Co-viability for the management of fisheries

Main ideas ... ... a little bit of mathematics ... ... and some examples

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Viability

Viability ??

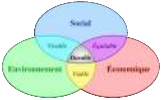
What about fisheries ?

Management renewable resources

- Interdisciplinary: Economy-Ecology-Social
- Complexity, Nonlinearity

New concepts

- Sustainability
  - **Reconciliation** Economy-Ecology



  - **Intergenerational equity**
- Resilience
- Precaution

Co-viability for a stylized bio-economic model

- An exploited population dynamics

$$x(t+1) = f\Big(x(t) - c(t)\Big), \qquad t = 0, 1, \ldots, +\infty$$

with catches

$$0 \leq c(t) \leq x(t)$$

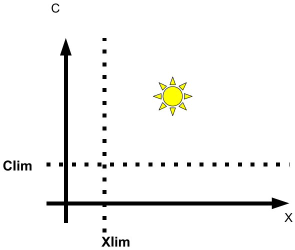
The co-viability constraints

- A conservation requirement:

$$x(t) \geq x_{\lim}, \qquad t = 0, 1, \ldots, +\infty$$

- A direct use value:

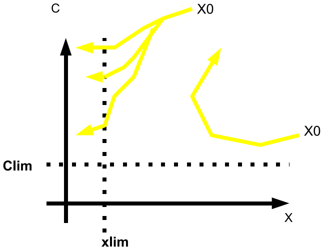
$$c(t) \geq c_{\lim}, \qquad t = 0, 1, \ldots, +\infty$$



The viability kernel

A feasibility set

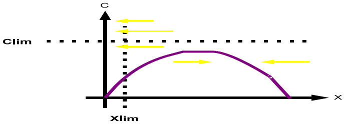
$$\text{Viab} = \left\{ x_0 \;\middle|\; \begin{array}{l} \exists\, c(t) \text{ and } x(t) \\ \text{starting from } x_0 \\ \text{satisfying} \\ \text{dyna. + constraints} \\ \text{for any time } t \in \mathbf{R}^+ \end{array} \right\}$$



A ceiling guaranteed catch & a floor stock

Assume f increasing; $f(0) = 0$

No viability



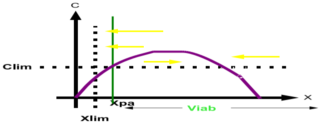
$$\mathrm{Viab} = \emptyset$$

- If $c_{\lim} > c_{\mathrm{MSY}}$
  where Maximum Sustainable Yield

$$c_{\mathrm{MSY}} = \max_{x \geq 0,\ f(x-c)=x} c$$

- A ceiling guaranteed catch

Partial viability



$$\mathrm{Viab} = [x_{\mathrm{pa}}, +\infty[$$

- if $0 \leq c_{\lim} \leq c_{\mathrm{MSY}}$
- with the precautionary threshold

$$x_{\mathrm{pa}} = \min\left(x,\ x \geq c_{\lim},\ x \geq x_{\lim}\ f(x-c_{\lim}) \geq x\right)$$

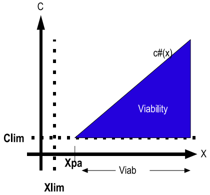
- Viability margin: $x_{\mathrm{pa}} > c_{\lim}$

The viable quotas corridor

- Method: Maintaining x in Viab
- Assume $0 \leq c_{\lim} \leq c_{\mathrm{MSY}}$.
  Then Viable Quotas are

$$C_{\mathrm{Viab}}(x) = [c_{\lim}, c_{\sharp}(x)]$$

where $c_{\sharp}(x) = x - x_{\mathrm{pa}} + c_{\lim}$



- Flexibility:
  - Conservative $c_{\lim}(x)$
  - Greedy $c_{\sharp}(x)$
  - Trade-off: $\alpha c_{\lim}(x) + (1-\alpha) c_{\sharp}(x)$
  - More efficient strategy: NPV, maximin, Chichilnisky, ...

An illustration from nephrops in the Bay of Biscay

Martinet-Thébaud-Doyen,2007

- Dynamics: Beverton-Holt:

$$f(x) = \frac{Rx}{1+Sx}, \quad R = 1.78, \ K = 30800$$

- Rent $\Pi(x,h) = ph - c\frac{h}{qx}$ with

$p = 8500$ €.ton^{-1}, $c = 377$ €.day^{-1}, $q = 72{*}10^{-7}$ day^{-1}

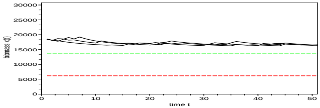
- Co-viability constraints:

$$x_{\text{lim}} = 6160 \text{ tons}$$

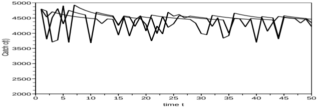
$$\Pi_{\text{lim}} = 19500 \text{ Keuros}$$

- Viability kernel

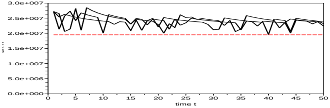
$$x \geq x_{pa} = 13775 \text{ tons}$$



Stock $x(t)$



Catch $c(t)$



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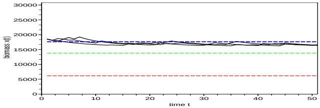

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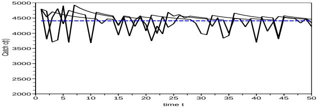

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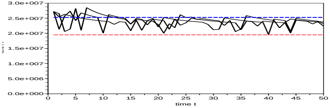

Rent $\Pi(t)$

An abstract model

The framework: Control theory of noisy dynamic systems

Ecosystem dynamics:
$$x(t+1) = F\big(x(t), y(t), u(t), \omega(t)\big)$$

Fleet and economic dynamics:
$$y(t+1) = G\big(x(t), y(t), u(t), \omega(t)\big)$$

Anthropogenic decisions
$u(t)$

Uncertainties scenarios
$\omega(t) \in \Omega$

- Uncertainty, stochasticity, scenarios, controversy

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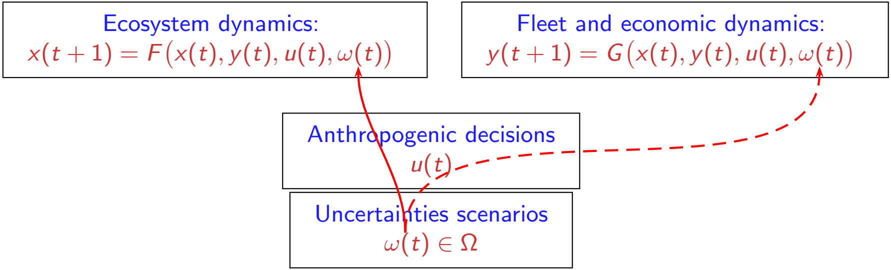
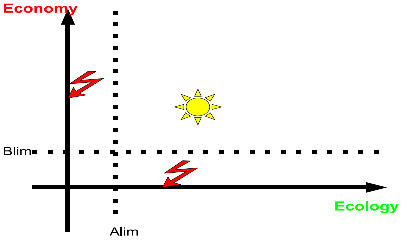


- Uncertainty, stochasticity, scenarios, controversy

Co-viability constraints

Ecological Constraints:
Conservation
$A(x(t)) \geq A_{\lim}$
for $t = t_0, \ldots, T$

Economic constraints:
Utilities, rent, ..
$B(x(t), y(t), u(t)) \geq B_{\lim}$
for $t = t_0, \ldots, T$

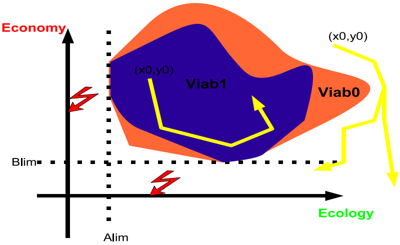


- Multi-criteria: Ecology, Economy
- PVA: a focus the ecological constraint
- Intergenerational equity: present & future

Stochastic viability kernel

- Assume a probability $\mathbb{P}$ i.i.d on Ω.
- Viability kernel at confident rate β:

$$\mathrm{Viab}_\beta(t_0) = \left\{ (x_0, y_0) \;\middle|\; \exists u(.) \text{ s.t. } \mathbb{P}_\omega\Big(\text{constraints} \quad t = t_0, \dots, T \Big) \geq \beta \right\}.$$



- Robust: a particular case $\beta = 1$: no probability required
- Irreversibility: outside $\mathrm{Viab}_0(0)$

Stochastic viability: a Dynamic programming approach

DeLara-Doyen, 2008

- Maximal viability probability before T

$$V(t_0, x_0, y_0) = \max_{u(.)} \mathbb{P}\Big((x(t), y(t), u(t)) \in \mathcal{K},\ t = t_0, \dots, T \Big)$$

- Value function by backward induction

$$\begin{cases} V(T, x, y) & = \mathbb{1}_{\mathcal{K}}(\mathrm{x}, \mathrm{y}) \\ V(t, x, y) & = \max_{u} \mathbb{E}_{\omega} \Big[\mathbb{1}_{\mathcal{K}}(\mathrm{x}, \mathrm{y}, \mathrm{u}) * \mathrm{V}\left(\mathrm{t}+1, \mathrm{F}(\mathrm{x}, \mathrm{y}, \mathrm{u}), \mathrm{G}(\mathrm{x}, \mathrm{y}, \mathrm{u})\right) \Big] \end{cases}$$

where $\mathbb{1}_{\mathcal{K}}(.)$ characteristic function of $\mathcal{K}$

Viable decisions

- Feedback $u(t, x, y)$: adaptive
- Viable decisions:

$$u(t, x, y) \in \mathrm{Arg}\max_{u} \mathbb{E}_{\omega}\left[\mathbb{1}_{K(t)}(x, y) * V\left(t+1, F(x, y, u), G(x, y, u)\right)\right]$$

- No uniqueness: freedom
  - Conservative policy
  - Economics oriented policy
  - Trade-off

Steady states, equilibrium and viability

- MSY
- Equilibrium: state (x^*, y^*) and decision u^* s.t.

$$x^* = F(x^*, y^*, u^*), \dots.$$

- Equilibria are viable states

$$(x^*, y^*) \in \mathrm{Viab}(t),$$

- Effort equilibria u^* are viable decisions

Intergenerational equity, Maximin and viability

- Maximin ≈ a particular ("extreme") case of viability

$$\max_{u(t)} \min_{t=0,..,T} B(x(t), y(t), u(t)) = \max_{(x_0,y_0)\in \mathrm{Viab}(0)} B_{\lim}$$

- Intergenerational equity of viability approach

Other good news

- Recovery, restoration: Martinet-Thébaud-Doyen, 2007
- Resilience: Martin, 2006
- Co-management, ITQ, coalition: Eisenack et al., 2005; Doyen-Pereau, 2009
- Precautionary approach & PVA:

  Delara-Doyen-Rochet, 2007, Doyen-Pereau, 2008, Tichit et al.,2007
- Sustainability, Maximin (intergenerational equity):

  Martinet-Doyen, 2007, Martinet, 2006, Baumgartner-Quaas, 2008
- Ecosystem

  Cury-Mullon-Garcia-Shanon, 2005; Doyen-DeLara-Pelletier-Ferraris, 2007
- Bounded rationality and "‘satisficing” H. Simon Krawczyk, 2008

Limits of the approach

- Maths are difficult especially in the stochastic case !!
- Informatics: Dynamic programming
  $\longrightarrow$ Curse of dimensionality !!!

Another example

- Management of fisheries
- Stochastic case
- Simulation approach

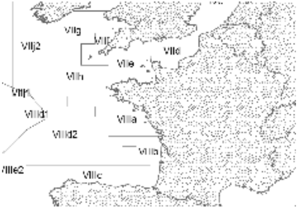
Bay of Biscay fisheries

Doyen-Thébaud-Béné-Bertignac-Fifas, Eco. Eco

ANR biodiversity program



- Multi-species: nephrops, hake, ...
- Multi-fleets ICES Fishery Units :
- By-catch problem
- Hake decline
- Calibration: ICES 2006



The exploited community dynamics: MSVPA

Mortalities

$$N_{s,a}(t+1) = N_{s,a}(t) \exp\left(-M_{s,a} - \sum_{f=1}^{K} u_f(t) F_{s,a,f}\right) ,$$

where

- s species, a age, f fleet
- $M_{s,a}$ natural mortality ;
- $F_{s,a,f}$ fishing mortality ;
- $u_f(t)$ fishing effort multipliers

The catches

$$\begin{aligned} C_{s,a,f}(t) &= N_{s,a}(t) u_f(t) F_{s,a,f} \\ &\times \frac{1 - \exp\left(-M_{s,a} - \sum_l u_l(t) F_{s,a,l}\right)}{M_{s,a} + \sum_l u_l(t) F_{s,a,l}} \end{aligned}$$

Recruitment

$$N_{s,1}(t+1) = \varphi_s\Big(SSB(N_s(t)), \omega(t) \Big) ,$$

where

- SSB_s spawning stock biomass of species s

$$SSB_s(N_s) = \sum_{a=1}^{A} \gamma_{s,a} \upsilon_{s,a} N_{s,a} ,$$

- $\omega(t)$ the uncertainties $\omega(t) \rightsquigarrow \mathcal{N}(\overline{B_s}, \sigma_s)$

Income of fleet f

$$\mathrm{Income}_f(t) = \sum_s p_{s,a} \sum_{a=1}^{A} w_{s,a}\, C_{s,a,f}(t)(1 - d_{s,a,f})$$

where

- $p_{s,a}$ the price of species
- $d_{s,a,f}$ discard

Viability constraints and probabilities

Ecological Viability PVA

ICES precautionary approach

$$SSB_s(t) \geq B_s^{\lim}$$

Economic Viability EVA

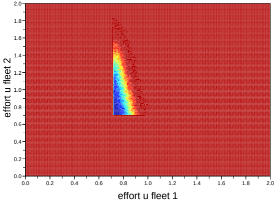
Sustainability of incomes

$$\mathrm{Income}_f(t) \geq \mathrm{Income}_f^{\lim}$$

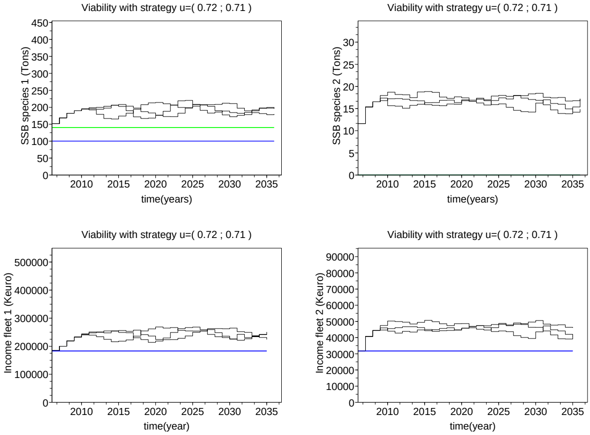
Co-viability probability

$\mathbb{P}(\text{constraints satisfied } t = 0, .., T)$

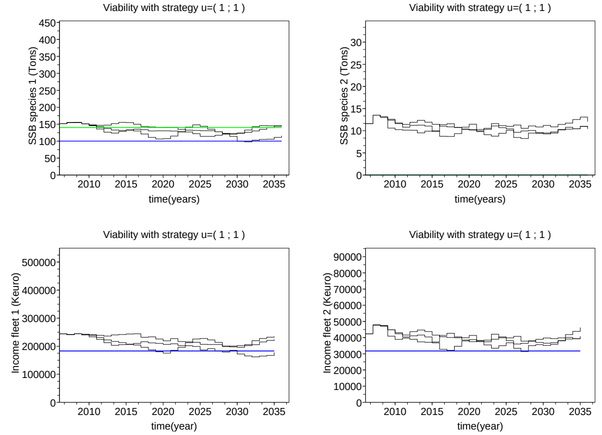
Co-viability probability



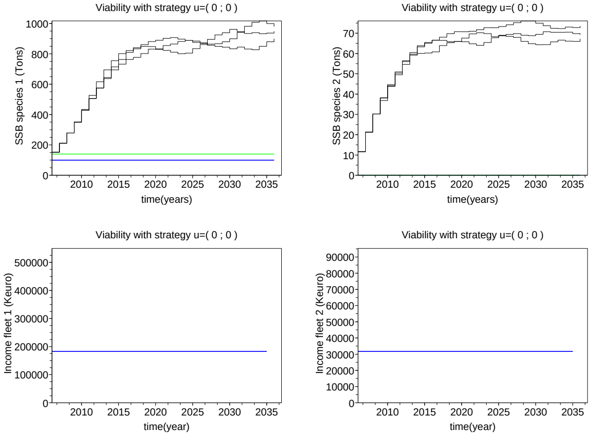
Co-viability strategy $u_{\mathrm{CVA}} = (0.72, 0.71)$



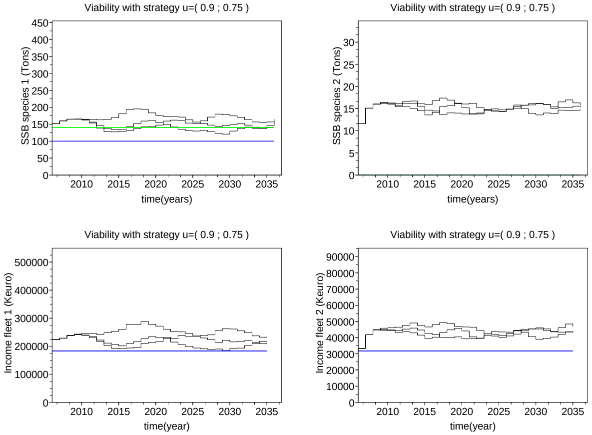
2006 baseline strategy $u_{\mathrm{BAU}} = (1, 1)$



Ecological strategy $u_{\text{PVA}} = (0, 0)$



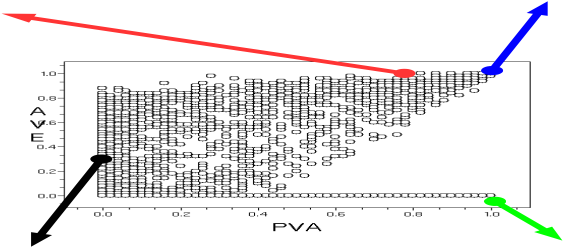
Economic strategy $u_{\mathrm{EVA}} = (0.85; 0.79)$



Viable and non viable patterns

Economic strategy $u_{\text{EVA}} = (0.85; 0.79)$

Co-viability strategy $u_{\text{CVA}} = (0.72, 0.71)$
$\max_u \mathbb{P}(\text{Co-viability})$



2006 baseline strategy $u_{\text{BAU}} = (1, 1)$

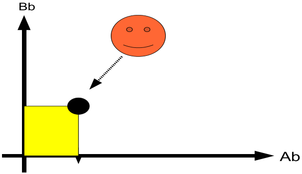
Ecological strategy $u_{\text{PVA}} = (0, 0)$

General conclusion and perspectives

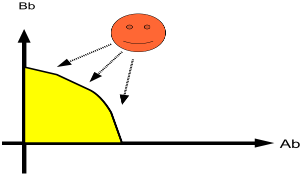
- Co-viability diagnostic:
  $\longrightarrow$ Interesting for sustainability and integrated diagnostic
- Co-viability approach:
  $\longrightarrow$ between conservation biology and bio-economics
- Co-viability mathematics:
  $\longrightarrow$ between equilibrium and optimality under constraints
  $\longrightarrow$ risk management

An inverse problem

Given initial bio-economic state (x_0, y_0);
Which guaranteed $(A_{\lim}, B_{\lim})$ such that $(x_0, y_0) \in \mathrm{Viab}??$



or

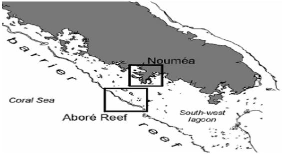


Win-win or Trade-off ??

Management through protected areas

Doyen-DeLara-Pelletier-Ferraris,2007

- A trophic web: **Piscivors**, **Carnivors**, **Herbivors**, ...
- Habitat dynamics: Coral
- Uncertain cyclonic event
- Strong catch pressure
- Some data in New-Caledonian



Dynamic model

Trophodynamics

$$x_i(t+1) = x_i(t)\left(R + \exp\left(y_1^\sharp - y_1(t)\right) Sx(t)\right)_i - c_i(t)$$

- trophic web matrix S

$$S = \begin{pmatrix} -0.093 & 0.013 & 0.013 & 0.013 \\ -0.106 & -0.012 & 0.002 & 0.002 \\ -0.076 & -0.01 & 0. & 0. \\ -0.53 & -0.069 & 0. & 0. \end{pmatrix}$$

- growth $R = (0.975, 1.007, 1.008, 1.054)'$
- A refuge effect through coral $y_1(t)$ covering:

$$\exp\left(y_1^\sharp - y_1(t)\right)$$

- Gordon Schaefer production

$$c_i(t) = q_i(1 - \text{MPA})e(t)x_i(t)$$

Coral dynamics

$$y_1(t+1) = y_1(t).\begin{cases} R_{\text{cor}}\left(1 - \frac{y_1(t)}{K_{\text{cor}}}\right) & \text{with proba}(1-p) \\ 0.3 & \text{with proba } p \end{cases}$$

where

- $p = 1/5 * 365$ probability of a cyclonic event.
- $R_{\text{cor}} = 1.002$ intrinsic productivity at low cover levels.
- K_{cor} *carrying capacity*

$$1 = R_{\text{cor}}\left(1 - \frac{y_1^\star}{K_{\text{cor}}}\right), \quad y_1^\sharp = \frac{R_{\text{cor}} - 1}{R_{\text{cor}}} K_{\text{cor}} = 0.8.$$

Co-viability

Direct use

$$U(c_1(t), c_2(t), c_3(t)) \geq U_{\lim}$$

where

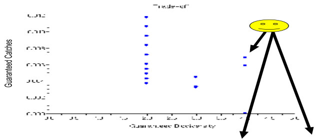
- $U_{\lim} > 0$ guaranteed utility
- $U(c_1, c_2, c_3) = w_1 c_1 + w_2 c_2 + w_3 c_3$
  where w_i mean weight of group i.

Conservation

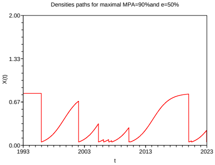
A trophic richness is guaranteed

$$I(x(t)) = \sum_i \mathbf{1}_{\mathbb{R}_*^+}(x_i(t)) \geq I_{\lim}.$$

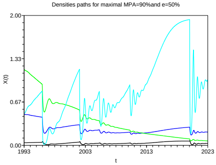
Trade-off



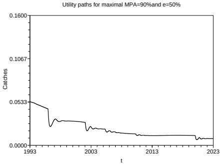
$\text{MPA} = 90\%$



Coral $x_5(t)$



Fish $x(t)$



Catch weight $c(t)$