

**A dynamic model for estimating the economic costs of roe deer
browsing in the Gascogne forests.**

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Abstract.

Roe deer are responsible of browsing damage on the Gascogne forests in France and are source of conflicts between hunters and foresters. However, the economic incidence has never been examined in large scale and in long term because of the insufficiency of data. In order to understand and to evaluate this environmental problem, we present a dynamic simulation model which integrates the biological systems of roe deer population, the forest growth and the economic loss generated. We consider that planner's aim is to minimize the costs of roe deer damage and to maintain the existence of these species. Graphic supports and mathematic formula are used with the Vensim software to synthesize the complexity of the problem. Six scenarios were been calibrated and simulated and a multivariate sensitivity simulation was used to test the robustness of the model face to uncertain parameters. The results show that the impact of roe deer population on forests sector is small if damage is homogenously distributed in this region.

Keywords: wildlife management, forest damage, economic cost, dynamic model, Monte-Carlo Simulation.

1. Introduction

The excessive number of ungulates in the northern forests creates three types of forestry damage: browsing, bark stripping and scarping. Damage to forestry occurs by feeding on plants and rubbing antlers against trees. In the Gascogne forests areas, roe deer (*Capreolus capreolus*) become the major source of browsing damage. They can pose a serious aesthetic and economic threat for the maritime pine forests (*Pinus Pinaster*) which supply all wooden industry in the region of the South West of France. With this type of damage, the mortality of the tree and the development of diseases are rare (CEMAGREF, 1992) but browsed trees can develop a multiple-stemming that means they develop more than one leading shoot. Landowners can ask a financial compensation to the hunters' federation only for agriculture damage in France, the idea to compensate forestry damage is now studied. Taking into account of these impacts, foresters and hunters are currently in a situation of conflict.

The impact of roe deer browsing on young seedlings is then difficult to quantify due to a lot of spatio-temporal factors to consider (Ward et al., 2004). The average cycle of pine maritime is 50 years and during this time many factors can intervene in the growth of the tree (climate change, drought, soil fertility, etc.). We have to ask specific questions: What is the impact of roe deer browsing in long term? How much does the browsing damage cost for forestry? How to implement a sustainable hunting policy to satisfy hunters and foresters?

Many scientific studies were undertaken to quantify deer-forest interactions in France. The methodology used is based on data collect and statistic analyses (Gaillard, 1986;

1998; Vincent, 1991; Ballon, 1985; 2003; Cemagref, 1992). They permit to identify explicative variables of damage and have lead to the creation of tools for following forestry damage (ONC, 1991; 1994; 1998; 1999). However, they give only static analysis at a given moment and on a precise site. The information cost is also too high for long term studies.

Tremblay et al. (2004) made a detailed review of models linking herbivores population with forests. Compared with statistical analyses, these models can be more interesting as they require limited data. Among those, we quote in particular FORGRA (Jorritsma et al., 1999), FORSPACE (Kramer et al., 2001), SAVANNA (Weisberg, Coughenour, 2003) and REMUS (Weclaw, Hudson, 2004). These models quantify the impacts of herbivores on forests. Some of them are focalised on the biology of herbivores by introducing biological variables (impact of carnivores, body weight, diet selection, etc.) and the structure of the population (Raghu et al., 2007). Other models give details rather on the dynamics of the vegetation by introducing environmental factors (light availability, soil moisture, etc.).

We have chosen to create another dynamic model for four main reasons: (i) accessibility: these models are not available to general public and publications on them are rare and incomplete, (ii) simplicity : we integer few biological variables on population dynamics but we take into account the heterogeneity of forests through different age groups (iii) long-term economic valuation: the models quoted previously are only biological models and none deals with the costs generated by herbivores, (iv) calibration with real ecological data: the study site is the Landes de Gascogne forests where conflict situation between foresters and hunters is problematic.

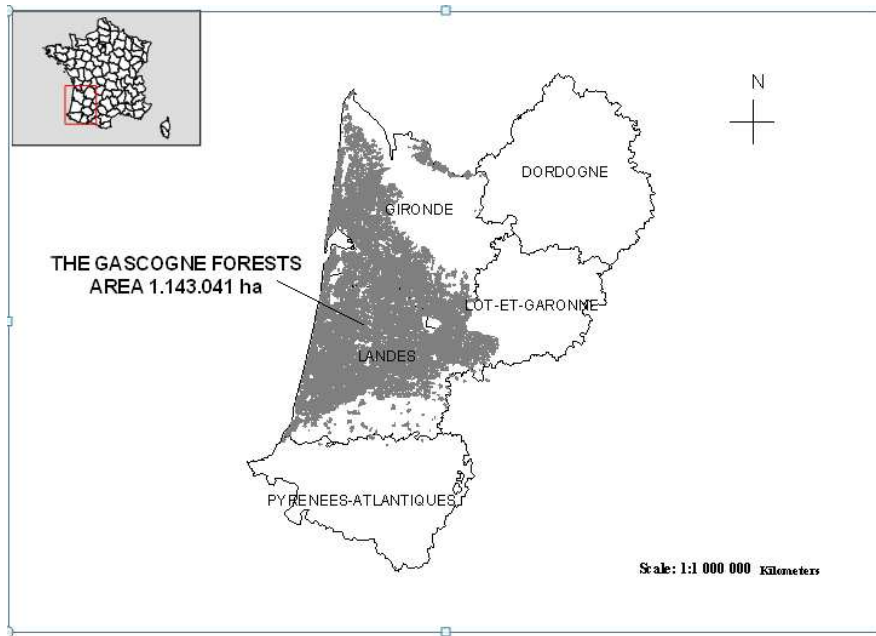
The goal of this article is to build a dynamic model to assess the economic impact of roe deer population on forestry. To this end, section 2 briefly presents the study site. The different components of the model are described in section 3. Section 4 describes the results, and section 5 is devoted to discussions.

2. Materials and methods

2.1. The study site

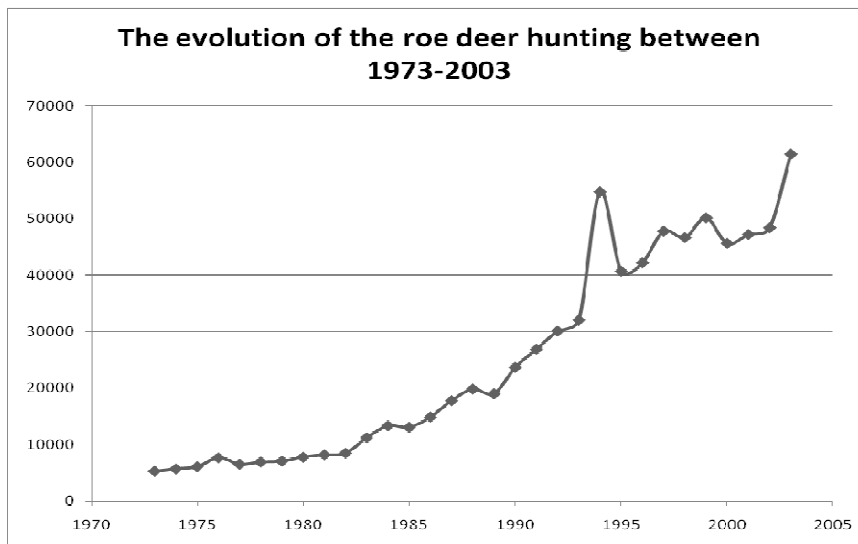
The study site is the Landes de Gascogne region, which represents a remarkable unit in the South-west of France by its extent 1.143.041 ha, with 75.4% of forests. It is the largest woodland area of France and covers 3 departments: Gironde, Landes, and Lot et Garonne. Established artificially by the man in the 19th century, it is dominated by the maritime pine (*Pinus Pinaster*). The Gascogne forests play an important economic role for the Aquitaine region with 148 million m³ of standing biomass and 7.5 million m³ of annual wood production. They represent the greatest wood reserve in Europe (Groupe Sciage Pin des Landes, 2006). The finished products resulting from these forests are diversified: firewood, paper, industrial packing (pallets, cases, formworks, etc.), building materials (floors, skirting, ceilings, etc.) and furnishing (www.frencwood.com).

Fig. 1 : The Gascogne Forests



About roe deer hunting, this activity began in 1973. Roe deer is spread all over the area with density levels from 5 to 15 animals per km² (Ballon et al., 1991). As figure n°2 shows, the number of animals culled each year grows exponentially.

Fig. 2 : Roe deer hunting in the Aquitaine region



The application of the model on the Landes de Gascogne forests is interesting as under wood (lichens, grasses...) is rare with an intensive cultivation of forests. The impact of

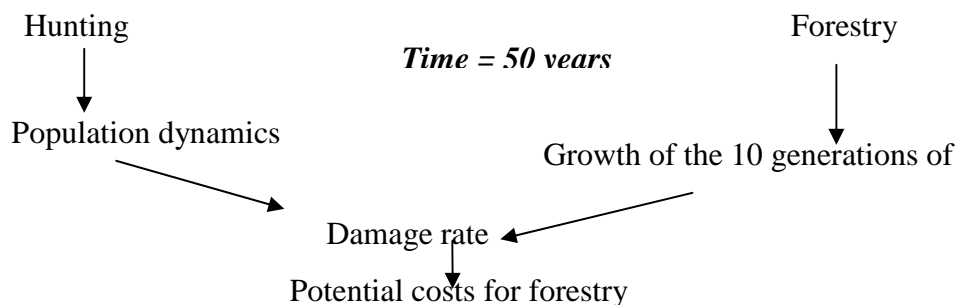
roe deer on the habitat may reduce directly maritime pine forests production. There is no carnivore as wolves in this region, only hunters can control roe deer population.

2.2. Methods

The methodology chosen for studying the impact of roe deer browsing on forest is the system dynamics which are based on systemic approach. Our work is a research on environmental modeling as Andrew Ford (1999) with an orientation to economic valuation. We build a computer simulation model with Vensim DSS (Decision Support System) software to create the model. It offers an interface easy to handle, a possibility to integrate complex scientific equations within a dynamic framework (www.vensim.com) compared with other well known systems like Stella.

The dynamic model is divided into three parts: the biological sector, which describes the dynamics of the population, the forest sector which describes the pine forests growth and finally, the economic sector which analyzes the potential costs for forestry. The three parts are connected by the fact that roe deer generate browsing damage. Taking into account the culture rotation carried out by foresters, we have considered 10 generations of pine forests, with 5 years of gap between each generation. Figure 2 presents a simple conceptual diagram of the model.

Fig. 3. : The general structure of the model



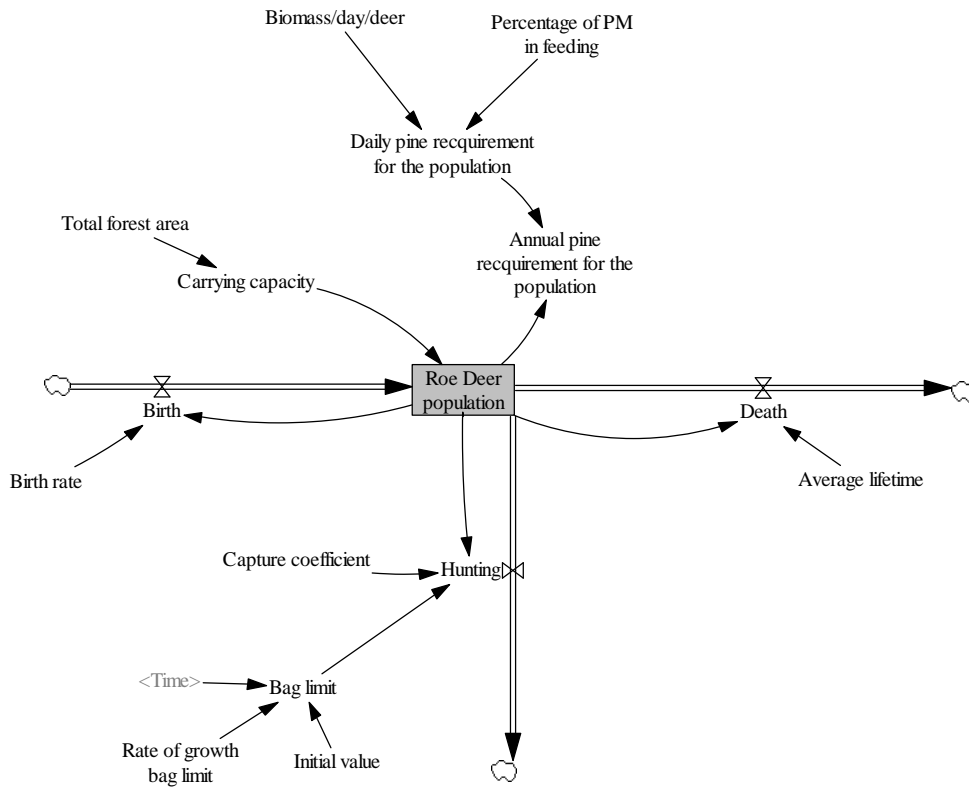
Inside each sector, the essential features of the system are defined in terms of stock variables, flow variables (input and output variables) and auxiliary variables. The stock variables are a physical accumulation per year and they grow with input variables and decrease with output. In the following figures, flow variables appear in the form of double lines. Stocks and flows have the same units. The auxiliary variables are the factors being able to intervene on the other variables; they are represented by single lines. The total number of variables included in the model is 364 but most of them come from the repetition of the variables on the growth of 10 generations of pine forests. For each variable, we put either a fixed value or an equation linked with other variables. The time unit used in the model is year and the time frame of the study is 50 years, from the year 2002 to 2051. In all the graphics in this paper, time axis is only noted 0 to 50 years. The model is focalized on the analysis of the evolution of the system. The time is symbolized by t and it plays a central role.

3. Model description

3.1. Population dynamics

Roe deer population is responsible of pine forests damage by consuming the branch of the tree. Damage will then vary with the dynamics of the population. The first step is to understand all the variables influencing the size of the population. The model shown in figure n°4 does not give any structure of population. Even if the knowledge of the number of males, females, and fawns in a troop is important to study the growth of the population (Gaillard, 1998; Kjellander, 2004), we do not have enough detailed data on the study site to calibrate the model.

Fig. 4. : a visual representation of the dynamic of the deer population



The stock variable is here the roe deer population. The number of roe deer present in forests increases with “birth” and decreases with “mortality” and “hunting”. We denote $N(t)$ the roe deer population at time t . To describe the growth of the population, we use the famous logistic growth (Gordon, 1954; Clark, 1990; Delorme, 1998), at discrete scale. This one is interesting as it permits to introduce the first feedback from animal growth to their number. So, we have:

$$N(t+1) = N(t) + rN(t) \left(1 - \frac{N(t)}{K} \right) - H(t) \quad (1)$$

r the maximum specific growth rate of the population is obtained by making the difference between birth rate TN and death rate TM , so $r = TN - TM$. The death rate is obtained by the inverse of the average lifetime L , so $TM = 1/L$.

Hunting noted $H(t)$ depends on the annual bag limit fixed by wildlife manager, noted $PDC(t)$, and the capture coefficient, noted q , which represents the part of the bag limit realized during the season. The equation of hunting is then:

$$H(t) = q \cdot PDC(t) \quad (2)$$

During the last 30 years, we note, the annual bag limit in the Landes de Gascogne follows an exponential growth. So, we have:

$$PDC(t) = PDC(0) \times (1+g)^t \quad (3)$$

$PDC(0)$ is the initial number of roe deer hunted. g is the annual growth rate of the bag limit. The choice of this parameter depends on the management objectives of the region and may change each year. It will take a positive value if the objective is to decrease the density of the population, zero to maintain a constant hunting and negative to decrease the hunting pressure. The size of the population $N(t)$ is a state variable. If the planner wants to define the best optimal allowance of the resource, he has to play on hunting $H(t)$ which is the only variable of control of the model.

The annual consumption of pine branch noted $C_{br}(t)$ corresponds to the biomass taken by the population during one year. The equation of annual consumption is:

$$C_{Branch}(t) = \alpha \cdot \text{Biomass/day/deer} \cdot 365 \cdot N(t) \quad (4)$$

α represents the percentage of pine branch in roe deer one's. All the variables used for the population model is summarized in table 1.

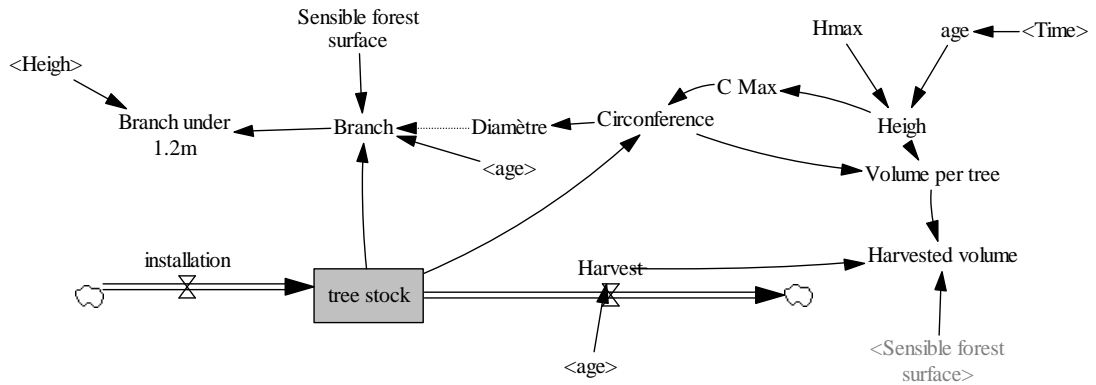
Table 1. List of variables used for roe deer population

Variable	Description	Value	Reference
$N(t)$	Number of roe deer at time t (deer)	Variable	Calculated
r	Maximum specific growth rate of the population (%)	40%	Ballon (unpublished)
TN	Birth rate (%)	50%	--
TM	Death rate (%)	10%	--
L	Average lifetime (year)	10 years	--
K	Carrying capacity for roe deer population (deer)	14 roe deer/100ha	Gaillard (1998)
$H(t)$:	Hunting at time t (deer)	Variable	Calculated
Q	Capture coefficient (%)	90%	Departmental hunters' Federation
PDC(0)	Initial number of roe deer bagged (deer)	12909 roe deer	--
G	Annual growth rate of the bag limit (%)	9%	--
$C_{br}(t)$	Biomass taken by the population during one year (kg/year)	Variable	Calculated
α	the percentage of the bark in the diet of red deer and the percentage of pine leaves in roe deer one's	5% for roe deer 10% for red deer	Maizeret (1983)

3.2. Pine forest growth

To evaluate the total stock of biomass available for roe deer population, we model the dynamics of trees on one hectare of pine forest. This model will be extended to all the surface of forests in the same generation and then to the whole of the Aquitaine region. Graphically, the model of forest is shown in figure n° 5.

Fig. 5. : Visual representation of the growth of pine forests



The symbols are like used in the population dynamics sector, the stock of trees increases with the installation of young seedlings and it decreases according to harvests. The dynamics of the trees follow the equation:

$$S(t+1) = S(0) - E(t) \quad (5)$$

$S(t+1)$ is the stock of trees in one hectare of forest at the time $t+1$, $E(t)$ is the number of trees harvested at the time t . $S(0)$ is the initial density of tree. Our assumption is that forestry is conducted according to Lemoine's recommendations (1991). He proposed an initial density of 1275 trees, 5 harvests and the last one at 50 years. In order to calculate the stock of biomass available for roe deer, 3 distinct parts on the maritime pine tree are considered: stem wood, bark and branch. Porté et al. (2002) shows that the biomass W of these various parts depends on the diameter and the age of the tree.

$$W_{Branch} = a_1 \cdot d_t^{a_2} \cdot age^{a_3} \quad (6)$$

d_t is the diameter of the tree at the time t . age is the age of the tree, there is a lag of 5 years between each generation. a_1 , a_2 and a_3 are the different coefficients given in table n° 2.

Table n°2: Values of parameter to calculate biomass per tree.

Part of the tree	a_1	a_2	a_3
Branch	0.03775	2.033	- 0.0885

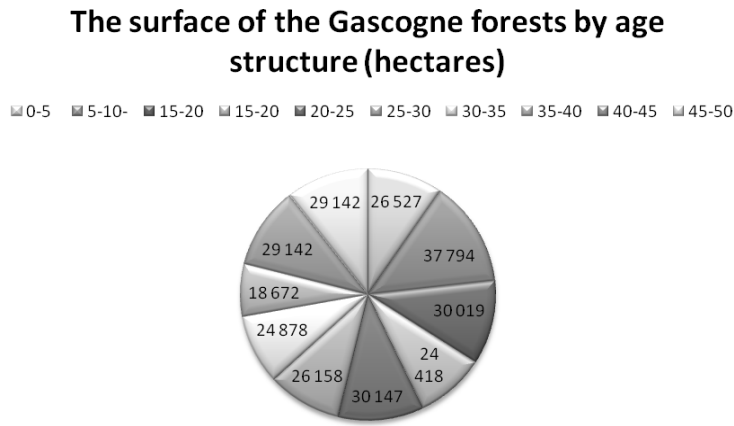
The physical characteristics of the tree as the diameter, the circumference and the height are calculated in the model with the age, the number of trees in one hectare. The equations are detailed in the annex.

We consider that all the forests surfaces in the same generation i produce the same quantity of branch as calculated in equation (6). We use the following formula to obtain the total biomass of branch available for roe deer in each generation.

$$B_{Branch}(i, t) = W_{Branch} * S_i(t) * Surf(i) \quad (7)$$

$B_{Branch}(i, t)$ is the total biomass of branch, in kg for the generation i at the time t . It gives the food availability for roe deer population. We multiply the biomass W_{Branch} by the stock of trees in 1ha of forest $S_i(t)$ calculated in equation (5) for the generation i , and the surfaces potentially being able to be damaged noted $Surf(i)$ given by IFN in 2000 (fig.6).

Fig. 6. : The real age structure of the Gascogne forests



Browsing damage begins at the 1st year then finishes at the 3rd year because they are out of the period of sensitivity, moreover branches must be under 1.2m height to be accessible for roe deer. The first class concerned by browsing is then [0-5[, secondly the class [45-50[in 2000 which will be replaced by new plantations and so on.

3.3. Pine forest growth sector with damage

The damage rate is calculated by considering the food ingested by the whole of the population and the food available offered by the forest ecosystem. The rate of damage noted $D_{Branch}(t)$ is written as:

$$D_{Branch}(t) = \frac{C_{Branch}(t)}{B_{Branch}(i,t)} \quad (8)$$

$C_{Branch}(t)$ is the total consumption of branch by the population calculated in the equation (4) and $B_{Branch}(i,t)$ is the biomass of branch available in the Gascogne forest in the equation (7).

Variable	Description	Value	Reference
$S(t)$	Stock of trees in one hectare of forest (trees)	Variable	Calculated
$S(0)$	Initial stock of trees in one hectare of pine forest (trees)	1275 trees	Lemoine (2001)
$Surf(i)$	Surfaces potentially being able to be browsed for the generation i (hectares)	<i>Vary with age</i>	<i>IFN (2000)</i>
$B_{Branch}(i,t)$	Total biomass of branch (kg) for the generation i at the time t .	Variable	Calculated
d_t	Diameter of the tree at the time t (cm)	Variable	Calculated
$D_{Branch}(t)$	Rate of browsing noted (%)	Variable	Calculated
T_R	Risk of multiple leadering (%)	12% the 2nd year 43% the 3rd year	CEMAGREF, (1992)

3.4. Economic sector

3.4.1. The cost of multiple leading shoot on pine forests

As Ward et al. (2004), the objective of the planner is to minimize the costs of damage on forest while maintaining a constant population of roe deer. After a roe deer browsing, a pine tree develops generally two or more shoots. The economic loss appears for two reasons. First, some authors talk about smaller diameter. As stem is divided by minimum two, we use the assumption that the circumference is divided by two. It is a simplifying assumption as tree can develop more than two stems. In that case, there is a loss of volume as demonstrated in the annex. Secondly due to this smaller volume, wood has less value since it can only be used for chipboard manufacture, fuels or pulp for paper manufacture, whereas wood of greater diameters can be used to manufacture more expensive items such as planks and furniture.

However, the long term effects of a multiple leading shoot had not yet been studied scientifically (Ward et al, 2004). There is uncertainty on the circumference of a tree

browsed 50 years ago, on the use change of the product and the loss of quality. Let's formalize the economic cost of damage for 50 years and for the 10 generations as following:

$$NPV_{\text{cost}} = \sum_{i=0}^9 \sum_{t=0}^{50} \Delta p \times ND(t) \times \frac{1}{(1+\delta)^t} \quad (10)$$

NPV_{cost} is the net present value of total costs for 50 years, and Δp is the difference of price due to a smaller diameter. i indicates the generation of the tree, $ND(t)$ is the number of trees presenting a multiple-stemming during the time t and in the generation i which is calculated in the equation (8). δ is the discount rate.

Table 4. List of variables used for economic damage

Variable	Description	Value	Reference
NPV_{cost}	Net present value of total costs for 50 years (euros)	Variable	Calculated
Δp	The difference of price due to roe deer browsing (euros)	Variable	Calculated
v	Volume of a tree (m ³)	Variable	Calculated
C	Unit cost for cutting a browsed tree (euros)	0.10 euros/tree	CRPF-France
δ	Discount rate. (%)	3%	

The difference of price Δp due to roe deer browsing was built from a price function developed by Pajot (2006, page 119). It links the variation of price due browsing inside a polynomial function. Details are given in the annex.

$$\Delta p(v) = -8,03 v^2 + 17,34v - 3,39 \quad (11)$$

The difference of price $\Delta p(v)$ is expressed in euros. v is the unitary volume of the tree in cubic meter. All the variables used for economic model is summarized in table 4.

3.4.2. The cost of repairing browsed pine forests

We consider that every tree presenting multiple leading shoot requires a repair work. The repair work consists in cutting of the multiple shoot to stop the development of two stems. The economic cost due to roe deer browsing can be calculated from the equation n°10 but we replace Δp by c , which the unit cost of cutting a tree.

4. Results

4.1. Roe deer population dynamics

For roe deer population, a literature review permits to fix the growth rate $r=40\%$ and the average lifetime $L = 10$ years. K is the carrying capacity for roe deer. A literature review shows that this parameter varies widely between 6 to 21 roe deer/ 100ha of forests (Gaillard, 1998). We had chosen the average value of 14 roe deer/100ha. It is then extended to the whole forests surfaces to obtain a carrying capacity of 117 262 roe deer.

A data analysis on the Gironde, Landes and Lot et Garonne departments shows that about 12909 roe deer were hunted in 2002 (table n°5). The annual growth rate of the bag limit between 1973 and 2003 was 9% (figure n°2).

Table n°5: Number of roe deer hunted per department in 2002

Departments	Roe deer hunted
Gironde	5335
Landes	6425
Lot et Garonne	1149
TOTAL	12909

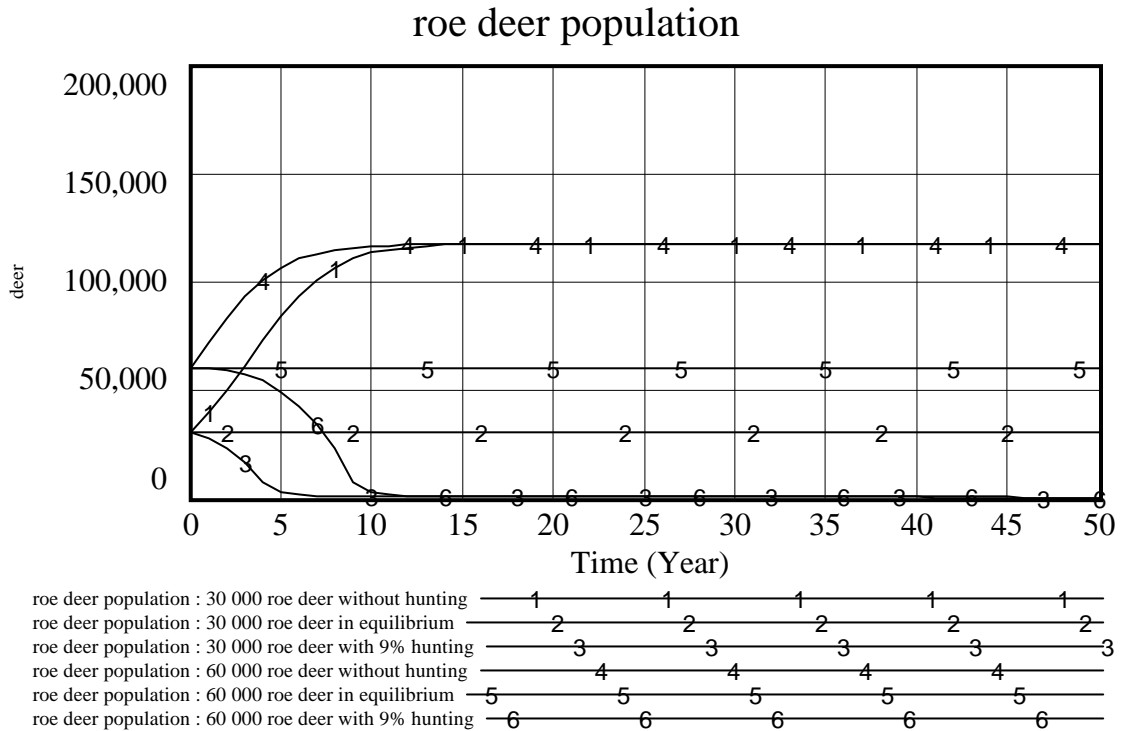
Source: National and departmental hunters' federation.

A roe deer needs every day 2kg of biomass and *pinus pinaster* represents only 5% of its diet (Maizeret, 1983). Our model functions on an annual step, which raises the

difficulties of seasonal variations of feeding behavior. Roe deer can consume less leaves in summer when fruits are available but the proportion of pine in its diet ratio seems to be constant (Maizeret, 1983).

It is difficult to find the initial size of the roe deer population in the study site as there was no information on it. In Dourdan, France, the roe deer population density varies widely to 3 to 36 deer per km² (Kjellander et al, 2004) making it difficult to transfer to the Aquitaine region. In 2001-2002, the various indices of the populationⁱ were stable in the Aquitaine region which means that the population was in equilibrium around this period. If 13 000 roe deer were hunted in 2002, it means that there are about 60 000 roe deer in the Aquitaine region, so around 7 animals/km². We will make 6 scenarios: a population of 60000 roe deer with 3 options of policy hunting: (i) stop hunting and let the population grow naturally: the population reaches quickly the carrying capacity; (ii) maintain a constant number of population by hunting exactly the same number of the natural growth ;(iii) to practice an intensive hunting policy as a bag limit growing at 9% per year. It is the growth rate measured in the Aquitaine region during the last thirty years (fig.). We will consider also the 3 scenarios with 30000 roe deer as initial population. The following graph is then obtained:

Fig. 8. The dynamic of the roe deer population with the 6 scenarios

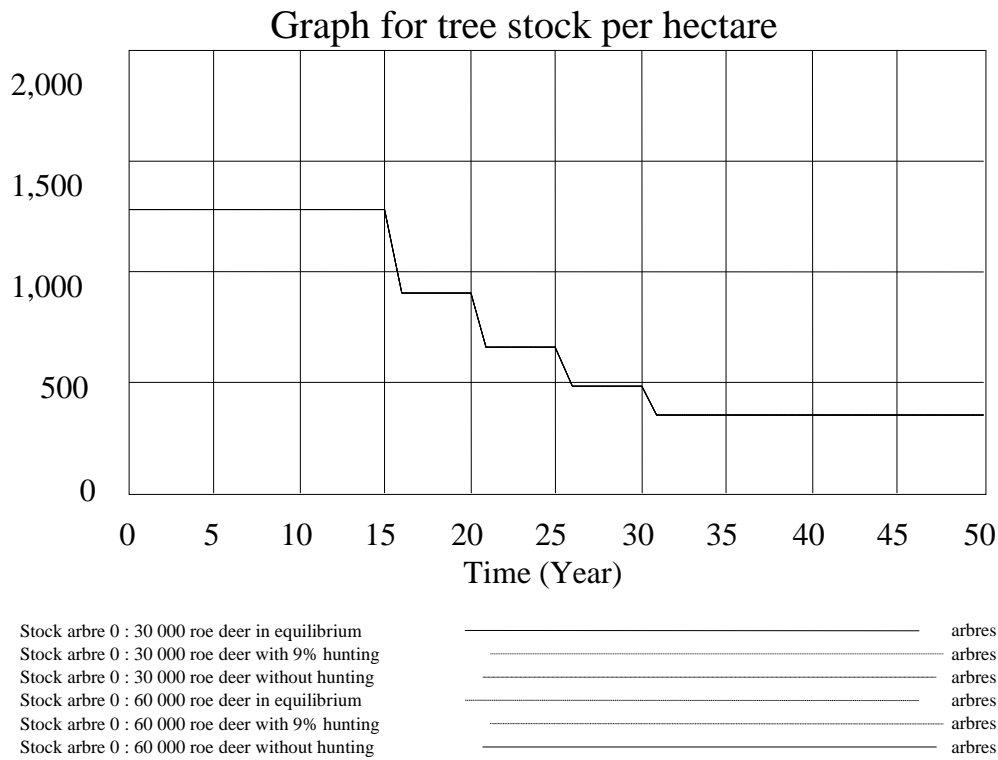


In the first and fourth scenarios, we suppose the activity of hunting is stopped, the population then reaches the carrying capacity of the environment after ten years. The opposite effect is obtained if we apply the growth rate of the current hunting 9% per year (scenario 3 and 6). The population disappears then after ten years, it is a situation of the extinction of the species. The biological equilibrium of the population is reached in the scenarios (2) and (4) by the fact that hunters take exactly the growth of the population. The number of roe deer in the site is then theoretically stable whether the initial population is 30000 or 60000. These various scenarios show the importance of the management of hunting on the future of these species. This reveals that the knowledge of the size of the population is key information to implement a sustainable policy.

4.2. Pine forest growth

The forest management does not change with all the scenarios as we put the assumption of inexistence of mortality due to browsing. In reality, mortality is possible if a large part of the tree is damaged. Moreover, every forester can chose the date of the harvest but here but we use the sylviculture methods proposed by Lemoine (2001) which is the most used in Gascogne Forests. The stock of trees present on one hectare of forest evolves as illustrated in fig7.

Fig. 9. Density of trees on one hectare of pine forest.

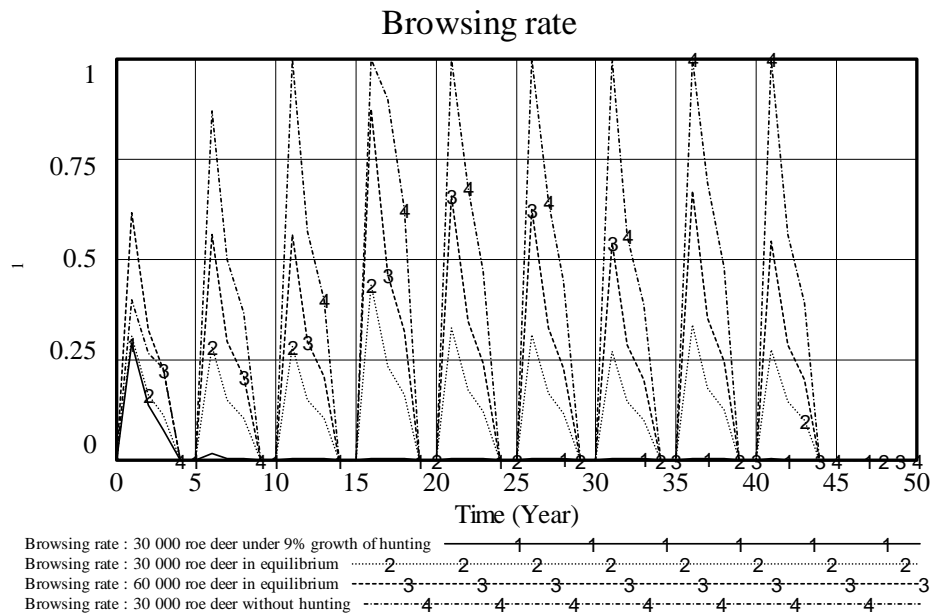


This forest management can change depending the choice of the tree grower. In this paper, it will be the basic model used to calculate the biomass available for roe deer population.

4.2.1. The browsing rate

The damage rate varies cyclically over time. The damage is always important in the first year of culture. It is diffused when the total stock increases in the second and third years of culture for each generation. This result comes from the food availability in the study area. The average browsing rate obtained with the six scenarios of population is described in fig 10:

Fig. 10. : The browsing rate calculated by the model with the 6 scenarios.



The browsing rates change in parallel with the population dynamics and are null when this one disappears. It is the case with an increasing hunting of 9% per year. The highest rates of damage correspond to the scenario with 30000 and 60 000 roe deer without hunting, with an average of 40%. The scenario with 60.000 roe deer gives a rate of browsing of approximately 40%. Lastly, a constant population of 30.000 roe deer gives an average damage of 11,5% and 60 000 roe deer create around 23% of damage. Data collected by the CEMAGREF show a rate of 25% damage in 2000 (Ballon, Hamard,

2003). This result permits to confirm that the assumption of an initial population of 60.000 roe deer can be the most realistic scenario.

4.2.1. The number of trees presenting a multiple leading shoot

According to studies of the CEMAGREF, the trees browsed by roe deer have a risk of 12% to present a multiple leading shoot at the second year of plantation and 43% of risk if browsing takes place at the 3rd year (CEMAGREF, 1992). Secondly, only 20% of the damage is recent (Ballon, Hamard, 2003). Multiplied by the rate of damage and the number of trees in one hectare, the number of trees presenting a multiple leading shoot is described in table n°6 for all the ten generation of forests in the Gascogne Forests.

Table 6. The number of trees presenting a multiple leading shoot

i =0, ...9	Age		Number of trees harvested at 15th years with multiple leading shoot per ha					
	Min	Max	60 000 roe deer with 9% hunting	60 000 roe in equilibri um	60 000 roe deer without hunting	30 000 roe deer with 9% hunting	30 000 roe in equilibri um	30 000 roe deer without hunting
0	0	5	72	74	106	26	37	66
1	5	10	34	68	128	0	34	116
2	10	15	0	68	132	0	34	130
3	15	20	0	105	206	0	53	206
4	20	25	0	79	155	0	40	155
5	25	30	0	75	147	0	38	147
6	30	35	0	65	128	0	33	128
7	35	40	0	81	158	0	40	158
8	40	45	-	-	-	-	-	-
9	45	50	-	-	-	-	-	-

As exposed before the first harvest takes place approximately at the 15th of culture in the Lemoine’s model. The results of the model show that for every scenario, the number of trees presenting a multiple leading are inferior to 375. There is a high probability that tree grower can eliminate them at the first harvest.

4.3. The economic costs of roe deer browsing

4.3.1. The cost of multiple leading shoot on pine forests

The difference of price between a undamaged tree and another one presenting two stems are obtained with the equation (10). The table n°7 shows a part of the variation of price during 50 years.

Table 7. : The price variation due to roe deer browsing

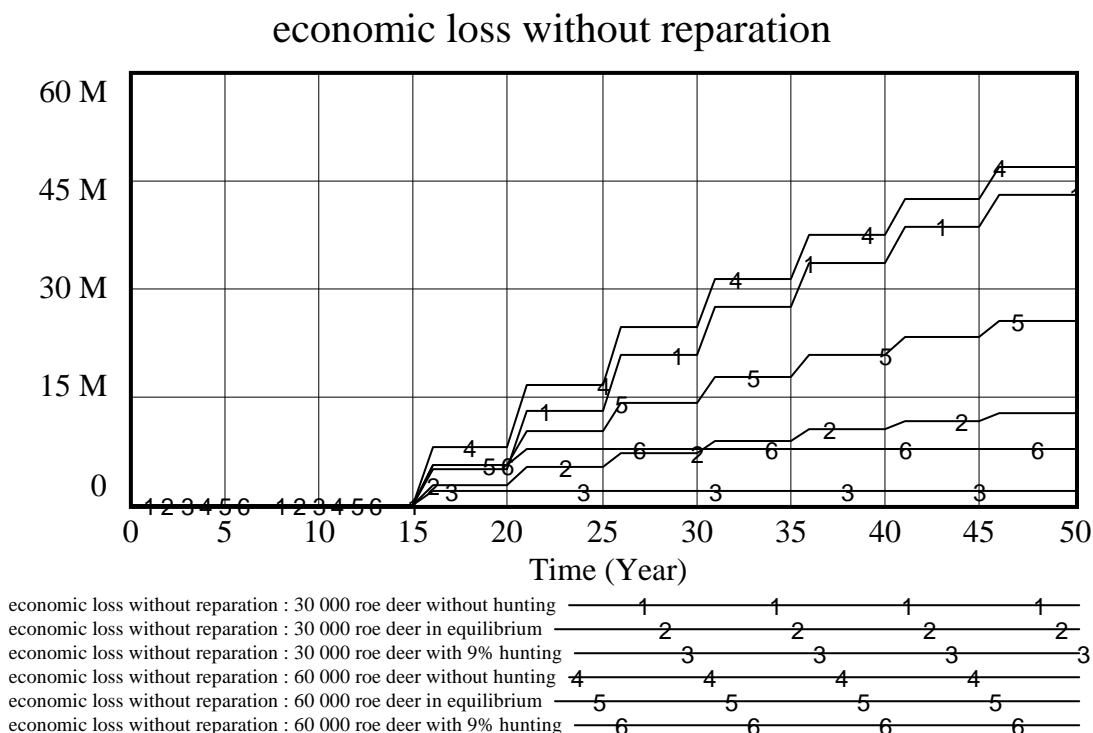
	Age	Volume (m3)	Variation of price estimated (euros)
Harvest 1	15	0,128	-1,31
Harvest 2	20	0,248	0,41
Harvest 3	25	0,399	2,23
Harvest 4	30	0,569	3,85
Final Product	50	1,279	5,60
Average for 50 years			1,72

Curiously, the variation of price after a roe deer browsing can be positive if they are harvested at the first harvest. This is due to the polynomial form of the price function and also that browsing develops two stems. If he decides to eliminate them at the second harvest, the value loss will be 0,41 euros and so on. The economic loss will be more important as long as he waits to eliminate them.

If damage is homogeneously distributed in the territory, tree grower can eliminate them at the first or second harvest. The economic loss due to roe deer browsing is then null as products are used for firewood and paper production. The damaged trees cannot be eliminated for different reasons. For example, they are too much concentrated in the area. Their elimination will disturb all the silvicultural management. The tree grower can also be discouraged by the cost of repairing damaged trees. In that case, the

potential economic loss presented in figure n° 11 is calculated with an average variation price of 1,72 euros per tree.

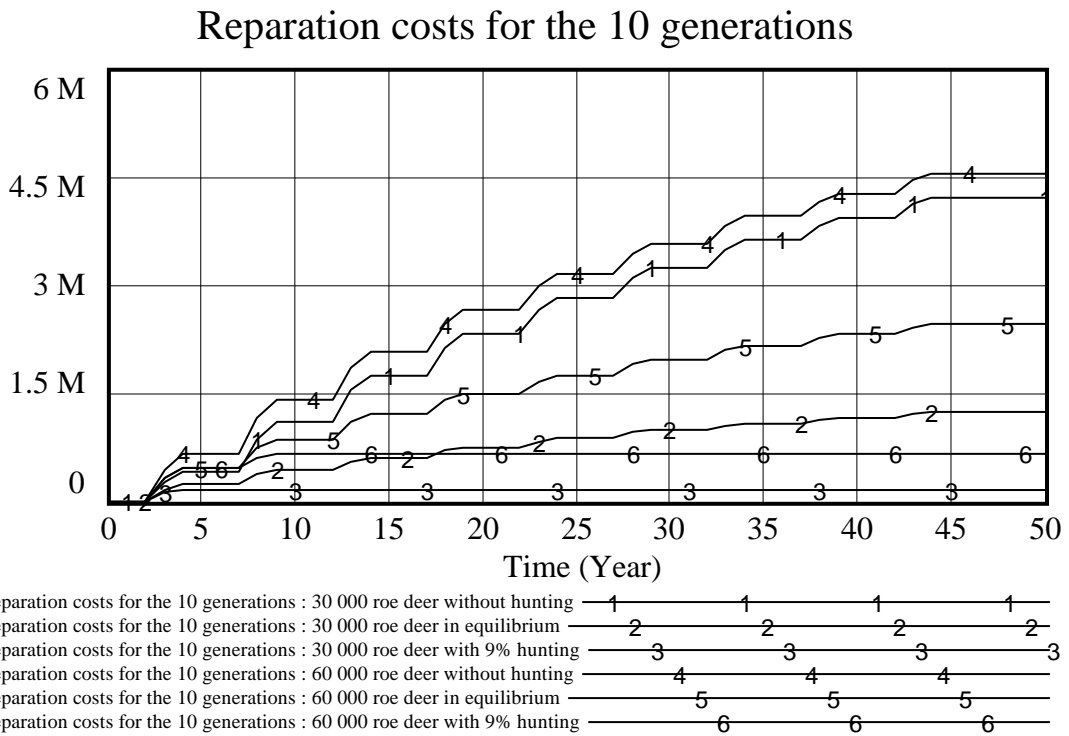
Fig. 11. : The potential economic loss without reparation under the six scenarios.



4.3.2. The cost of repairing browsed trees

The economic costs due to the roe deer damage are related to the costs of treatment carried out by foresters. The economic loss considered here is the expenses of repair work engaged by foresters, which take place as of the 4th year. We pose that the cost of treatment is 0.10 euros/tree, the discount rate δ is fixed at 3%, and the actual potential costs for foresters is then described in figure n°12.

Fig. 12. : The potential repairing costs for 10 generations of forests under the six scenarios.



The repairing cost is ten times lower than the economic losses for all the scenarios. The principal results of the model with roe deer browsing are given in table n°8.

Table 8. Main results of simulations for roe deer

Size of the initial population (deer)	Average rate of browsing	Damage costs for 50 years (millions euros)	Repairing costs for 50 years (millions euros)	Average Loss per hectare (euros)	Average Loss per deer (euros)
30 000 roe deer without hunting	38%	42,78	4,21	51,07	8,49
30 000 roe in equilibrium	11,5%	12,74	1,23	15,22	7,3
30 000 roe deer with 9% hunting	0%	1,92	0,16	2,29	0
60 000 roe deer without hunting	39,7%	46,68	4,54	55,73	8,5
60 000 roe in equilibrium	23%	25,49	2,46	30,43	7,96
60 000 roe deer with 9% hunting	3,6%	7,66	0,65	9,15	0
Sensitivity run	11,5%	12,74	1,23	15,22	7,3

The highest economic losses correspond to the situation with 30 000 deer and 60 000 deer without hunting. The total costs without any reparation are respectively 42,78 million euros and 46,68 million euros for 50 years. If we decide to repair these damage, they costs respectively 4,21 and 4,54 million euros. Even if the initial size of the population is not similar, the difference of total costs after 50 years is not significant. The average loss per animal is around 8,5 euros per year. This is due to the assumption on the existence of carrying capacity of the environment.

The lowest values are obtained with 30 000 and 60 000 roe deer at the beginning but with a high pressure of hunting. The total loss in these cases are 1,92 million euros and 7,66 million euros. This result is due to a rapid extinction of the population. It is

important to notice that 9% is the growth rate measured during the last three decades in France. The reparation costs are 0.16 and 0,65 million euros.

The net benefit of hunting policy is then the difference between these extreme situations but we must consider that the loss of the biodiversity is not evaluated here.

The two other scenarios represent a compromise for two different values of population and they are based on the assumption of equilibrium of the roe deer population. It supposes that hunters will hunt exactly the growth of the population. These scenarios can be difficult to apply as hunters 'federations don't know the real size of the population and the number of hunters and their practice can change in time.

4.4. A multivariate sensitivity simulation for imprecise parameters

We have, however, built a model that contains quite a few assumptions, and these assumptions are known to be uncertain: especially the initial number of roe deer in the Gascogne forest and the price of damage. We could go in and change the assumptions and simulate the model to understand the implications. A Monte-Carlo Simulation or Multivariate Sensitivity Simulation (MVSS) is used to verify the robustness of the model. We will set ranges on the uncertain assumptions, then Vensim will simulate the model multiple times randomly selecting values for the uncertain assumptions.

For the initial number of roe deer, the results of the model show that 30 000 roe deer produce an average rate of browsing of 10%. For the variation of price due to roe deer browsing, we used the average result of 1,72 euros per tree. For the price of damage repair, the average value is 0.10 euros. We will use a normal distribution value around these averages to test the sensitivity of the model. After 200 simulations, the results for economic loss and repairing cost are shown in figure n°13 and 14.

Fig. 13. : The sensitivity graph for economic cost without reparation.

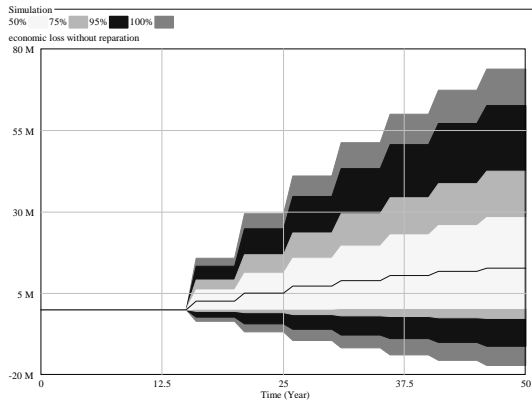
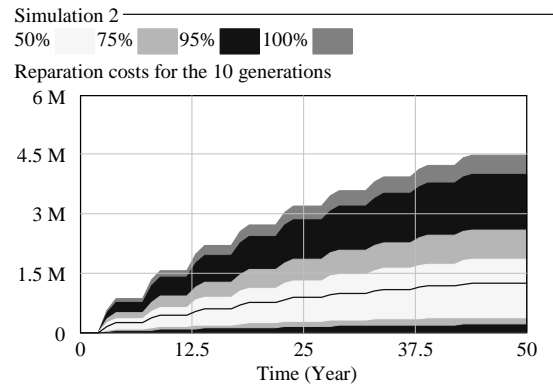


Fig. 14. : The sensitivity graph for repair cost.



The distribution is presented in the form of zones of different colors indicating the confidence intervals corresponding to certain levels of probability. In the figure n°14, the probability that the repair cost is situated between 500 000 euros and 2 million euros is equal to 50%. The average damage appears in a form of line in this figure. The probabilities that damage repair costs between 3 million and 200 000 euros is 75%. The outer bounds of uncertainty (95% and 100%) show maximum values of approximately 4.5 million and minimum values of 0.

5. Discussions

This article produces three main results. First, we can conclude that the impact of roe deer damage on forest is not as high as it seems. Taking into account the natural rate of cicatrisation of the trees as well as the risks of having trees with multiple leading shoot, the physical impact on pine forests is weak. Only the first harvest of the forest production is really damaged by roe deer.

Secondly, if damage is concentrated, roe deer browsing can create an important economic loss as stems are divided by two. In contraction of Ward et al (2004), we find that there is a loss of volume. The cost of repair is ten times less than the damage cost.

Finally, the model underlines once again the importance of implementing a sustainable management of wildlife. The roe deer population, studied here, evolves quickly according to the pressure of hunting. A too fast increase in the hunting pressure can lead to the extinction of these species while stopping hunting leads to overpopulation. The original contribution of this study is the economic evaluation of the damage of the roe-deer in large scale and in long term.

This result should be interpreted with caution due to the simplifying assumptions and the existence of uncertain parameters. On the dynamics of the population, there are two uncertain parameters. The density of the population is unknown on the Aquitaine area and the use of the density from other areas did not give the anticipated results. The population is thus supposed to be distributed homogeneously on the area, as data on their spatial movements does not exist in this region. We considered also that all the forest surfaces have the same characteristics even though it is not possible to extrapolate the model to the Aquitaine region. The consequence of these assumptions is that the model does not capture local problems of high rate of damage. Further studies must be undertaken about the development of multiple leading trees. On the economic part, the assumption that foresters carry out a repair work is criticable for two reasons: either the multiple leading on the trees can disappear naturally, or the repair costs discourage foresters. The loss of volume has not yet been measured on the final production.

The bioeconomic model does not search deterministic results on the costs of damage but rather seeks to synthesize information to open exchanges between the different agents.

Finally, this work focuses on a specific methodology which is the dynamic system. This method permits to make predictions for the future. It can also be applied to other regions, other species or to different time by adjusting the parameters of the model.

The results of this work are one part of the analysis of the total economic value of roe deer as they create other benefits for society (venison, sports, relationships...) and also other costs (crop damage, collisions with vehicles). The model created can thus be used as a tool of support for decision-making on the management of hunting, and more generally natural resources.

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Annexes:

The physical characteristics the stem of a maritime pine tree are summarized in the following equations:

$$H = H_{\max} \left(1 - e^{-\alpha age_i} \right)$$

$$\alpha = 0.03$$

$$H_{\max} = 25 \text{ m}$$

$$C = C_{\max} - (a * S_i(t) * C_{\max})$$

$$a = 8e-006.$$

$$C_{\max} = 0.08 H_{\max}$$

$$v = \frac{0.45 * H * C^2}{4 * \pi}$$

$$v_B = \frac{0.45 * H * (C/2)^2}{4 * \pi} = \frac{v}{4}$$

$$C(t) = 2\pi * d(t)$$

Variable	Description
H	Height (m)
H_{\max}	The maximum height (m)
C	Circumference (m)
C_{\max}	The maximum circumference (m)
$d(t)$	Diameter (m)
$S_i(t)$	Number of trees per hectare
v	Volume of stem of one tree (m3)
v_b	Volume of the stem after a multiple leading shoot (m3)

Pajot (2006) shows that the price of pine forest is:

$$p(v) = -9,17v^2 + 34,69v + 3,39$$

If we pose that roe deer browsing develops two stems as exposed by Ward et al (2006), we can consider that the value of a browsed tree is the price of two smaller stems.

$$pb(v) = 2 * (-9,17(v/4)^2 + 34,69(v/4) + 3,39)$$

The difference of price is then

$$\Delta p(v) = p(v) - pb(v) = -8,03 v^2 + 17,34v - 3,39$$

ⁱ The population indices used to follow roe deer population in the Aquitaine region are: the hunting table (fig.1); kilometer indices of abundance (IKA) and hunters' opinion survey.