Modeling fish dynamics around FADs

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OUTLINE

- Aggregation
  - Generic concepts
  - Homogeneous and heterogeneous environment
- Modelling
- Interaction artificial agents-animals
  - Mobile robots
  - Autonomous heterogeneities

Aggregation

Mechanisms

- In heterogeneous environment : same response of the individuals to the the environmental heterogeneities

  Ecologists

- Social interaction

  Clustering around a leader (individuals are different)

  Inter-attraction between “identical” individuals (signals or cues identical)

  Homogeneous environment

  Highly widespread from unicellular societies to mammals group

  Large functional diversity (reproduction, feeding,...)

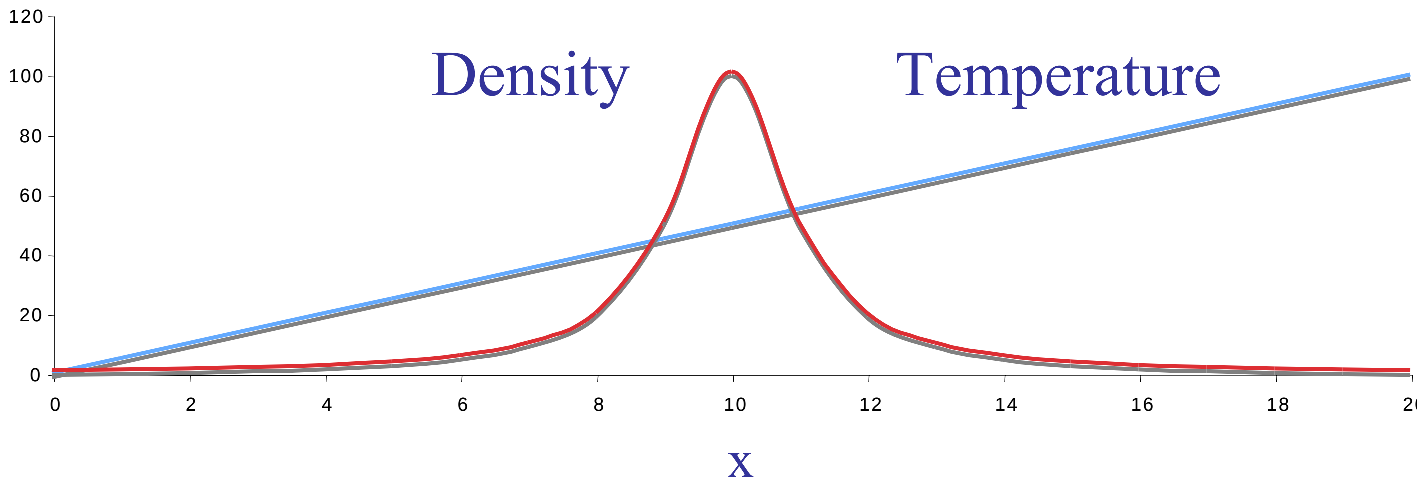
  Permanent or transitory

  Immobile to highly mobile (school, shoal)

- Social interaction is often associated to response to the environmental heterogeneities.

(Camazine et al, 2001)

Spatial heterogeneities



Kinesis : Speed (Temperature)≈ $(T_M - T)^2$

Spatial distribution is density independant

Leaders

Interattraction

Lasius niger
N = 100
T = 2’30”

(From Depickère)

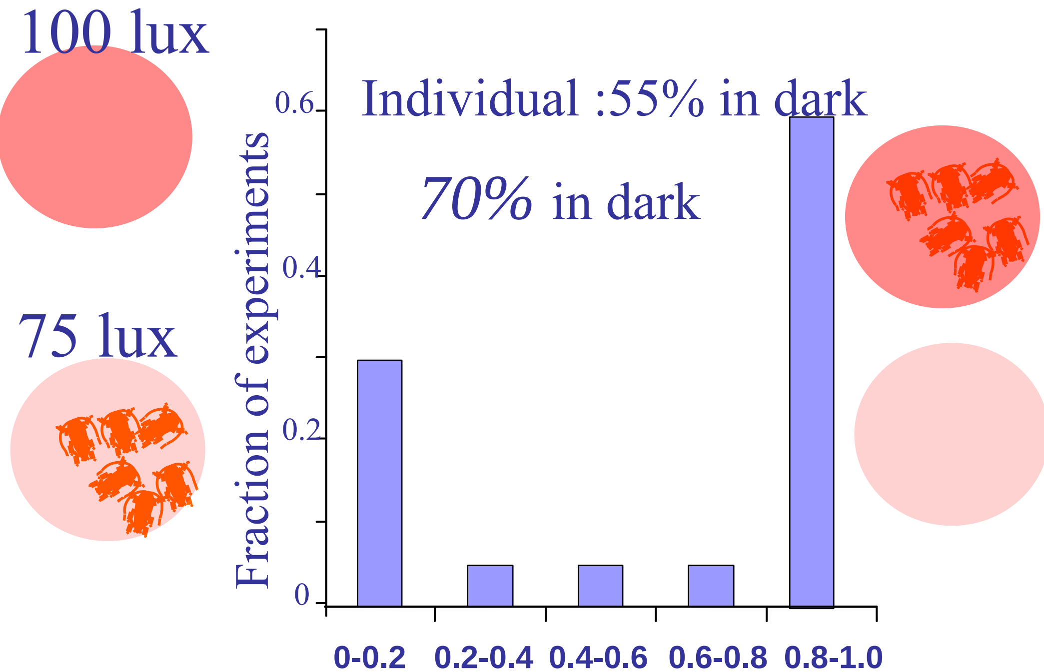
Lasius niger

N = 100

(From Depickère et al)

By-product of aggregation: collective choice, sorting, synchronization,....

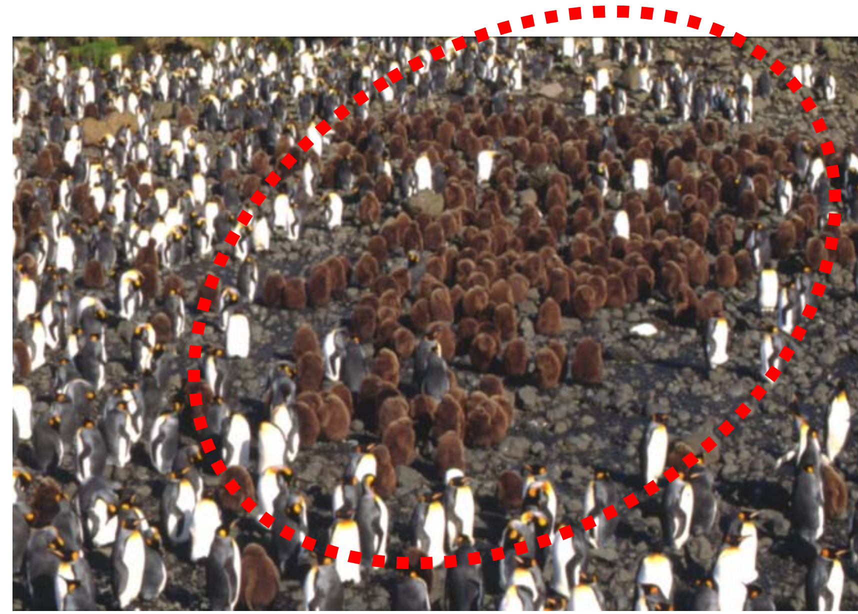
Collective choice



Proportion of cockroaches under the dark shelter

Canonge et al, in prep

Sorting



(Nursery)

Modified from Lebohec *et al*

Aggregation in heterogeneous environment

Modeling aggregation around FAD

The models are TOOLS

- To analyze the relation between individual behavior, population parameters (density) and environmental characteristics
  AND
  the spatio-temporal organization of the population around FADs
  → to integrate different types of data (acoustic data + tagging data)

- To use the FADs to make prediction
  e.g. : is it possible to estimate the total fish density measuring the populations around FAD?

Theoretical tools

• Ordinary differential equations (ODE)

$$\frac{dx_i}{dt} = Birth - death = F_i(x_1, \ldots, x_n) \qquad i = 1, \ldots, n$$

•Partial differential equations (PDE) : Advection-diffusion-reaction model

$$\frac{\partial x}{\partial t} = Movement + Birth - death$$

$$\frac{\partial x}{\partial t} = D\frac{\partial^2 x}{\partial x^2} + D\frac{\partial^2 x}{\partial y^2} - \lambda x$$

(M.S. Adam & J.R. Sibert, 2002, Aquat. Living Resour., 15, 13-23)

Analytical treatment (Stability analysis,...) + numerical solution

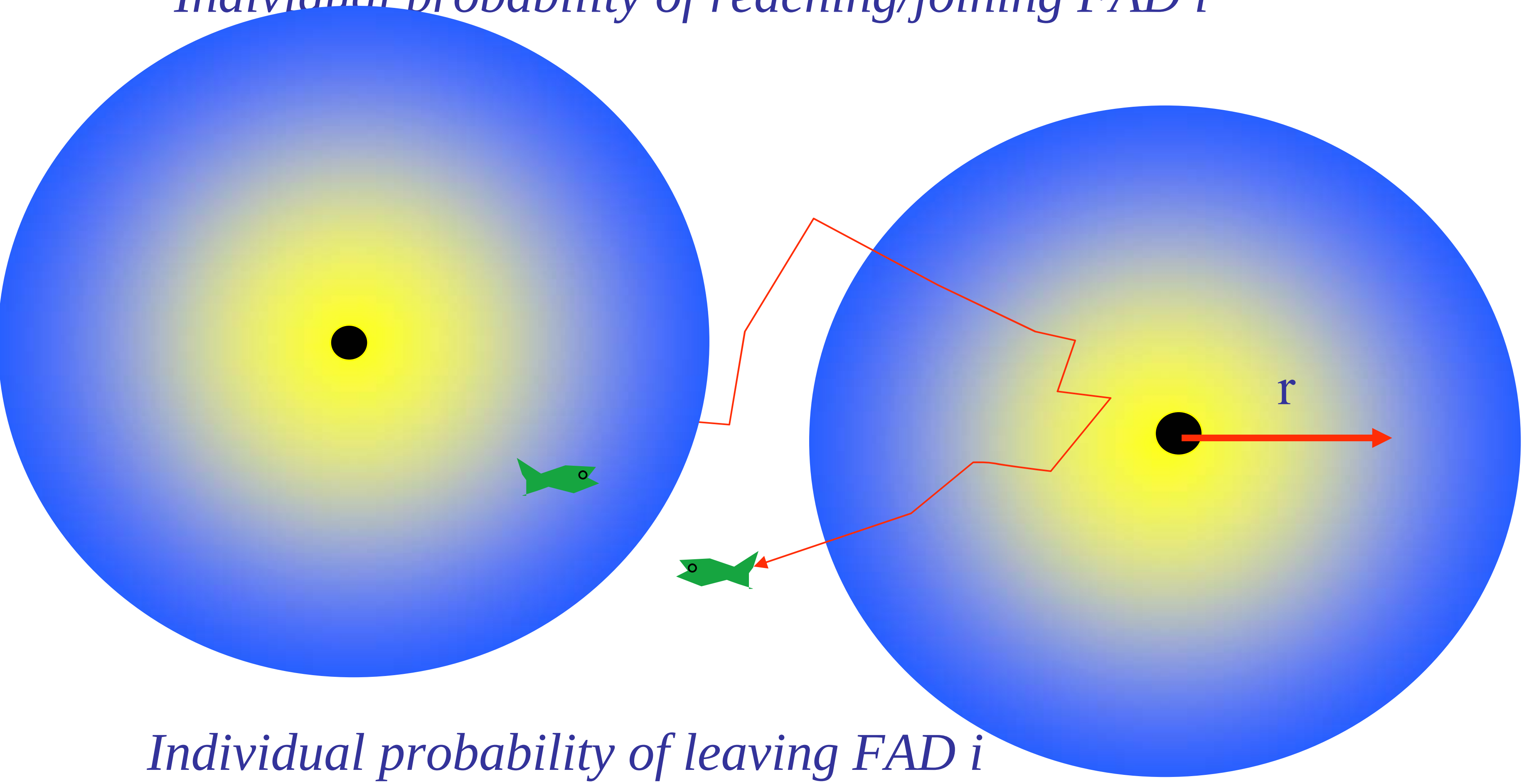
•Fluctuation : Stochastic simulation (individual based model)
Master equation

(Camazine et al., 2001)

Aggregation in heterogeneous environment

Time evolution of the population around each FAD x_i

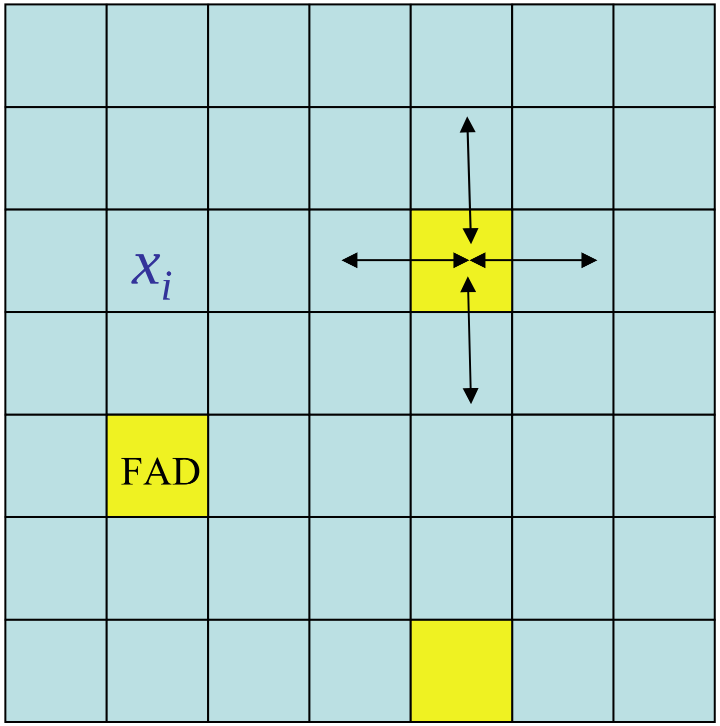
Individual probability of reaching/joining FAD i



Individual probability of leaving FAD i

Aggregation in heterogeneous environment

Numerical model : Simple lattice



FAD are identical

$$\frac{dx_i}{dt} = -Q_i x_i + \sum_{j}^{nb} \frac{Q_j x_j}{4}$$

Differential equation : dynamics of x_i and behavior

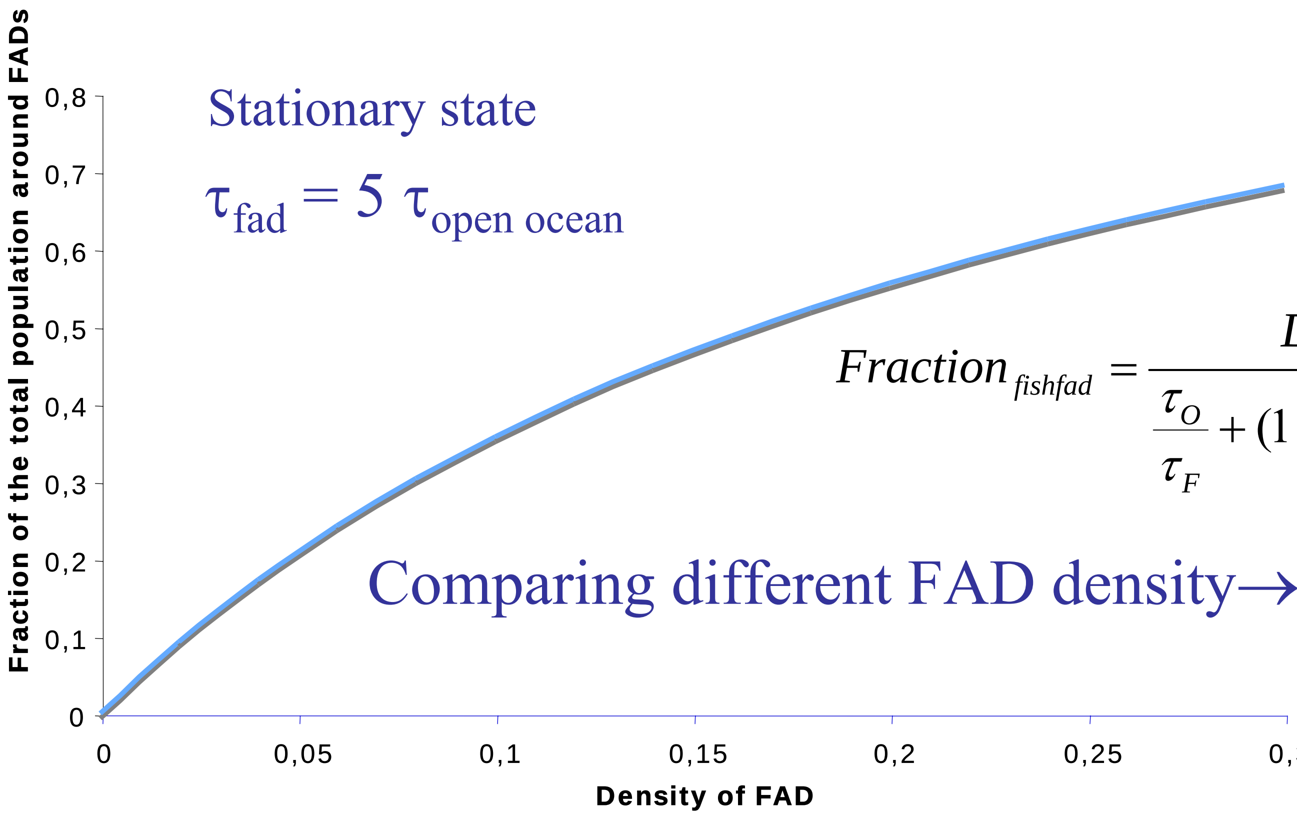
Model 1: No interaction between the fishes

FADs are identical

Three parameters: fish population, resting time around FAD (τ_F), resting time in others cells (τ_O)

Stationary state: Population around each FAD≈Total population

$x_1 = \ldots = x_n$



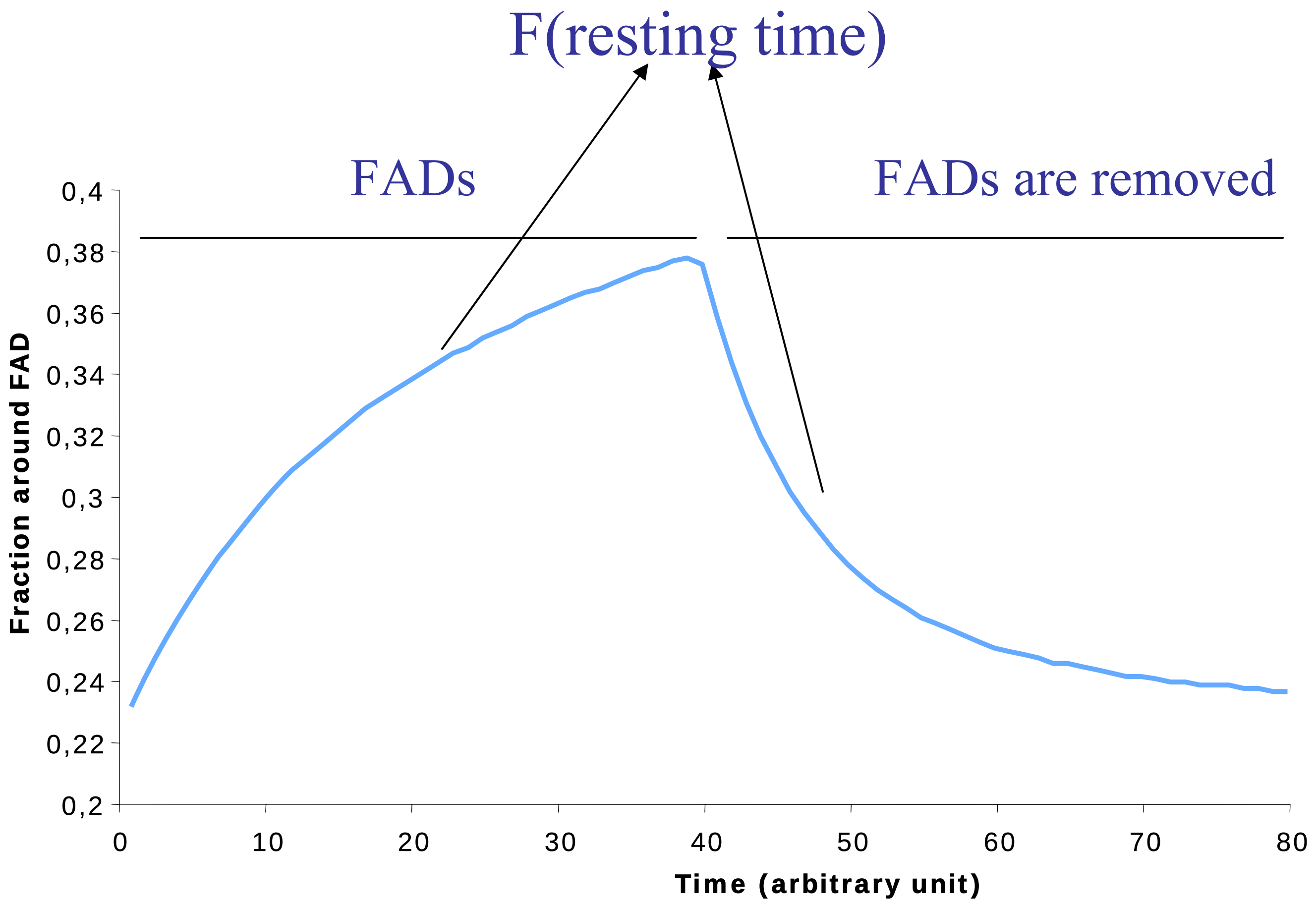
Stationary state

$\tau_{fad} = 5\ \tau_{open\ ocean}$

$$Fraction_{fishfad} = \frac{D_{fad}}{\frac{\tau_O}{\tau_F} + (1 - \frac{\tau_O}{\tau_F}) D_{fad}}$$

Comparing different FAD density→Fish density

No interaction between the fishes (2)



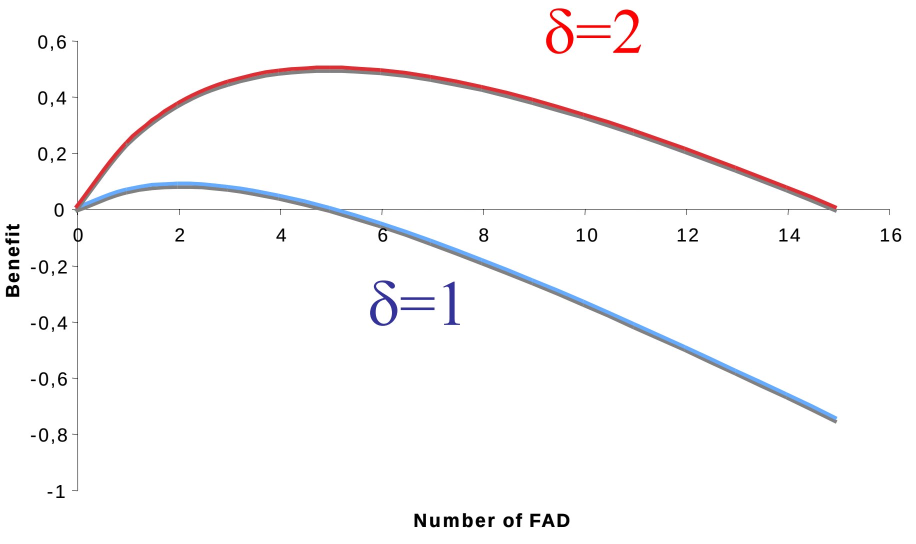
No interaction between the fishes (3)

Point of view of the fisherman

Model →strategy: Optimal density/number of FAD

$$Benefit = \frac{\delta D_{fad}}{K + D_{fad}} - \chi D_{fad} \qquad D_{opt} = \sqrt{\left(\frac{K}{\delta\chi}\right)} - K$$

δ = fish density



(R. Hilborn & P. Medley (1999)

Can. J. Fish Aquat. Sci. 46: 28-32)

Model 2 : Interattraction

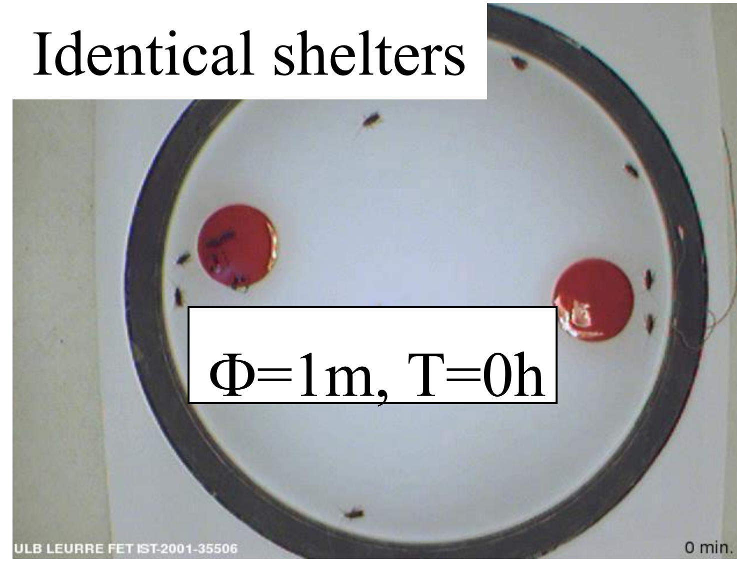
$$\frac{dx_i}{dt} = -Q_i x_i + \sum_{j}^{nb} \frac{Q_j x_j}{nb}$$

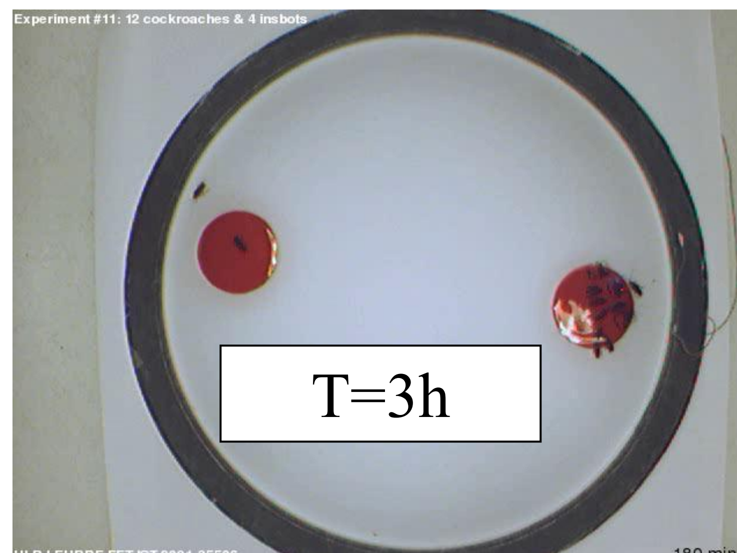
$$Q_i = \frac{\theta}{1 + \beta x_i^n}$$

$$Q_i = (1 + \beta x_j^n)$$

An easy case study: collective decision making in cockroach group

Periplaneta americana





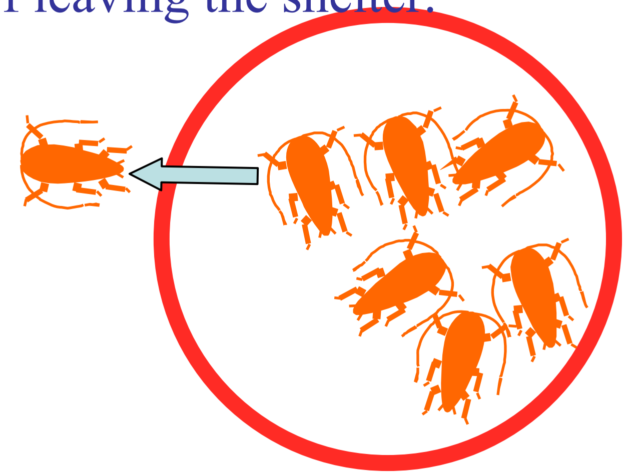
(Jeanson &Deneubourg, Am Nat. 2007
Amé *et al*, PNAS 2006,
Halloy *et al*, Science , November 2007)

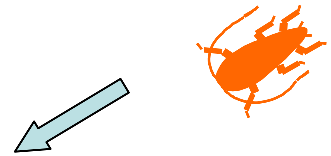
Collective decision making in cockroach group based on inter-attraction

Individuals are capable of detecting the shelters and estimate their quality (θ_i)

The inter-attraction between individuals decreases the probability of leaving the shelter.

$$Q_i = \frac{\theta_i}{1 + \rho\left(\frac{x_i}{S_i}\right)^n}$$





$$P_i = \mu_i\left(1 - \frac{x_i}{S_i}\right)$$

Individuals randomly explore the system & encounter the shelters

They are constrained by a crowding effect

x_i number of individuals in shelter i

S_i carrying capacity of the shelters

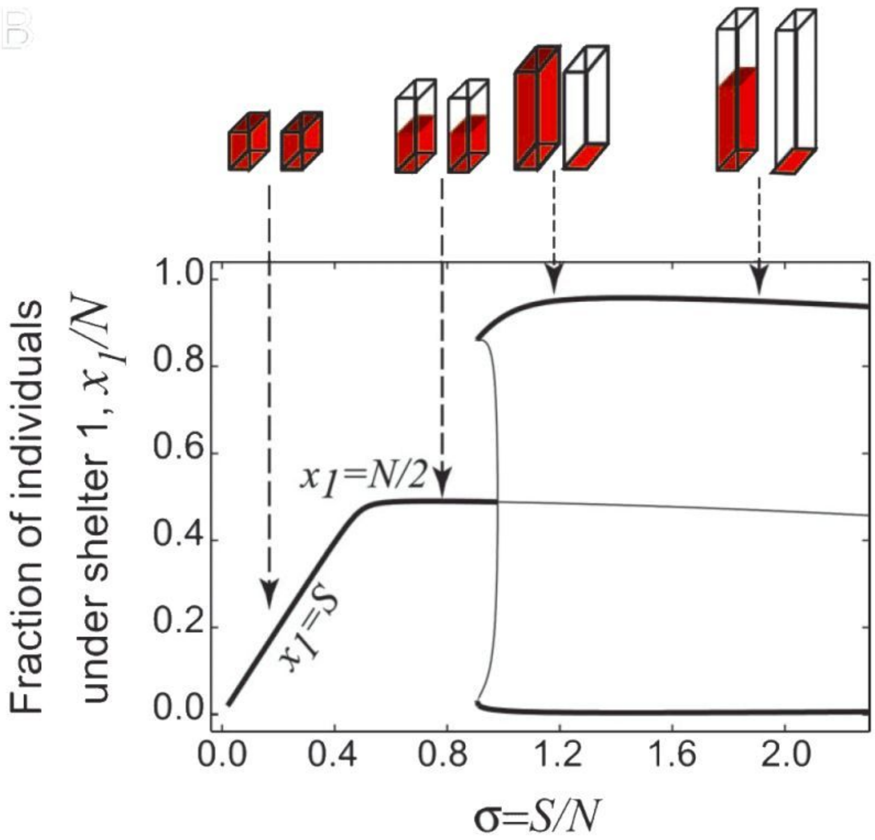
n inter-attraction factor ($n \approx 2$)

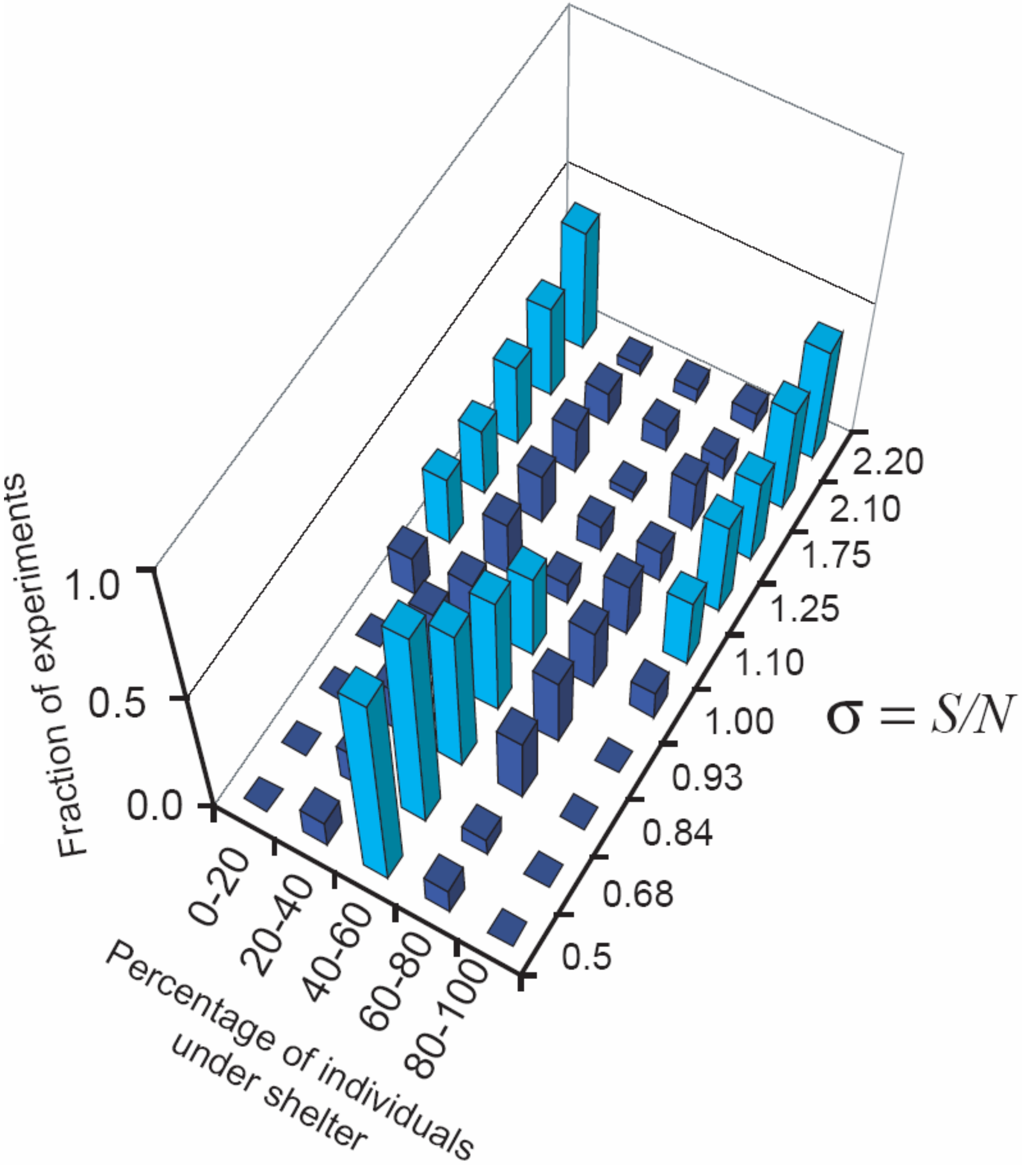
x_e number of individuals outside the shelters

p number of shelters present in the system

N total number of individuals = $x_e + x_1 \ldots + x_p$

Collective decision making: experimental bifurcation diagram





Amé et al, PNAS, 2006

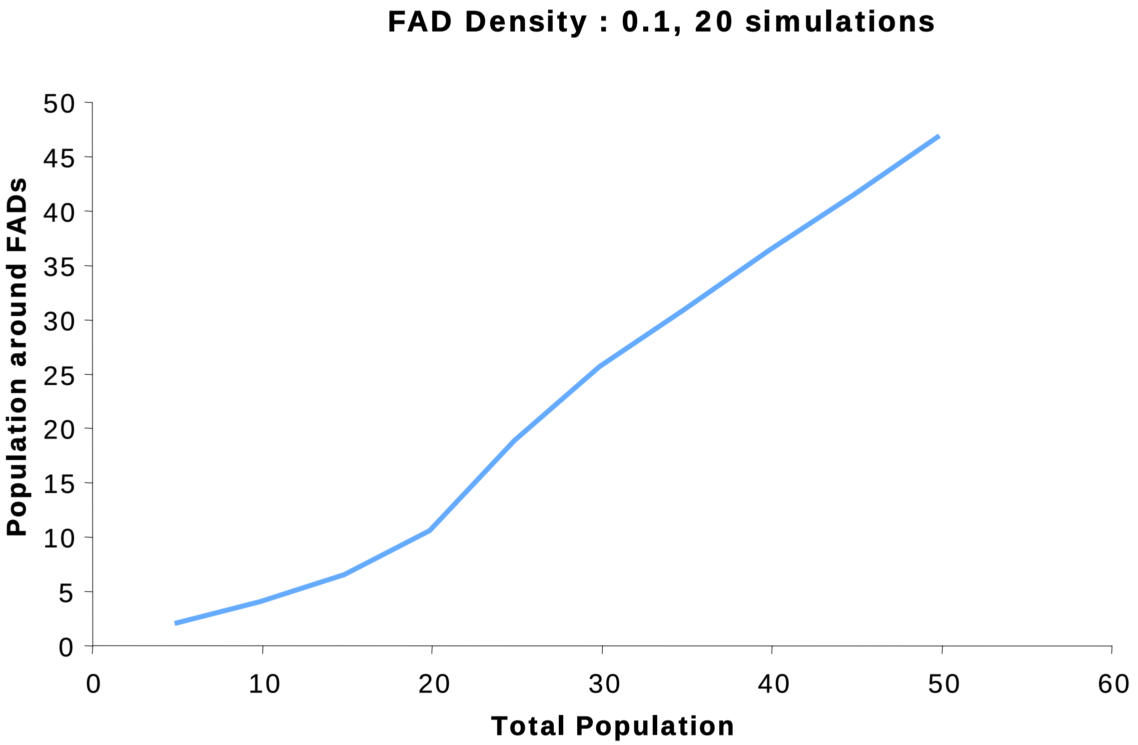
Model 2 : Interattraction

$$\frac{dx_i}{dt} = -Q_i x_i + \sum_{j}^{nb} \frac{Q_j x_j}{nb}$$

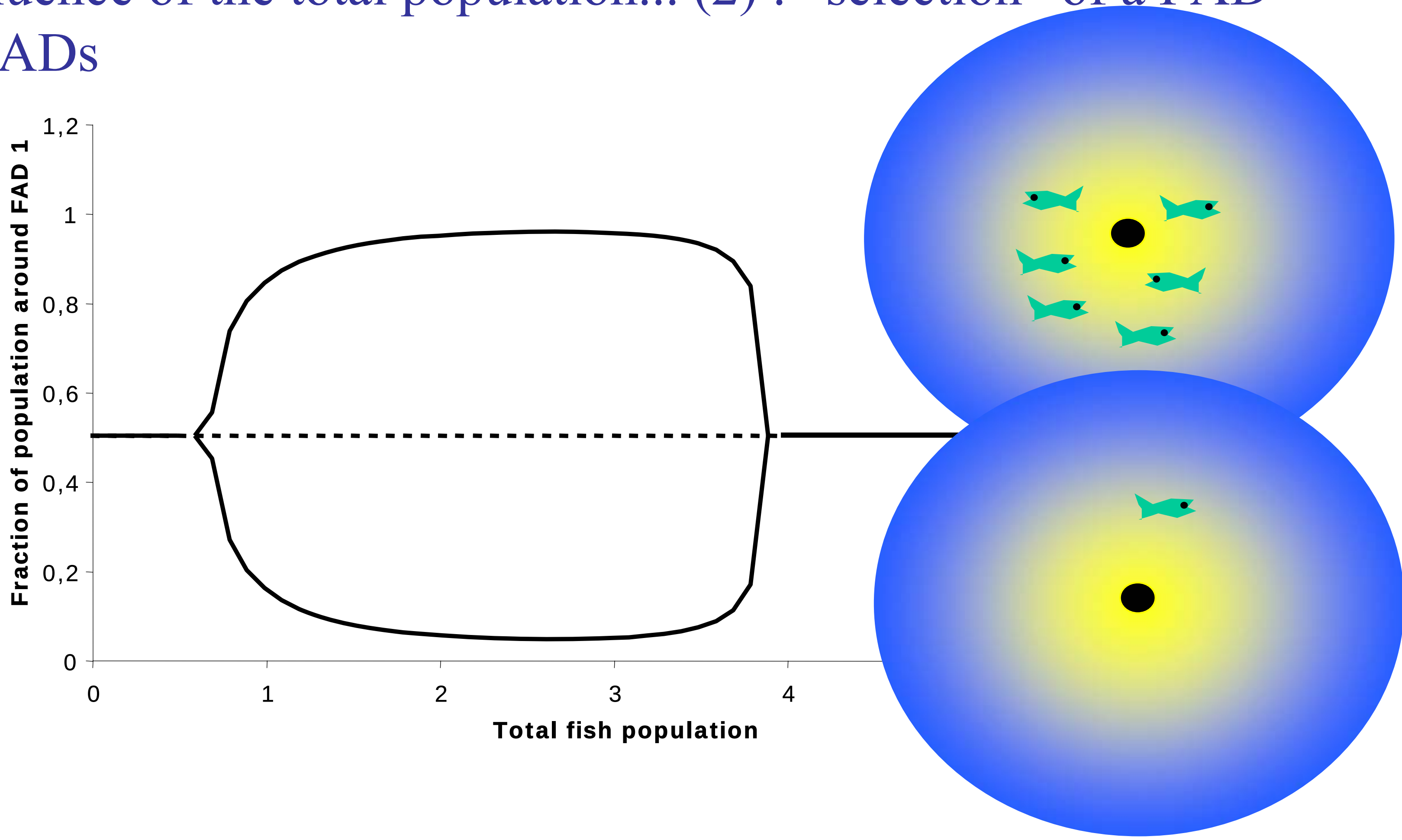
$$Q_i = \frac{\theta_i}{1 + \beta x_i^n}$$

Diversity of responses but some generic properties

Influence of the total population or total population estimation from FAD population (1)



Influence of the total population... (2) : “selection” of a FAD
2 FADs



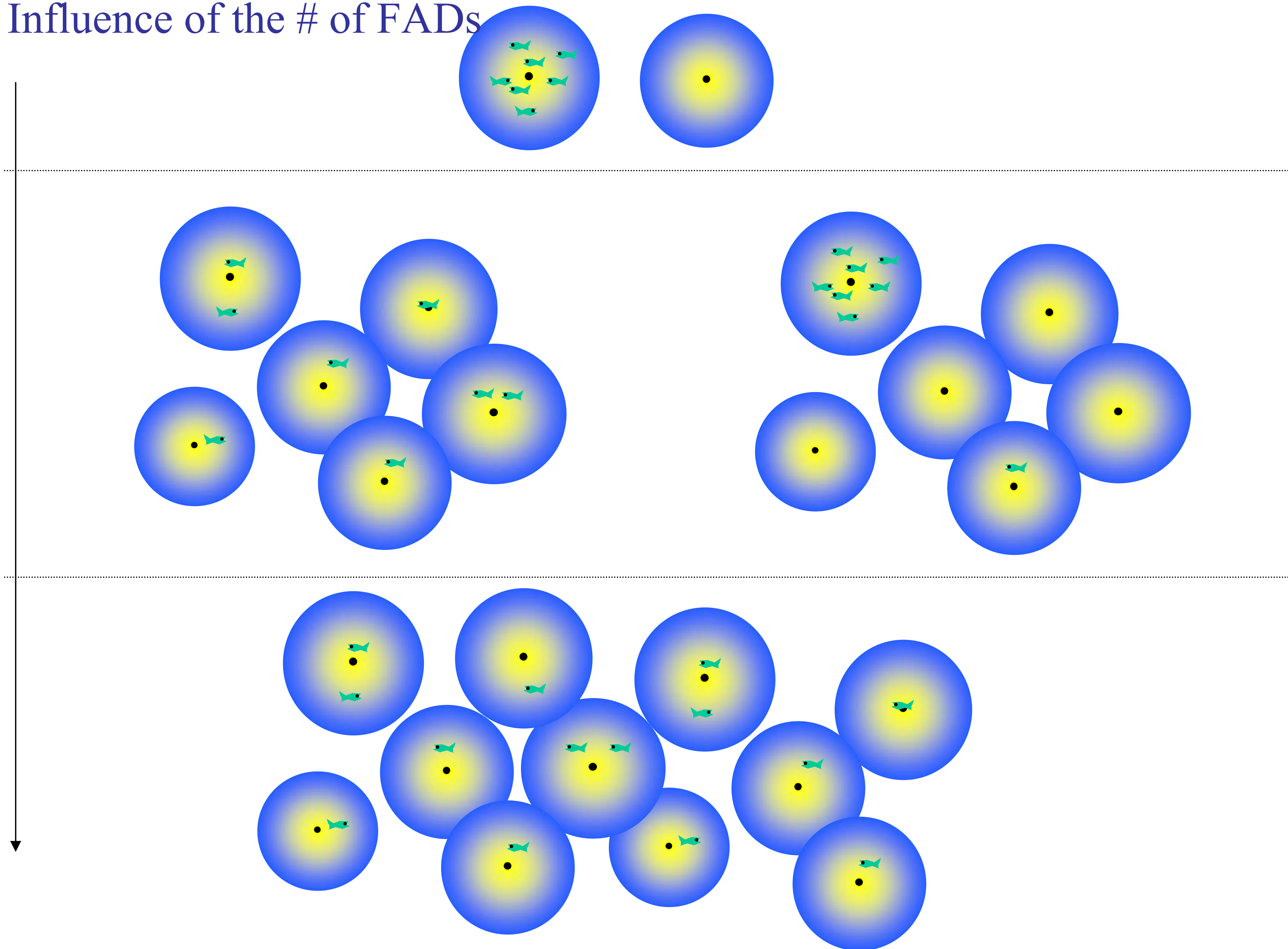
Influence of the total population... (3)

(1) Acoustic data + tagging data $\rightarrow$ Model

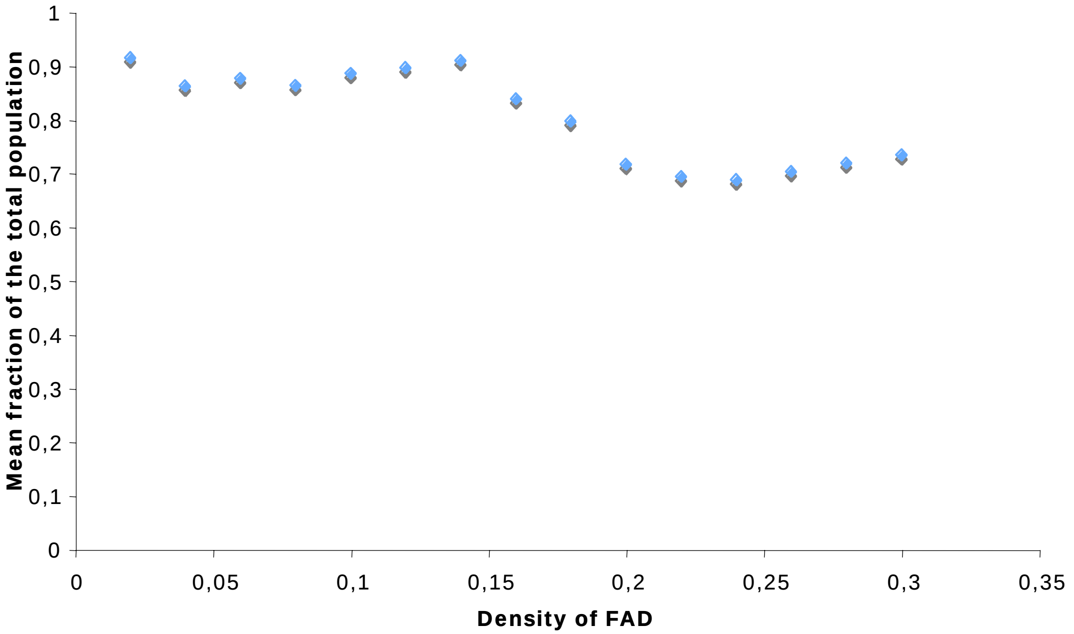
(2) Model $\rightarrow$ Relation between population around FAD and the total population

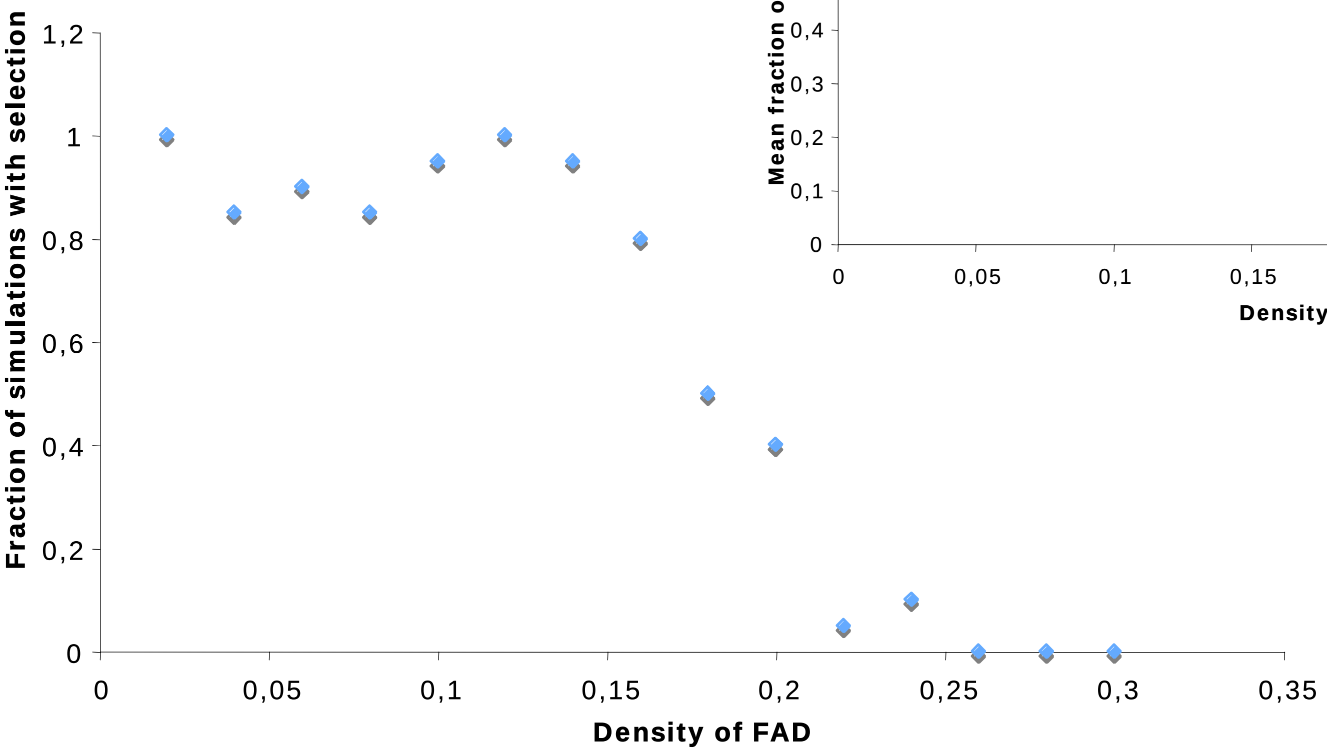
(3) Data collection with j FADs $\rightarrow$estimation of the total population

Influence of the # of FADs



Influence of the # of FADs (2)





50 simulations per condition with random initial conditions (Stationary states)

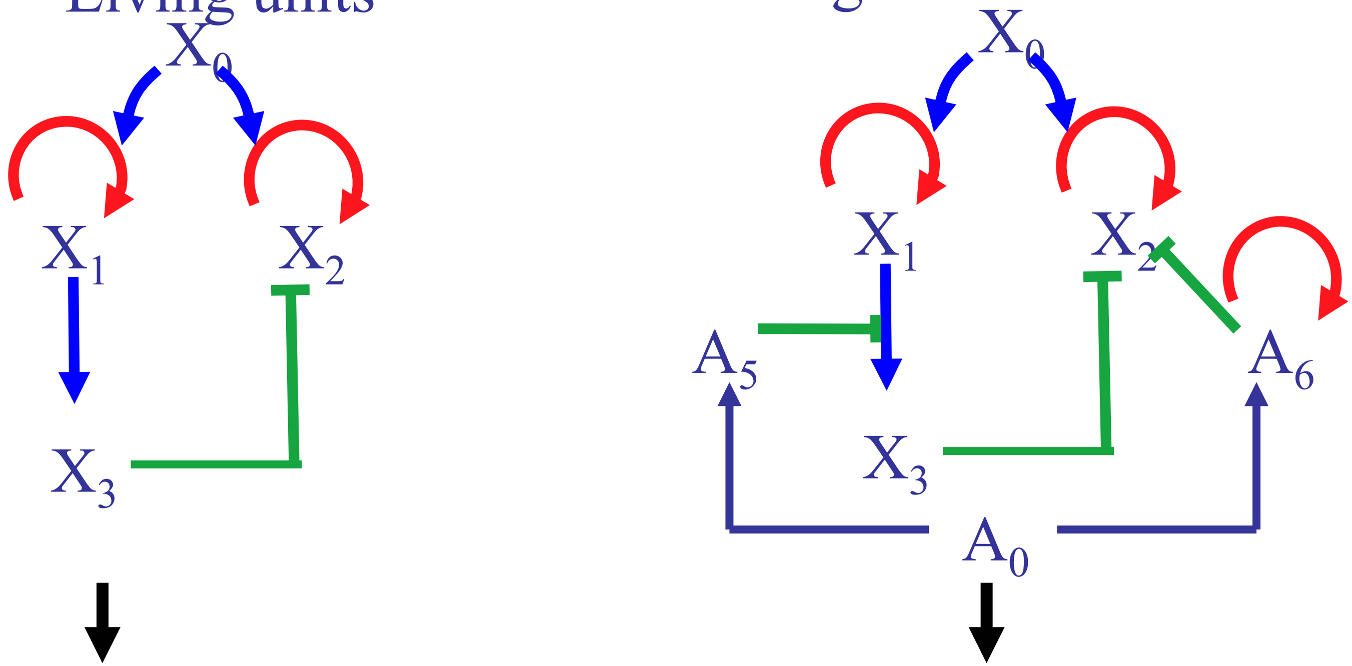
Mixed societies: mixed groups of social animals and robots.
Animals and robots (artificial agents) interact and communicate.

Control means: That it is possible to trigger the emergence of some new global patterns by adding artificial agents with specific behaviors to the society.

X_i, A_i : number of agent *i* — Negative feedback — Positive feedback — Flow

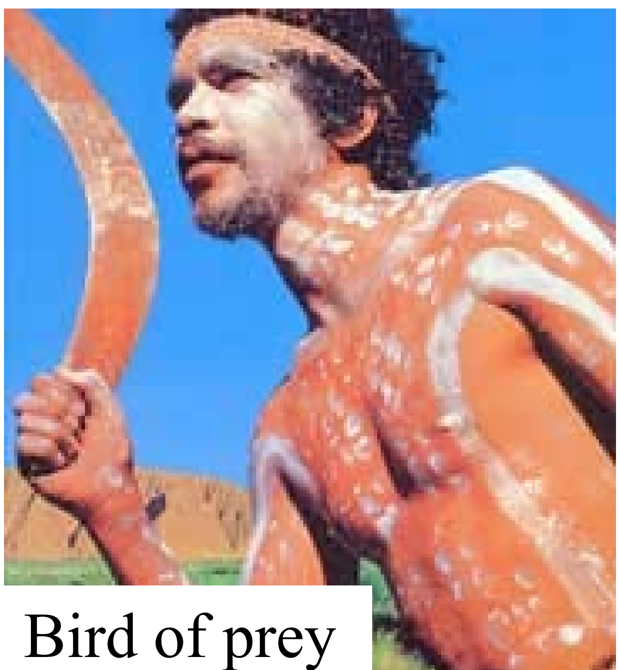
Society is a network of interactions

Living units | Living units + Artificial agents



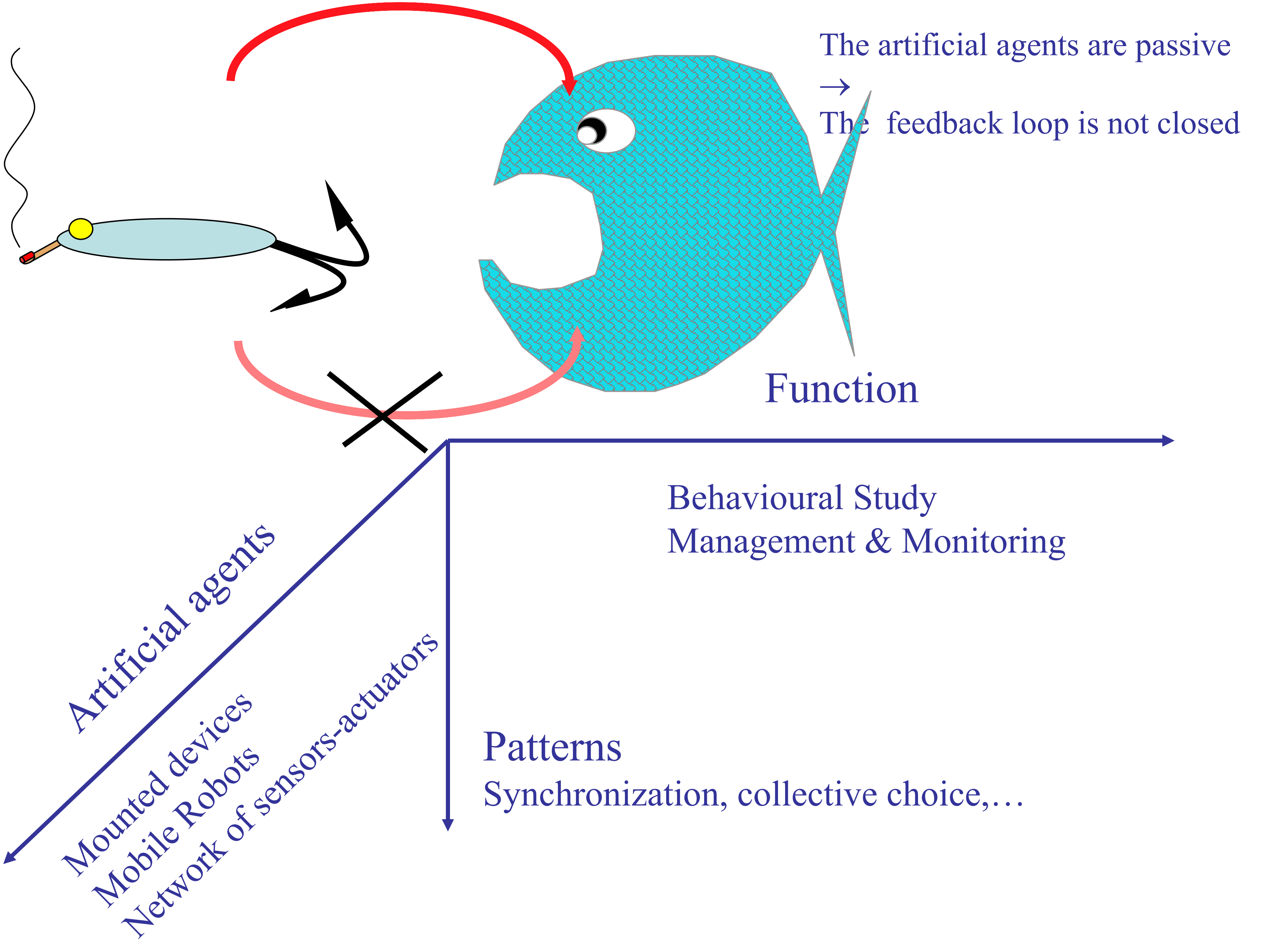
Dynamics, attractors | New dynamics, new attractors

Lure/Decoy

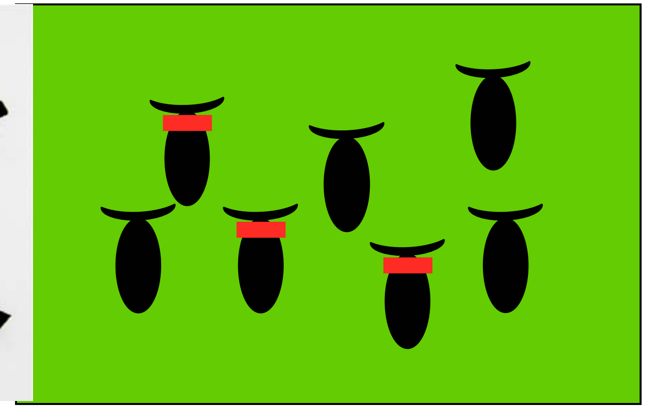


Bird of prey

≈ 1925-1926
Arctic (Canada)

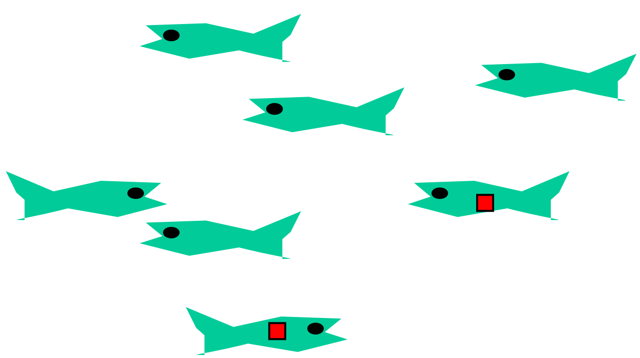

The artificial agents are passive
→
The feedback loop is not closed
Function
Behavioural Study
Management & Monitoring
Artificial agents
Mounted devices
Mobile Robots
Network of sensors-actuators
Patterns
Synchronization, collective choice,…

Mounted devices



Smart collar (Mounted device): GPS, PDA, sound amplifier & wireless networking, affects the behaviour of some individuals & of the group (D. Rus et al, MIT)

What about schools with some fishes tagged with a smart device?



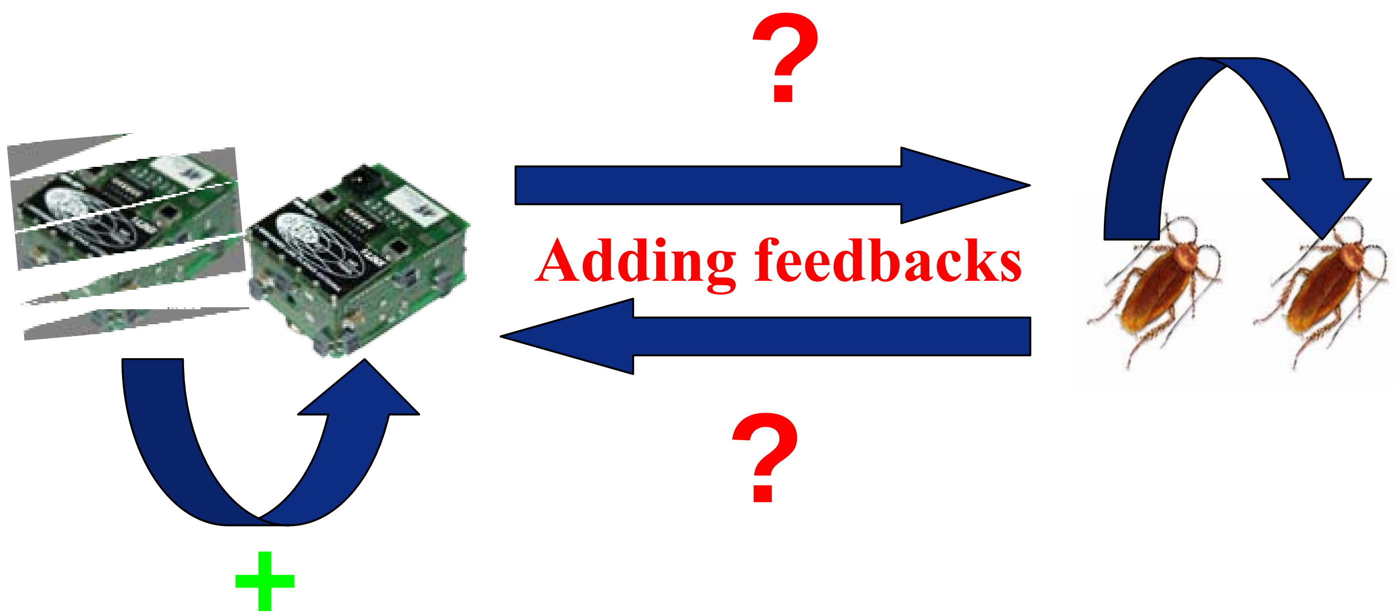
Collective decision making in mixed groups of robots and cockroaches

The lure robots allow the implementation of new feedbacks and the modification of the collective choice (dynamics).

Building interactions and communication:

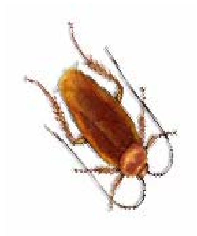
❖Perception of individual presence

❖Modulation of the behavior according to individual presence



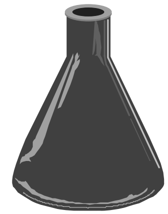
Caprari G., Colot A., Siegwart R., Halloy J. and Deneubourg, J.-L..Animal and Robot Mixed Societies- Building Cooperation Between Microrobots and Cockroaches. IEEE Robotics & Automation Magazine. Vol.12, No 2, June, pp 58-65. 2005.

Robot-insect



Identification
analysis

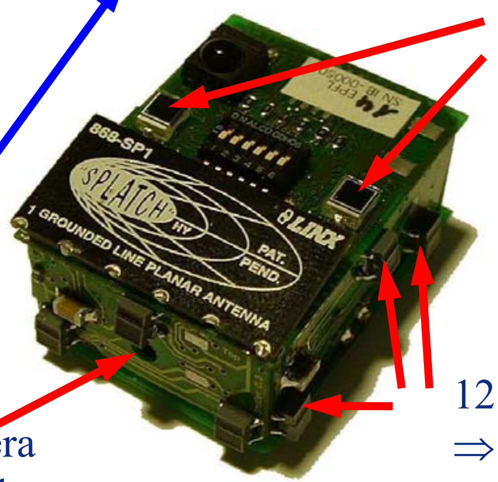
Cuticular
hydrocarbons



Extraction/Synthesis of the blend
Concentration

Marking

≈ 40mm



2 Photodiodes
⇒ Shelter detection

Linear Camera
⇒ Cockroach
detection

12 IR Proximity Sensors
⇒ Cockroach detection
⇒ Wall detection
⇒ Robot detection

UNIVERSITE DE RENNES 1

C. Rivault, I. Said
V. Durier

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

F. Tâche, M. Asadpour, A. Colot
G. Caprari, F. Mondada,
R. Siegwart

Summary

- Both machines and insects are capable, independently of each other, to perform such collective decision (don’t show here).

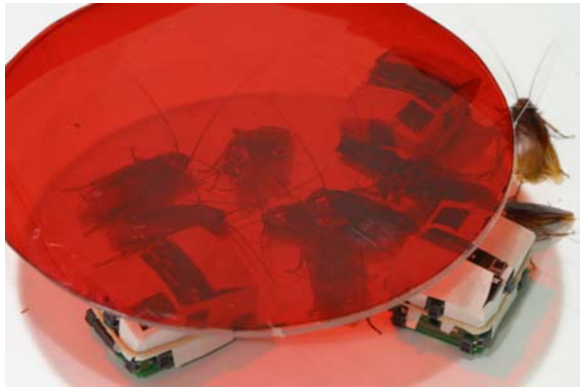
- The robots are accepted by the cockroaches groups and actively take part in the collective choice. Most of the time, they gather with the cockroaches under the same shelter.

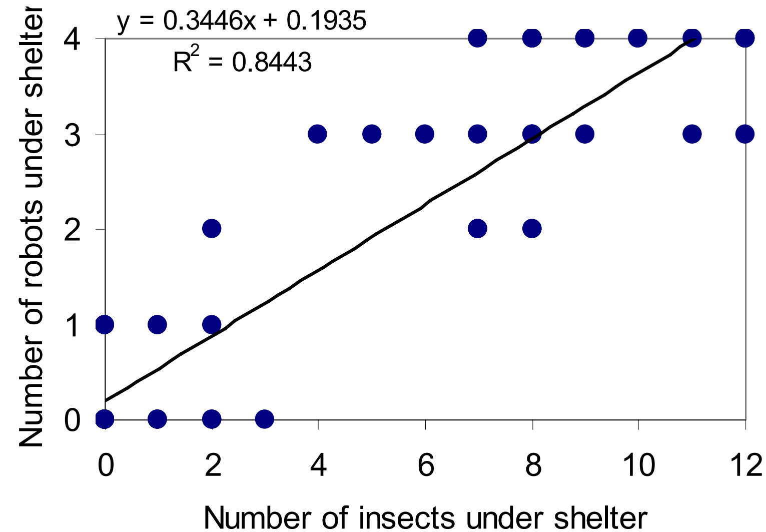
- When the robots are programmed to have an opposite preference compared to insects, they are able to induce a change in the global pattern by reversing the collective shelter preference. The mixed group of robots and insects gather in the less preferred shelter by the insects.

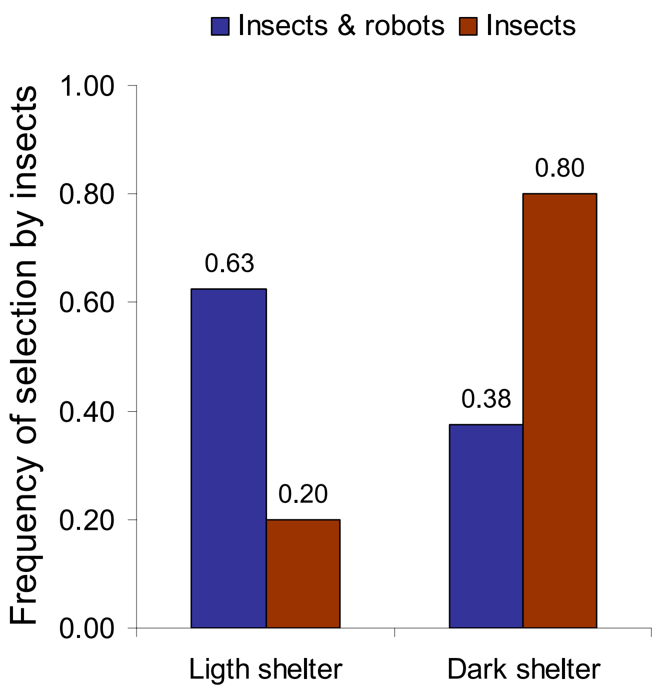
G Sempo *et al*. LNCS, 4095 2006
J. Halloy *et al*. Social Integration of Robots in Groups of Cockroaches to Control Self-organized Choices. *Science* November 15 2007.

Experimental demonstration : 12 cockroaches & 4 robots

Shared collective decision between identical shelters







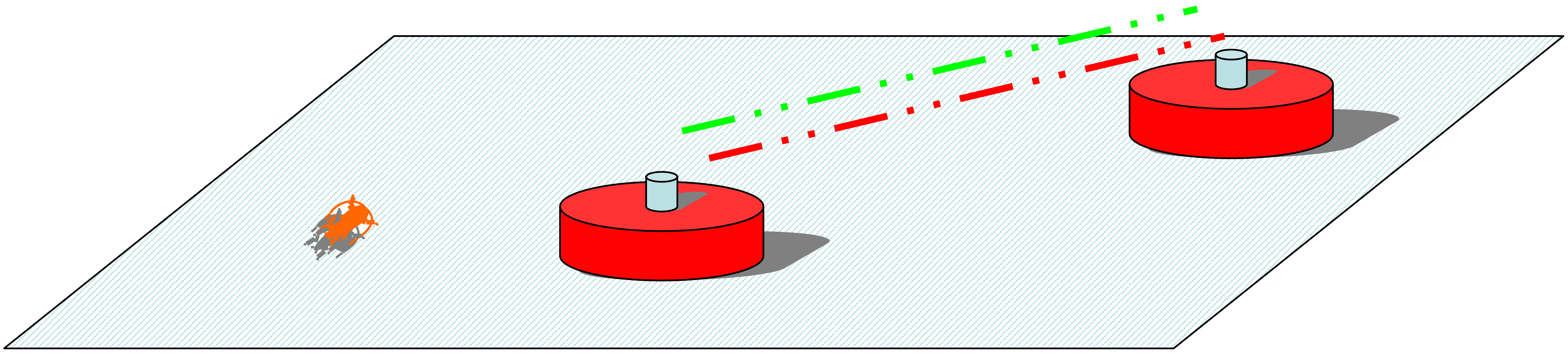
2 shelters: dark & light
Insects prefer dark & Robots prefer light

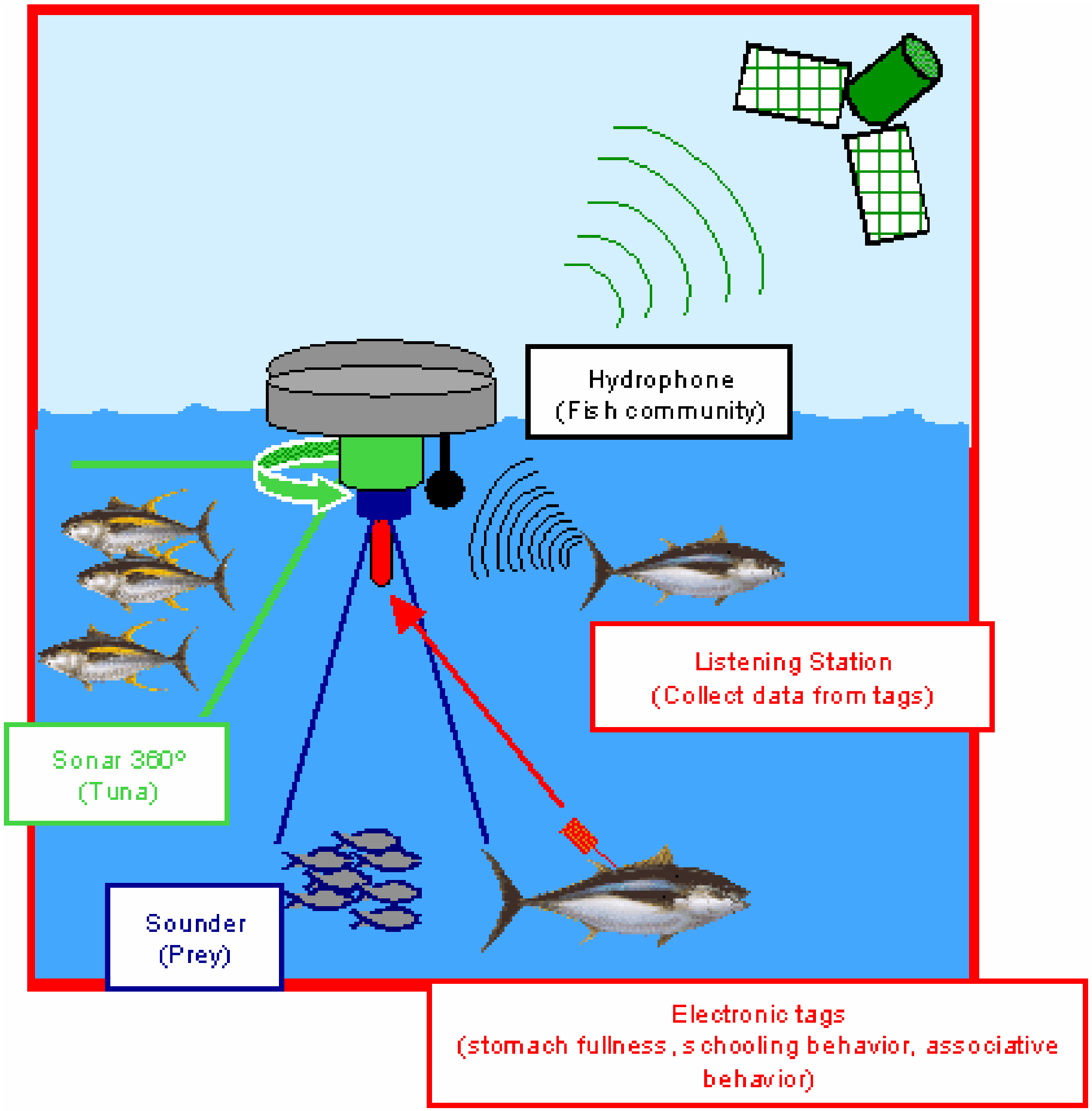
Network of sensors-actuators : shelters, FADs,...

$$\frac{dx_i}{dt} = \mu_i x_e - \frac{\theta_i x_i}{1 + \rho\left(\frac{x_i}{S_i}\right)^n}$$

$$\frac{\mathrm{d}\theta_\mathrm{i}}{dt} = F_i(x_1, x_2, \theta_1, \theta_2)$$

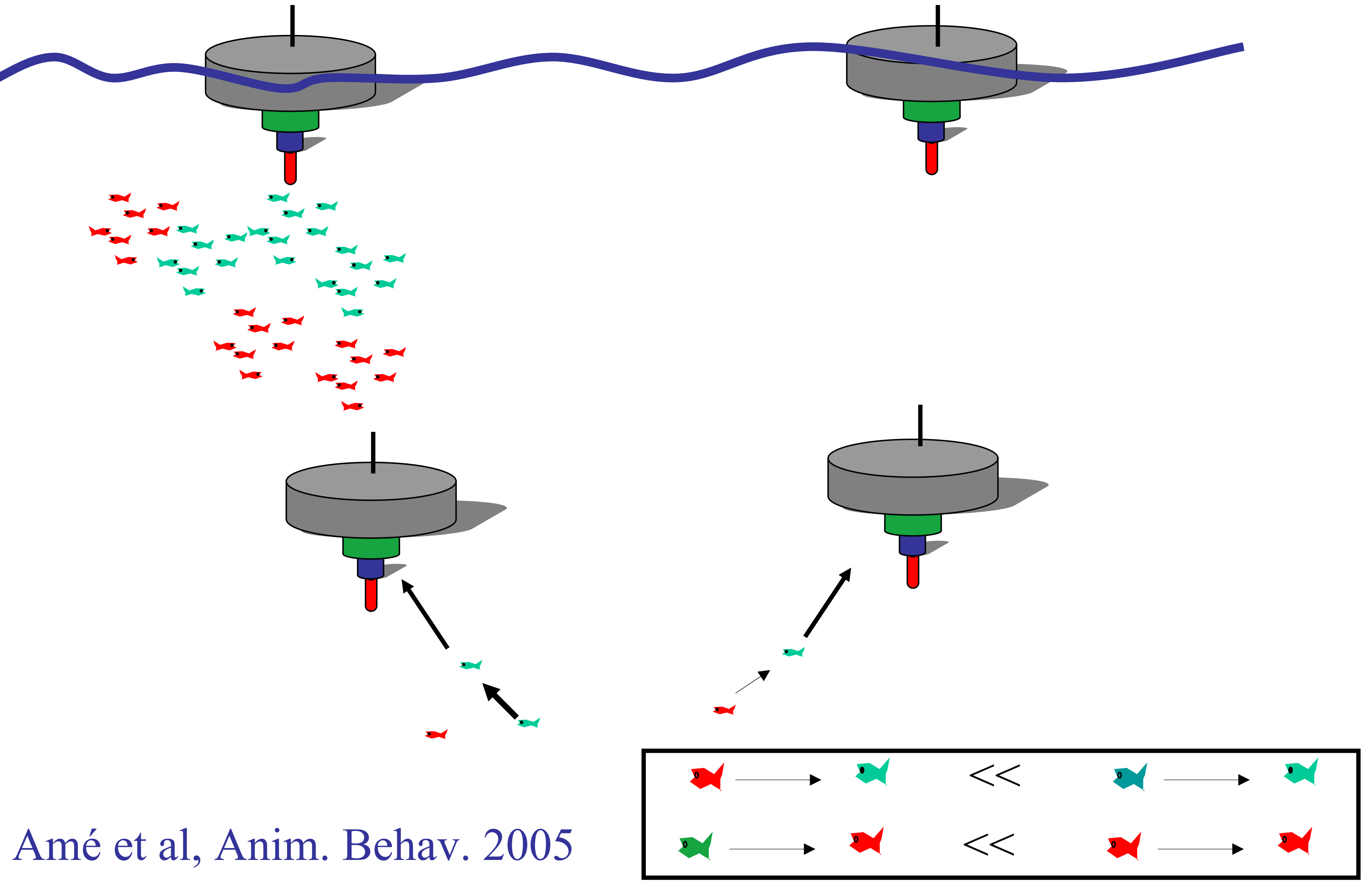
Different patterns, responses of the systems
→Information on the total population
→Optimal control





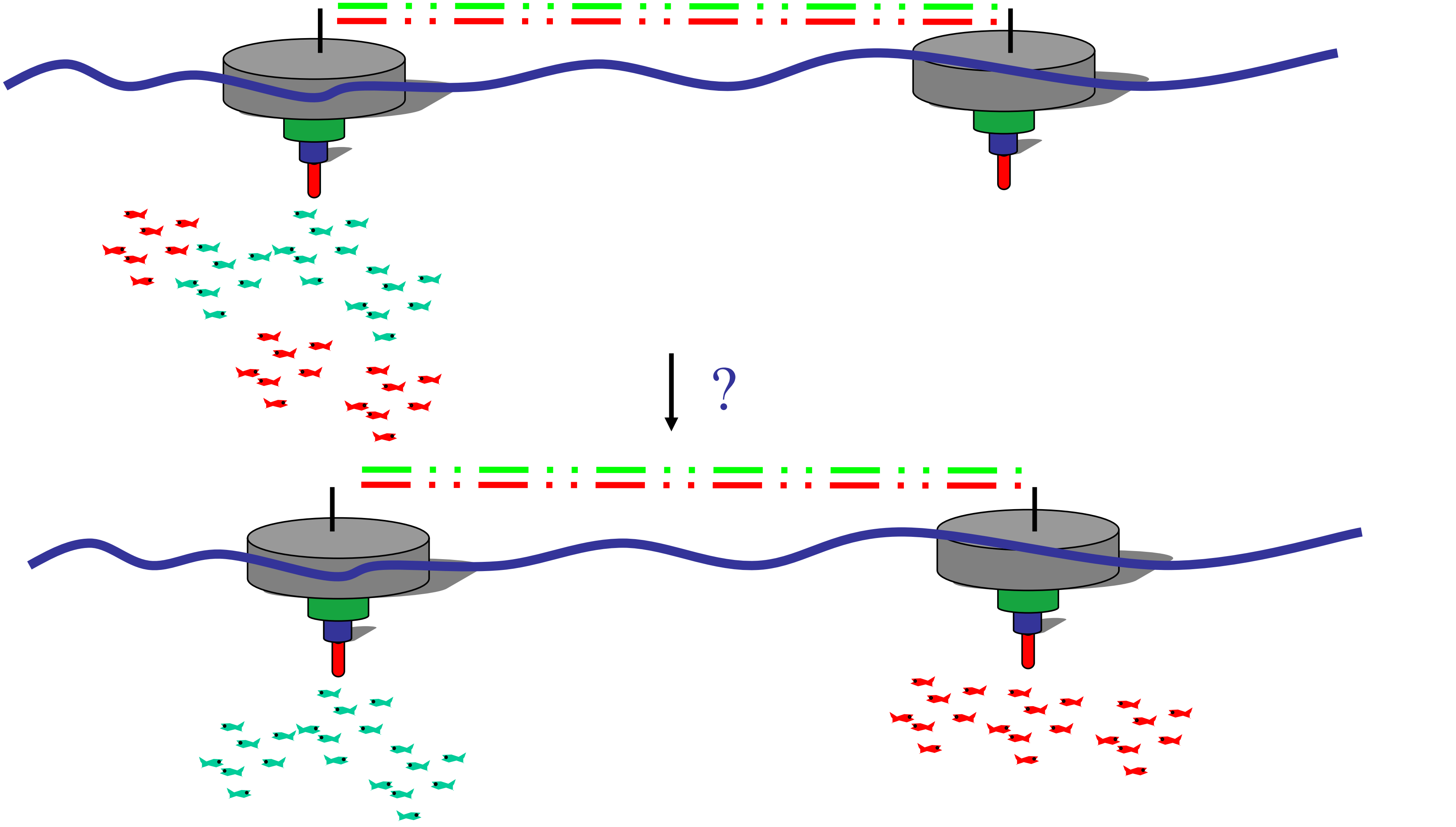
From FADIO (Quality of Life; FP5)

Aggregation-sorting : by-catch



Amé et al, Anim. Behav. 2005

Aggregation-sorting : by-catch



Selective attraction?

Robot-decoy acting selectively on one species e.g. by imitation