Achieving Sustainable Fisheries: Gradually or Abruptly?

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Presentation milestones

• General issue
  – Sustainability and Viability
  – Crisis, crisis duration and recovery strategies

• Recovering sustainable fisheries
  – How to represent the sustainability of a fishery?
  – Viable bioeconomic states of the fishery
  – Minimal Time of Crisis and recovery paths

• Case-study: Bay of Biscay Nephrops fishery
  – Recovering from 1994 crisis situation
  – Trade-offs between time of crisis and transition cost
Sustainability of a Bioeconomic system

- Objectives of different natures (Economic, social, ecological)
- If one of the objective is not achieved, the system faces a crisis
  - Sustainable management of natural resources can be seen more like a “satisficing” problem than like a maximizing one.
  - Sustainability is the ability to avoid crisis in the long-run: it is a dynamical issue
- Need for a framework that encompasses the diversity of sustainability objectives: Need for a multicriteria approach (Charles, 1994)

Recovering sustainable bioeconomic systems

- Several ecosystems are already overexploited (Millenium Ecosystem Assessment, 2005), raising the issue of their recovery.

- Bioeconomic system restoration are dynamic issues
  - Choice of adequate objectives (viability goals)
  - Identification of the paths leading to these objectives
  - Selection of a recovery trajectory

- An implicit political objective is to avoid crisis; Recovery issue consists in reducing the crisis duration

- BUT: to succeed, recovery programs must be accepted and applied.

- Trade-off between speed of recovery and acceptability of the recovery program
Recovering a sustainable fishery

- Objectives of fisheries management (Hilborn, 2007)
  - Biological: preserve stocks and ecosystems, and maximize their productivity
  - Economic: Maximize rents
  - Social: Employment, income distribution, maintenance of traditional communities
  - Political: Avoid conflicts (often implicit)

- Overexploitation of natural stocks (FAO, 2004; Garcia & Gainger, 2005): conflicts in objectives and restoration issues

- Bibliography elements
A fishery model

- Two state variables: Fleet size $K$ (number of vessels) and Biomass of a renewable resource $B$

- Two control variables: Fishing effort $e$ (days at sea per vessel) and Enter/exit of vessels in the fleet $\xi$

\[
0 \leq e_t \leq e_{sup} \quad -\xi_{inf} \leq \xi_t \leq \xi_{sup}.
\]

- Dynamics

\[
K_{t+1} = K_t + \xi_t
\]

\[
B_{t+1} = B_t + r B_t \left( 1 - \frac{B_t}{B_{sup}} \right) - qB_t e_t K_t
\]

- Per vessel profit

\[
\pi(B_t, e_t) = \left( p(1 - \tau_d)qB_t e_t \right) \frac{1}{\lambda} - (\omega_f + \omega_v e_t)
\]
Viability constraints

• Biological objective: minimal stock size

\[ B_t \geq B_{\text{min}} \]

• Economic objective: minimal per vessel profit (micro-economic viability)

\[ \pi_t \geq \pi_{\text{min}} \]

• Social objective: minimal fleet size to maintain activity and employment

\[ K_t \geq K_{\text{min}} \]
Crisis indicator, time of crisis

- Crisis indicator of the fishery: does the fishery satisfy the viability constraints at a given time period?

\[ \mathbb{I}(B, K, e, \xi) = \begin{cases} 0 & \text{if } (B, K, e, \xi) \text{ satisfy constraints} \\ 1 & \text{otherwise} \end{cases} \]

- Time of crisis of an intertemporal exploitation path

\[ \mathcal{T}(B(.), K(.), e(.), \xi(.)) = \sum_{t=0}^{\infty} \mathbb{I}(B_t, K_t, e_t, \xi_t) \]
Recovering from crisis situations

- Acceptability of recovery programs: minimal guaranteed transition profit constraint

\[ \pi_t \geq \pi_{\text{trans}} \]

- Admissible recovery decisions

\[
U_{\text{trans}}(B_t, K_t, \pi_{\text{trans}}) = \left\{ (e_t, \xi_t) \Bigg| e_t \in [0, \bar{e}] \text{ and } \pi(B_t, e_t) \geq \pi_{\text{trans}} \right\}
\]

\[ \xi_{\text{sup}} \geq \xi_t \geq \max(K_{\text{min}} - K_t, -\xi_{\text{min}}) \]

- Minimal time of crisis under transition profit constraint

\[
C(B_0, K_0, \pi_{\text{trans}}) = \inf \sum_{t=0}^{\infty} \mathbb{1}(B_t, K_t, e_t, \xi_t)
\]

\[
(B(\cdot), K(\cdot), e(\cdot), \xi(\cdot)) \text{ admissible path}
\]
Map of minimal times of crisis

(a) Minimal time of crisis without transition profit constraint
Maps of minimal times of crisis under transition profit constraints

(b) Minimal time of crisis with $\pi_{trans} = 30$

(c) Minimal time of crisis with $\pi_{trans} = 110$
The Bay of Biscay Nephrops Fishery
Viability of the fishery and historical trajectory

- Viability profit constraint: 130 k€ per year
- Minimal fleet size: 100 vessels
- Fleet’s adjustment speed: 5 vessels
- Minimal resource stock: 5,000 tons

<table>
<thead>
<tr>
<th>Year</th>
<th>Estimated resource stock (tons)</th>
<th>Observed fleet size (vessels)</th>
<th>Observed fishing effort (days at sea per vessel — mean)</th>
<th>Profit (k-euros per vessel — mean)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1994</td>
<td>14,281</td>
<td>309</td>
<td>164</td>
<td>78</td>
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<td>1995</td>
<td>15,054</td>
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<td>1997</td>
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<td>1998</td>
<td>16,871</td>
<td>282</td>
<td>139</td>
<td>88</td>
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<tr>
<td>1999</td>
<td>18,082</td>
<td>270</td>
<td>126</td>
<td>87</td>
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<td>2001</td>
<td>20,721</td>
<td>259</td>
<td>137</td>
<td>133</td>
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<td>2002</td>
<td>20,728</td>
<td>245</td>
<td>147</td>
<td>148</td>
</tr>
<tr>
<td>2003</td>
<td>18,600</td>
<td>235</td>
<td>163</td>
<td>165</td>
</tr>
</tbody>
</table>
Recovering from an historical crisis situation (1/2)
Recovering from an historical crisis situation (2/2)

(a) Profit $\pi_t$

Historical profit

- without transition profit constraint
- with $\pi_{\text{trans}} = 50$ k-euros
- with $\pi_{\text{trans}} = 80$ k-euros
- with $\pi_{\text{trans}} = 100$ k-euros

Minimal time of crisis profit

(b) Resource stock biomass $B_t$

Historical stock

- without transition profit constraint
- with $\pi_{\text{trans}} = 50$ k-euros
- with $\pi_{\text{trans}} = 80$ k-euros
- with $\pi_{\text{trans}} = 100$ k-euros

Minimal time of crisis stock
Time of crisis vs. Individual recovery cost

The higher the transition profit constraint, the longer the recovery process:
If acceptability conditions are important, the recovery time increases.
Hare or tortoise? Trade-offs in recovering sustainable bioeconomic systems

- Being a Hare?
  - High recovery speed, associated with high sacrifices
  - Strong resistance to recovery program
  - A risk to stop in the middle of the road
- Or being a Tortoise?
  - Very low recovery speed
  - Well accepted by individual agents
  - A risk to never achieve the recovery program
- We exhibit these trade-offs using the viability approach and computing the minimal time of crisis under constraint
Appendix: Parameters values

<table>
<thead>
<tr>
<th>Parameter</th>
<th>value</th>
<th>Constraint</th>
<th>level</th>
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</thead>
<tbody>
<tr>
<td>$r$</td>
<td>0.78</td>
<td>$B_{min}$</td>
<td>5,000 tons</td>
</tr>
<tr>
<td>$B_{sup}$</td>
<td>30800 tons</td>
<td>$K_{min}$</td>
<td>100 vessels</td>
</tr>
<tr>
<td>$q$</td>
<td>$72 \cdot 10^{-7}$ j$^{-1}$</td>
<td>$\pi_{min}$</td>
<td>130,000 euros</td>
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<tr>
<td>$p$</td>
<td>8,500 euros per tons</td>
<td>$\xi_{inf}$</td>
<td>5 vessels</td>
</tr>
<tr>
<td>$\omega_f$</td>
<td>70,000 euros per year</td>
<td>$\xi_{sup}$</td>
<td>5 vessels</td>
</tr>
<tr>
<td>$\omega_v$</td>
<td>377 euros per day at sea</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$e_{sup}$</td>
<td>220 days</td>
<td></td>
<td></td>
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<tr>
<td>$\tau_d$</td>
<td>33%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\lambda$</td>
<td>43%</td>
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</table>
Addressing the sustainability issue in the viability framework of analysis

- The viability framework:
  - A dynamic system: bioeconomic system, with state variables, controls...
  - Sustainability objectives are described by a set of constraints
  - Sustainable paths are intertemporal trajectories that respect the constraints at any time

- The viability analysis: [Aubin (1991) *The viability theory*]
  - studies the consistency between the dynamics and the constraints
  - defines bioeconomic states from which it is possible to satisfy the constraints forever
  - defines associated decisions
Viability kernel: sustainable fisheries configurations

- Set of fisheries states (Fleet size and resource stock) from which start viable trajectories

\[
\text{Viab} = \left\{ (B_0, K_0) \mid \exists (e(.), \xi(.)) \text{ and } (B(.), K(.)), \text{ starting from } (B_0, K_0) \right. \\
\text{satisfying dynamics (8) and (11)} \\
\text{and constraints (14), (15) and (17) for any } t \in \mathbb{N}^+ \right\}
\]

- A sustainable fishery will evolve among these states