MODELLING OF MULTI-PREY/MULTI-PREDATOR SYSTEMS AND THE TROPHIC TRANSMISSION OF PARASITES; APPLICATION TO *ECHINOCOCCUS MULTILOCULARIS*

LIREUX Ségolène – PhD Student day 2022

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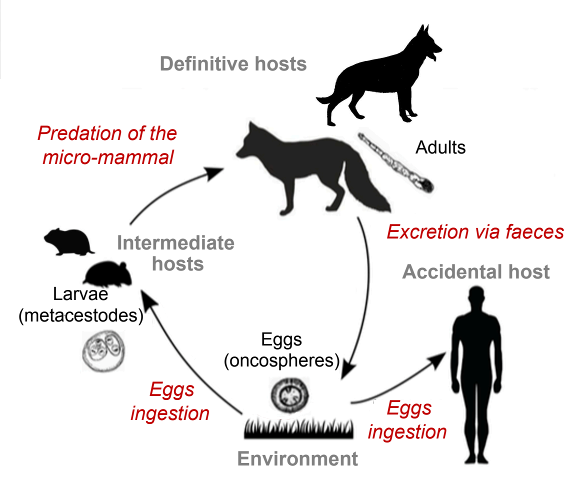
Environnements - Santé
Bourgogne I Franche-Comté

CONTEXT :

Echinococcus multilocularis
Class : *Cestoda*
Family : *Taeniidae*



Adapted from Baudrot et *al.* 2016, PhD thesis

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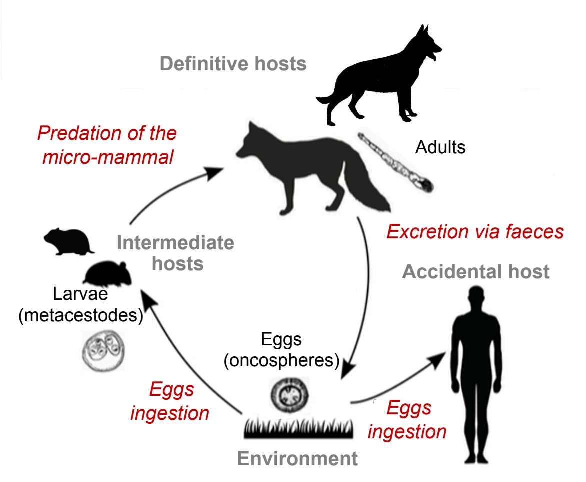

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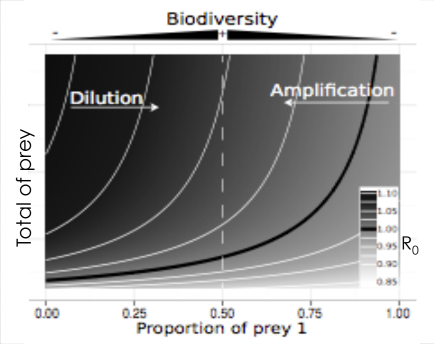
Prey / Predators models

+

Epidemiological models

System of ordinary differential equations



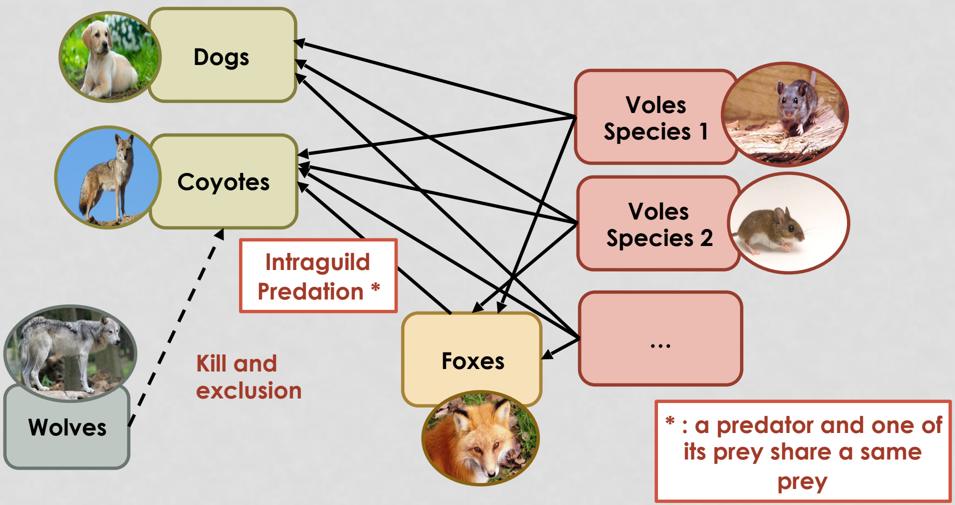
Baudrot *et al.* 2016

<u>Results</u>

1 predator (Fox) and 2 prey (*Microtus arvalis* and *Arvicola terrestris*)
Competence prey 1 < prey 2

=> Questioning of the *dilution hypothesis*

System of transmission of *Em* in North America



Data from Romig *et al.* 2017, Flagel *et al.* 2017

Emergent effects in multi-predators context

- Inferior predation :
  - Competition
  - Exclusion
  - Intraguild predation
- Superior predation via facilitation

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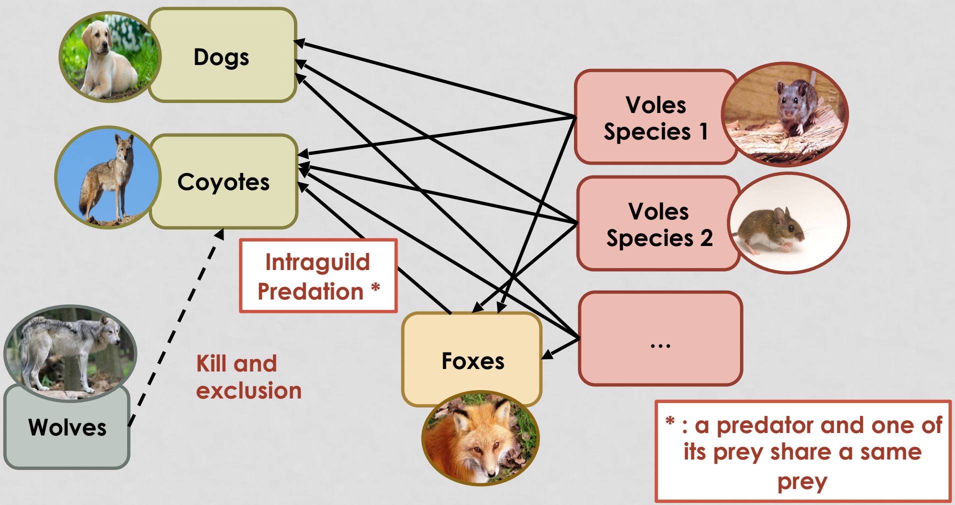

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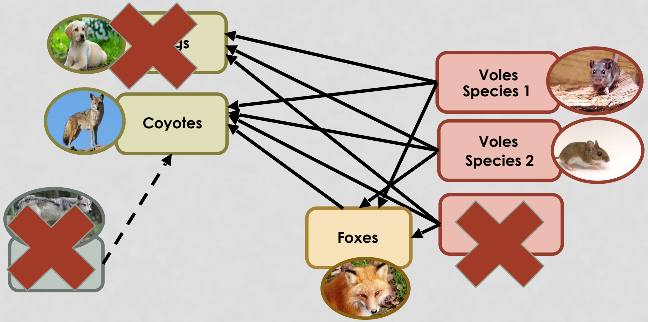
Goals of my PhD:

- To build a generic framework with n prey/m predators
- To incorporate these results into a predictive model for *E. multilocularis* transmission

CONSTRUCTION OF PREY/PREDATOR MODEL

- Adapted de Wei *et al.*, 2019, *Math Comput Simul,* finalized thanks to discussion with Alessandro Massolo (ecologist, parasitologist, University of Pisa)

- 2 generalist predators with intraguild predation, 2 preys, Holling equations



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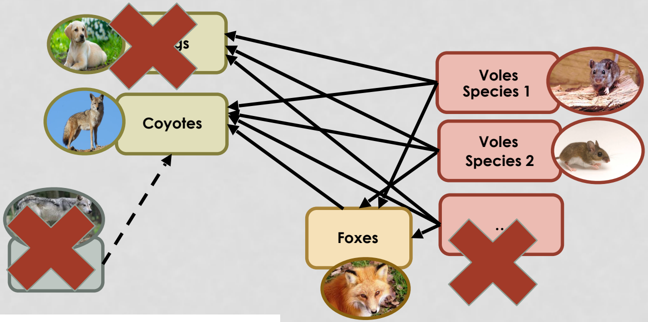

Prey 1 $$\frac{dX}{dt} = r_X X(t)$$

Prey 2 $$\frac{dY}{dt} = r_Y Y(t)$$

Foxes $$\frac{dF}{dt} = r_F F(t)$$

Coyotes $$\frac{dC}{dt} = r_C C(t)$$

Birth rates

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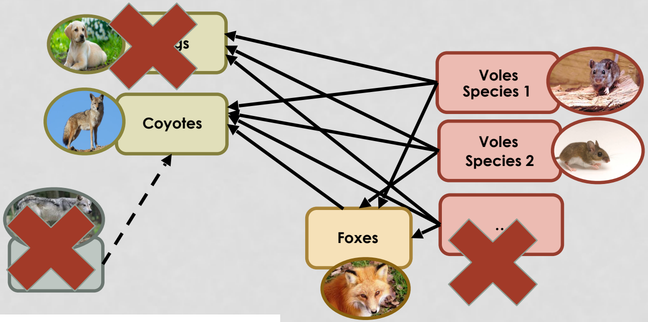

Prey 1 $$\frac{dX}{dt} = r_X X(t) - m_X X(t)$$

Prey 2 $$\frac{dY}{dt} = r_Y Y(t) - m_Y Y(t) \cdot$$

Mortality rates

Foxes $$\frac{dF}{dt} = r_F F(t) - m_F F(t) \cdot$$

Coyotes $$\frac{dC}{dt} = r_C C(t) - m_C C(t) \cdot$$

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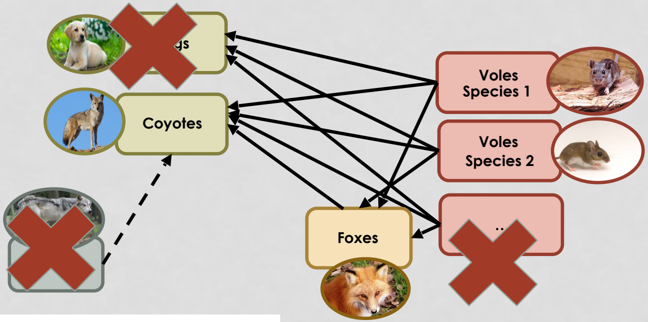

Prey 1
$$\frac{dX}{dt} = r_X X(t) - m_X X(t) - b_X X(t)^2$$

Prey 2
$$\frac{dY}{dt} = r_Y Y(t) - m_Y Y(t) - b_Y Y(t)^2$$

Intraspecific competition rates

Foxes
$$\frac{dF}{dt} = r_F F(t) - m_F F(t) - b_F F(t)^2$$

Coyotes
$$\frac{dC}{dt} = r_C C(t) - m_C C(t) - b_C C(t)^2$$

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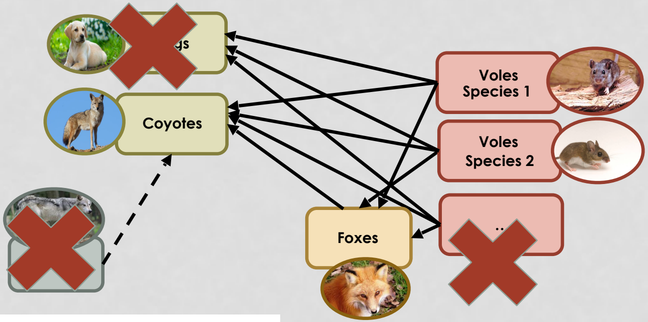

Prey 1

$$\frac{dX}{dt} = r_X X(t) - m_X X(t) - b_X X(t)^2 - \phi_{\mathbf{F},\mathbf{X}} F(t)$$

Prey 2

$$\frac{dY}{dt} = r_Y Y(t) - m_Y Y(t) - b_Y Y(t)^2$$

Predation of foxes on prey 1

Foxes

$$\frac{dF}{dt} = r_F F(t) - m_F F(t) - b_F F(t)^2 + e_X \phi_{\mathbf{F},\mathbf{X}} F(t)$$

Coyotes

$$\frac{dC}{dt} = r_C C(t) - m_C C(t) - b_C C(t)^2$$

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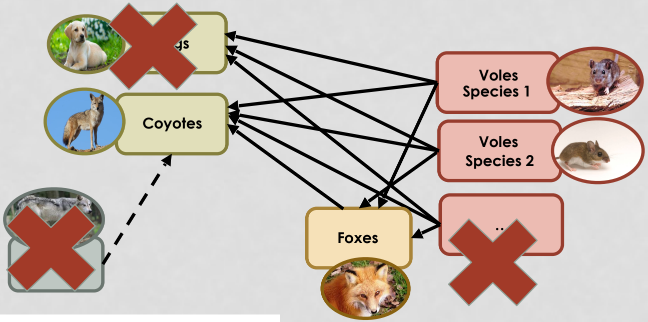

Prey 1 $$\frac{dX}{dt} = r_X X(t) - m_X X(t) - b_X X(t)^2 - \phi_{\mathbf{F},\mathbf{X}} F(t)$$

Prey 2 $$\frac{dY}{dt} = r_Y Y(t) - m_Y Y(t) - b_Y Y(t)^2 - \phi_{\mathbf{F},\mathbf{Y}} F(t)$$

Predation of foxes on prey 2

Foxes $$\frac{dF}{dt} = r_F F(t) - m_F F(t) - b_F F(t)^2 + e_X \phi_{\mathbf{F},\mathbf{X}} F(t) + e_Y \phi_{\mathbf{F},\mathbf{Y}} F(t)$$

Coyotes $$\frac{dC}{dt} = r_C C(t) - m_C C(t) - b_C C(t)^2$$

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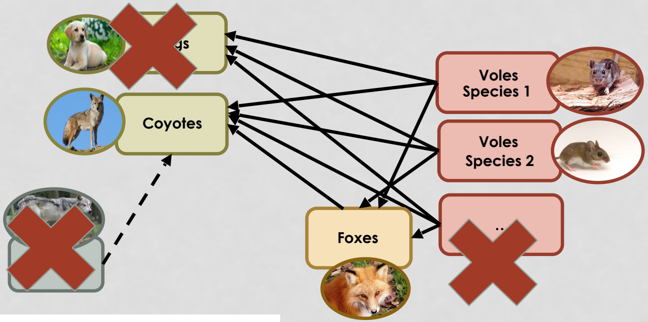

Prey 1 $$\frac{dX}{dt} = r_X X(t) - m_X X(t) - b_X X(t)^2 - \phi_{\mathbf{F},\mathbf{X}} F(t) - \phi_{\mathbf{C},\mathbf{X}} C(t)$$

Prey 2 $$\frac{dY}{dt} = r_Y Y(t) - m_Y Y(t) - b_Y Y(t)^2 - \phi_{\mathbf{F},\mathbf{Y}} F(t)$$

Foxes $$\frac{dF}{dt} = r_F F(t) - m_F F(t) - b_F F(t)^2 + e_X \phi_{\mathbf{F},\mathbf{X}} F(t) + e_Y \phi_{\mathbf{F},\mathbf{Y}} F(t)$$

Coyotes $$\frac{dC}{dt} = r_C C(t) - m_C C(t) - b_C C(t)^2 + w_X \phi_{\mathbf{C},\mathbf{X}} C(t)$$

Predation of coyotes on prey 1

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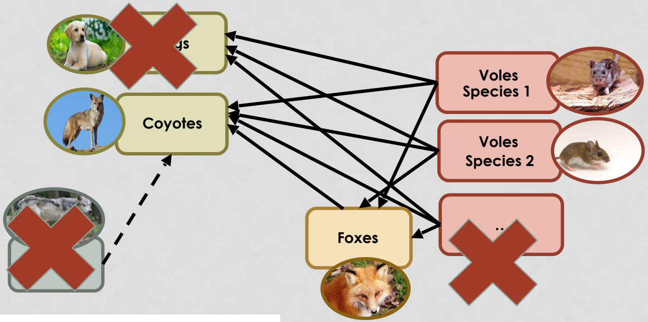

Prey 1 $$\frac{dX}{dt} = r_X X(t) - m_X X(t) - b_X X(t)^2 - \phi_{\mathbf{F},\mathbf{X}} F(t) - \phi_{\mathbf{C},\mathbf{X}} C(t)$$

Prey 2 $$\frac{dY}{dt} = r_Y Y(t) - m_Y Y(t) - b_Y Y(t)^2 - \phi_{\mathbf{F},\mathbf{Y}} F(t) - \phi_{\mathbf{C},\mathbf{Y}} C(t)$$

Foxes $$\frac{dF}{dt} = r_F F(t) - m_F F(t) - b_F F(t)^2 + e_X \phi_{\mathbf{F},\mathbf{X}} F(t) + e_Y \phi_{\mathbf{F},\mathbf{Y}} F(t)$$

Coyotes $$\frac{dC}{dt} = r_C C(t) - m_C C(t) - b_C C(t)^2 + w_X \phi_{\mathbf{C},\mathbf{X}} C(t) + w_Y \phi_{\mathbf{C},\mathbf{Y}} C(t)$$

Predation of coyotes on prey 2

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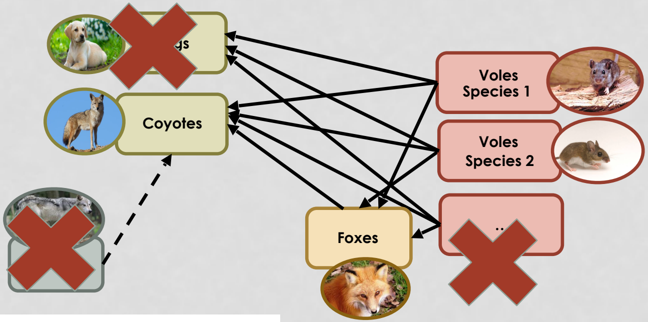

Prey 1
$$\frac{dX}{dt} = r_X X(t) - m_X X(t) - b_X X(t)^2 - \phi_{\mathbf{F},\mathbf{X}} F(t) - \phi_{\mathbf{C},\mathbf{X}} C(t)$$

Prey 2
$$\frac{dY}{dt} = r_Y Y(t) - m_Y Y(t) - b_Y Y(t)^2 - \phi_{\mathbf{F},\mathbf{Y}} F(t) - \phi_{\mathbf{C},\mathbf{Y}} C(t)$$

Foxes
$$\frac{dF}{dt} = r_F F(t) - m_F F(t) - b_F F(t)^2 + e_X \phi_{\mathbf{F},\mathbf{X}} F(t) + e_Y \phi_{\mathbf{F},\mathbf{Y}} F(t) - \phi_{\mathbf{C},\mathbf{F}} C(t)$$

Coyotes
$$\frac{dC}{dt} = r_C C(t) - m_C C(t) - b_C C(t)^2 + w_X \phi_{\mathbf{C},\mathbf{X}} C(t) + w_Y \phi_{\mathbf{C},\mathbf{Y}} C(t) + w_F \phi_{\mathbf{C},\mathbf{F}} C(t)$$

Intraguild predation

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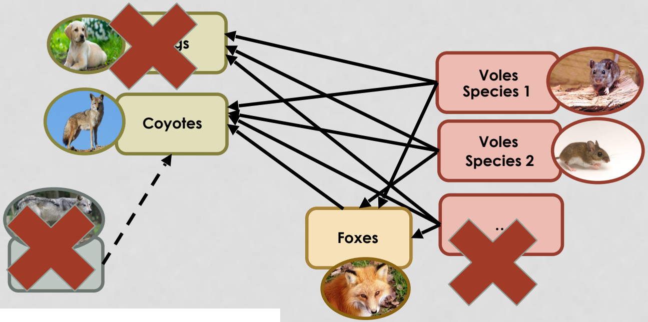

Prey 1

Prey 2

Foxes
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Coyotes
$$\frac{dC}{dt} = r_C C(t) - m_C C(t) - b_C C(t)^2$$

CONSTRUCTION OF PREY/PREDATOR SYSTEM

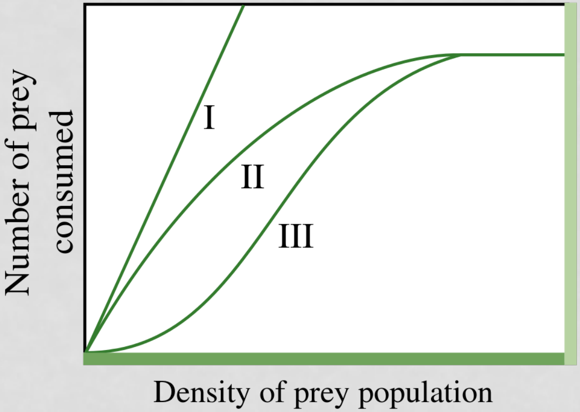
- Beddington-DeAngelis Functional Responses
- Holling III type

Attack rates

$$\phi_{\mathbf{F},\mathbf{X}} = \frac{p_X X(t)^2}{1 + g_X p_X X(t)^2 + g_Y p_Y Y(t)^2 + v_F F(t)}$$

Handling times

Interference between predators



WHAT TO DO WITH SUCH A MODEL ?

1. Use real data (time series) to test my model and fix the parameters

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   => No such data

WHAT TO DO WITH SUCH A MODEL ?

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2. Proceed more theoritically !

➢ Try to fix most of the 29 parameters with litterature
➢ Assess the impact of the others on equilibria via simulations

WHAT TO DO WITH SUCH A MODEL ?

$$\begin{cases} \frac{dX}{dt} = 0 \\ \frac{dY}{dt} = 0 \\ \frac{dF}{dt} = 0 \\ \frac{dC}{dt} = 0 \end{cases}$$

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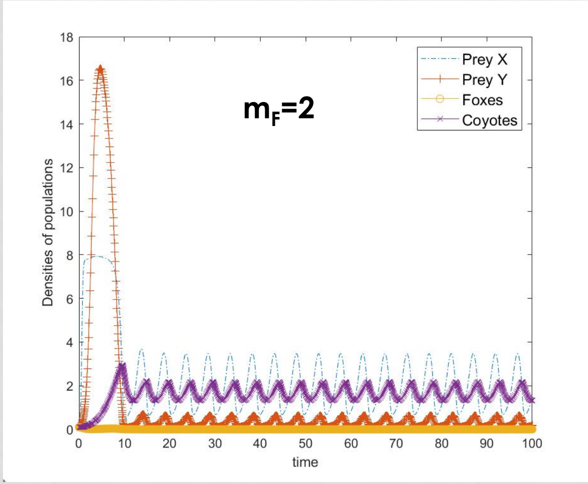

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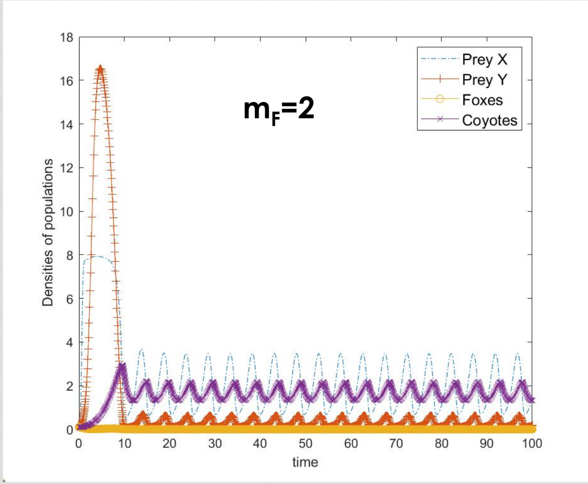

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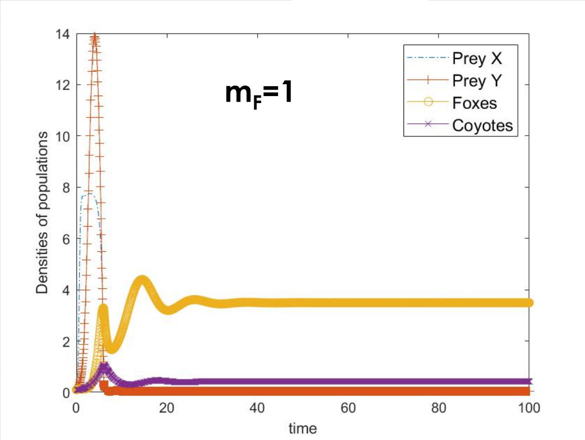

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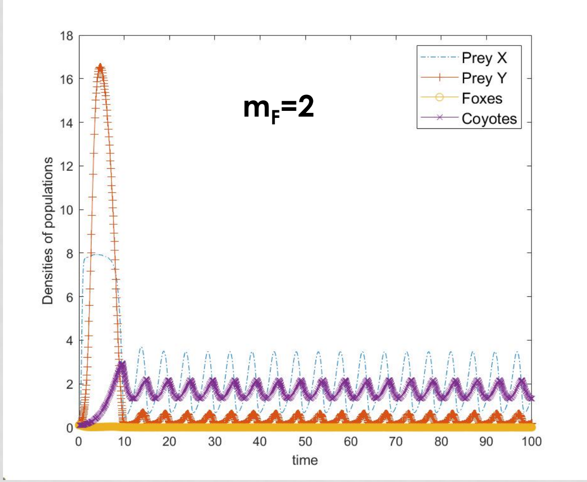
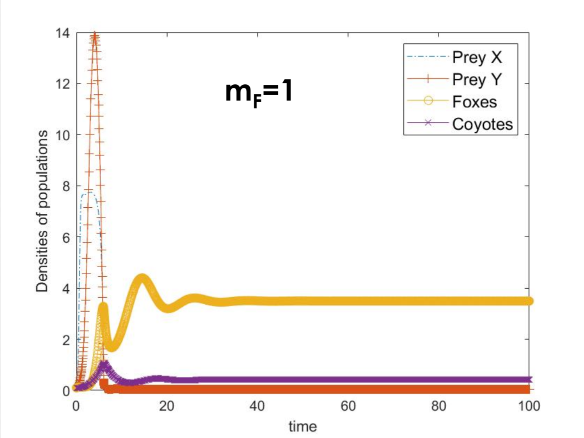


A bifurcation



=> Interesting because mortality of foxes can be effectively variable

PERSPECTIVES

- Refine the value of my parameters
- Look for bifurcations
- Draw conclusions if terms of population control

Thanks to Ezio Venturino, University of Turin