

# Scenario templates to analyse qualitative ecosystem models

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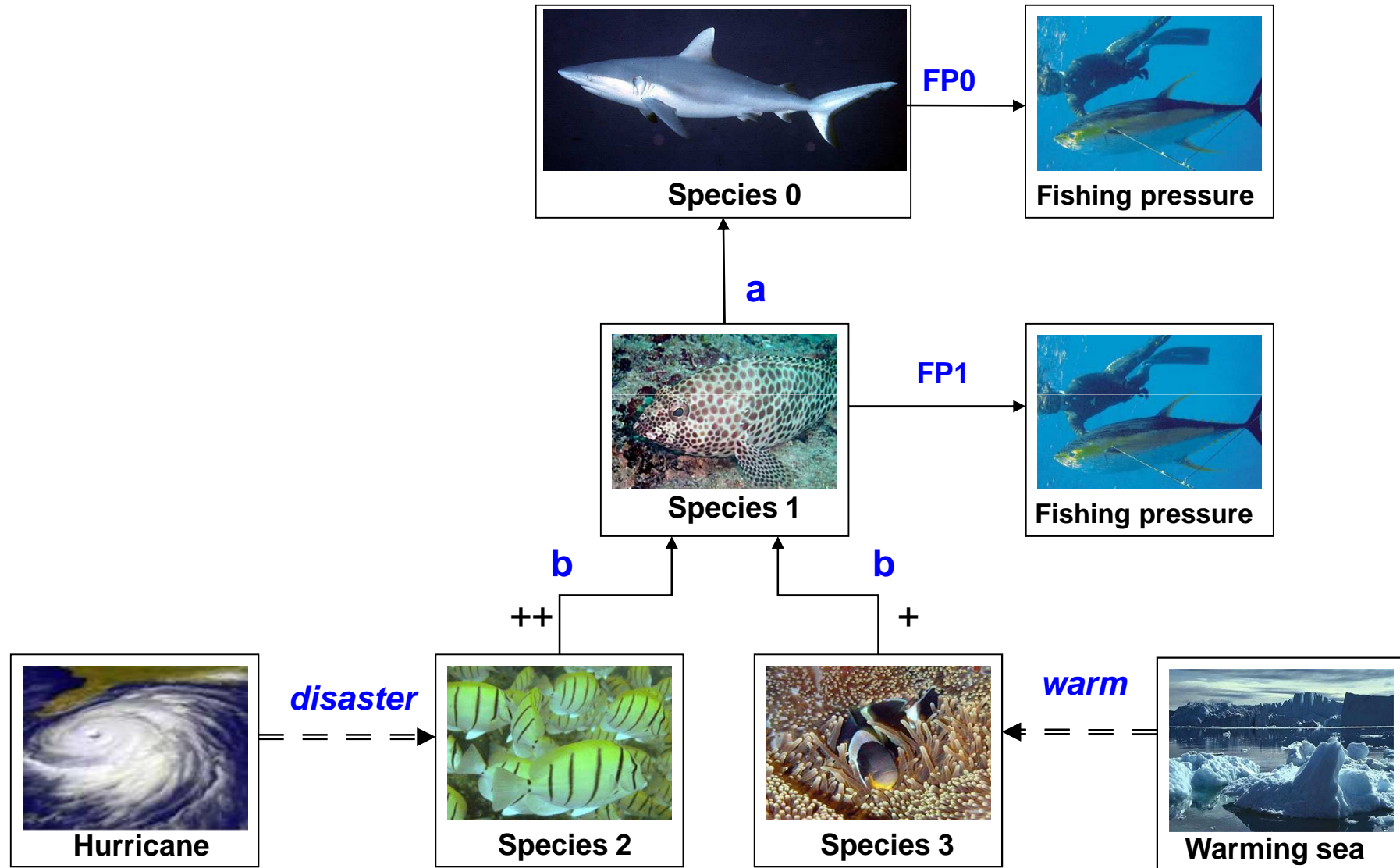
# Introduction

- 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 :**

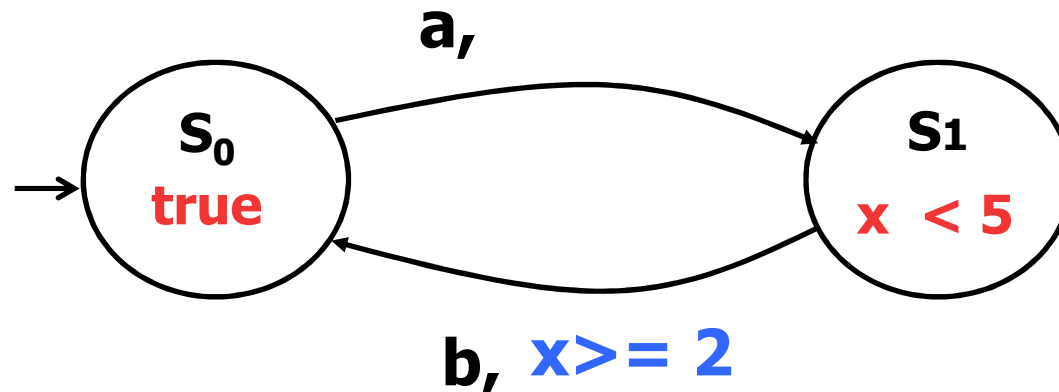
- Propose time automata formalism to represent a simplified trophic web and fisheries resource system to be used as a toy-example
- Formalize scenarios as queries in logic representation

# A simplified fisheries ecosystem



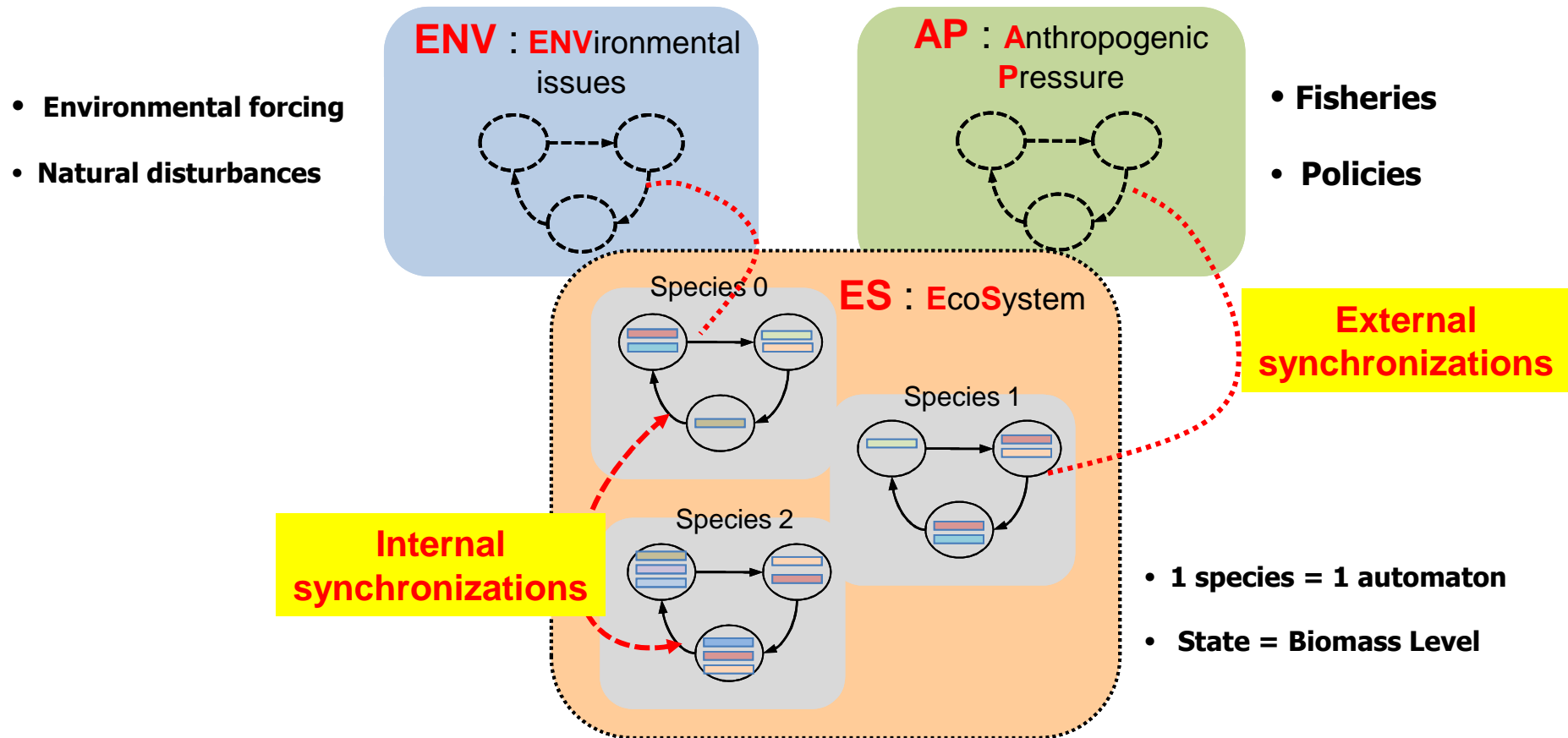
# Timed Automata (some principles)

- **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

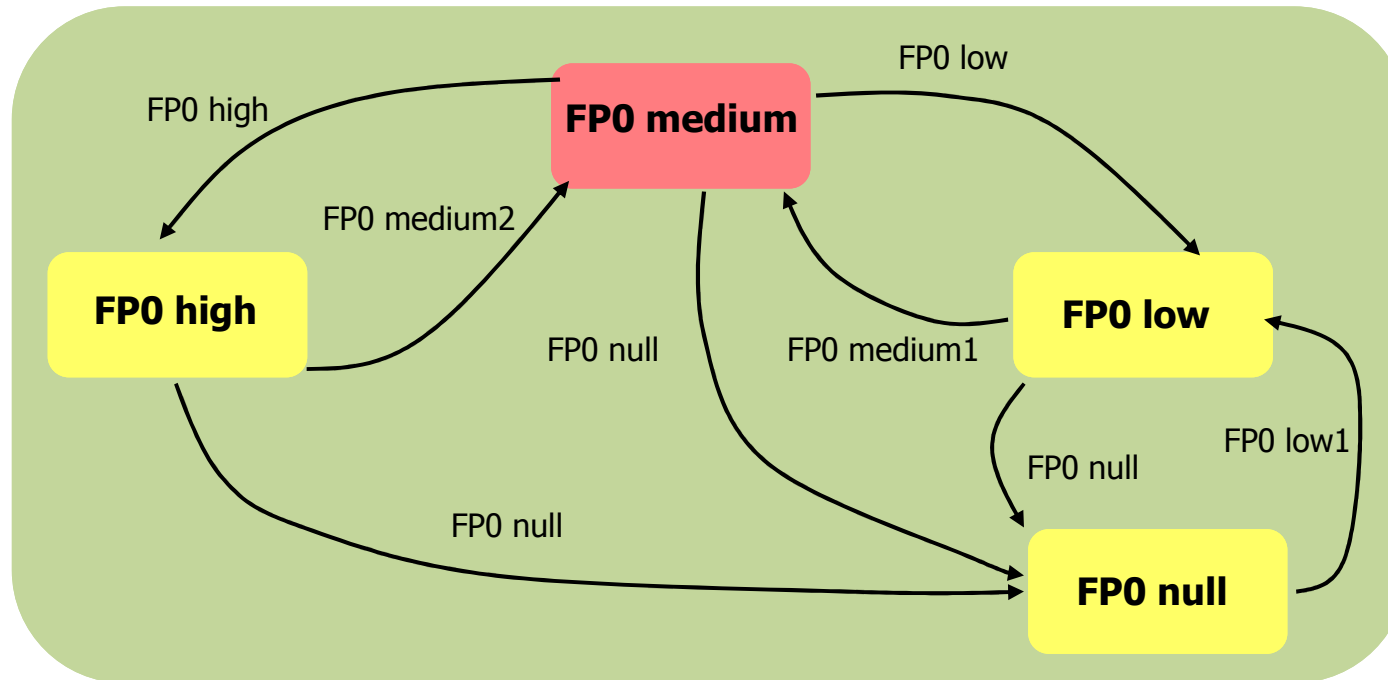
## 3 model subsystems



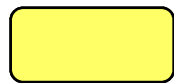
**Given ES,** ENV and AP are redefined for every new scenario

# AP : modelling anthropogenic pressure (fishing)

**FPO** = fishing pressure on Species 0



*initial state*

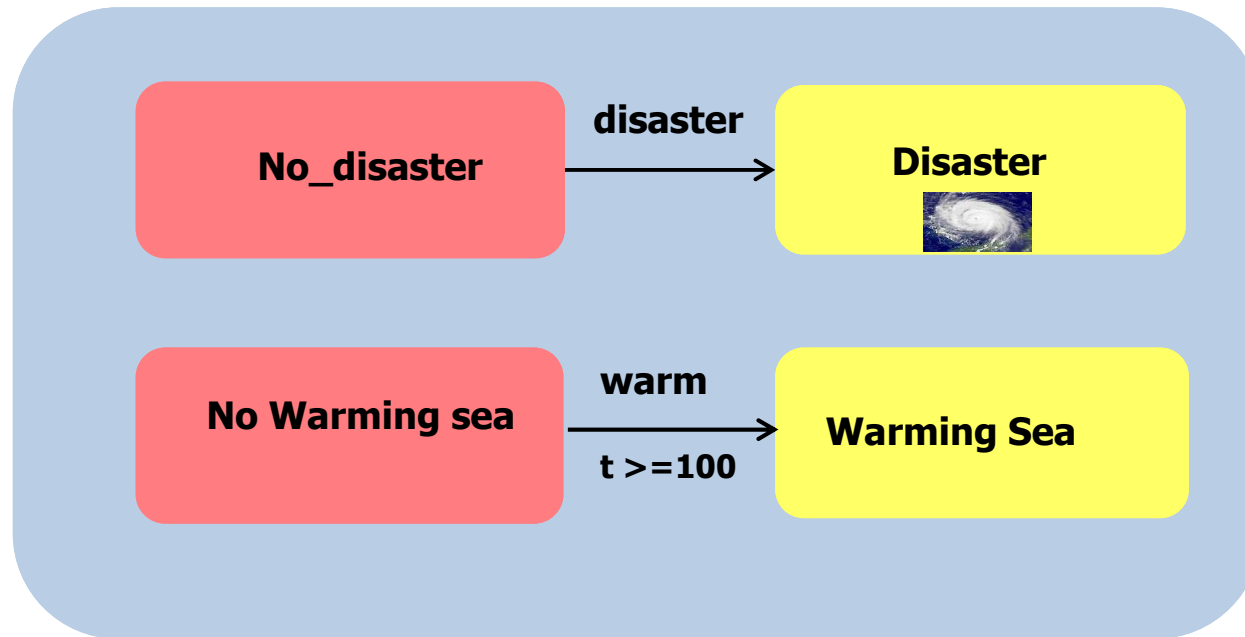


*later possible states*

- 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

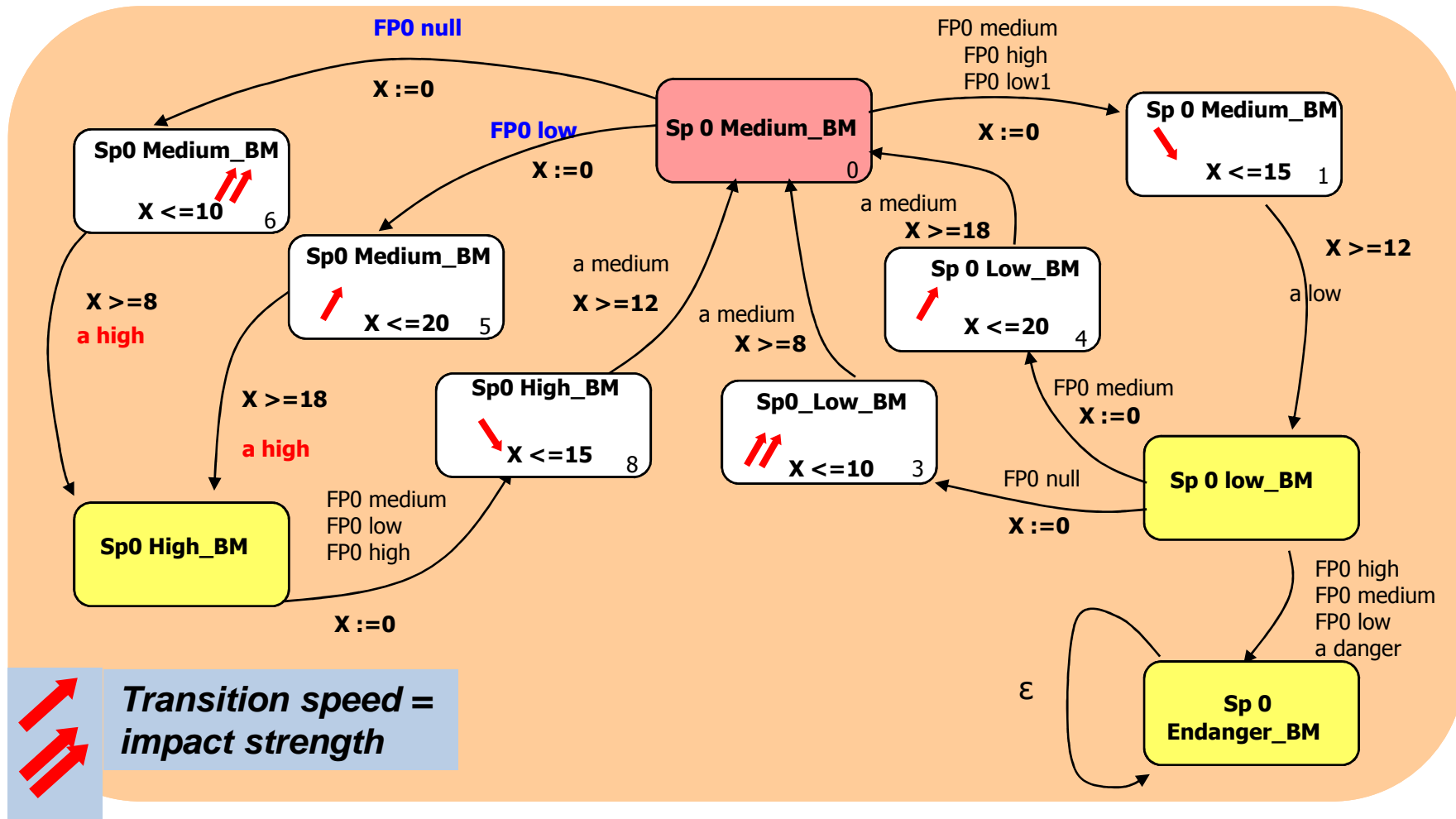


 *initial state*

 *later states*

# ES : modelling biomass dynamics

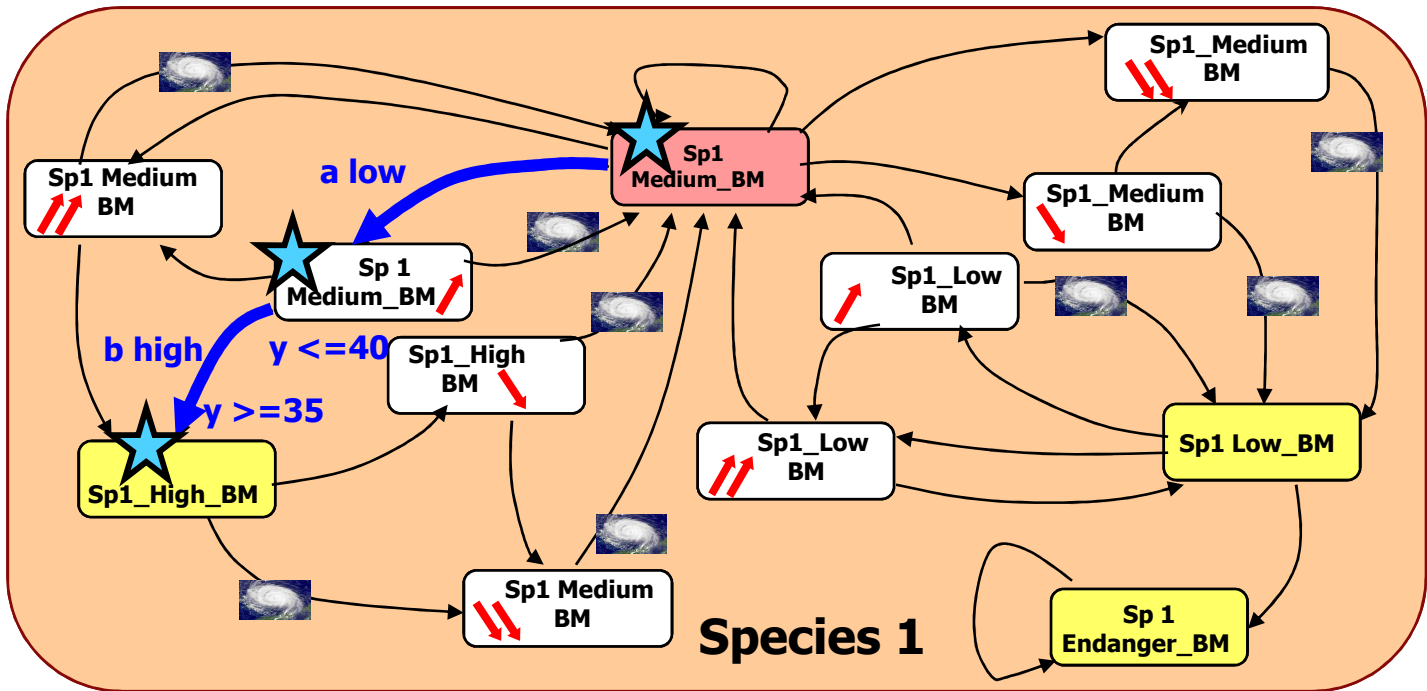
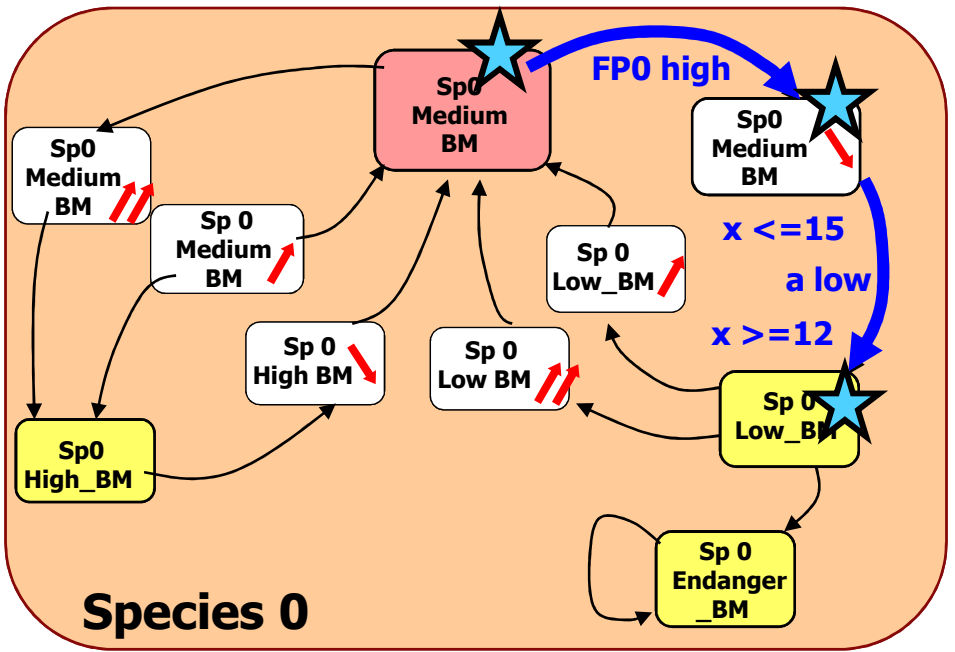
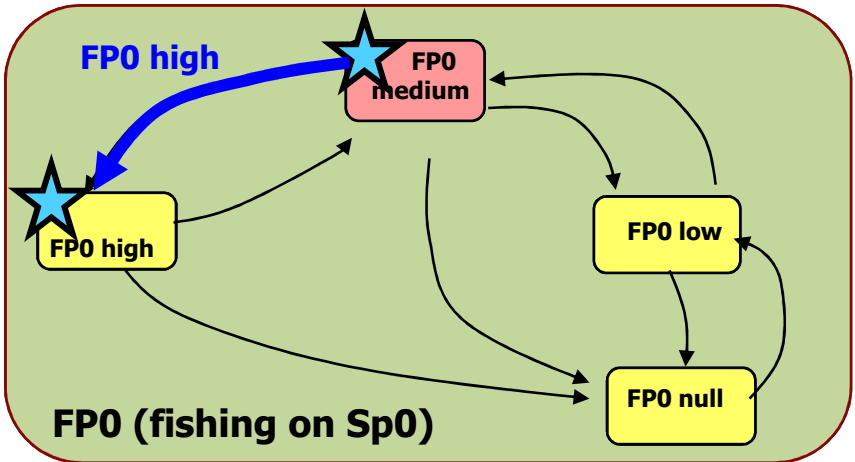
## Species 0



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



# 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?* »

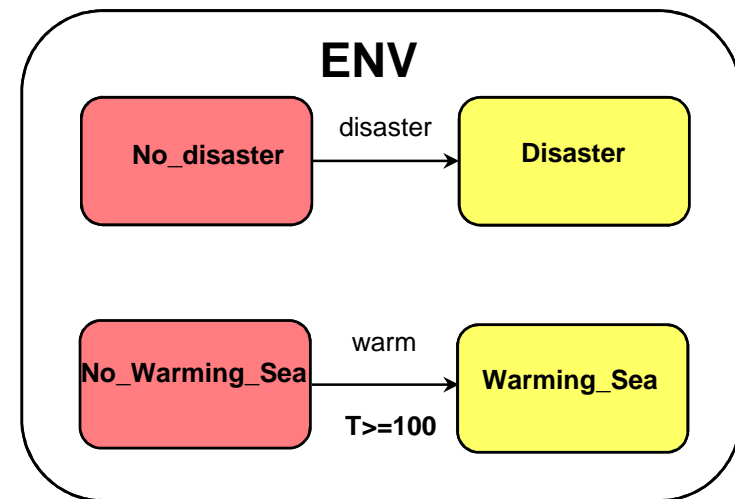
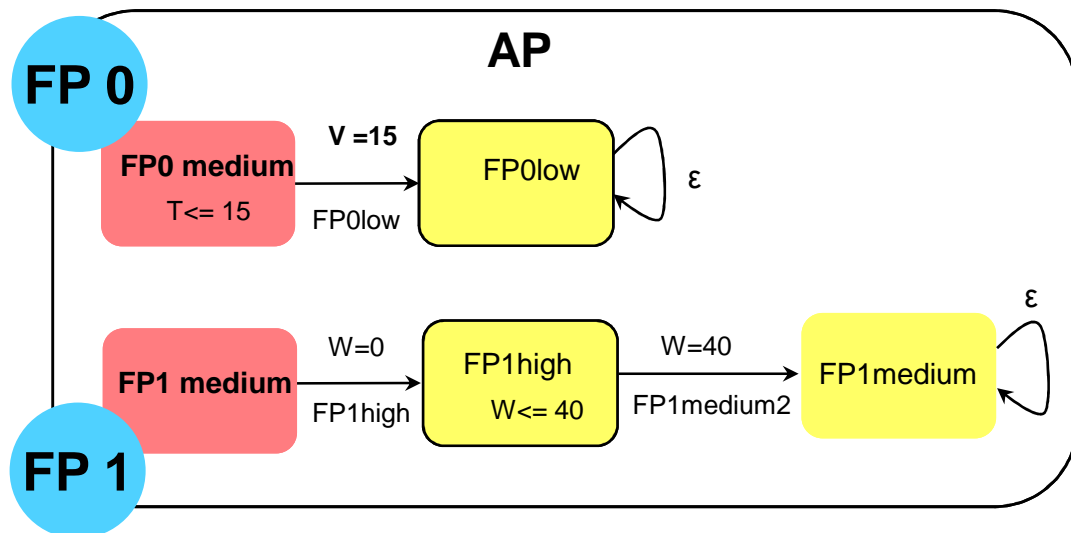
# Example : Scenario 1 - definition

## Step 1 (Predictive scenario)

- Definition of **ENV** and **AP**
- **ENV** : general scheme
- **AP**: 2 fishing pressures together
  - Declining fishing on **Species0** for 15 months
  - Increasing fishing on **Species1** 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    | BM_Medium    |
| Species1         | BM_Endanger  | BM_Low       | BM_Medium    | BM_Medium    | BM_Low                  | BM_Endanger  | BM_Endanger  |
| Species3         | BM_Medium    | 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    | BM_Medium    |
| Result at $W=35$ | possible     | not possible | not possible | not possible | possible                | not possible | not possible |
| Result at $W=40$ | possible     |              |              |              | <del>not possible</del> |              |              |

# 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

$init \Rightarrow \neg \exists \diamond risky$  (or  $init \Rightarrow \forall \square not\_risky$ )

*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?*
  - ...

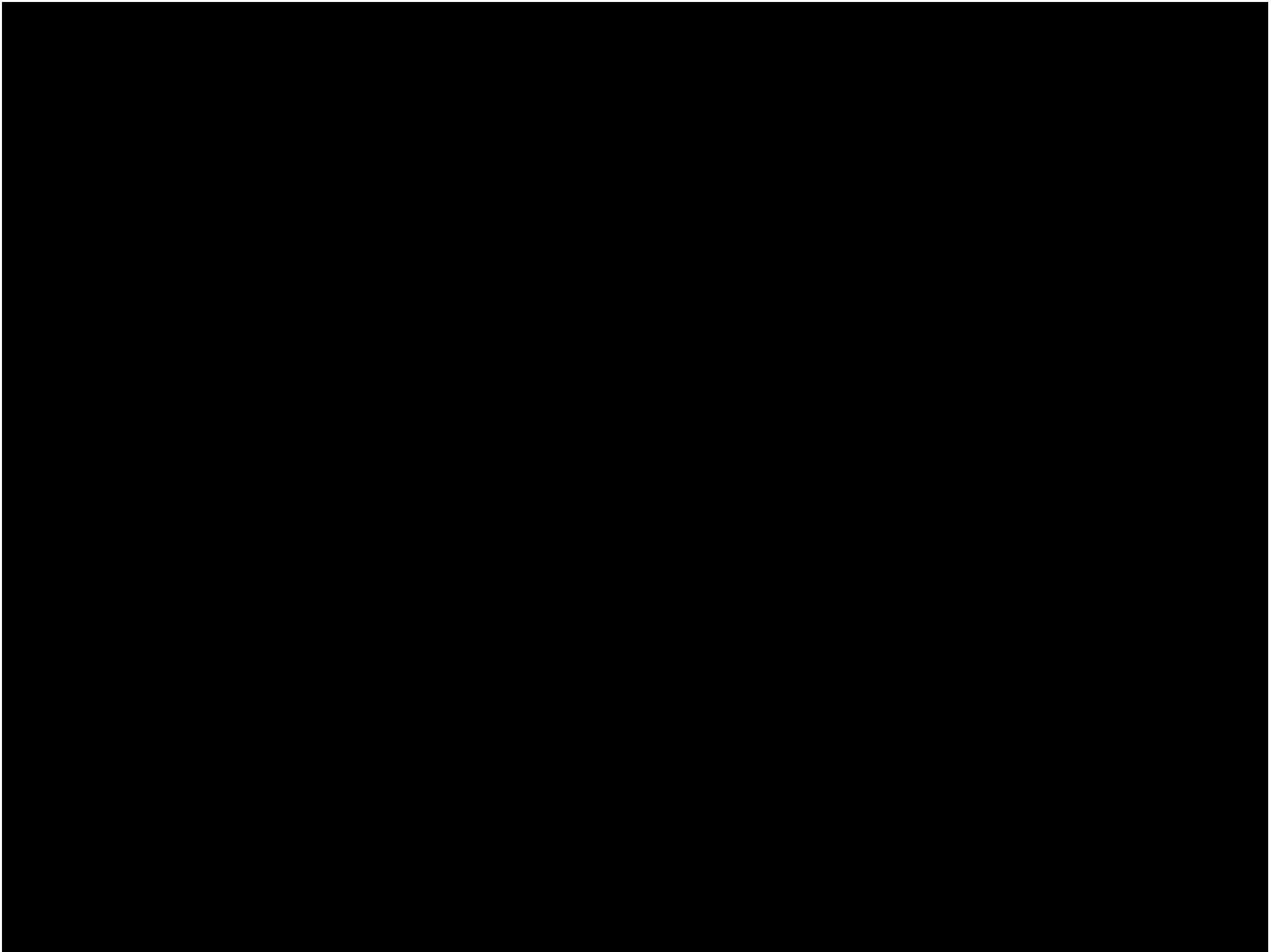
# In progress ...

- 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

*Thank you for your attention*

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*Photo : V. Cornuet*



# Model-checking techniques

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

