

## 3 Days MESSH Brest 2024

# Bio-economic modelling of small-scale fishery in French Guiana : review and perspectives

**A-A. Cissé<sup>1</sup>, H. Gomes<sup>2</sup>, C. Kersulec<sup>3</sup>, M. Cuilleret<sup>4</sup>, L. Doyen<sup>4</sup>**

<sup>1</sup> Université de Guyane, LEEISA, Guyane Française

<sup>2</sup> AZTI, Spain

<sup>3</sup> University of Warsaw, Poland

<sup>4</sup> CEEM, Montpellier, France

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## How to operationalize Ecosystem-Based Fishery Management for tropical Small Scale Fishery ?

- Bio-economic modelling
- MICE models (Plagányi *et al.*, 2014)
- Scenarios for Viability (Bene *et al.*, 2001)
- Scenarios for Resilience (Grafton *et al.*, 2019) : Resistance, Robustness and Recovery

French Guiana coastal fishery as a perfect case study  
(complexity, uncertainties, tropical SSF issues, data, etc.)

# 1- Case study: The French Guiana SSF



- 140 vessels (2022) / 2500 tones per year
- 450 fishermen
- Gross value of landings : 6 millions € (2021)
- Main landed species:
  - Acoupa Weak fish (31% Vol)
  - Green weakfish (26% Vol )
  - Crucifix catfish (18 % Vol )
- Main fleets:
  - "Canots créoles " (18% )
  - " Canots créoles améliorés " ( 74% TGV)
  - " Tapouilles " (6% TGV)



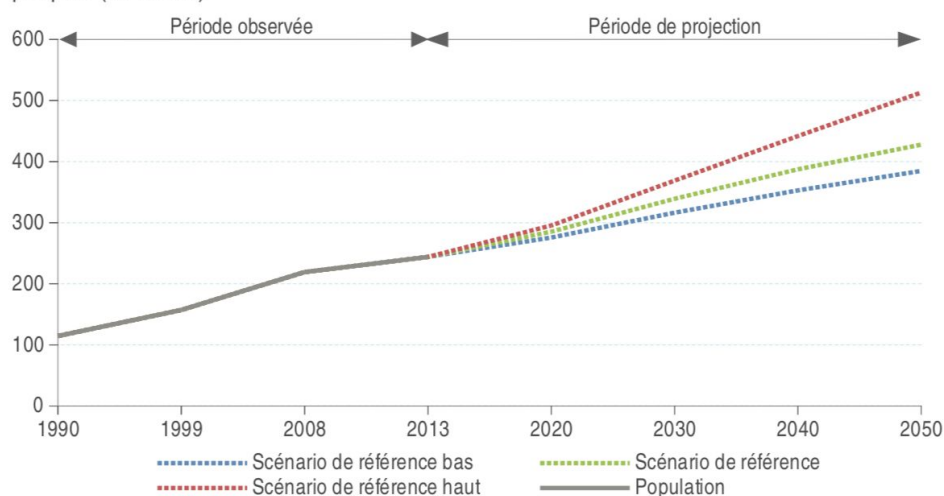


# 1- Case study: The issues of French Guiana SSF

## • Issue of local seafood demand increase

### 5 Entre 385 000 et 513 000 habitants en Guyane à l'horizon 2050

Évolution de la population guyanaise à l'horizon 2050 selon les trois scénarios démographiques (en millier)



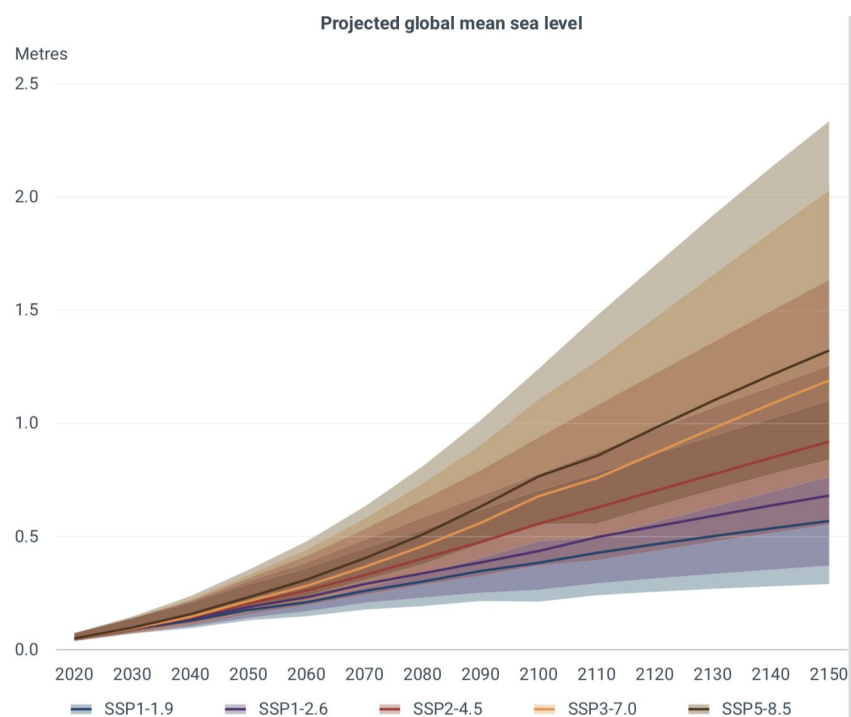
Lecture : la courbe grise représente l'évolution réelle de la population guyanaise entre 1990 et 2013, puis les courbes de couleur représentent les évolutions futures basées sur les trois scénarios envisagés dans cette étude.

Sources : Insee, Recensements de la population & projections de population Omphale 2017.

## • Issue of profitability

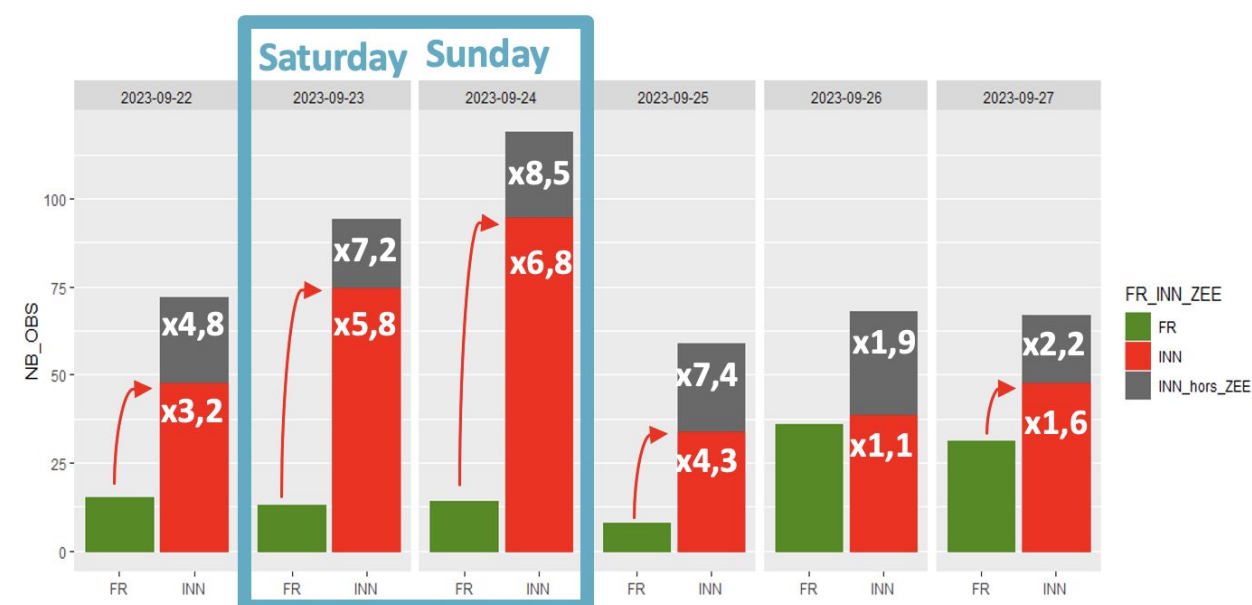


## • Issue of climate changes



## • Issue of illegal fishing

Total number of illegal ships observed during aerial surveillance



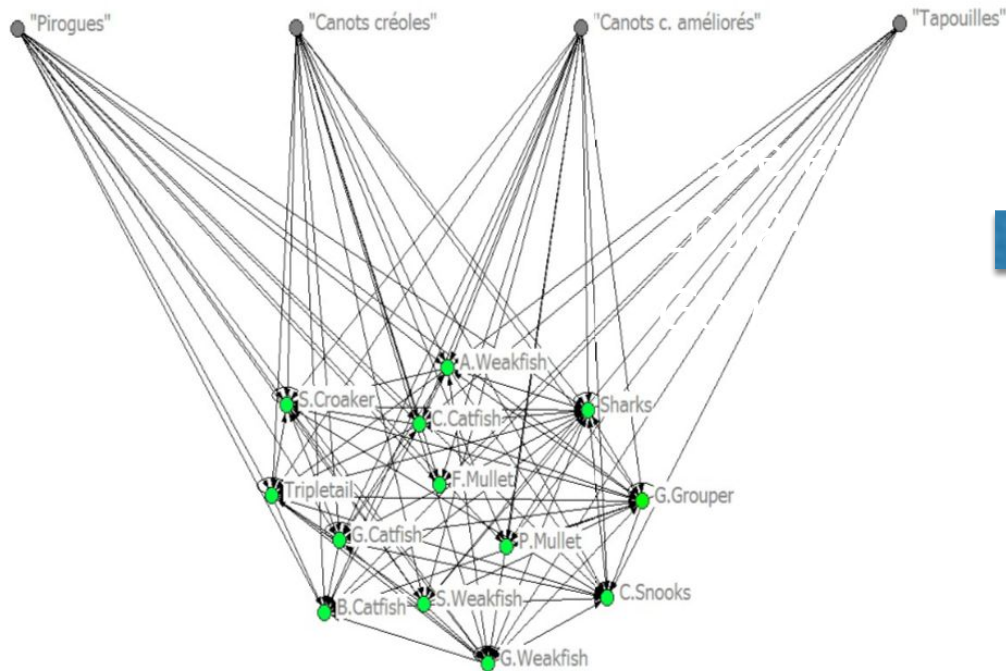
# 2- Methods: Multi-species and multi fleets bioeconomic models

- Lotka-Volterra prey-predator dynamics

$$B_i(t + 1) = g_i(B(t) - H(t), \epsilon_i(t)),$$

with

$$g_i(B_1, \dots, B_n, \epsilon_i) = B_i \cdot \left( 1 + r_i - \frac{r_i}{K_i} B_i + \sum_{j \neq i} s_{i,j} B_j + \epsilon_i \right),$$



Cissé *et al.* 2013,2015; Tromeur and Doyen 2018

- Schaefer production function

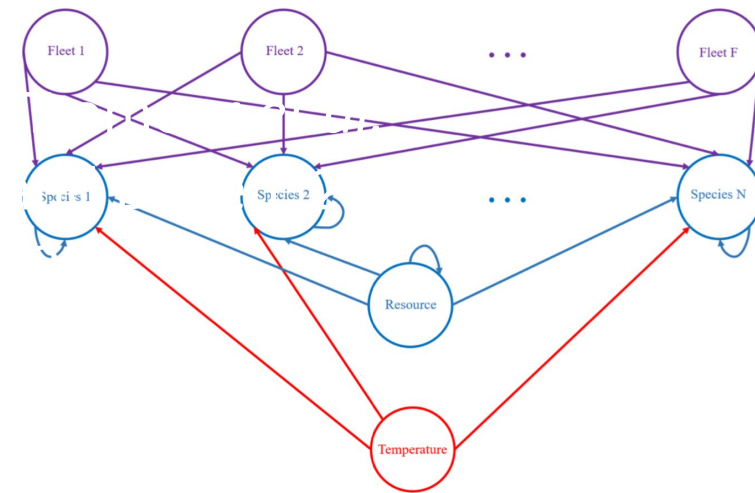
$$H_{i,f}(t) = q_{i,f} E_f(t) B_i(t),$$

- Resource-based model (Tilman and Sterner, 1984)

$$B_i(t + 1) = B_i(t) (1 - M_i + G_i(t)) - H_i(t).$$

with

$$G_i(t) = g_i a_{res,i} B_{res}(t) \gamma_i (\theta(t - \tau_i))$$

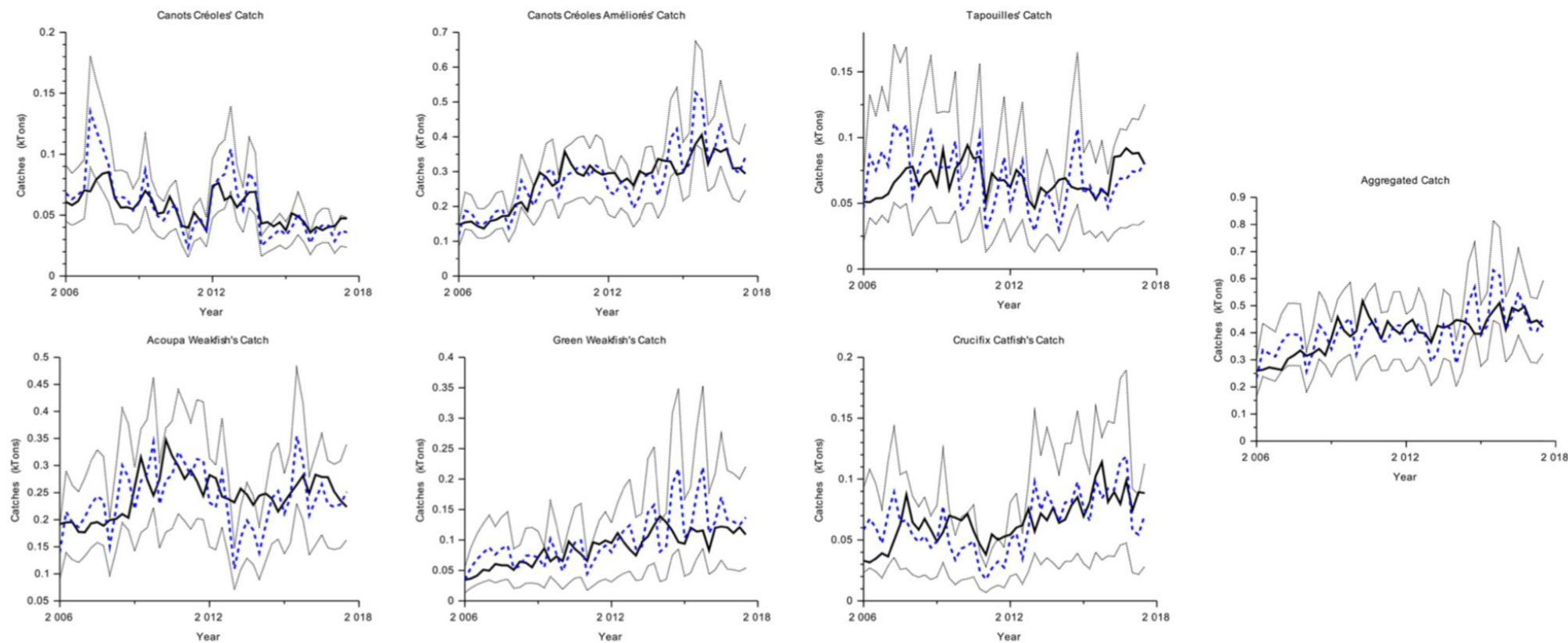


Gomes *et al.* 2021; Kersulec *et al.* 2023; Cuilleret *et al.* 2022

# 2- Methods: model calibration

- Data for calibration : quaterly catches by species and fleet and efforts by fleet since 2006

$$\min_{M_i; q_{i,f}; a_{res,i}; g_i; B_i(t_0); \tau_i} \sum_{t=t_0}^{t_1-1} \sum_{i=1}^N \sum_{f=1}^F (H_{i,f}^{data}(t) - H_{i,f}(t))^2,$$



**Fig. 5** Historical (dark blue points) and calibrated (black line) catch by fleet (first row), by stock (second row), and aggregated (last graph) with 95% confidence intervals (dotted black lines) from the first quarter of 2006 to the last quarter of 2017



# 2- Methods : Economic compartment

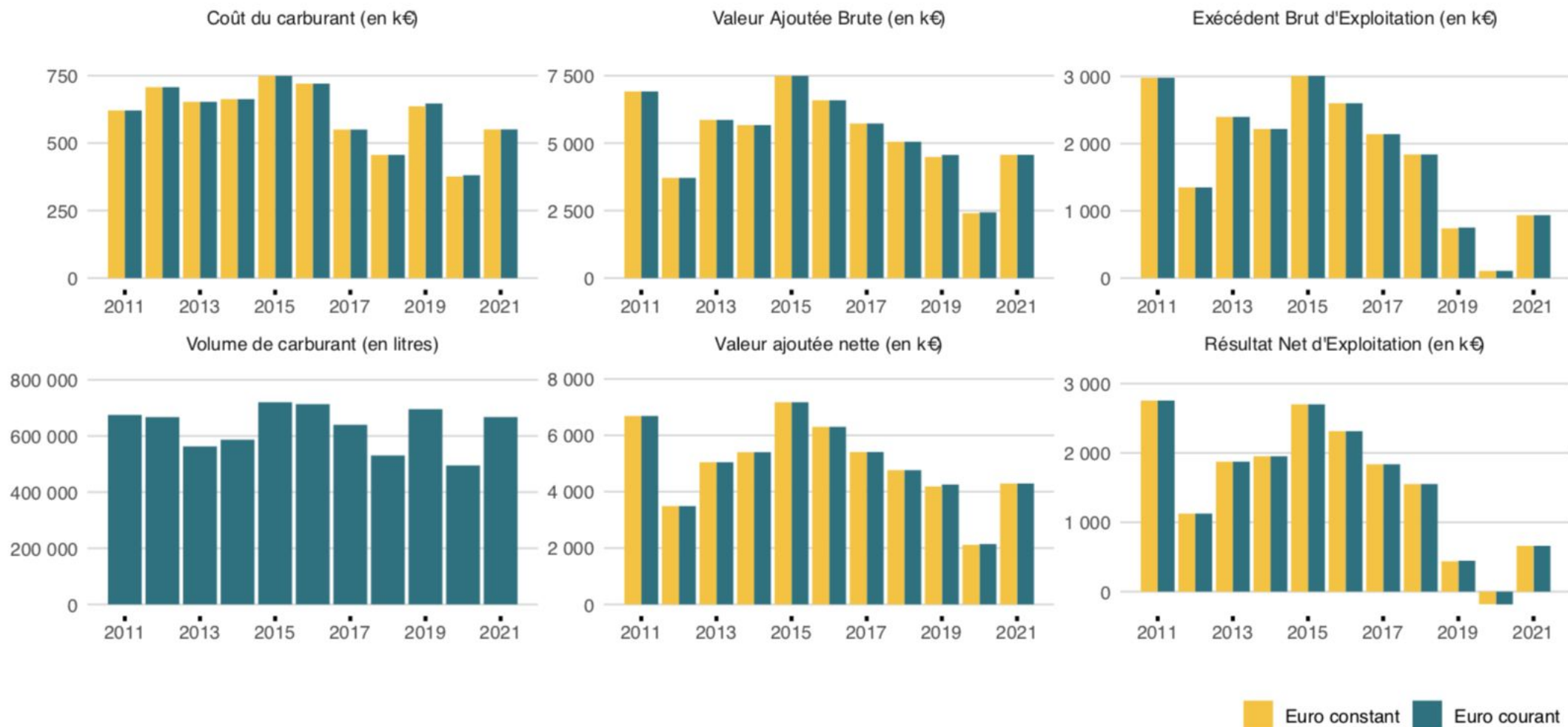
- Economic data collection : 2010 and 2022
- Average species prices by fleet and marketing channel
- Fixed and variables costs by fleet
- Subsidies
- Revenues
- Profits

$$\pi(t) = \sum_{f=1}^F (1 - Bet_f)(Inc_f(t) - Co_f(t)).$$

$$Co_f(t) = E_f(t) (OilCon_f Coil(t) + Ice_f + Fix_f) .$$

$$Inc_f(t) = \sum_{s=1}^S h_{s,f}(t)p_s(t) + Inc_{Ots}(t),$$

## Evolution des performances économiques totales des navires actifs



## 2- Methods : Scenarios

### Explorative scenarios :

- Business as usual and Closure (Cissé *et al.* 2015; Cuilleret *et al.* 2022)
- Impacts of Climate changes (Gomes *et al.* 2021)
- Impacts of Illegal fishing (Kersulec *et al.* 2023)

### Normative scenarios :

- Economic (NPV) (Cissé *et al.* 2015; Cuilleret *et al.* 2022)
- MMEY and MMSY (Tromeur and Doyen 2018; Cuilleret *et al.* 2022)
- Ecoviability (Cissé *et al.* 2015)



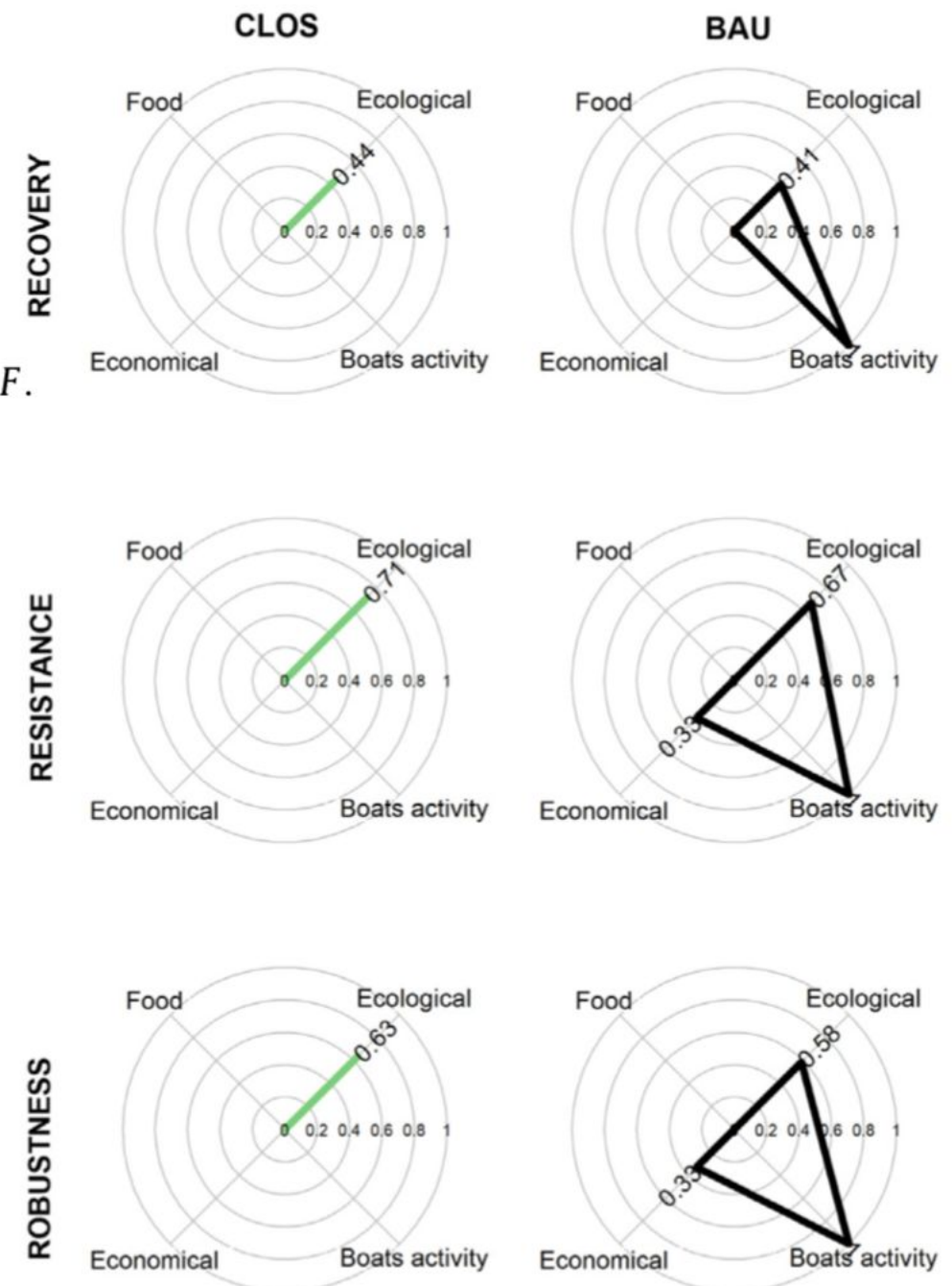
# 2- Methods and main results : Explorative scenarios

- Business as usual (status quo) scenario :  
=> Weak Economically and Unviable for food security (Cissé *et al.* 2015, Cuilleret *et al.* 2022)

$$E_f^{\text{BAU}}(t + 1) = E_f^{\text{BAU}}(t)(1 + \delta_f^{\text{hist}}), \quad \forall t = t_c, \dots, T, \quad \forall f = 1, \dots, F.$$

- Closure :  
=> Unviable from social viewpoint and for food security (Cissé *et al.* 2013, Cuilleret *et al.* 2022)

$$E_f^{\text{CLOS}}(t) = 0, \quad \forall t = t_c, \dots, T, \quad \forall f = 1, \dots, F.$$

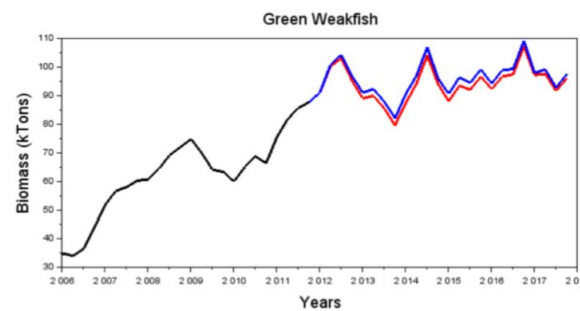
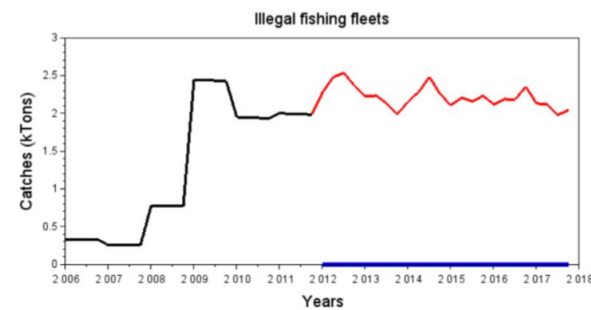
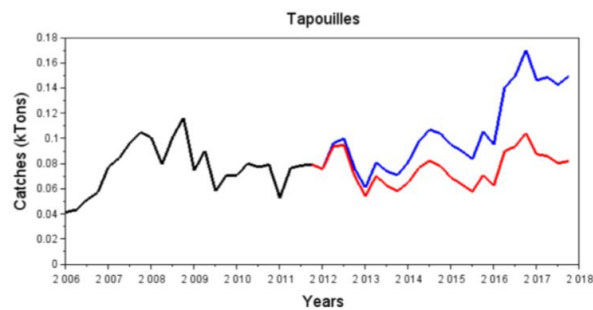
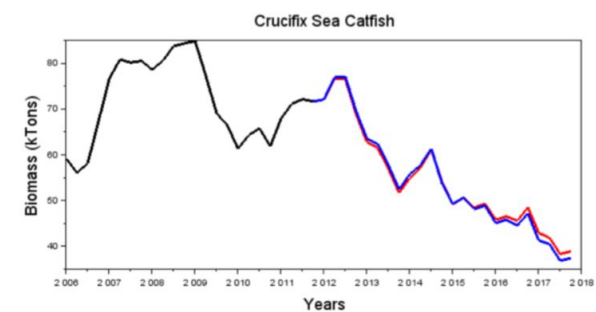
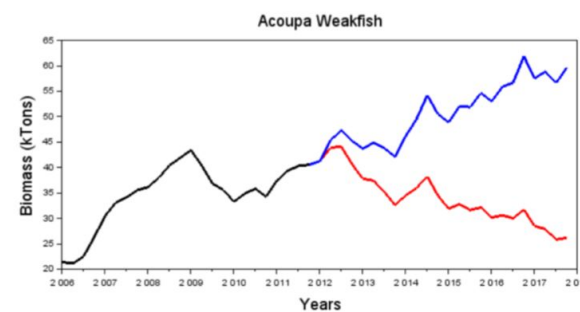
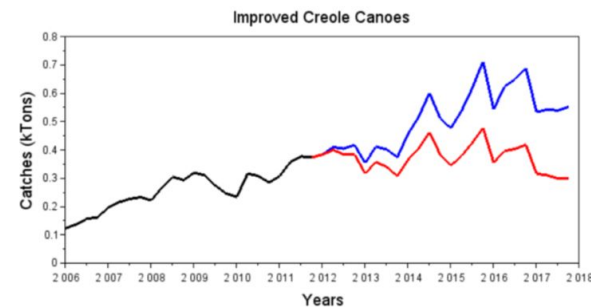
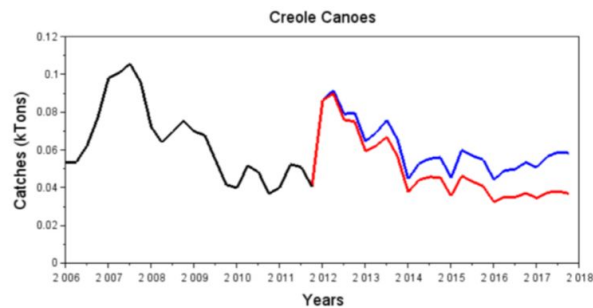


# 2- Methods and main results : Explorative scenarios

Explorative IUU fishing scenarios 4th fleet => calibration

$$H_{i,IUU}^{data}(t) = H_{IUU}^{data}(t) * \frac{H_i^{data}(t)}{\sum_{j=1,\dots,N} H_j^{data}(t)}$$

- Monetary and biodiversity losses with IUU activities
- Economic gains biodiversity perservation with no IUU fishing : around 5 millions euros per year



## 2- Methods and main results : Explorative scenarios

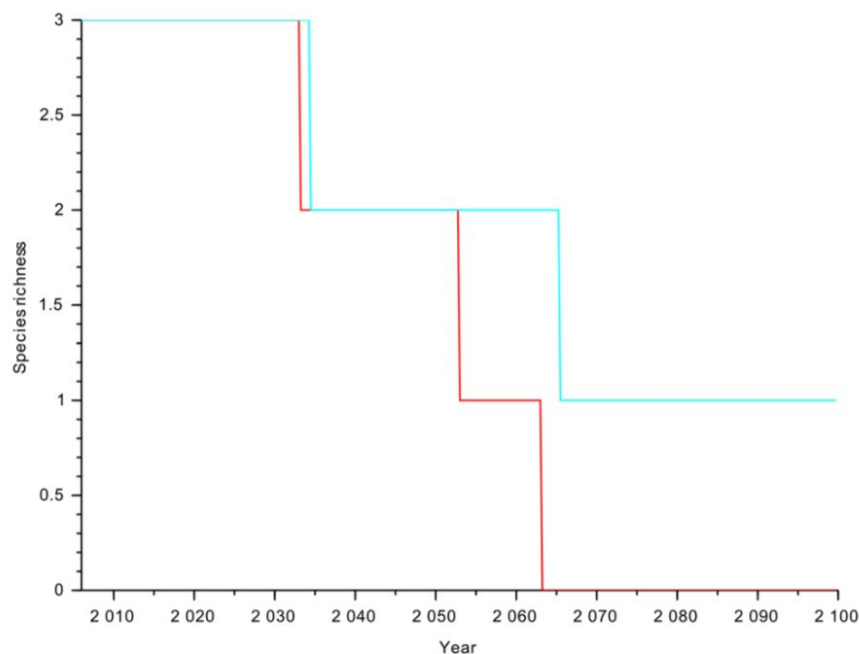
### Explorative climate change scenarios (RCP2.6, RCP8.5)

$$B_i(t+1) = B_i(t)(1 - M_i + G_i(t)) - H_i(t).$$

with

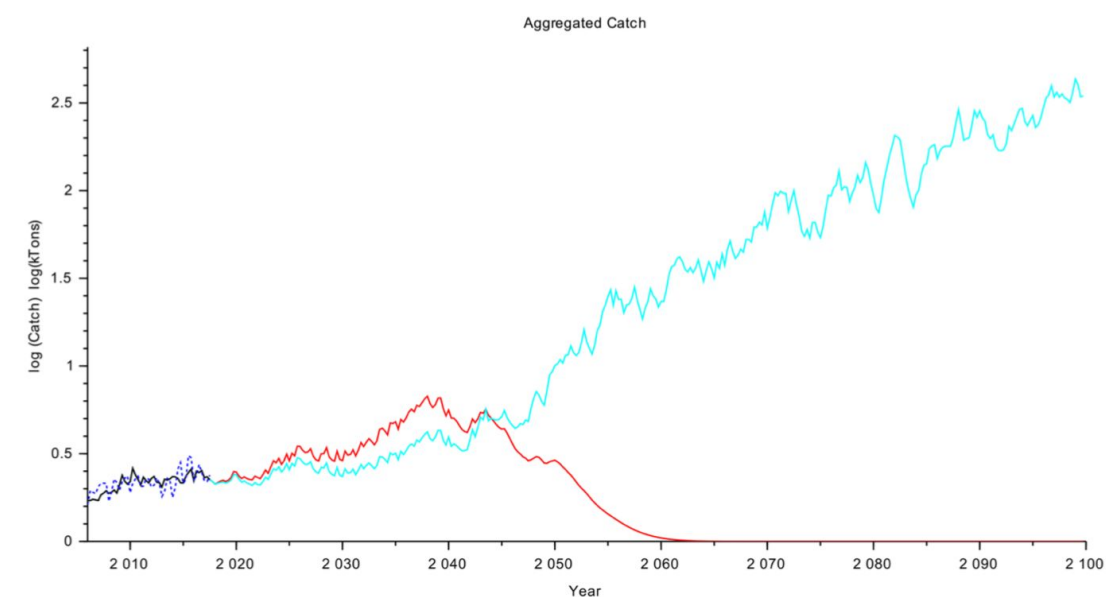
$$G_i(t) = g_i a_{res,i} B_{res}(t) \gamma_i (\theta(t - \tau_i))$$

- Explorative climate change scenarios (RCP2.6, RCP8.5)
- Intergovernmental Panel on Climate Change (IPCC) scenarios
- RCP2.6 : optimistic climatic scenario (increase on average by about 0.64° C in 2031–2050 and by about 0.73° C in 2081–2100)
- RCP8.5 : pessimistic climate scenario (a mean increase of 0.95° C in global SST in 2031-2050 and of 2.58° C in 2081–2100)



**Fig. 9** Estimated number of non extinct species among the three species taken into account for RCP 8.5 (red) and RCP 2.6 (blue) under the PS fishing scenario

**Fig. 10** Aggregated catch on a logarithmic scale for RCP 8.5 (red) and RCP 2.6 (blue) under the PS fishing scenario



Gomes *et al.* 2021

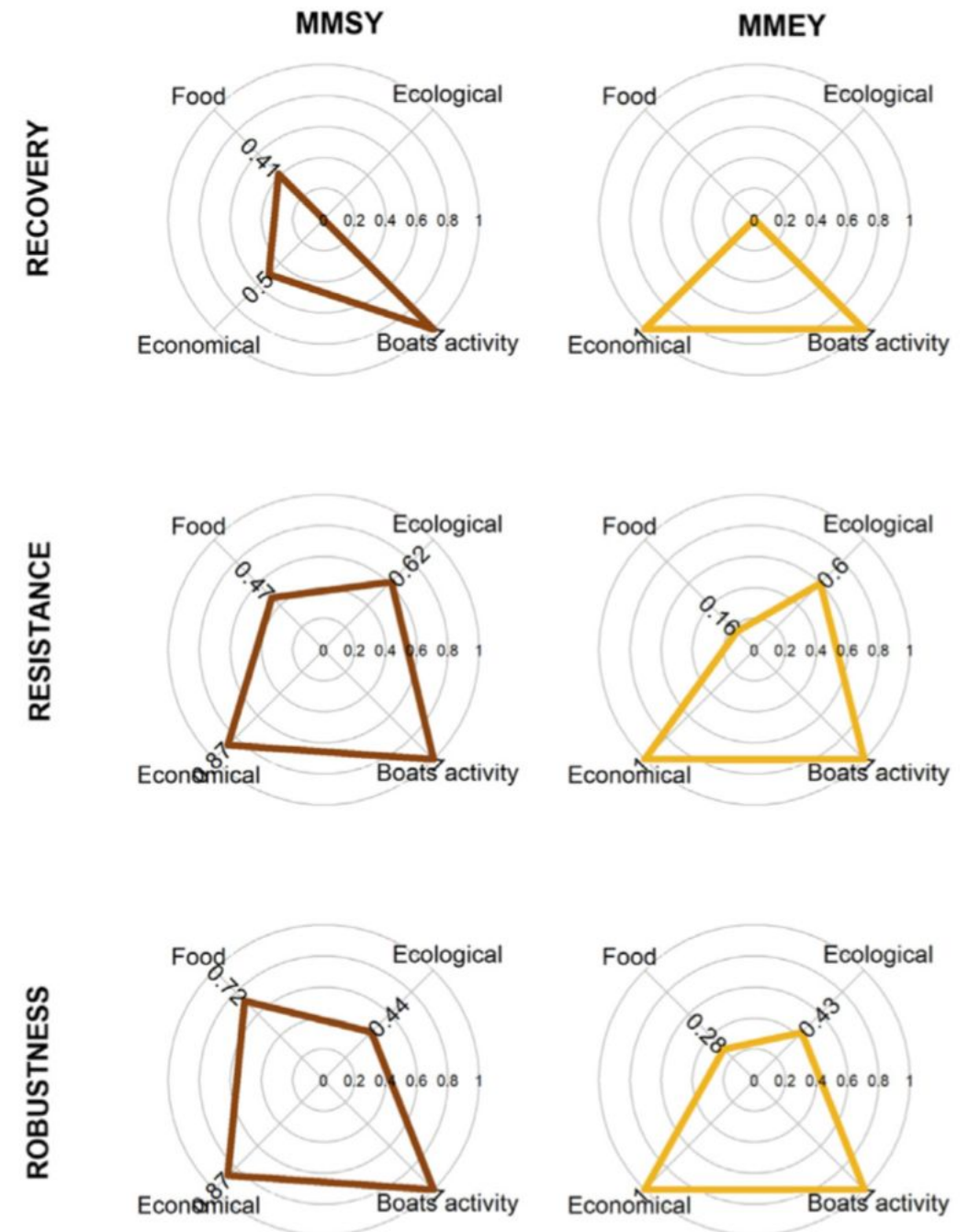
# 2- Methods and main results : Normative scenarios

- Multi-species maximum sustainable yield (MMSY) :  
=> maximizing the expected aggregated catches over the projected period with respect to the fishing effort.  
=> Better resilience for food security (Tromeur and Doyen 2018, Cuilleret *et al.* 2022)

$$H(E^{\text{MMSY}}) = \max_{E_f, f=1, \dots, F} \mathbb{E}_{\theta, \text{Coil}} [H(E)]$$

- Multi-species maximum economic yield (MMEY) :  
=> maximizing, the net present value of the fishery over the simulation period.  
=> Better economic resilience (Tromeur and Doyen 2018, Cuilleret *et al.* 2022)

$$\text{NPV}(E^{\text{MMEY}}) = \max_{E_f, f=1, \dots, F} \mathbb{E}_{\theta, \text{Coil}} [\text{NPV}(E)]$$





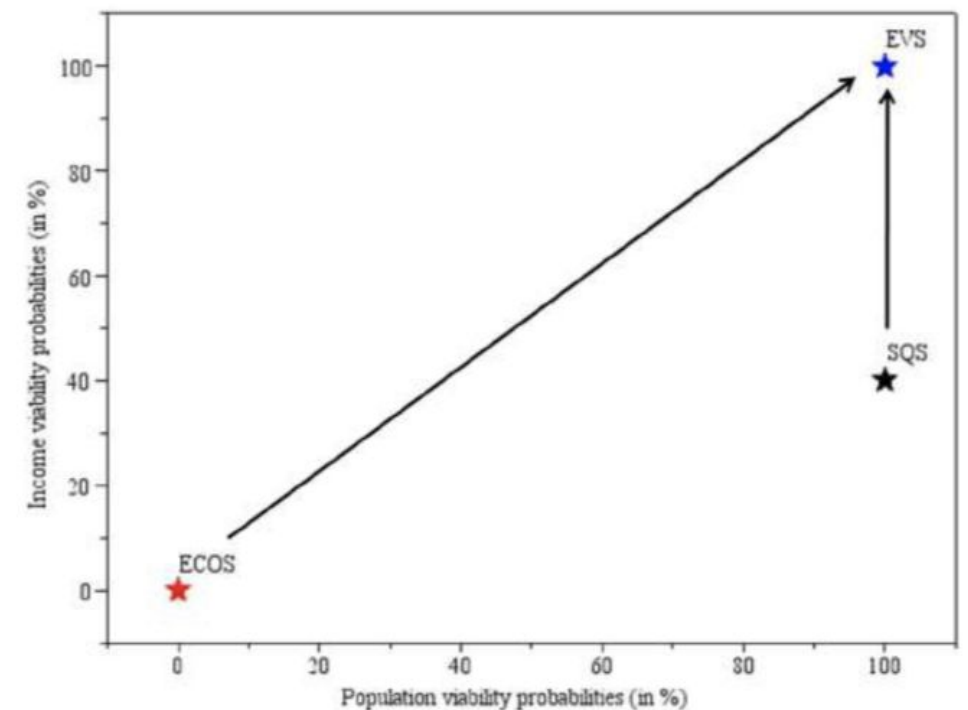
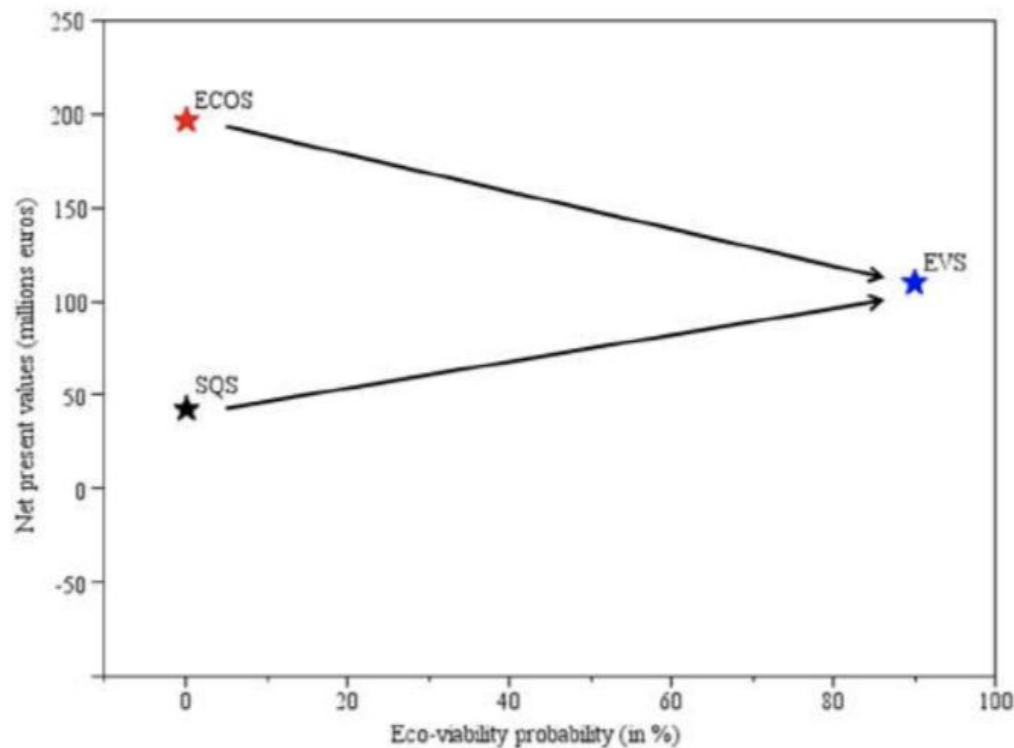
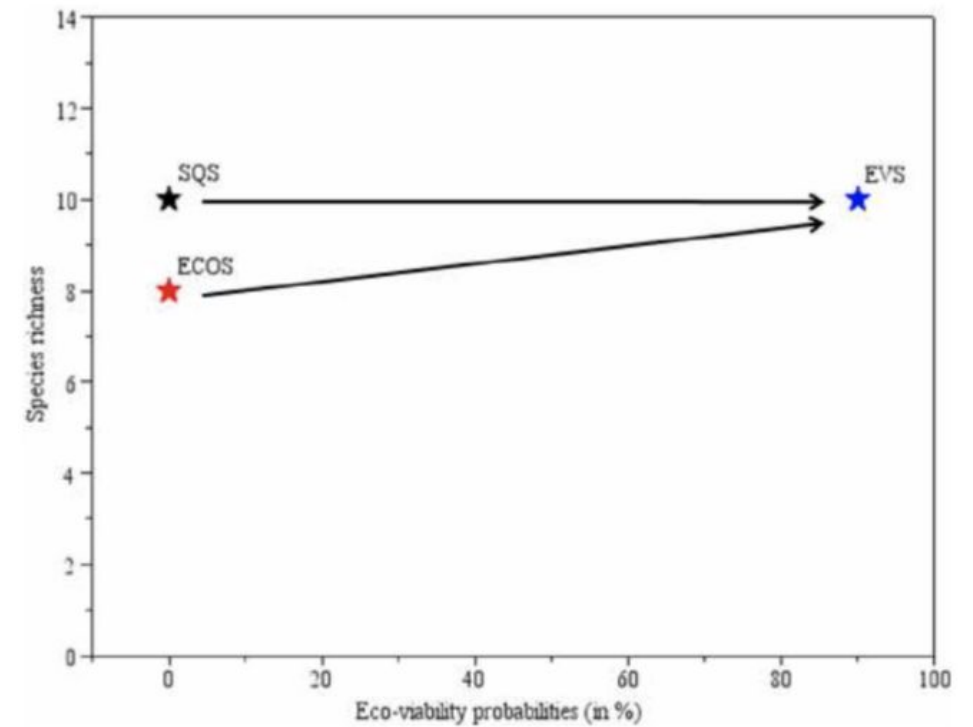
# 2- Methods and main results : Normative scenarios

## Ecoviability scenario :

- Economic constraint : profitability
- Ecological constraint : Blim
- Social constraint : seafood demand

$$\max_{e_k(t)} \prod_{t=t_1}^{t_f} \mathbf{1}_{\{]0,+\infty[ \}}(\pi_k(t)) \mathbf{1}_{\{]0,+\infty[ \}}(SR(t) - 11) \mathbf{1}_{\{]0,+\infty[ \}} \cdot (H(t) - H(2009)) \cdot (1 + d)^t$$

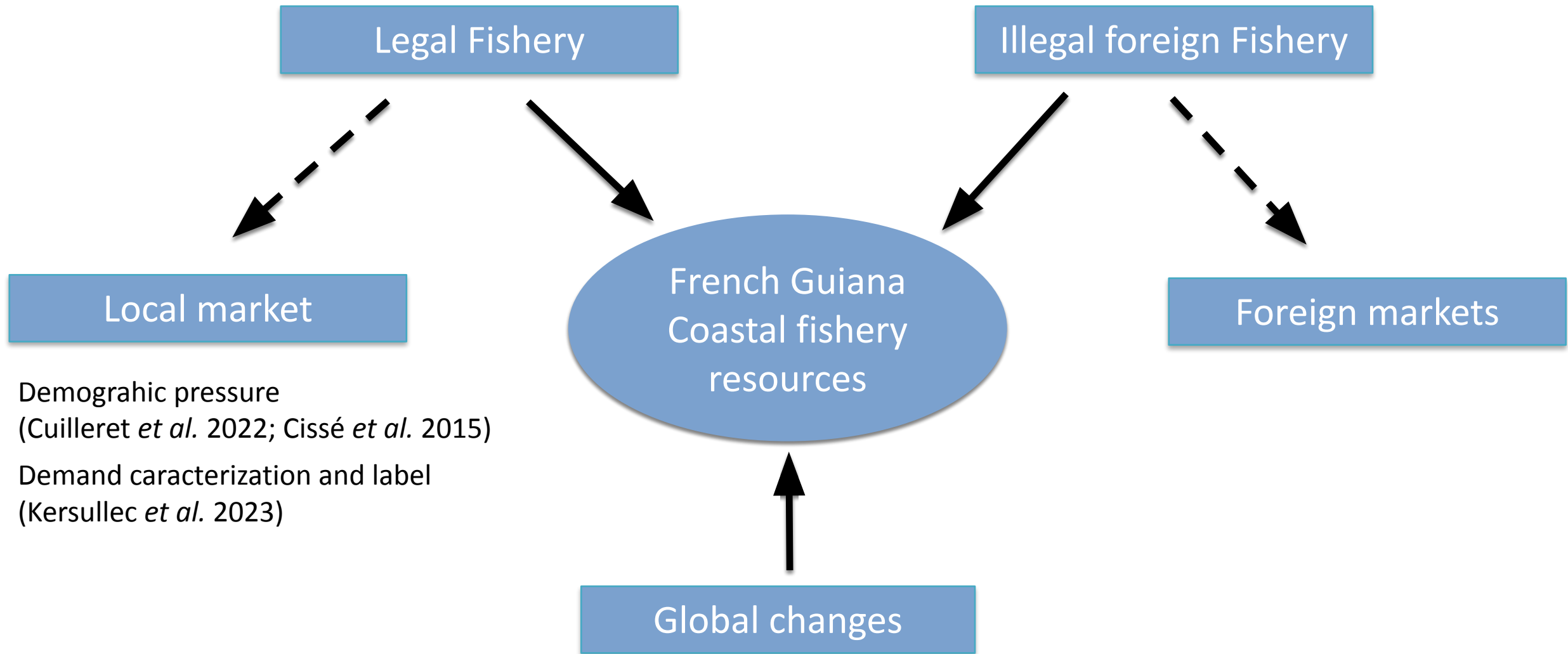
Ecoviability scenario : a way to integrate ecological, economics but also Social considerations (Cissé *et al.* 2015)



# 3- Resume : Bioeconomic modelling and scenarios

Profitability and viability under conditions  
(Cuilleret *et al.* 2022; Gomes *et al.* 2021; Cissé *et al.* 2013)

Negative impacts on the resource  
(Kersullec *et al.* 2023)



Demographic pressure  
(Cuilleret *et al.* 2022; Cissé *et al.* 2015)

Demand characterization and label  
(Kersullec *et al.* 2023)

Long term detrimental impact of climate change  
(Cuilleret *et al.* 2022; Gomes *et al.* 2021)



# 4- Perspectives

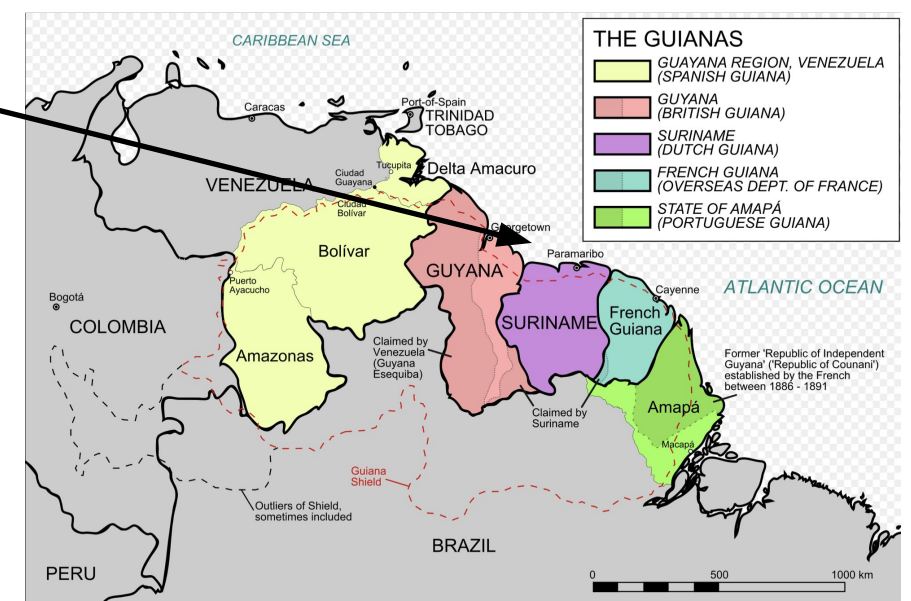
□ On going stock assessments and socio-economic survey  
=> first results in 2024

□ On going illegal fishing evaluation  
=> first results in 2024

Refine bioeconomic parameters for calibration and simulations

Analyse the IUU fishing activities with the rational choice theory and the game theory approaches

Bioeconomic model for SSF in the north eastern south america



# Thank you for your attention!!

Cissé A.A., S. Gourguet, L. Doyen, F. Blanchard and J.C. Péreau (2013), *A bioeconomic model for the ecosystembased management of the coastal fishery in French Guiana*. *Environment and Development Economics*, 8-03 pp 245-269

Cissé A.A., L. Doyen, F. Blanchard, C. Béné, J.-C. Péreau (2015), *Ecoviability for small-scale fisheries in the context of food security constraints*. *Ecological Economics*, 119, pp 39–52

Cuilleret M., L. Doyen a, H. Gomes, F. Blanchard (2022), *Resilience management for coastal fisheries facing with global changes and uncertainties*, *Economic Analysis and Policy*, 74, pp 634–656

Doyen L, Béné C, Bertignac M, et al. (2017), *Ecoviability for ecosystem-based fisheries management*. *Fish and Fisheries*, pp 1–17

Gomes H., C. Kersulec, L. Doyen L, F. Blanchard F., A.A. Cisse, N. Sanz (2021), *The Major Roles of Climate Warming and Ecological Competition in the Small-scale Coastal Fishery in French Guiana*, *Environmental Modeling & Assessment*, 26 pp 655–675

Kersulec C., H. Gomes, L. Doyen, F. Blanchard (2023), *The role of illegal fishing on the sustainability of the small-scale fishery in French Guiana*. *Environment, Development and Sustainability*

Tromeur E. and L. Doyen (2018), *Optimal harvesting policies threaten biodiversity in mixed fisheries*. *Environmental Modeling and Assessment*, 17-00132

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## A bio-economic model for the ecosystem-based management of the coastal fishery in French Guiana

A.A. Cissé, S. Gourguet, L. Doyen, F. Blanchard, J.C. Péreau  
*Environmental Modelling & Assessment* (2019) 24:387–403  
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## Optimal Harvesting Policies Threaten Biodiversity in Mixed Fisheries

Eric Tromeur<sup>1,2,3</sup> · Luc Doyen<sup>3</sup>

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### Abstract

As marine ecosystems are under pressure worldwide, many scientists and stakeholders advocate the use of ecosystem-based approaches for fishery management. In particular, management policies are expected to account for the multispecies nature of fisheries. However, numerous fisheries management plans remain based on single-species concepts, such as maximum sustainable yield (MSY) and maximum economic yield (MEY), that respectively aim at maximizing catches or profits of single species or stocks. In this study, we assess the bioeconomic sustainability of multispecies MSY and MEY in a mixed fishery, characterized by technical interactions and therefore joint production. First, we analytically show how multispecies MSY and MEY can induce overharvesting and extinction of species with low productivity and low value. Second, we identify and discuss incentives on effort costs and landing prices, as well as technical regulations, that could promote biodiversity conservation and more globally sustainability. Finally, a numerical example based on the coastal fishery in French Guiana illustrates the analytical findings.

**Keywords** Multispecies fishery · Ecosystem-based fisheries management · Maximum sustainable yield · Maximum economic yield · Overexploitation · Technical interaction

*Environmental Modelling & Assessment* (2021) 26:655–675  
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## The Major Roles of Climate Warming and Ecological Competition in the Small-scale Coastal Fishery in French Guiana

Helene Gomes<sup>1</sup> · Coralie Kersulec<sup>2</sup> · Luc Doyen<sup>3</sup> · Fabian Blanchard<sup>1</sup> · Abdoul Ahad Cissé<sup>4</sup> · Nicolas Sanz<sup>5</sup>

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### Abstract

Marine ecosystems, biodiversity, and fisheries are under strain worldwide due to global changes including climate warming and demographic pressure. To address this issue, many scientists and stakeholders advocate the use of an ecosystem approach for fisheries that integrates the numerous ecological and economic complexities at play rather than focusing on the management of individual target species. However, the operationalization of such an ecosystem approach remains challenging, especially from a bio-economic standpoint. Here, to address this issue, we propose a bio-economic model (MICE) relying on multi-species, multi-fleet, and resource-based dynamics. Climatic growth of fish species as a function of sea surface temperature and fishing effort projection and RCP climate scenario are used to project the evolution of the fishery production at the horizon 2100. Our results demonstrate that ecological competition on fish biodiversity. The projection, with a potential collapse of both biomass target and economic yield.

*Ecological Economics* 119 (2015) 39–52



## Ecological Economics

journal homepage: [www.elsevier.com/locate/econecol](http://www.elsevier.com/locate/econecol)

· Multi-species · Multi-fleet fishery · Models of In

### Analysis

## Ecoviability for small-scale fisheries in the context of food security constraints

A.A. Cissé<sup>1,2,3</sup> · L. Doyen<sup>3</sup> · F. Blanchard<sup>4</sup> · C. Béné<sup>4</sup> · J.-C. Péreau<sup>5</sup>

<sup>1</sup> IFREMER, Direction de Saint-Pierre, BP 477, 97311 Cayenne, French Guiana, France  
<sup>2</sup> CERISMA, University of French West Indies and Guiana, 2091 route de Bédard, BP 206, 97226 Cayenne, French Guiana, France  
<sup>3</sup> GRETA, CNRS, University of Bordeaux, Avenue Jean Daguin, 33080 France, France  
<sup>4</sup> Institute of Development Studies, University of Sussex, Brighton, UK

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Scenario

### ABSTRACT

This paper applies a stochastic viability approach to a tropical small-scale fishery, offering a theoretical and empirical example of ecosystem-based fishery management approach that accounts for food security. The model integrates multi-species, multi-fleet and uncertainty as well as profitability, food production, and demographic growth. It is calibrated over the period 2006–2010 using monthly catch and effort data from the French Guiana's coastal fishery, involving thirteen species and four fleets. Using projections at the horizon 2040, different management strategies and scenarios are compared from a viability viewpoint, thus accounting for biodiversity preservation, fleet profitability and food security. The analysis shows that under certain conditions, viable options can be identified which allow fishing intensity and production to be increased to respond to food security requirements but with minimum impacts on the marine resources.

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Full length article

## Resilience management for coastal fisheries facing with global changes and uncertainties

Mathieu Cuilleret<sup>1,2</sup>, Luc Doyen<sup>3</sup>, Hélène Gomes<sup>4</sup>, Fabian Blanchard<sup>5</sup>

<sup>1</sup> CNRS, GRETA, University of Bordeaux, France  
<sup>2</sup> IFREMER, LEISA (LR 3456), CNRS, Université de Guyane, (St-Joseph), Cayenne, French Guiana

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### ABSTRACT

Operationalizing resilience in fisheries management is a challenging issue in the face of global changes. In this perspective, Gratton et al. (2019) propose the '3R' of resilience, namely resistance, recovery, and robustness here applies this generic framework to the coastal fishery of French Guiana under pressure because of both climate change, energy costs and To this end, a dynamic multi-species, resource-based and multi-fleet model is developed. The search for a more resilient management strategies and projections include (MSY), 'Multispecies Maximum Sustainable Yield' (MSY) and 'Economic Yield' (MEY) strategies. The comparison between ecological-economic viability goals and thresholds. The two no and more turn out to provide major gains in terms of the 3R's a resilience as compared to MSY. They both suggest major redist effort of the different fleets.

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### ORIGINAL ARTICLE

## Ecoviability for ecosystem-based fisheries management

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

<sup>1</sup>GRETA, CNRS, University of Bordeaux, France, France  
<sup>2</sup>CEAT, Decision and Policy Analysis Program, Cali, Colombia  
<sup>3</sup>IFREMER, Unité Sciences et Technologies Halieutiques, Plouzané, France  
<sup>4</sup>LEISA, Institut Universitaire de Guyane - CNRS - IFREMER, Cayenne, France  
<sup>5</sup>CSIRO, Oceans and Atmosphere, Brisbane, QLD, Australia  
<sup>6</sup>IFREMER, Unité Bioécologie, UMR 8308, Plouzané, France  
<sup>7</sup>ANR-RE, James Cook University, Townsville, QLD, Australia  
<sup>8</sup>CSIRO, Oceans and Atmosphere, Hobart, TAS, Australia  
<sup>9</sup>WoodsBath, Hobart, Tasmania, Australia  
<sup>10</sup>ARC Centre of Excellence for Coral Reef Studies, James Cook University, Townsville, QLD, Australia  
<sup>11</sup>ARC Centre of Excellence for Coral Reef Studies, James Cook University, Townsville, QLD, Australia  
<sup>12</sup>ARC Centre of Excellence for Coral Reef Studies, James Cook University, Townsville, QLD, Australia

Correspondence:  
Luc Doyen, GRETA, CNRS, University of Bordeaux, France.  
Email: [luc.doyen@univ-bordeaux.fr](mailto:luc.doyen@univ-bordeaux.fr)  
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### Abstract

Reconciling food security, economic development and biodiversity conservation is a key challenge, especially in the face of the demographic transition characterizing many countries in the world. Fisheries and marine ecosystems constitute a difficult application of this bio-economic challenge. Many experts and scientists advocate an ecosystem approach to manage marine socio-ecosystems for their sustainability and resilience. However, the ways by which to operationalize ecosystem-based fisheries management (EBFM) remain poorly specified. We propose a specific methodological framework—viability modeling—to do so. We show how viability modeling can be applied using four contrasted case-studies: two small-scale fisheries in South America and Pacific and two larger-scale fisheries in Europe and Australia. The four fisheries are analyzed using the same modeling framework, structured around a set of common methods, indicators and scenarios. The calibrated models are dynamic, multispecies and multifleet and account for various sources of uncertainty. A multicriteria evaluation is used to assess the scenarios' outcomes over a long time horizon with different constraints based on ecological, social and economic reference points. Results show to what extent the bio-economic and ecosystem risks associated with the adoption of status quo strategies are relatively high and challenge the implementation of EBFM. In contrast, strategies called ecoviability or co-viability strategies, that aim at satisfying the viability constraints, reduce significantly these ecological and economic risks and promote EBFM. The gains associated with those ecoviability strategies, however, decrease with the intensity of regulations imposed on these fisheries.

### KEYWORDS

biodiversity, ecological economics, ecosystem approach, fisheries, scenario, viability



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# Bio-economic modelling of small-scale fishery in French Guiana : review and perspectives

**A-A. Cissé<sup>1</sup>, H. Gomes<sup>2</sup>, C. Kersulec<sup>3</sup>, M. Cuilleret<sup>4</sup>, L. Doyen<sup>4</sup>**

<sup>1</sup> Université de Guyane, LEEISA, Guyane Française

<sup>2</sup> AZTI, Spain

<sup>3</sup> University of Warsaw, Poland

<sup>4</sup> CEEM, Montpellier, France

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