EDS230: Assignment 7

Allie Cole, Daniel Kerstan, and Sydney Rilum

5/12/2022

Consider the following model of forest growth (where forest size in measured in units of carbon (C))

- dC/dt=r*C for forests where C is below a threshold canopy closure
- dC/dt=g*(1-C/K) for forests where carbon is at or above the threshold canopy closure
- and K is a carrying capacity in units of carbon

The size of the forest (C), Canopy closure threshold and carrying capacity are all in units of carbon

You could think of the canopy closure threshold as the size of the forest at which growth rates change from exponential to linear

You can think of r, as early exponential growth rate and g as the linear growth rate once canopy closure has been reached

1. Implement this model in R (as a differential equation)

```
# source function
source("dforest.R")
```

2. Run the model for 300 years (using the ODE solver)

Starting with an initial forest size of 10 kg/C, and using the following parameters:

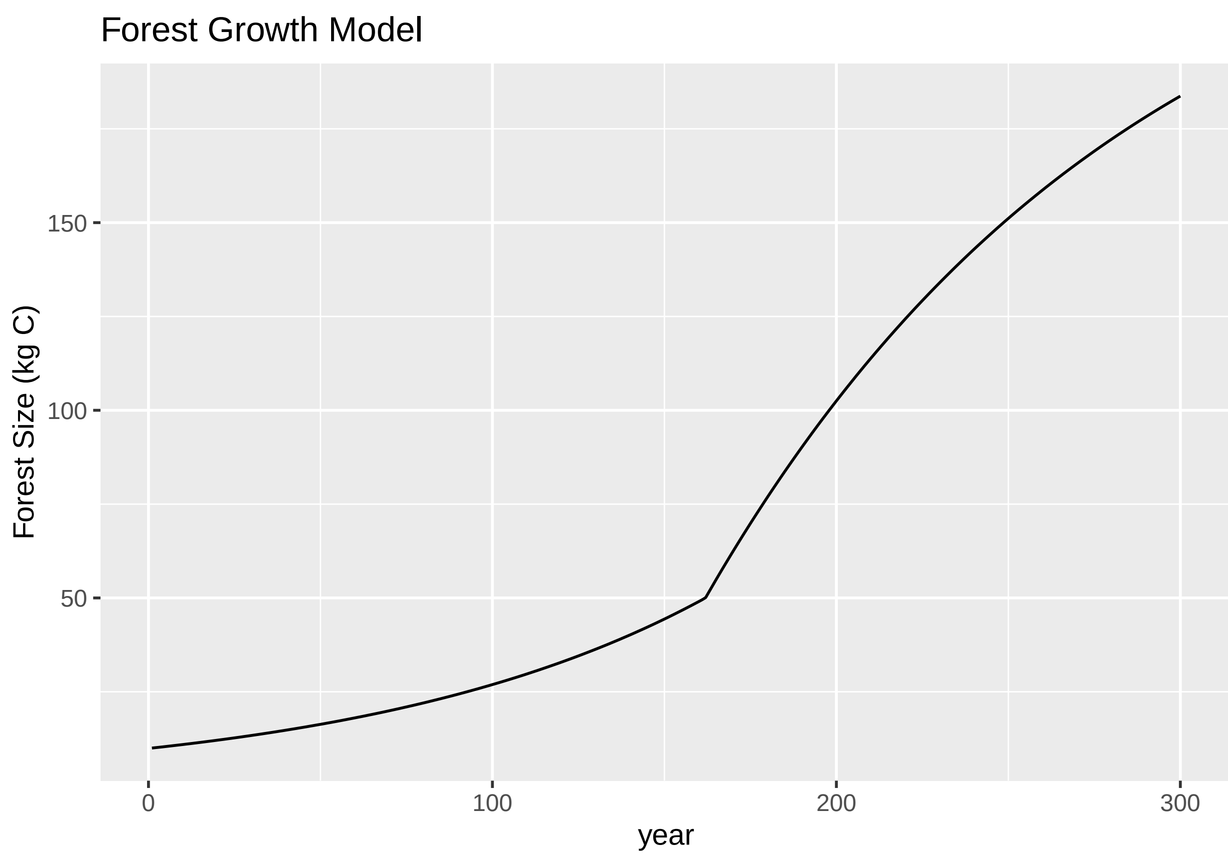
- canopy closure threshold of 50 kgC
- K = 250 kg C (carrying capacity)
- r = 0.01 (exponential growth rate before before canopy closure)
- g = 2 kg/year (linear growth rate after canopy closure)

```
# set parameters
r = 0.01
K = 250
g = 2
cct = 50

C = 10

# gets results for 300 years (evaluating every year)
nyears = seq(from = 1, to = 300)
parameters = list(r = r,
                  K = K,
                  g = g,
                  cct = cct)

# use ODE solver to run forest growth function
```

```
results = ode(y = C, times = nyears, func = dforest, parms = parameters)

colnames(results) = c("year", "C")

# turn it into a data frame
results = as.data.frame(results)
```

Graph the results. (15% - we look for an appropriate graphs and good visualization practice - labels, etc)

```
# graph model results
ggplot(results, aes(year, C)) +
  geom_line() +
  labs(y = "Forest Size (kg C)",
       title = "Forest Growth Model")
```



3. Run a Sobol sensitivity analysis

Run a Sobol sensitivity analysis that explores how the estimated maximum and mean forest size (e.g maximum and mean values of C over the 300 years) varies with the pre canopy closure growth rate (r) and post-canopy closure growth rate (g) and canopy closure threshold (cct) and carrying capacity (K).

Assume that parameters are all normally distributed with means as given above and standard deviation of 10% of mean value.

```
# set parameter estimates for sensitivity analysis
nyears = 300
r = rnorm(mean = 0.01, sd = 0.01*0.1, n = nyears)
K = rnorm(mean = 250, sd = 250*0.1, n = nyears)
```

```
g = rnorm(mean = 2, sd = 2*0.1, n = nyears)
cct = rnorm(mean = 50, sd = 50*0.1, n = nyears)

# bind parameters to data frame
X1 = cbind.data.frame(r = r, K = K, g = g, cct = cct)

# repeat for second random sample
r = rnorm(mean = 0.01, sd = 0.01*0.1, n = nyears)
K = rnorm(mean = 250, sd = 250*0.1, n = nyears)
g = rnorm(mean = 2, sd = 2*0.1, n = nyears)
cct = rnorm(mean = 50, sd = 50*0.1, n = nyears)

# bind parameters to data frame
X2 = cbind.data.frame(r = r, K = K, g = g, cct = cct)

# create sobel object and get sets of parameters for running the model
sens_P = sobolSalt(model = NULL, X1, X2, nboot = 300)

# add column names
colnames(sens_P$X) = c("r","K","g","cct")

# our parameter sets are
head(sens_P$X)
```

```
##               r        K        g      cct
## [1,] 0.01177555 213.5424 2.077026 47.76025
## [2,] 0.00946555 279.0086 2.244300 51.96477
## [3,] 0.01043172 274.4930 1.755222 46.93457
## [4,] 0.01101281 247.0041 1.999168 40.39058
## [5,] 0.01007741 264.6074 2.062471 43.78352
## [6,] 0.01082231 252.0732 1.898528 51.68441
```

```
# run our differential equation and keep the output
# find maximum and mean forest size, running the model for 300 years, and see how it varies with r, g, 

# for illustration lets look at running just one parameter sets and summarizing results
sens_P$X[1,]
```

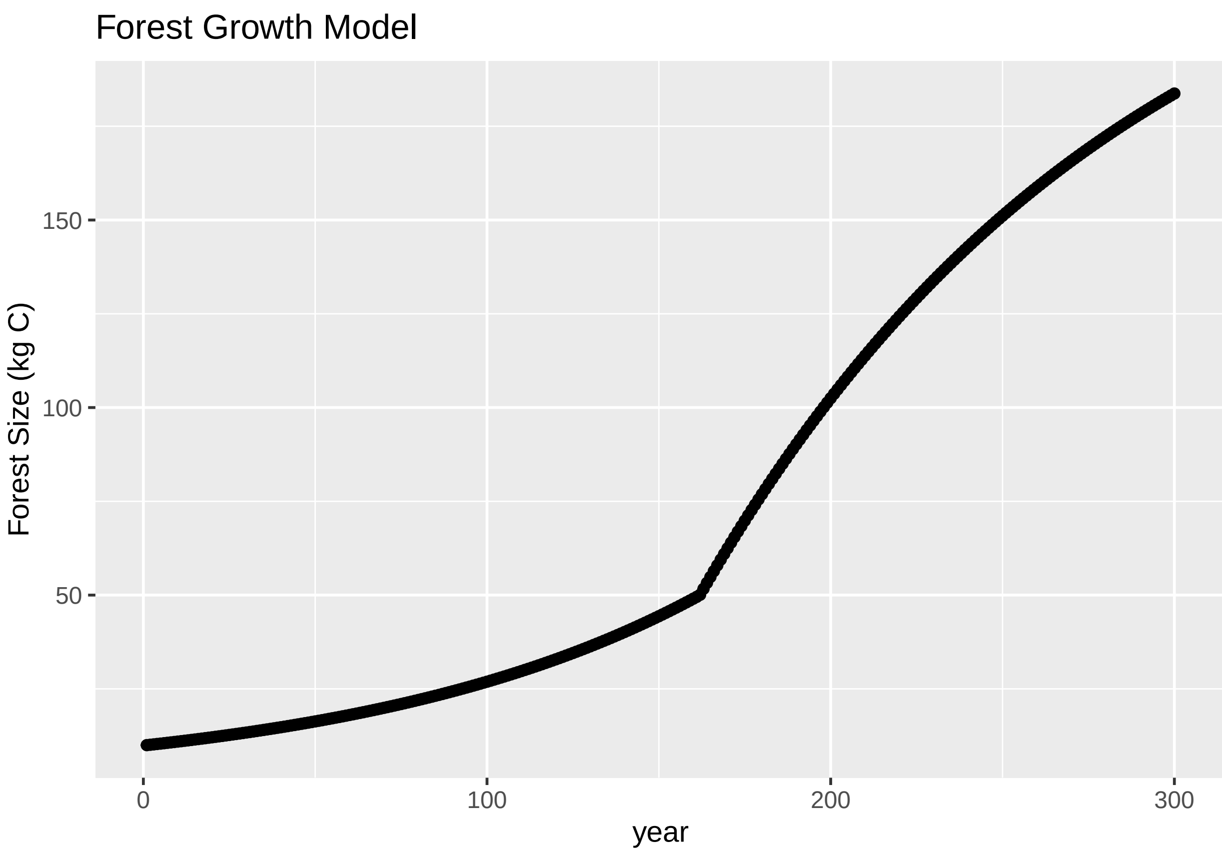
```
##            r            K            g          cct
##   0.01177555 213.54241513   2.07702600  47.76025266
```

```
# recall ODE needs ALL of our parameters in a single list

# set initial population
C = 10

# gets results for 300 years (evaluating every year)
nyears = seq(from = 1, to = 300)
parmaters = list(r=sens_P$X[1,"r"],
                 K = sens_P$X[1,"K"],
                 g = sens_P$X[1,"g"],
                 cct = sens_P$X[1,"cct"])

# use ODE solver to run function for varying parameters over 300 years
result = ode(y= C, times = nyears, func = dforest, parms = parameters)
```

```r
# check results
head(result)
```

```
##      time        1
## [1,]    1 10.00000
## [2,]    2 10.10050
## [3,]    3 10.20202
## [4,]    4 10.30455
## [5,]    5 10.40811
## [6,]    6 10.51271
```

```r
colnames(result) = c("time","C")

# turn it into a data frame
result = as.data.frame(result)

# visualization
ggplot(result, aes(time, C)) +
  geom_point() +
  labs(x = "year",
       y = "Forest Size (kg C)",
       title = "Forest Growth Model")
```



Graph the results of the sensitivity analysis as a box plot of maximum forest size and a plot of the two Sobol indices (S and T).

```r
maxsize = max(result$C)
maxsize
```

```
## [1] 183.7213
```

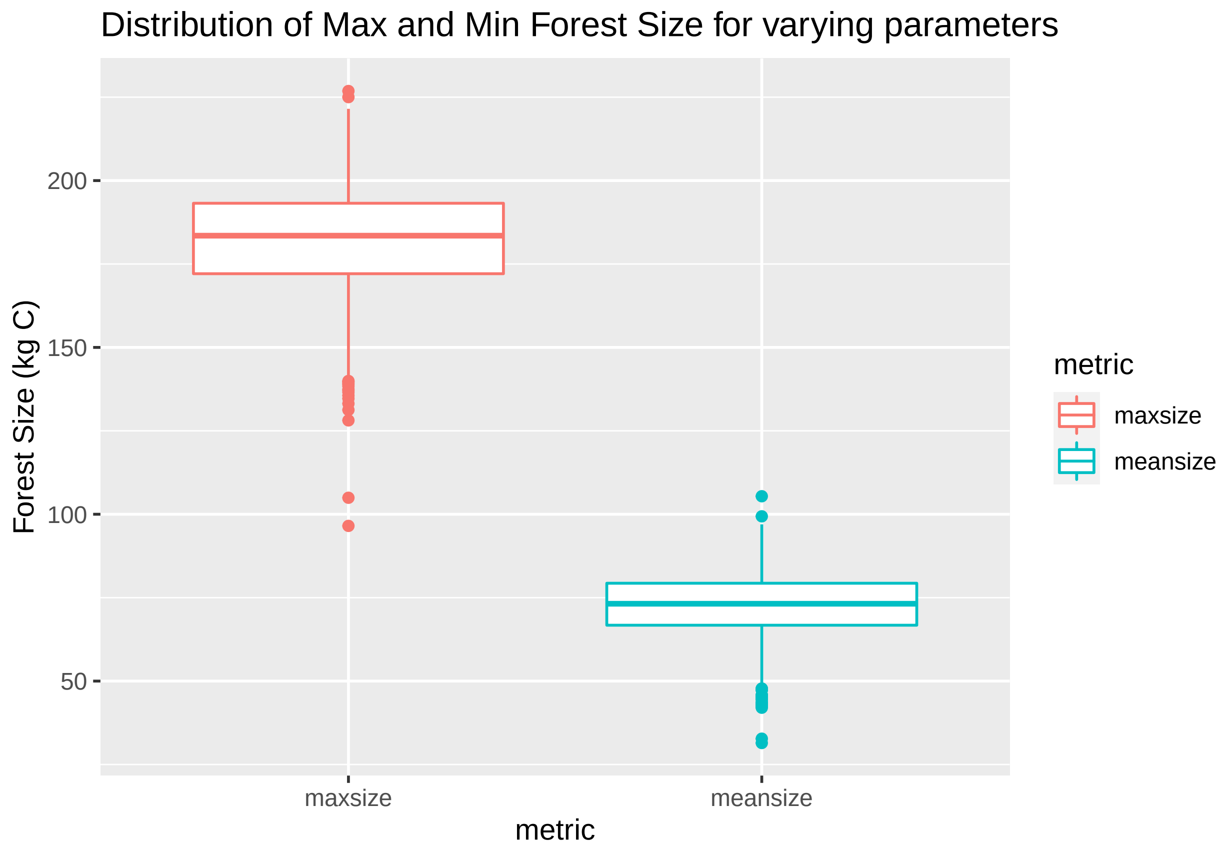
```r
meansize = mean(result$C)
meansize
```

```
## [1] 72.98569
```

```r
compute_metrics = function(result) {
  maxsize = max(result$C)
  meansize = mean(result$C)
return(list(maxsize=maxsize, meansize=meansize))}

compute_metrics(result)
```

```
## $maxsize
## [1] 183.7213
##
## $meansize
## [1] 72.98569
```

```r
p_wrapper = function(r, K, g, C, nyears, dforest, cct) {
    parms = list(r=r, K=K, g=g, cct=cct)
    result = ode(y= C, times = nyears, func = dforest, parms = parms)
    colnames(result)=c("time","C")
  # get metrics
  metrics=compute_metrics(as.data.frame(result))
  return(metrics)
}

allresults <- as.data.frame(sens_P$X) %>% pmap(p_wrapper, C = C, nyears=nyears, dforest=dforest)

allres <- allresults %>% map_dfr(`[`, c("maxsize", "meansize"))

tmp <- allres %>% gather(key = "metric", value = "value")

ggplot(tmp, aes(metric, value, col = metric)) +
  geom_boxplot() +
  labs(y = "Forest Size (kg C)",
       title = "Distribution of Max and Min Forest Size for varying parameters")
```




```
sens_P_maxsize = sensitivity::tell(sens_P,allres$maxsize)

sens_P_meansize = sensitivity::tell(sens_P,allres$meansize)

sens_P_maxsize$S
```

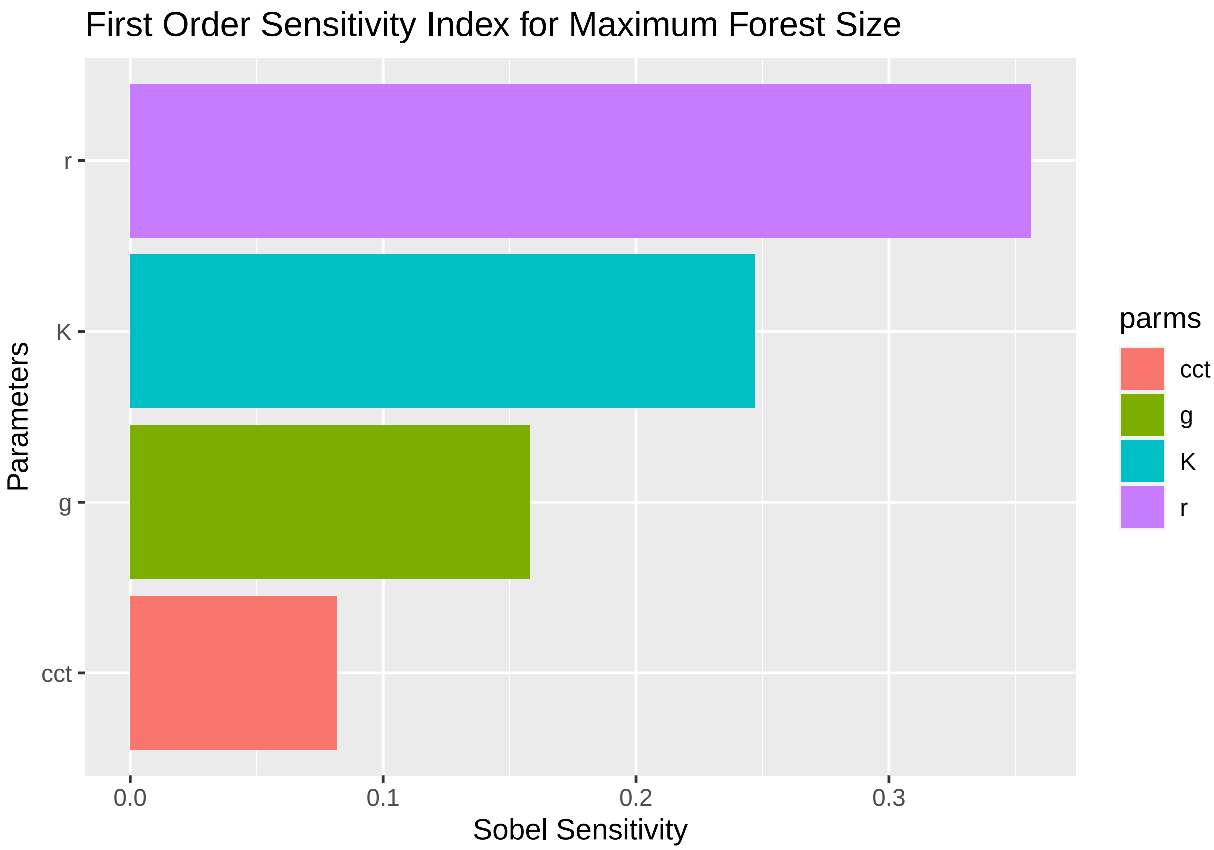
```
##       original          bias std. error    min. c.i. max. c.i.
## X1 0.35595548 -0.0046328933 0.07688860  0.19533747 0.5025089
## X2 0.24712189  0.0026878754 0.06687526  0.11624597 0.3882213
## X3 0.15785904  0.0007582112 0.05496156  0.04448628 0.2616658
## X4 0.08175244  0.0014472448 0.05610733 -0.03400039 0.1933986
```

```
sens_P_maxsize$T
```

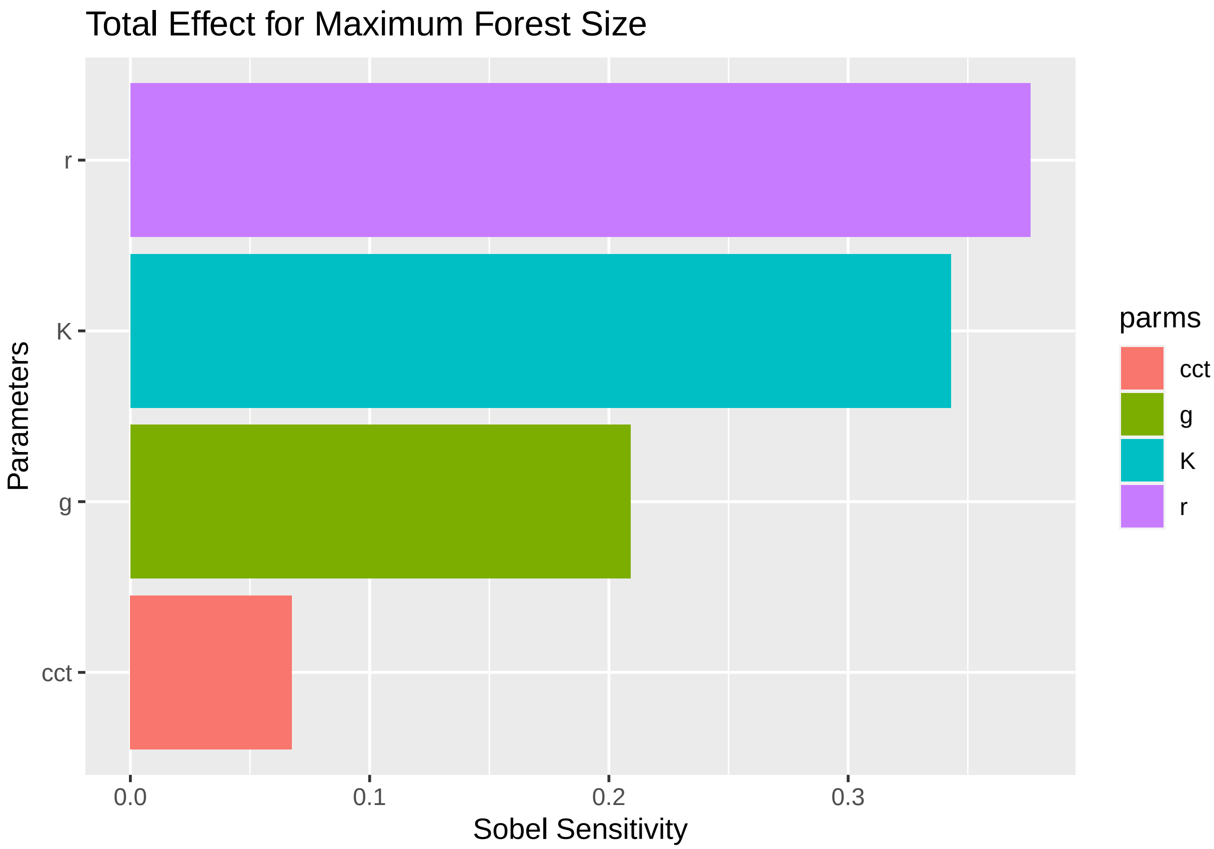
```
##       original         bias std. error  min. c.i.  max. c.i.
## X1 0.37612700 0.0010547017 0.04712727 0.27040322 0.45133467
## X2 0.34288340 0.0005883686 0.03112307 0.28210013 0.40393904
## X3 0.20907318 0.0003526093 0.02075365 0.16977604 0.25109255
## X4 0.06750155 0.0012773290 0.01028713 0.04433228 0.08436583
```

```
sens_max_s = as.data.frame(sens_P_maxsize$S) %>% rowid_to_column(var = "parms")

sens_max_s[1,1] <- "r"
sens_max_s[2,1] <- "K"
sens_max_s[3,1] <- "g"
sens_max_s[4,1] <- "cct"


sens_max_t = as.data.frame(sens_P_maxsize$T) %>% rowid_to_column(var = "parms")
```

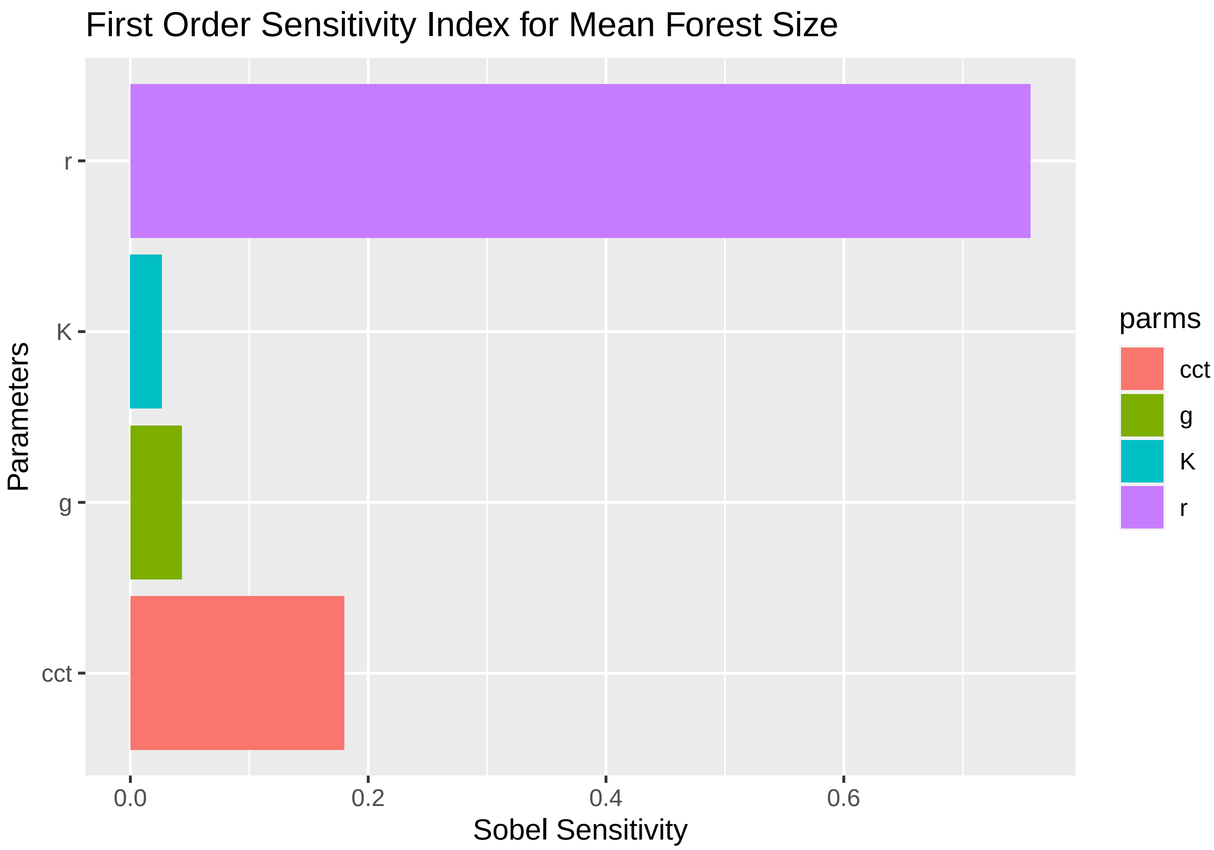
```
sens_max_t[1,1] <- "r"
sens_max_t[2,1] <- "K"
sens_max_t[3,1] <- "g"
sens_max_t[4,1] <- "cct"


sens_mean_s = as.data.frame(sens_P_meansize$S) %>% rowid_to_column(var = "parms")

sens_mean_s[1,1] <- "r"
sens_mean_s[2,1] <- "K"
sens_mean_s[3,1] <- "g"
sens_mean_s[4,1] <- "cct"


sens_mean_t = as.data.frame(sens_P_meansize$T) %>% rowid_to_column(var = "parms")

sens_mean_t[1,1] <- "r"
sens_mean_t[2,1] <- "K"
sens_mean_t[3,1] <- "g"
sens_mean_t[4,1] <- "cct"


ggplot(sens_max_s, aes(x = original, y = parms, fill = parms)) +
  geom_col() +
  labs(title = "First Order Sensitivity Index for Maximum Forest Size", y = "Parameters", x = "Sobel Se
```



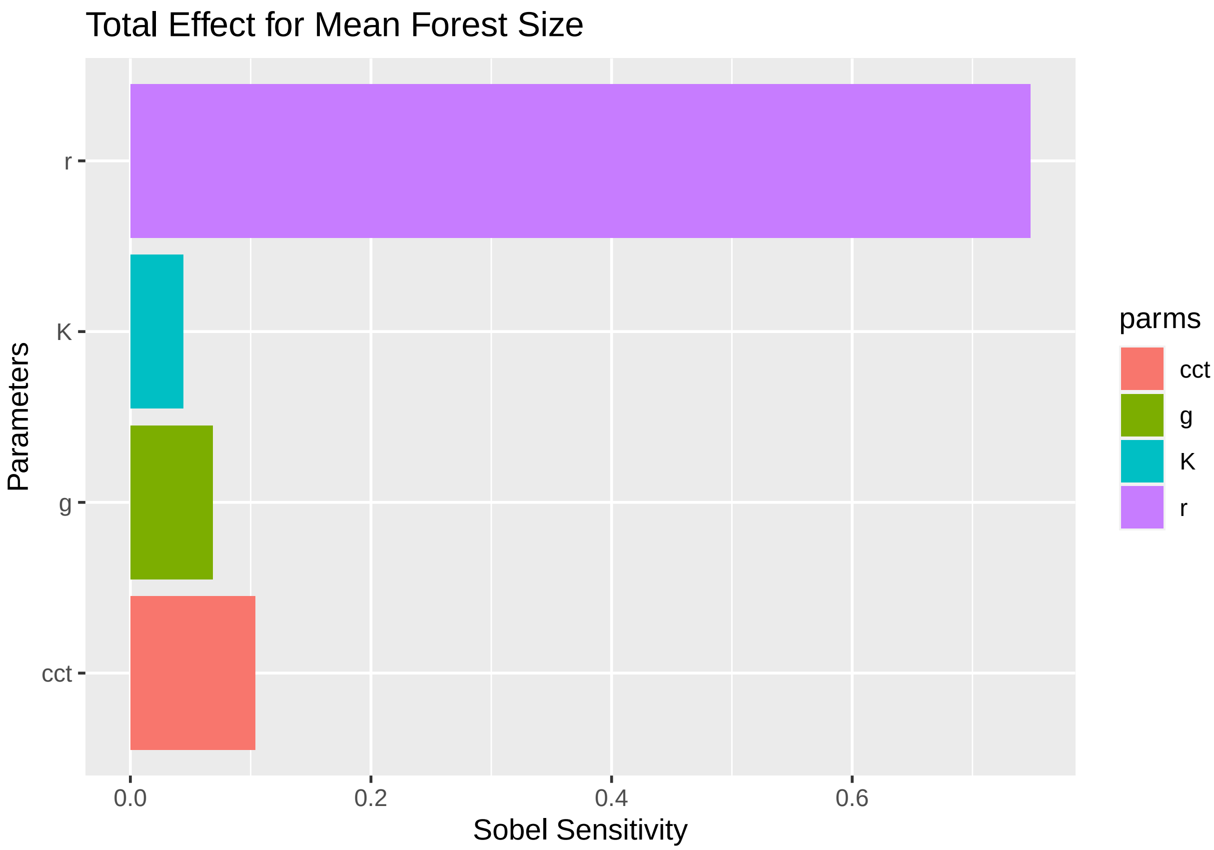
```
ggplot(sens_max_t, aes(x = original, y = parms, fill = parms)) +
  geom_col() +
  labs(title = "Total Effect for Maximum Forest Size", y = "Parameters", x = "Sobel Sensitivity")
```




```
ggplot(sens_mean_s, aes(x = original, y = parms, fill = parms)) +
  geom_col() +
  labs(title = "First Order Sensitivity Index for Mean Forest Size", y = "Parameters", x = "Sobel Sensi
```




```r
ggplot(sens_mean_t, aes(x = original, y = parms, fill = parms)) +
  geom_col() +
  labs(title = "Total Effect for Mean Forest Size", y = "Parameters", x = "Sobel Sensitivity")
```



Discussion

In 2-3 sentences, discuss what the results of your simulation might mean for climate change impacts on forest growth (e.g think about what parameters climate change might influence).

Our simulation results indicate that the parameters r (pre-canopy closure growth rate) and K (carrying capacity) have the largest sensitivity to change maximum forest size estimates over 300 years. Pre-canopy closure growth rate (r) appears to have a largest impact on mean forest size, compared to the other parameters. Climate change is likely to influence canopy growth rate parameters most because as global temperatures increase, the tree canopy growth rate will likely change (dependent on the species).