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Controlling the biological invasion of a commercial fishery by a space competitor

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Presentation framework

1. Real case study
2. Theoretical bioeconomic model
3. Application to the bay of Saint-Brieuc scallop fishery

1. Real case study: slipper-limpet *versus* common scallop in the bay of Saint-Brieuc (France)

An invasive species void of market value (slipper-limpet) competes for space with a commercial native species (scallop). This competition is asymmetric.

Invasive species: *Crepidula fornicata*

- Native from Northeastern America

- First noticed in the bay in 1974

- Invaded area (with negative impact on scallop beds): 10,65% of the bay in 1994 (Hamon et Blanchard, 1994)

⇒ **Threats the long term viability of the 2nd largest French scallop fishery**

The 2nd largest French scallop fishery

→ Common scallop *Pecten maximus*

→ Seasonal fishing activity

2007 / 2008 Scalloping Campaign:

- ≈ 250 vessels
- 7,099 tons of landings
- 13 million euros of turnover

2. Theoretical bioeconomic model

(Frésard, 2008; Frésard and Boncoeur, 2008)

2.1. Model

We consider the combined dynamics of 2 harvested species, a native valuable one (i = 1) and an invasive one (i = 2), void of commercial value and acting as a space competitor:

– 2 state variables: native stock biomass and the part of the invaded area in the whole area of the bay (X_1 , X_2)

– 2 control variables: harvesting effort applied to each species (E_1, E_2)

– Objective: to maximize the discounted flow of surplus π generated by the combined harvest of both species (profit generated by harvesting the native stock, minus cost of cleaning the invaded areas)

2.2. Invaded fishery problem

Determine: $\left(E_1, E_2\right)$ over $t \in [0;\infty[$

such that: $\int_0^\infty \pi e^{-at}\,dt \rightarrow \max.$

subject to:

$$dX_1/dt = rX_1\left(1 - \frac{X_1}{K\left(1 - X_2\right)}\right) - q_1 E_1 X_1$$

space competition

$$dX_2/dt = \left(s + gE_1\right)X_2\left(1 - X_2\right) - q_2 E_2 X_2$$

impact of native stock fishers behaviour

$$\left.\begin{aligned} X_i(0) &= X_{i0} \\ 0 \le E_i &\le E_{i\max} \end{aligned}\right\} \quad (i = 1,2)$$

2.3. Results of the dynamic optimization

- A time-path leading to an optimal steady-state equilibrium where the native species is sustainable harvested and the invasive species is kept under control exists, provided harvesting costs, natural and anthropogenic invasive species dispersal coefficients and time discount rate are moderate.
- However, this time-path is optimal only if the invasion problem is addressed early enough.
- In other circumstances, the optimal time path leads to an asymptotic eradication of the native stock.
- In this case, the fishery will close once the invasion has reached a level corresponding to the breakeven point for harvesting the native stock.

3. Application to the bay of Saint-Brieuc case

3.1. Materials and methods

- *Common scallop dynamics and harvest*

→ age-structured bioeconomic model (developed by Guyader and Fifas, 1999; Guyader et al., 2004, and upgraded by Fifas and Frésard in 2008), period of simulation : 2008-2030.

- *Slipper-limpet spatial invasion dynamics*

→ previous theoretical model used as a simulation tool in discrete time;

→ conventional data (derived from Hamon and Blanchard, 1994; Blanchard and Hamon, 2006).

- *Slipper-limpet control*

→ previous theoretical model used as a simulation tool;

→ harvest data from the invasion control program implemented (Anon., 2005).

- *Space competition*

→ a negative relation between the level of invasion and the probability of scallop recruitment success (Frésard, 2008):

$$GR1_{inva} = (1\text{-}X_2)\ GR1$$

where: $GR1_{inva}$ is the abundance of scallop of age 1 with invasion

$(1\text{-}X_2)$ is the part of the whole area of the bay which is not invaded by slipper-limpet

$GR1$ is the abundance of scallop of age 1 without invasion

⇒ Scallop recruitment success (and ensuing harvestable biomass) depends on the unharmed area of the bay.

! Due to the lack of data concerning the slipper-limpet impact on the scallop recruitment, **$(1\text{-}X_2)$ is a conventional term**.

- *Cost-benefit analysis of the control program (vs laisser-faire)*

3.2. Main results and limits

- *Impact of the control program on the scallop fishery*

→ after 23 years, the part of the unharmed area of the bay is 29% and the scallop catches are 18% higher with invasion control than without it.

- *Economic results of the control program*

Cumulated time discounted economic results of invasion control and *laisser-faire* scenarios (unit : million euros, period 2002-2024, time-discount rate 5%)

	Laisser-faire scenario	Control scenario
Scallop fishery gross margin	181.6	193.1
Cleaning cost of invaded area	0	2.8
Net benefit	**181.6**	**190.3**

→ the control program generates a net benefit higher by +5% than the *laisser-faire* scenario.

!this result have to be carefully considered: the difference between the scenarios results is low and invasion dynamics remains uncertain.

- *Limits*

→ limited empirical knowledge of invasion dynamics and space competition ⇒ the cost-benefit analysis methodology developed for this case study would be operational if those observable data were better known.

→ exogenous scallop prices

Thank you!

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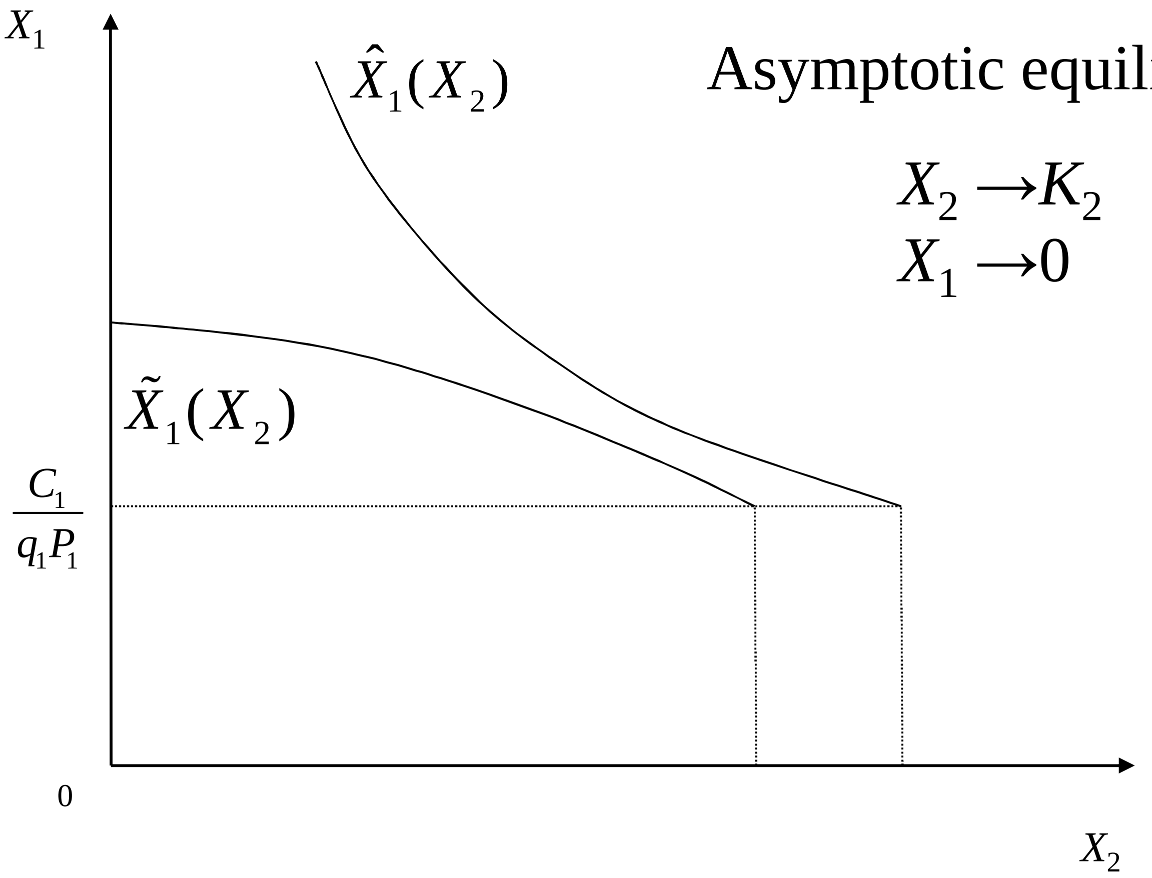
Dynamic optimization of the theoretical model

First case: quasi-eradication of native stock

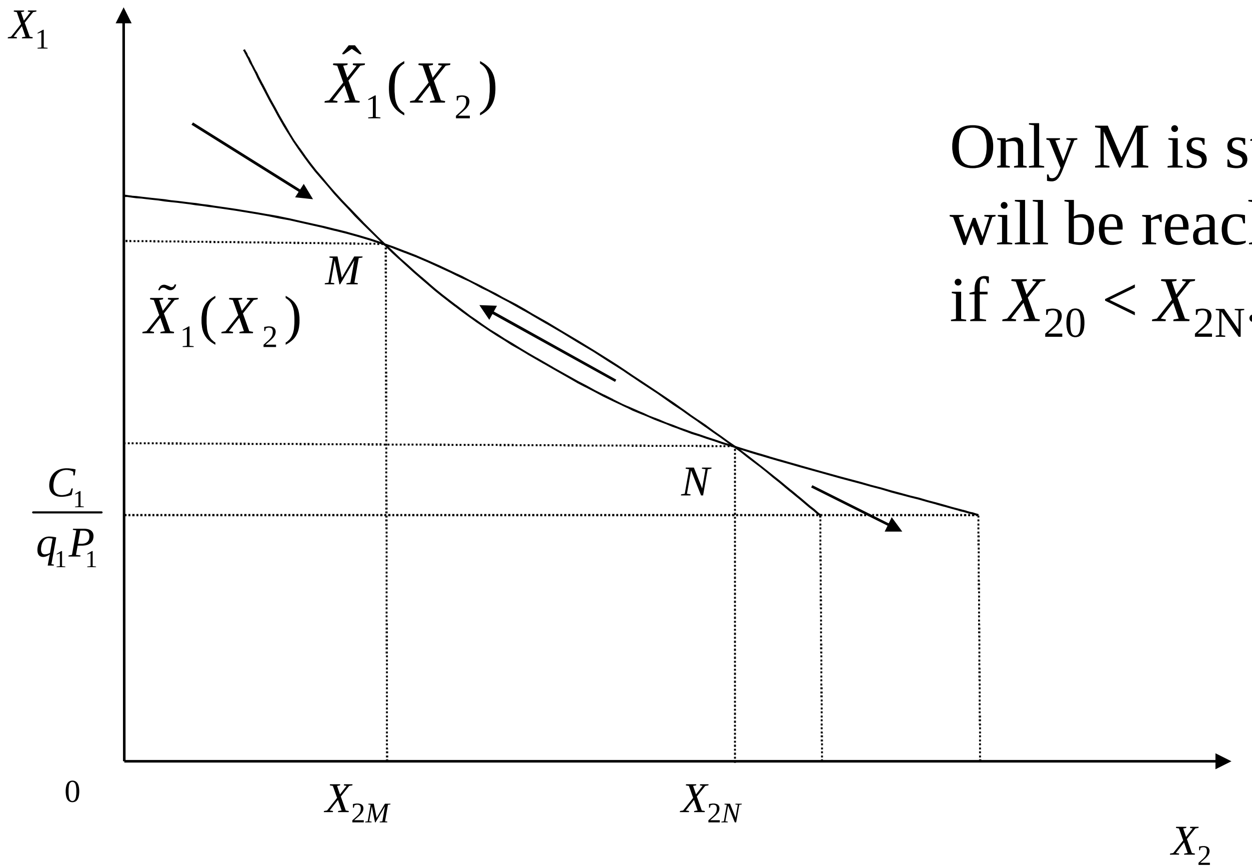


Asymptotic equilibrium:

$$X_2 \to K_2$$
$$X_1 \to 0$$

This case corresponds to a situation where harvesting costs, natural and anthropogenic invasive species dispersal coefficients and time discount rate too high for controlling invasion.

2nd case: two equilibria corresponding to economically sustainable harvests of both species.



Only M is stable. It will be reached only if $X_{20} < X_{2N}$.

Assuming this, during the convergence process, $E_i(t) = 0$ or $E_i(t) = E_{i\max}$ ($i = 1, 2$), according to initial conditions.

Once M is reached $E_i^*(t) = E_{iS}^* \quad , \quad 0 < E_{iS}^* < E_{i\max}$