COST-BENEFIT ANALYSIS OF A PROJECT CONCERNING THE MANAGEMENT OF AN INVASIVE SPECIES IN A COASTAL FISHERY: THE CASE OF CREPIDULA FORNICATA IN THE BAY OF BREST (FRANCE)

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ABSTRACT

This paper studies the economic consequences of the invasion of a coastal fishery (Bay of Brest) by an exotic species (*Crepidula fornicata*) which was accidentally imported some decades ago. This species is a space competitor for the main targeted species of the fishery (*Pecten maximus*), and its development is a threat to the sustainability of the restocking program which is operated in the bay. Facing this situation, the local fishers organization has elaborated a project intending to make the restocking program consistent with the presence of the invasive species in the fishery. The paper presents a model dealing with the social cost of the invasive process, and a methodology for a cost-benefit analysis of the fishers project. Based on provisional data, a numerical simulation is proposed as an illustration, and sensitivity tests concerning both biological and economic exogenous variables are presented.

Keywords: invasive alien species; fishery management; cost-benefit analysis; biodiversity loss

INTRODUCTION

Biological invasions are supposed to be the second most important cause of biodiversity loss worldwide [1]. According to Article 8 (h) of the Convention on Biological Diversity (CBD), 1992, Invasive Alien Species (IAS) are exotic species that are introduced and whose establishment and spread threaten ecosystems, habitats or species with economic or environmental harm. The use of exotic species in economic activities, the conversion of habitat and the liberalization of markets with expansion of exchange and mobility of people cause an increase of invasions all around the planet [2]. Biological invasions are the intended or unintended consequence of economic activities and impose real costs on society by altering the relative abundance of harvested and non-harvested species and by changing ecological services. The value of species in an ecosystem derives from the value of the goods and services they support: the analysis has to be ecological as well as economic. Understanding the problem requires understanding the interactions between social and natural processes. Biological invasions in aquatic systems impose significant costs in terms of forgone output or costs of control in every major system except for pelagic marine systems [3].

Biological invasions are an economic problem [4]. The effects of IAS are external to the market because the costs they impose are not borne by the activities which cause the invasion. Furthermore, common property regimes of aquatic systems require collective action. Because common pool resources are non exclusive, anyone has a strong incentive to take a free ride on the efforts of others which may lead too less control than is socially desirable. Thus, the control of invasions is in the nature of a public good and requires public policy. We need to understand IAS implications for human welfare and measure the social cost of the invasive process.

The fact that biological invasions belong to the category of low-probability events but with a high potential cost and irreversible effects implies a precautionary approach. The precautionary approach expresses that where the effects of some activity are uncertain, but potentially costly and irreversible, society should take action to limit them before the uncertainty is resolved. The CBD tells Parties to "prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species." Assessing the social cost enables us to elaborate a public policy to reduce the damages.

Once invasion has taken place, eradication is often impossible. The control, or containment, of the IAS should involve economic analysis and economic instruments in order to guarantee the efficiency of public policies. A classic method for evaluation of management options is Cost-Benefit Analysis. This method, which evaluates the social yield of public projects, may be applied to environmental economics [5]. In the case of IAS, a control program is economically justified if the expected present value of the benefits it generates are no less than the expected present value of the costs of control.

This paper deals with the case of the IAS *Crepidula fornicata* in the Bay of Brest which damages the local scallop fishery. This exotic shellfish was accidentally imported in ships ballast water during World War II and started to spread two decades ago. By altering biodiversity, this invasion has transformed the ecosystem into a new configuration with consequences for human welfare. Biological knowledge shows that this IAS is a space competitor for the main targeted species of the fishery (*Pecten maximus*) inducing stock depletion [6 and 7]. It damages the welfare of the fishers by reducing the space occupied by the harvest species and so threatens the viability of this economic activity. Furthermore, following a collapse of the stock in the 1960s a restocking program (R-Pg) was developed in the bay [8] and his now operated on a cost-recovery basis: the yearly cost of licences paid by fishers is now equivalent to the global operating cost of the program. The development of the IAS is a threat to its technical and financial sustainability. Facing this situation, the local fishers organisation has elaborated a project intended to make the restocking program consistent with the presence of the invasive species in the fishery.

At the intersection of environmental and fisheries economics, the paper presents a model dealing with the cost of the invasive process for the scallop fishery, and a methodology for a cost-benefit analysis of the fishers containment project. As the present level of knowledge concerning the population dynamics of the IAS does not allow complete elaboration of a realistic optimal control program, we will limit this presentation to a few alternative scenarios.

The paper has two sections. The first section develops an economic assessment of the social cost of the invasive process. The second one presents a Cost-Benefit Analysis of the IAS containment program. In each section, we first develop the model in algebraic terms; then we illustrate it by a numerical simulation, based on provisional data; finally we present sensitivity tests concerning both biological and economic exogenous variables.

SOCIAL COST OF THE INVASIVE PROCESS

Model

The Invasive Alien Species imposes costs on the Bay of Brest fishers by two ways: a direct cost, due to time spending to scrape the exotic species fixed on the scallop shells; an indirect cost, caused by the IAS spread which induces a reduction of harvestable areas, and therefore threatening the R-Pg. We propose an assessment method of the invasive global (direct and indirect) cost for the fishery, based on a comparison of two scenarios:

- Scenario I: maintain of the R-Pg in its present state, without biological invasion and costs generated;
- Scenario II: simulation of the fishery evolution subject to invasive process.

In each scenario, the value of the R-Pg is calculated, defined as the discounted value of the intertemporal flow of net incomes. The global cost of invasion is estimated by the difference between the two calculated values.

Scalloping in the Bay of Brest is only a part time activity for fishers. We will consider only costs and benefits which are directly related to this activity. This means that we assume the global sustainability of their business is not affected by the future of the scallop fishery. This is a questionable assumption [9], the abandon of which would impose to build a more complex and general model.

Scenario I: value of the fishery R-Pg without invasion

Supposing that the fishery level of activity for the reference year (t =0) is a sustainable state of equilibrium, the value of the R-Pg is given by the following relation:

$$V_I = (M-L)\cdot\lim_{m\to\infty}\left[\sum_{t=1}^{m}\frac{1}{(1+a)^t}\right] = \frac{M-L}{a} \qquad \text{(Eq. 1)}$$

with:
$M = PY - C$
M = gross margin of the R-Pg (K€)
P = unit price net from tax (€/kg)
Y = aquaculture scallops catches (tons)
C = specific variable cost (K€, proportional to effort)
L = yearly licenses cost (K€)
a = time discount rate (%)

Scenario II: value of the R-Pg subject to invasion

We assume that invasion harms the R-Pg by two ways:
- *Direct cost*: scraping the shells on which the IAS is fixed represents an additional work, proportional to catches. SY is the opportunity cost of this additional work for the reference period. Thus, the gross margin corrected with the direct cost, for the reference period, is formulated as (M - SY), where S is the unit scraping cost (K€/ton).
- *Indirect cost*: the IAS spread does not change the level of CPUE but induces a gradual reduction of harvestable areas, at constant yearly rate noted b. As long as the corrected gross margin taking account of scraping costs is high enough for covering licenses cost, fishers are supposed to dredge all the remaining harvestable area, with a constant effort rate per unit area. In these conditions, the corrected gross margin decreases year by year proportionally to the harvestable area:

$$M_t = (M-SY)\cdot(1-b)^t \quad \text{if } M_t \geq L \qquad \text{(Eq. 2)}$$

$$M_t = 0 \quad \text{if } M_t < L \qquad \text{(Eq.3)}$$

with: b= rate of decrease in harvestable area due to IAS (%)

According to Eq. 2 and 3, the last year of R-Pg operating is the whole number n such that:

$$n \in \left]\tilde{n}-1;\tilde{n}\right] \quad \text{with } \tilde{n} \text{ as } (M-SY)\cdot(1-b)^{\tilde{n}} = L \qquad \text{(Eq. 4)}$$

with: n= R-Pg life duration with the invasive process

The value of the R-Pg with invasion is expressed as:

$$V_{II} = \sum_{t=1}^{n}\frac{(M-SY)\cdot(1-b)^t - L}{(1+a)^t} \qquad \text{(Eq. 5)}$$

Global cost of the invasive process for the fishery R-Pg

It is the difference between the value of the R-Pg subject to the invasive process, and its value without invasion. The result shows the global damage caused by the spread of the exotic species. It gives an assessment of the loss of welfare due to the invasive process.
The global cost of the IAS is equivalent to:

$$V_{II} - V_I \qquad \text{(Eq. 6)}$$

Numerical Simulation

As an illustration of the model, we propose a numerical simulation using available data concerning the fishery [9] and the invasive process [6 and 7]. The following assumptions are made:
H1: The reference period (t = 0) used is the 2000-2001 scalloping campaign.
H2: Considered costs include landings tax, oil, gear, labour and part of maintenance costs.
H3: The opportunity cost of labour is assessed by the legal minimum wage.
H4: Scallop shell scraping represents a working time of 15,5 hour per ton.
H5: The annual rate of harvestable area reduction is supposed to be b=25%. It represents a decrease in harvestable area of 97% in 12 years.
H6: The time discount rate is 5%.

It should be stressed that the R-Pg is in progress in the Bay, and its long term equilibrium has not yet been reached. Therefore, the level of catches allowed by the R-Pg is uncertain, influencing our results. The main simulation uses the 2000-2001 landings as a proxy for the long term equilibrium level of catches. According to the simulation, the value of the R-Pg without invasion is 11414 K€ and the one subject to the invasive process falls to 478 K€ (Table I). Thus, the evaluation of the social cost imposed by the spread of the IAS is about 10935 K€ (absolute value). It represents a reduction of 96% in the R-Pg value, due to biological invasion. Furthermore, the development of the exotic species makes the R-Pg unsustainable: its life duration is reduced to 3 years instead of an infinite one. Therefore, the simulation suggests that the spread of the IAS imposes substantial costs to fishers.

Table I: Assessing the social cost of invasion: numerical simulation

Discounted values, in '000 euros	*Restocking program*		
	No invasion	*Invasion*	*Social cost of invasion*
	V_I	V_{II}	V_{II} - V_I
Main simulation	11414	478	- 10935

Sensitivity Tests

Sensitivity tests on the main parameters are made in order to evaluate their influence on results of the simulation. A first series of tests consists in testing the impact of the parameters on the social cost of invasion. Each time, we consider a high and a low hypothesis concerning the parameters value (Table II). According to the results of the tests, social cost of invasion is an increasing function of the sustainable level of catches of the non invaded fishery, of prices and of the rate of invasion. It is a decreasing function of time discount rate. Tests show a high sensitivity of results to the assumption concerning the permanent sustainable level of catches of the non invaded fishery. However under most realistic assumptions, the social cost of invasion is high.

Table II: Assessing the social cost of invasion: sensitivity tests

Discounted values, in '000 euros	*Restocking program* No invasion V_I	Invasion V_{II}	Soc. cost of invasion V_{II} - V_I
Main simulation	11414	478	- 10935
Sensitivity tests			
Catches			
Y_1 = 123 tons [1]	2170	0	- 2170
Y_2 = 350 tons [2]	21420	1329	- 20091
Prices			
P_1 = 2.96 euros / kg [3]	5474	96	- 5379
P_2 = 5.85 euros / kg [4]	18884	1119	- 17765
Invasive process			
b_1 = 15% [5]	11414	979	- 10435
b_2 = 40% [6]	11414	181	- 11232
Time discount rate			
a_1 = 3%	19023	491	- 18531
a_2 = 10%	5707	448	- 5239

[1] Average yearly catches during period 1995-2001. [2] Theoretical yield of juvenile sowing.
[3] Minimum yearly average price during the past 20 years (constant euros).
[4] Maximum yearly average price during the past 20 years (constant euros).
[5] 95% reduction rate of harvestable area within 19 years.
[6] 95% reduction rate of harvestable area within 6 years.

Another sensitivity test consists in testing the impact of the speed of invasion on the technical and financial sustainability of the R-Pg (Figure 1).

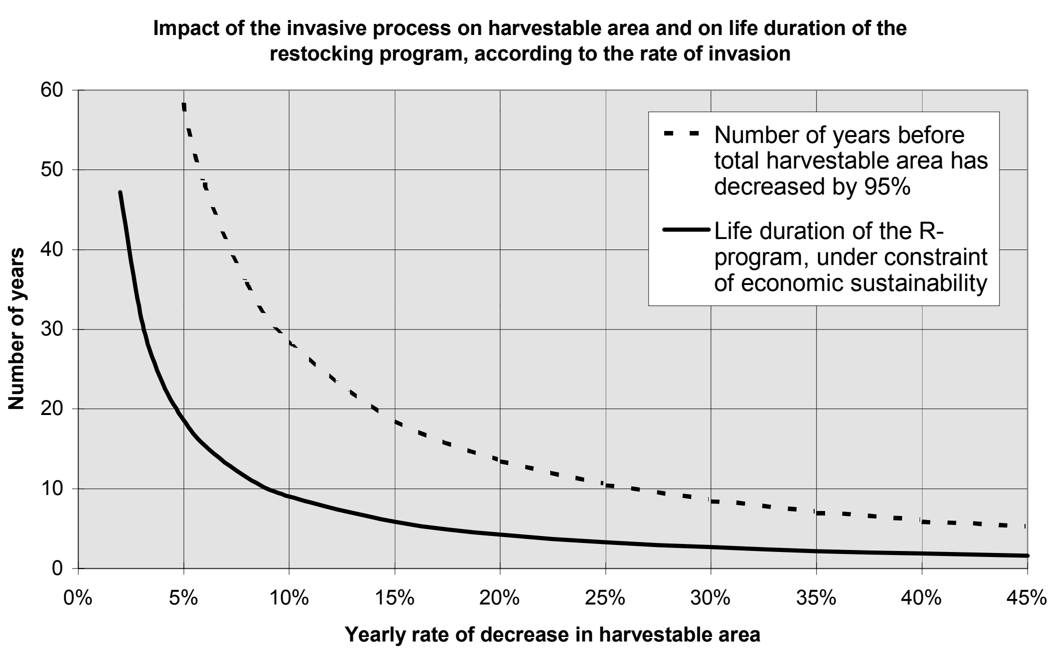

Figure 1. Impact of the invasive process

For every level of the rate of invasion (*b*), the number of years before total harvestable area has decreased by 95% is always substantially higher than the life duration of the R-Pg under constraint of cost recovery. This is due to the fact that yearly licenses paid by fishers have to cover the operating cost of the R-Pg, which are fixed costs. The realistic range for *b* is generally supposed to be between 15% and 40%. For such rates, Figure 1 shows that the R-Pg economic viability is threatened in the near future. Hence the interest for a program aiming at IAS containment.

COST-BENEFIT ANALYSIS OF A CONTAINMENT PROGRAM (C-Pg)

Model

Complete eradication of the IAS from the Bay is not technically realistic under present conditions. In order to control the spread of the IAS and its negative effects on the scallop fishery, the Local Fisheries Committee has elaborated a containment program (C-Pg) combining IAS cleaning operations with aquaculture scallop sowing operations.
We use Cost-Benefit Analysis (CBA) to assess the social efficiency of this program. CBA aims at evaluating the social yield of various alternatives concerning a public project in order to rank them and to allow public authorities to choose the one which is the most profitable to society. The philosophy of this method [10] is i) to list all the stakeholders, ii) for each of them to assess, in monetary terms, costs and benefits generated by each alternative, iii) for each alternative, to aggregate all costs and benefits in order to obtain a global balance.
Cost-Benefit Analysis of the C-Pg is based on the comparison of the following two values:

- Value (V_{II}) of the R-Pg submitted to the invasion (see Scenario II in the former section of the paper);
- Value (V_{III}) of the C-Pg (Scenario III).

We first determine V_{III} , then we calculate the social yield of the C-Pg.

<u>Scenario III: value of the C-Pg</u>

The C-Pg has not started yet and its precise content is still subject to possible changes. Therefore, what we present here is based on provisional data, and should be regarded mainly as a methodological approach. The time schedule of the combined cleaning and sowing operations is described in Table III.

Table III: Timetable of the C- Program

Year	Clean and sow in the area	Harvest in the area	Costs of C- Program	Gross margin
0	-	-	I	-
1	[1]	-	$C'+L$	$(M-SY)(1-b)$
2	[2]	-	$C'+L$	$(M-SY)(1-b)^2$
3	[3]	-	$C'+L$	$(M-SY)(1-b)^3$
4	[1]	[1]	$C'+L$	M
5	[2]	[2]	$C'+L$	M
6	[3]	[3]	$C'+L$	M
7	[1]	[1]	$C'+L$	M
8	[2]	[2]	$C'+L$	M
9	[3]	[3]	$C'+L$	M
etc.	etc.	etc.	etc.	etc.

Each year, a small area (300 ha) is cleaned up, and 10 million aquaculture juvenile scallops are sown in this area (this quantity is the same as the one formerly sown each year within the R-Pg). They are harvested three years later. The program functions with 3 different areas on a crop rotation basis. One year prior to the beginning of the program (year 0), a boat specially designed for cleaning operations is bought (price: *I*). Cleaning operations start at year 1 (yearly cost: *C'*). During this year and the two following ones no harvest takes place on the cleaned areas, and fishers go on dredging in other (invaded) areas. From year 4, they start harvesting the cleaned areas.

The C-Pg can be regarded as an investment: initial expenditures are made for cleaning the area and a flow of future net benefits is expected from them. Thus, the net present value of the C-Program is:

$$V_{III} = -I + \sum_{t=1}^{3} \frac{(M - SY)(1-b)^t - L - C'}{(1+a)^t} + \lim_{n\to\infty} \sum_{t=4}^{n} \frac{M - L - C'}{(1+a)^t} \qquad \text{(Eq. 7)}$$

or alternatively, combining Eq.7 with Eq.1:

$$V_{III} = \sum_{t=1}^{3} \frac{(M - SY)(1-b)^t - L}{(1+a)^t} + \frac{V_I}{(1+a)^3} - \left(I + \frac{C'}{a}\right) \qquad \text{(Eq.8)}$$

In Eq.8, the first part of the right hand side is the present value generated by harvesting aquaculture scallops before scalloping on cleaned areas starts. The second part is the present value of gross margins generated by harvesting cleaned areas. Except for the time discount factor, this value is the same as the one generated by the initial R-Pg when there is no invasion (see Scenario I). The third part is the present value of cleaning costs (including initial purchase of the boat).

Social yield of the containment program

The social yield of the C-Pg is the net additional wealth which it generates. It is the difference between its value and the value of the R-Pg with a fishery subject to invasion:

$$V_{III} - V_{II} \qquad \text{(Eq. 9)}$$

Numerical Simulation

As an illustration, Table IV describes a numerical simulation using available data concerning the fishery [9] and a draft of the control program [11]. We add the following assumptions to assumptions *H1-H6* (see first section of this paper):
H7: The purchase price of the boat (*I*) is 152 K€.
H8: The yearly cleaning cost of the C-Pg (*C'*) is 132 K€.

Table IV: Assessing the social yield of containment program. Numerical simulation

Discounted values, in '000 euros	*Invasion* V_{II}	*C-Pg* V_{III}	*Soc. yield of program* V_{III} - V_{II}
Main simulation	478	7546	7067

According to the simulation, the value of the C-Pg (V_{III}) is positive, which means that the present value of the gross margins it generates is higher than the present value of the costs of combined cleaning and sowing operations. Moreover, V_{III} is significantly higher than V_{II} (15 times higher, according to the simulation). This tends to justify the implementation of the containment program, rather than sticking to the initial restocking program, which is bound to unsustainability under invasive conditions (see first section).

Comparing the value of the C-Pg (V_{III}) with that of the R-Pg without invasion (V_I) gives a new indication of the loss of welfare due to biological invasion (Table V). The initial cost of invasion is reduced by the implementation of the C-Pg: (V_{III} - V_I) is lower than (V_{II} - V_I) in absolute terms. Moreover, with the C-Pg, the fishery returns to sustainability. (V_{III} - V_I) represents that part of the damages due to the IAS which is not compensated by the containment program.

Table V: Impact of the C-Pg on the social cost of invasion. Numerical simulation

Discounted values, in '000 euros	*Initial value* $V_{II} - V_I$	*Modified value* $V_{III} - V_I$
Main simulation	-10935	-3868

Sensitivity Tests

The sensitivity tests presented in Table VI rely on the same parameter values as the ones of the first section of the paper (see Table II).

Table VI: Assessing the social yield of containment program. Sensitivity tests

Discounted values, in '000 euros	*Invasion* V_{II}	*C-Pg* V_{III}	*Soc. yield of program* $V_{III} - V_{II}$
Main simulation	478	7546	7067
Sensitivity tests			
Catches			
Y_1 = 123 tons [1]	0	- 917	**- 917**
Y_2 = 350 tons [2]	1329	16964	15635
Prices			
P_1 = 2.96 euros / kg [3]	96	2033	1937
P_2 = 5.85 euros / kg [4]	1119	14592	13474
Invasive process			
b_1 = 15% [5]	979	7906	6927
b_2 = 40% [6]	181	7249	7067
Time discount rate			
a_1 = 3%	491	13348	12856
a_2 = 10%	448	3264	2816

[1] Average yearly catches during period 1995-2001. [2] Theoretical yield of juvenile sowing.
[3] Minimum yearly average price during the past 20 years (constant euros).
[4] Maximum yearly average price during the past 20 years (constant euros).
[5] 95% reduction rate of harvestable area within 19 years.
[6] 95% reduction rate of harvestable area within 6 years.

There is a high similarity between the results of these tests and the ones that have been realized in section 1. The main new thing is that the social yield of the containment program becomes negative if the level of catches does not exceed the average level of years 1995-2001. This result is based on a pessimistic assumption, since the R-Pg was still in progress during the 90'. However, it suggests that a positive yield should not be taken for granted.

Table VII compares parameter values corresponding to the main simulation and the ones that make the social yield of the C-Pg equal to zero. Break-even values of catches and prices are 58% of main simulation values, and not far from the low assumptions made for these parameters in Table VI. Contrasting with this result, break-even values of invasion speed and time discount rate are off-limits compared to realistic values of these parameters.

Table VII : Assessing the social yield of the containment program. Main simulation values and critical values of major parameters

Parameter values	Catches (tons)	Price (euros / kg)	Invasion process	Time disc. rate
[1] Main simulation	232	4,24	25 %	5 %
[2] Break-even point*	135	2,48	1 %	43 %
[2] / [1]	0,58	0,58	0,04	8,6

* Value of considered parameter such that (V_{III} - V_{II} = 0), with main simulation values for other parameters

As a conclusion to sensitivity tests, it appears that the most sensitive parameter concerning the economic justification of the C-Pg is the sustainable level of catches of the non-invaded fishery.

CONCLUSION

This paper has studied the economic impact of the spread of an invasive species on an inshore fishery operated with the help of a restocking program. According to the simulations made, this process is to be regarded in the short run as a serious threat to the economic viability of the restocking program, and therefore to the fishery itself. Making use of Cost-Benefit Analysis, we have also studied the social yield of a draft program combining containment of the invasive species with restocking operations. The results of the main simulation indicate that the social yield of this program would be positive, i.e. that it would reduce substantially the social cost of invasion. Moreover, the program would help maintaining the long term sustainability of the fishery.

However, according to the tests realized, the social yield of the containment program is sensitive to the landing price of the targeted species, and even more to the assumption made regarding its long term equilibrium catches. This parameter is not well known for several reasons. First, regardless of the invasive process, the technical performance of scallop farming in the Bay of Brest is not yet stabilized. Second, it is suspected that an artificial decrease in the stock of the IAS in the bay would affect the ecosystem with possible negative consequences for the targeted species [7]. A deeper analysis should take into account this possible feedback effect of IAS containment on targeted species through ecosystem. It should also take into account the economic interaction between scalloping in the Bay of Brest and other fishing activities of the fleet operating this fishery [9].

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