A cost benefit analysis of big game: the case of wild boar in the Aquitaine region.

Hanitra RAKOTOARISON
GREThA, Université Montesquieu - Bordeaux IV.
ISTOM, Ecole d'Ingénieur d'Agro-développement international.
Email : rakot009@u-bordeaux.4.fr

Patrick POINT
GREThA, Université Montesquieu - Bordeaux IV.
Email : patrick.point@u-bordeaux4.fr

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Abstract:

Big game is a natural resource which creates at the same time benefits and costs for the society. To implement a sustainable management of the resource, it is necessary to take into account the Total Economic Value of big game. This one is composed by four elements: (i) the hunting benefits; (ii) the non consumptive benefits; (iii) the private costs for hunters and (iv) the sum of the damage costs in agriculture, forestry and collisions with vehicles. All these economic values are integrated inside a dynamic bioeconomic model. In this article, we show that it is possible to find the optimal size population and to calculate the sustainable hunting. Curiously, the system has multiple optimal solutions. When we calibrate the model for the wild boar in the Aquitaine region n France, we found four solutions. This work shows the importance of the information on the size of the population and its value for the society.

Key words: bioeconomic model, hunting, big game, management, nuisance, multiple equilibia.

Résumé en français:

Le grand gibier est une ressource naturelle renouvelable qui produit à la fois des bénéfices et des coûts économiques pour la société. Pour gérer durablement cette ressource, il est nécessaire de prendre en compte la Valeur Economique Totale du grand gibier. Celle-ci est composée de quatre éléments : (i) les bénéfices d’usage liés à la chasse, (ii) les bénéfices de non usage liés à la préservation de la ressource soit pour un usage récréatif soit pour un report de l’usage pour le futur, (iii) les coûts privés pour les chasseurs, (iv) et enfin, la somme des dommages pour l’agriculture, la sylviculture et les automobilistes victimes des accidents. Toutes ces valeurs sont intégrées dans un modèle bioéconomique dynamique. Dans cet article, nous montrons qu'il est possible de définir une taille optimale de la population et d'en déduire le niveau de prélèvement soutenable. Cependant, le système admet plusieurs états d'équilibre. En calibrant le modèle sur les contextes du sanglier de la région Aquitaine, nous en avons trouvé 4. Ce travail souligne l'importance de l'information sur la taille de la population et les valeurs qu'elle crée pour la société.

Mots-clés : modèle bioéconomique, chasse, grand gibier, gestion, nuisance, équilibre multiple.

Introduction

Big game such as red deer, roe-deer and wild boar can be considered at the same time as a "resource" and a "nuisance". These animals have symbolic values: the stags are for example regarded as an emblematic animal of temperate forests whereas roe deer are present in cartoon movies (eg: Bambi). These species are also appreciated by hunters in France as well as in other northern countries. Big game population is currently increasing thus generates negative impacts: damages on agriculture and forests and collisions with vehicles. These species create human wildlife conflicts (HWC) because conservation actions go against the economic interests of local stakeholders. The total economic value of big game is composed by four components: (i) use benefits related to hunting, (ii) nonuse benefits related to the conservation of the resource for an entertaining use or for future use, (iii) private costs supported by hunters, (iv) damages for farmers, forest owners and motorists, victims of collisions with big game. All these values are linked in a complex way to the size of big game population, the individual behavior of each agent, the social perceptions, the public attitudes, the characteristics of land use and the policies on big game management. Moreover, these values can be contradictory for different groups particularly hunters' ones whose activity can generate externalities for the other actors.

In the literature, bioeconomic models taking into account of the multiple values of natural resources are rare except some recent works on endangered species (Skonhoft & Schulz, 2003; Solstad, 2004; Boman, Bostedt & Persson, 2003; Horan & Bulte, 2004). However, big game differs from these species due to the importance of hunting benefits and the damage caused by the population. Using these studies, we tried to build a specific model for big game. We propose to treat the problem at a macro level with a bioeconomic model, i.e. model which connects the net social benefit with the dynamic of the population. The goal of this paper is first to highlight the notion of public values of big game according to the economic theory.

Secondly, this paper searches to link the different values to the dynamic of big game. Finally, it contributes to the development of a sustainable game policy.

In the beginning, we will introduce a brief description of the benefits and the costs of big game. Then, we will show how to integrate them in a theoretical model to find the optimal size of the population. Finally, we will apply the model to the case of wild boar in the Aquitaine region in France.

1. The Total Economic Value of big game

We bring a highlight on the various economic values and an adaptation to the case of big game. We will start by developing the economic values composing the total economic value of big game.

1.1. The use benefits of big game

The use benefits of big game come from the harvest of the resource. The most evident benefits of hunting are the value of venison, which can be consumed during hunting events as dinners, for individual use and rarely sold to local restaurants. Hunters hunt as well for meats as for trophies when they hunt male red deer (stag). Decker and Connelly (1989 adds three other categories of hunters' motivation: (i) the social aspect of hunting: attachment to old culture and research of social relationships between hunters (ii) the sporting aspect of hunting: it is considered as an art requiring an address of shooting, tactics and experiments (iii) the research of recreation: hunting is an outdoor activity which permits to evacuate stress and to view wild animals in forests. The use benefits depend on individual preference of each hunter, which is the result of his culture, his education and all other social characteristics. We aggregate them with $B_H = B_H(H)$ with H the level of hunting, $B'_H(H) > 0$ and $B''_H(H) \leq 0$.

1.2. The private costs of hunting

The private costs of hunting are composed by two elements:

(i) the expenditure of each hunter for the practice of the activity: travel costs, bag game purchase, … (Creel & Loomis, 1992; Pinet, 1987, Johansson, Kristöm & Mattson, 1988);

(ii) the opportunity cost of hunting lands, that is the economic value of the activities which could have been developed without hunting. Some outdoor activities can be incompatible with hunting, for example walking, picnics… (Norton-Griffiths, 1996; Mburu, 2003).

All these costs depend on the level of hunting noted *H*. We will note them $C_H = C_H(H)$ with $C_H(0) = 0$ in order to pose the assumption that there is no cost without hunting. It is an increasing function with hunting $C'_H > 0$. Moreover, we suppose that costs are convex $C''_H \geq 0$.

In a well known work of Clark (1990), harvesting cost depends on the efforts of harvesting such as the numbers of days used. Both are justified because the level of hunting depends on the efforts of hunting.

The difference between the use benefits and the private costs for hunters is the consumer's surplus. It is a monetary value for which a hunter would agree to pay for an improvement in his activity. Depending to the context of the study, the consumer's surplus can be the willingness to pay (WTP) for hunting another deer per year (Loomis, Updike & Unkel, 1989; Waddington, Boyle & Cooper, 1991), the willingness to accept (WTA) to reduce recreation use to 50% of the current use level (McCollum, Peterson, Arnold, Markstrom & Hellerstein, 1990), WTP to double the chance to capture one more animal (Loomis & Cooper, 1988.; Duffield & Neher, 1990) or to improve the quality of the hunting sites (Sorg & Nelson, 1986). We can consider that this difference represents also the net benefit *in situ* of big game population.

1.3. The non use benefits of big game

The non use benefits of big game come from the value of knowing the existence of big game. They are based on wildlife value orientations (WVO) which emphasize wildlife protection and oppose to hunting (Manfredo & Dayer, 2004). Krutilla (1967) explains that nonuse benefits is composed by two elements: (i) the well being felt by walkers by the sight of an animal, which can create the opportunity to take photographs, to feed animals or to pay the access for a park conserving big game; (ii) the existence value[1] and the option value[2] which come from the marginal utility of the knowledge that these species exist (Brookshire; Eubanks & Randall, 1983). Non use benefits are strongly associated with attitudes, beliefs and an altruistic sense of responsibility toward the preservation of the environment and a desire to reduce environmental degradation (Krutilla, 1967).

For threatened species like bears, tigers, elephants, vultures, and so on, we find evidence for non use values (Bandara & Tisdell, 2005; Kotchen & Reiling, 2000; Eagle & Betters, 1998, Loomis, Douglas & White, 1996). For big game which is currently overabundant, the answer is not so obvious. Historically, when big game population was considered to be in danger, hunters and scientists had worked together to maintain the existence of these species. In France, Lang (2003) reports that 4.860 stags and hinds, 6.200 roe deer, 2.600 wild boars, 910 chamois and izards, 910 wild sheeps were captured and released since 1955 to 1985 for repopulation. Currently, this effort is slowed down now but the national reserve of Chizé in France continues to regularly export roe deer to other European countries. There are more than 2.5 millions hectares of hunting parks in France (Lang, 2003), which play an important role in the preservation of wildlife. Hunters can also introduce big game with a special

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[1] This is derived from the satisfaction of knowing that a particular species has a sustainable population in its native habitat (Loomis & White, 1996).

[2] This is the value that an individual places on the potential future use of the resource (Loomis & White, 1996).

authorization from the administration. These facts show the potential economic value of conserving big game, but a complete monetary evaluation is not currently possible. These benefits can be regarded as positive externalities of the resource.

Nonuse benefits, noted $B_E = B_E(N)$ depend on the size of the population with $B_E(0) = 0$, $B_E'(N) \geq 0$ and $B_E''(N) \leq 0$. We consider also that B_E is a continuous function. However, it can be discrete if the Society takes into account the minimal viable population size (Clark, 1990).

1.4. Big game damage

Big game causes also multiple negative externalities which can be classified into four groups:

- Crop damage: big game, especially wild boar, eats young plants and fruits and reduces production (Yoder, 2002; Rollins, Heigh & Kanetkar, 2004; Rakotoarison, 2008). The annual costs of the agricultural losses generated by wild boar are estimated at approximately 800.5 million $ in the United States, 80 million $ in Australia (Pimentel D., et al. 2001). In England, they are estimated at 4.3million £ per year (www.defra.gov). In France, the agricultural damage due to big game is estimated at approximately 38 million euros per year, including the administrative costs (Bourcet et al, 2003).
- Forest damage: Red deer and roe deer remove bark and browse young trees. The economic impact is related to a loss of quality and/or quantity of forestry production (Cemagref, 1992; Ballon & Hamard, 2001, 2003).
- Collision between big game and vehicles can lead to serious material damages and loss of human life (Putman, Langbein & Staines, 2004; Schwabe, Schuhmann, Tonkovich & Wu, 2002; Saint-Andrieux, 2005).
- Destruction of the local ecosystem: Red deer, for example, have been shown as responsible of the destruction of the ecosystem in the Haida Gwaii archipelago (Martin, 2006). They can also enter in food competition with cattle (Verheyden,

2006). Wild boars can transmit diseases towards human (Fenichel, 2005; Bourcet, Bracque, Nonancourt & Sapor, 2003).

We note $D_N = D_N(N)$ the sum of these damages which depends on the size of the population *N*. We pose $D_N(0) = 0$ to advance that damage is null when there is no big game. Damage increases when the population *N* increases $D'_N > 0$. The damage function can be concave or convex according to the feedback of the physical environment on the big game damage (Hone, 2004). If the physical environment strongly reacts, i.e. damage increases quickly when the size of the population increases, then $D''_N > 0$. If the physical environment manages to compensate for the impacts of big game, then $D''_N < 0$.

2. The theoretical model

2.1. The planner program

The model presented in this section, is a theoretical model which is based on the works of Boman et al. (2003), Skonhoft (2006) on wolves in Scandinavia; Horan and Erwin (2003) on wildlife in general and then applied to African elephants (2004). In long term, the total economic value of big game is given by the sum of the whole benefits and costs within an intertemporal framework. The program of the manager can be aggregated in the following way:

$$Max\int_0^{\infty}\left[B_H(H)-C_H(H)+B_E(N)-D_N(N)\right]e^{-\delta t}dt \qquad \textbf{(1)}$$

This is a continuous time model with an infinite horizon. δ is the discount rate and *t* the unit of time. This model depends on the dynamic of the big game population.

$$\dot{N} = \frac{\partial N}{\partial t} = F(N) - H \qquad \textbf{(2)}$$

We denote *F(N)* the natural growth rate of the big game population and *H* the level of harvest by hunting. In general, we pose that *F'(N) >0* and *F''(N) <0.* The size of the population *N* is thus the state variable of the model and the level of hunting *H*, is the variable of control.

The current Hamiltonian associated with (1) and (2) is

$$\mathrm{H} = B_E(N) + B_H(H) - C_H(H) - D_N(N) + \lambda\big(F(N) - H\big) \qquad \textbf{(3)}$$

λ is the implicit price of big game. The necessary conditions for an interior solution are equation (2) and

$$\frac{\partial \mathrm{H}}{\partial h} = B_H'(H) - C_H'(H) - \lambda = 0 \qquad \textbf{(4)}$$

$$-\dot{\lambda} + \delta\lambda = \frac{\partial \mathrm{H}}{\partial N} = B_E'(N) - D_N'(N) + \lambda F'(N) \qquad \textbf{(5)}$$

These equations give:

$$\lambda = B_H'(H) - C_H'(H) \qquad \textbf{(6)}$$

$$\dot{\lambda} = -B_E'(N) + D_N'(N) - \lambda F'(N) + \delta\lambda \qquad \textbf{(7)}$$

Conditions (6) et (7) are commons for renewable resources (forests, fishery, etc) but unlike classical bioeconomic models (Gordon, 1954 ; Clark, 1990; ….), the implicit price of big game λ can be positive or negative (Zivin et al., 2000; Rondeau; 2003; Horan and Bulte, 2004). Big game hunting may represent a rent-generating activity or a costly activity mainly for damage control. If it is the case, the system will have multiple equilibria.

2.2. Steady states and species classifications

Interior steady states are found by setting $\dot{N} = 0$ and $\dot{\lambda} = 0$ in equation (2) and (7). If $\dot{N} = 0$, we can find the optimal level of hunting which corresponds exactly to the growth of the population

$$H^* = F\left(N^*\right) \qquad \textbf{(8)}$$

If the variation of the implicit price is null $\dot{\lambda} = 0$, the equation (7) gives the rule of the management of big game

$$\delta = F'\left(N^*\right) + \frac{B_E'\left(N^*\right) - D_N'\left(N^*\right)}{\mathrm{B}_H'\left(H^*\right) - C_H'\left(H^*\right)} = F_N' + \frac{\phi}{\lambda} \qquad \textbf{(9)}$$

$$\begin{array}{lcl} \frac{\partial B_h}{\partial H} = B_h' > 0 & & B_h'' < 0 \\ \frac{\partial C_h}{\partial H} = C_h' > 0 & & C_h'' \geq 0 \\ \frac{\partial B_E}{\partial N} = B_E' > 0 & \text{and} & B_E'' < 0 \\ \frac{\partial D}{\partial N} = D_N' > 0 & & D'' \gtrless 0 \end{array}$$

The equation (9) permits to create a classification of big game following the marginal social values. This type of classification is formalized in table n°1 according to the theory developed on multi-use species (Rondeau, 2001; Horan & Bulte, 2004):

Table 1**:** A classification of big game species according to the marginal benefit.

	Ex situ marginal net benefits (externalities)	
In situ marginal net benefits	$\phi = B_E'(N) - D_N'(N) > 0$	$\phi = B_E'(N) - D_N'(N) < 0$
$\lambda = \mathrm{B}_H{}'(H) - C_H{}'(H) \geq 0$	I. Commodity/asset	II. Commodity/liability
$\lambda = \mathrm{B}_H{}'(H) - C_H{}'(H) < 0$	III. Nuisance/asset	IV. Nuisance/liability

This classification of big game population is carried out by analyzing two criteria.

- The first dimension of the table is $\lambda = \mathrm{B}_H{}'(H) - C_H{}'(H)$ which represents the marginal net benefit *in situ* according to the level of hunting *H*, i.e. for hunters. If $\lambda \geq 0$, big game is harvested as a resource or commodity (class I or II). Alternatively if $\lambda < 0$, big game is harvested as a nuisance or pest (class III or IV).
- The second dimension of the table is $\phi = B_E'(N) - D_N'(N)$ which is the marginal net benefit *ex situ* according to the size of the population *N*. It is the external effect of big game for the other actors: the victims of damages (farmers, foresters and motorists), walkers, tourists and the general society. If $\phi > 0$, there is a marginal incentive to preserve big game as they are considered as a natural capital or an asset (class I or

III). If $\phi < 0$, there is a marginal incentive to deplete the stock, we speak then about liability to control stock.

These different classifications influence the social optimal size of big game population. A strong value of ϕ / λ implies a high size of optimal population. Indeed, this corresponds to a weak growth rate of the population F'_N. The optimal population in the class I and III, which it is considered as a capital, is more important than the optimal population in the class II and IV which it is considered as a liability. Lastly, the discount rate and the growth rate of the resource impose conditions on the equilibrium of the various classes. Classes I and IV require that $\delta > F'_N$ and classes II and III require that $\delta < F'_N$ (Horan, Bulte, 2004).

2.3. Functional forms

To apply the theoretical model, we will use some simple functional forms for the different economic values and the growth function. For this one, we will use a logistic form developed by Gordon (1954) and used inside bioeconomic models.

$$F(N) = rN\left(1 - \frac{N}{K}\right) \qquad \textbf{(10)}$$

r is the intrinsic growth for big game. *K* is the parameter on the carrying capacity of the environment. The marginal growth function is

$$F'(N) = r\left(1 - \frac{2N}{K}\right)$$

This growth function reflects the phenomena of density-dependent of the stock. It supposes that at one moment *t*, the growth of big game population is stopped when the size of the population reaches the maximum carrying capacity of the environment, denoted *K*. So, *F(0)=F(K)=0*.

We need also to find adequate functional forms for the different economic functions. To value big game hunting, we will use directly the net value of hunting. It is the difference between hunting benefits and hunting costs. $p(H)$ is the demand function for one animal with a linear form and two parameters α is the slope of the demand function and β is the intercept.

$$p(H)=\left(\alpha-\frac{\beta}{2}H\right)$$

The net benefit of hunting is then:

$$B_H - C_H = p(H).H = \left(\alpha-\frac{\beta}{2}H\right).H = \alpha H-\frac{\beta}{2}H^2$$

The marginal benefit of hunting is then

$$B'_H - C'_H = \alpha-\beta H$$

We will adopt the same specification for non consumptive value of big game B_N with two parameters a and b.

$$B_N = \left(a-\frac{b}{2}N\right)N = aN-\frac{b}{2}N^2$$

The marginal benefit for non consumptive value is then $B'_N = a-bN$

For damage function, we will use an exponential form to describe the rapid growth of damage when the size of the population increases. $D_N = cN^d$. There are two parameters c and d.

The marginal damage function is then $D'_N = cdN^{d-1}$

If we introduce all these functional forms inside the model, equation (1) becomes

$$Max\int_0^\infty \left[\alpha H-\frac{\beta}{2}H^2+aN-\frac{b}{2}N^2-cN^d\right]e^{-\delta t}dt \qquad \textbf{(11)}$$

Equation (6) on the implicit price of big game becomes:

$$\lambda=\alpha-\beta H \qquad \textbf{(12)}$$

Steady states of the model are given by the equations

$$H^*=rN^*\left(1-\frac{N^*}{K}\right) \qquad \textbf{(13)}$$

It is the first form to express the optimal harvesting by considering biological function.

$$\delta=r\left(1-\frac{2N^*}{K}\right)+\frac{a-bN^*-cdN^{*d-1}}{\alpha-\beta H^*} \qquad \textbf{(14)}$$

From this last equation, we can deduce a second expression of the optimal harvesting which links economic functions with biological function.

$$H^{*}=\frac{1}{\beta}\left[\alpha-\frac{a-bN^{*}-cdN^{*d-1}}{\delta-r\left(1-\frac{2N^{*}}{K}\right)}\right] \quad \textbf{(15)}$$

The optimal solutions of the problem will satisfy equation (13) and (15).

3. Empirical results for wild boar in the Aquitaine region

3.1. Parameter values

To apply the model to real data, we will study the case of the Aquitaine region. This one forms a relatively large area (approximately 41 806 km²) in the South West of France. The problem of wild boar overpopulation causes conflicting situation between farmers and hunters. The hunting law in France permits for a farmer victims of big game damage to ask a a financial compensation to the hunters federation. They cost around 1 million per year for the Aquitaine region and are financed by hunting fees.

Data in this region are absent on the economic values of big game hunting. In this case, the method of transfer value is interesting (Rosenberger, Loomis, 2001). The USDA furnishes on line a database containing the 195 values of the consumer surplus of a hunter for one day of hunting big game. They come from economic valuation studies on big game hunting in USA and Canada. We complete them with recent studies to obtain 250 values. A descriptive statistic is presented in table n°2.

Table n°2: Description statistics of consumer's surplus of one day of hunting.

	WTP (euros/day)
Average	62,47
Median	47,06
Maximum	1 118,41
Minimum	1,34
Standard deviation	92,88
Observations	250

The average value of the hunter surplus is 62$ per day. However, we note a standard deviation of +/-92$ around this average which comes from the localization of the study sites, the methods used and the social and environmental characteristics of the study sites. By applying the procedure of a transfer method with a meta-analysis, the WTP for one animal in the Aquitaine region is estimated at 79,23$ or 51 euros (Rakotoarison, 2008). The slope of the function of price is the inverse of the WTP so $\beta/2 = -0.02$ and $\beta = -0.04$.

The parameter α is the maximal price given to one hunted animal. From table n°1, it is 1118,41$ for big game, so $\alpha = 717$. The demand function for one wild boar is then $p(H) = 717 - 0.02H$.

The existence of non consumptive values is not so evident for the case of wild boar, in contradiction to red deer, roe deer or bear and so on. The meeting of a walker with a wild boar can create a sense of fear and even represent a dangerous situation. We make the assumption that non use values are null for this specie. The parameters of the non consumptive function are null $a = b = 0$.

About damage, data collected from the farmers' claims for crop damage give the damage function $D(N) = 5917.N^{0.63}$ (Rakotoarison, 2008). The marginal damage function is

$D'(N) = 3728.N^{-0.37}$

For the choice of the discount rate, we will use the results of Weitzman (1998) who asked to 1740 economists which interest rate they are going to use to value the benefit and the cost of a project which will limit the impact of climatic change. The average response was 3.967%. We will use $\delta = 0.04$ for all the rest of the article.

For the biological parameters of wild boar, Stone and Dunn (2008) show that 100 females give born to 373 young wild boars and the rate fecundity is 81%. The birth rate is then $T_N = 0.5*0.81*3.73 = 1.51$. The average lifetime of a wild boar is 10 years, which give a mortality rate of $T_M = 0.1$. The growth rate of the wild boar population is then $r = T_N - T_M = 1.51 - 0.1 = 1.41$.

Stone and Dunn (2008) shows also that the average carrying capacity of the environment is between 3 to 5 wild boar per km². The Aquitaine region has 21815 km² of agricultural fields, forests and wetlands where wild boar population can live. We take the average value 4 wild boar per km², so $K = 87260$.

$r = 1.41$; $K = 87260$; $\beta = 0.04$; $\alpha = 717$; $a = b = 0$; $cd = 3728$; $d - 1 = -0.37$;

3.2. Multiple optimality candidates

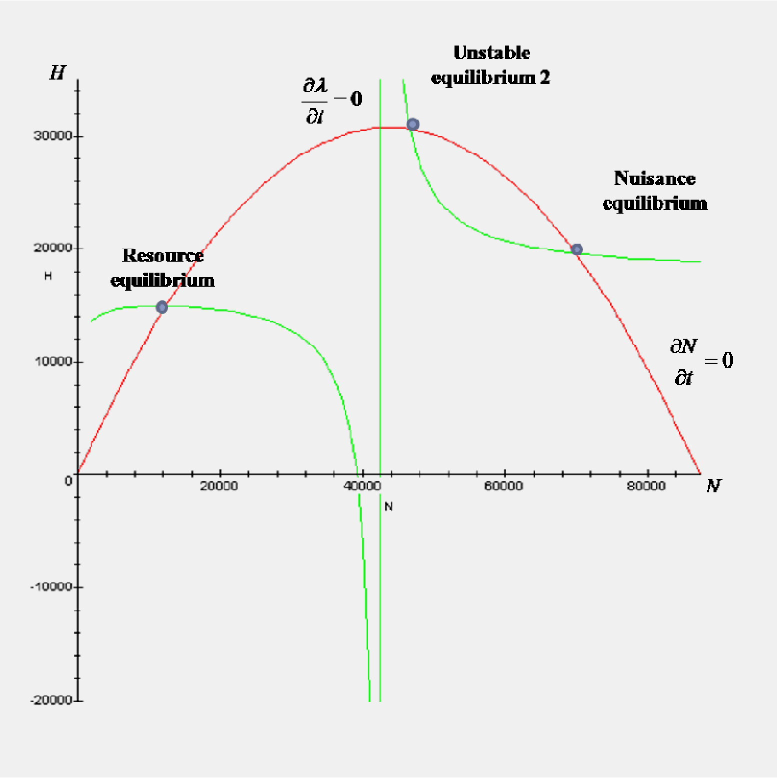
We replace all these values inside the equations (13) and (15). We omit the symbol * indicating that they describe optimal situations.

$$H = 1.41N\left(1 - \frac{N}{87260}\right) \qquad \textbf{(16)}$$

$$H=\frac{1}{0.04}\left[717+\frac{3728N^{-0.37}}{0,04-1,41\left(1-\frac{2N}{87260}\right)}\right]=17925+\frac{93200N^{-0.37}}{\frac{2.82N}{87260}-1.37} \qquad \textbf{(17)}$$

There are two variables and two equations. We trace in figure n°1 these two equations to find the solutions. The equation (16) intersects four times the equation (17).

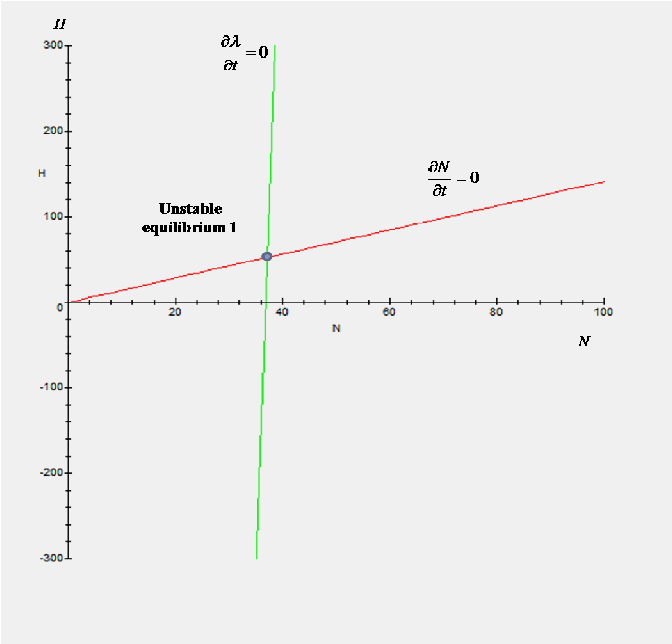
Figure n°1: The optimal solutions.



The four solutions correspond to the size of population 37, 12 385, 46 650 and 69 890 wild boar. A zoom zero show the first solution in figure n° 2.

Figure n°2: The optimal solution around 0.

H



The economic and the biological results are detailed in table n°3.

Table n°3: Solutions of the model in the Aquitaine region.

Steady states	**Symbols**	**Unstable equilibrium 1**	**Commodity equilibrium**	**Unstable equilibrium 2**	**Nuisance equilibrium**
Stock of population	N	37	12 385	46 650	69 890
Hunting *t+1*	H	52	14 984	30 612	19 616
Annual benefits for hunting (euros)	$B_H(H)-C_H(H)$	37 336	6 253 159	3 207 026	6 368 897
Non use benefits (euros)	$B_E(N)$	0	0	0	0
Annual crop damage (euros)	$D_N(N)$	57 553	2 241 951	5 169 852	6 669 343
Net social benefit (euros)	$B_H(H)-C_H(H)$ $+B_E(N)-D_N(N)$	- 20 217	4 011 209	- 1 962 826	- 300 445
Net marginal benefit on site (euros)	$B'_H(H)-C'_H(H)$	715	118	- 507	- 68
Net marginal benefit off site (euros)	$B'_E(N)-D'_N(N)$	- 980	- 114	- 70	- 60
Class of big game following Erwin and Bulte (2004)		II	II	IV	IV
		Commodity/ liability	Commodity/ liability	Nuisance/ liability	Nuisance / Liability

Due to the assumption that wild boar do not produce non consumptive values, the net marginal benefit off site is always negative for the four solutions. For the first and second solutions called “commodity equilibrium”, hunters’ harvests correspond to their demand function and wild boar is considered as an interesting environmental resource (Class II). The value of wild boar hunting is however 6 times higher for the first solution compared with the second one. In the third and forth solutions, wild boar is considered as a nuisance for hunters and the rest of the society (Class IV). Hunters must hunt over their demand to control damage. The rest of the society support high damage. The value of annual crop damage is doubled compared with the second solution. However, the marginal damage is lower.

3.3. Saddle solutions

The equation (17) forms an asymptote towards + /-infinity when the denominator is null. It is the case when N=0 and when $\delta - F'(N) = 0 \Leftrightarrow N = 42392$. The first solution *N=37* and the third solution *N*=46 650 are around these asymptotes making them unstable. Only the second and the forth solutions are saddles and are actually candidates for optimality (Tahvonnen and Salo, 1996; Huffaker and Wilen 1989; Horan and Bulte, 2004). With multiple optimality candidates, it is necessary to study transition paths as they indicate which steady states are optimal. As Boman et al. (2003), we build new implicit functions from the equations (16) and (17).

$$G_1(N,H) = 1.41N\left(1 - \frac{N}{87260}\right) - H \tag{18}$$

$$G_2(N,H) = 17925 + \frac{93200N^{-0.37}}{\frac{2.82N}{87260} - 1.37} - H \tag{19}$$

Depending the signs of $G_1(N,H)$ and $G_2(N,H)$, we find two paths: Path A and path B as shown in figure n°3. If $N < 42392$, the system will follow path A and wild boar is hunted as commodity and liability (class II). If $N > 46650$, the system will follow path B and wild boar is hunted as nuisance and liability (class IV). Finally, when $42392 \leq N \leq 46650$, path A and path B are both options.

Figure n°3: Phase diagram and saddles.

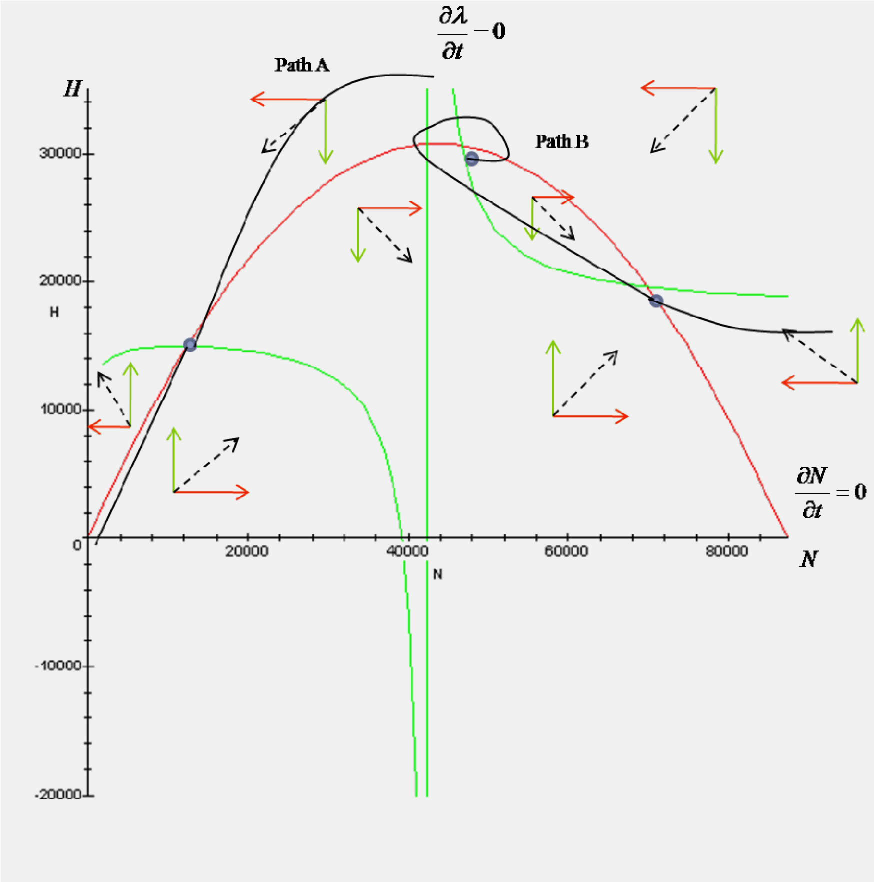
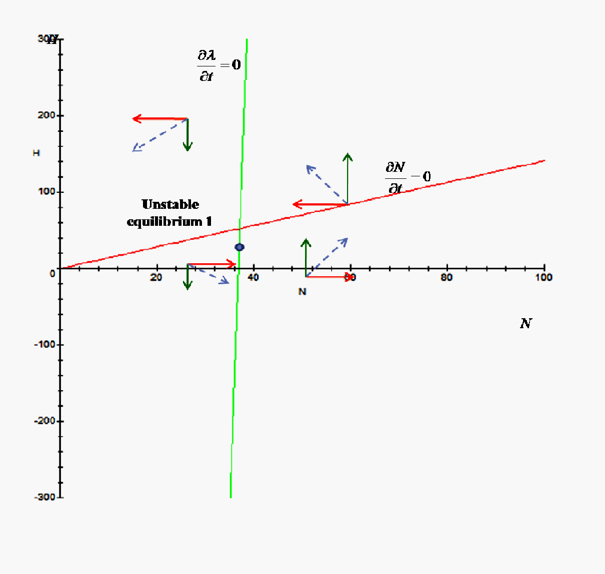


Figure n° 4: a zoom of the phase diagram around 0.



Conclusion

The management of big game must take into account the different economic values of the resource: the positive impacts as the negative ones and the population growth. We integrate them into a formalized equation to synthesize the problem and to study the solutions of the model. We used classical functional forms and tried to find the value of the parameters for the case of wild boar in the Aquitaine region. It resorts to this analysis that the system may have four optimal solutions depending the size of the population. However, there are only two paths.

First, wild boar is regarded as a commodity in the way that it is an interesting resource for hunters and as a liability, even if it creates to the crop damage. The trajectory will tend to only one point called “the commodity equilibrium”. At a certain threshold size of the population, the trajectory of the system changes completely. The system will tend to another point called “nuisance equilibrium”. Wild boar is hunted for hunting values but much more to control damage as the interests of hunters decrease due to the high number of the population.

For every situation, it is important to mention the importance played by hunters in the control of the resource. Hunting is the main control variable in which the planner can use to change the situation. Concretely, the results of this article can pose two major problems for wildlife managers (Hunters’ federations, local administration, farmers’ group, etc). First, the real size of wild boar is unknown and the level of hunting each year is fixed by the demand of the hunters. For example in 2003, 18 000 wild boar were hunted in the Aquitaine region. In which situation in table n°1 are we? Class II or IV? It is necessary to make much more biological studies on the size of the population. Secondly, if this demand does not correspond to the optimal level as defined in this paper, it is necessary to use regulation instruments. Tax, hunting fee and quota are adequate if the resource is considered as commodity. Subsidies are adequate when the resource represents a nuisance.

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