Achieving Sustainability: Slowly or Costly?

Vincent MARTINET

INRA Grignon
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Outline

- Some words about the paper
- The issue
- Recovering sustainable bioeconomic systems (a glimpse at the general case as a starter)
- A Fishery application case
- Conclusion

About the paper

- Joint work with
  - Olivier Thébaud (Ifremer, Marine economist)
  - Alain Rapaport (INRA, Mathematician)
- Purpose of the paper
  - Sustainability of natural resources use
  - Recovering from natural resources over-exploitation situations
  - Trade-offs between achievment speed and the acceptability of the recovery program

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
  - Sustainability issues 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 of analysis that encompasses the diversity of sustainability objectives (multicriteria approach)

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
  - Identification of the paths leading to these objectives
  - Selection of a recovery trajectory
- If 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-offs between speed of recovery and acceptability of the recovery path

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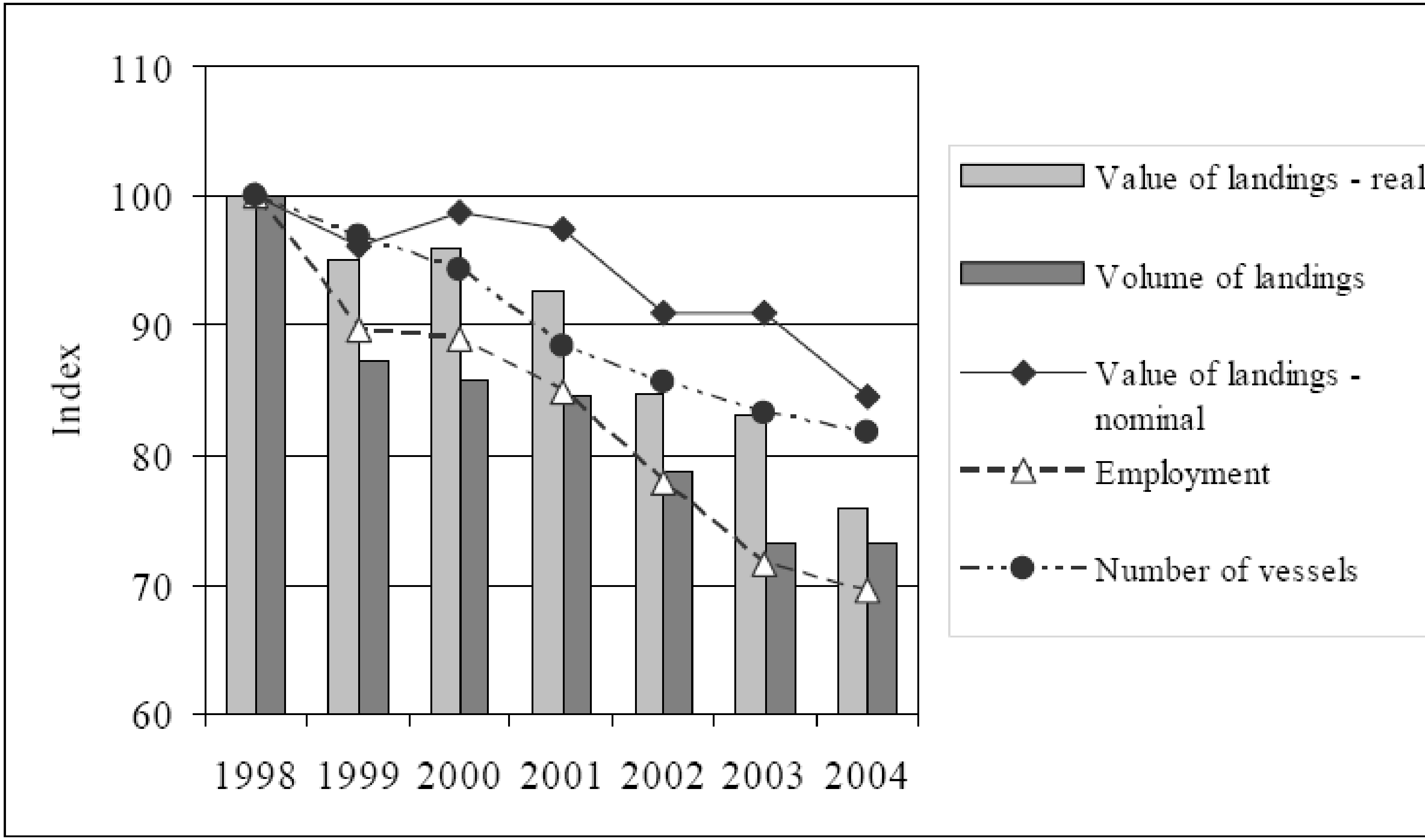
Crisis of the fishery sector

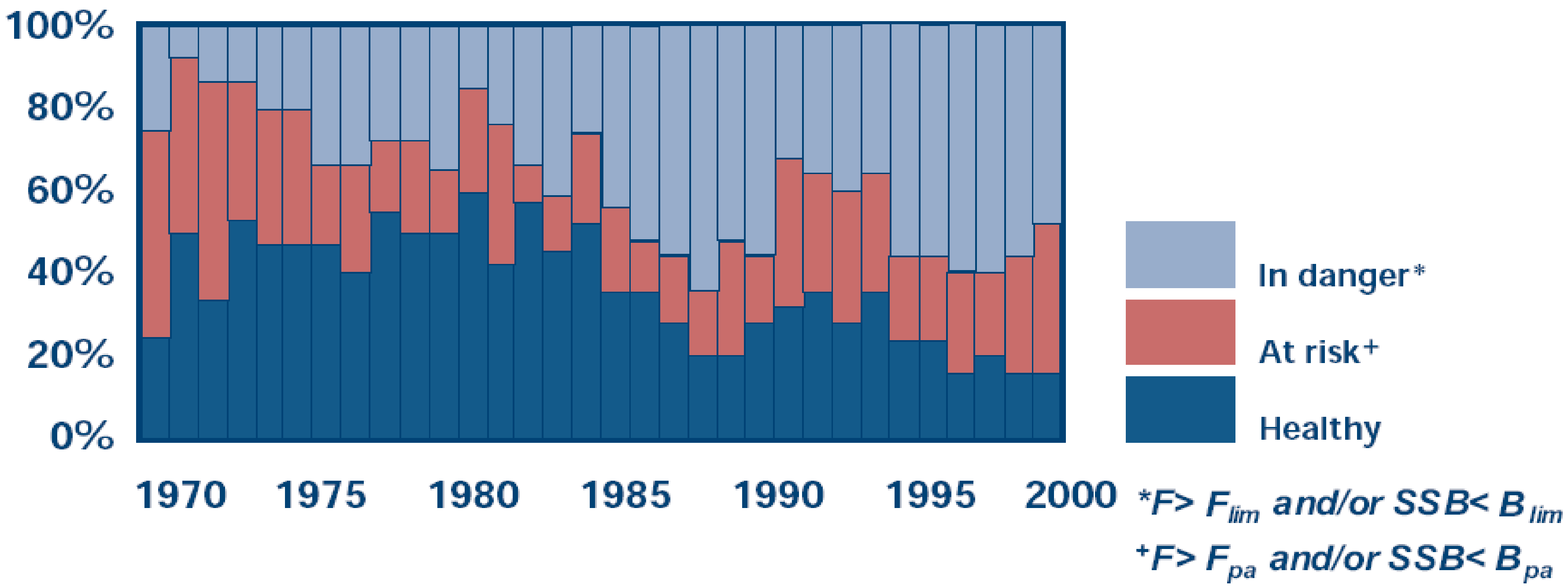


Source: EAEF Annual Report, 2006, p12

→ decline in production, fleet size and employment: a growing number of fleets are at or below economic viability constraints

Crisis in the European fisheries

Quota stocks



Source: Net Benefits: a sustainable and profitable future for UK fishing, March 2004, p52

→ Declining stocks / excess capacity in E.U. fleets

Sustainability of a Bio-economic system

- A system with n capital stocks $X_t \in \mathbb{R}^n$
- u_t is a decision (or control) vector in $\mathbb{R}^m$
- Admissible decisisons: $\mathcal{U}(X)$
- Intertemporal dynamics $X_{t+1} = F(X_t, u_t)$

- Sustainability objectives are represented by a set of constraints $\mathcal{K}$
- Sustainable paths: (X(.),u(.)) such that

$$(X_t, u_t) \in \mathcal{K} \text{ for all } t \in \mathbb{N}$$

Crisis situation and time of crisis

- Crisis indicator

$$1\!\!I(X,u,\mathcal{K}) = \begin{cases} 0 & \text{if } (X,u) \in \mathcal{K} \\ 1 & \text{otherwise} \end{cases}$$

- Time of crisis of a trajectory (X(.),u(.)):

$$\mathcal{T}(X(.),u(.)) = \sum_{t=0}^{\infty} 1\!\!I(X_t,u_t,\mathcal{K}).$$

$$s.t.\ X_{t+1} = F(X_t,u_t)$$
$$X_{t=0} = X_0$$

Achieving sustainability and the Minimal Time of Crisis concept

- Management objective: minimize the crisis duration
  - Chichilnisky (1977) Economic development and efficiency criteria in the satisfaction of basic needs, *Appl. Math. Modelling*
  - Martinet et al. (2007) Defining viable recovery paths toward sustainable fisheries, *Ecological Economics*
- Acceptability constraints (acceptable social cost of the recovery program for individual agents)

Admissible recovery decisions: $\mathcal{U}_{trans}(X) \subseteq \mathcal{U}(X)$

- Optimization problem

$$\mathcal{C}_{\mathcal{U}_{trans}}(X_0) = \inf_{u(.)\in\mathcal{U}_{trans}} \mathcal{T}(X(.), u(.))$$

$$s.t.\ X_{t+1} = F(X_t, u_t)$$

$$X_{t=0} = X_0$$

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 ξ

$$0 \leq e_t \leq e_{sup} \qquad -\xi_{inf} \leq \xi_t \leq \xi_{sup}$$

- Dynamics

$$K_{t+1} = K_t + \xi_t$$

$$B_{t+1} = B_t + rB_t\left(1 - \frac{B_t}{B_{sup}}\right) - qB_t e_t K_t$$

- Per vessel profit

$$\pi(B_t, e_t) = \Big(p(1-\tau_d)qB_t e_t\Big)\frac{1}{\lambda} - (\omega_f + \omega_v e_t)$$

Viability constraints

- Biological objective: minimal stock size

$$B_t \geq B_{min}$$

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

$$\pi_t \geq \pi_{min}$$

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

$$K_t \geq K_{min}$$

Crisis indicator, time of crisis

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

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

- Time of crisis of an intertemporal exploitation path

$$\mathcal{T}(B(.), K(.), e(.), \xi(.)) = \sum_{t=0}^{\infty} \mathbb{1}(B_t, K_t, e_t, \xi_t)$$

Recovering from crisis situations

- Acceptability of recovery programs: minimal guaranteed transition profit constraint

$$\pi_t \geq \pi_{trans}$$

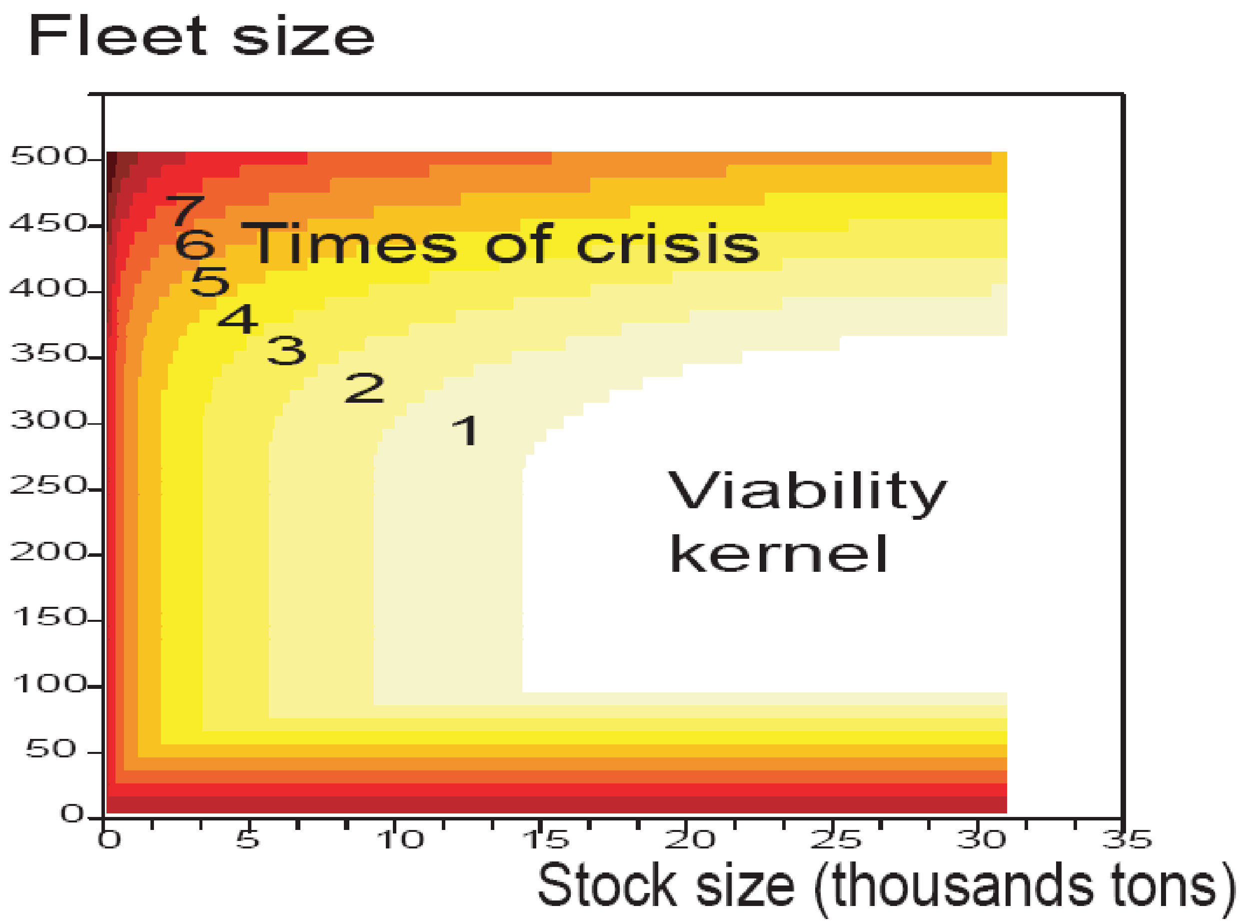
- Admissible recovery decisions

$$\mathcal{U}_{trans}(B_t, K_t, \pi_{trans}) = \left\{ (e_t, \xi_t) \middle| \begin{array}{l} e_t \in [0, \bar{e}] \text{ and } \pi(B_t, e_t) \geq \pi_{trans} \\ \\ \xi_{sup} \geq \xi_t \geq \max(K_{min} - K_t, -\xi_{min}) \end{array} \right\}$$

- Minimal time of crisis under transition profit constraint

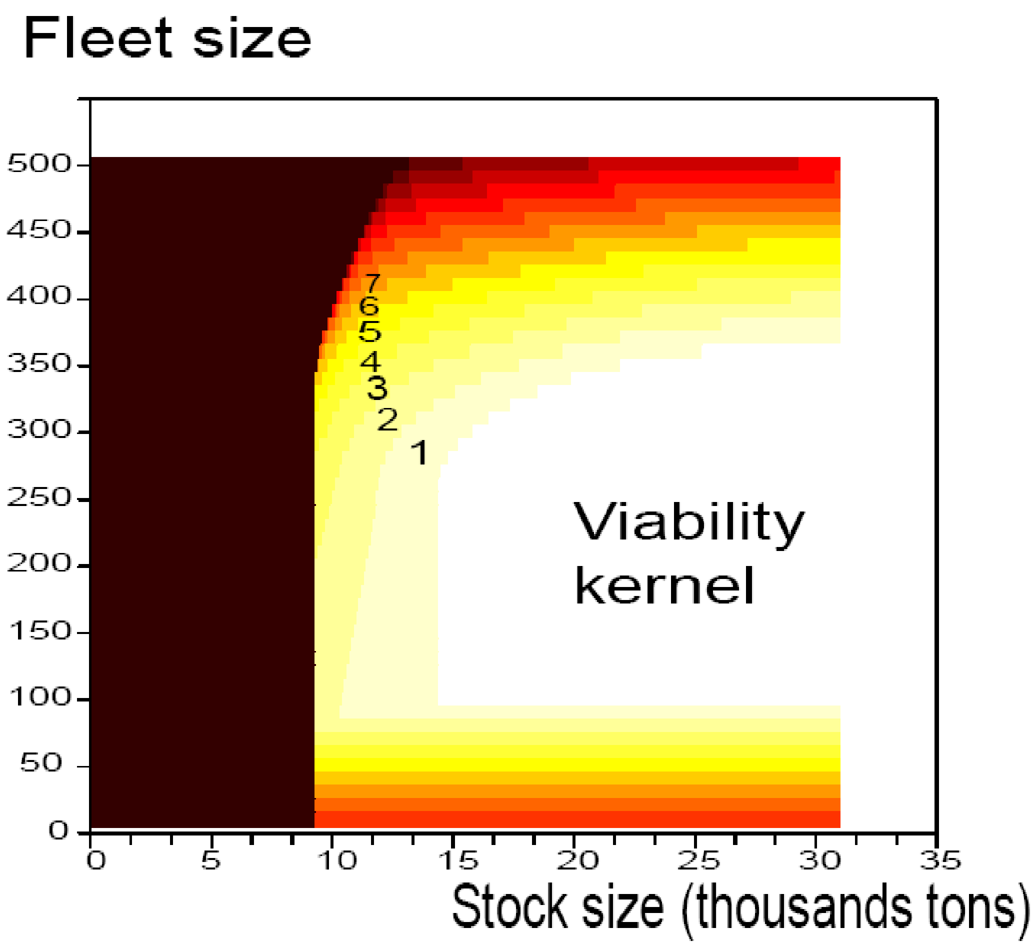
$$\mathcal{C}(B_0, K_0, \pi_{trans}) = \inf_{\left\{ \begin{array}{l} (B(.), K(.), e(.), \xi(.)) \\ \\ \text{admissible path} \end{array} \right.} \sum_{t=0}^{\infty} \mathbb{1}(B_t, K_t, e_t, \xi_t)$$

Map of minimal times of crisis

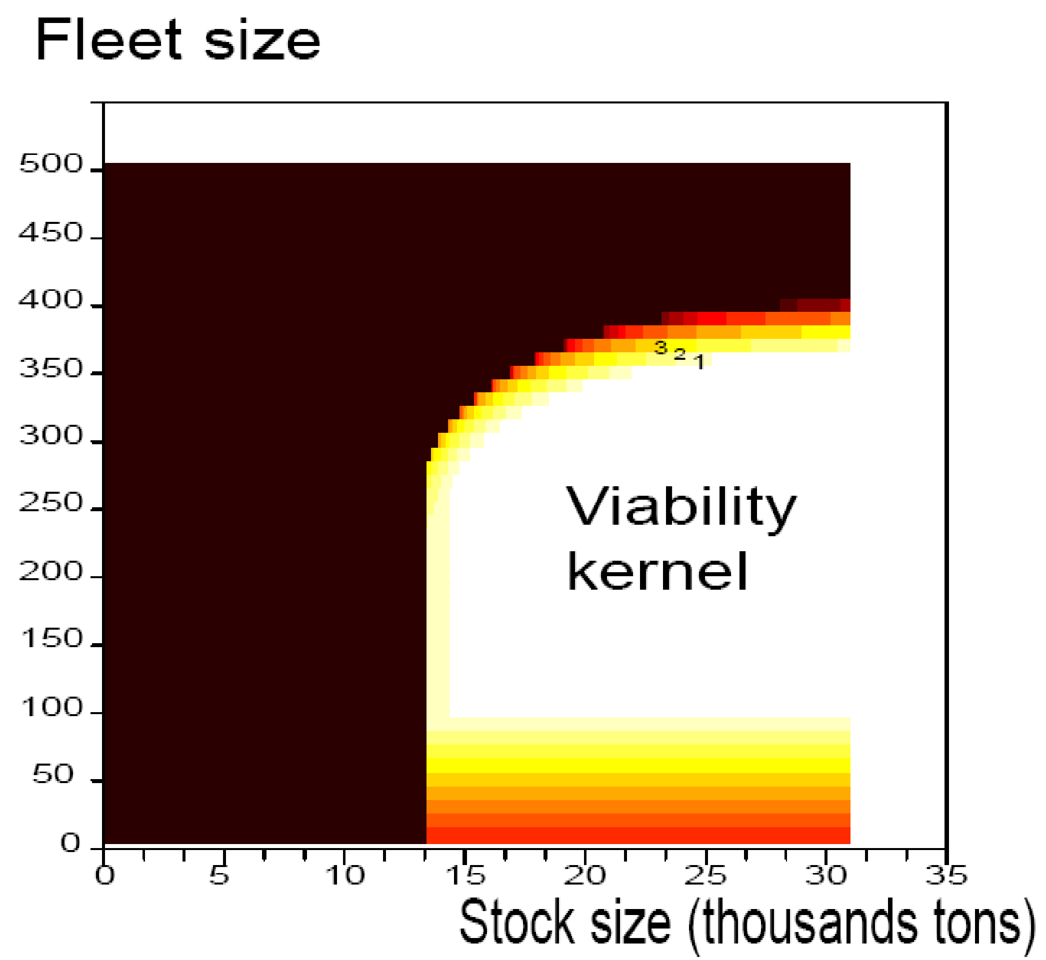


(a) Minimal time of crisis without transition profit constraint

Maps of minimal times of crisis under transition profit constraints

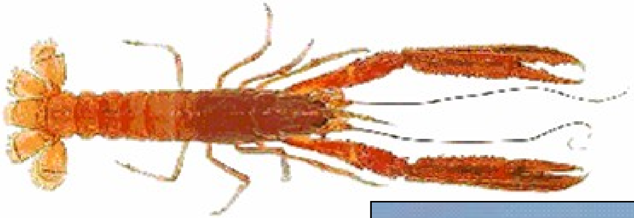


(b) Minimal time of crisis with $\pi_{\text{trans}} = 30$



(c) Minimal time of crisis with $\pi_{\text{trans}} = 110$

The Bay of Biscay Nephrops Fishery



Viability of the fishery and historical trajectory

- Viability profit constraint:

130,000 euros per year

- Minimal fleet size:

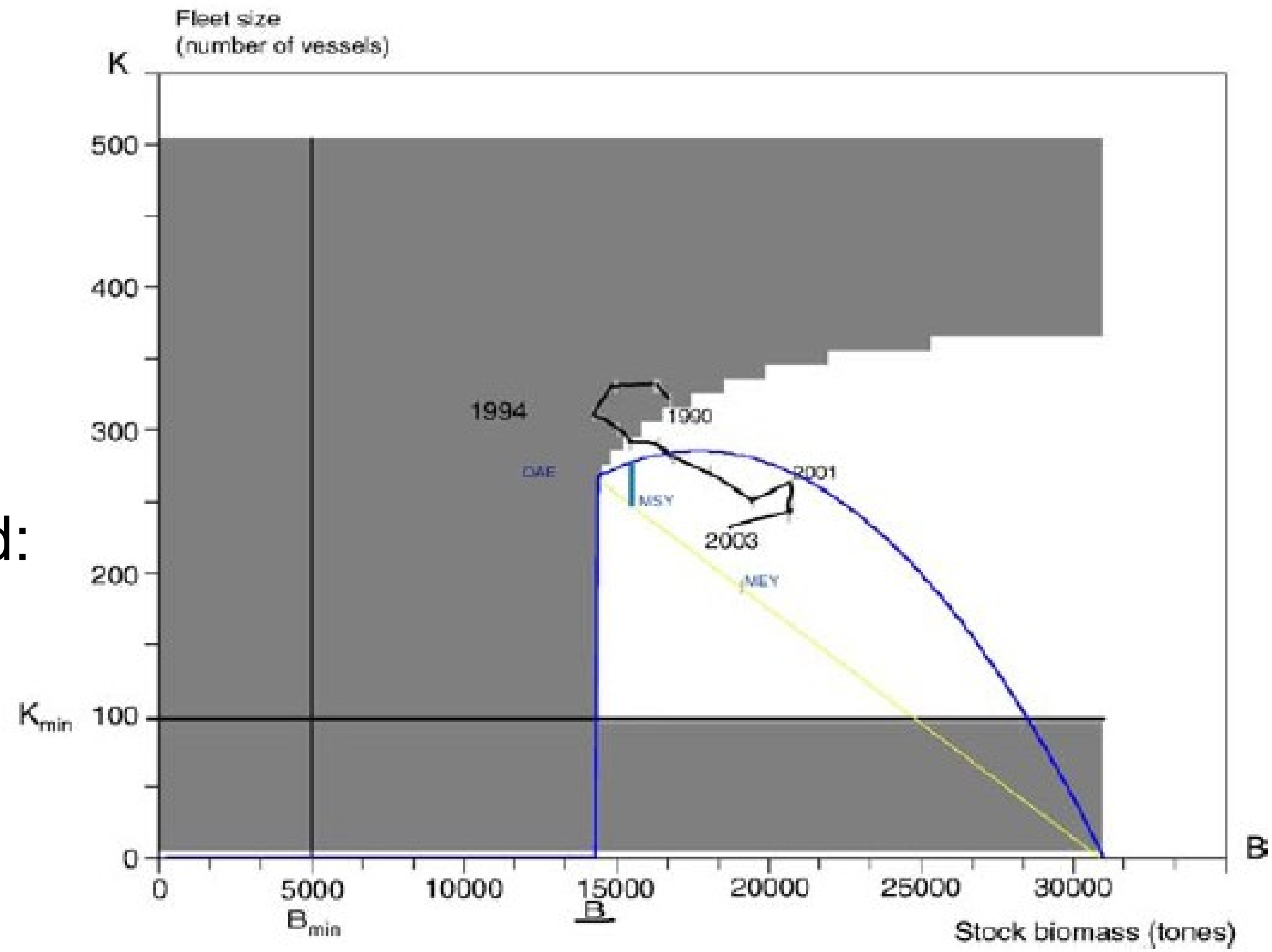
100 vessels

- Fleet's adjustment speed:

10 vessels

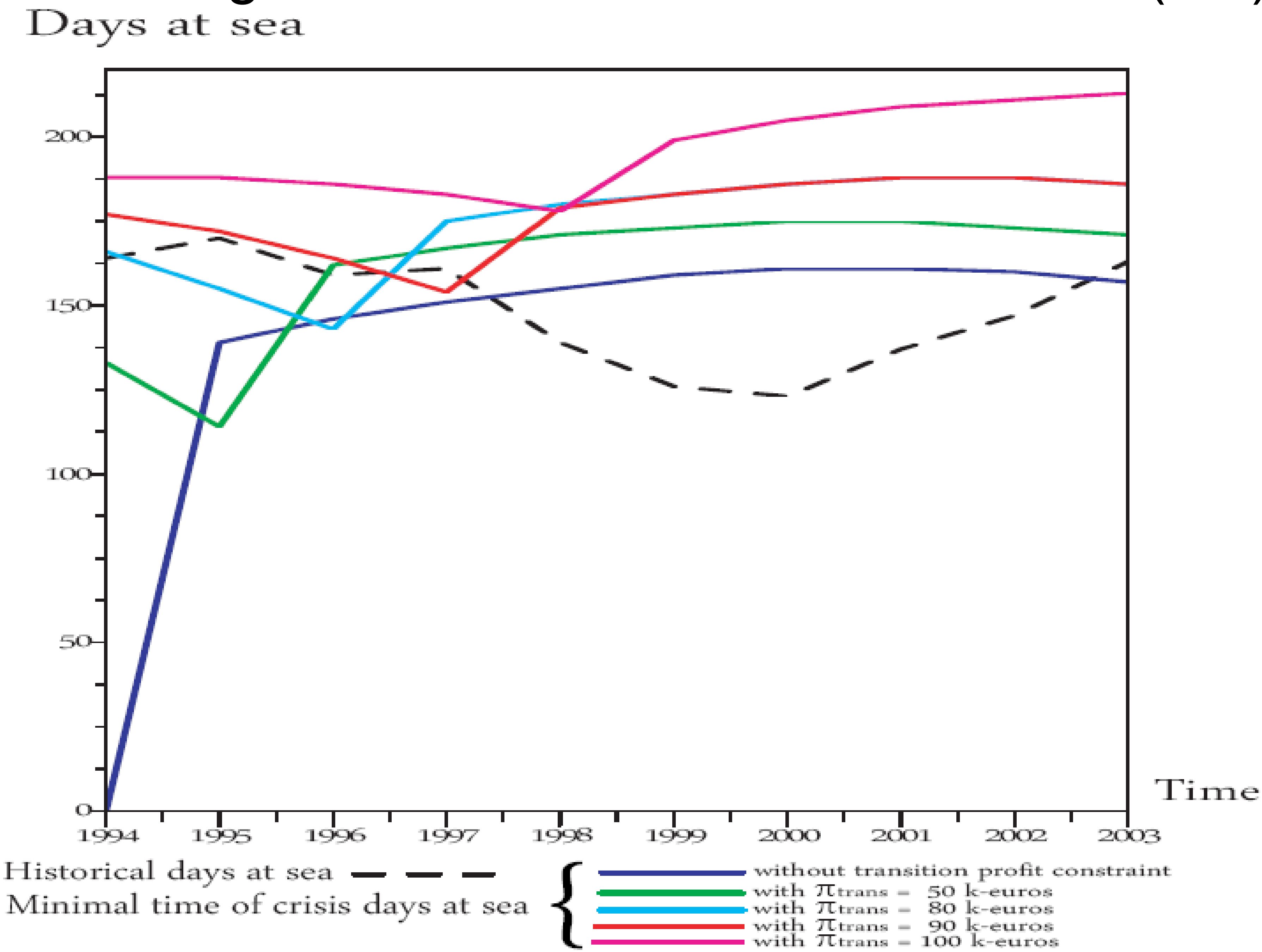
- Minimal resource stock:

5,000 tons



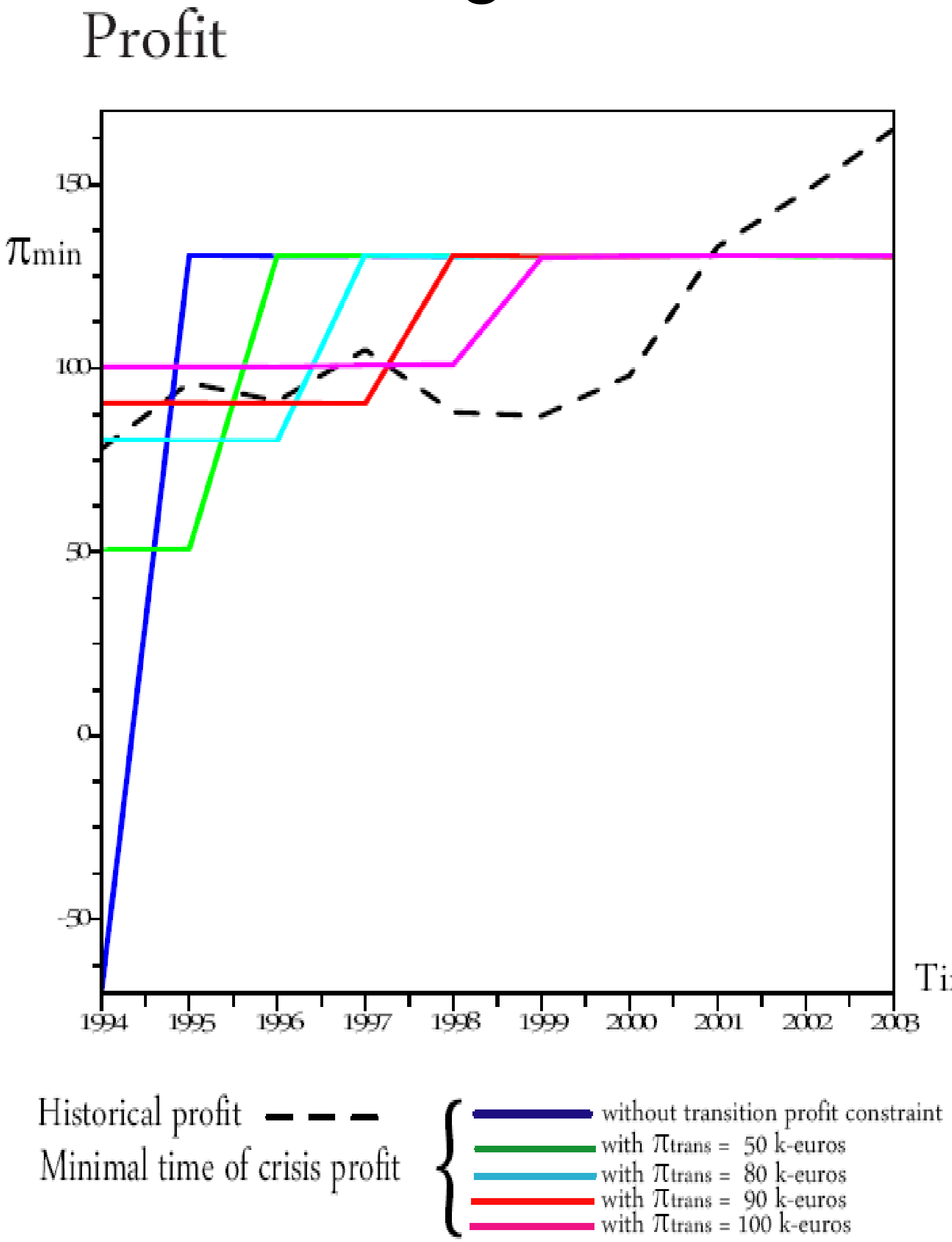
	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Estimated resource stock (tons)	14,281	15,054	15,482	16,328	16,871	18,082	19,471	20,721	20,728	18,600
Observed fleet size (vessels)	309	303	291	287	282	270	252	259	245	235
Observed fishing effort (days at sea per vessel — mean)	164	170	159	161	139	126	123	137	147	163
Profit (k-euros per vessel — mean)	78	96	91	105	88	87	98	133	148	165

Recovering from an historical crisis situation (1/2)

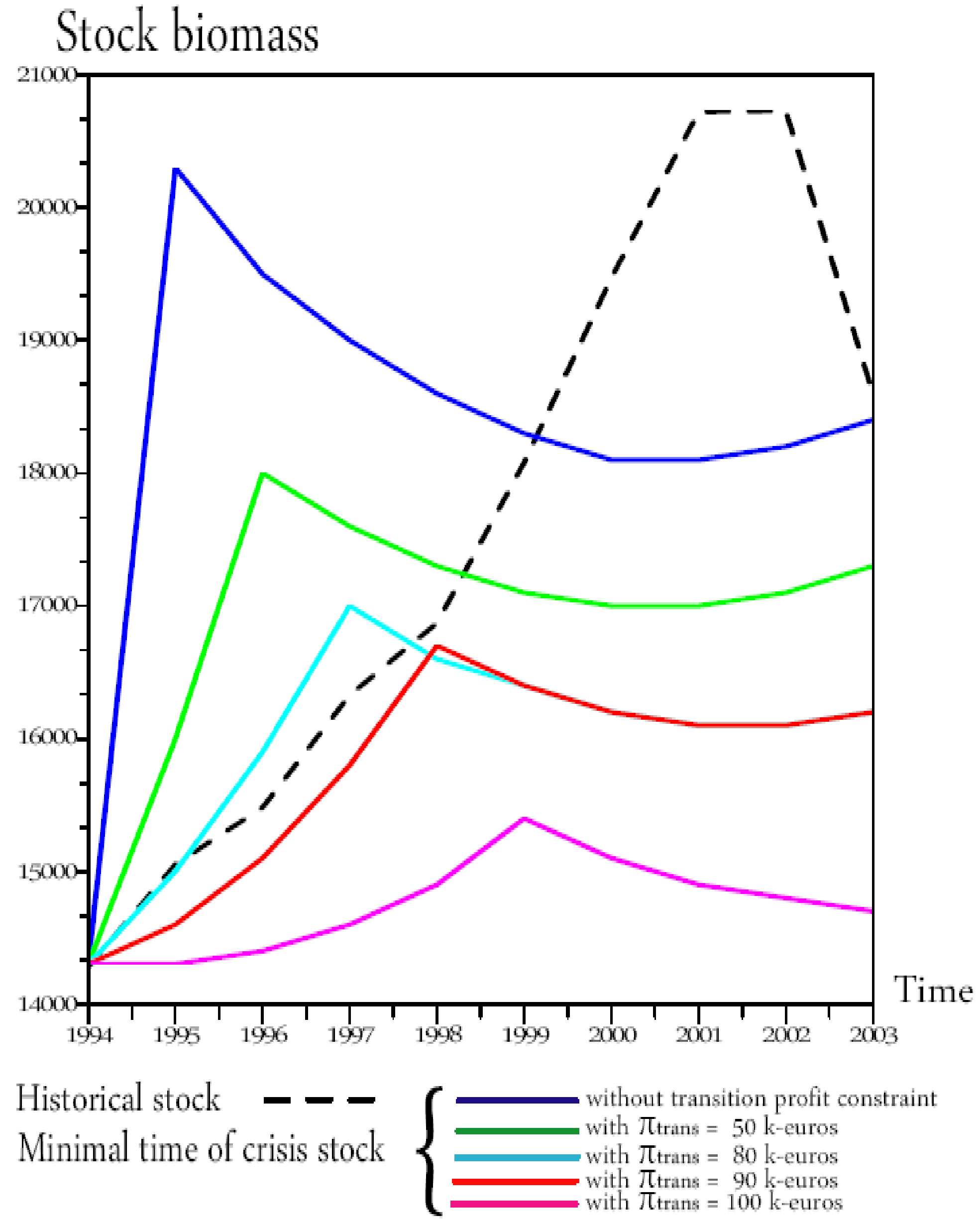


(b) Days of sea e_t

Recovering from an historical crisis situation (2/2)

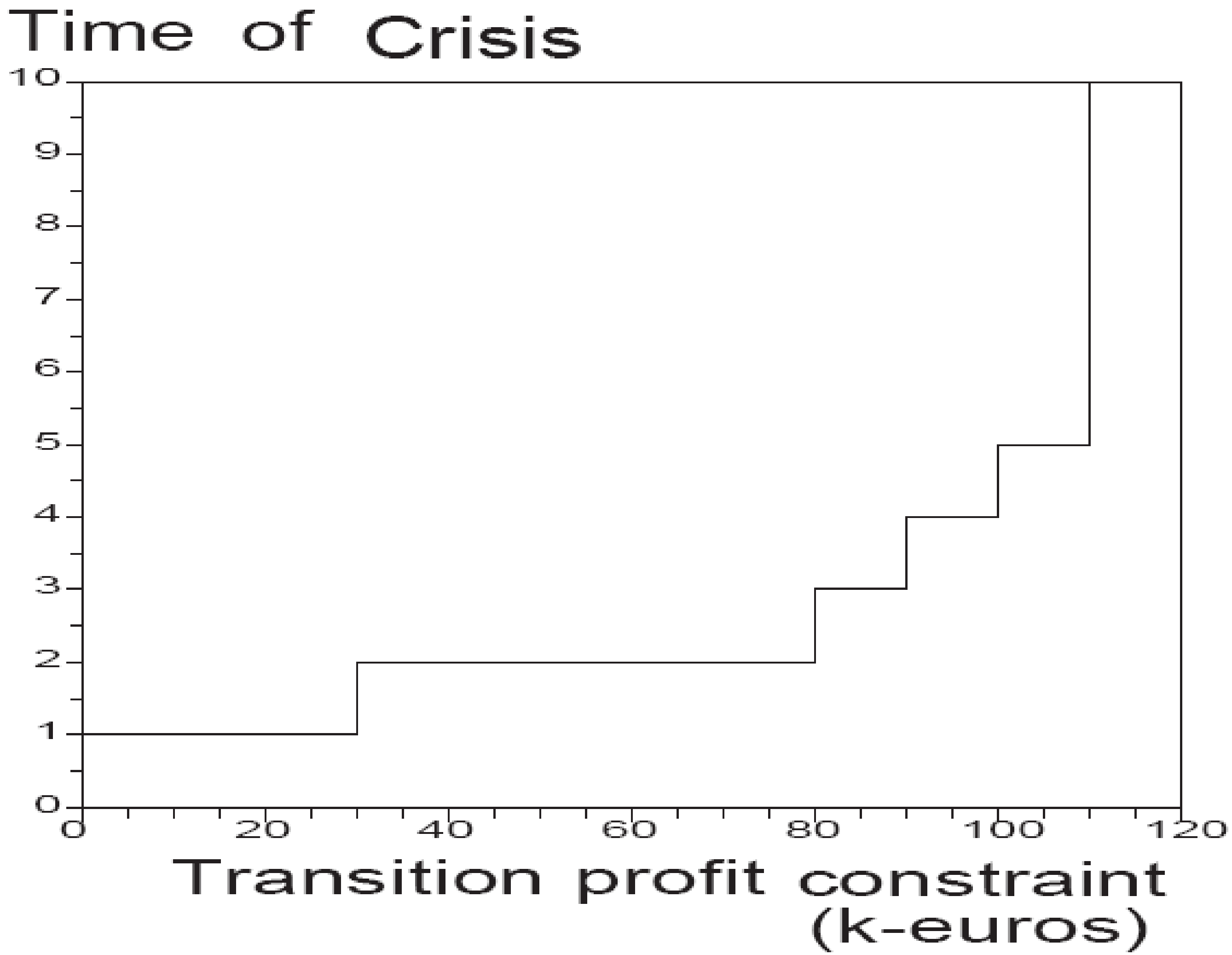


(a) Profit π_t



(b) Resource stock biomass B_t

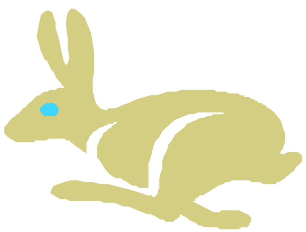
Time of crisis *vs.* Individual recovery cost



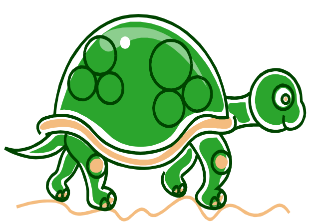
The higher the transition profit constraint, the longer the recovery process:
If acceptability conditions are important, the recovery time increases.

Hare or tortoise? Trade-offs in recovering sustainable bioeconomic systems

- Being a Hare?



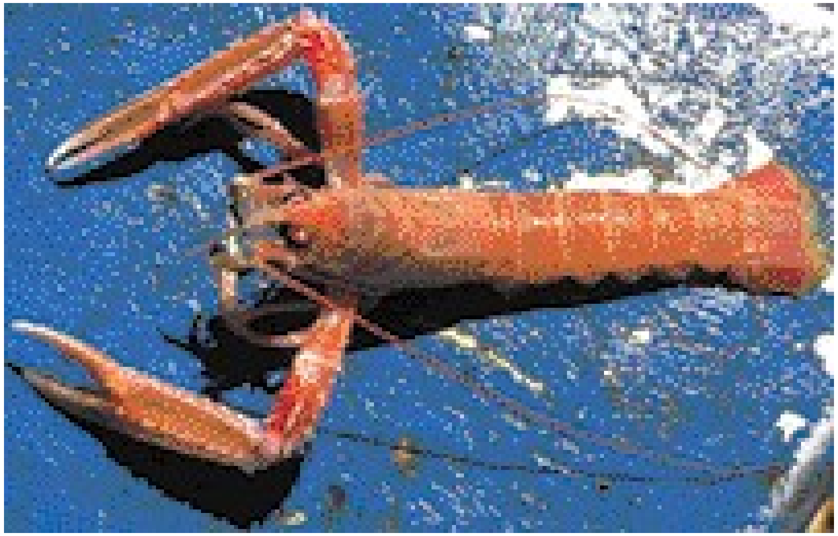
  - High recovery speed, associated with high sacrifices
  - Strong resistance to recovery program
  - A risk to stop in the middle of the road
- Or being a Tortoise?



  - 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

Thank you for your attention

vincent.martinet@grignon.inra.fr



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 contraints
  - defines bioeconomic states from which it is possible to satisfy the constraints forever
  - defines associated decisions

Viability kernel: sustainable bioeconomic configurations

$$\mathrm{Viab}_F(\mathcal{K}) = \left\{ X_0 \;\middle|\; \begin{array}{l} \exists (X(.), u(.)) \text{ starting from } X_0 \\ \text{and satisfying eq. (1)} \\ \text{such that } (X_t, u_t) \in \mathcal{K},\ \forall\, t \in \mathbb{N} \end{array} \right\}.$$

- Crisis situation
- Irreversibility
- Viable decisions: $X \in \mathrm{Viab}_F(\mathcal{K}) \Longrightarrow \mathcal{U}_{viab}(X) \neq \emptyset$
- Unviable decisions: $\mathcal{U}_{viab}(X) \subseteq \mathcal{U}(X)$

Viability kernel: sustainable fisheries configurations

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

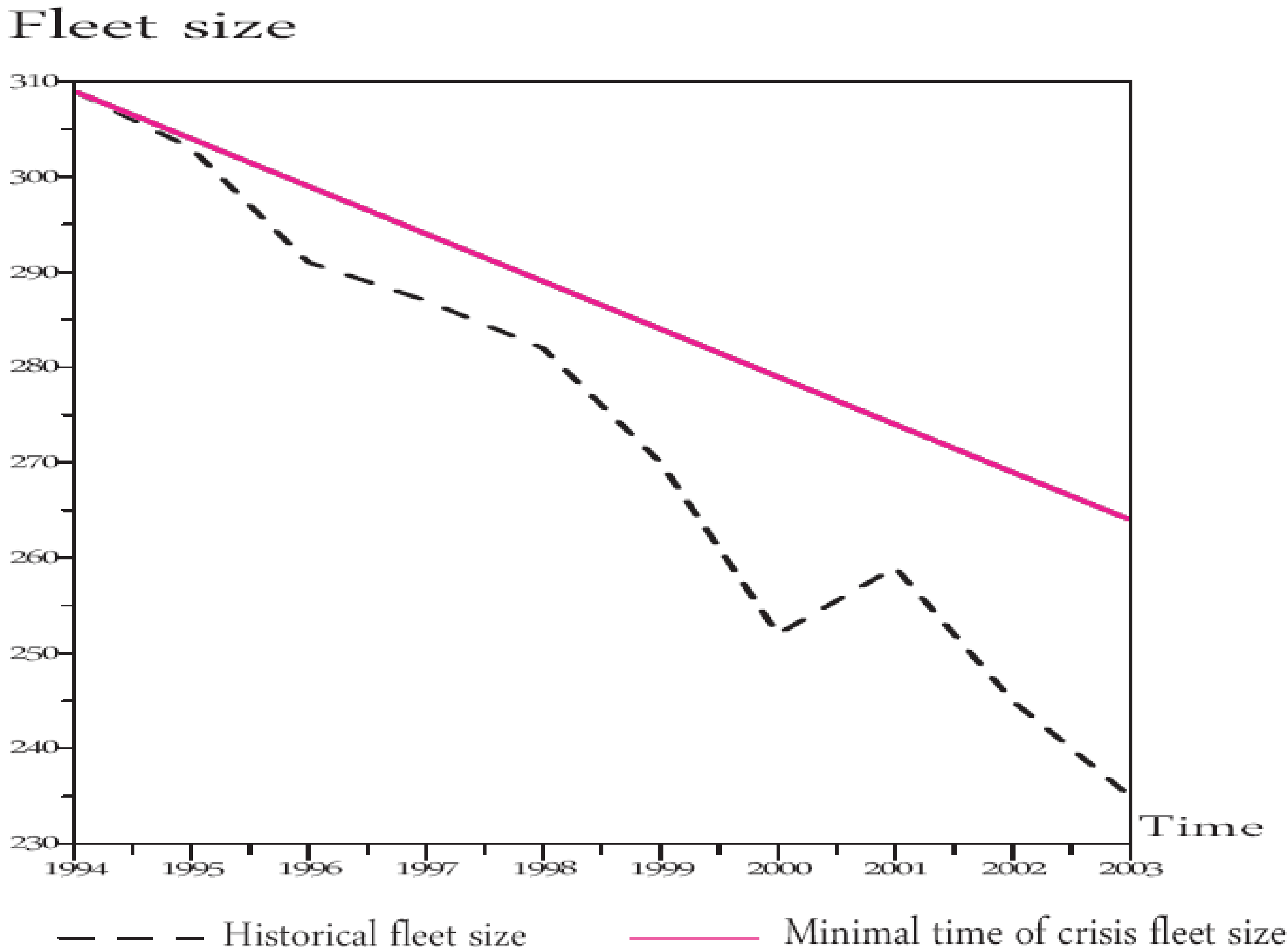
$$\mathrm{Viab} = \left\{ (B_0, K_0) \;\middle|\; \begin{array}{l} \exists (e(.), \xi(.)) \text{ and } (B(.), K(.)), \text{ starting from } (B_0, K_0) \\ \text{satisfying dynamics (8) and (11)} \\ \text{and constraints } (14), (15) \text{ and } (17) \text{ for any } t \in \mathbb{N}^+ \end{array} \right\}$$

- A sustainable fishery will evolve among these states

Appendix: Parameters values

Parameter	value
$r =$	0.78
$B_{sup} =$	30800 tons
$q =$	72.10^{-7} j^{-1}
$p =$	8,500 euros per tons
$\omega_f =$	70,000 euros per year
$\omega_v =$	377 euros per day at sea
$e_{sup} =$	220 days
$\tau_d =$	33%
$\lambda =$	43%

Constraint	level
$B_{min} =$	5,000 tons
$K_{min} =$	100 vessels
$\pi_{min} =$	130,000 euros
$\xi_{inf} =$	5 vessels
$\xi_{sup} =$	5 vessels



(a) Fleet size K_t