

# Modèle de gestion adaptative du loup

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12/01/2024

## Introduction

Nous allons ici reprendre différents modèles d'estimation de population afin de l'appliquer à la population de loups en France. Nous allons également y ajouter un cadre prédictif dans une optique de gestion adaptative sur un intervalle de temps de 2 ans. Les modèles utilisés d'estimation utilisés dans ce code proviennent des articles de Andrén et al. et de Koons et al.

## Préparation

```
library(R2jags)
```

```
## Loading required package: rjags

## Loading required package: coda

## Linked to JAGS 4.3.0

## Loaded modules: basemod,bugs

##
## Attaching package: 'R2jags'

## The following object is masked from 'package:coda':
##
##   traceplot
```

```
library(tidyverse)
```

```
## -- Attaching core tidyverse packages ----- tidyverse 2.0.0 --
## v dplyr      1.1.4      v readr      2.1.4
## v forcats    1.0.0      v stringr    1.5.1
## v ggplot2     3.4.4      v tibble     3.2.1
## v lubridate  1.9.3      v tidyr      1.3.0
## v purrr       1.0.2

## -- Conflicts ----- tidyverse_conflicts() --
## x dplyr::filter() masks stats::filter()
## x dplyr::lag()     masks stats::lag()
## i Use the conflicted package (<http://conflicted.r-lib.org/>) to force all conflicts to become errors
```

## Les données

Le nombre de prélèvements :

```
harvest <- c(0,0,0,0,0,1,0,0,2,1,2,0,0,1,0,4,4,6,18,36,34,42,51,98,105,103,169)
```

Les estimations d'effectifs par CMR :

```
CMR <- c(17.1,35.4,47.7,25.1,62.6,47.9,81.7,110.5,102.7,135.9,132.6,101.7,130.3,141.4,141.5,175.5,210.3,174.5,353.6,280.2,376.7,561.2,571.9,682.4,645.7,783.8,868)
```

Erreur d'observation :

```
ObsSE=rep(0.3,27)
```

On met ensemble les effectifs estimés par CMR ainsi que les nombres de loups tués.

```
dat <- cbind(round(CMR), ObsSE, harvest)
colnames(dat) <- c("N", "se", "H")
dat <- as.data.frame(dat)
nyears <- nrow(dat)
```

## Les modèles

### Modèle exponentiel

$$\begin{aligned}N_t &= \lambda(N_{t-1} - H_{t-1}). \\ \log(N_t) &\sim \text{Normale}(\mu_t, \sigma_{\text{proc}}) \\ \mu_t &= \log(N_t) = \log(\lambda(N_{t-1} - H_{t-1})) \\ y_t &\sim \text{Poisson}(N_t).\end{aligned}$$

```
modelexp = function(){

  # Priors
  sigmaProc ~ dunif(0,10)
  tauProc = 1/sigmaProc^2
  lambda ~ dunif(0,5)

  N[1] ~ dgamma(1.0E-6, 1.0E-6)

  # Process model
  for (t in 2:(nyears)){
    mu[t] = lambda * (N[t-1])
    NProc[t] = log(max(1, mu[t]))
    N[t] ~ dlnorm(NProc[t], tauProc)
  }

  # Observation model
  for (t in 1:nyears){
```

```

    y[t] ~ dpois(N[t])
  }
}

```

Initialisation des données

```

bugs.data = list(
  nyears = nrow(dat),
  y = dat$N)

```

Paramètres JAGS

```

bugs.monitor = c("lambda", "sigmaProc", "N", "tauProc")
bugs.chains = 3
bugs.inits = function(){
  list(
  )
}

```

Lancement du modèle

```

library(R2jags)
wolf_modelexp = jags(data = bugs.data,
  inits = bugs.inits,
  parameters.to.save = bugs.monitor,
  model.file = modelexp,
  n.chains = bugs.chains,
  n.thin=10,
  n.iter=100000,
  n.burnin=50000)

```

```
## module glm loaded
```

```

## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 27
##   Unobserved stochastic nodes: 29
##   Total graph size: 143
##
## Initializing model

```

```
print(wolf_modelexp, intervals = c(2.5/100, 50/100, 97.5/100))
```

```

## Inference for Bugs model at "/tmp/RtmpJsJuFc/model586e2cd7f62f.txt", fit using jags,
## 3 chains, each with 1e+05 iterations (first 50000 discarded), n.thin = 10
## n.sims = 15000 iterations saved
##      mu.vect sd.vect   2.5%    50%   97.5%  Rhat n.eff
## N[1]    21.747   3.803  14.923  21.530  29.795 1.001  6300
## N[2]    32.145   4.322  24.464  31.902  41.199 1.001 15000

```

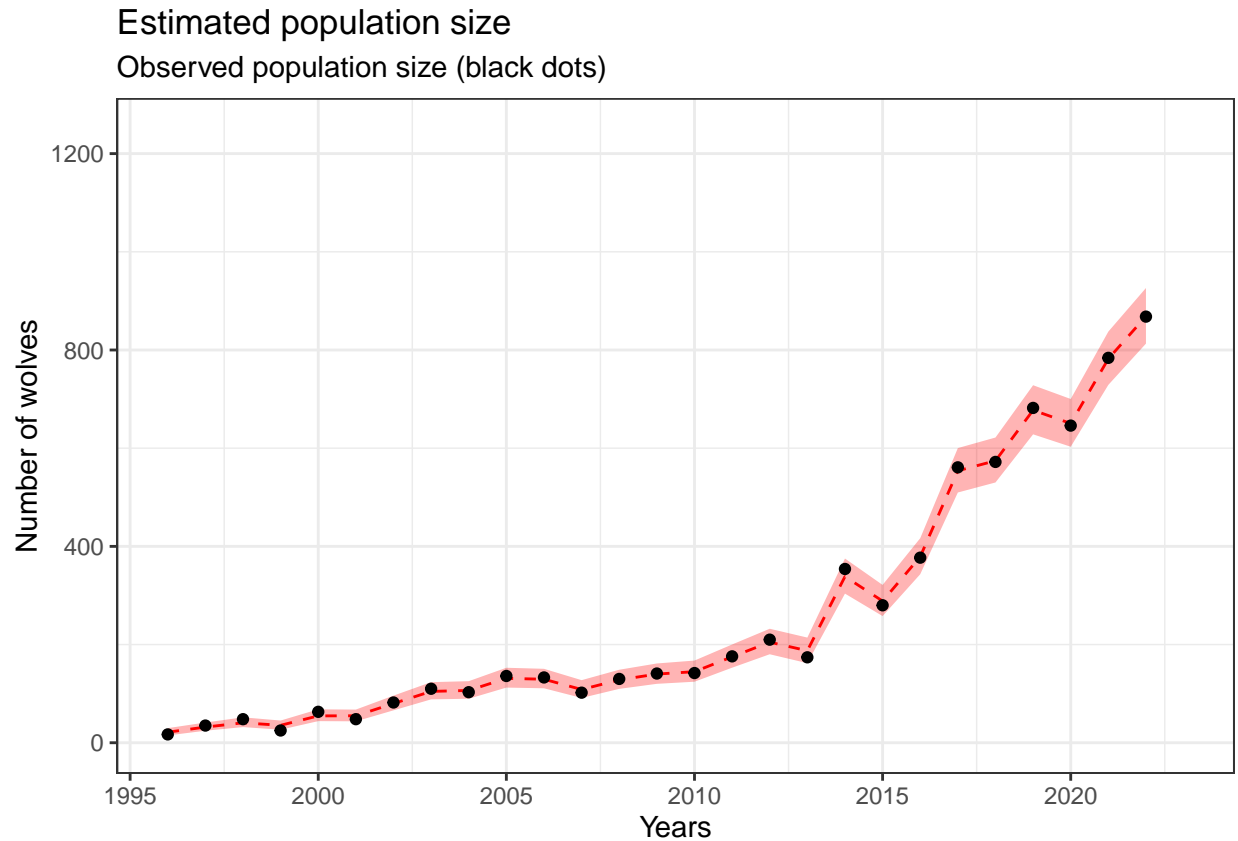
```
## N[3]      40.944   5.116  31.915  40.592  51.771  1.001  5000
## N[4]      35.660   4.785  26.599  35.524  45.278  1.001  13000
## N[5]      55.044   6.113  43.990  54.694  68.096  1.001  15000
## N[6]      55.122   6.142  43.620  54.928  67.587  1.001  14000
## N[7]      80.138   7.511  65.986  79.908  95.999  1.001  5700
## N[8]     104.943   8.975  88.333 104.584 123.418  1.001  15000
## N[9]     106.735   9.010  89.632 106.522 125.462  1.001  15000
## N[10]    131.555  10.296 112.368 131.159 152.781  1.001  15000
## N[11]    129.753  10.128 110.922 129.388 150.651  1.001  15000
## N[12]    108.700   9.198  91.286 108.428 127.476  1.001  15000
## N[13]    128.460  10.014 109.733 128.072 148.761  1.001  15000
## N[14]    140.114  10.611 120.017 139.864 161.509  1.001   6900
## N[15]    145.022  10.885 124.304 144.762 167.432  1.001  15000
## N[16]    175.386  12.072 152.864 175.029 200.169  1.001   5900
## N[17]    205.164  13.308 180.251 204.827 232.221  1.001  15000
## N[18]    187.655  13.221 162.122 187.452 214.240  1.001   7600
## N[19]    338.823  18.321 303.783 338.528 375.243  1.001  14000
## N[20]    288.890  16.084 258.007 288.626 321.511  1.001  13000
## N[21]    379.213  18.640 343.243 378.998 416.636  1.001  15000
## N[22]    554.144  23.140 509.726 554.028 600.240  1.001   6800
## N[23]    574.688  23.354 530.139 574.420 621.740  1.001  15000
## N[24]    677.794  25.614 628.231 677.405 728.281  1.001   4500
## N[25]    650.559  24.988 602.956 650.310 700.203  1.001   7200
## N[26]    782.548  27.460 728.966 782.198 837.552  1.001  15000
## N[27]    868.766  29.149 812.981 868.635 926.279  1.001  15000
## lambda      1.157   0.055   1.053   1.155   1.272  1.001   5100
## sigmaProc    0.235   0.053   0.151   0.229   0.354  1.001  15000
## tauProc     20.875   9.461   8.001  19.075  43.934  1.001  15000
## deviance    219.815   8.479 205.077 219.164 238.244  1.001   5100
##
## For each parameter, n.eff is a crude measure of effective sample size,
## and Rhat is the potential scale reduction factor (at convergence, Rhat=1).
##
## DIC info (using the rule, pD = var(deviance)/2)
## pD = 35.9 and DIC = 255.8
## DIC is an estimate of expected predictive error (lower deviance is better).
```

```
wolf_modelexp$BUGSoutput$sims.matrix %>%
  as_tibble() %>%
  pivot_longer(cols = everything(), values_to = "value", names_to = "parameter") %>%
  filter(str_detect(parameter, "N")) %>%
  group_by(parameter) %>%
  summarize(medianN = median(value),
            lq = quantile(value, probs = 2.5/100),
            hq = quantile(value, probs = 97.5/100)) %>%
  mutate(years = parse_number(parameter) + 1995) %>%
  arrange(years) %>%
  ggplot()+
  geom_line(aes(x = years, y = medianN), colour = "red", lty = "dashed")+
  geom_ribbon(aes(x = years, ymin = lq, ymax = hq), fill = "red", alpha = 0.3)+
  geom_point(data = bugs.data %>% as_tibble, aes(x = 1995 + 1:unique(nyears), y = y)) +
  coord_cartesian(xlim=c(1996,2023),ylim=c(0,1250))+
  theme_bw()+
  labs(title = "Estimated population size",
```

```

subtitle = "Observed population size (black dots)",
x = "Years",
y = "Number of wolves")

```



## Prédiction

Prédiction sur 2 ans en faisant varier le taux de prélèvement.

```

modelexp = function(){

  # Priors
  sigmaProc ~ dunif (0,10)
  tauProc = 1/sigmaProc^2
  lambda ~ dunif(0,5)

  N[1] ~ dgamma(1.0E-6, 1.0E-6)

  # Process model
  for (t in 2:(nyears)){
    mu[t] = lambda * (N[t-1] - H[t-1])
    NProc[t] = log(max(1, mu[t]))
    N[t] ~ dlnorm(NProc[t], tauProc)
  }
}

```

```

# Observation model
for (t in 1:nyears){
  y[t] ~ dpois(N[t])
}

# Projected model
for (t in (nyears+1):(nyears+2)){
  mu[t] = (lambda - dH) * N[t-1]
  NProc[t] = log(max(1, mu[t]))
  N[t] ~ dlnorm(NProc[t], tauProc)
}
}

```

Initialisation des différents taux de prélèvement :

```
dH = c(0, 0.10, 0.20, 0.30)
```

On lance la machine pour chaque taux et on affiche la courbe d'effectifs :

```

## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 27
##   Unobserved stochastic nodes: 31
##   Total graph size: 206
##
## Initializing model

```

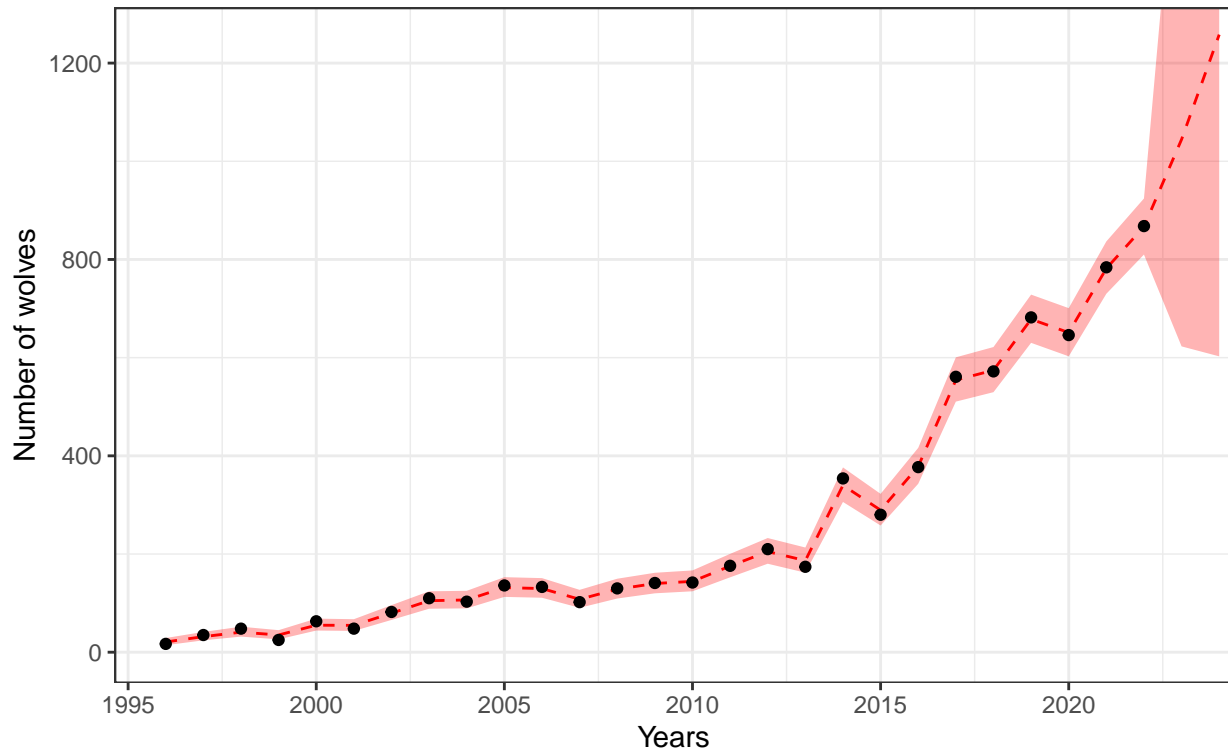
```

wolf_modelexp$BUGSoutput$sims.matrix %>%
  as_tibble() %>%
  pivot_longer(cols = everything(), values_to = "value", names_to = "parameter") %>%
  filter(str_detect(parameter, "N")) %>%
  group_by(parameter) %>%
  summarize(medianN = median(value),
            lq = quantile(value, probs = 2.5/100),
            hq = quantile(value, probs = 97.5/100))%>%
  mutate(years = parse_number(parameter) + 1995)%>%
  arrange(years)%>%
  ggplot()+
  geom_line(aes(x = years, y = medianN), colour = "red", lty = "dashed")+
  geom_ribbon(aes(x = years, ymin = lq, ymax = hq), fill = "red", alpha = 0.3)+
  geom_point(data = bugs.data %>% as_tibble, aes(x = 1995 + 1:unique(nyears), y = y)) +
  coord_cartesian(xlim=c(1996,2023),ylim=c(0,1250))+
  theme_bw()+
  labs(title = "Estimated and projected population size",
       subtitle = "Harvest rate : 0%",
       x = "Years",
       y = "Number of wolves")

```

## Estimated and projected population size

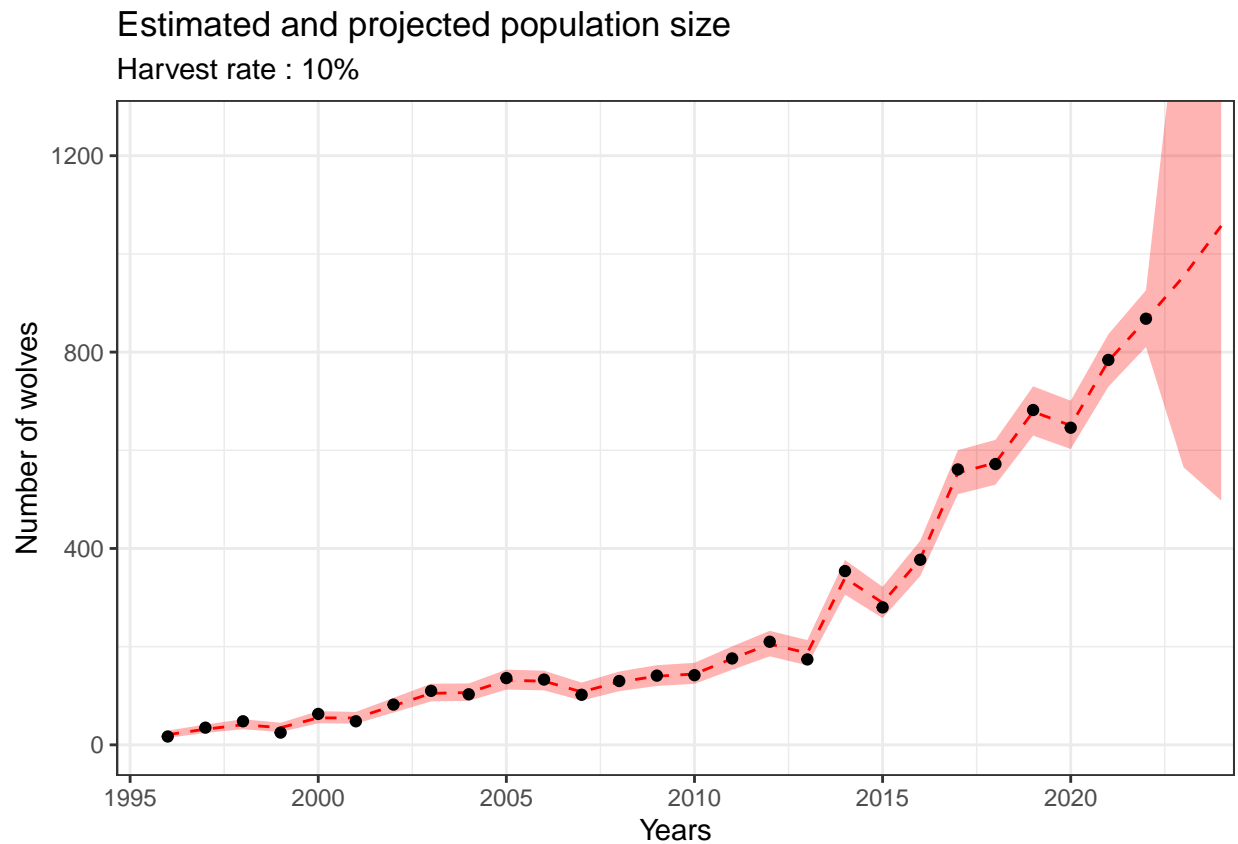
Harvest rate : 0%



```
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 27
##   Unobserved stochastic nodes: 31
##   Total graph size: 206
##
## Initializing model
```

```
wolf_modelexp$BUGSoutput$sims.matrix %>%
  as_tibble() %>%
  pivot_longer(cols = everything(), values_to = "value", names_to = "parameter") %>%
  filter(str_detect(parameter, "N")) %>%
  group_by(parameter) %>%
  summarize(medianN = median(value),
            lq = quantile(value, probs = 2.5/100),
            hq = quantile(value, probs = 97.5/100)) %>%
  mutate(years = parse_number(parameter) + 1995) %>%
  arrange(years) %>%
  ggplot() +
  geom_line(aes(x = years, y = medianN), colour = "red", lty = "dashed") +
  geom_ribbon(aes(x = years, ymin = lq, ymax = hq), fill = "red", alpha = 0.3) +
  geom_point(data = bugs.data %>% as_tibble, aes(x = 1995 + 1:unique(nyears), y = y)) +
  coord_cartesian(xlim=c(1996,2023),ylim=c(0,1250)) +
```

```
theme_bw()+
labs(title = "Estimated and projected population size",
      subtitle = "Harvest rate : 10%",
      x = "Years",
      y = "Number of wolves")
```



```
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 27
##   Unobserved stochastic nodes: 31
##   Total graph size: 206
##
## Initializing model
```

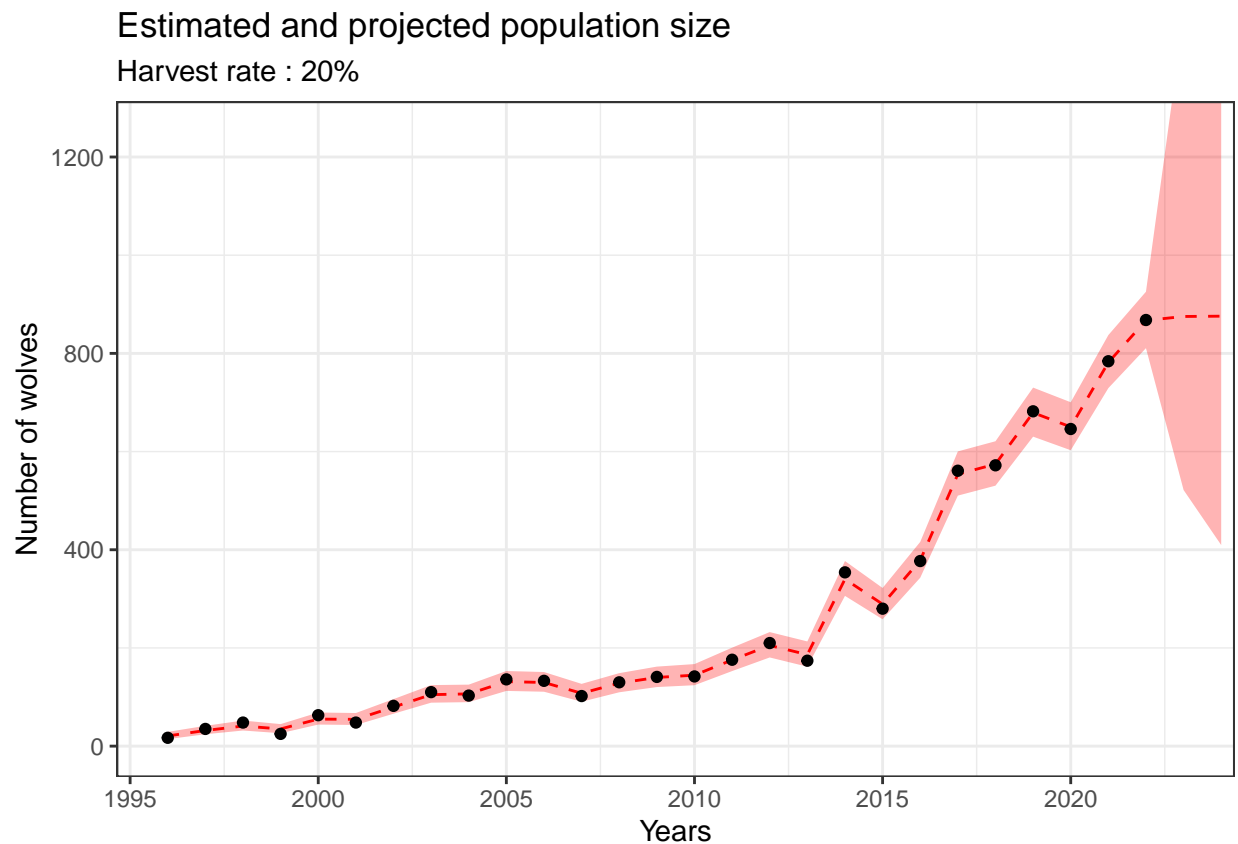
```
wolf_model$exp$BUGSoutput$sims.matrix %>%
  as_tibble() %>%
  pivot_longer(cols = everything(), values_to = "value", names_to = "parameter") %>%
  filter(str_detect(parameter, "N")) %>%
  group_by(parameter) %>%
  summarize(medianN = median(value),
            lq = quantile(value, probs = 2.5/100),
            hq = quantile(value, probs = 97.5/100)) %>%
  mutate(years = parse_number(parameter) + 1995) %>%
```



```

arrange(years)%>%
ggplot()+
geom_line(aes(x = years, y = medianN), colour = "red", lty = "dashed")+
geom_ribbon(aes(x = years, ymin = lq, ymax = hq), fill = "red", alpha = 0.3)+
geom_point(data = bugs.data %>% as_tibble, aes(x = 1995 + 1:unique(nyears), y = y)) +
coord_cartesian(xlim=c(1996,2023),ylim=c(0,1250))+
theme_bw()+
labs(title = "Estimated and projected population size",
      subtitle = "Harvest rate : 20%",
      x = "Years",
      y = "Number of wolves")

```



```

## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 27
##   Unobserved stochastic nodes: 31
##   Total graph size: 206
##
## Initializing model

```

```

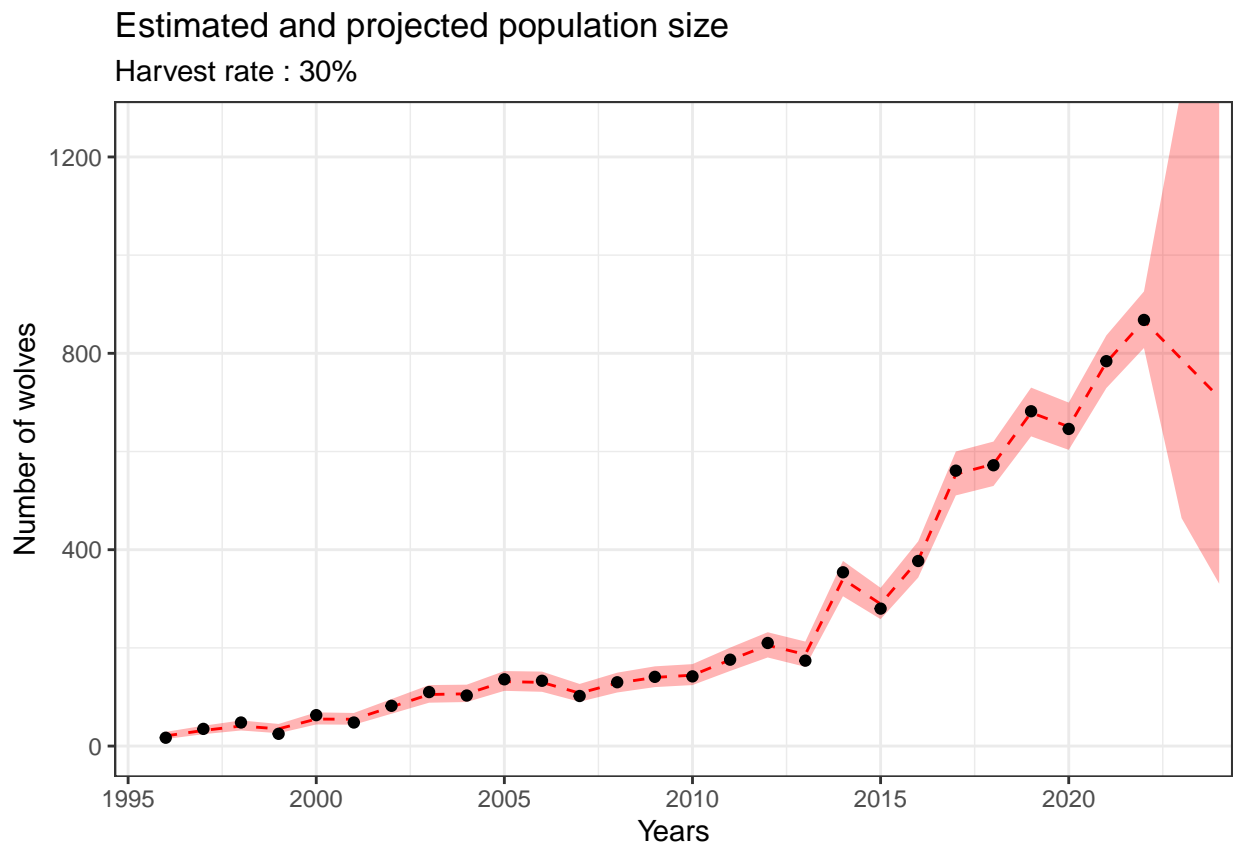
wolf_modelexp$BUGSoutput$sims.matrix %>%
as_tibble() %>%
pivot_longer(cols = everything(), values_to = "value", names_to = "parameter") %>%

```

```

filter(str_detect(parameter, "N")) %>%
group_by(parameter) %>%
summarize(medianN = median(value),
          lq = quantile(value, probs = 2.5/100),
          hq = quantile(value, probs = 97.5/100))%>%
mutate(years = parse_number(parameter) + 1995)%>%
arrange(years)%>%
ggplot()+
geom_line(aes(x = years, y = medianN), colour = "red", lty = "dashed")+
geom_ribbon(aes(x = years, ymin = lq, ymax = hq), fill = "red", alpha = 0.3)+
geom_point(data = bugs.data %>% as_tibble, aes(x = 1995 + 1:unique(nyears), y = y)) +
coord_cartesian(xlim=c(1996,2023),ylim=c(0,1250))+
theme_bw()+
labs(title = "Estimated and projected population size",
      subtitle = "Harvest rate : 30%",
      x = "Years",
      y = "Number of wolves")

```



On définit un objectif d'un maximum d'effectifs à 1250, et un minimum à 1000. Pour atteindre cet objectif on peut imposer un taux de prélèvement de 0% ou 10% sur 2 ans.

## Modèle Marche aléatoires

$$N[t + 1] = N[t] + eps$$

$$\begin{aligned} \epsilon_t &\sim \text{Normale}(0, \sigma_{\text{proc}}) \\ \sigma_{\text{proc}} &\sim \text{Uniforme}(0, 5) \\ y[t] &\sim \text{Normale}(N[t], y\text{Se}[t]^{-2}) \end{aligned}$$

```

modelnull = function(){
  # Priors
  sigmaProc ~ dunif(0,5)
  tauProc = pow(sigmaProc,-2)

  N1 ~ dnorm(17,1/0.28^2)
  N[1] = max(0,N1)

  # Process model
  for (t in 1:years){
    N[t+1] = N[t] + eps[t]
    eps[t] ~ dnorm(0,tauProc)
  }

  # Observation model
  for (t in 1:years){
    y[t] ~ dnorm(N[t],pow(yse[t],-2))
  }
}

```

```

perspredictwolf=matrix(NA,27,1)
perspredictwolf[1]=dat$N[1]

quantile=matrix(NA,27,2)
quantile[1,1] = quantile(dat$N[1], probs = 2.5/100)
quantile[1,2] = quantile(dat$N[1], probs = 97.5/100)

for (i in 2:length(dat$N)){
  y = dat$N[1:i]
  yse = ObsSE[1:i]
  years = i
  # Initialisation des données
  bugs.data = list(
    years = years,
    y = y,
    yse = yse)

  # Paramètres JAGS
  bugs.monitor = c("sigmaProc","N", "tauProc")
  bugs.chains = 3
  bugs.inits = function(){
    list(
    )
  }

  # Lancement du programme
  wolf_modelnull = jags(data = bugs.data,
    inits = bugs.inits,

```

```

        parameters.to.save = bugs.monitor,
        model.file = modelnull,
        n.chains = bugs.chains,
        n.thin=10,
        n.iter=100000,
        n.burnin=50000)

perspredictwolf[i] = median(wolf_modelnull$BUGSoutput$sims.list$N[,i+1])
quantile[i,1] = quantile(wolf_modelnull$BUGSoutput$sims.list$N[,i+1], probs = 2.5/100)
quantile[i,2] = quantile(wolf_modelnull$BUGSoutput$sims.list$N[,i+1], probs = 97.5/100)

}

```

```

## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 2
##   Unobserved stochastic nodes: 4
##   Total graph size: 23
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 3
##   Unobserved stochastic nodes: 5
##   Total graph size: 27
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 4
##   Unobserved stochastic nodes: 6
##   Total graph size: 31
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 5
##   Unobserved stochastic nodes: 7
##   Total graph size: 35
##
## Initializing model
##

```

```

## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 6
##   Unobserved stochastic nodes: 8
##   Total graph size: 39
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 7
##   Unobserved stochastic nodes: 9
##   Total graph size: 43
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 8
##   Unobserved stochastic nodes: 10
##   Total graph size: 47
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 9
##   Unobserved stochastic nodes: 11
##   Total graph size: 51
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 10
##   Unobserved stochastic nodes: 12
##   Total graph size: 55
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:

```

```

##   Observed stochastic nodes: 11
##   Unobserved stochastic nodes: 13
##   Total graph size: 59
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 12
##   Unobserved stochastic nodes: 14
##   Total graph size: 63
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 13
##   Unobserved stochastic nodes: 15
##   Total graph size: 67
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 14
##   Unobserved stochastic nodes: 16
##   Total graph size: 71
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 15
##   Unobserved stochastic nodes: 17
##   Total graph size: 75
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 16
##   Unobserved stochastic nodes: 18
##   Total graph size: 79
##

```

```

## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 17
##   Unobserved stochastic nodes: 19
##   Total graph size: 83
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 18
##   Unobserved stochastic nodes: 20
##   Total graph size: 87
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 19
##   Unobserved stochastic nodes: 21
##   Total graph size: 91
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 20
##   Unobserved stochastic nodes: 22
##   Total graph size: 95
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 21
##   Unobserved stochastic nodes: 23
##   Total graph size: 99
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables

```

```

##      Allocating nodes
## Graph information:
##      Observed stochastic nodes: 22
##      Unobserved stochastic nodes: 24
##      Total graph size: 103
##
## Initializing model
##
## Compiling model graph
##      Resolving undeclared variables
##      Allocating nodes
## Graph information:
##      Observed stochastic nodes: 23
##      Unobserved stochastic nodes: 25
##      Total graph size: 107
##
## Initializing model
##
## Compiling model graph
##      Resolving undeclared variables
##      Allocating nodes
## Graph information:
##      Observed stochastic nodes: 24
##      Unobserved stochastic nodes: 26
##      Total graph size: 111
##
## Initializing model
##
## Compiling model graph
##      Resolving undeclared variables
##      Allocating nodes
## Graph information:
##      Observed stochastic nodes: 25
##      Unobserved stochastic nodes: 27
##      Total graph size: 115
##
## Initializing model
##
## Compiling model graph
##      Resolving undeclared variables
##      Allocating nodes
## Graph information:
##      Observed stochastic nodes: 26
##      Unobserved stochastic nodes: 28
##      Total graph size: 119
##
## Initializing model
##
## Compiling model graph
##      Resolving undeclared variables
##      Allocating nodes
## Graph information:
##      Observed stochastic nodes: 27
##      Unobserved stochastic nodes: 29

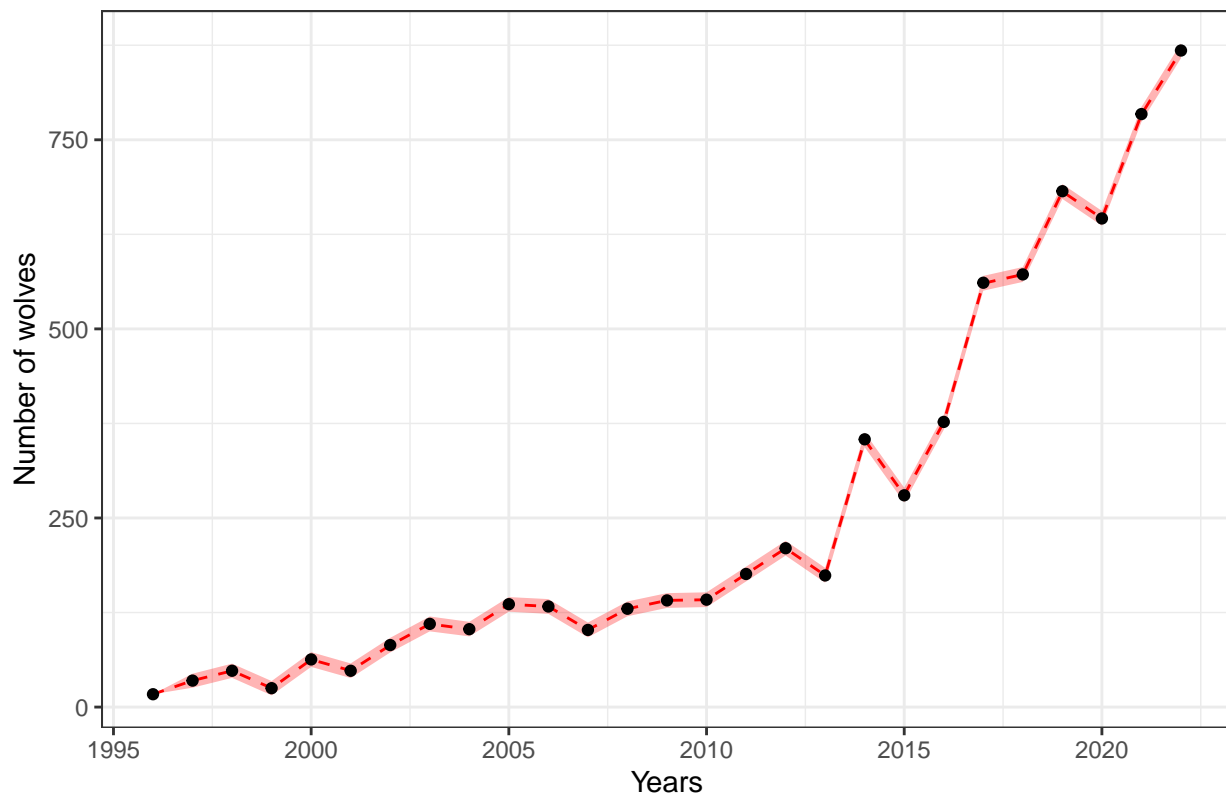
```



```
## Total graph size: 123
##
## Initializing model
```

```
ggplot()+
  geom_line(aes(x = 1995 + 1:unique(nyears), y = perspreditwolf), colour = "red", lty = "dashed")+
  geom_ribbon(aes(x = 1995 + 1:unique(nyears), ymin = quantile[,1], ymax = quantile[,2]), fill = "red",
  geom_point(data = bugs.data %>% as_tibble, aes(x = 1995 + 1:unique(nyears), y = y)) +
  #coord_cartesian(xlim=c(1996,2023),ylim=c(0,1250))+
  theme_bw()+
  labs(title = "Estimated population size",
        x = "Years",
        y = "Number of wolves")
```

Estimated population size



## Prédiction

```
modelnull = function(){
  # Priors
  sigmaProc ~ dunif(0,5)
  tauProc = pow(sigmaProc,-2)

  N1 ~ dnorm(17,1/0.28^2)
  N[1] = max(0,N1)
```

```

# Process model
for (t in 1:years){
  N[t+1] = N[t] + eps[t]
  eps[t] ~ dnorm(0,tauProc)
}

# Observation model
for (t in 1:years){
  y[t] ~ dnorm(N[t],pow(yse[t],-2))
}

# Prediction model
for (t in (years+1):(years+2)){
  N[t+1] = N[t] + eps[t] - dH
  eps[t] ~ dnorm(0,tauProc)
}
}

```

```

perspredictwolf=matrix(NA,27,1)
perspredictwolf[1]=dat$N[1]

quantile=matrix(NA,27,2)
quantile[1,1] = quantile(dat$N[1], probs = 2.5/100)
quantile[1,2] = quantile(dat$N[1], probs = 97.5/100)

for (i in 2:length(dat$N)){
  y = dat$N[1:i]
  yse = ObsSE[1:i]
  years = i
  # Initialisation des données
  bugs.data = list(
    years = years,
    y = y,
    yse = yse,
    dH = dH[1])

  # Paramètres JAGS
  bugs.monitor = c("sigmaProc","N", "tauProc")
  bugs.chains = 3
  bugs.inits = function(){
    list(
    )
  }

  # Lancement du programme
  wolf_modelnull = jags(data = bugs.data,
    inits = bugs.inits,
    parameters.to.save = bugs.monitor,
    model.file = modelnull,
    n.chains = bugs.chains,
    n.thin=10,
    n.iter=100000,

```

```

        n.burnin=50000)

perspredictwolf[i] = median(wolf_modelnull$BUGSoutput$sims.list$N[,i+1])
quantile[i,1] = quantile(wolf_modelnull$BUGSoutput$sims.list$N[,i+1], probs = 2.5/100)
quantile[i,2] = quantile(wolf_modelnull$BUGSoutput$sims.list$N[,i+1], probs = 97.5/100)
}

```

```

## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 2
##   Unobserved stochastic nodes: 6
##   Total graph size: 30
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 3
##   Unobserved stochastic nodes: 7
##   Total graph size: 34
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 4
##   Unobserved stochastic nodes: 8
##   Total graph size: 38
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 5
##   Unobserved stochastic nodes: 9
##   Total graph size: 42
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 6

```

```

##   Unobserved stochastic nodes: 10
##   Total graph size: 46
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 7
##   Unobserved stochastic nodes: 11
##   Total graph size: 50
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 8
##   Unobserved stochastic nodes: 12
##   Total graph size: 54
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 9
##   Unobserved stochastic nodes: 13
##   Total graph size: 58
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 10
##   Unobserved stochastic nodes: 14
##   Total graph size: 62
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 11
##   Unobserved stochastic nodes: 15
##   Total graph size: 66
##
## Initializing model

```

```

##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 12
##   Unobserved stochastic nodes: 16
##   Total graph size: 70
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 13
##   Unobserved stochastic nodes: 17
##   Total graph size: 74
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 14
##   Unobserved stochastic nodes: 18
##   Total graph size: 78
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 15
##   Unobserved stochastic nodes: 19
##   Total graph size: 82
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 16
##   Unobserved stochastic nodes: 20
##   Total graph size: 86
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes

```

```

## Graph information:
##   Observed stochastic nodes: 17
##   Unobserved stochastic nodes: 21
##   Total graph size: 90
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 18
##   Unobserved stochastic nodes: 22
##   Total graph size: 94
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 19
##   Unobserved stochastic nodes: 23
##   Total graph size: 98
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 20
##   Unobserved stochastic nodes: 24
##   Total graph size: 102
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 21
##   Unobserved stochastic nodes: 25
##   Total graph size: 106
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 22
##   Unobserved stochastic nodes: 26
##   Total graph size: 110

```

```

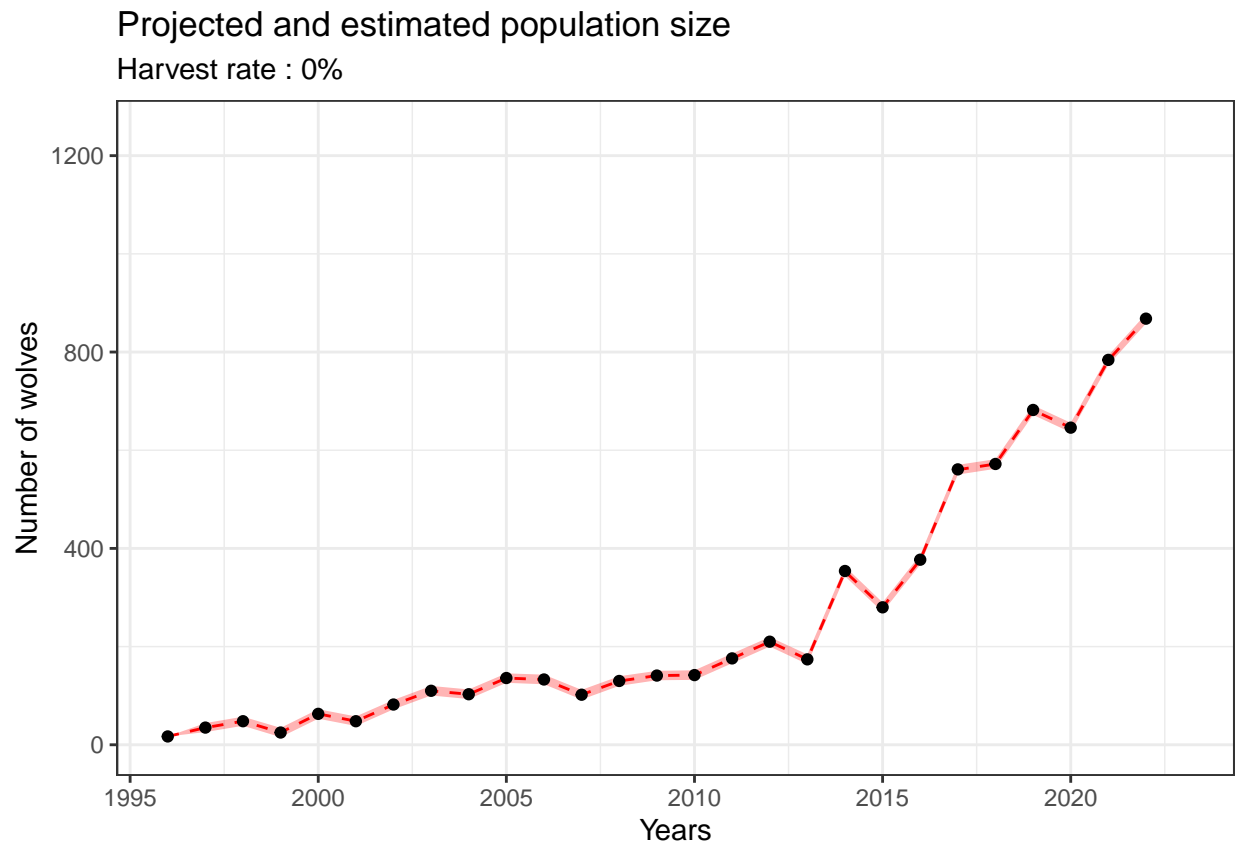
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 23
##   Unobserved stochastic nodes: 27
##   Total graph size: 114
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 24
##   Unobserved stochastic nodes: 28
##   Total graph size: 118
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 25
##   Unobserved stochastic nodes: 29
##   Total graph size: 122
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 26
##   Unobserved stochastic nodes: 30
##   Total graph size: 126
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 27
##   Unobserved stochastic nodes: 31
##   Total graph size: 130
##
## Initializing model

```

```

ggplot()+
  geom_line(aes(x = 1995 + 1:unique(nyears), y = perspredictwolf), colour = "red", lty = "dashed")+
  geom_ribbon(aes(x = 1995 + 1:unique(nyears), ymin = quantile[,1], ymax = quantile[,2]), fill = "red",
  geom_point(data = bugs.data %>% as_tibble, aes(x = 1995 + 1:unique(nyears), y = y)) +
  coord_cartesian(xlim=c(1996,2023),ylim=c(0,1250))+
  theme_bw()+
  labs(title = "Projected and estimated population size",
        subtitle = "Harvest rate : 0%",
        x = "Years",
        y = "Number of wolves")

```



```

perspredictwolf=matrix(NA,27,1)
perspredictwolf[1]=dat$N[1]

quantile=matrix(NA,27,2)
quantile[1,1] = quantile(dat$N[1], probs = 2.5/100)
quantile[1,2] = quantile(dat$N[1], probs = 97.5/100)

for (i in 2:length(dat$N)){
  y = dat$N[1:i]
  yse = ObsSE[1:i]
  years = i
  # Initialisation des données
  bugs.data = list(
    years = years,

```



```

    y = y,
    yse = yse,
    dH = dH[2])

# Paramètres JAGS
bugs.monitor = c("sigmaProc", "N", "tauProc")
bugs.chains = 3
bugs.inits = function(){
  list(
  )
}

# Lancement du programme
wolf_modelnull = jags(data = bugs.data,
                      inits = bugs.inits,
                      parameters.to.save = bugs.monitor,
                      model.file = modelnull,
                      n.chains = bugs.chains,
                      n.thin=10,
                      n.iter=100000,
                      n.burnin=50000)

perspredictwolf[i] = median(wolf_modelnull$BUGSoutput$sims.list$N[,i+1])
quantile[i,1] = quantile(wolf_modelnull$BUGSoutput$sims.list$N[,i+1], probs = 2.5/100)
quantile[i,2] = quantile(wolf_modelnull$BUGSoutput$sims.list$N[,i+1], probs = 97.5/100)
}

```

```

## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 2
##   Unobserved stochastic nodes: 6
##   Total graph size: 30
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 3
##   Unobserved stochastic nodes: 7
##   Total graph size: 34
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 4

```

```

##   Unobserved stochastic nodes: 8
##   Total graph size: 38
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 5
##   Unobserved stochastic nodes: 9
##   Total graph size: 42
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 6
##   Unobserved stochastic nodes: 10
##   Total graph size: 46
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 7
##   Unobserved stochastic nodes: 11
##   Total graph size: 50
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 8
##   Unobserved stochastic nodes: 12
##   Total graph size: 54
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 9
##   Unobserved stochastic nodes: 13
##   Total graph size: 58
##
## Initializing model

```

```

##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 10
##   Unobserved stochastic nodes: 14
##   Total graph size: 62
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 11
##   Unobserved stochastic nodes: 15
##   Total graph size: 66
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 12
##   Unobserved stochastic nodes: 16
##   Total graph size: 70
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 13
##   Unobserved stochastic nodes: 17
##   Total graph size: 74
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 14
##   Unobserved stochastic nodes: 18
##   Total graph size: 78
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes

```

```

## Graph information:
##   Observed stochastic nodes: 15
##   Unobserved stochastic nodes: 19
##   Total graph size: 82
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 16
##   Unobserved stochastic nodes: 20
##   Total graph size: 86
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 17
##   Unobserved stochastic nodes: 21
##   Total graph size: 90
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 18
##   Unobserved stochastic nodes: 22
##   Total graph size: 94
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 19
##   Unobserved stochastic nodes: 23
##   Total graph size: 98
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 20
##   Unobserved stochastic nodes: 24
##   Total graph size: 102

```

```

##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 21
##   Unobserved stochastic nodes: 25
##   Total graph size: 106
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 22
##   Unobserved stochastic nodes: 26
##   Total graph size: 110
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 23
##   Unobserved stochastic nodes: 27
##   Total graph size: 114
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 24
##   Unobserved stochastic nodes: 28
##   Total graph size: 118
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 25
##   Unobserved stochastic nodes: 29
##   Total graph size: 122
##
## Initializing model
##
## Compiling model graph

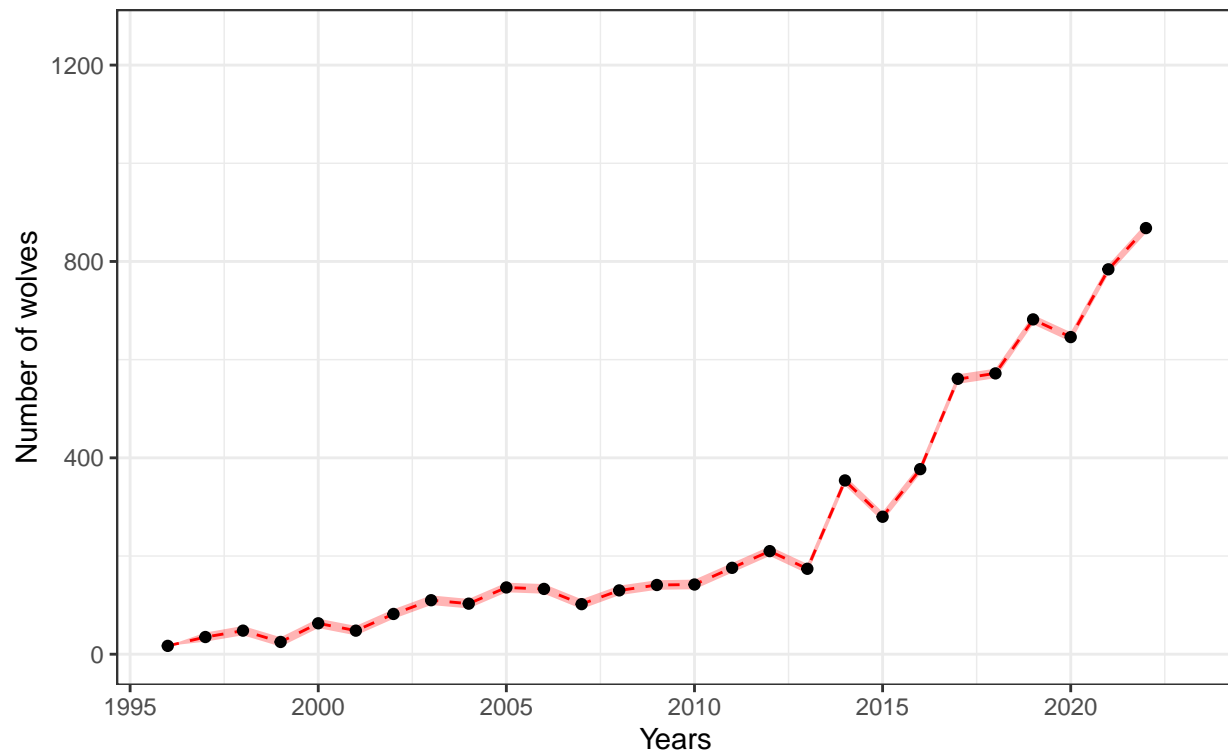
```

```
## Resolving undeclared variables
## Allocating nodes
## Graph information:
## Observed stochastic nodes: 26
## Unobserved stochastic nodes: 30
## Total graph size: 126
##
## Initializing model
##
## Compiling model graph
## Resolving undeclared variables
## Allocating nodes
## Graph information:
## Observed stochastic nodes: 27
## Unobserved stochastic nodes: 31
## Total graph size: 130
##
## Initializing model
```

```
ggplot()+
  geom_line(aes(x = 1995 + 1:unique(nyears), y = perspredictwolf), colour = "red", lty = "dashed")+
  geom_ribbon(aes(x = 1995 + 1:unique(nyears), ymin = quantile[,1], ymax = quantile[,2]), fill = "red",
  geom_point(data = bugs.data %>% as_tibble, aes(x = 1995 + 1:unique(nyears), y = y)) +
  coord_cartesian(xlim=c(1996,2023),ylim=c(0,1250))+
  theme_bw()+
  labs(title = "Projected and estimated population size",
        subtitle = "Harvest rate : 10%",
        x = "Years",
        y = "Number of wolves")
```

## Projected and estimated population size

Harvest rate : 10%



```
perspredictwolf=matrix(NA,27,1)
perspredictwolf[1]=dat$N[1]

quantile=matrix(NA,27,2)
quantile[1,1] = quantile(dat$N[1], probs = 2.5/100)
quantile[1,2] = quantile(dat$N[1], probs = 97.5/100)

for (i in 2:length(dat$N)){
  y = dat$N[1:i]
  yse = ObsSE[1:i]
  years = i
  # Initialisation des données
  bugs.data = list(
    years = years,
    y = y,
    yse = yse,
    dH = dH[3])

  # Paramètres JAGS
  bugs.monitor = c("sigmaProc","N", "tauProc")
  bugs.chains = 3
  bugs.inits = function(){
    list(
    )
  }
}
```

```

# Lancement du programme
wolf_modelnull = jags(data = bugs.data,
                      inits = bugs.inits,
                      parameters.to.save = bugs.monitor,
                      model.file = modelnull,
                      n.chains = bugs.chains,
                      n.thin=10,
                      n.iter=100000,
                      n.burnin=50000)

perspredictwolf[i] = median(wolf_modelnull$BUGSoutput$sims.list$N[,i+1])
quantile[i,1] = quantile(wolf_modelnull$BUGSoutput$sims.list$N[,i+1], probs = 2.5/100)
quantile[i,2] = quantile(wolf_modelnull$BUGSoutput$sims.list$N[,i+1], probs = 97.5/100)

}

```

```

## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 2
##   Unobserved stochastic nodes: 6
##   Total graph size: 30
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 3
##   Unobserved stochastic nodes: 7
##   Total graph size: 34
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 4
##   Unobserved stochastic nodes: 8
##   Total graph size: 38
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 5
##   Unobserved stochastic nodes: 9
##   Total graph size: 42

```



```

##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 6
##   Unobserved stochastic nodes: 10
##   Total graph size: 46
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 7
##   Unobserved stochastic nodes: 11
##   Total graph size: 50
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 8
##   Unobserved stochastic nodes: 12
##   Total graph size: 54
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 9
##   Unobserved stochastic nodes: 13
##   Total graph size: 58
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 10
##   Unobserved stochastic nodes: 14
##   Total graph size: 62
##
## Initializing model
##
## Compiling model graph

```

```

##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 11
##   Unobserved stochastic nodes: 15
##   Total graph size: 66
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 12
##   Unobserved stochastic nodes: 16
##   Total graph size: 70
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 13
##   Unobserved stochastic nodes: 17
##   Total graph size: 74
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 14
##   Unobserved stochastic nodes: 18
##   Total graph size: 78
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 15
##   Unobserved stochastic nodes: 19
##   Total graph size: 82
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 16

```

```

##      Unobserved stochastic nodes: 20
##      Total graph size: 86
##
## Initializing model
##
## Compiling model graph
##      Resolving undeclared variables
##      Allocating nodes
## Graph information:
##      Observed stochastic nodes: 17
##      Unobserved stochastic nodes: 21
##      Total graph size: 90
##
## Initializing model
##
## Compiling model graph
##      Resolving undeclared variables
##      Allocating nodes
## Graph information:
##      Observed stochastic nodes: 18
##      Unobserved stochastic nodes: 22
##      Total graph size: 94
##
## Initializing model
##
## Compiling model graph
##      Resolving undeclared variables
##      Allocating nodes
## Graph information:
##      Observed stochastic nodes: 19
##      Unobserved stochastic nodes: 23
##      Total graph size: 98
##
## Initializing model
##
## Compiling model graph
##      Resolving undeclared variables
##      Allocating nodes
## Graph information:
##      Observed stochastic nodes: 20
##      Unobserved stochastic nodes: 24
##      Total graph size: 102
##
## Initializing model
##
## Compiling model graph
##      Resolving undeclared variables
##      Allocating nodes
## Graph information:
##      Observed stochastic nodes: 21
##      Unobserved stochastic nodes: 25
##      Total graph size: 106
##
## Initializing model

```

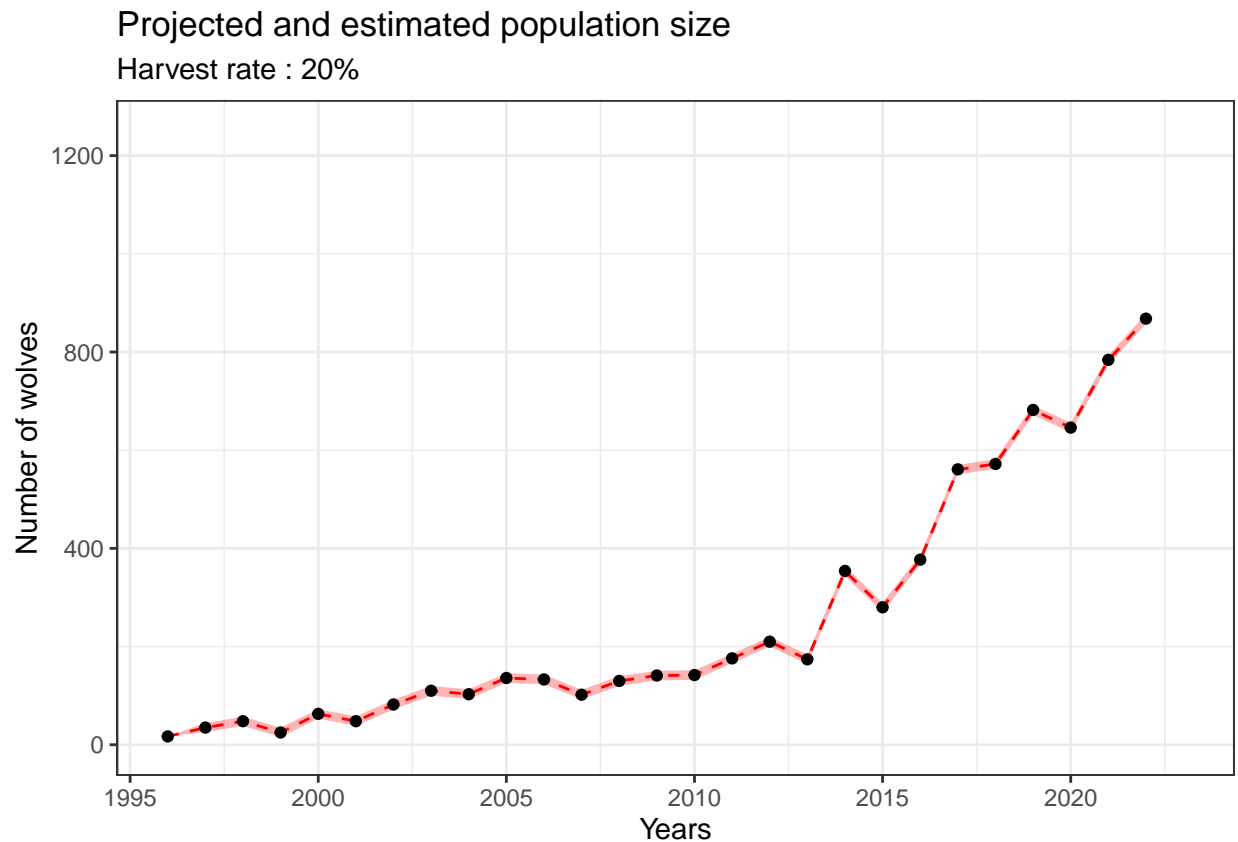
```

##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 22
##   Unobserved stochastic nodes: 26
##   Total graph size: 110
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 23
##   Unobserved stochastic nodes: 27
##   Total graph size: 114
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 24
##   Unobserved stochastic nodes: 28
##   Total graph size: 118
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 25
##   Unobserved stochastic nodes: 29
##   Total graph size: 122
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 26
##   Unobserved stochastic nodes: 30
##   Total graph size: 126
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes

```

```
## Graph information:
##   Observed stochastic nodes: 27
##   Unobserved stochastic nodes: 31
##   Total graph size: 130
##
## Initializing model
```

```
ggplot()+
  geom_line(aes(x = 1995 + 1:unique(nyears), y = perspredictwolf), colour = "red", lty = "dashed")+
  geom_ribbon(aes(x = 1995 + 1:unique(nyears), ymin = quantile[,1], ymax = quantile[,2]), fill = "red",
  geom_point(data = bugs.data %>% as_tibble, aes(x = 1995 + 1:unique(nyears), y = y)) +
  coord_cartesian(xlim=c(1996,2023),ylim=c(0,1250))+
  theme_bw()+
  labs(title = "Projected and estimated population size",
        subtitle = "Harvest rate : 20%",
        x = "Years",
        y = "Number of wolves")
```



```
perspredictwolf=matrix(NA,27,1)
perspredictwolf[1]=dat$N[1]

quantile=matrix(NA,27,2)
quantile[1,1] = quantile(dat$N[1], probs = 2.5/100)
quantile[1,2] = quantile(dat$N[1], probs = 97.5/100)
```

```

for (i in 2:length(dat$N)){
  y = dat$N[1:i]
  yse = ObsSE[1:i]
  years = i
  # Initialisation des données
  bugs.data = list(
    years = years,
    y = y,
    yse = yse,
    dH = dH[4])

  # Paramètres JAGS
  bugs.monitor = c("sigmaProc", "N", "tauProc")
  bugs.chains = 3
  bugs.inits = function(){
    list(
    )
  }

  # Lancement du programme
  wolf_modelnull = jags(data = bugs.data,
    inits = bugs.inits,
    parameters.to.save = bugs.monitor,
    model.file = modelnull,
    n.chains = bugs.chains,
    n.thin=10,
    n.iter=100000,
    n.burnin=50000)

  perspredictwolf[i] = median(wolf_modelnull$BUGSoutput$sims.list$N[,i+1])
  quantile[i,1] = quantile(wolf_modelnull$BUGSoutput$sims.list$N[,i+1], probs = 2.5/100)
  quantile[i,2] = quantile(wolf_modelnull$BUGSoutput$sims.list$N[,i+1], probs = 97.5/100)
}

```

```

## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 2
##   Unobserved stochastic nodes: 6
##   Total graph size: 30
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 3
##   Unobserved stochastic nodes: 7
##   Total graph size: 34

```

```

##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 4
##   Unobserved stochastic nodes: 8
##   Total graph size: 38
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 5
##   Unobserved stochastic nodes: 9
##   Total graph size: 42
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 6
##   Unobserved stochastic nodes: 10
##   Total graph size: 46
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 7
##   Unobserved stochastic nodes: 11
##   Total graph size: 50
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 8
##   Unobserved stochastic nodes: 12
##   Total graph size: 54
##
## Initializing model
##
## Compiling model graph

```

```

##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 9
##   Unobserved stochastic nodes: 13
##   Total graph size: 58
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 10
##   Unobserved stochastic nodes: 14
##   Total graph size: 62
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 11
##   Unobserved stochastic nodes: 15
##   Total graph size: 66
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 12
##   Unobserved stochastic nodes: 16
##   Total graph size: 70
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 13
##   Unobserved stochastic nodes: 17
##   Total graph size: 74
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 14

```



```

##   Unobserved stochastic nodes: 18
##   Total graph size: 78
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 15
##   Unobserved stochastic nodes: 19
##   Total graph size: 82
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 16
##   Unobserved stochastic nodes: 20
##   Total graph size: 86
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 17
##   Unobserved stochastic nodes: 21
##   Total graph size: 90
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 18
##   Unobserved stochastic nodes: 22
##   Total graph size: 94
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 19
##   Unobserved stochastic nodes: 23
##   Total graph size: 98
##
## Initializing model

```

```

##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 20
##   Unobserved stochastic nodes: 24
##   Total graph size: 102
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 21
##   Unobserved stochastic nodes: 25
##   Total graph size: 106
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 22
##   Unobserved stochastic nodes: 26
##   Total graph size: 110
##
## Initializing model
##
## Compiling model graph
##   Resolving undeclared variables
##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 23
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## Initializing model
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## Graph information:
##   Observed stochastic nodes: 25
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##   Allocating nodes
## Graph information:
##   Observed stochastic nodes: 27
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##   Total graph size: 130
##
## Initializing model

```

```

ggplot()+
  geom_line(aes(x = 1995 + 1:unique(nyears), y = perspredictwolf), colour = "red", lty = "dashed")+
  geom_ribbon(aes(x = 1995 + 1:unique(nyears), ymin = quantile[,1], ymax = quantile[,2]), fill = "red",
  geom_point(data = bugs.data %>% as_tibble, aes(x = 1995 + 1:unique(nyears), y = y)) +
  coord_cartesian(xlim=c(1996,2023),ylim=c(0,1250))+
  theme_bw()+
  labs(title = "Projected and estimated population size",
        subtitle = "Harvest rate : 30%",
        x = "Years",
        y = "Number of wolves")

```

## Projected and estimated population size

Harvest rate : 30%

