Rabbits & Hawks

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```r
# Upload packages
library(sensitivity)
library(tidyverse)
library(ggplot2)
library(dplyr)
library(ggpubr)
library(tinytex)
```

```r
# read in function
source("evolve_pop.r")
```

Rabbit fertility and survivability over 20 years

```r
# set up fertility and survivability of rabbits
# fertility rates
f1 = 0
f2 = 1
f3 = 3
f4 = 0.5

# survivability
p1 = 0.8
p2 = 0.85
p3 = 0.65
p4 = 0.1

# set up initial population parameters
ini = c(0, 0, 10, 0)
nyears = 20
fert_rabbits = c(f1,f2,f3,f4)
surv_rabbits = c(p1, p2, p3, p4)
rabbits_pop=evolve_pop(fert_rabbits, surv_rabbits, ini, nyears)

head(rabbits_pop)
```

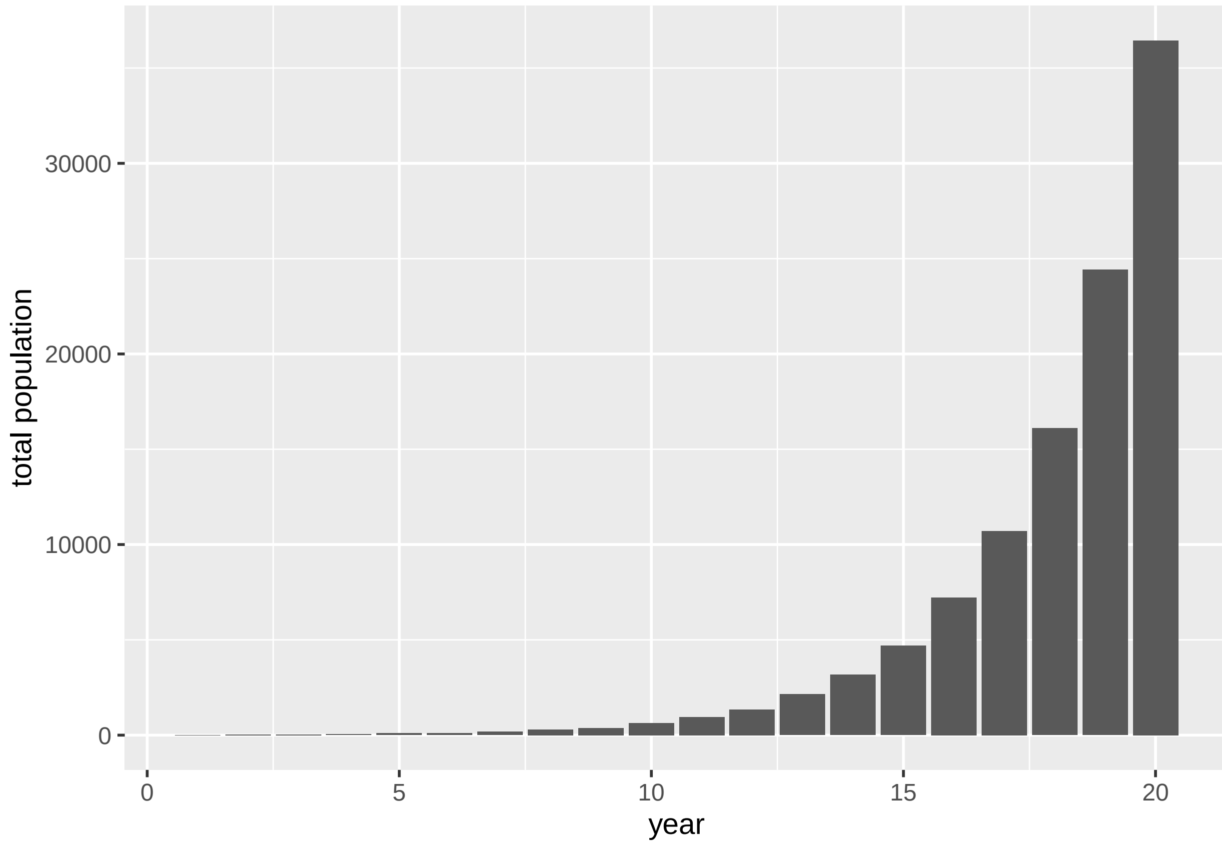
```
## $popbyage
##      [,1] [,2]  [,3]   [,4]    [,5]     [,6]      [,7]      [,8]      [,9]
## [1,]    0 30.0  3.25 24.325 63.8325 32.72325 102.07058 161.91088 163.07027
## [2,]    0  0.0 24.00  2.600 19.4600 51.06600  26.17860  81.65646 129.52871
```

```
## [3,]   10  0.0  0.00 20.400  2.2100 16.54100  43.40610  22.25181  69.40799
## [4,]    0  6.5  0.65  0.065 13.2665  2.76315  11.02797  29.31676  17.39535
##          [,10]     [,11]     [,12]     [,13]     [,14]     [,15]     [,16]
## [1,] 346.45036 484.18178 647.94868 1133.9552 1586.6404 2344.0387 3737.2835
## [2,] 130.45622 277.16028 387.34543  518.3589  907.1641 1269.3123 1875.2310
## [3,] 110.09940 110.88778 235.58624  329.2436  440.6051  771.0895 1078.9155
## [4,]  46.85473  76.25008  79.70207  161.1013  230.1185  309.4052  532.1487
##          [,17]    [,18]     [,19]     [,20]
## [1,] 5378.0517 8148.921 12482.258 18371.878
## [2,] 2989.8268 4302.441  6519.137  9985.806
## [3,] 1593.9463 2541.353  3657.075  5541.266
## [4,]  754.5099 1111.516  1763.031  2553.402
##
## $poptot
##  [1]    10.0000    36.5000    27.9000    47.3900    98.7690   103.0934
##  [7]   182.6832   295.1359   379.4023   633.8607   948.4799  1350.5824
## [13]  2142.6590  3164.5281  4693.8457  7223.5786 10716.3348 16104.2309
## [19] 24421.5004 36452.3518
```

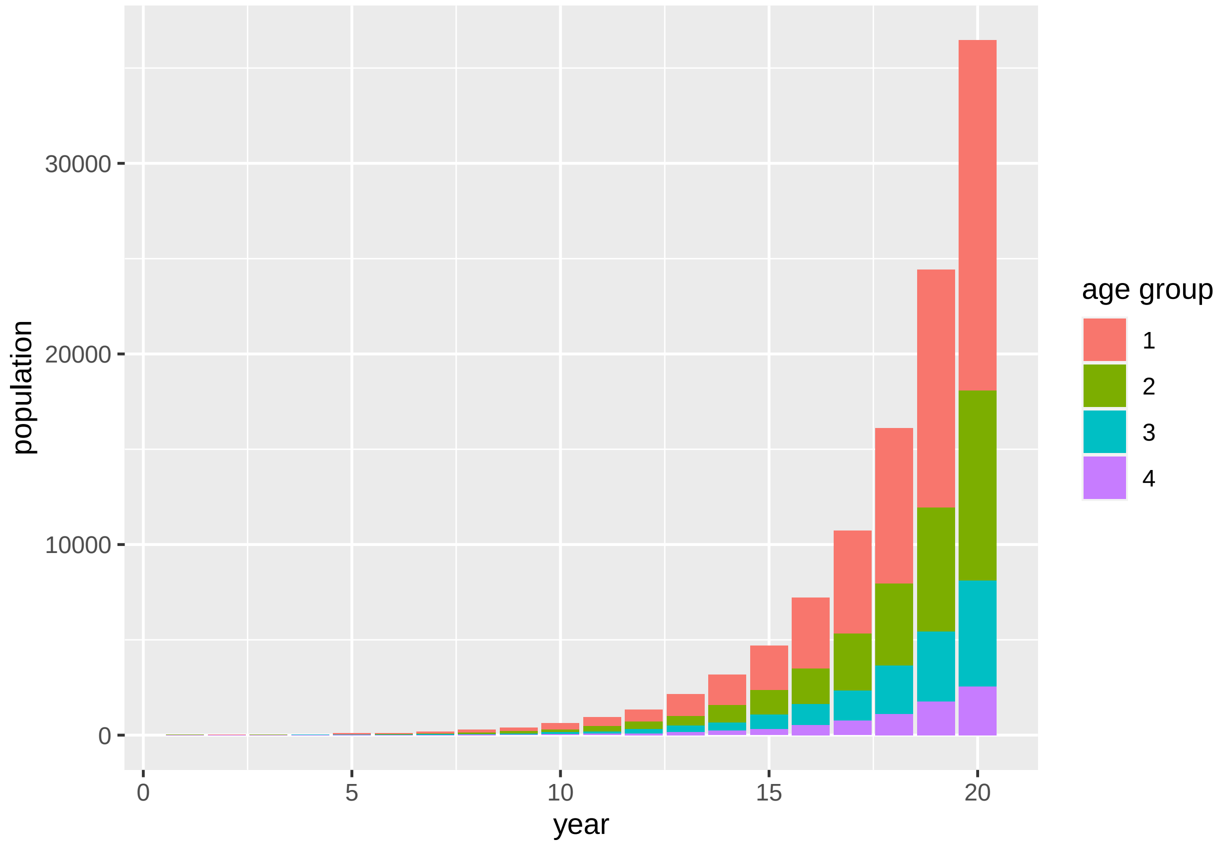
```
# q1: what is the total rabbit population after 20 years?
tot_pop_20 <- round(rabbits_pop$poptot[20],0)
tot_pop_20
```

```
## [1] 36452
```

```
## ---------------------------------------------------------------------------
# plots to visualize rabbit population
# add year
year = seq(from=1, to=nyears)
rabbits_tot = cbind.data.frame(year=year, poptot=rabbits_pop$poptot)
ggplot(rabbits_tot, aes(year, poptot))+geom_col()+labs(y="total population")
```




```
# plot information about ages
rabbits_ages = cbind.data.frame(year=year, t(rabbits_pop$popbyage))
rabbits_agesl = rabbits_ages %>% gather(key="agecat", value="pop",-year)
ggplot(rabbits_agesl, aes(year, pop, fill=agecat))+geom_col()+labs(y="population", fill="age group")
```




```
# q2: how many young rabbits (first age class) are there in the population at that time?
young_20 <- rabbits_agesl %>%
  filter(agecat == "1",
         year == "20")

young_20_pop <- round(young_20$pop[1],0)
young_20_pop
```

```
## [1] 18372
```

Sensitivity analysis

```
nsample = 200
# set up fertility and survivability of rabbits
# fertility rates
parm_sample_1 <- cbind.data.frame(
  # fertility
  f1 = 0,
  f2 = 1,
  f3 = 3,
  f4 = 0.5,
  # survivability
  p1 = runif(min=0.65,max=0.75,n=nsample),
```

```r
  p2 = runif(min=0.75,max=0.85,n=nsample),
  p3 = 0.65,
  p4 = 0.1
)

parm_sample_2 <- cbind.data.frame(
  # fertility
  f1 = 0,
  f2 = 1,
  f3 = 3,
  f4 = 0.5,
  # survivability
  p1 = runif(min=0.65,max=0.75,n=nsample),
  p2 = runif(min=0.75,max=0.85,n=nsample),
  p3 = 0.65,
  p4 = 0.1
)

sensitivity_data <- soboljansen(model=NULL,parm_sample_1,parm_sample_2,nboot=100)

head(sensitivity_data$X)
```

```
##   f1 f2 f3  f4        p1        p2   p3  p4
## 1  0  1  3 0.5 0.6859496 0.8093427 0.65 0.1
## 2  0  1  3 0.5 0.7281339 0.8039303 0.65 0.1
## 3  0  1  3 0.5 0.7118573 0.8255973 0.65 0.1
## 4  0  1  3 0.5 0.6942154 0.7839440 0.65 0.1
## 5  0  1  3 0.5 0.7392514 0.7612459 0.65 0.1
## 6  0  1  3 0.5 0.6714141 0.8068402 0.65 0.1
```

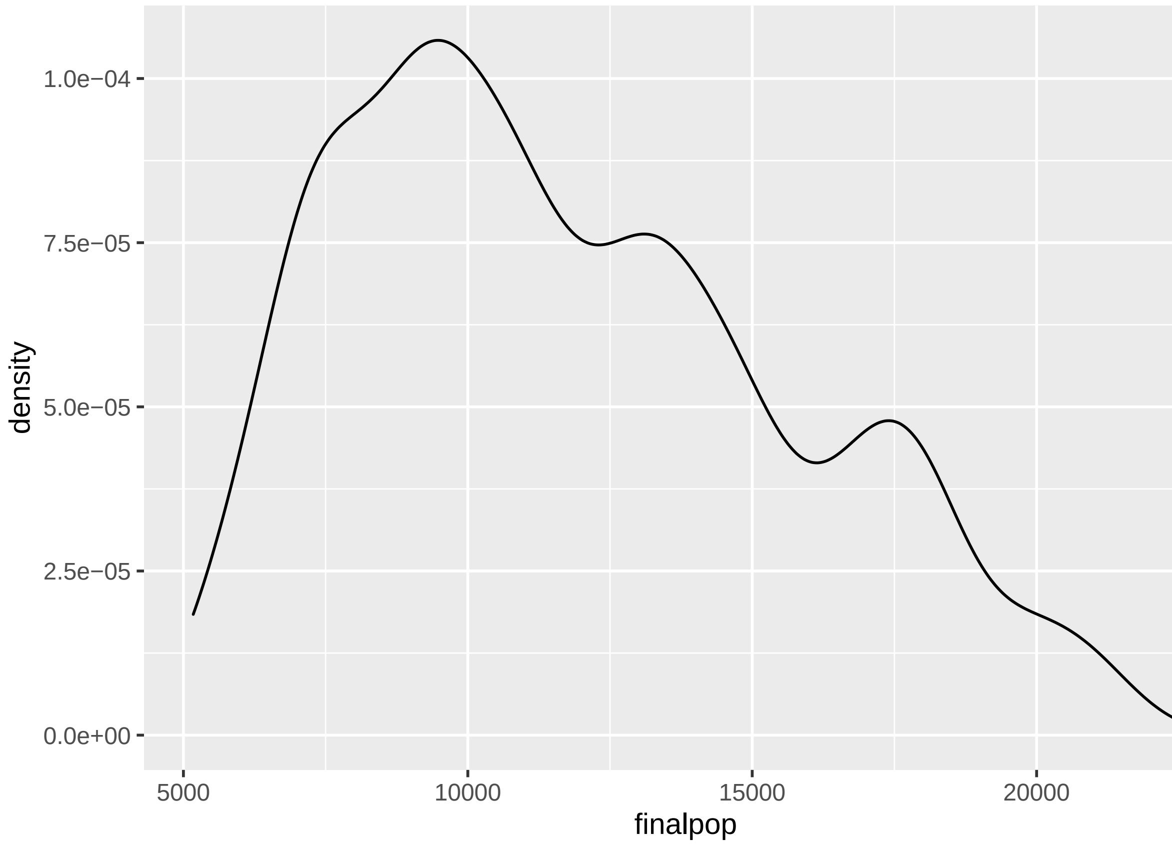
```r
nrow(sensitivity_data$X)
```

```
## [1] 2000
```

```r
p_wrapper_tot = function(p1, p2, p3, p4, f1, f2, f3, f4, use_func, initialpop, nstep) {
  fertility=c(f1,f2,f3,f4)
  survivability= c(p1, p2, p3, p4)
  res = use_func(survivability =survivability, fertility = fertility, initialpop=initialpop, nstep=nstep
  # return the final population total
  return(finalpop=res$poptot[nstep])
}
```

```r
nyears=20
# use pmap here so we can specify rows of our sensitivity analysis parameter object
res_tot = as.data.frame(sensitivity_data$X) %>% pmap_dbl(p_wrapper_tot, initialpop=ini, nstep=nyears, us
```

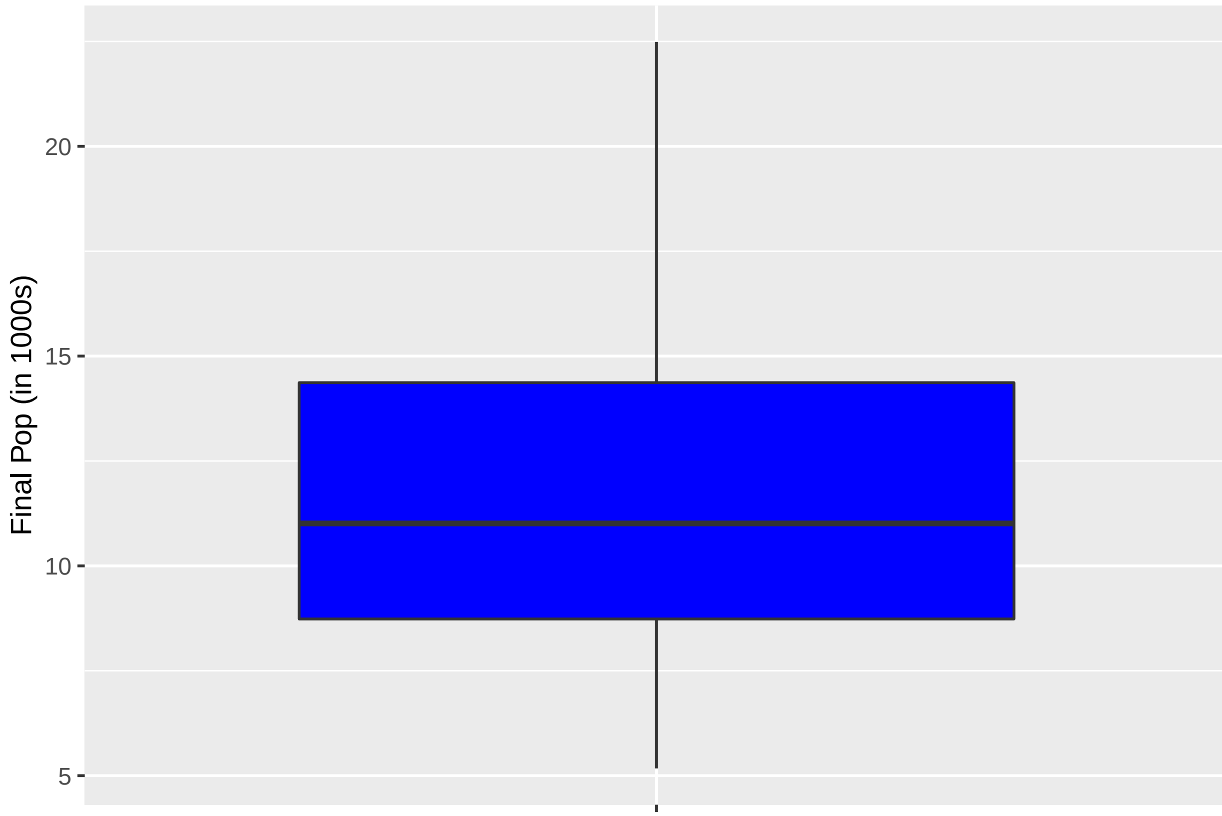
```r
# plot results (variation in population at year 20 across survivability of young age and young adult ra
# ggplot needs a dataframe - so do a quick conversion with data.frame
ggplot(data.frame(finalpop=res_tot), aes(x=finalpop))+geom_density()
```



Sensitivity results

```
# most of the values result in populations less than 15,000 rabbits

# boxplot of the same data
ggplot(data.frame(finalpop=res_tot), aes(x="", y=finalpop/1000) )+geom_boxplot(fill="blue")+
  theme(axis.title.x = element_blank())+labs(y="Final Pop (in 1000s)")
```




```
# give our results to sensitivity structure

sens_rabbits=tell(sensitivity_data, res_tot)

# look at results
sens_rabbits$S
```

```
##     original          bias std. error   min. c.i. max. c.i.
## f1 0.1250677 -0.0068988986 0.07968589 -0.03182398 0.2842132
## f2 0.1250677 -0.0068988986 0.07968589 -0.03182398 0.2842132
## f3 0.1250677 -0.0068988986 0.07968589 -0.03182398 0.2842132
## f4 0.1250677 -0.0068988986 0.07968589 -0.03182398 0.2842132
## p1 0.8077642 -0.0032672826 0.02369574  0.77046330 0.8654826
## p2 0.3390179 -0.0007918041 0.06519748  0.18863138 0.4512260
## p3 0.1250677 -0.0068988986 0.07968589 -0.03182398 0.2842132
## p4 0.1250677 -0.0068988986 0.07968589 -0.03182398 0.2842132
```

```
sens_rabbits$T
```

```
##     original        bias std. error min. c.i. max. c.i.
## f1 0.0000000 0.000000000 0.00000000 0.0000000 0.0000000
## f2 0.0000000 0.000000000 0.00000000 0.0000000 0.0000000
## f3 0.0000000 0.000000000 0.00000000 0.0000000 0.0000000
## f4 0.0000000 0.000000000 0.00000000 0.0000000 0.0000000
## p1 0.6922761 0.003535826 0.06194911 0.5776354 0.8300418
```

```
## p2 0.2019336 0.001899896 0.02307125 0.1482131 0.2408769
## p3 0.0000000 0.000000000 0.00000000 0.0000000 0.0000000
## p4 0.0000000 0.000000000 0.00000000 0.0000000 0.0000000
```

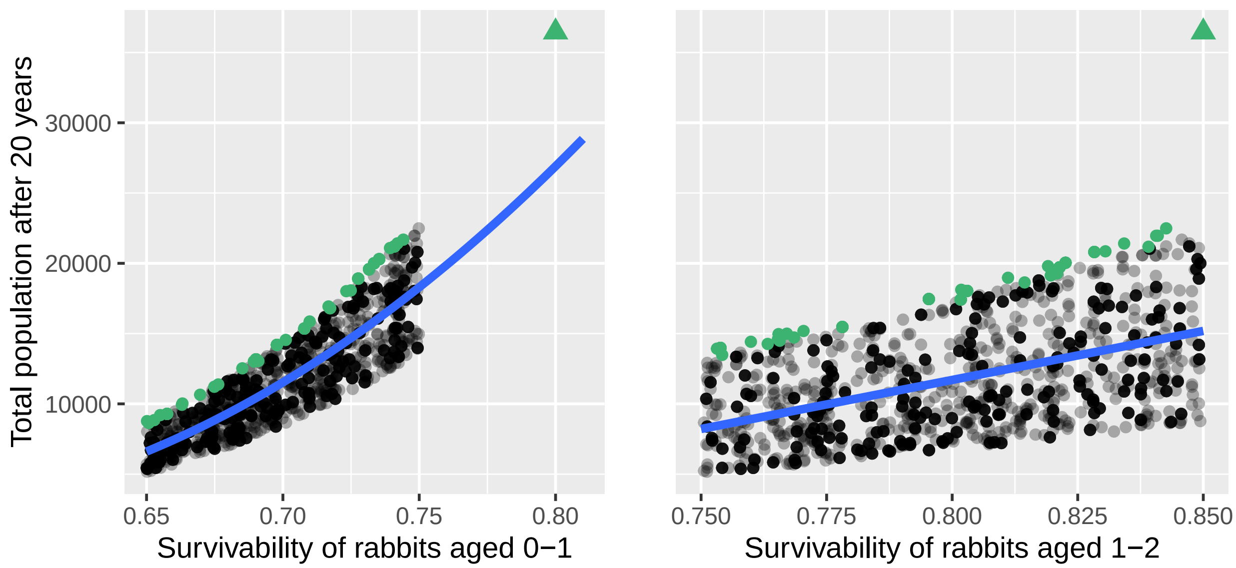
graph the most sensitive parameter (survivability of young rabbits S-value: 0.8077642, T-value of: 0.6922761)

```
orig_8 <- data.frame(x=0.8,y=tot_pop_20)
orig_85 <- data.frame(x=0.85,y=tot_pop_20)


tmp = cbind.data.frame(sens_rabbits$X, poptot=sens_rabbits$y)
p1_plot <- ggplot()+
  geom_point(data=filter(tmp, p2< .845), aes(p1, poptot), color= "black", alpha=.3)+
  geom_point(data=filter(tmp, p2> .845), aes(p1, poptot), color= "mediumseagreen", alpha=1)+
  geom_smooth(data=tmp,method="lm",formula=y~poly(x,2),aes(p1, poptot), se=FALSE, size=1.5, alpha=.7, fu
  labs(x="Survivability of rabbits aged 0-1",y="Total population after 20 years")+
  scale_x_continuous(limits=c(.65,.81))+
  geom_point(data=orig_8, aes(x=x,y=y), color= 'mediumseagreen', fill= 'mediumseagreen', size=3, shape=

p2_plot <- ggplot()+
  geom_point(data=filter(tmp, p1< .745), aes(p2, poptot), color= "black", alpha=.3)+
  geom_point(data=filter(tmp, p1> .745), aes(p2, poptot), color= "mediumseagreen", alpha=1)+
  stat_smooth(data=tmp,method="lm",formula=y~poly(x,1), aes(p2, poptot), se=FALSE, size=1.5, alpha=.7, f
  labs(x="Survivability of rabbits aged 1-2",y="")+
  scale_x_continuous(limits=c(.75,.85))+
  geom_point(data=orig_85, aes(x=x,y=y), color= 'mediumseagreen', fill= 'mediumseagreen', size=3, shape=
  theme(axis.text.y = element_blank(),
        axis.ticks.y = element_blank())

ggpubr::ggarrange(p1_plot,p2_plot,ncol = 2) %>%
  annotate_figure(bottom = text_grob(str_wrap("The dots depict the predicted total population of rabbits
```



The dots depict the predicted total population of rabbits at the end of 20 years when the survivability of ages 0−1 ranges between 0.65 and 0.75, and the survivability for ages 1−2 is between 0.75 and 0.85 so as to simulate the presence of hawk predation. The central tendancy and trend of the data is indicated by the blue line − a second order polynomial for young rabbit survivability and a first order polynomial for the sub adult survivability. The predicted rabbit population without hawks (survivability 0−1 = 0.8, 1−2 = 0.85) is also shown with a triangle. For comparison, all results with the survivability for ages 1−2 roughly equal to 0.85 are colored in seagreen, since this corresponds to the age 1−2 survivability of the no−hawk scenario. Compared to the no−hawk scenario, rabbit populations will be noteably smaller with hawks. In fact, the maximum population size possible with hawk predation is 21,997, which is roughly 40% smaller than without hawks.