Scenario templates to analyse qualitative ecosystem models

Christine Largouët[1], Marie-Odile Cordier[2] & Guy Fontenelle[1]

1 AGRO CAMPUS OUEST

2 UNIVERSITÉ DE RENNES 1 — IRISA — institut de recherche en informatique et systèmes aléatoires

Rennes, France

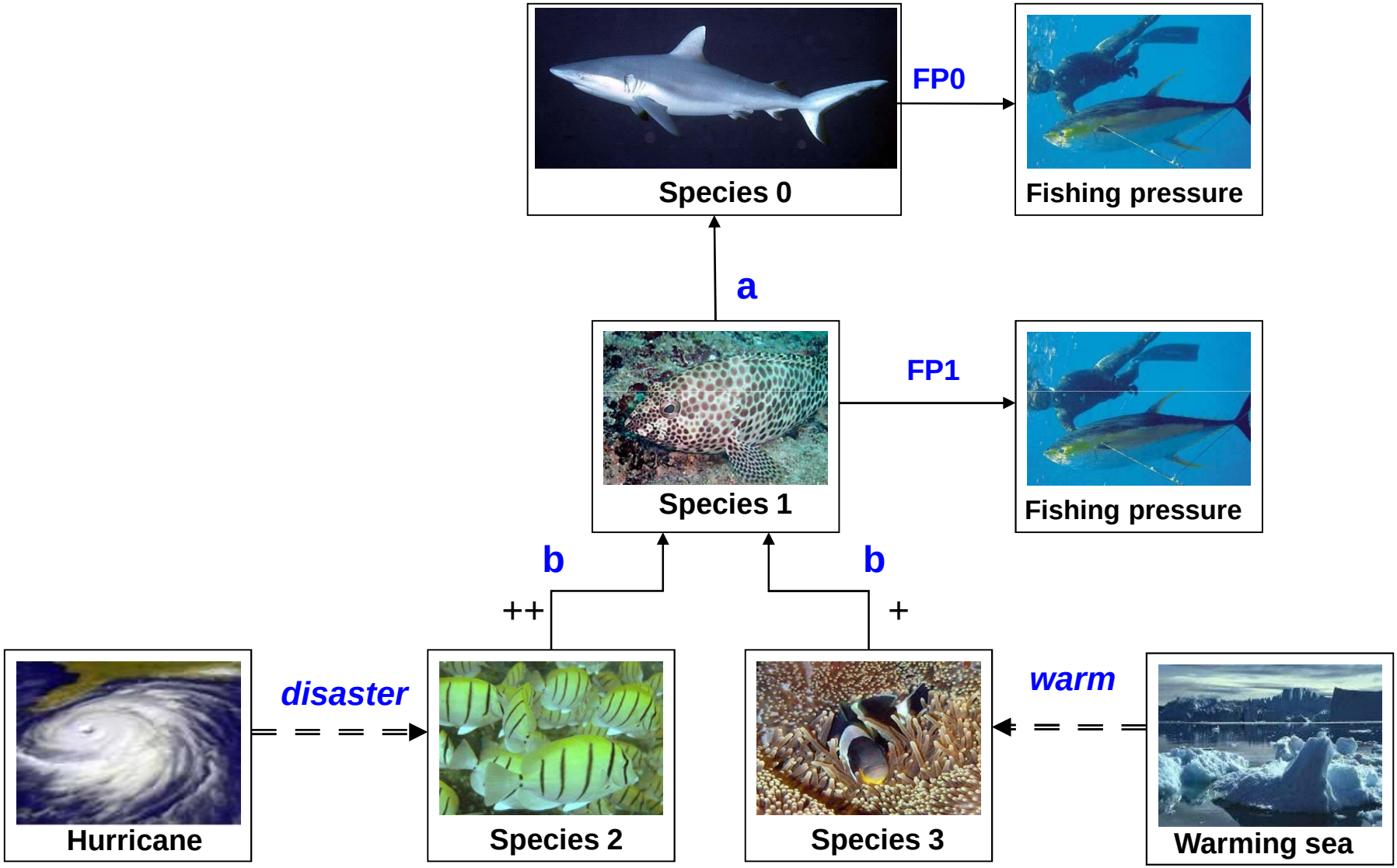
Introduction

- Qualitative modelling:
  - A relevant way for representing eco & human systems dynamics?
  - Incorporating time
  - Simulations to facilitate decision processes
    - to better understand systems
    - to propose predictive – proactive scenarios

Objectives :

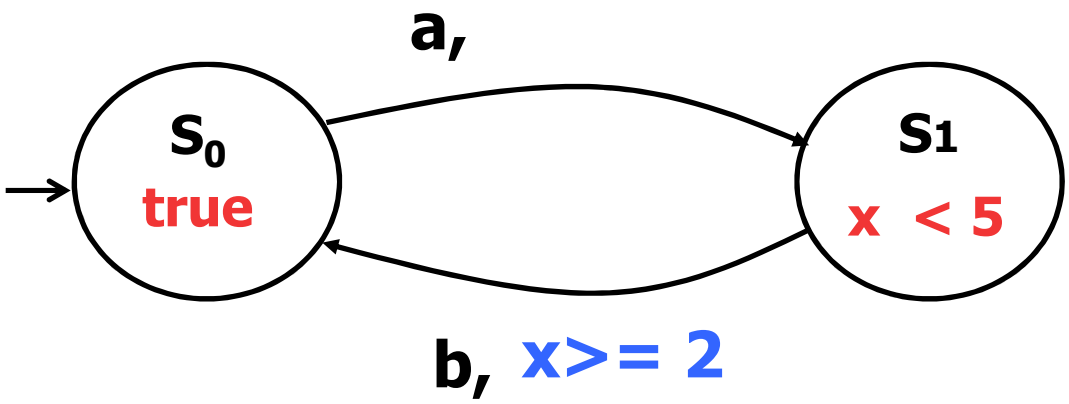
- Propose time automata formalism to represent a simplified trophic web and fisheries resource system to be used as a toy-example
- Formalize scenarios as queries in logic representation

A simplified fisheries ecosystem



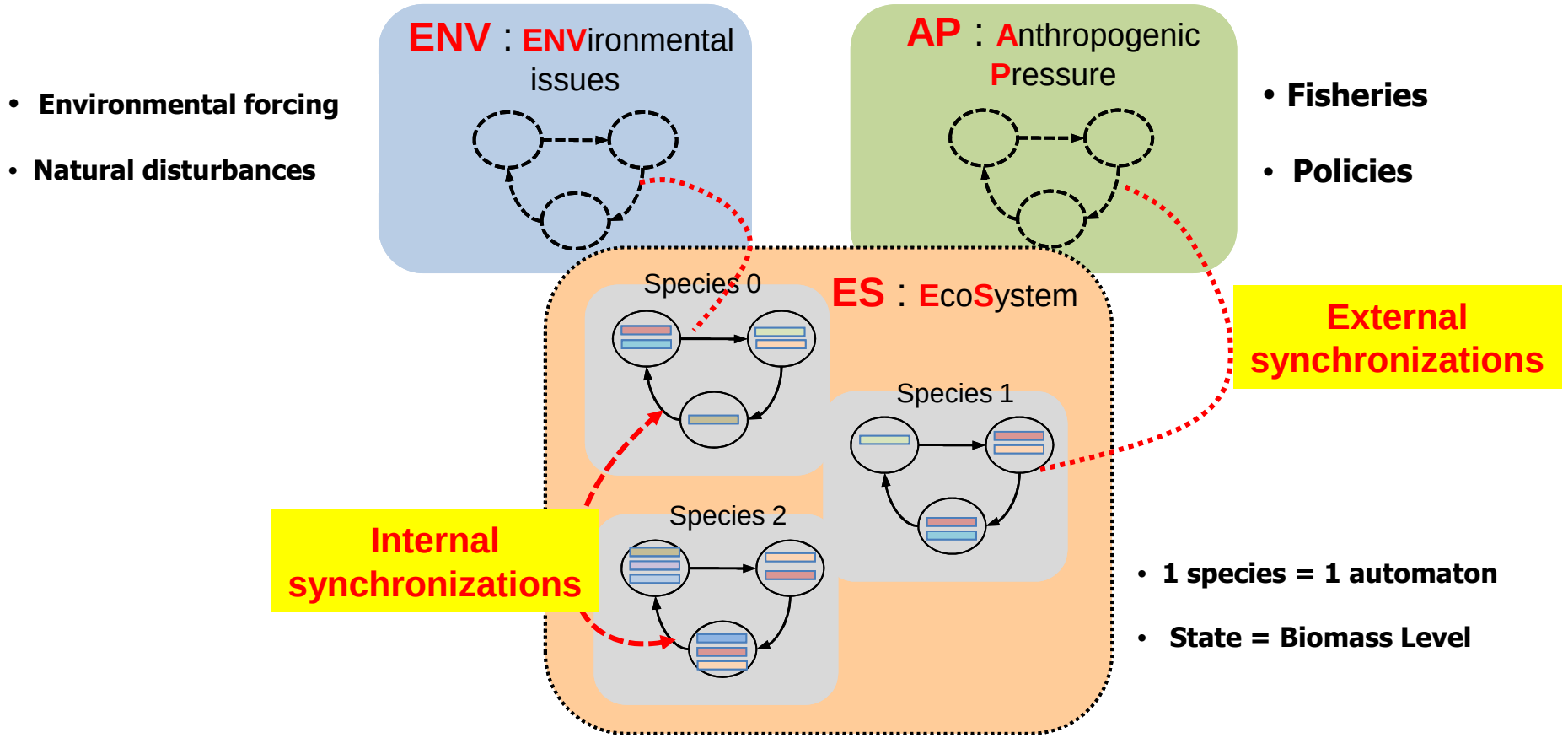
Timed Automata (some principles)

- **Automaton**: a graph representing a system's behavior that evolves from a initial state to others **(WITH clocks variables for timing constraints)**
  - **states** (S_0 S_1)
  - **Transitions**
- **Time** (x) may elapse within a state (*uncertainty*)



Qualitative model : a general framework

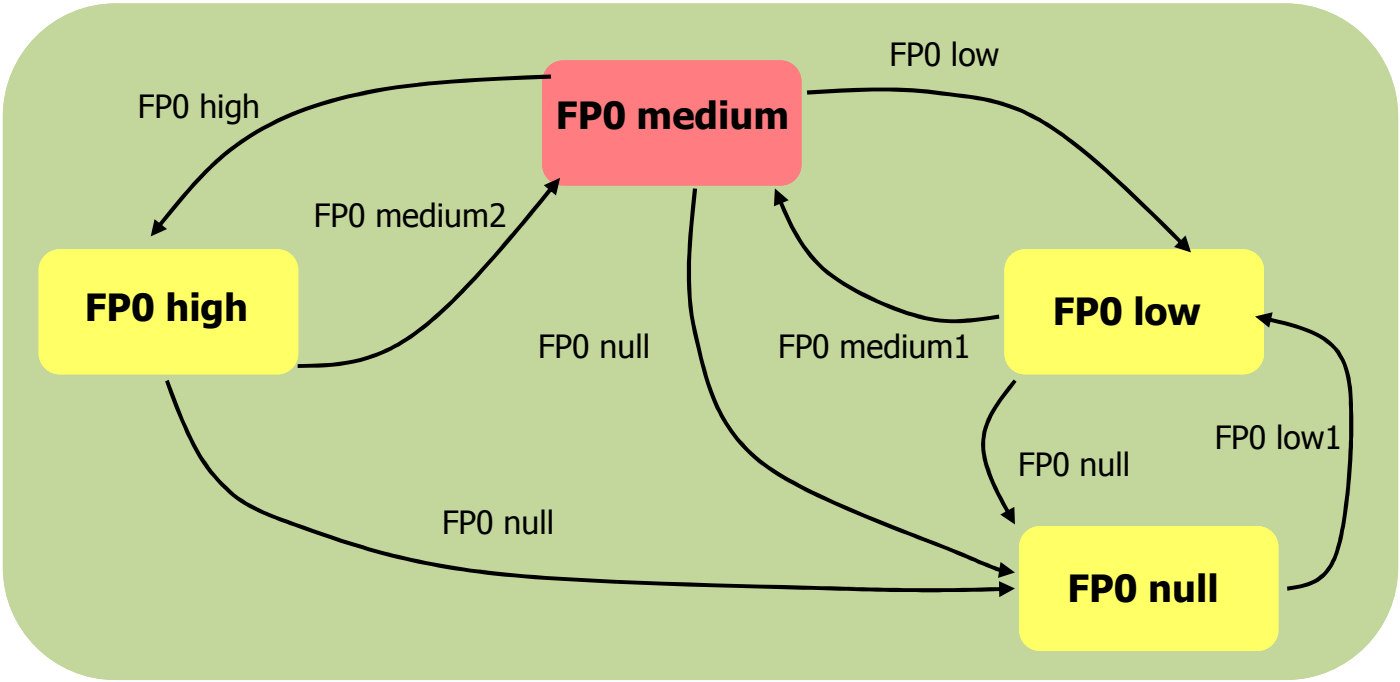
3 model subsystems



Given ES, ENV and AP are redefined for every new scenario

AP : modelling anthropogenic pressure (fishing)

FP0 = fishing pressure on Species 0



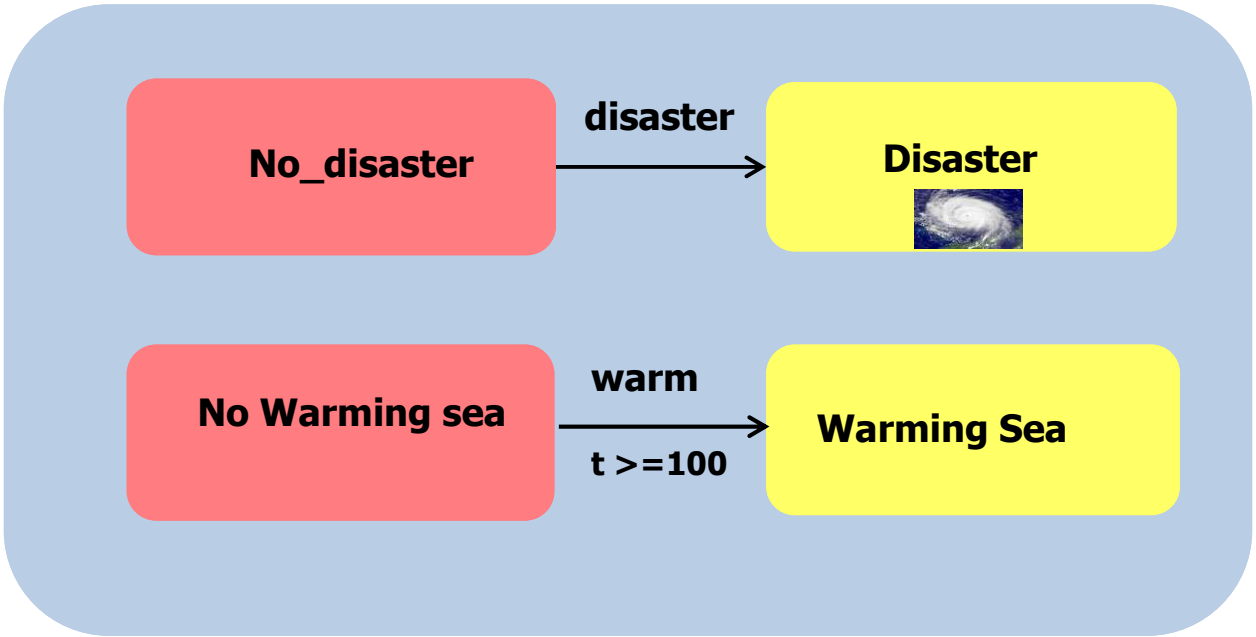
initial state

later possible states

- redefined for any scenario
- 4 gradual fishing pressures (null – low – medium – high)
- All events are synchronized (with Species 0's ones)

ENV : modelling environmental forcing

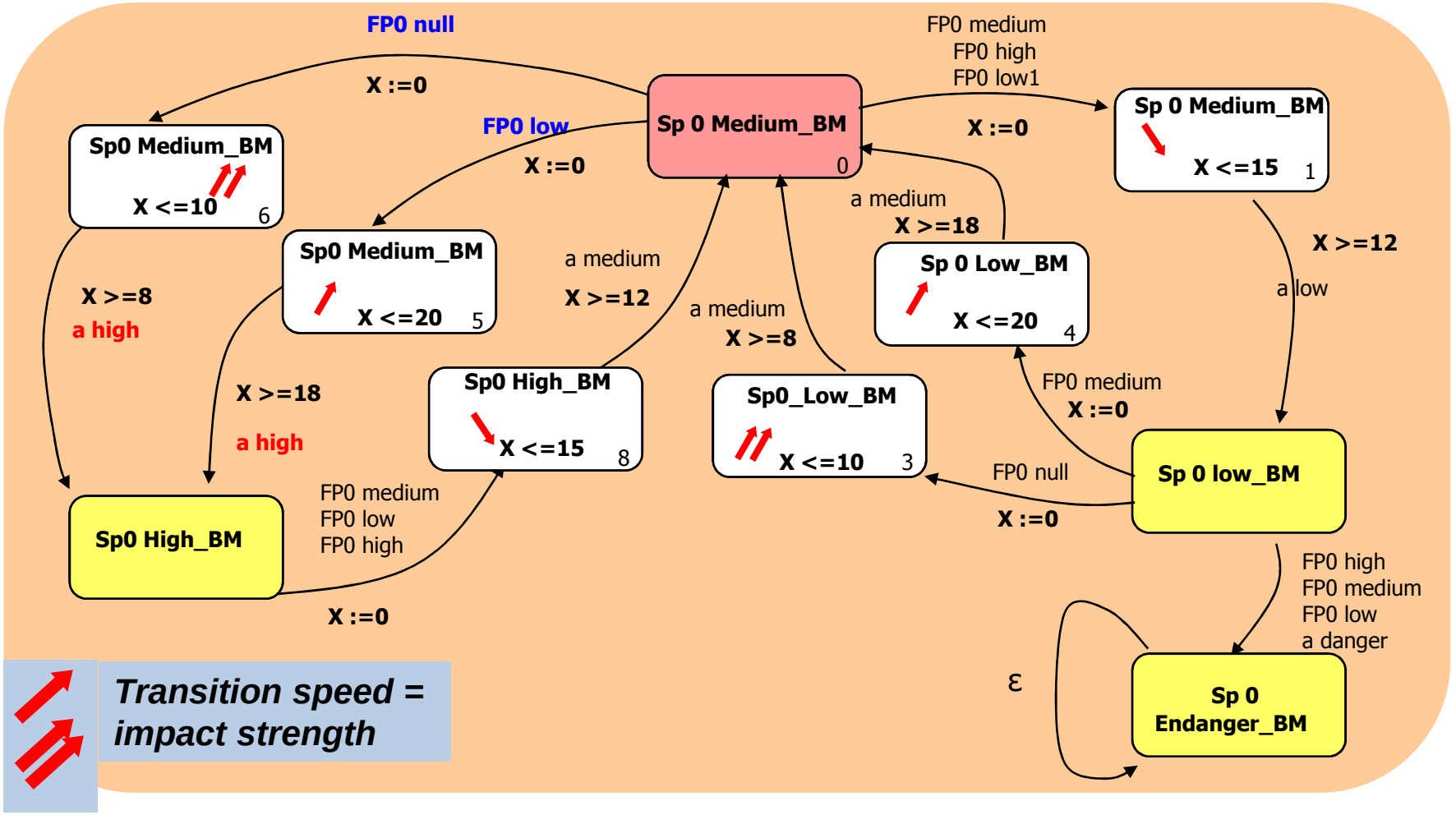
2 distinct automata : disaster and water warming



initial state

later states

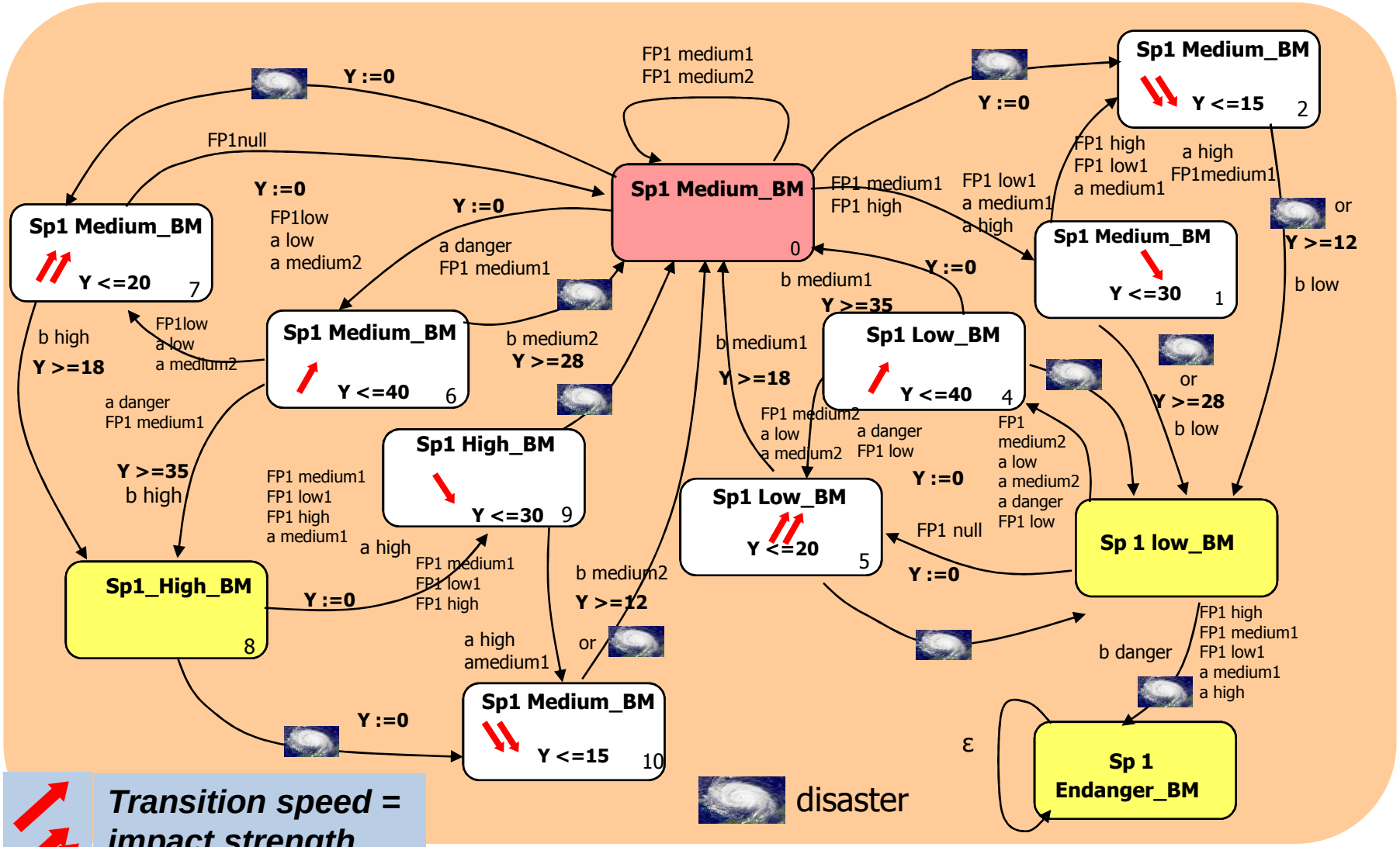
ES : modelling biomass dynamics **Species 0**



4 Different Biomass (**BM**) states of **Sp**ecies **0** (High, Medium, Low, Endanger) under different fishing pressures (**FP0** : null, low, medium, high)

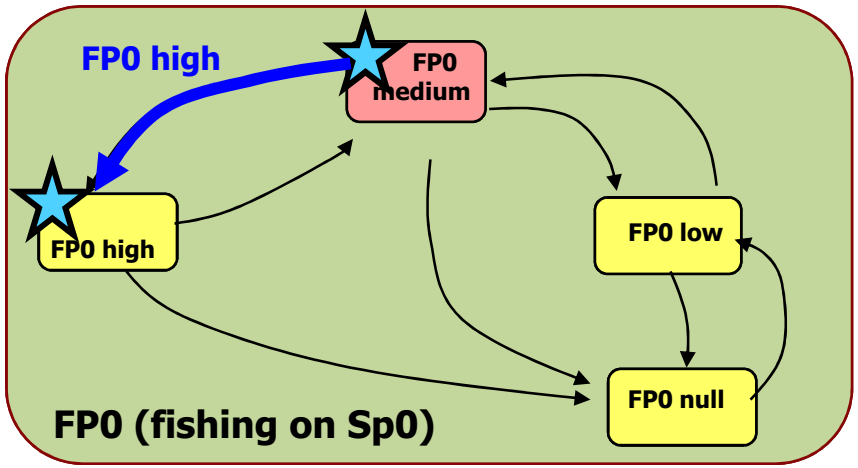
ES : modelling biomass dynamics

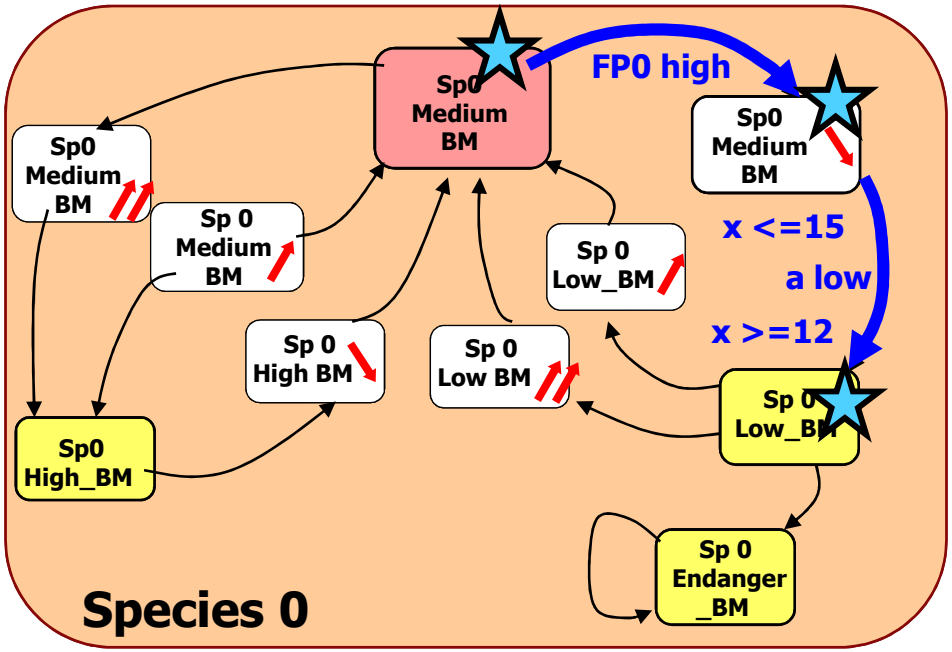
Species 1

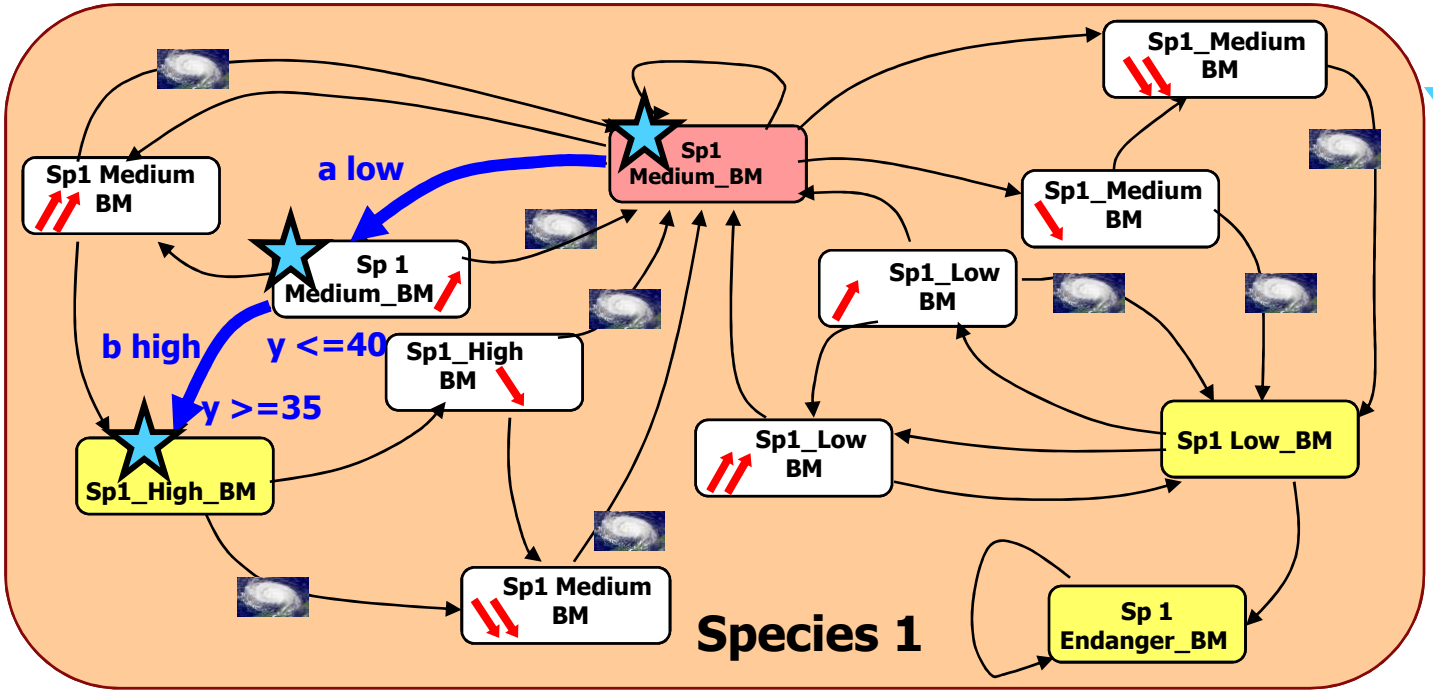


Species**1** Biomass (BM) dynamics under various Fishing pressures (**FP1**) **+ predator** (**Sp**ecies**0**)

SYNCHRONIZATION







Synchronized Top- Down Regulation

Cascading impacts of fisheries ?

Different possible scenarios

- **Predictive Scenario**

« *From a starting situation and a given policy, what should be the outcome?* »

- **Prospective Scenario** (proactive scenario) :

« *What to do to reach an expected state?* »

or

« *Which policy to apply to reach a specific goal?* »

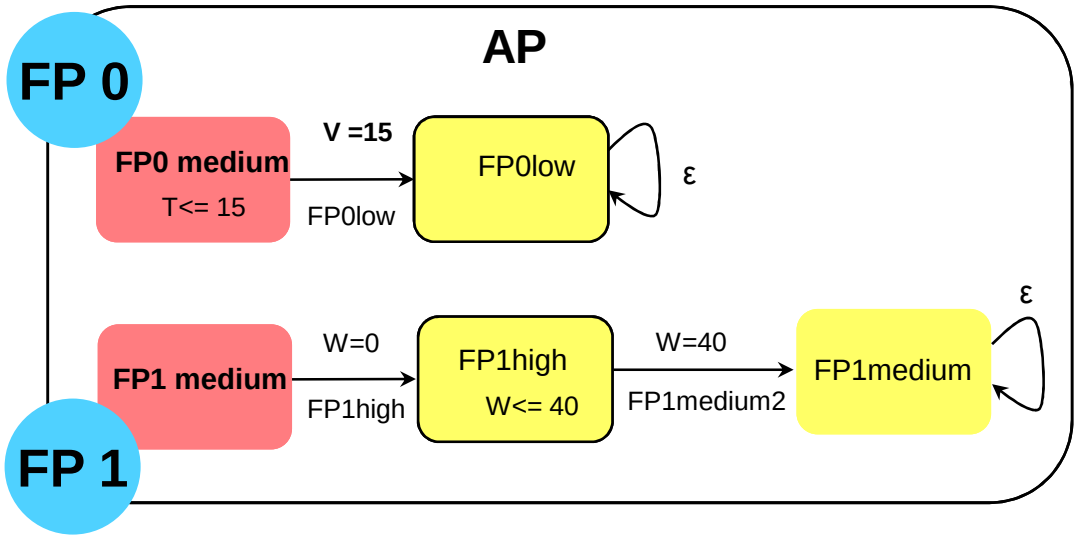
Example : Scenario 1 - definition

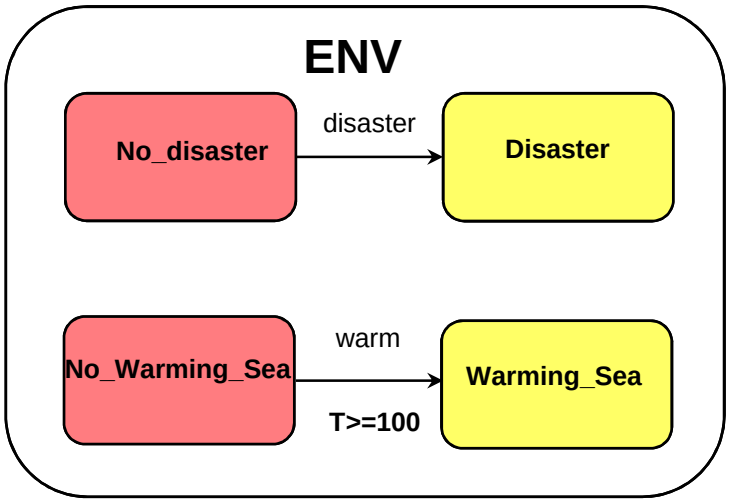
Step 1 (Predictive scenario)

- Definition of **ENV** and **AP**
- **ENV** : general scheme
- **AP**: 2 fishing pressures together
  - Declining fishing on **Sp**ecies**0** for 15 months
  - Increasing fishing on **Sp**ecies**1** for 40 months, then back to a mean fishing pressure

Step 2 : Temporal window (W) : 35 months

Step 3 : *What are the possible species biomass around 35 months* ?





Example : Scenario 1 - results

- TCTL formulation : query of reachability

$$init \Rightarrow \exists\Diamond(final\_state \wedge W = 35)$$

Starting from an initial state (W=0), there is at least one path leading to the final state at W=35 (True/False).

- What are reachable final states (biomass patterns) given W ?

final_state1 ..... final_state5

Species0	BM_High	BM_High	BM_High	BM_Medium	BM_Medium	BM_Medium
Species1	BM_Endanger	BM_Low	BM_Medium	BM_Medium	BM_Low	BM_Endanger
Species3	BM_Medium	BM_Medium	BM_Medium	BM_Medium	BM_Medium	BM_Medium
Species4	BM_Medium	BM_Medium	BM_Medium	BM_Medium	BM_Medium	BM_Medium
Result at W=35	possible	not possible	not possible	not possible	possible	not possible
Result at W=40	possible				not possible	

Example : Scenario 2

- Step 1 : Scenario of model « robustness »

  Given the same framework : ENV and AP

- Step 2 : temporal window : **no limit**

- Step 3 : «*Can we ever reach a risky state* ***(all biomasses low or collapsed)*** *with the proposed policies* ?»

- TCTL formulation

  $$init \Rightarrow \neg\exists\Diamond risky \text{ (or } init \Rightarrow \forall\Box not\_risky)$$

  There is no path leading to a risky state (True/False)

- Definition of risky state

  $$((Sp0\_BM\_Low \vee Sp0\_BM\_endanger) \wedge (Sp1\_BM\_Low \vee Sp1\_BM\_endanger) \wedge (Sp2\_BM\_Low \vee Sp2\_BM\_endanger) \wedge (Sp3\_BM\_Low \vee Sp3\_BM\_endanger))$$

- Result : here, this risky state **never can be reached**

Conclusion

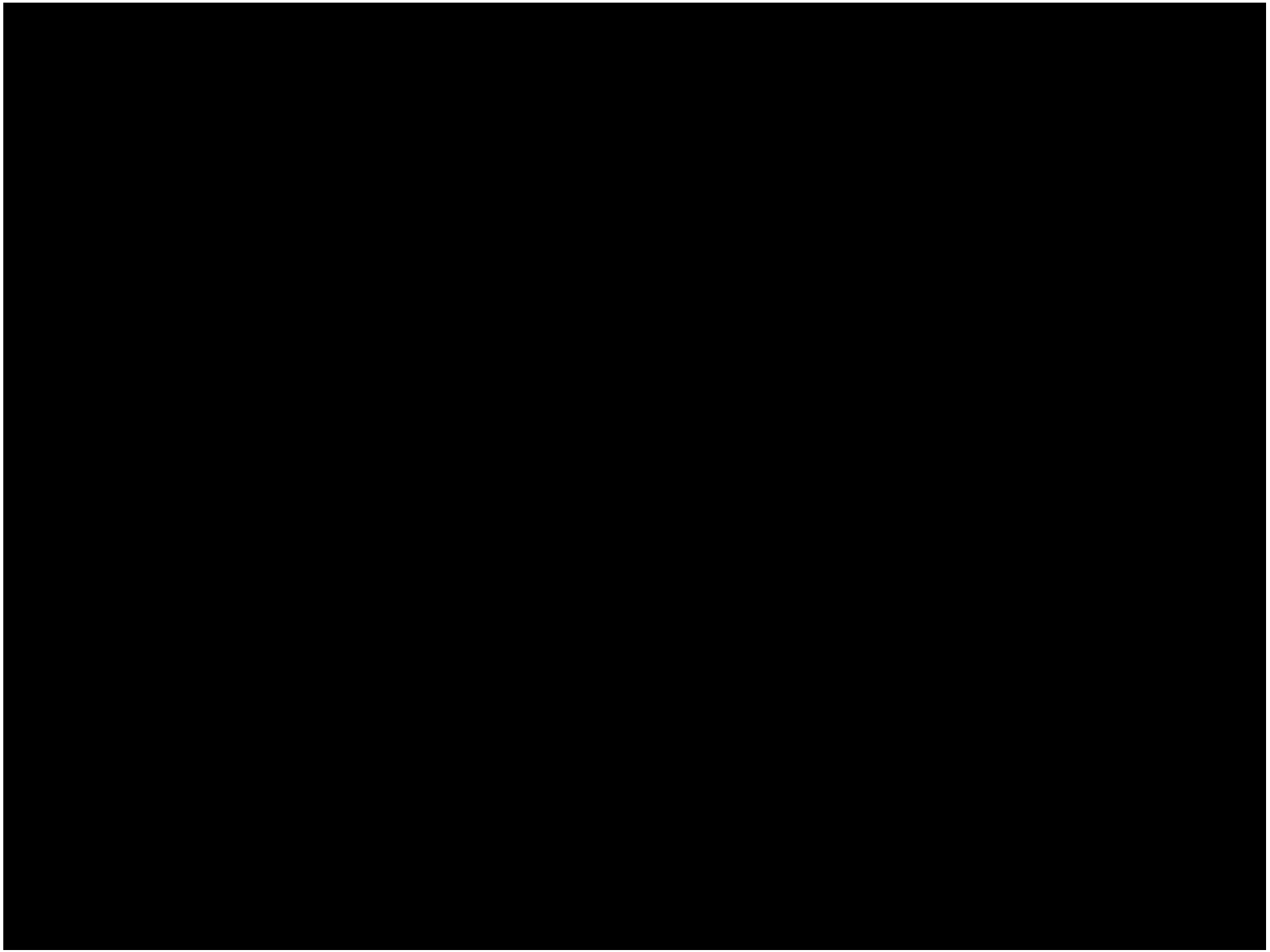
- Is qualitative modelling with timed automata relevant to address ecosystem dynamics along with drivers & pressures ?
  - **YES …**
- Looks a good adaptive framework for exploring ecosystems' behaviors through queries expressed as a « high level (logical)» language
  - *Possible duration of a pressure before noticing the impacts on the ecosystem?*
  - *If we suppress the pressure, how long does it take for a stock to recover an acceptable biomass?*
  - *Can some species collapse be avoided?*
  - *What are all pathways that allow to reach expected policies and goals?*
  - *…*

In progress …

- Application on Coral reef ecosystem in New Caledonia *
- Improvement of modelling options (*trophic networks, various regulation policies, time values*…)
- Integration of habitat within the general framework *
- Development of a platform generating calls for checking formulas

* ***Y.M. Bozec, Post doc Agrocampus ouest***


Thank you for your attention
Contact: Christine LARGOUET largouet@agrocampus-ouest.fr
Photo : V. Cornuet



Model-checking techniques

One of the most successful method for automatic verification of real-time systems