Growth Model & Sensitivity Analysis - Sobol

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Growth Model & Sobol Sensitivity Analysis

This environmental model was completed as an assignment for the course, Environmental Data Science 230 | Environmental Science & Management: Modeling Environmental Systems. The goal of this assignment was to code a function to compute forest growth and conduct a sobol sensitivity analysis that explores how the estimated maximum and mean forest size varies. This assignment focuses on developing skills to create a model of forest growth and conduct a sobol sensitivity analysis.

Parameters

- K = carrying capacity (C)
- r = pre-canopy closure rate
- g = post-canopy closure rate

Load Libraries

```
library(here)
library(tidyverse)
library(kableExtra)
library(deSolve)
library(sensitivity)
library(purrr)
library(viridis)
library(patchwork)
```

1. Implement a forest growth rate model

Forest size is measured in units of carbon (C)

```
# source the function

source(here("R","forestgrowthrate.R"))

dgrowthrate
```

```
## function (time, C, parms)
## {
##     if (C < parms$threshold) {
##         dC = parms$r * C
##     }
##     if (C >= parms$threshold) {
##         dC = parms$g * (1 - C/parms$K)
```

```
##     }
##     if (C > parms$K) {
##         dC = 0
##     }
##     return(list(dC))
## }
```

2. Run the model for 300 years (with ODE solver) and plot the result

Parameters for model

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

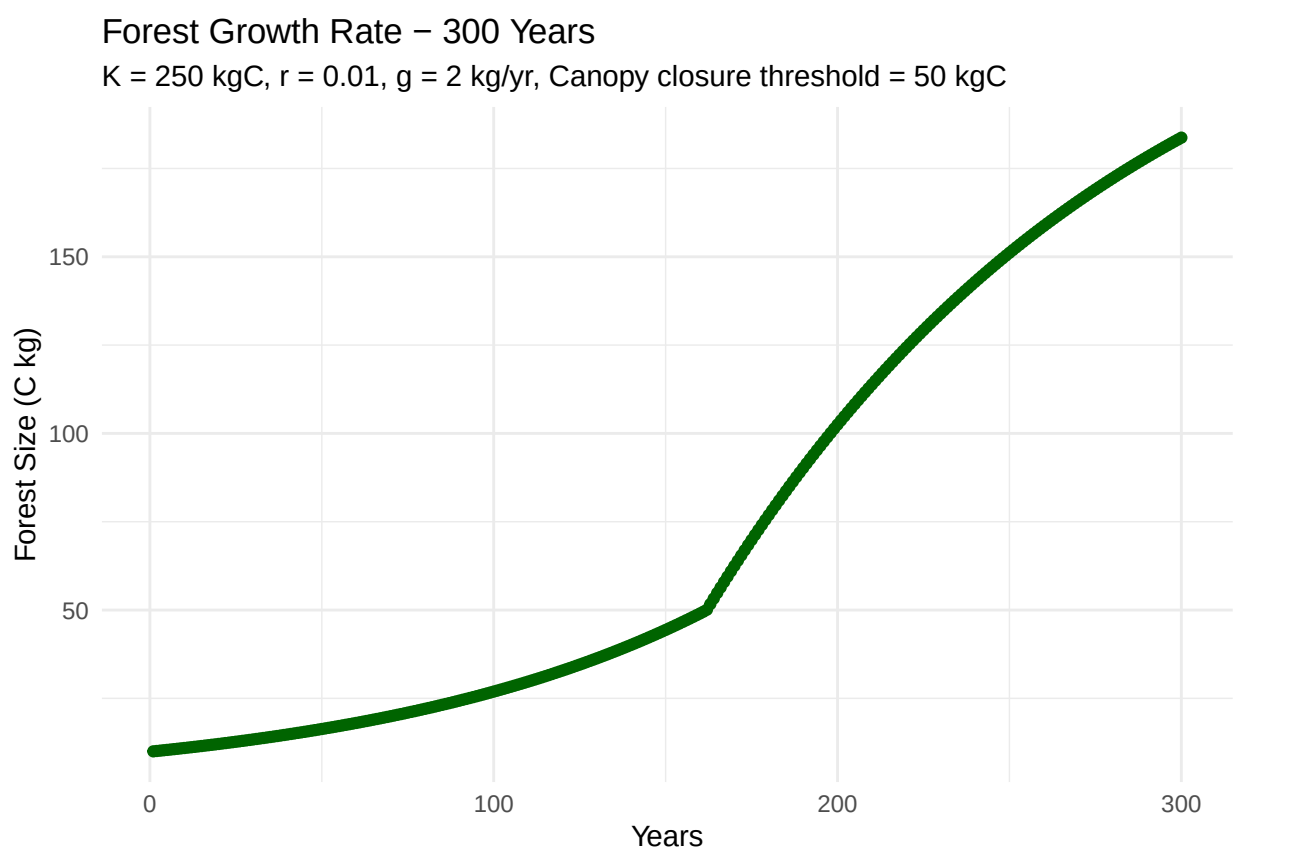
```
# create parameter list and specify the initial size and years to run the model

# set parameters
K = 250
r = 0.01
g = 2
threshold = 50

initialsize <- 10
years <- seq(from = 1, to = 300, by = 1)
parms <- list(K = K, r = r, g = g,  threshold = threshold)

#apply solver
results <- ode(initialsize, years, dgrowthrate, parms)

# convert results to data frame
results <- as.data.frame(results)

#add meaningful names to columns of results
colnames(results) = c("year", "C")
```

```
# view sample of df
results_sample <- head(results)

results_table <- kable(results_sample,
                       caption = "Sample of Forest Growth ODE Model Results") %>%
  kable_styling(latex_options = "HOLD_position")

results_table
```

Table 1: Sample of Forest Growth ODE Model Results

year	C
1	10.00000
2	10.10050
3	10.20202
4	10.30455
5	10.40811
6	10.51271

```
# plot results
model01_plot <- results %>%
  ggplot(aes(x = year, y = C)) +
  geom_point(color = "darkgreen") +
  labs(x = "Years", y = "Forest Size (C kg)",
       title = "Forest Growth Rate - 300 Years",
       subtitle = "K = 250 kgC, r = 0.01, g = 2 kg/yr, Canopy closure threshold = 50 kgC") +
  theme_minimal()

model01_plot
```



3.A. 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 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 the number of parameters
np = 200

K = rnorm(mean = K, sd = K*0.10, n = np)
r = rnorm(mean = r, sd = r*0.10, n = np)
g = rnorm(mean = g, sd = g*0.10, n = np)
threshold = rnorm(mean = threshold, sd = threshold*0.10, n = np)

X1 = cbind.data.frame(r = r, K = K, g = g, threshold = threshold)

# repeat to calculate second set of samples
np = 200

K = rnorm(mean = K, sd = K*0.10, n = np)
r = rnorm(mean = r, sd = r*0.10, n = np)
g = rnorm(mean = g, sd = g*0.10, n = np)
threshold = rnorm(mean = threshold, sd = threshold*0.10, n = np)

X2 = cbind.data.frame(r = r, K = K, g = g, threshold = threshold)
```

```
# create sobol object and get parameters
sens_forest <- sobolSalt(model = NULL, X1, X2, nboot = 300)

sens_forestSize_df <- as.data.frame(sens_forest$X)

sens_forestSize_df <- sens_forestSize_df %>%
  rename(r = "V1",
         K = "V2",
         g = "V3",
         threshold = "V4")
```

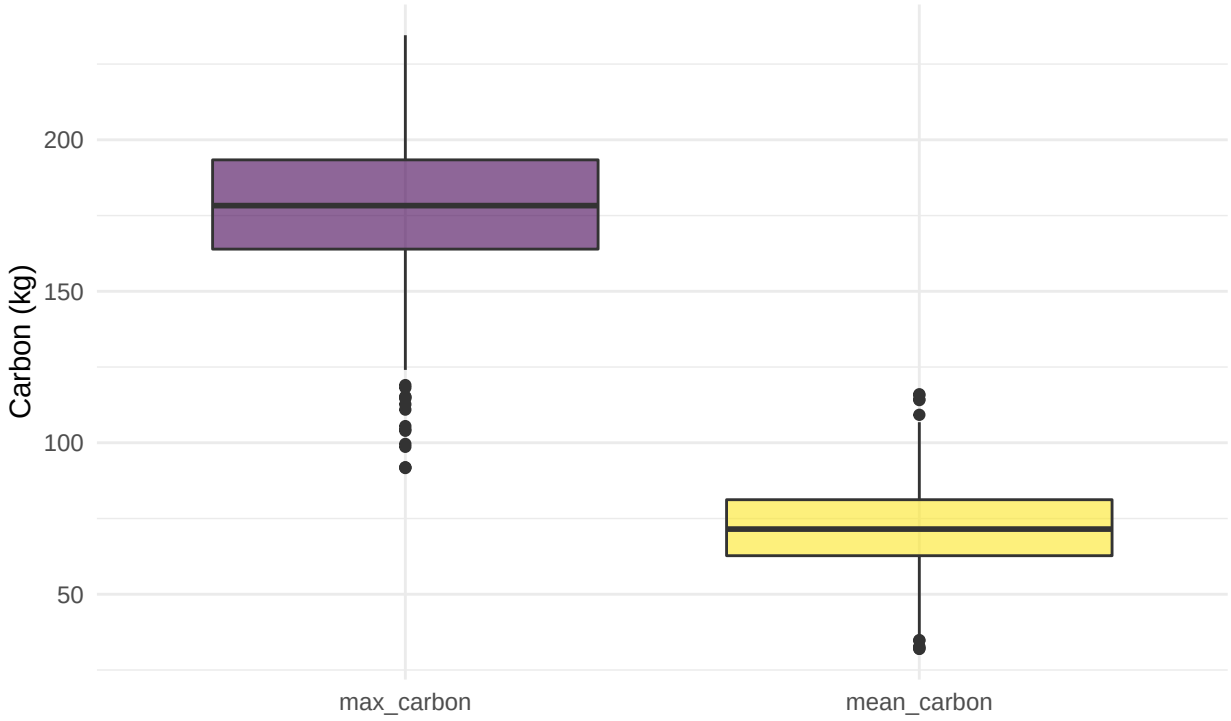
```
p_wrapper = function(threshold, r, g, K, initialsize, years, func) {

  parms <- list(threshold = threshold, r = r, g = g, K = K)

  forest_sensitivity <- ode(func = dgrowthrate, y = initialsize, times = years,
                            parms = parms)

  forest_sensitivity <- as.data.frame(forest_sensitivity)

  colnames(forest_sensitivity) = c("years","C")

  # get metrics
```

```
  max_carbon <- max(forest_sensitivity$C)
  mean_carbon <- mean(forest_sensitivity$C)

  return(list(max_carbon=max_carbon, mean_carbon=mean_carbon))
}
```

```
allresults = sens_forestSize_df %>%
  pmap(p_wrapper, initialsize = initialsize, years = years,
       func = dgrowthrate)

allres = allresults %>%
  map_dfr(`[`,c("max_carbon","mean_carbon"))

all_results <- pivot_longer(allres, cols = c(max_carbon, mean_carbon), names_to = "name", values_to = "
```

3.B. 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).

```
results_plot <- all_results %>%
  ggplot(aes(y = carbon, x = name, fill = name)) +
  geom_boxplot() +
  scale_fill_viridis(discrete = TRUE, alpha=0.6) +
  labs(x= "", y = "Carbon (kg)",
       title = "Sobol Analysis - Forest Growth",
       subtitle = "Max & mean values of Carbon over 300 years") +
  theme_minimal() +
  theme(legend.position="none")

results_plot
```




```
sense_mean <- sensitivity::tell(sens_forest, allres$mean_carbon)

sense_mean_S <- as.data.frame(sense_mean$S)

sense_mean_S <- sense_mean_S %>%
  rowid_to_column(var = "parms")

sense_mean_S[1,1] <- "threshold"
sense_mean_S[2,1] <- "r"
sense_mean_S[3,1] <- "g"
sense_mean_S[4,1] <- "K"

sense_mean_T <- as.data.frame(sense_mean$T)

sense_mean_T <- sense_mean_T %>%
  rowid_to_column(var = "parms")

sense_mean_T[1,1] <- "threshold"
sense_mean_T[2,1] <- "r"
sense_mean_T[3,1] <- "g"
sense_mean_T[4,1] <- "K"
```

```
sense_max <- sensitivity::tell(sens_forest, allres$max_carbon)

sense_max_S <- as.data.frame(sense_max$S)

sense_max_S <- sense_max_S %>%
  rowid_to_column(var = "parms")
```

```
sense_max_S[1,1] <- "threshold"
sense_max_S[2,1] <- "r"
sense_max_S[3,1] <- "g"
sense_max_S[4,1] <- "K"

sense_max_T <- as.data.frame(sense_max$T)

sense_max_T <- sense_max_T %>%
  rowid_to_column(var = "parms")

sense_max_T[1,1] <- "threshold"
sense_max_T[2,1] <- "r"
sense_max_T[3,1] <- "g"
sense_max_T[4,1] <- "K"
```

```
plotSmean <- sense_mean_S %>%
  ggplot(aes(x = original, y = parms, fill = parms)) +
  geom_col() +
  scale_fill_manual(values = c("goldenrod2", "indianred1","slateblue3", "darkolivegreen"), labels = c("
  labs(fill = "Parameter",
       x = "Sobol Sensitivity Value",
       y = "Parameter",
       title = "Mean First Order Sensitivity Index") +
  theme_minimal()

plotSmean
```

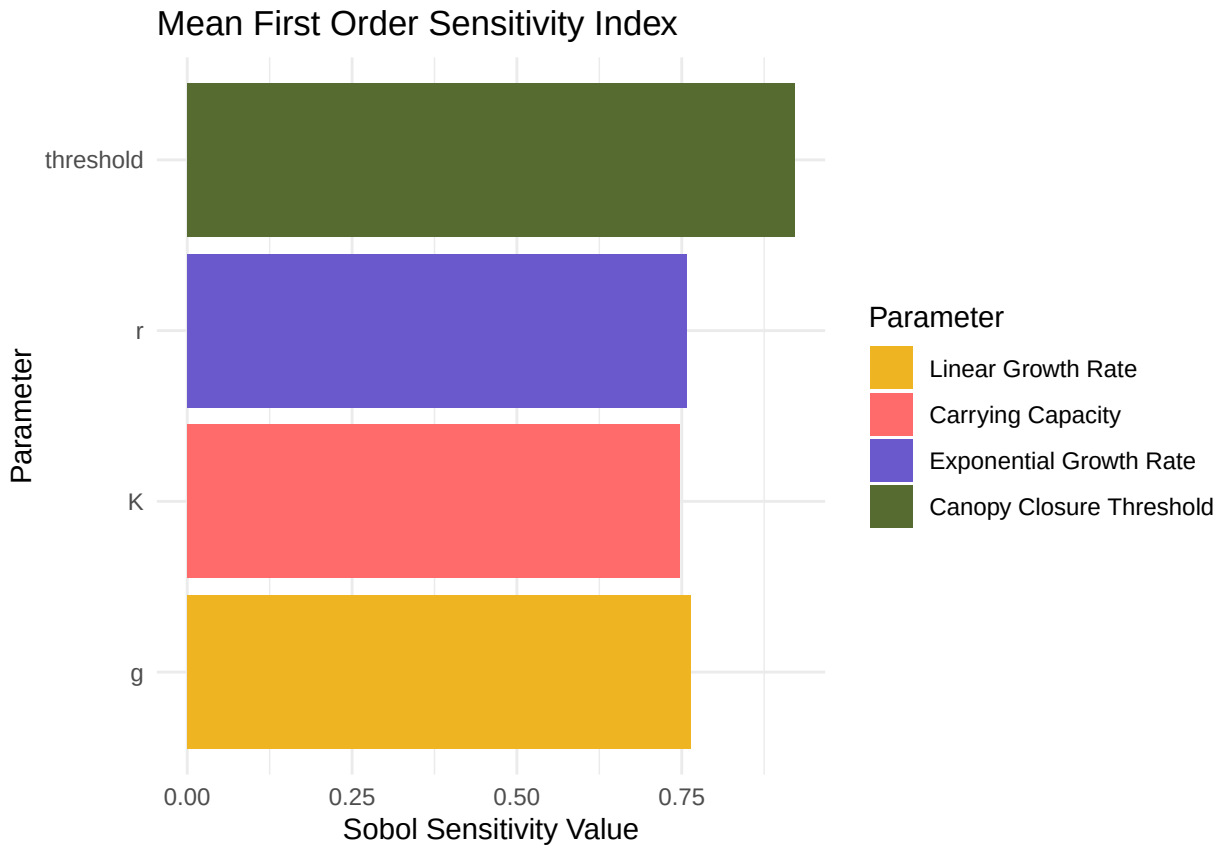


Figure 1: Mean First Order Effect Sensitivity Index of forest growth

```
plotSmax <- sense_max_S %>%
  ggplot(aes(x = original, y = parms, fill = parms)) +
  geom_col() +
  scale_fill_manual(values = c("goldenrod2", "indianred1","slateblue3", "darkolivegreen"),
                    labels = c("Linear Growth Rate", "Carrying Capacity", "Exponential Growth Rate", "Ca
  labs(fill = "Parameter",
       x = "Sobol Sensitivity Value",
       y = "Parameter",
       title = "Maximum First Order Sensitivity Index") +
  theme_minimal()

plotSmax
```

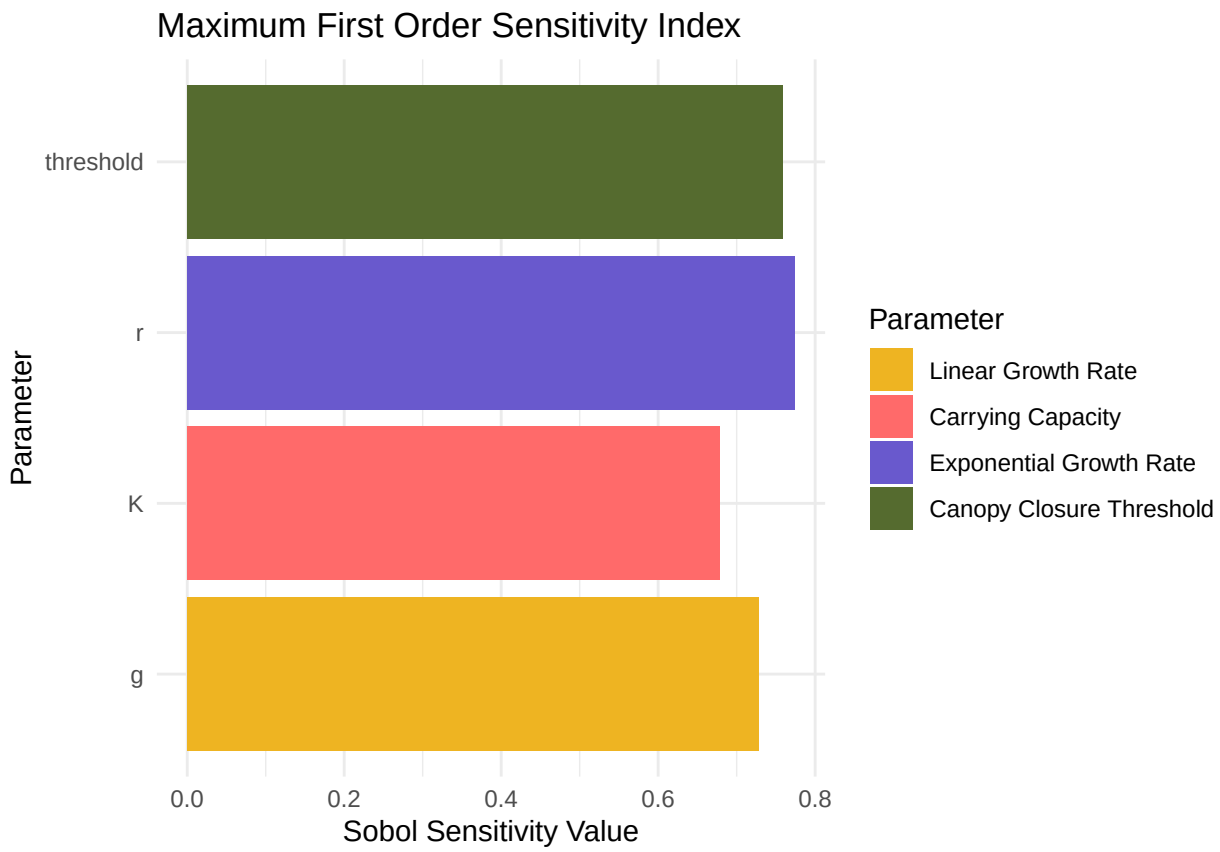


Figure 2: Maximum First Order Effect Sensitivity Index of forest growth

```
plotTmean <- sense_mean_T %>%
  ggplot(aes(x = original, y = parms, fill = parms)) +
  geom_col() +
  scale_fill_manual(values = c("goldenrod2", "indianred1","slateblue3", "darkolivegreen"), labels = c("
  labs(fill = "Parameter",
       x = "Sobol Sensitivity Value",
       y = "Parameter",
       title = "Mean Total Effect Sensitivity Index") +
  theme_minimal()

plotTmean
```

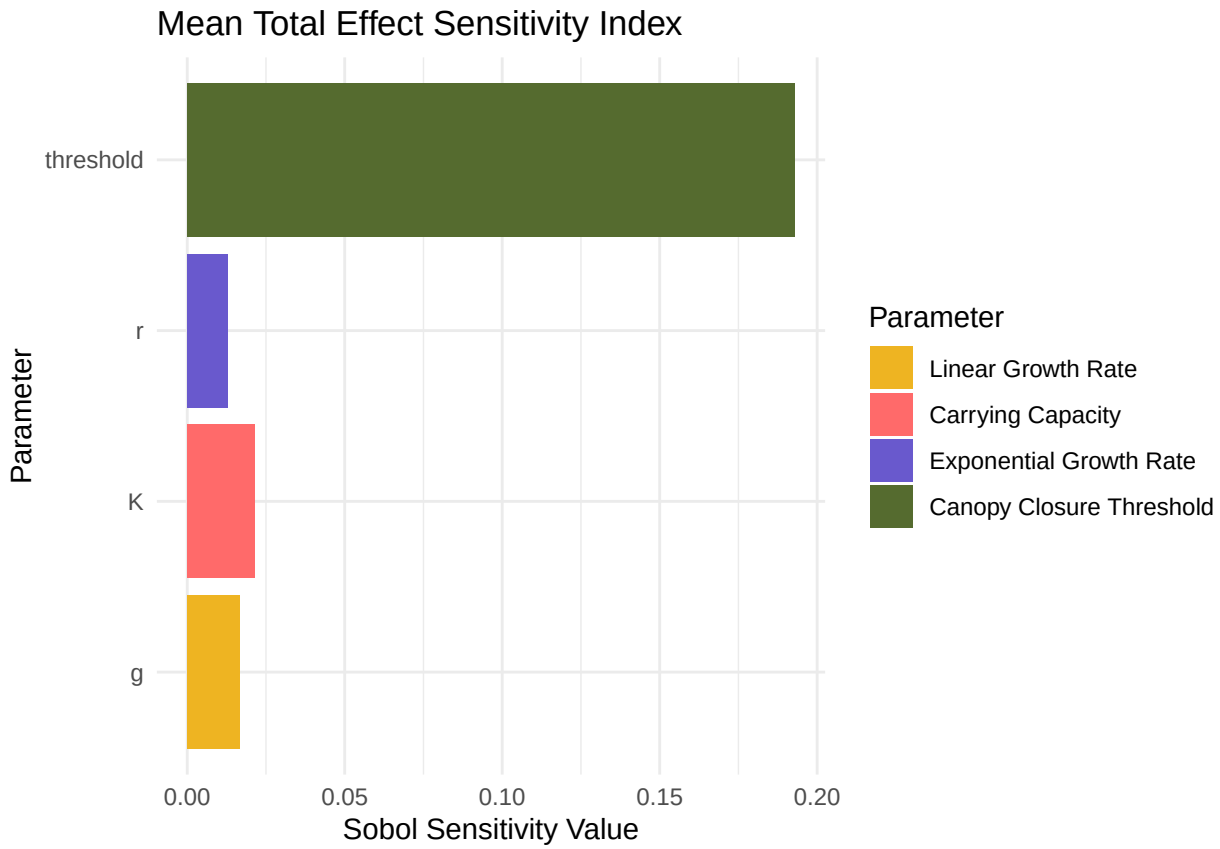


Figure 3: Mean Total Effect Sensitivity Index of forest growth

```
plotTmax <- sense_max_T %>%
  ggplot(aes(x = original, y = parms, fill = parms)) +
  geom_col() +
  scale_fill_manual(values = c("goldenrod2", "indianred1","slateblue3", "darkolivegreen"),
                    labels = c("Linear Growth Rate", "Carrying Capacity", "Exponential Growth Rate", "Ca
  labs(fill = "Parameter",
       x = "Sobol Sensitivity Value",
       y = "Parameter",
       title = "Maximum Total Effect Sensitivity Index") +
  theme_minimal()

plotTmax
```

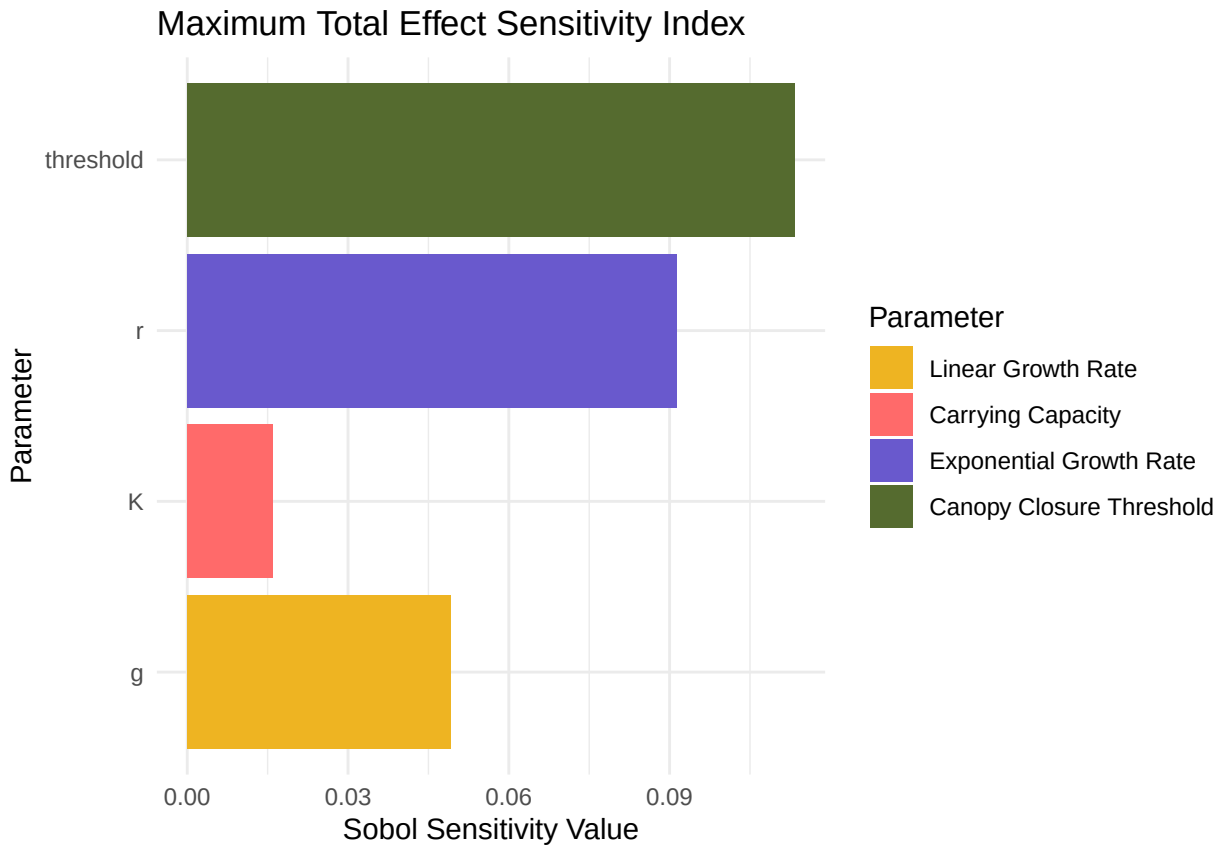


Figure 4: Maximum Total Effect Sensitivity Index of forest growth

3.C. Discuss what the results of your simulation might mean for climate change impacts on forest growth