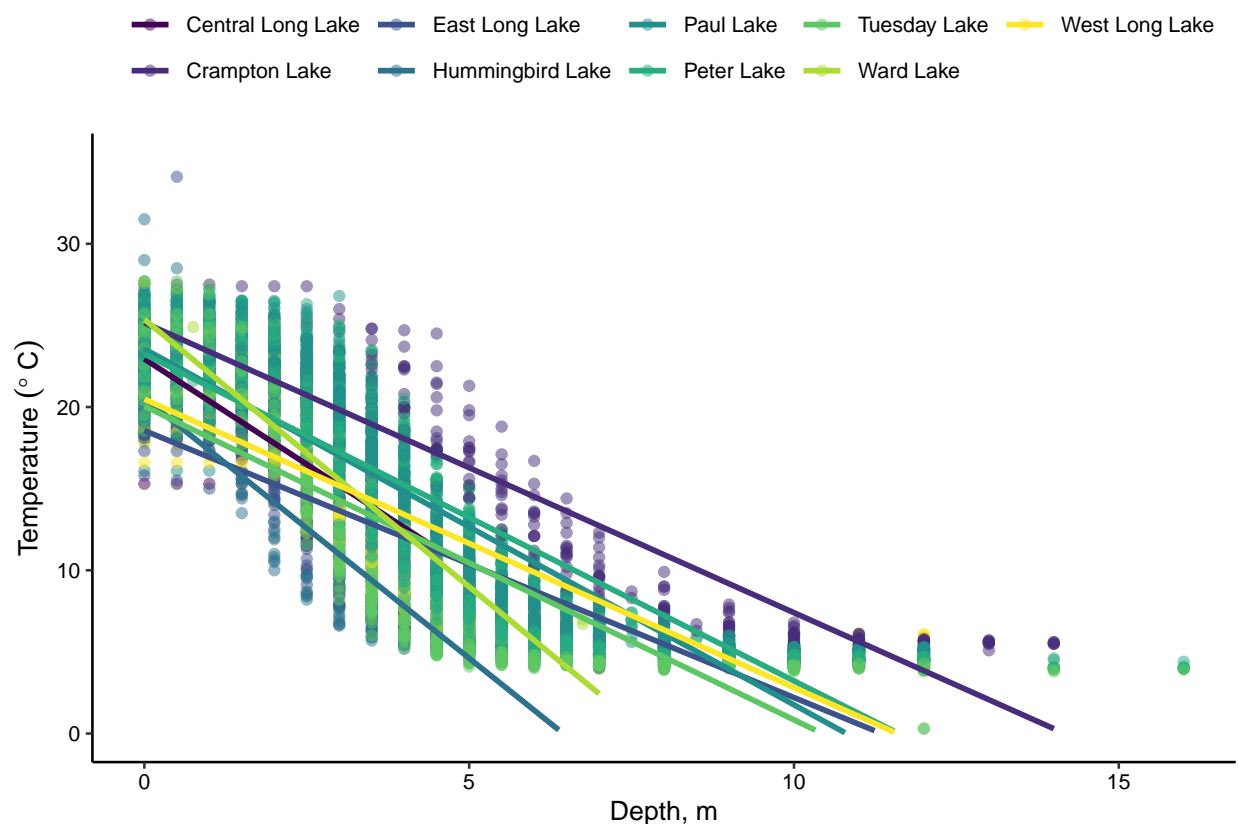
Answer: There is a significant interaction between depth and lakenam for predicting lake temperature (ANCOVA,  $p < 0.1$  for all levels,  $R^2 = 0.7857$ ). This model accounts for 78.57% of the variance. The interaction between Paul Lake and depth is the least significant of the interactions ( $p = 0.09664$ ).

8. Create a graph that depicts temperature by depth, with a separate color for each lake. Add a `geom_smooth` (method = "lm", se = FALSE) for each lake. Make your points 50 % transparent. Adjust your y axis limits to go from 0 to 35 degrees. Clean up your graph to make it pretty.

```
#8 Plot of temperature vs depth for each lake
NTL.plot <-
  ggplot(NTL.chemphys.Filtered, aes(x = depth, y = temperature_C, color = lakenam)) +
  geom_point(alpha = 0.5) + # Set transparency
  geom_smooth(method = "lm", se = FALSE) + # Add best-fit line for each lake (w/out std. error)
  ylim(0,35) + # Restrict y-axis
  labs(x = "Depth, m", y = expression("Temperature " ( degree~C)), color = "") +
  scale_color_viridis_d()

print(NTL.plot)
```

```
## Warning: Removed 73 rows containing missing values (geom_smooth).
```



9. Run a mixed effects model to predict dry mass of litter. We already know that `nlcdClass` and `functionalGroup` have a significant interaction, so we will specify those two variables as fixed effects with an interaction. We also know that litter mass varies across plot ID, but we are less interested in the actual effect of the plot itself but rather in accounting for the variance among plots. Plot ID will be our random effect.

- Build and run a mixed effects model.
- Check the difference between the marginal and conditional R<sup>2</sup> of the model.

```
# 9a Mixed effects model
LitterTest.mixed <- lme(data = Litter.Processed, # Mixed effects model
                        dryMass ~ nlcdClass * functionalGroup, # Fixed effects
                        random = ~1 | plotID) # Random effects
summary(LitterTest.mixed)
```

```
## Linear mixed-effects model fit by REML
## Data: Litter.Processed
##      AIC      BIC    logLik
## 9038.575 9179.479 -4493.287
##
## Random effects:
## Formula: ~1 | plotID
##      (Intercept) Residual
## StdDev:  0.5899105 3.456817
##
## Fixed effects: dryMass ~ nlcdClass * functionalGroup
##                                     Value Std.Error
```

## (Intercept)	0.155492	0.4863580
## nlcdClassgrasslandHerbaceous	-0.156004	0.7789816
## nlcdClassshrubScrub	-0.107080	0.6636775
## functionalGroupLeaves	-0.126008	0.5501061
## functionalGroupMixed	1.477797	0.6323043
## functionalGroupNeedles	7.284064	0.5313161
## functionalGroupOther	-0.048525	0.5500878
## functionalGroupSeeds	-0.058702	0.5501061
## functionalGroupTwigs/branches	1.929441	0.5385556
## functionalGroupWoody material	1.068772	0.5259330
## nlcdClassgrasslandHerbaceous:functionalGroupLeaves	0.181416	0.8847246
## nlcdClassshrubScrub:functionalGroupLeaves	0.173857	0.7510320
## nlcdClassgrasslandHerbaceous:functionalGroupMixed	-0.467648	1.1201304
## nlcdClassshrubScrub:functionalGroupMixed	0.633876	0.9217911
## nlcdClassgrasslandHerbaceous:functionalGroupNeedles	-2.118299	0.8705440
## nlcdClassshrubScrub:functionalGroupNeedles	-2.909142	0.7347172
## nlcdClassgrasslandHerbaceous:functionalGroupOther	0.143603	0.8976715
## nlcdClassshrubScrub:functionalGroupOther	0.104935	0.7528434
## nlcdClassgrasslandHerbaceous:functionalGroupSeeds	0.049290	0.8976827
## nlcdClassshrubScrub:functionalGroupSeeds	0.076708	0.7547591
## nlcdClassgrasslandHerbaceous:functionalGroupTwigs/branches	-0.986627	0.8850639
## nlcdClassshrubScrub:functionalGroupTwigs/branches	-1.503446	0.7409024
## nlcdClassgrasslandHerbaceous:functionalGroupWoody material	-1.017803	0.8802289
## nlcdClassshrubScrub:functionalGroupWoody material	-0.979078	0.7317033
##	DF	t-value
## (Intercept)	1659	0.319706
## nlcdClassgrasslandHerbaceous	9	-0.200266
## nlcdClassshrubScrub	9	-0.161343
## functionalGroupLeaves	1659	-0.229061
## functionalGroupMixed	1659	2.337160
## functionalGroupNeedles	1659	13.709474
## functionalGroupOther	1659	-0.088213
## functionalGroupSeeds	1659	-0.106711
## functionalGroupTwigs/branches	1659	3.582622
## functionalGroupWoody material	1659	2.032144
## nlcdClassgrasslandHerbaceous:functionalGroupLeaves	1659	0.205053
## nlcdClassshrubScrub:functionalGroupLeaves	1659	0.231490
## nlcdClassgrasslandHerbaceous:functionalGroupMixed	1659	-0.417495
## nlcdClassshrubScrub:functionalGroupMixed	1659	0.687657
## nlcdClassgrasslandHerbaceous:functionalGroupNeedles	1659	-2.433305
## nlcdClassshrubScrub:functionalGroupNeedles	1659	-3.959540
## nlcdClassgrasslandHerbaceous:functionalGroupOther	1659	0.159972
## nlcdClassshrubScrub:functionalGroupOther	1659	0.139385
## nlcdClassgrasslandHerbaceous:functionalGroupSeeds	1659	0.054908
## nlcdClassshrubScrub:functionalGroupSeeds	1659	0.101632
## nlcdClassgrasslandHerbaceous:functionalGroupTwigs/branches	1659	-1.114752
## nlcdClassshrubScrub:functionalGroupTwigs/branches	1659	-2.029209
## nlcdClassgrasslandHerbaceous:functionalGroupWoody material	1659	-1.156293
## nlcdClassshrubScrub:functionalGroupWoody material	1659	-1.338081
##	p-value	
## (Intercept)	0.7492	
## nlcdClassgrasslandHerbaceous	0.8457	
## nlcdClassshrubScrub	0.8754	
## functionalGroupLeaves	0.8188	

## functionalGroupMixed	0.0195		
## functionalGroupNeedles	0.0000		
## functionalGroupOther	0.9297		
## functionalGroupSeeds	0.9150		
## functionalGroupTwigs/branches	0.0003		
## functionalGroupWoody material	0.0423		
## nlcdClassgrasslandHerbaceous:functionalGroupLeaves	0.8376		
## nlcdClassshrubScrub:functionalGroupLeaves	0.8170		
## nlcdClassgrasslandHerbaceous:functionalGroupMixed	0.6764		
## nlcdClassshrubScrub:functionalGroupMixed	0.4918		
## nlcdClassgrasslandHerbaceous:functionalGroupNeedles	0.0151		
## nlcdClassshrubScrub:functionalGroupNeedles	0.0001		
## nlcdClassgrasslandHerbaceous:functionalGroupOther	0.8729		
## nlcdClassshrubScrub:functionalGroupOther	0.8892		
## nlcdClassgrasslandHerbaceous:functionalGroupSeeds	0.9562		
## nlcdClassshrubScrub:functionalGroupSeeds	0.9191		
## nlcdClassgrasslandHerbaceous:functionalGroupTwigs/branches	0.2651		
## nlcdClassshrubScrub:functionalGroupTwigs/branches	0.0426		
## nlcdClassgrasslandHerbaceous:functionalGroupWoody material	0.2477		
## nlcdClassshrubScrub:functionalGroupWoody material	0.1811		
## Correlation:			
##	(Intr)	nlcdCH	nlcdCS
## nlcdClassgrasslandHerbaceous	-0.624		
## nlcdClassshrubScrub	-0.733	0.458	
## functionalGroupLeaves	-0.559	0.349	0.409
## functionalGroupMixed	-0.485	0.303	0.356
## functionalGroupNeedles	-0.579	0.361	0.424
## functionalGroupOther	-0.559	0.349	0.409
## functionalGroupSeeds	-0.559	0.349	0.409
## functionalGroupTwigs/branches	-0.571	0.356	0.418
## functionalGroupWoody material	-0.584	0.365	0.428
## nlcdClassgrasslandHerbaceous:functionalGroupLeaves	0.347	-0.586	-0.255
## nlcdClassshrubScrub:functionalGroupLeaves	0.409	-0.255	-0.569
## nlcdClassgrasslandHerbaceous:functionalGroupMixed	0.274	-0.462	-0.201
## nlcdClassshrubScrub:functionalGroupMixed	0.333	-0.208	-0.464
## nlcdClassgrasslandHerbaceous:functionalGroupNeedles	0.353	-0.595	-0.259
## nlcdClassshrubScrub:functionalGroupNeedles	0.418	-0.261	-0.582
## nlcdClassgrasslandHerbaceous:functionalGroupOther	0.342	-0.577	-0.251
## nlcdClassshrubScrub:functionalGroupOther	0.408	-0.255	-0.568
## nlcdClassgrasslandHerbaceous:functionalGroupSeeds	0.342	-0.577	-0.251
## nlcdClassshrubScrub:functionalGroupSeeds	0.407	-0.254	-0.566
## nlcdClassgrasslandHerbaceous:functionalGroupTwigs/branches	0.347	-0.586	-0.254
## nlcdClassshrubScrub:functionalGroupTwigs/branches	0.415	-0.259	-0.577
## nlcdClassgrasslandHerbaceous:functionalGroupWoody material	0.349	-0.589	-0.256
## nlcdClassshrubScrub:functionalGroupWoody material	0.420	-0.262	-0.584
##	fnctGL	fnctGM	fnctGN
## nlcdClassgrasslandHerbaceous			
## nlcdClassshrubScrub			
## functionalGroupLeaves			
## functionalGroupMixed	0.429		
## functionalGroupNeedles	0.511	0.445	
## functionalGroupOther	0.494	0.430	0.511
## functionalGroupSeeds	0.494	0.429	0.511
## functionalGroupTwigs/branches	0.504	0.439	0.522

## functionalGroupWoody material	0.516	0.449	0.535
## nlcdClassgrasslandHerbaceous:functionalGroupLeaves	-0.622	-0.267	-0.318
## nlcdClassshrubScrub:functionalGroupLeaves	-0.732	-0.314	-0.374
## nlcdClassgrasslandHerbaceous:functionalGroupMixed	-0.242	-0.564	-0.251
## nlcdClassshrubScrub:functionalGroupMixed	-0.295	-0.686	-0.305
## nlcdClassgrasslandHerbaceous:functionalGroupNeedles	-0.312	-0.272	-0.610
## nlcdClassshrubScrub:functionalGroupNeedles	-0.370	-0.322	-0.723
## nlcdClassgrasslandHerbaceous:functionalGroupOther	-0.303	-0.263	-0.313
## nlcdClassshrubScrub:functionalGroupOther	-0.361	-0.314	-0.374
## nlcdClassgrasslandHerbaceous:functionalGroupSeeds	-0.303	-0.263	-0.313
## nlcdClassshrubScrub:functionalGroupSeeds	-0.360	-0.313	-0.373
## nlcdClassgrasslandHerbaceous:functionalGroupTwigs/branches	-0.307	-0.267	-0.318
## nlcdClassshrubScrub:functionalGroupTwigs/branches	-0.367	-0.319	-0.380
## nlcdClassgrasslandHerbaceous:functionalGroupWoody material	-0.309	-0.268	-0.320
## nlcdClassshrubScrub:functionalGroupWoody material	-0.371	-0.322	-0.384
##	fnctG0	fnctGS	fncGT/
## nlcdClassgrasslandHerbaceous			
## nlcdClassshrubScrub			
## functionalGroupLeaves			
## functionalGroupMixed			
## functionalGroupNeedles			
## functionalGroupOther			
## functionalGroupSeeds	0.494		
## functionalGroupTwigs/branches	0.504	0.504	
## functionalGroupWoody material	0.516	0.517	0.528
## nlcdClassgrasslandHerbaceous:functionalGroupLeaves	-0.307	-0.307	-0.314
## nlcdClassshrubScrub:functionalGroupLeaves	-0.362	-0.362	-0.369
## nlcdClassgrasslandHerbaceous:functionalGroupMixed	-0.243	-0.242	-0.248
## nlcdClassshrubScrub:functionalGroupMixed	-0.295	-0.294	-0.301
## nlcdClassgrasslandHerbaceous:functionalGroupNeedles	-0.312	-0.312	-0.319
## nlcdClassshrubScrub:functionalGroupNeedles	-0.370	-0.370	-0.378
## nlcdClassgrasslandHerbaceous:functionalGroupOther	-0.613	-0.303	-0.309
## nlcdClassshrubScrub:functionalGroupOther	-0.731	-0.361	-0.369
## nlcdClassgrasslandHerbaceous:functionalGroupSeeds	-0.303	-0.613	-0.309
## nlcdClassshrubScrub:functionalGroupSeeds	-0.360	-0.729	-0.368
## nlcdClassgrasslandHerbaceous:functionalGroupTwigs/branches	-0.307	-0.307	-0.608
## nlcdClassshrubScrub:functionalGroupTwigs/branches	-0.367	-0.367	-0.727
## nlcdClassgrasslandHerbaceous:functionalGroupWoody material	-0.309	-0.309	-0.315
## nlcdClassshrubScrub:functionalGroupWoody material	-0.371	-0.371	-0.379
##	fncGWm	nCH:GL	nCS:GL
## nlcdClassgrasslandHerbaceous			
## nlcdClassshrubScrub			
## functionalGroupLeaves			
## functionalGroupMixed			
## functionalGroupNeedles			
## functionalGroupOther			
## functionalGroupSeeds			
## functionalGroupTwigs/branches			
## functionalGroupWoody material			
## nlcdClassgrasslandHerbaceous:functionalGroupLeaves	-0.321		
## nlcdClassshrubScrub:functionalGroupLeaves	-0.378	0.455	
## nlcdClassgrasslandHerbaceous:functionalGroupMixed	-0.253	0.406	0.178
## nlcdClassshrubScrub:functionalGroupMixed	-0.308	0.183	0.410
## nlcdClassgrasslandHerbaceous:functionalGroupNeedles	-0.326	0.524	0.229



## nlcdClassshrubScrub:functionalGroupNeedles	-0.387	0.230	0.514
## nlcdClassgrasslandHerbaceous:functionalGroupOther	-0.316	0.508	0.222
## nlcdClassshrubScrub:functionalGroupOther	-0.377	0.224	0.502
## nlcdClassgrasslandHerbaceous:functionalGroupSeeds	-0.317	0.508	0.222
## nlcdClassshrubScrub:functionalGroupSeeds	-0.376	0.224	0.500
## nlcdClassgrasslandHerbaceous:functionalGroupTwigs/branches	-0.321	0.515	0.225
## nlcdClassshrubScrub:functionalGroupTwigs/branches	-0.384	0.228	0.510
## nlcdClassgrasslandHerbaceous:functionalGroupWoody material	-0.597	0.518	0.226
## nlcdClassshrubScrub:functionalGroupWoody material	-0.719	0.231	0.516
##	nCH:GM	nCS:GM	nCH:GN
## nlcdClassgrasslandHerbaceous			
## nlcdClassshrubScrub			
## functionalGroupLeaves			
## functionalGroupMixed			
## functionalGroupNeedles			
## functionalGroupOther			
## functionalGroupSeeds			
## functionalGroupTwigs/branches			
## functionalGroupWoody material			
## nlcdClassgrasslandHerbaceous:functionalGroupLeaves			
## nlcdClassshrubScrub:functionalGroupLeaves			
## nlcdClassgrasslandHerbaceous:functionalGroupMixed			
## nlcdClassshrubScrub:functionalGroupMixed	0.387		
## nlcdClassgrasslandHerbaceous:functionalGroupNeedles	0.414	0.186	
## nlcdClassshrubScrub:functionalGroupNeedles	0.182	0.419	0.441
## nlcdClassgrasslandHerbaceous:functionalGroupOther	0.401	0.181	0.517
## nlcdClassshrubScrub:functionalGroupOther	0.177	0.409	0.228
## nlcdClassgrasslandHerbaceous:functionalGroupSeeds	0.402	0.180	0.517
## nlcdClassshrubScrub:functionalGroupSeeds	0.177	0.408	0.227
## nlcdClassgrasslandHerbaceous:functionalGroupTwigs/branches	0.407	0.183	0.524
## nlcdClassshrubScrub:functionalGroupTwigs/branches	0.180	0.416	0.232
## nlcdClassgrasslandHerbaceous:functionalGroupWoody material	0.409	0.184	0.527
## nlcdClassshrubScrub:functionalGroupWoody material	0.182	0.420	0.235
##	nCS:GN	nCH:GO	nCS:GO
## nlcdClassgrasslandHerbaceous			
## nlcdClassshrubScrub			
## functionalGroupLeaves			
## functionalGroupMixed			
## functionalGroupNeedles			
## functionalGroupOther			
## functionalGroupSeeds			
## functionalGroupTwigs/branches			
## functionalGroupWoody material			
## nlcdClassgrasslandHerbaceous:functionalGroupLeaves			
## nlcdClassshrubScrub:functionalGroupLeaves			
## nlcdClassgrasslandHerbaceous:functionalGroupMixed			
## nlcdClassshrubScrub:functionalGroupMixed			
## nlcdClassgrasslandHerbaceous:functionalGroupNeedles			
## nlcdClassshrubScrub:functionalGroupNeedles			
## nlcdClassgrasslandHerbaceous:functionalGroupOther	0.227		
## nlcdClassshrubScrub:functionalGroupOther	0.513	0.448	
## nlcdClassgrasslandHerbaceous:functionalGroupSeeds	0.227	0.501	0.221
## nlcdClassshrubScrub:functionalGroupSeeds	0.512	0.221	0.499
## nlcdClassgrasslandHerbaceous:functionalGroupTwigs/branches	0.230	0.508	0.224

```

## nlcdClassshrubScrub:functionalGroupTwigs/branches      0.521  0.225  0.509
## nlcdClassgrasslandHerbaceous:functionalGroupWoody material  0.231  0.511  0.225
## nlcdClassshrubScrub:functionalGroupWoody material      0.528  0.227  0.515
##                                                         nCH:GS nCS:GS nCH:GT
## nlcdClassgrasslandHerbaceous
## nlcdClassshrubScrub
## functionalGroupLeaves
## functionalGroupMixed
## functionalGroupNeedles
## functionalGroupOther
## functionalGroupSeeds
## functionalGroupTwigs/branches
## functionalGroupWoody material
## nlcdClassgrasslandHerbaceous:functionalGroupLeaves
## nlcdClassshrubScrub:functionalGroupLeaves
## nlcdClassgrasslandHerbaceous:functionalGroupMixed
## nlcdClassshrubScrub:functionalGroupMixed
## nlcdClassgrasslandHerbaceous:functionalGroupNeedles
## nlcdClassshrubScrub:functionalGroupNeedles
## nlcdClassgrasslandHerbaceous:functionalGroupOther
## nlcdClassshrubScrub:functionalGroupOther
## nlcdClassgrasslandHerbaceous:functionalGroupSeeds
## nlcdClassshrubScrub:functionalGroupSeeds                0.447
## nlcdClassgrasslandHerbaceous:functionalGroupTwigs/branches 0.508  0.224
## nlcdClassshrubScrub:functionalGroupTwigs/branches        0.225  0.507  0.442
## nlcdClassgrasslandHerbaceous:functionalGroupWoody material 0.511  0.225  0.518
## nlcdClassshrubScrub:functionalGroupWoody material        0.228  0.514  0.231
##                                                         nCS:GT nCH:Gm
## nlcdClassgrasslandHerbaceous
## nlcdClassshrubScrub
## functionalGroupLeaves
## functionalGroupMixed
## functionalGroupNeedles
## functionalGroupOther
## functionalGroupSeeds
## functionalGroupTwigs/branches
## functionalGroupWoody material
## nlcdClassgrasslandHerbaceous:functionalGroupLeaves
## nlcdClassshrubScrub:functionalGroupLeaves
## nlcdClassgrasslandHerbaceous:functionalGroupMixed
## nlcdClassshrubScrub:functionalGroupMixed
## nlcdClassgrasslandHerbaceous:functionalGroupNeedles
## nlcdClassshrubScrub:functionalGroupNeedles
## nlcdClassgrasslandHerbaceous:functionalGroupOther
## nlcdClassshrubScrub:functionalGroupOther
## nlcdClassgrasslandHerbaceous:functionalGroupSeeds
## nlcdClassshrubScrub:functionalGroupSeeds
## nlcdClassgrasslandHerbaceous:functionalGroupTwigs/branches
## nlcdClassshrubScrub:functionalGroupTwigs/branches
## nlcdClassgrasslandHerbaceous:functionalGroupWoody material 0.229
## nlcdClassshrubScrub:functionalGroupWoody material        0.523  0.429
##
## Standardized Within-Group Residuals:
##           Min           Q1           Med           Q3           Max

```

```
## -1.96496855 -0.23842984 -0.01535880 0.09027291 14.27434811
##
## Number of Observations: 1692
## Number of Groups: 12
```

```
# 9b Compare marginal (no random effect) and conditional (mixed effects) r-squared values
rsquared(LitterTest.mixed) # Show R2 value
```

```
## Response family link method Marginal Conditional
## 1 dryMass gaussian identity none 0.2465822 0.2679023
```

b. continued... How much more variance is explained by adding the random effect to the model?

Answer: 2.1% more variance is explained by the random effects model compared to just the fixed effects ( $R^2_{\text{conditional}} = 0.268$ ,  $R^2_{\text{marginal}} = 0.247$ ).

c. Run the same model without the random effect.

d. Run an anova on the two tests.

```
# 9c Fixed effects model
LitterTest.fixed <- gls(data = Litter.Processed, dryMass ~ nlcdClass * functionalGroup)
summary(LitterTest.fixed)
```

```
## Generalized least squares fit by REML
## Model: dryMass ~ nlcdClass * functionalGroup
## Data: Litter.Processed
## AIC BIC logLik
## 9058.088 9193.573 -4504.044
##
## Coefficients:
## Value Std.Error
## (Intercept) 0.119625 0.3906950
## nlcdClassgrasslandHerbaceous -0.114199 0.6422303
## nlcdClassshrubScrub -0.104119 0.5383767
## functionalGroupLeaves -0.103599 0.5560568
## functionalGroupMixed 1.504750 0.6380023
## functionalGroupNeedles 7.312264 0.5369590
## functionalGroupOther -0.034817 0.5560568
## functionalGroupSeeds -0.046163 0.5560568
## functionalGroupTwigs/branches 1.959669 0.5443402
## functionalGroupWoody material 1.084311 0.5315555
## nlcdClassgrasslandHerbaceous:functionalGroupLeaves 0.128646 0.8941030
## nlcdClassshrubScrub:functionalGroupLeaves 0.147030 0.7591538
## nlcdClassgrasslandHerbaceous:functionalGroupMixed -0.381176 1.1302365
## nlcdClassshrubScrub:functionalGroupMixed 0.745929 0.9303798
## nlcdClassgrasslandHerbaceous:functionalGroupNeedles -2.138801 0.8799314
## nlcdClassshrubScrub:functionalGroupNeedles -2.921481 0.7425783
## nlcdClassgrasslandHerbaceous:functionalGroupOther 0.126058 0.9074253
## nlcdClassshrubScrub:functionalGroupOther 0.085888 0.7610116
## nlcdClassgrasslandHerbaceous:functionalGroupSeeds 0.046155 0.9074253
## nlcdClassshrubScrub:functionalGroupSeeds 0.059436 0.7629471
## nlcdClassgrasslandHerbaceous:functionalGroupTwigs/branches -1.015195 0.8946237
## nlcdClassshrubScrub:functionalGroupTwigs/branches -1.495591 0.7488092
## nlcdClassgrasslandHerbaceous:functionalGroupWoody material -1.040859 0.8897083
## nlcdClassshrubScrub:functionalGroupWoody material -0.971848 0.7395676
## t-value p-value
## (Intercept) 0.306185 0.7595
```

## nlcdClassgrasslandHerbaceous	-0.177817	0.8589
## nlcdClassshrubScrub	-0.193395	0.8467
## functionalGroupLeaves	-0.186311	0.8522
## functionalGroupMixed	2.358534	0.0185
## functionalGroupNeedles	13.617920	0.0000
## functionalGroupOther	-0.062615	0.9501
## functionalGroupSeeds	-0.083019	0.9338
## functionalGroupTwigs/branches	3.600082	0.0003
## functionalGroupWoody material	2.039883	0.0415
## nlcdClassgrasslandHerbaceous:functionalGroupLeaves	0.143882	0.8856
## nlcdClassshrubScrub:functionalGroupLeaves	0.193676	0.8465
## nlcdClassgrasslandHerbaceous:functionalGroupMixed	-0.337253	0.7360
## nlcdClassshrubScrub:functionalGroupMixed	0.801746	0.4228
## nlcdClassgrasslandHerbaceous:functionalGroupNeedles	-2.430645	0.0152
## nlcdClassshrubScrub:functionalGroupNeedles	-3.934239	0.0001
## nlcdClassgrasslandHerbaceous:functionalGroupOther	0.138919	0.8895
## nlcdClassshrubScrub:functionalGroupOther	0.112860	0.9102
## nlcdClassgrasslandHerbaceous:functionalGroupSeeds	0.050863	0.9594
## nlcdClassshrubScrub:functionalGroupSeeds	0.077903	0.9379
## nlcdClassgrasslandHerbaceous:functionalGroupTwigs/branches	-1.134773	0.2566
## nlcdClassshrubScrub:functionalGroupTwigs/branches	-1.997293	0.0460
## nlcdClassgrasslandHerbaceous:functionalGroupWoody material	-1.169888	0.2422
## nlcdClassshrubScrub:functionalGroupWoody material	-1.314076	0.1890
##		
## Correlation:		
##	(Intr)	nlcdCH nlcdCS
## nlcdClassgrasslandHerbaceous	-0.608	
## nlcdClassshrubScrub	-0.726	0.441
## functionalGroupLeaves	-0.703	0.427 0.510
## functionalGroupMixed	-0.612	0.373 0.444
## functionalGroupNeedles	-0.728	0.443 0.528
## functionalGroupOther	-0.703	0.427 0.510
## functionalGroupSeeds	-0.703	0.427 0.510
## functionalGroupTwigs/branches	-0.718	0.437 0.521
## functionalGroupWoody material	-0.735	0.447 0.533
## nlcdClassgrasslandHerbaceous:functionalGroupLeaves	0.437	-0.718 -0.317
## nlcdClassshrubScrub:functionalGroupLeaves	0.515	-0.313 -0.709
## nlcdClassgrasslandHerbaceous:functionalGroupMixed	0.346	-0.568 -0.251
## nlcdClassshrubScrub:functionalGroupMixed	0.420	-0.255 -0.579
## nlcdClassgrasslandHerbaceous:functionalGroupNeedles	0.444	-0.730 -0.322
## nlcdClassshrubScrub:functionalGroupNeedles	0.526	-0.320 -0.725
## nlcdClassgrasslandHerbaceous:functionalGroupOther	0.431	-0.708 -0.312
## nlcdClassshrubScrub:functionalGroupOther	0.513	-0.312 -0.707
## nlcdClassgrasslandHerbaceous:functionalGroupSeeds	0.431	-0.708 -0.312
## nlcdClassshrubScrub:functionalGroupSeeds	0.512	-0.312 -0.706
## nlcdClassgrasslandHerbaceous:functionalGroupTwigs/branches	0.437	-0.718 -0.317
## nlcdClassshrubScrub:functionalGroupTwigs/branches	0.522	-0.317 -0.719
## nlcdClassgrasslandHerbaceous:functionalGroupWoody material	0.439	-0.722 -0.319
## nlcdClassshrubScrub:functionalGroupWoody material	0.528	-0.321 -0.728
##	fnctGL	fnctGM fnctGN
## nlcdClassgrasslandHerbaceous		
## nlcdClassshrubScrub		
## functionalGroupLeaves		
## functionalGroupMixed	0.430	

## functionalGroupNeedles	0.511	0.446	
## functionalGroupOther	0.494	0.430	0.511
## functionalGroupSeeds	0.494	0.430	0.511
## functionalGroupTwigs/branches	0.504	0.440	0.522
## functionalGroupWoody material	0.516	0.450	0.535
## nlcdClassgrasslandHerbaceous:functionalGroupLeaves	-0.622	-0.268	-0.318
## nlcdClassshrubScrub:functionalGroupLeaves	-0.732	-0.315	-0.374
## nlcdClassgrasslandHerbaceous:functionalGroupMixed	-0.243	-0.564	-0.252
## nlcdClassshrubScrub:functionalGroupMixed	-0.295	-0.686	-0.306
## nlcdClassgrasslandHerbaceous:functionalGroupNeedles	-0.312	-0.272	-0.610
## nlcdClassshrubScrub:functionalGroupNeedles	-0.370	-0.322	-0.723
## nlcdClassgrasslandHerbaceous:functionalGroupOther	-0.303	-0.264	-0.313
## nlcdClassshrubScrub:functionalGroupOther	-0.361	-0.314	-0.374
## nlcdClassgrasslandHerbaceous:functionalGroupSeeds	-0.303	-0.264	-0.313
## nlcdClassshrubScrub:functionalGroupSeeds	-0.360	-0.314	-0.373
## nlcdClassgrasslandHerbaceous:functionalGroupTwigs/branches	-0.307	-0.267	-0.318
## nlcdClassshrubScrub:functionalGroupTwigs/branches	-0.367	-0.320	-0.380
## nlcdClassgrasslandHerbaceous:functionalGroupWoody material	-0.309	-0.269	-0.320
## nlcdClassshrubScrub:functionalGroupWoody material	-0.371	-0.324	-0.384
##	fncTG0	fncTGS	fncGT/
## nlcdClassgrasslandHerbaceous			
## nlcdClassshrubScrub			
## functionalGroupLeaves			
## functionalGroupMixed			
## functionalGroupNeedles			
## functionalGroupOther			
## functionalGroupSeeds	0.494		
## functionalGroupTwigs/branches	0.504	0.504	
## functionalGroupWoody material	0.516	0.516	0.528
## nlcdClassgrasslandHerbaceous:functionalGroupLeaves	-0.307	-0.307	-0.314
## nlcdClassshrubScrub:functionalGroupLeaves	-0.362	-0.362	-0.369
## nlcdClassgrasslandHerbaceous:functionalGroupMixed	-0.243	-0.243	-0.248
## nlcdClassshrubScrub:functionalGroupMixed	-0.295	-0.295	-0.301
## nlcdClassgrasslandHerbaceous:functionalGroupNeedles	-0.312	-0.312	-0.319
## nlcdClassshrubScrub:functionalGroupNeedles	-0.370	-0.370	-0.378
## nlcdClassgrasslandHerbaceous:functionalGroupOther	-0.613	-0.303	-0.309
## nlcdClassshrubScrub:functionalGroupOther	-0.731	-0.361	-0.368
## nlcdClassgrasslandHerbaceous:functionalGroupSeeds	-0.303	-0.613	-0.309
## nlcdClassshrubScrub:functionalGroupSeeds	-0.360	-0.729	-0.368
## nlcdClassgrasslandHerbaceous:functionalGroupTwigs/branches	-0.307	-0.307	-0.608
## nlcdClassshrubScrub:functionalGroupTwigs/branches	-0.367	-0.367	-0.727
## nlcdClassgrasslandHerbaceous:functionalGroupWoody material	-0.309	-0.309	-0.315
## nlcdClassshrubScrub:functionalGroupWoody material	-0.371	-0.371	-0.379
##	fncGWm	nCH:GL	nCS:GL
## nlcdClassgrasslandHerbaceous			
## nlcdClassshrubScrub			
## functionalGroupLeaves			
## functionalGroupMixed			
## functionalGroupNeedles			
## functionalGroupOther			
## functionalGroupSeeds			
## functionalGroupTwigs/branches			
## functionalGroupWoody material			
## nlcdClassgrasslandHerbaceous:functionalGroupLeaves	-0.321		

## nlcdClassshrubScrub:functionalGroupLeaves	-0.378	0.456	
## nlcdClassgrasslandHerbaceous:functionalGroupMixed	-0.254	0.408	0.178
## nlcdClassshrubScrub:functionalGroupMixed	-0.309	0.183	0.410
## nlcdClassgrasslandHerbaceous:functionalGroupNeedles	-0.326	0.524	0.229
## nlcdClassshrubScrub:functionalGroupNeedles	-0.387	0.230	0.514
## nlcdClassgrasslandHerbaceous:functionalGroupOther	-0.316	0.508	0.222
## nlcdClassshrubScrub:functionalGroupOther	-0.377	0.224	0.502
## nlcdClassgrasslandHerbaceous:functionalGroupSeeds	-0.316	0.508	0.222
## nlcdClassshrubScrub:functionalGroupSeeds	-0.376	0.224	0.500
## nlcdClassgrasslandHerbaceous:functionalGroupTwigs/branches	-0.321	0.516	0.225
## nlcdClassshrubScrub:functionalGroupTwigs/branches	-0.383	0.228	0.510
## nlcdClassgrasslandHerbaceous:functionalGroupWoody material	-0.597	0.518	0.226
## nlcdClassshrubScrub:functionalGroupWoody material	-0.719	0.231	0.516
##	nCH:GM	nCS:GM	nCH:GN
## nlcdClassgrasslandHerbaceous			
## nlcdClassshrubScrub			
## functionalGroupLeaves			
## functionalGroupMixed			
## functionalGroupNeedles			
## functionalGroupOther			
## functionalGroupSeeds			
## functionalGroupTwigs/branches			
## functionalGroupWoody material			
## nlcdClassgrasslandHerbaceous:functionalGroupLeaves			
## nlcdClassshrubScrub:functionalGroupLeaves			
## nlcdClassgrasslandHerbaceous:functionalGroupMixed			
## nlcdClassshrubScrub:functionalGroupMixed	0.387		
## nlcdClassgrasslandHerbaceous:functionalGroupNeedles	0.415	0.186	
## nlcdClassshrubScrub:functionalGroupNeedles	0.182	0.420	0.441
## nlcdClassgrasslandHerbaceous:functionalGroupOther	0.402	0.181	0.517
## nlcdClassshrubScrub:functionalGroupOther	0.177	0.409	0.228
## nlcdClassgrasslandHerbaceous:functionalGroupSeeds	0.402	0.181	0.517
## nlcdClassshrubScrub:functionalGroupSeeds	0.177	0.408	0.227
## nlcdClassgrasslandHerbaceous:functionalGroupTwigs/branches	0.408	0.183	0.524
## nlcdClassshrubScrub:functionalGroupTwigs/branches	0.180	0.416	0.232
## nlcdClassgrasslandHerbaceous:functionalGroupWoody material	0.410	0.184	0.527
## nlcdClassshrubScrub:functionalGroupWoody material	0.183	0.421	0.235
##	nCS:GN	nCH:GO	nCS:GO
## nlcdClassgrasslandHerbaceous			
## nlcdClassshrubScrub			
## functionalGroupLeaves			
## functionalGroupMixed			
## functionalGroupNeedles			
## functionalGroupOther			
## functionalGroupSeeds			
## functionalGroupTwigs/branches			
## functionalGroupWoody material			
## nlcdClassgrasslandHerbaceous:functionalGroupLeaves			
## nlcdClassshrubScrub:functionalGroupLeaves			
## nlcdClassgrasslandHerbaceous:functionalGroupMixed			
## nlcdClassshrubScrub:functionalGroupMixed			
## nlcdClassgrasslandHerbaceous:functionalGroupNeedles			
## nlcdClassshrubScrub:functionalGroupNeedles			
## nlcdClassgrasslandHerbaceous:functionalGroupOther	0.227		

## nlcdClasssshrubScrub:functionalGroupOther	0.513	0.448	
## nlcdClassgrasslandHerbaceous:functionalGroupSeeds	0.227	0.501	0.221
## nlcdClasssshrubScrub:functionalGroupSeeds	0.512	0.220	0.499
## nlcdClassgrasslandHerbaceous:functionalGroupTwigs/branches	0.230	0.508	0.224
## nlcdClasssshrubScrub:functionalGroupTwigs/branches	0.521	0.225	0.509
## nlcdClassgrasslandHerbaceous:functionalGroupWoody material	0.231	0.511	0.225
## nlcdClasssshrubScrub:functionalGroupWoody material	0.528	0.227	0.515
##	nCH:GS	nCS:GS	nCH:GT
## nlcdClassgrasslandHerbaceous			
## nlcdClasssshrubScrub			
## functionalGroupLeaves			
## functionalGroupMixed			
## functionalGroupNeedles			
## functionalGroupOther			
## functionalGroupSeeds			
## functionalGroupTwigs/branches			
## functionalGroupWoody material			
## nlcdClassgrasslandHerbaceous:functionalGroupLeaves			
## nlcdClasssshrubScrub:functionalGroupLeaves			
## nlcdClassgrasslandHerbaceous:functionalGroupMixed			
## nlcdClasssshrubScrub:functionalGroupMixed			
## nlcdClassgrasslandHerbaceous:functionalGroupNeedles			
## nlcdClasssshrubScrub:functionalGroupNeedles			
## nlcdClassgrasslandHerbaceous:functionalGroupOther			
## nlcdClasssshrubScrub:functionalGroupOther			
## nlcdClassgrasslandHerbaceous:functionalGroupSeeds			
## nlcdClasssshrubScrub:functionalGroupSeeds	0.447		
## nlcdClassgrasslandHerbaceous:functionalGroupTwigs/branches	0.508	0.224	
## nlcdClasssshrubScrub:functionalGroupTwigs/branches	0.225	0.507	0.442
## nlcdClassgrasslandHerbaceous:functionalGroupWoody material	0.511	0.225	0.518
## nlcdClasssshrubScrub:functionalGroupWoody material	0.227	0.514	0.231
##	nCS:GT	nCH:Gm	
## nlcdClassgrasslandHerbaceous			
## nlcdClasssshrubScrub			
## functionalGroupLeaves			
## functionalGroupMixed			
## functionalGroupNeedles			
## functionalGroupOther			
## functionalGroupSeeds			
## functionalGroupTwigs/branches			
## functionalGroupWoody material			
## nlcdClassgrasslandHerbaceous:functionalGroupLeaves			
## nlcdClasssshrubScrub:functionalGroupLeaves			
## nlcdClassgrasslandHerbaceous:functionalGroupMixed			
## nlcdClasssshrubScrub:functionalGroupMixed			
## nlcdClassgrasslandHerbaceous:functionalGroupNeedles			
## nlcdClasssshrubScrub:functionalGroupNeedles			
## nlcdClassgrasslandHerbaceous:functionalGroupOther			
## nlcdClasssshrubScrub:functionalGroupOther			
## nlcdClassgrasslandHerbaceous:functionalGroupSeeds			
## nlcdClasssshrubScrub:functionalGroupSeeds			
## nlcdClassgrasslandHerbaceous:functionalGroupTwigs/branches			
## nlcdClasssshrubScrub:functionalGroupTwigs/branches			
## nlcdClassgrasslandHerbaceous:functionalGroupWoody material	0.229		

```
## nlcdClasssshrubScrub:functionalGroupWoody material 0.523 0.429
```

```
##
```

```
## Standardized residuals:
```

```
##      Min      Q1      Med      Q3      Max
```

```
## -1.89209382 -0.13724016 -0.01672707 -0.00155260 14.03673076
```

```
##
```

```
## Residual standard error: 3.494483
```

```
## Degrees of freedom: 1692 total; 1668 residual
```

```
# 9d Compare results using ANOVA
```

```
anova(LitterTest.mixed, LitterTest.fixed)
```

```
##      Model df      AIC      BIC    logLik  Test  L.Ratio p-value
```

```
## LitterTest.mixed      1 26 9038.575 9179.479 -4493.287
```

```
## LitterTest.fixed      2 25 9058.088 9193.573 -4504.044 1 vs 2 21.51338 <.0001
```

d. continued... Is the mixed effects model a better model than the fixed effects model? How do you know?

Answer: The models have a significantly different fit (ANOVA,  $p < 0.0001$ ), and the mixed effects model has a lower AIC (9038 vs 9058), so it is the better model.