Bioeconomic resilience-based management and viability

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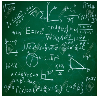
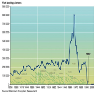

Recent advances for resilience-based management

nature sustainability

PERSPECTIVE

https://doi.org/10.1038/s41893-019-0376-1

Realizing resilience for decision-making

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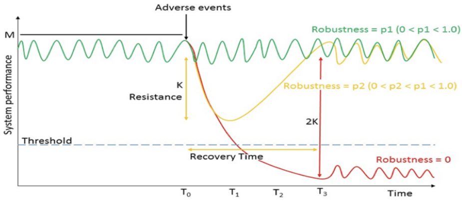
The 3 R's

Grafton, Doyen, Béné et al. 2019

System characteristics to measure resilience

1. **Recovery Time**: Holling (1973), Pimm (1984),
   time to achieve a desired state following adverse events
2. **Resistance**: Harrison (1979)
   magnitude of adverse events that can be coped with
3. **Robustness**: reliability, Carlson & Doyle (2002)
   the probability of a system to stay in a desired state facing adverse events



From the 3Rs to the 7Ss (steps) of resilience heuristic

Table 1 | Three management contexts using a socio-economic resilience heuristic

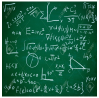
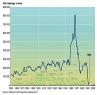
Management steps	Resilience for surface water flows	Resilience for emergency management of communities	Resilience for marine wild-capture fisheries
System definition, boundaries and drivers	Water catchment. Catchment dynamics are affected by both human activity and by natural fluctuations.	Small community (~2–3,000) well-defined spatially. Residents' activities include farming and timber extraction, and social interactions.	Multi-species fishery. Dynamics of the system depend on natural mechanisms (for example, growth and recruitment), fishing activities and environmental drivers.
Stakeholders	Farmers, tourists, water agencies and NGOs.	Community residents.	Fishers, consumers, regulating agencies and NGOs.
Metrics identification	Water quality and quantity, the net economic return of water users, and environmental quality scores.	Employment, production, and consumption/food security, and ecosystem services.	Biomass estimates and indicators of fishing production and profitability.
Viability goals and metrics	Positive net returns for farmers, guaranteed stream flows, cultural needs and safe thresholds.	Human safety, maintaining infrastructures, water and electricity supply, and economic activities.	Stock thresholds, such as precautionary limits, and also minimum profit levels for the harvesting sector.
Adverse events	Droughts or floods.	Wildfires.	Recruitment failures.
Quantification of the three Rs	Resistance: measures of ecosystem health (species diversity) or habitat functionality (vegetation cover). Recovery: recovery time for population of key species. Robustness: probability of 'normal' water inflows.	Resistance: safety margins for multiple metrics (environmental, economic, heath and social). Recovery: magnitude, type and scale of resources post-disaster. Robustness: probability of not having wildfires.	Resistance: population viability analysis of key fish stocks. Recovery: responses to annual recruitment variability, regime shift, climate change and socio-economic shocks. Robustness: probability of fish stocks, catches or fisher profits not falling below pre-defined thresholds.
Resilience-management actions and benefits	Construction of infrastructure for inter-basin transfers, storage (surface and aquifer), water extraction and policies that affect land-use and vegetation type.	For wildfire risk management, prescribed burning and fuel treatment.	Modern fisheries management includes active adaptive management as a response to large, and frequently unpredictable, adverse events and also uncertainty over fisher responses.

Links between resilience with Viability

Resilience as resulting from the tension between persistence and change (Enfors et al., 2011)

- Cuilleret et al., Economic Analysis and Policy, 2021
- Martin, Erdlenbruch et al., Environmental Science & Policy, 2022
- Karacaoglu & Krawczyk, MetroEconomica, 2021
- Bates & Saint-Pierre, 2018, *Ecological economics*
- De Lara, 2018, ENMO
- Hardy, Mills, Béné, Pereau, Doyen, 2016, *Envir. Dev. Economics*
- Hardy, Mills, Béné, Doyen, 2017, *Environmental Mod. and Software.*
- Sabatier, Oates, Jackson, 2015, *Agricultural Systems*
- Rouge et al., 2013, *Ecological Indicators*
- Deffuant & Gilbert, 2011, Springer.
- Martinet-Thebaud-Doyen, *Ecological Economics*, 2011.
- Martin, 2004, *Ecology and Society*
- Bene et al., *Ecological Economics*, 2001.
- Doyen & Saint-Pierre, 1997, *Set-valued Analysis*



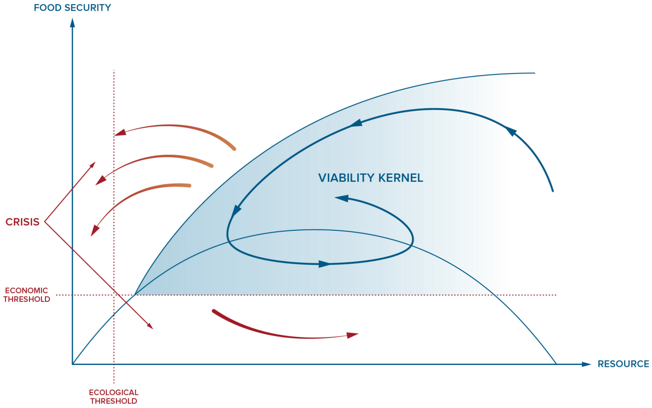
Viability ?

Schuhbauer & Sumaila, Eco. Eco., 2016

Oubraham & G. Zaccour, Eco. Eco., 2018

Doyen, Armstrong, Baumgartner et al. , Eco. Eco., 2019

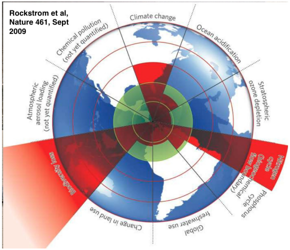
A focus on the safety of dynamic systems through thresholds:



Links with many approaches

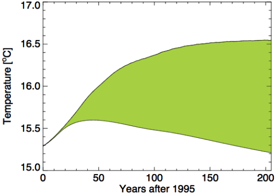
Doyen et al., Ecological Economics, 2019

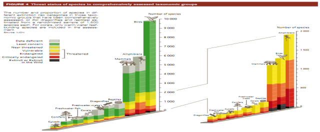
SOS



SDGs

TWA





PVA

Viability: controlled dynamics under constraints

- Controlled dynamics:

$$x_i(t+1) = F_i(\underbrace{\boxed{x(t)}}_{states}, \overbrace{\boxed{a(t)}}^{actions})$$

- Thresholds, Goals, Constraints:

$$I_k\big(x(t), a(t)\big) \geq I_k^{\lim}$$

- Viability kernel (*Aubin & Frankowska, 1990*):

$$\mathbb{V}\mathrm{iab} = \left\{ x_0 \;\middle|\; \begin{array}{c} \text{there exists } a(0), \dots, a(T) \text{ such that} \\ \text{constraints + dynamics satisfied for} t = 0, \dots, T \end{array} \right\}$$

Resistance and viability

Béné & Doyen, Earth's Future, 2018

Karacaoglu & Krawczyk, MetroEconomica, 2021

- Resistance: magnitude of viable shocks:

distance to non viable zone:

$$\min_{x \notin \mathbb{V}\mathrm{iab}} \|x_0 - x\|$$

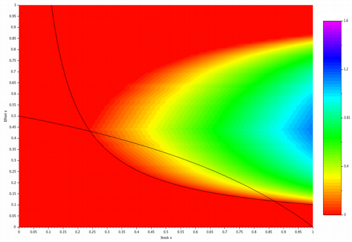
- Example: Renewable resource management

Renewable stock $x(t)$ harvested at rate $a(t)$

$$x(t+1) = x(t) + g(x(t)) - qa(t)x(t)$$

Profitability constraint and threshold:

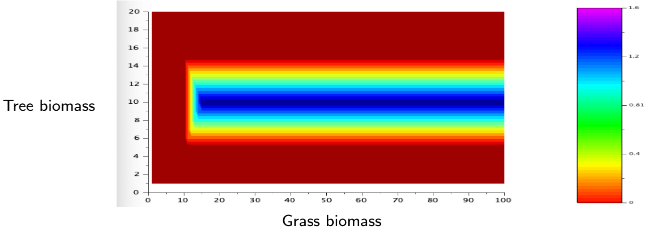
$$\pi(x(t), a(t)) = pqa(t)x(t) - ca(t) \geq \pi^{\lim}$$



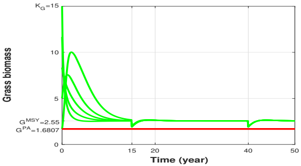
Resistance for savannas in Cameroon

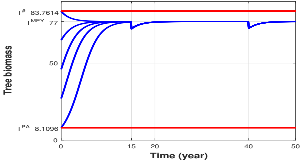
Yatat, Doyen, Tewa, Gosh, ENMO, 2024

Fire shocks on tree-grass systems with harvesting



Message: A corridor of Resistance





Recovery and viability

Béné et al., Eco. Econ. 2001, Martinet et al., Eco. Econ., 2010
Doyen-StPierre, 1997; Martin, 2006
Deffuant Gilbert, 2011; Rougé et al. 2013

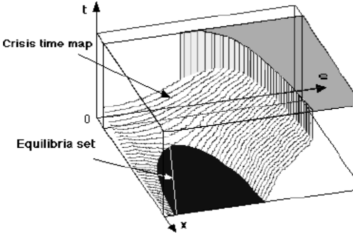
- Recovery: Time of crisis of a trajectory w.r. to viability thresholds

$$\sum_t \mathbb{1}_{\text{not viable}}(t)$$

- Extension of ideas of stability for equilibria
- Recovery strategy: minimal time of crisis

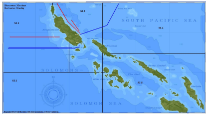
$$\min_{a(.)} \sum_t \mathbb{1}_{\text{not viable}}(t)$$

- Viability kernel: 0 minimal time of crisis



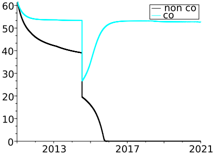
The positive role of cooperation for recovery

Hardy et al., EDE, 2015

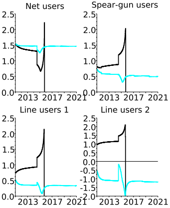


Solomon Islands

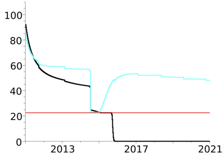
Catch



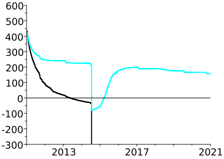
Efforts of heterogeneous agents



Biomass



Profit



Robustness: Stochastic viability

Summers-Lygeros, Automatica, 2010
Doyen-DeLara, Systems Control Letters, 2010

- Dynamics with shocks and stochasticities:

$$x_i(t+1) = F_i\Big(\underbrace{x(t)}_{\textit{states}},\ \underbrace{a(t)}_{\textit{actions}},\ \underbrace{\boxed{\omega(t)}}_{\textit{uncertainties}} \Big)$$

- Robustness: probability of viability of a trajectory

$$\mathbb{P}_\omega\Big(\text{constraints satisfied},\ t = t_0, \dots, T\Big)$$

- Robustness strategy: maximal robustness

$$\max_{\text{feedback controls } a(.)} \mathbb{P}_\omega\Big(\text{constraints satisfied},\ t = t_0, \dots, T\Big)$$

- Viability kernels: sections of maximal probability of viability

Robustness for fisheries

ORIGINAL ARTICLE

WILEY FISH and FISHERIES

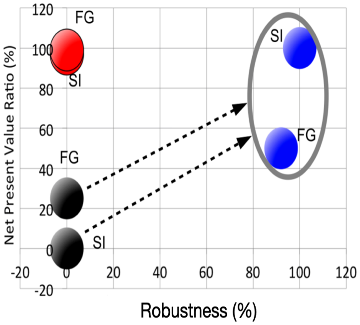
Ecoviability for ecosystem-based fisheries management

Luc Doyen[1] | Christophe Béné[2] | Michel Bertignac[3] | Fabian Blanchard[4] | Abdoul Ahad Cissé[4] | Catherine Dichmont[5] | Sophie Gourguet[6] | Olivier Guyader[6] | Pierre-Yves Hardy[7] | Sarah Jennings[8] | Lorne Richard Little[9] | Claire Macher[6] | David Jonathan Mills[10,11] | Ahmed Noussair[12] | Sean Pascoe[5] | Jean-Christophe Pereau[1] | Nicolas Sanz[4] | Anne-Maree Schwarz[10] | Tony Smith[9] | Olivier Thébaud[5,6]

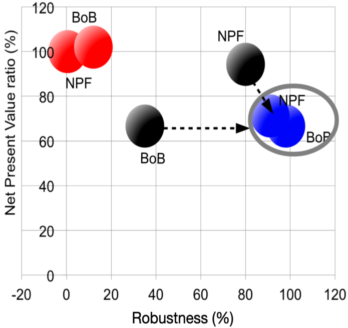
Robustness: Comparative analysis between case-studies

FG: French Guiana
NPF: Australian Northern Prawn;
SI: Solomon Islands;
BoB: Bay of Biscay

Status Quo Strategy
Maximal Robustness Strategy
Maximal NPV Strategy



a) Small scale fisheries



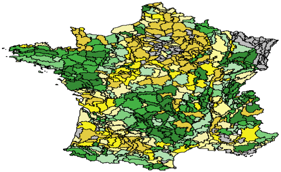
b) Large scale fisheries

Robustness for birds biodiversity and landuse

Mouysset, Doyen et al., Biol. Cons., 2015

Doyen, ENMO, 2018

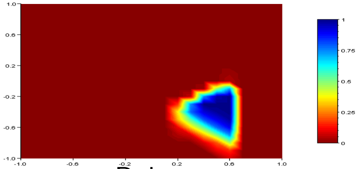
2050



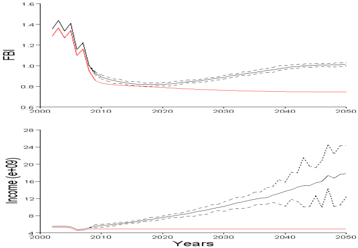
Bio-economic constraints:

$$\begin{array}{rcl} FBI(t) & \geq & \lambda * FBI^{SQ}(t) \\ CTI(t) & \geq & \lambda * CTI^{SQ}(t) \\ CSI(t) & \geq & \lambda * CSI^{SQ}(t) \\ Inc(t) & \geq & \lambda * Inc^{SQ}(t) \\ \textsc{Budget}(t) & \leq & \textsc{Budget}(t_0) \end{array}$$

Message: spatial diversification



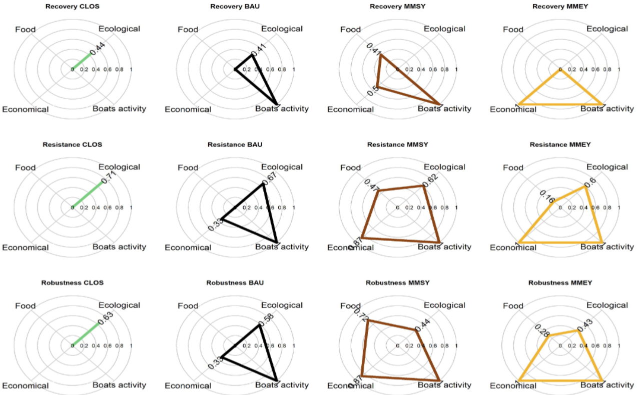
Robustness



Applying the 3Rs for the coastal fishery in Guiana

Cuilleret et al., Economic Analysis and Policy, 2022

3Rs vs. 4 fishing strategies versus 4 criteria



Message: 3Rs differ and bring complementary insights !!

Conclusion

- 3Rs: complementary ingredients of resilience
  between crisis and risk management
- Viable control: fruitful modeling framework for 3Rs-based management
- Insights for applications to ecosystem and biodiversity management
- New challenges:
  3Rs vs. prevention- adaptation - transformation- mitigation