Individual based models in movement ecology

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Ekenäs Herrgård
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What is a model?

Ecological models

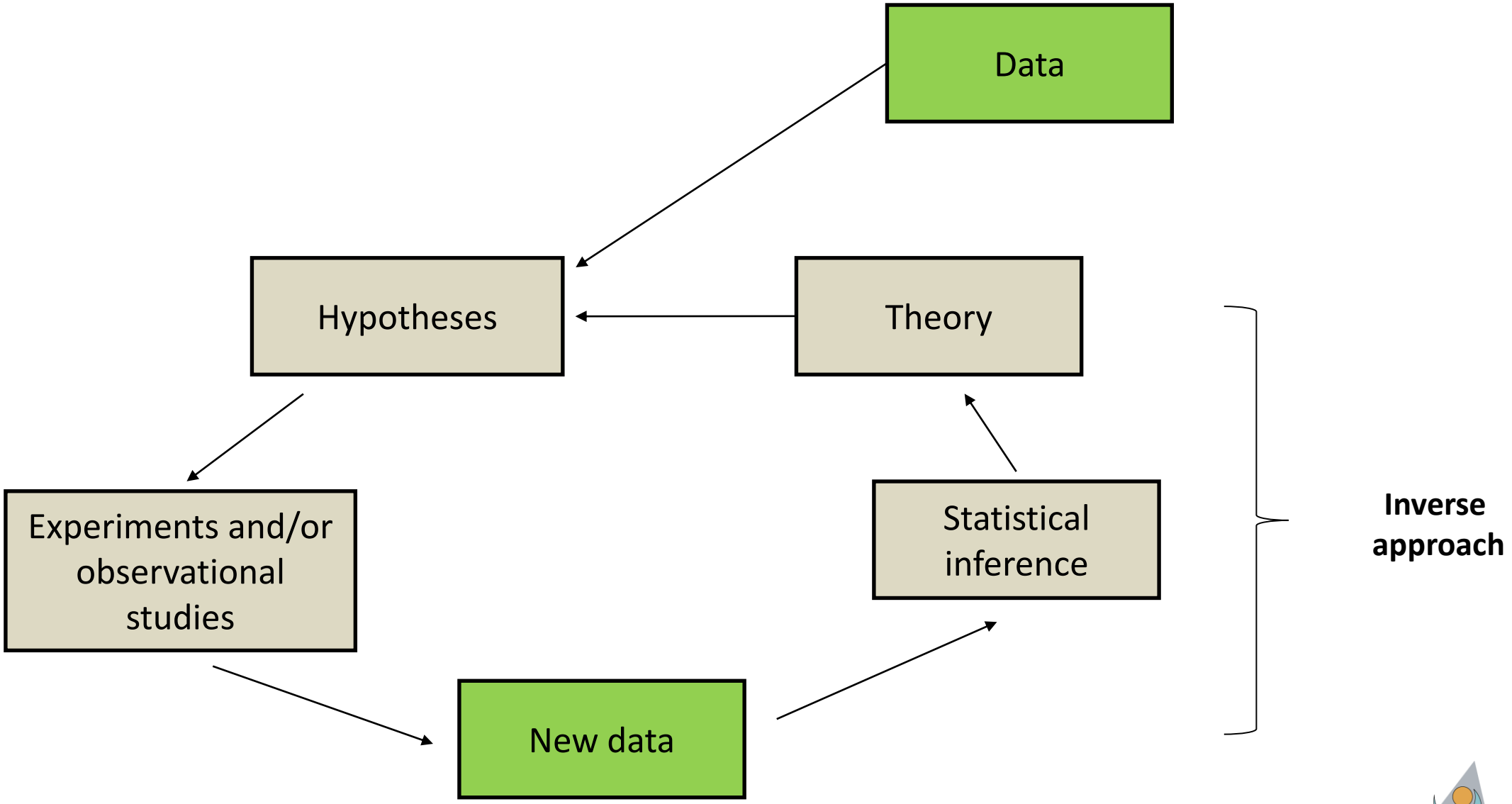
Forward approach: mathematical models

Aim: to understand causal relations in a general level

Inverse approach: statistical models

Aim: to find factors that influence observed data

Adapted from O. Ovaskainen



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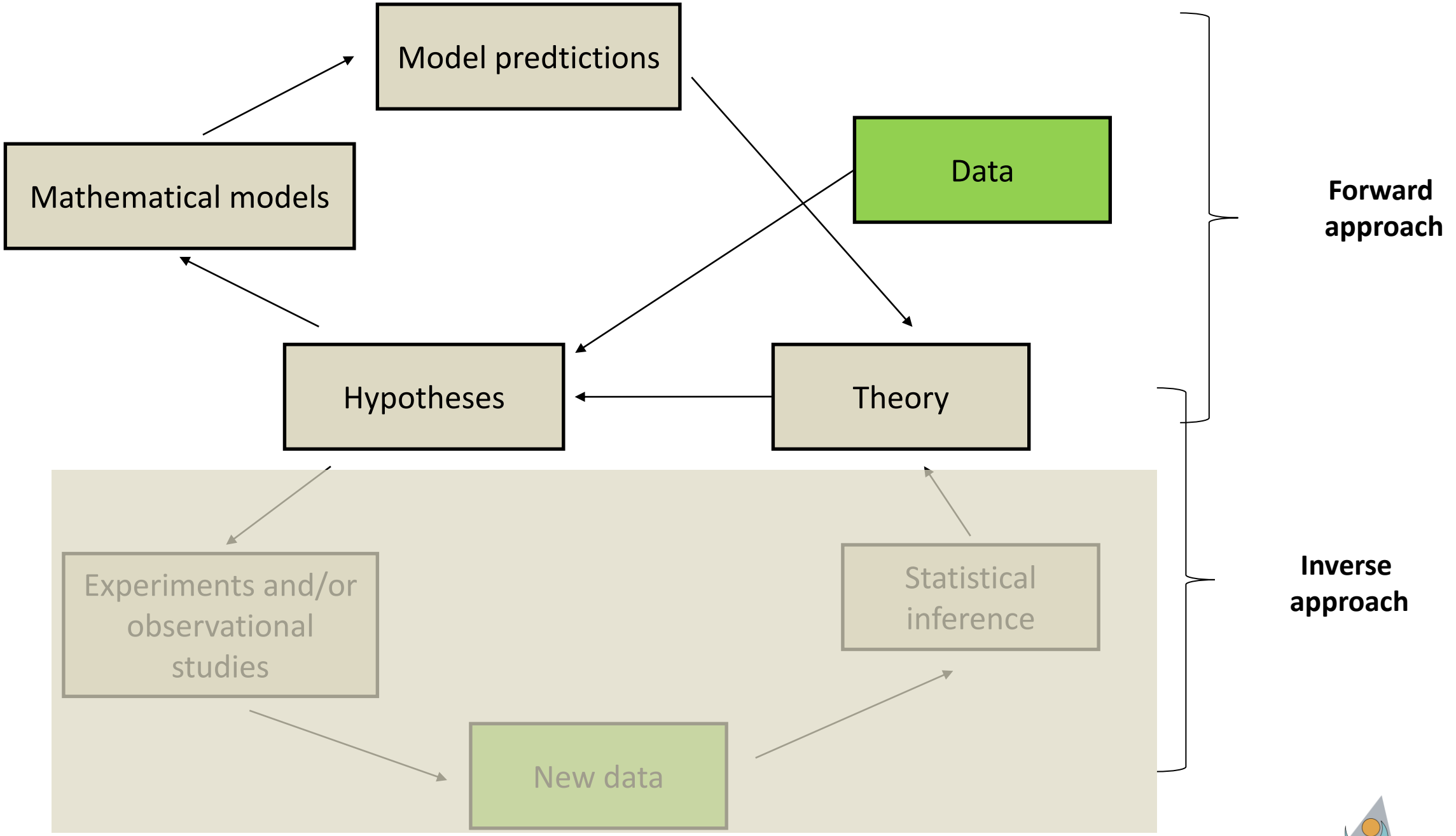

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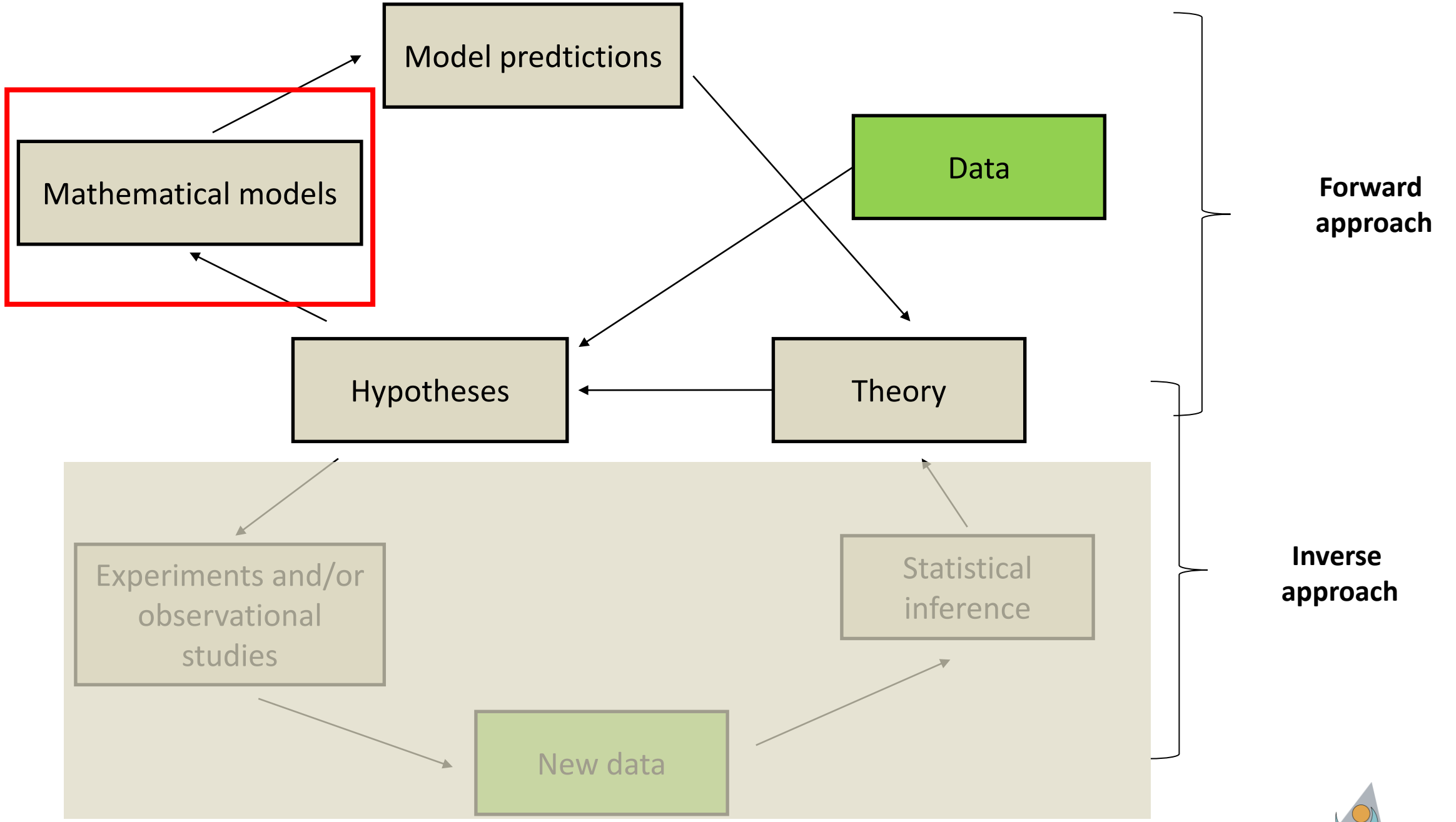

Model predtictions
Mathematical models
Data
Hypotheses
Theory
Experiments and/or observational studies
Statistical inference
New data
Forward approach
Inverse approach

Mathematical models

Mathematical models

What is the population growth dynamics once there are limited resources?

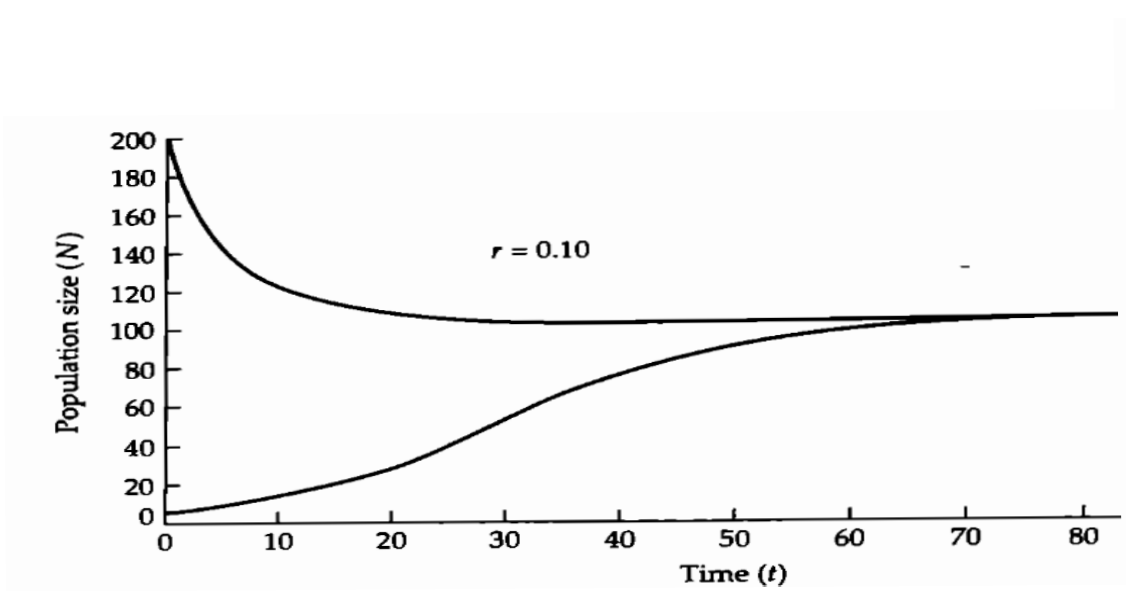
How is the dynamics of a predator-prey system?

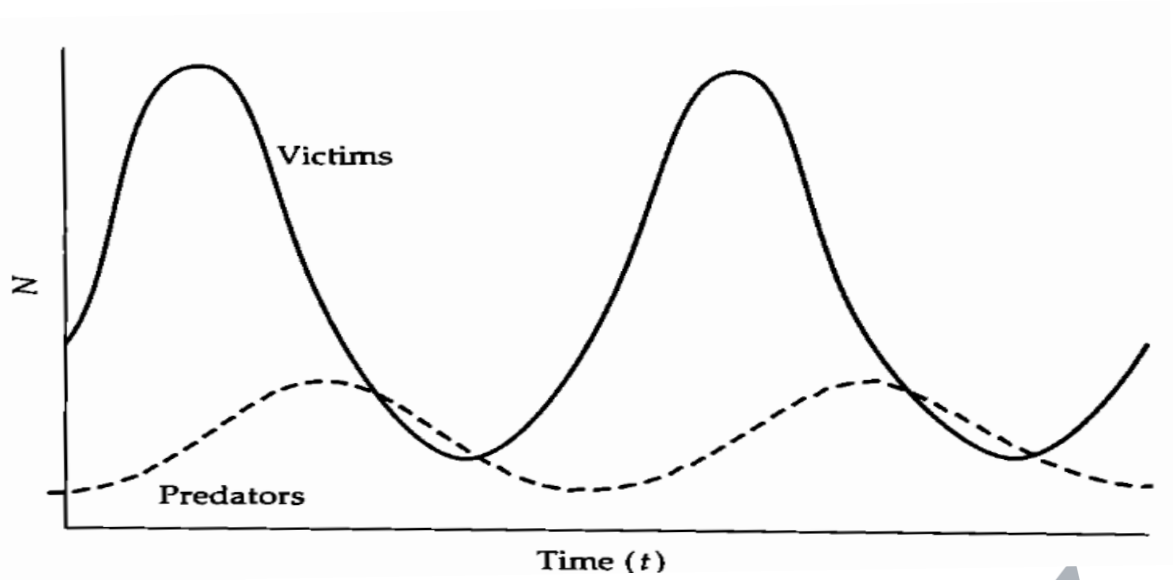
Mathematical models

$$\frac{dN}{dt} = rN\left(1 - \frac{N}{K}\right)$$

$$\frac{dN}{dt} = \alpha N - \beta NP$$

$$\frac{dP}{dt} = \sigma NP - \gamma P$$





Gotelli, A primer of ecology, 2001

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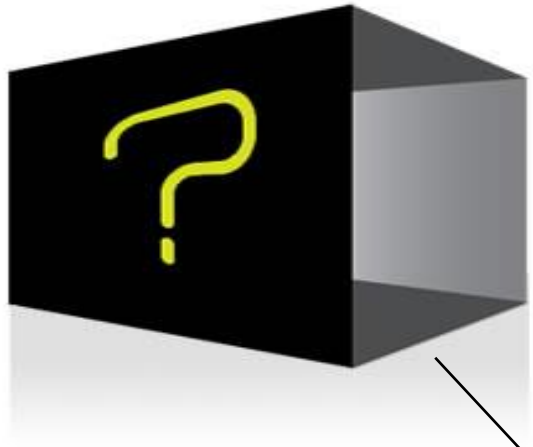
Individual-based models

Space

Individuals/agents

Movement
Behavior
Biology

Models
Simulations
“Rules”



Ecological questions
Conservation strategies

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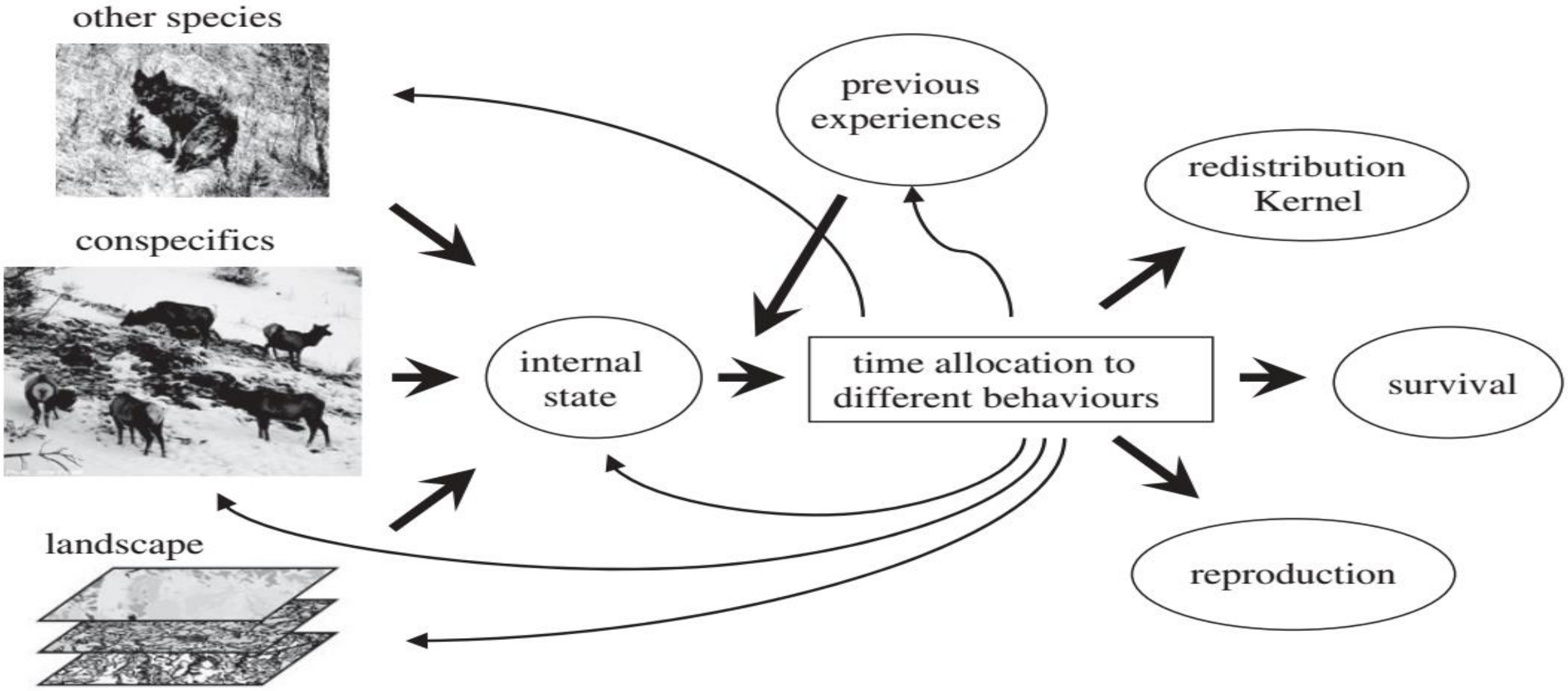
Individual-based models

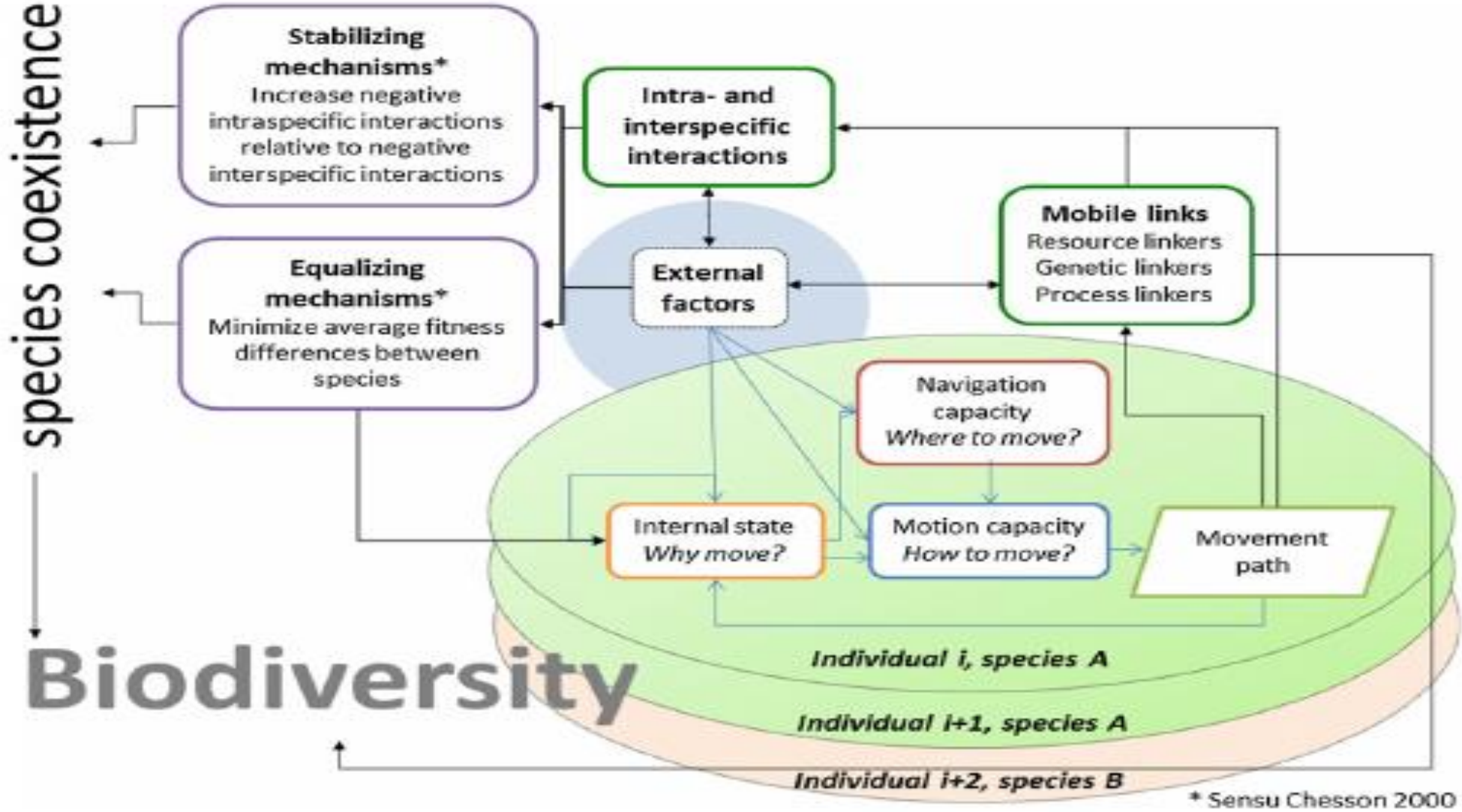
- Individual variation
- Variability in space
- Life history details
- Behavior and phenotipic variation
- Experience and learning
- Genetics and evolution
- Complexity and pattern emergence

Individual-based models



Morales et al. 2010

Individual-based models

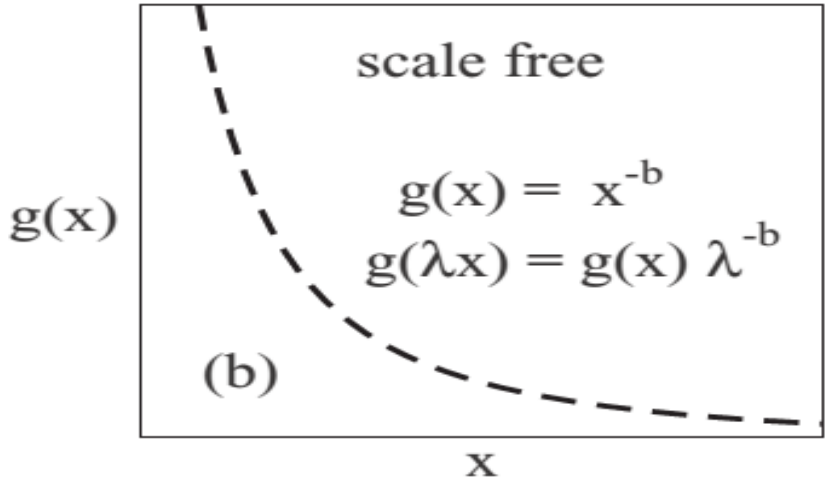


Jeltsch et al. 2013

Individual-based models

- Random walk model
- Population model
- Species interaction model

Lévy patterns



Viswanathan et al. 2011

log P(ℓ)

$P(\ell) \sim \ell^{-\mu}$

log ℓ

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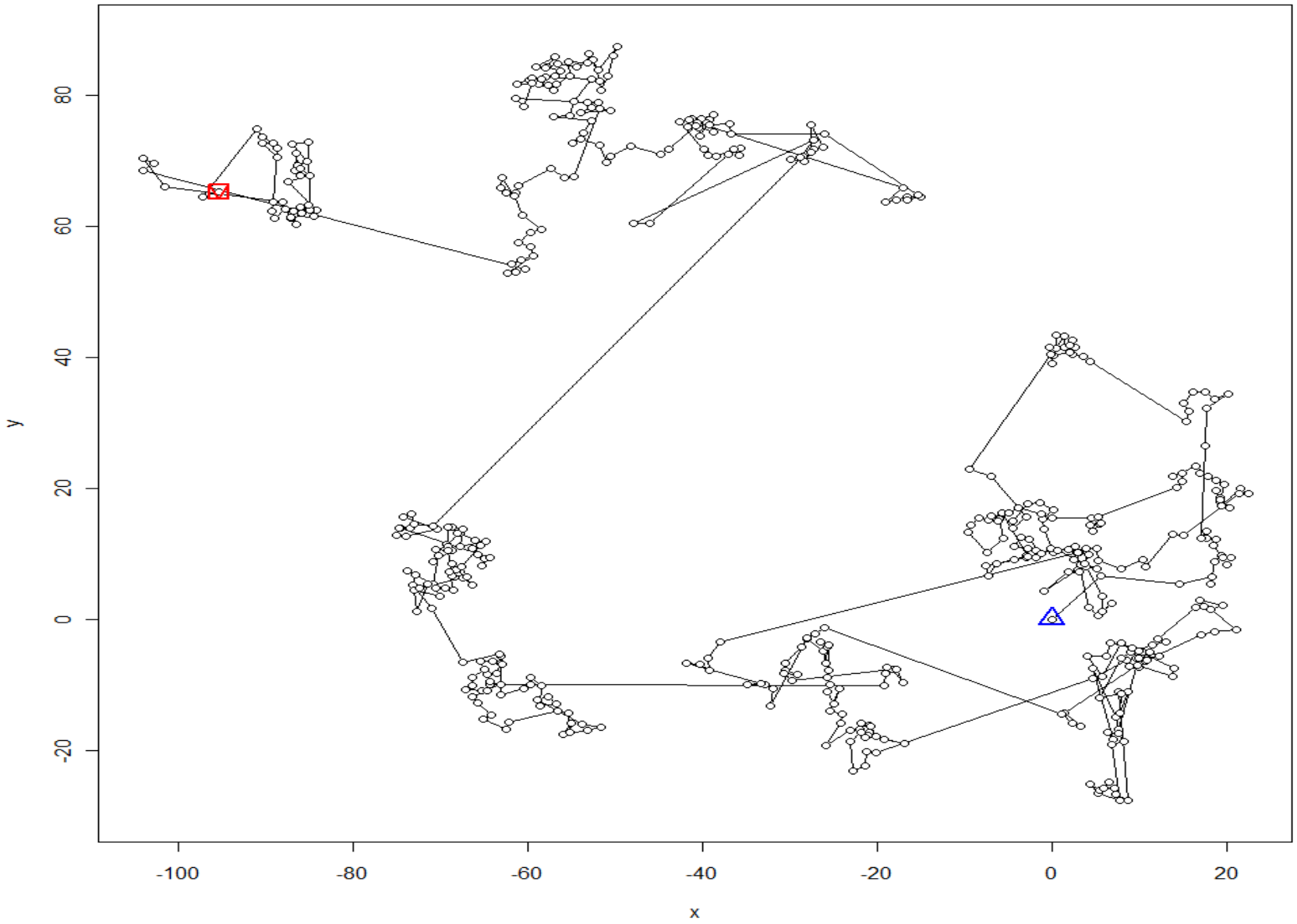
Lévy patterns



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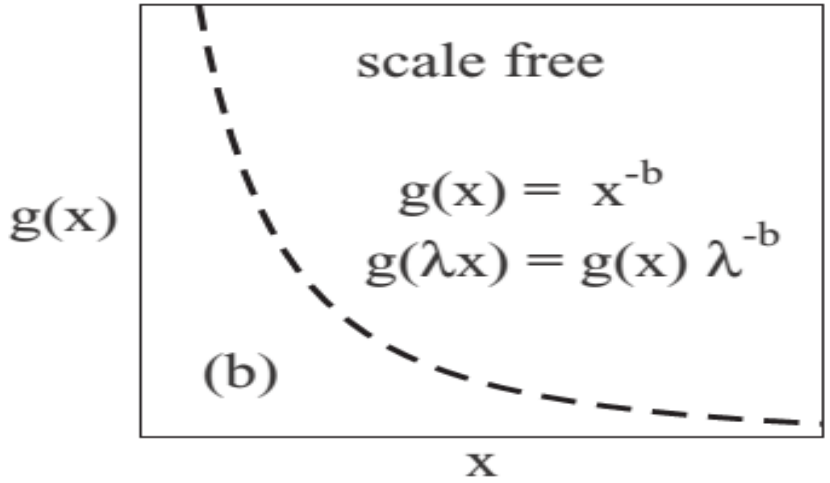
Lévy patterns



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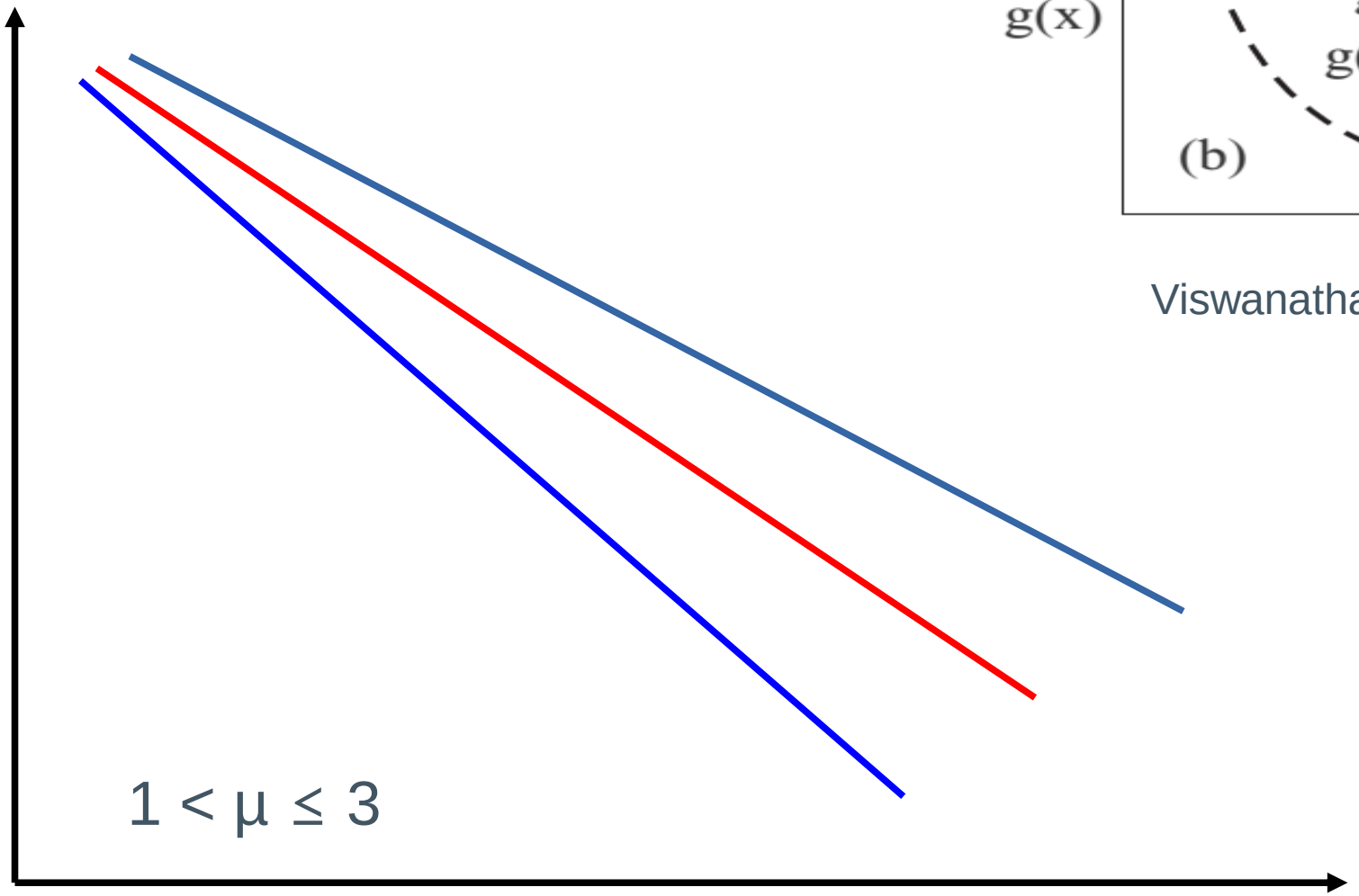

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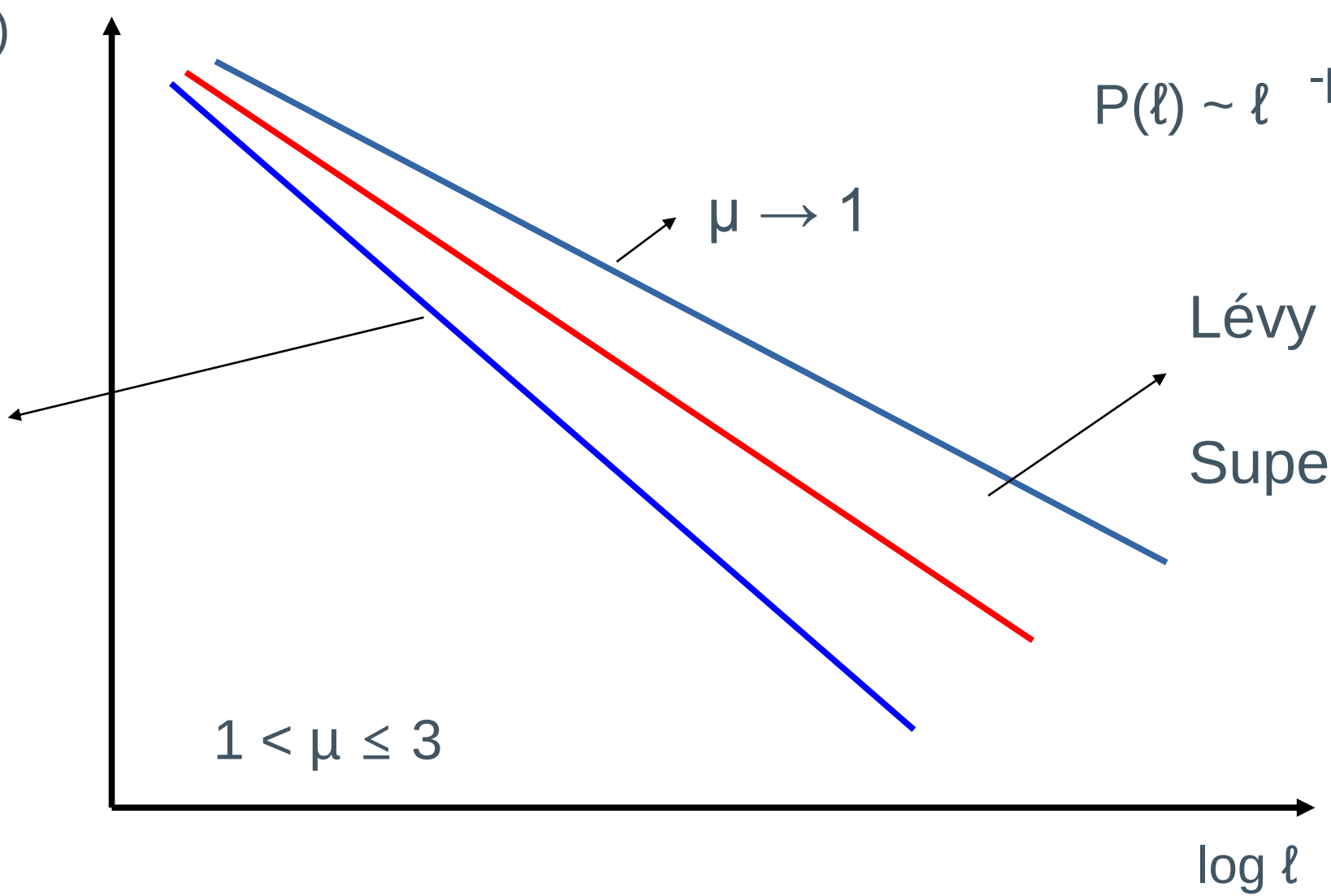
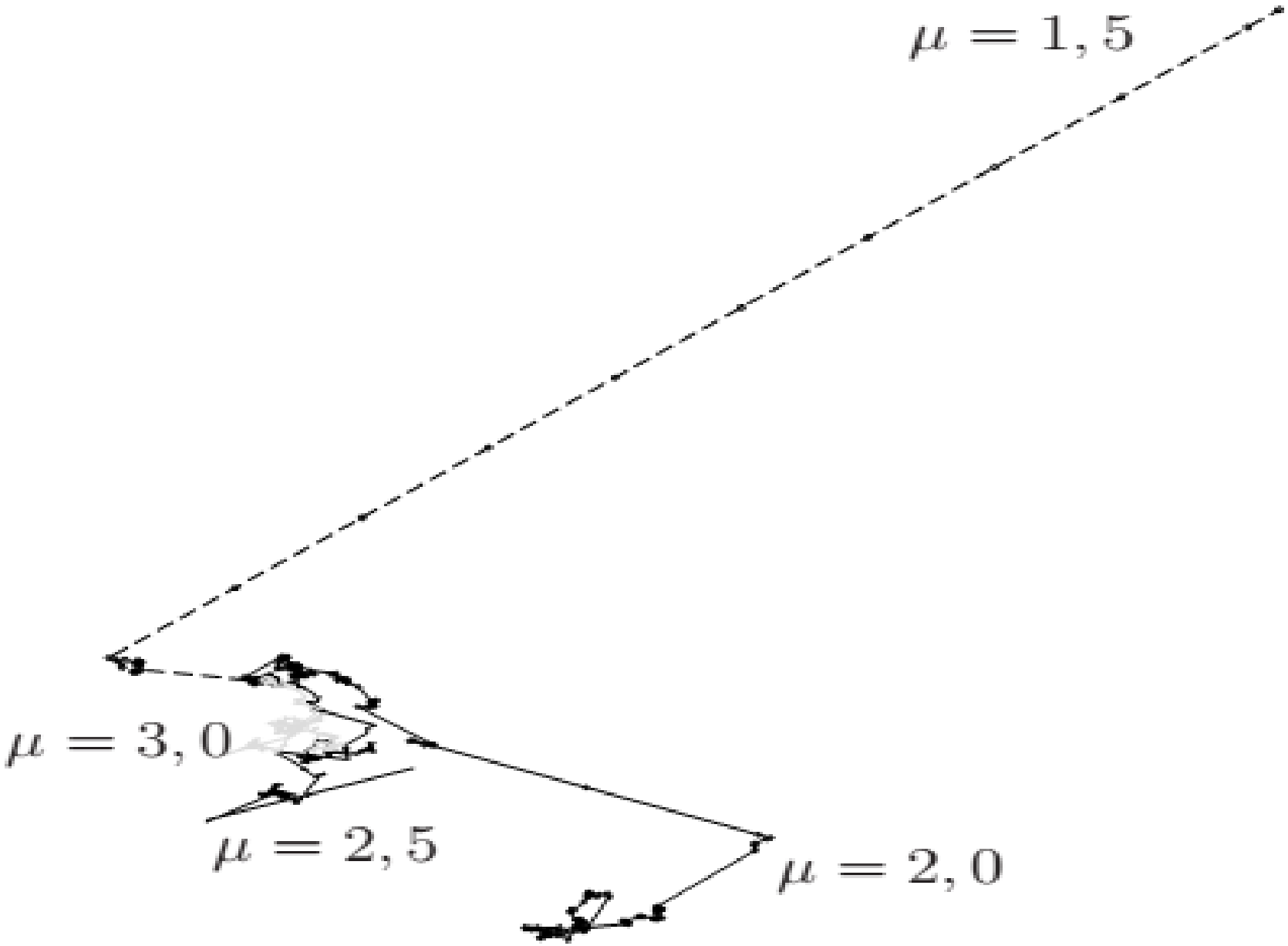
Lévy patterns



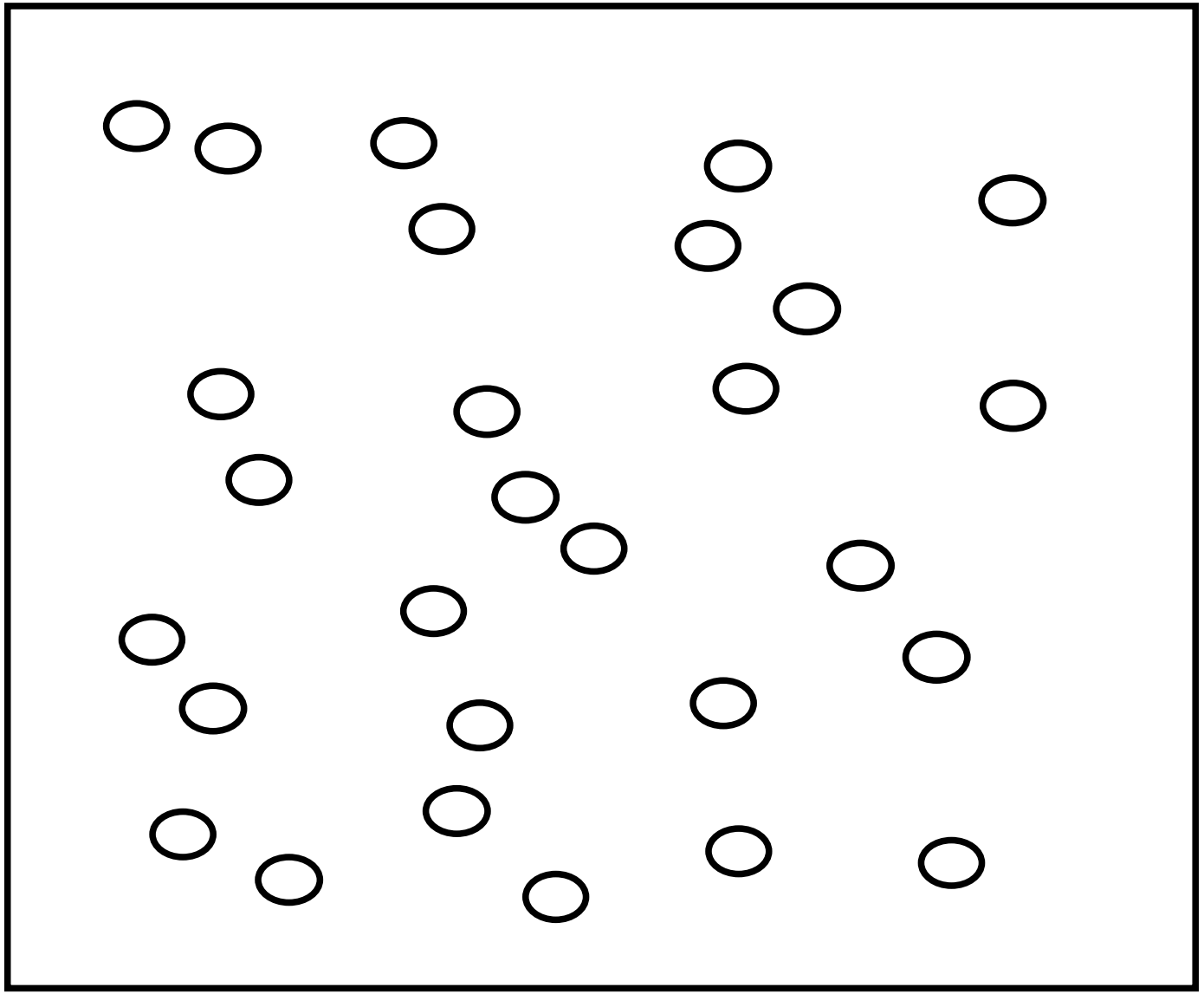

$\mu = 1,5$
$\mu = 3,0$
$\mu = 2,5$
$\mu = 2,0$

Optimizing the success of random searches

G. M. Viswanathan*†‡, Sergey V. Buldyrev*, Shlomo Havlin*§,
M. G. E. da Luz‖¶, E. P. Raposo‖# & H. Eugene Stanley*

→ Predator-prey interactions are ignored
→ Learning is minimized
→ Interaction among individuals are ignored (one individual simulated at a time)

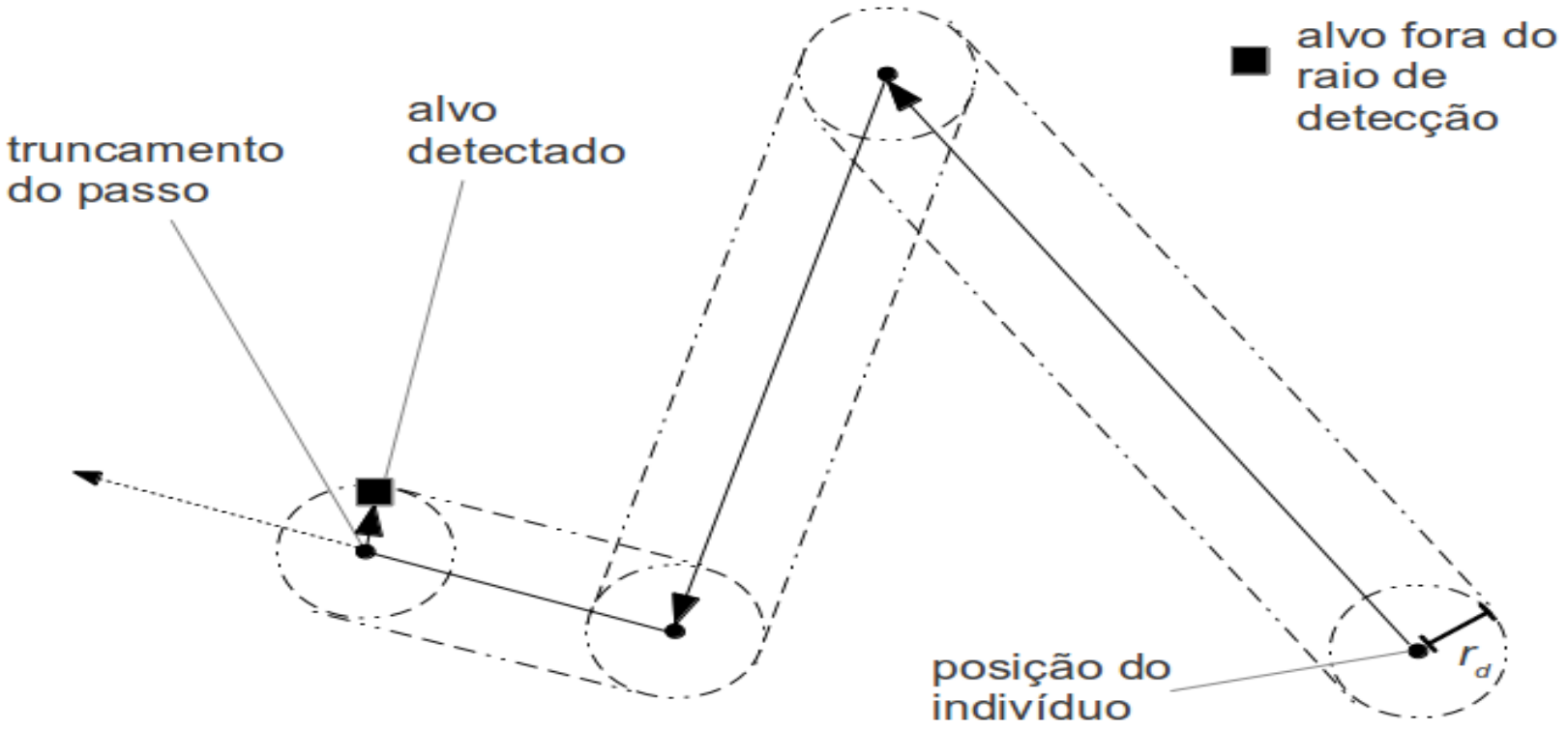
Environment:



Movement:

- radius of detection, r_d

(i) are there targets inside the radius?



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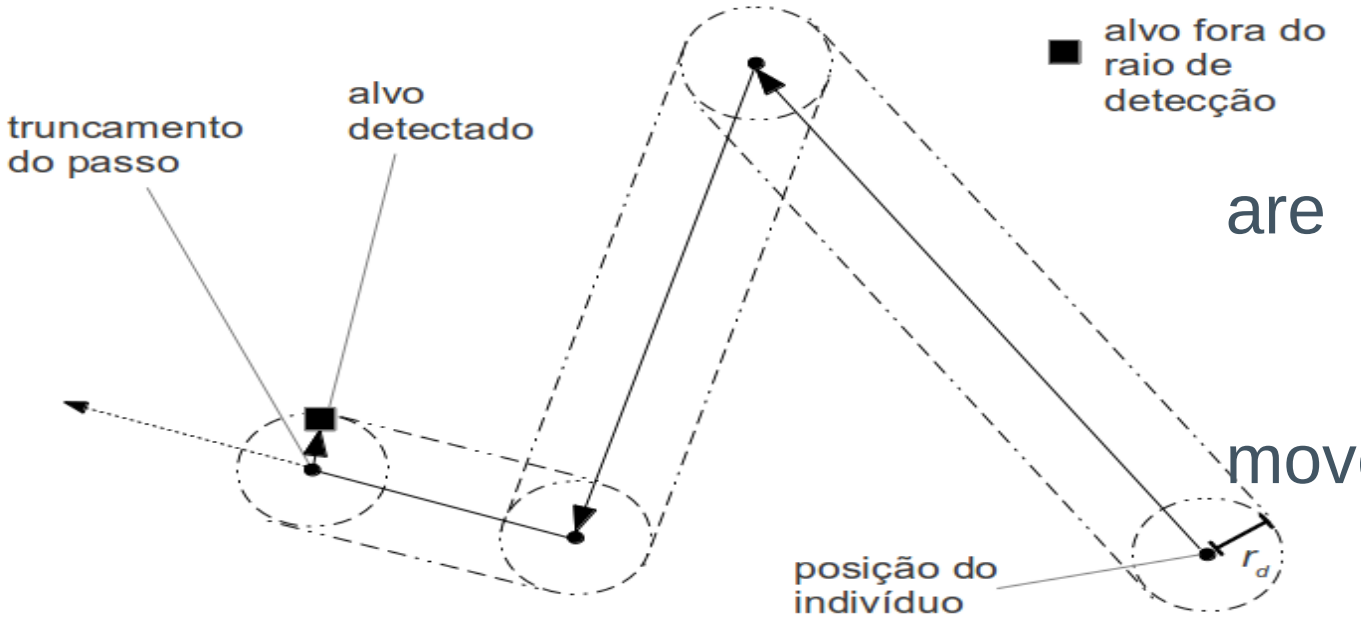
Movement:

- radius of detection, r_d

(i) are there targets inside the radius?

(ii) chose of move length and direction

(iii) if there are targets, truncate the move and go straight to them



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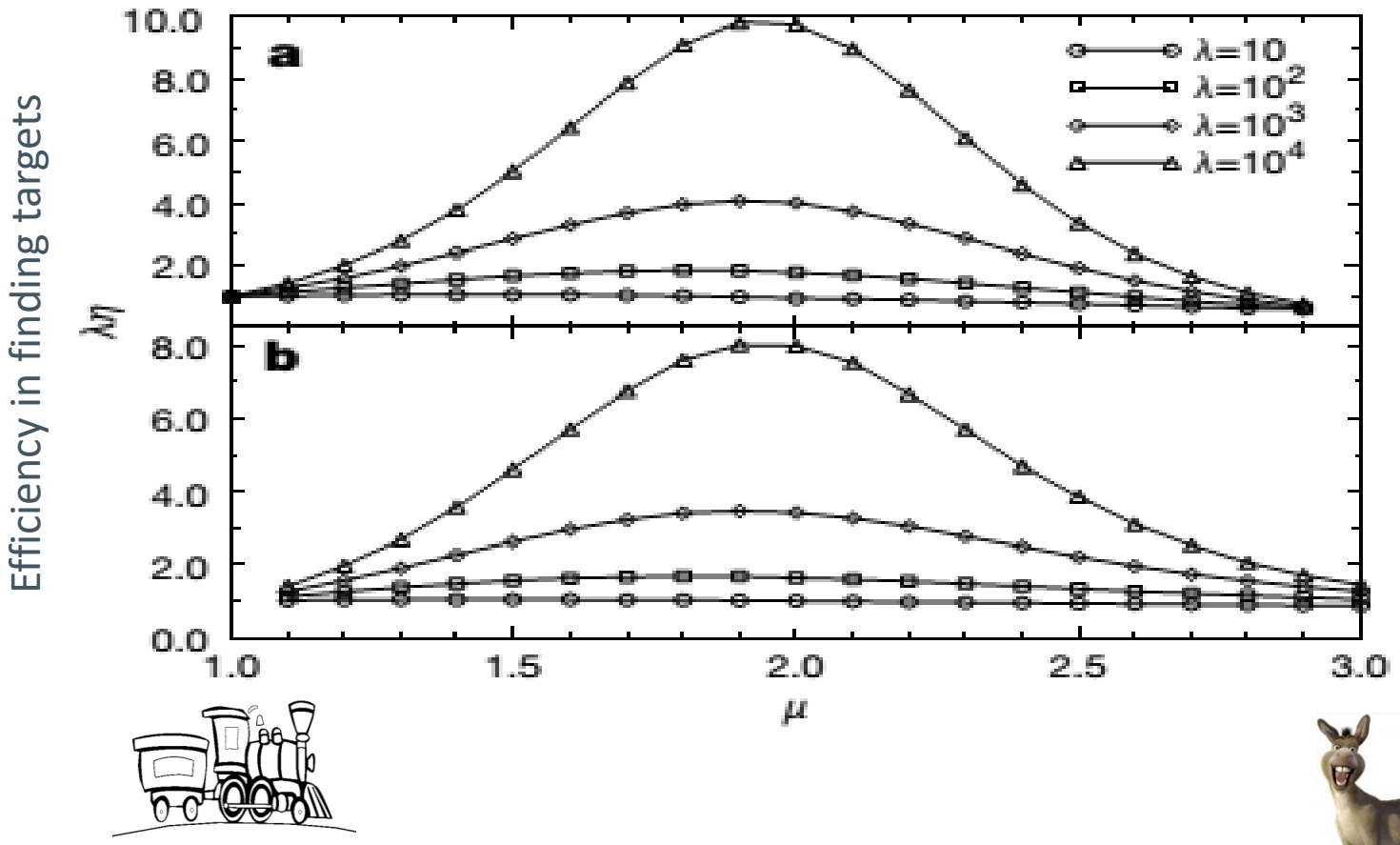
Which is the movement strategy that maximizes the search efficiency?

In each kind of enviroment?

Results:

Scarce environments:
$\mu \approx 2$

Dense environments:
$\mu \rightarrow 3$



λ = mean distance among targets

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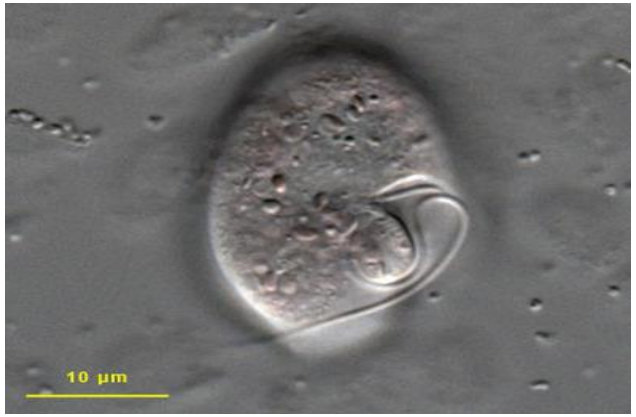
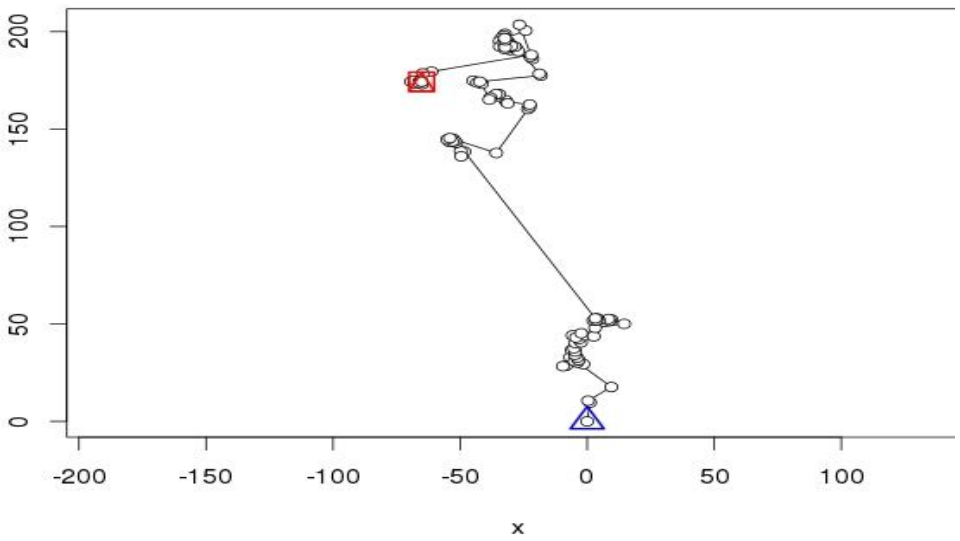


Oxyrrhis marina (Bartumeus et al., 2003)

Apis mellifera (Reynolds *et al.*, 2007a, b)

Makaira nigricans e outros predadores marinhos (Humphries et al., 2010; Sims et al., 2008, 2012; Hays et al., 2012)

Drosophila melanogaster (Reynolds e Frye, 2007)



Diomedea exulans (Humphries et al., 2012)

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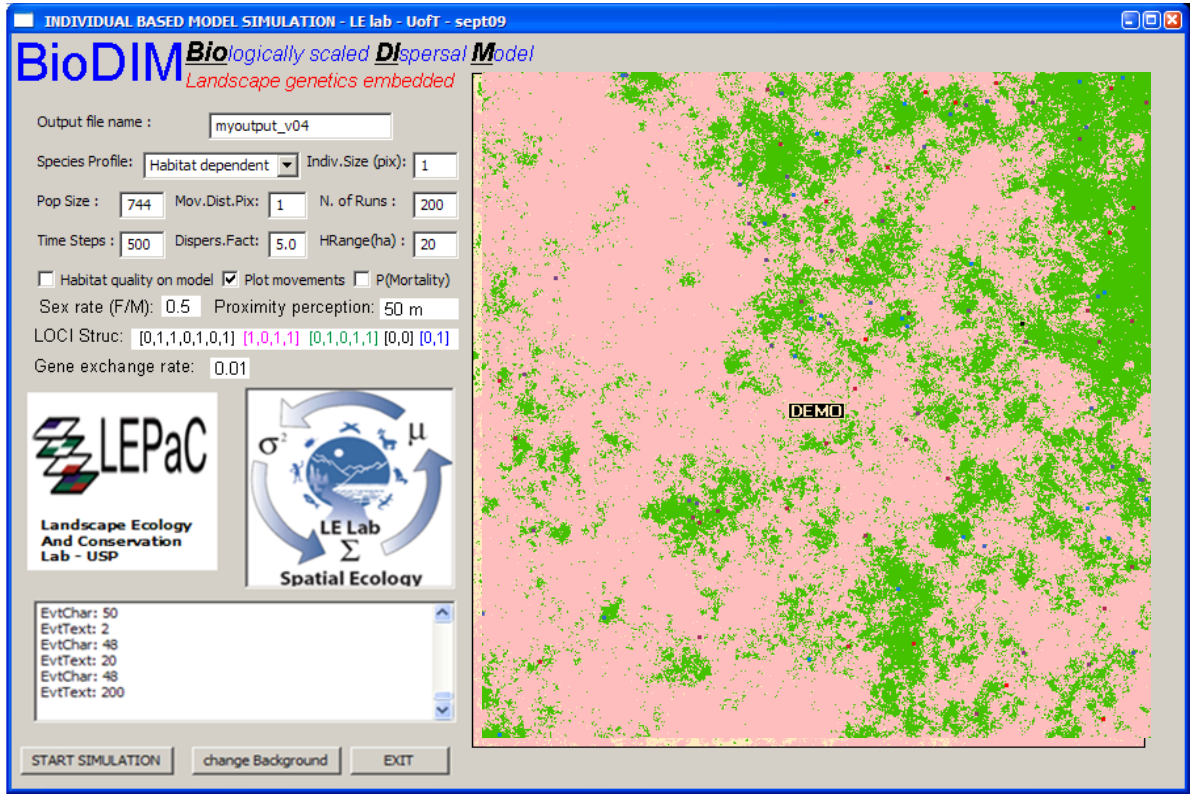
Individual-based model

BioDIM – Biologically scaled Dispersal Model



Explicit movement!

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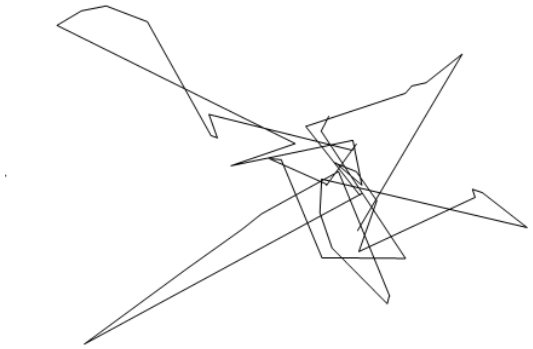
BioDIM

Movement behavior

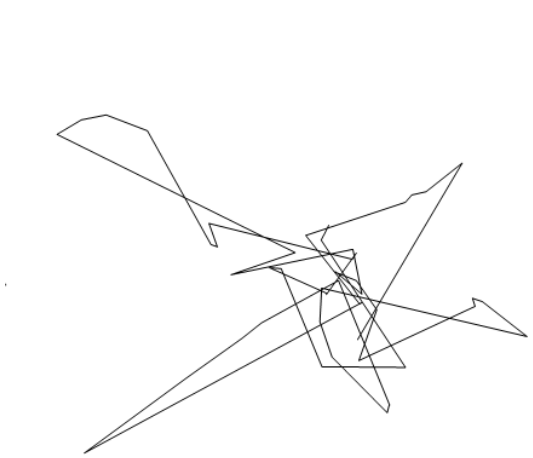


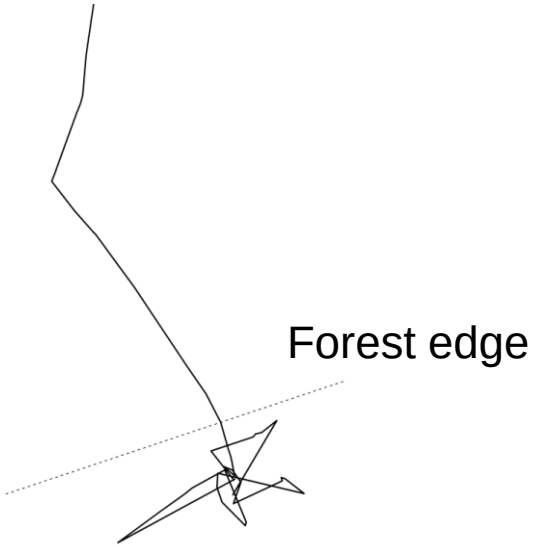
Groups

Routine movement

BioDIM

Movement behavior





Groups

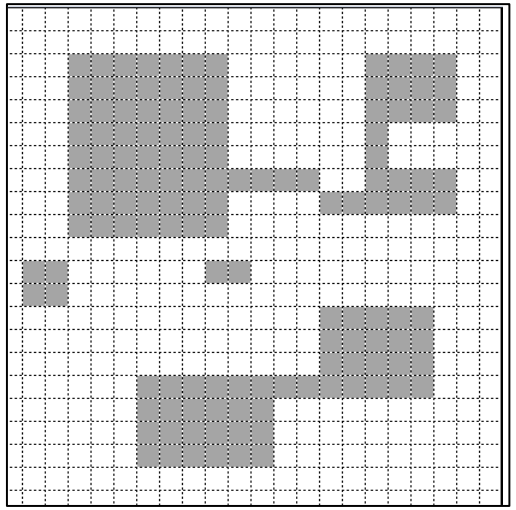
Routine movement

Individuals dispersing

Dispersal movement

BioDIM

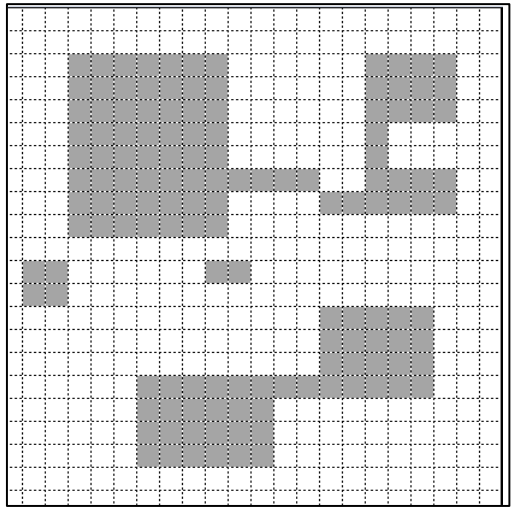
Landscape perspective



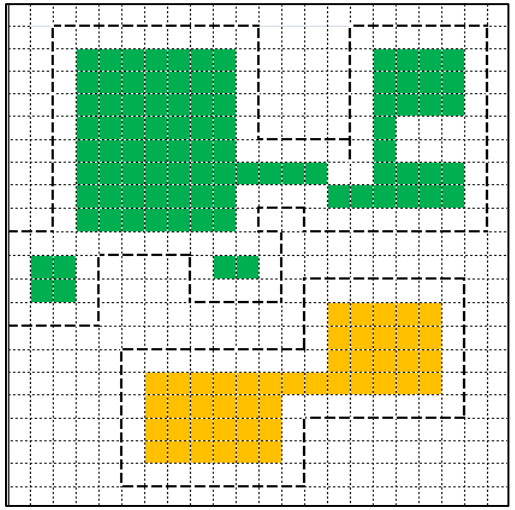
Binary landscape

BioDIM

Landscape perspective



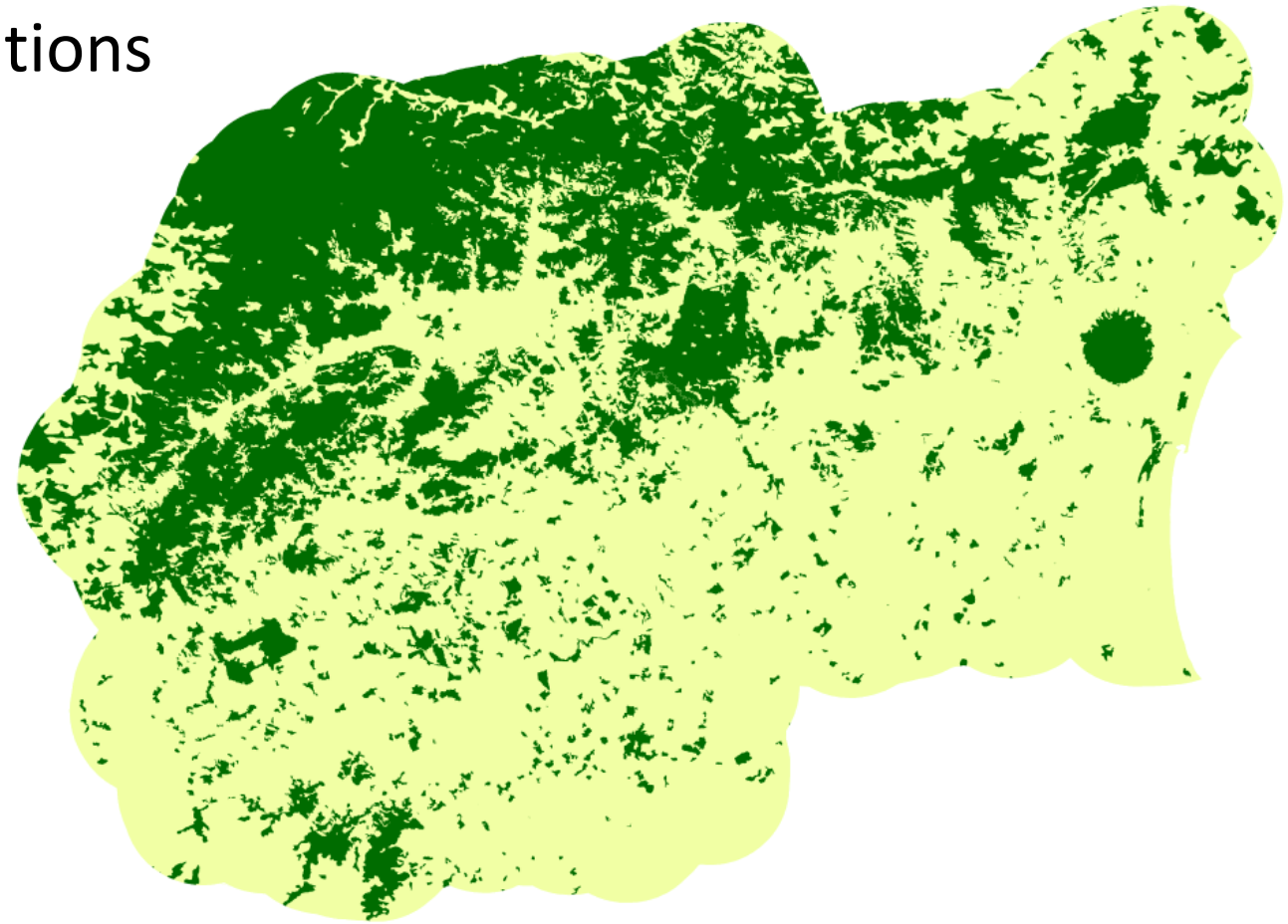
Binary landscape



Golden lion tamarins can cross ~100m in matrix

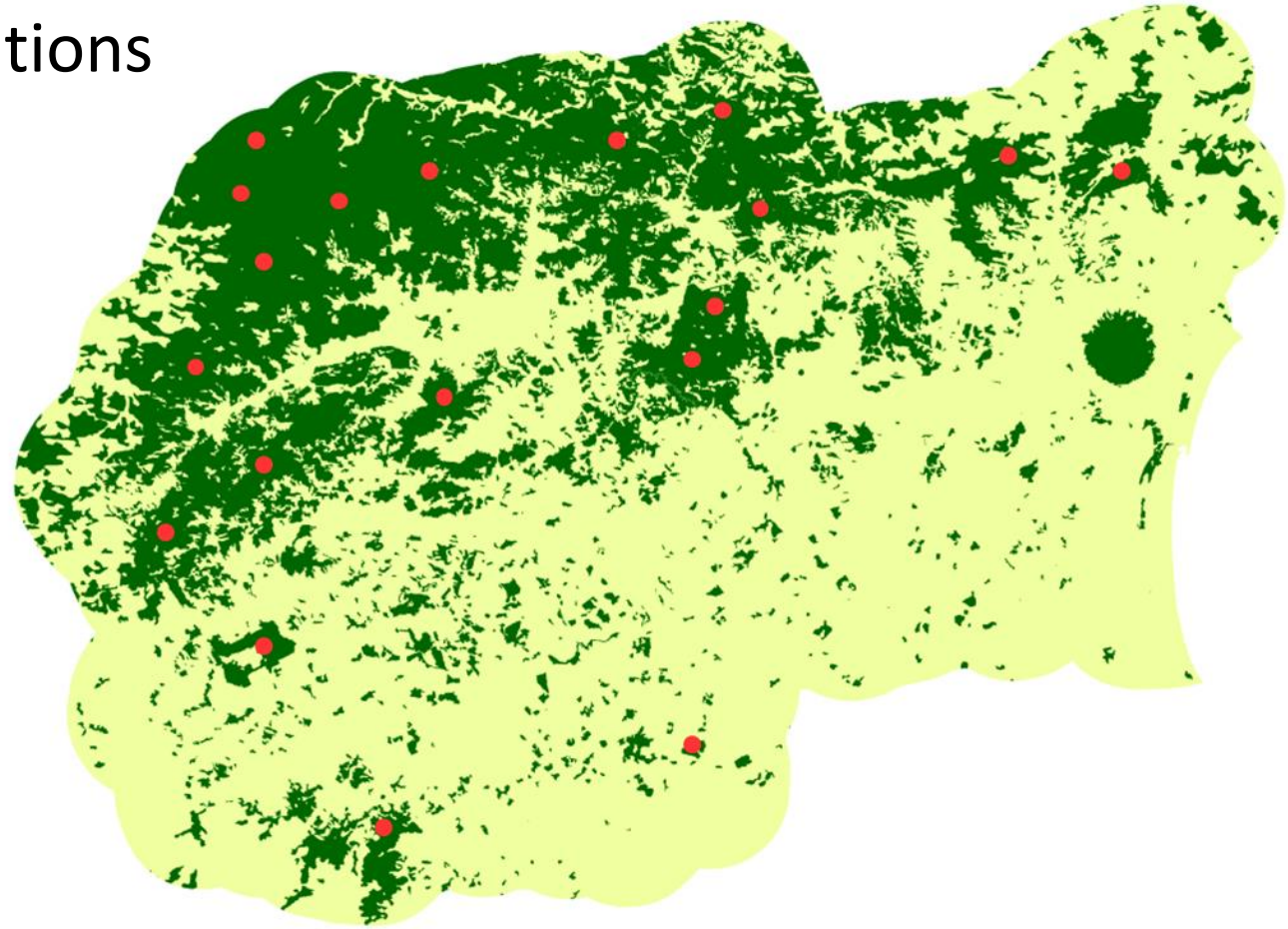
BioDIM

Initial conditions



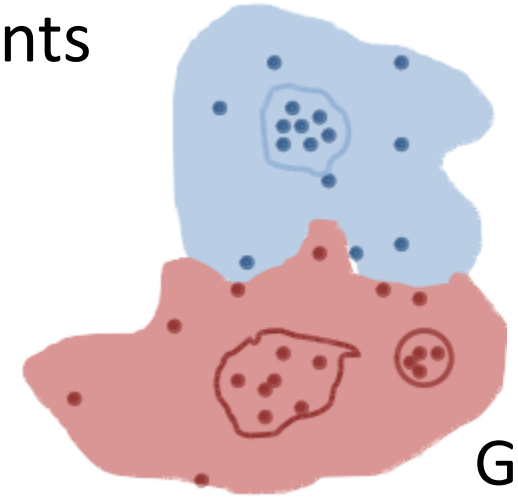
BioDIM

Initial conditions



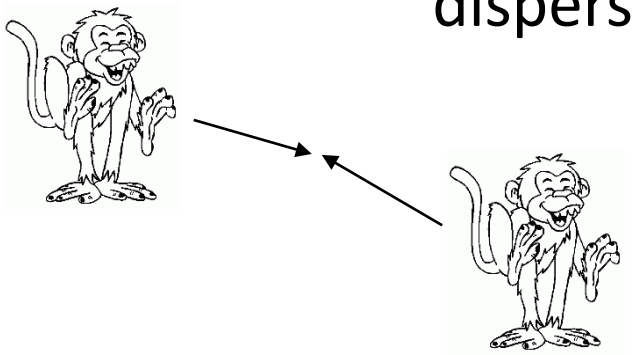
BioDIM

Interaction among agents



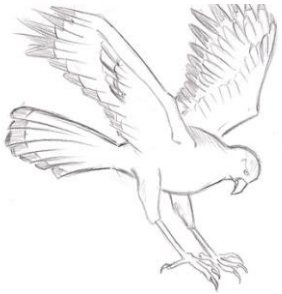
Group

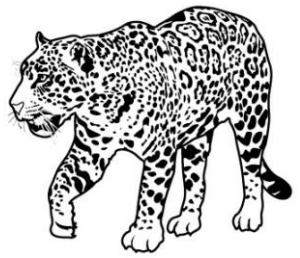
Individuals dispersing



Reproduction

Mortality





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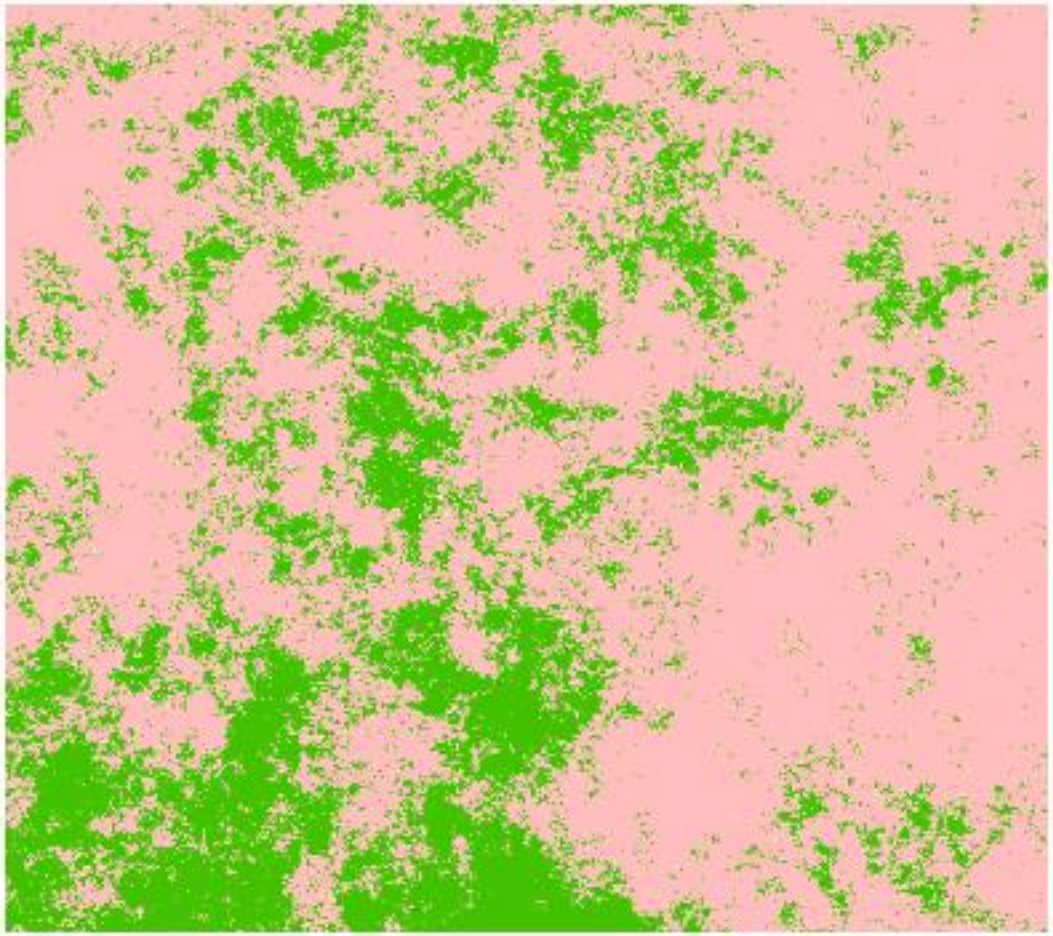
BioDIM



Simulation
Step: 1 week

10 years
of simulation

Which
fragments are
connected?

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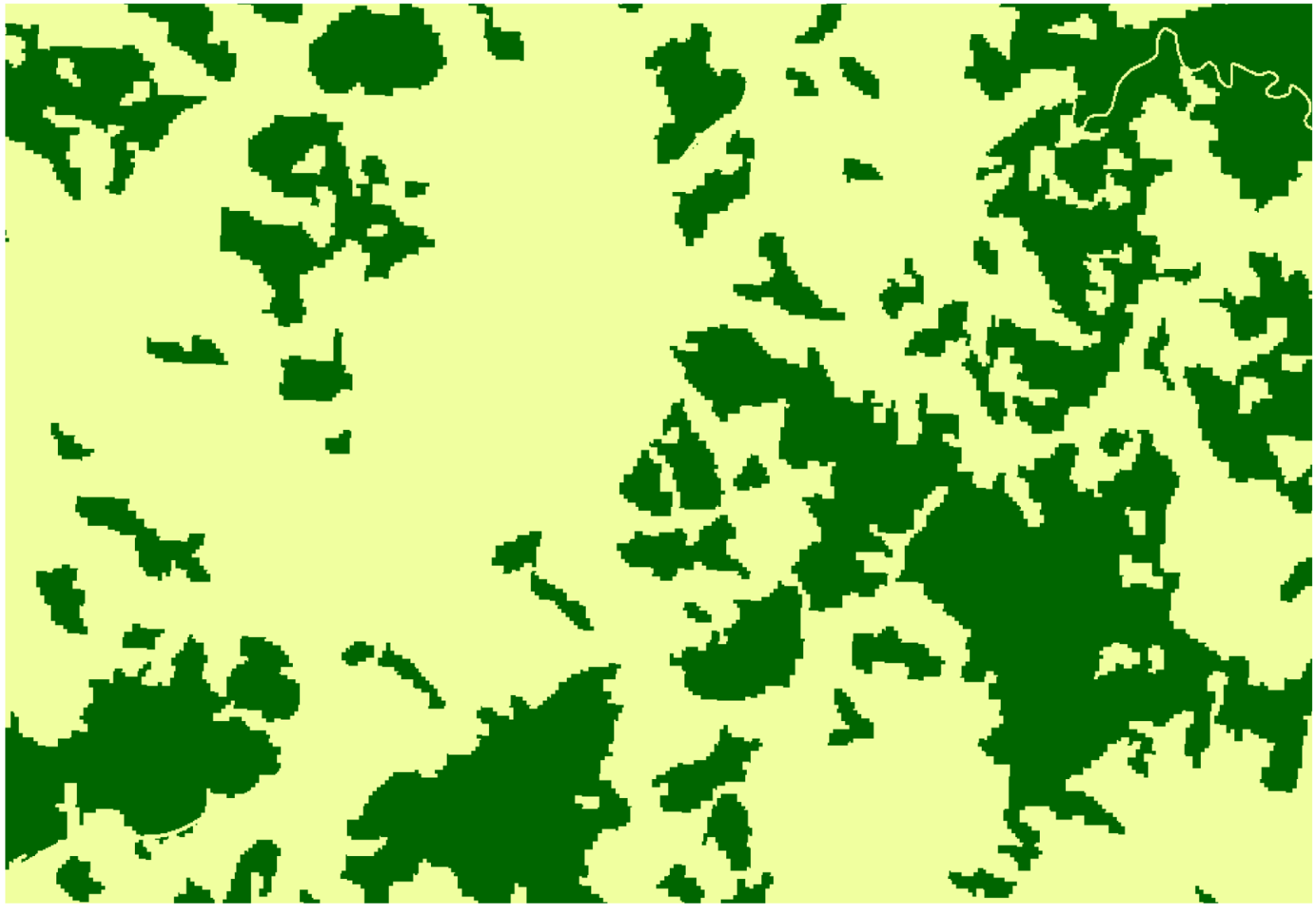

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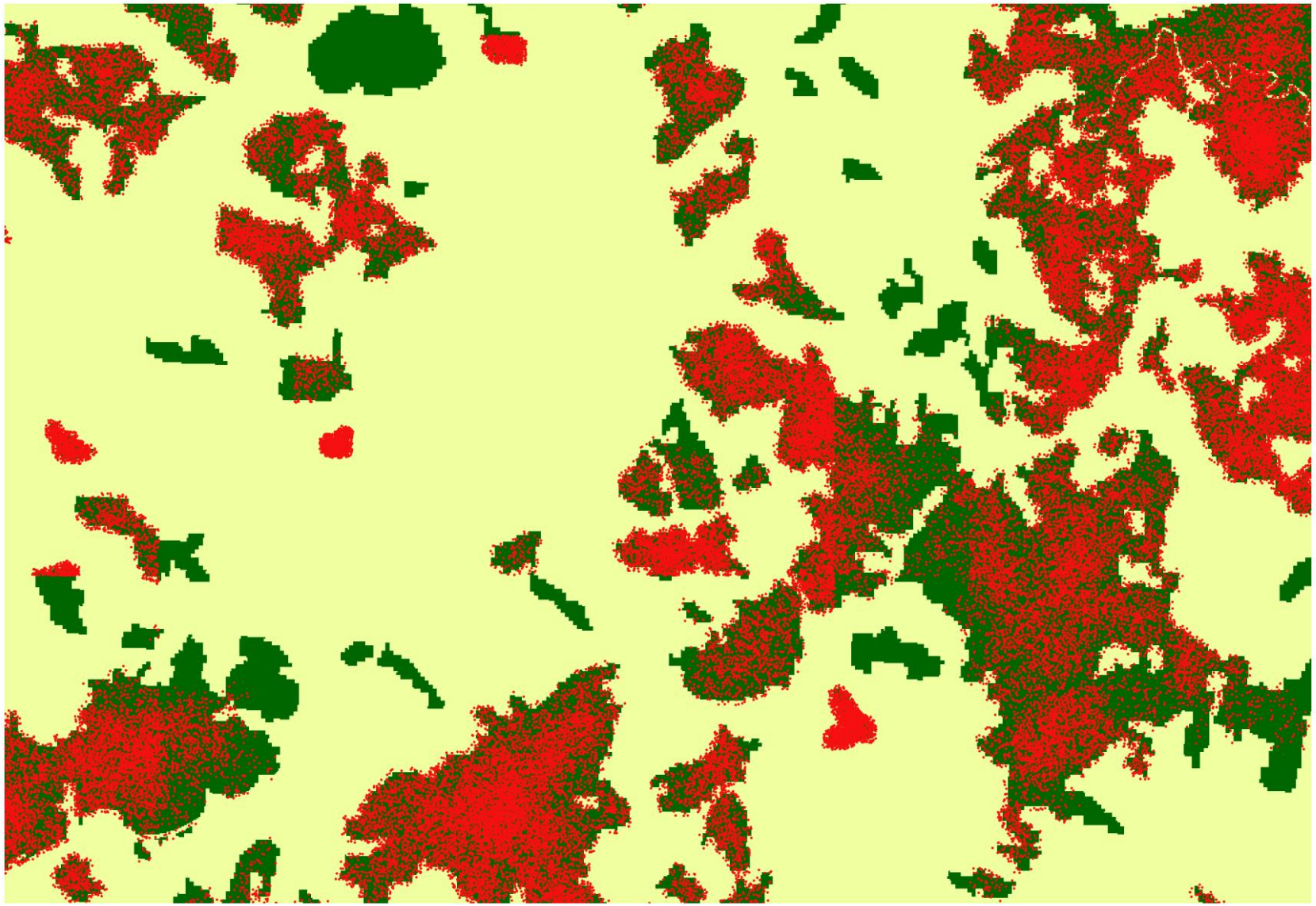
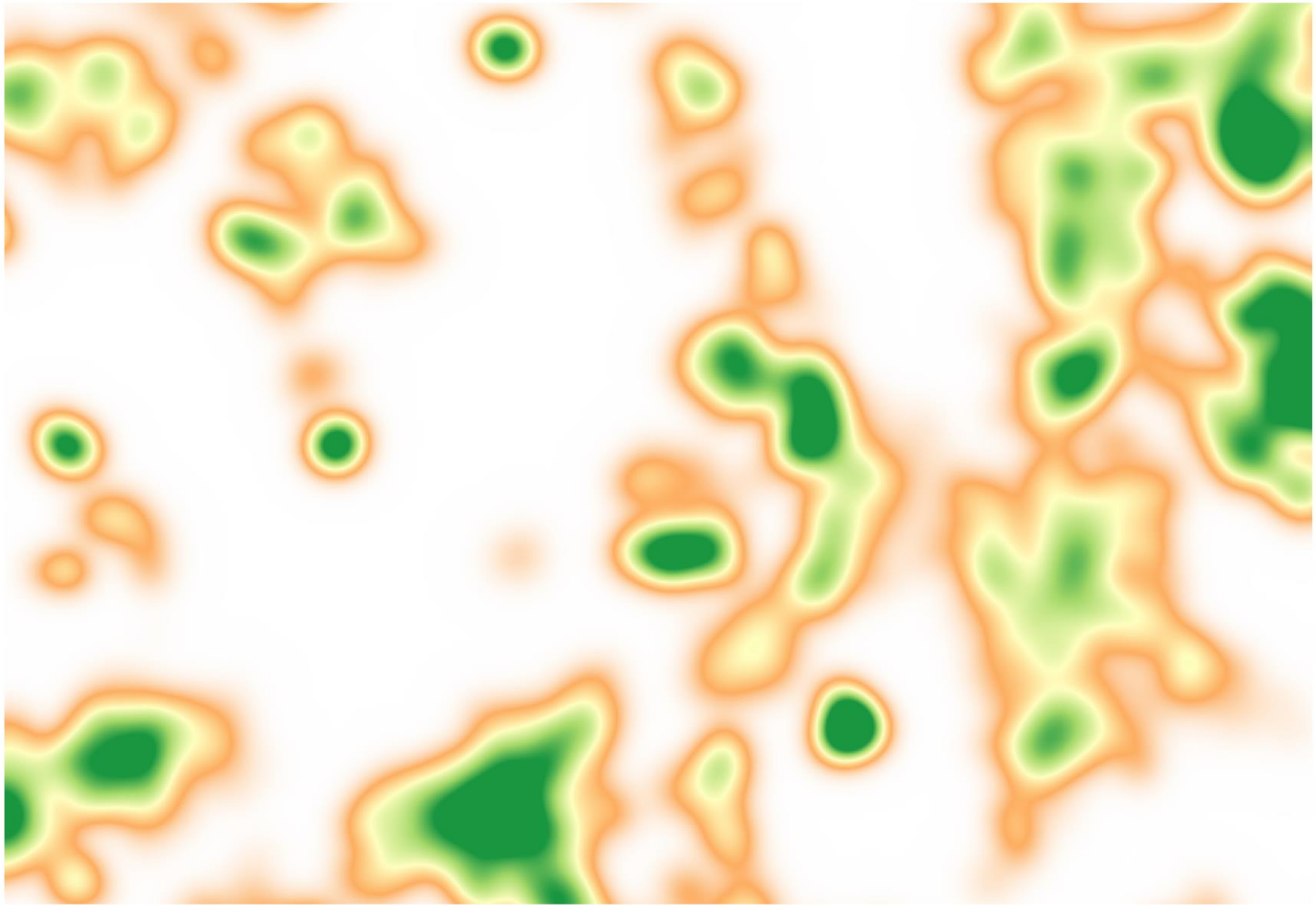
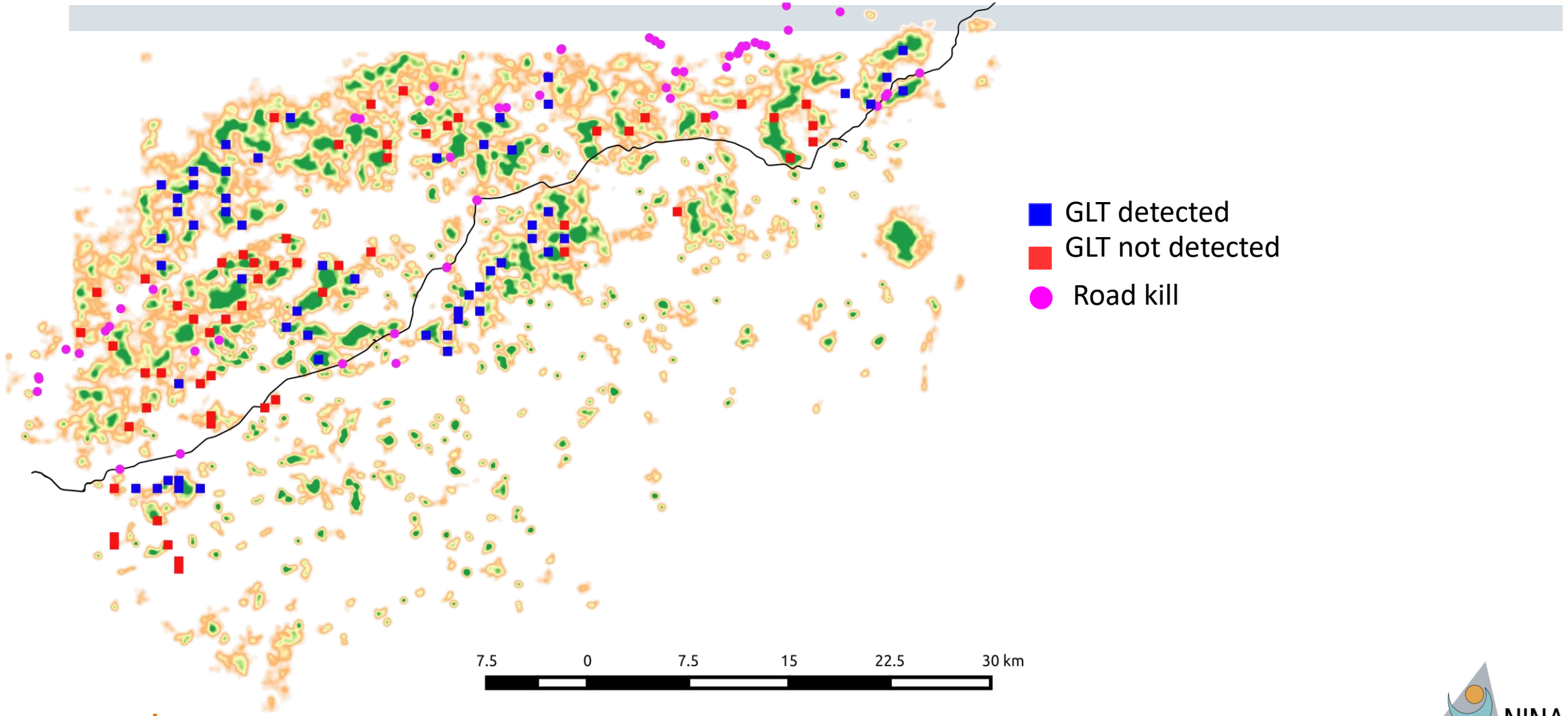
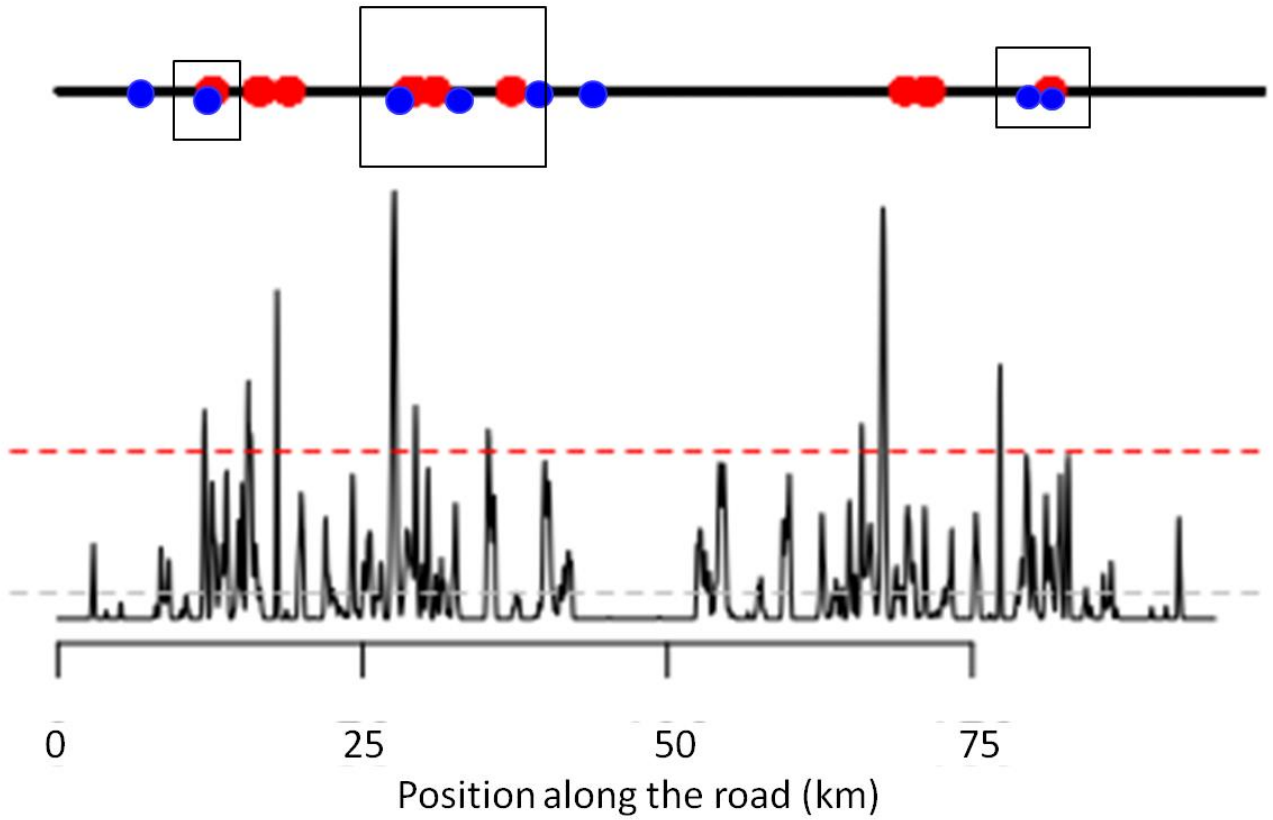





GLT detected
GLT not detected
Road kill
7.5
0
7.5
15
22.5
30 km

Movement simulation



- Real data
- Modeled data

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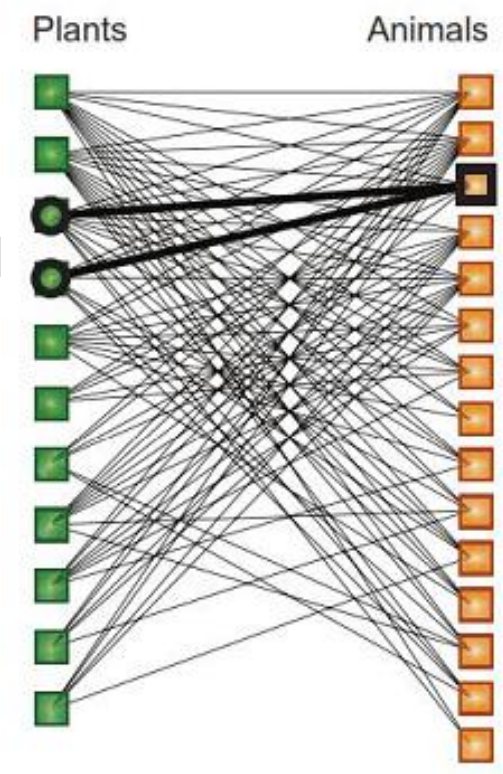

Bascompte & Jordano 2007
Ann. Rev. Ecol. Evol.

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UNIVERSIDADE FEDERAL DO PARANÁ

Laboratory of Plant Ecology

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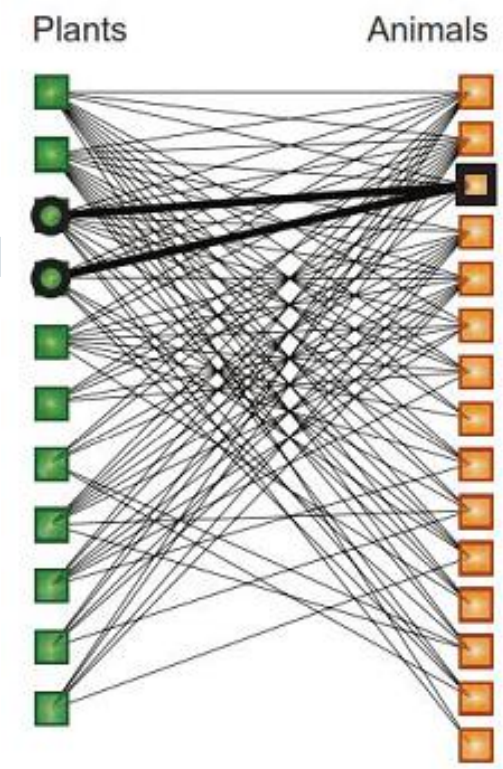

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Laboratory of Plant Ecology

The effect of space in plant–animal mutualistic networks: insights from a simulation study

Juan M. Morales and Diego P. Vázquez

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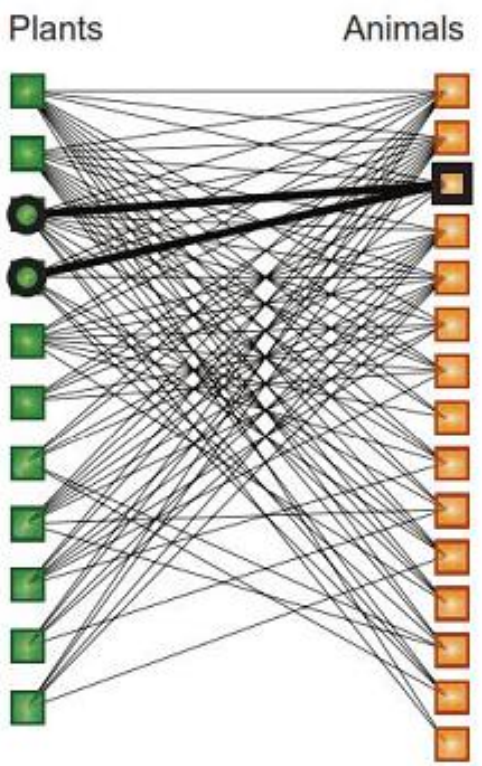
Space

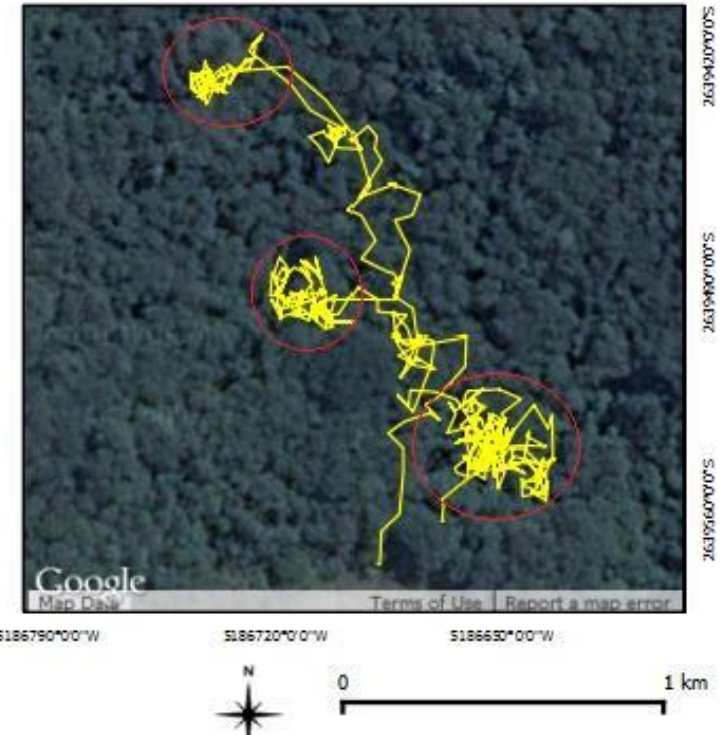
Movement



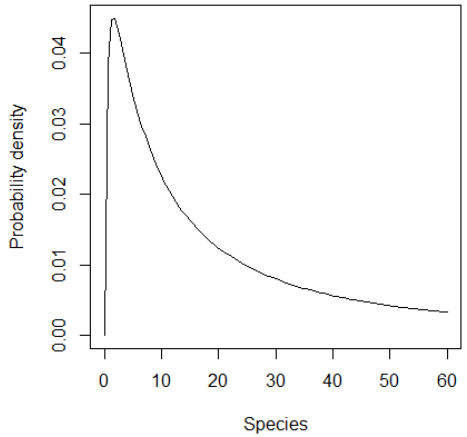
Bascompte & Jordano 2007
Ann. Rev. Ecol. Evol.

Space

Animal behavior



Abundance distribution



Morales & Carlo 2006 Ecology
Morales & Vázquez 2008 Oikos

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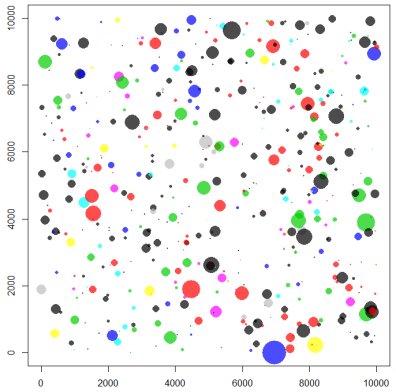
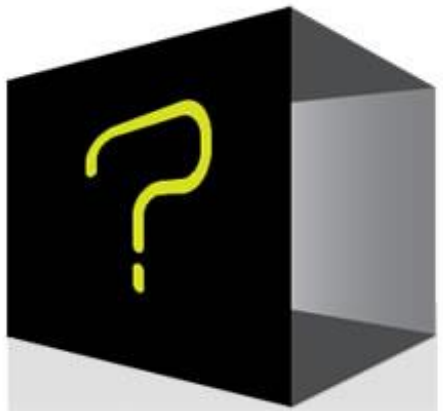


Landscape



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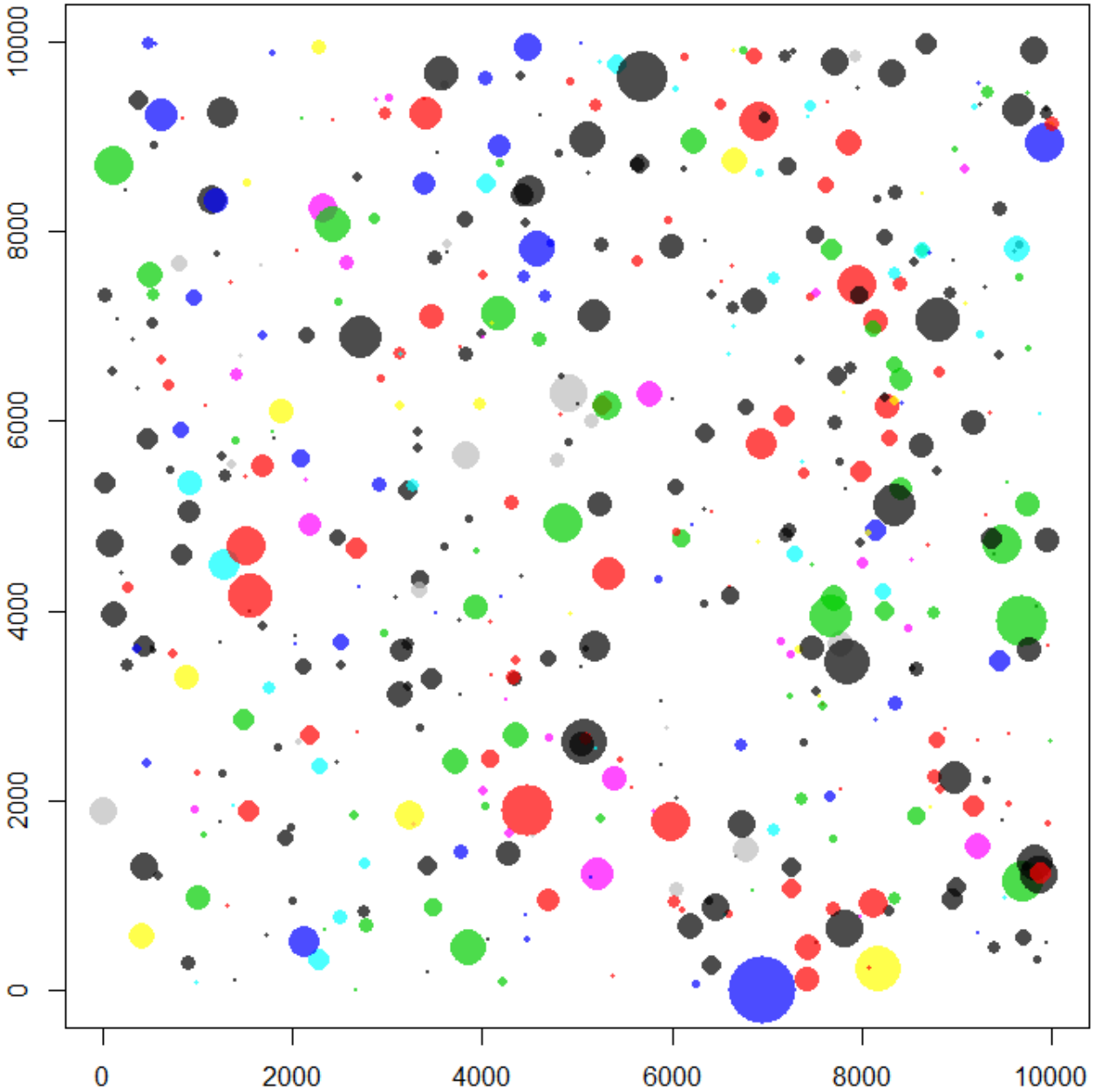

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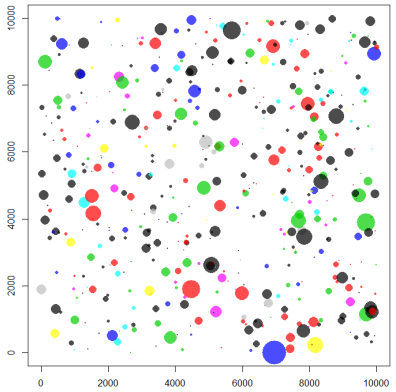

Landscape

Individuals/agents

Movement
Behavior
Biology

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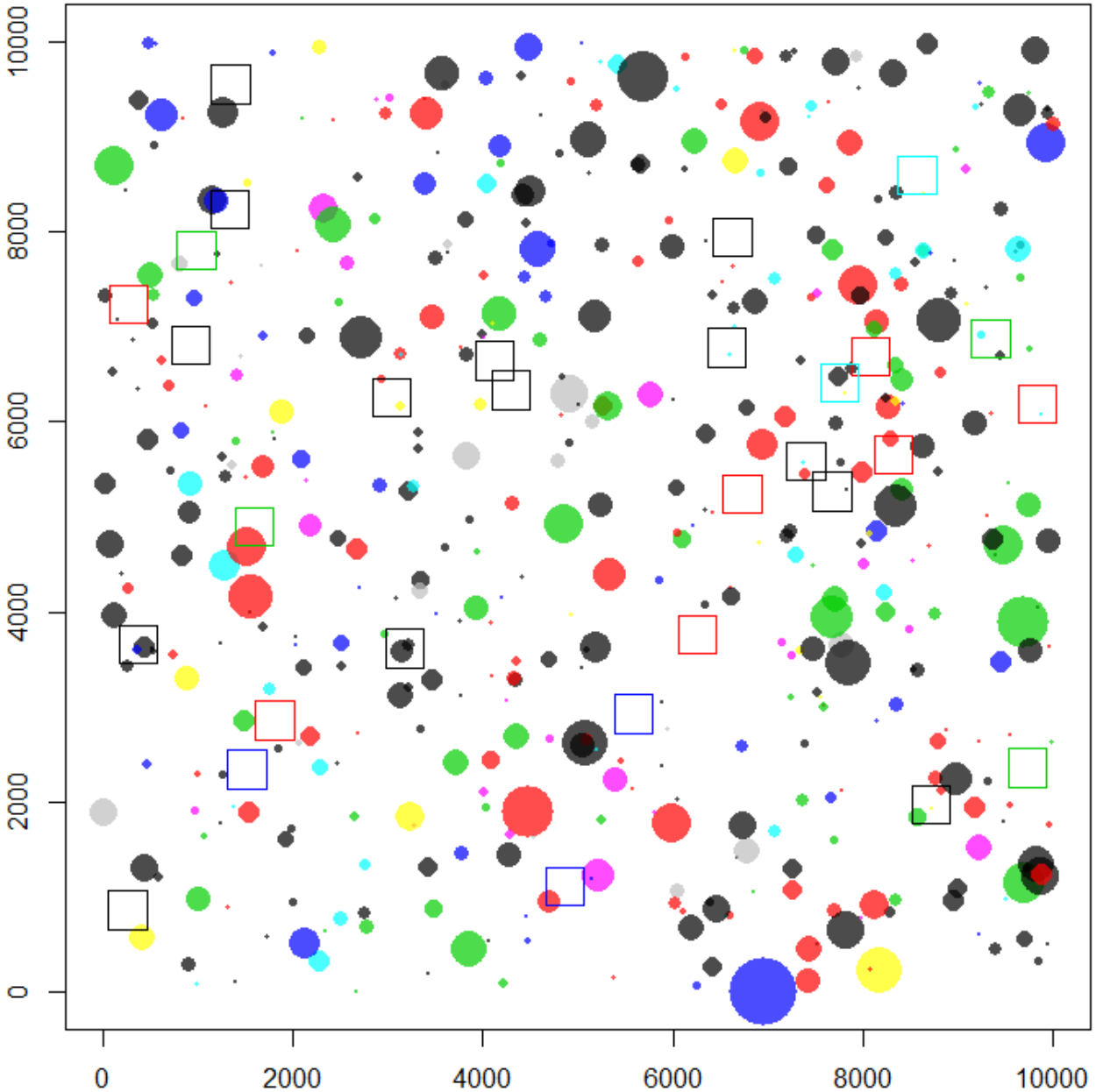

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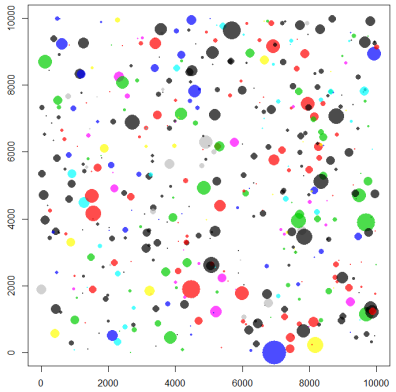

Landscape

Individuals/agents

Movement
Behavior
Biology

Movement
Frugivory
Seed dispersal

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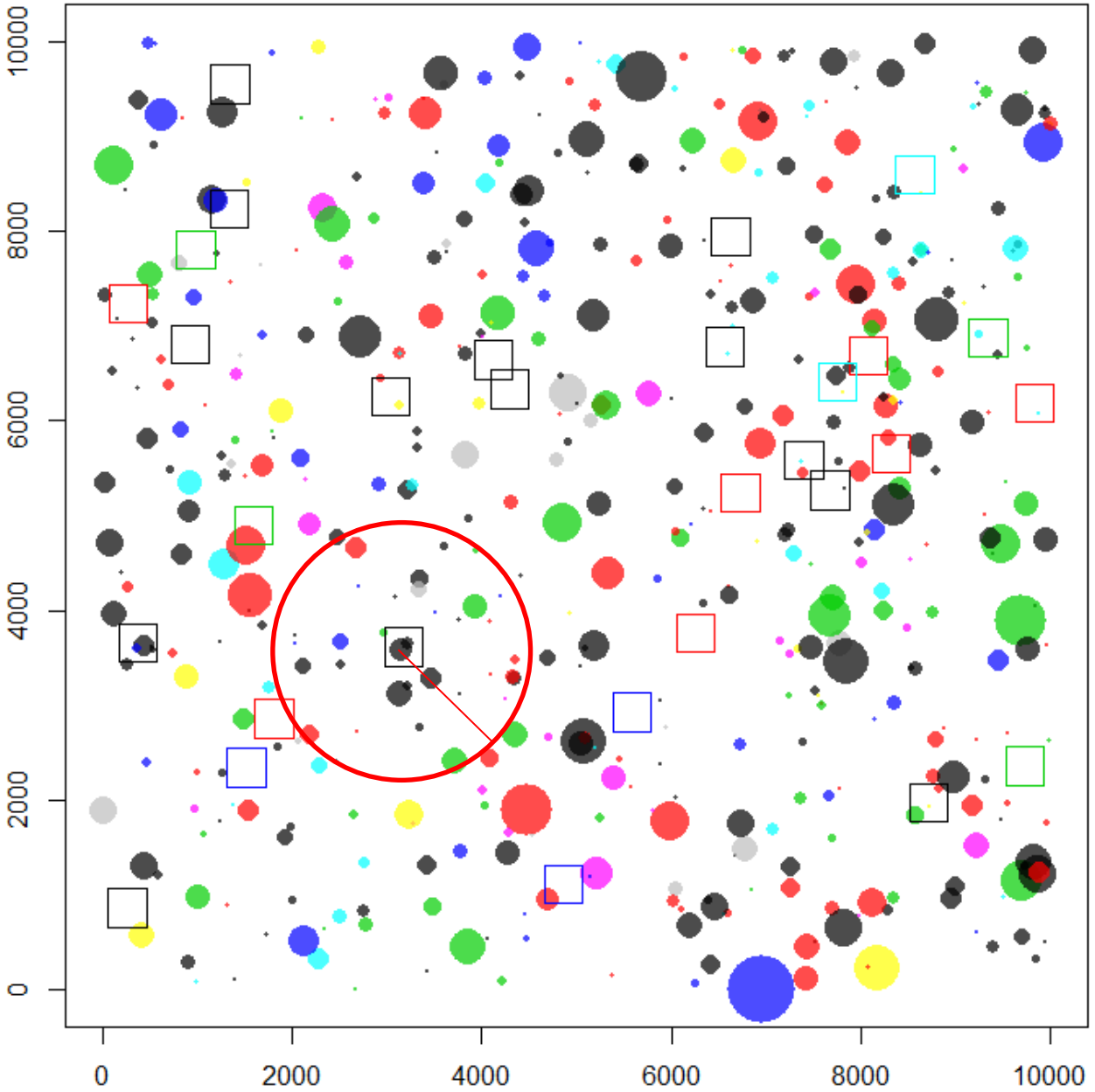

- Decision scale
- Fruit consumption
- Time stopped
- Gut retention time
- Foraging: 5 h/day
- Fruit regrowth

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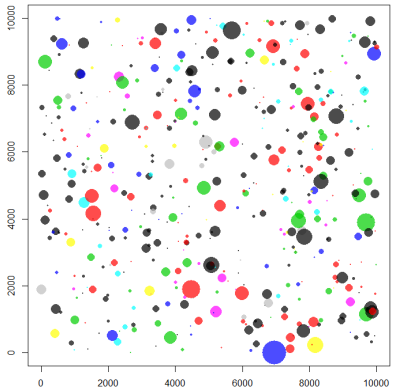

Landscape

Individuals/agents

Movement
Behavior
Biology

Movement
Frugivory
Seed dispersal

Frugivory process
Reconstruction of interaction networks

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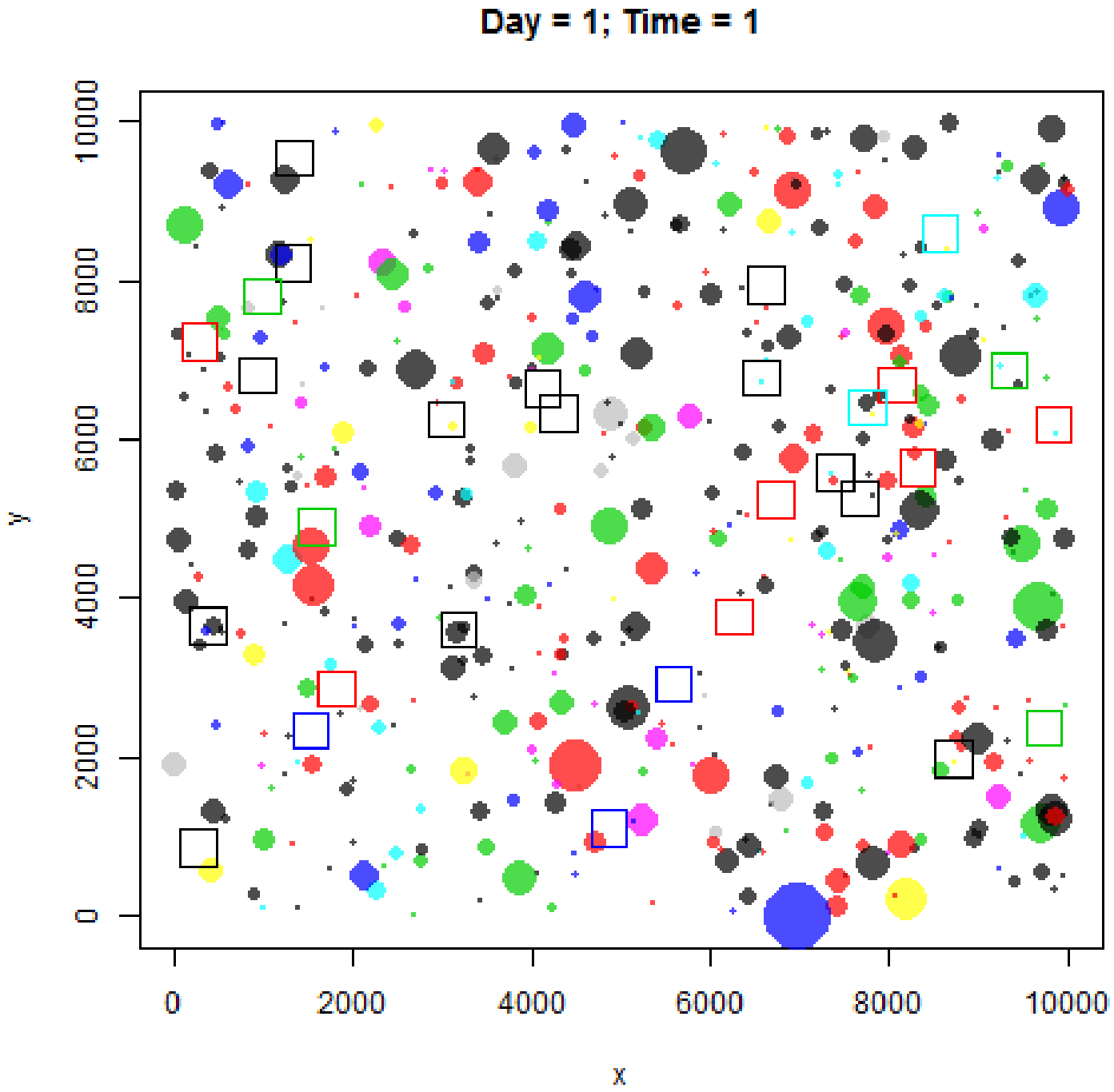

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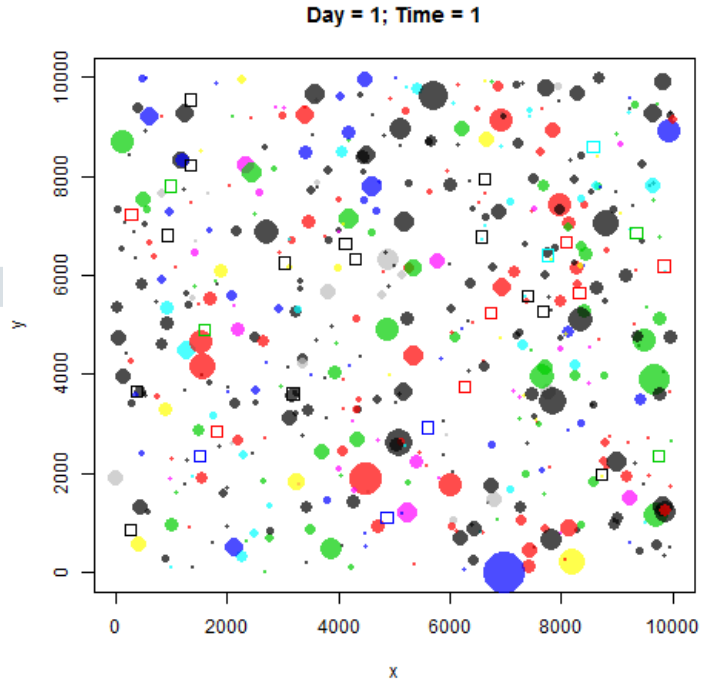
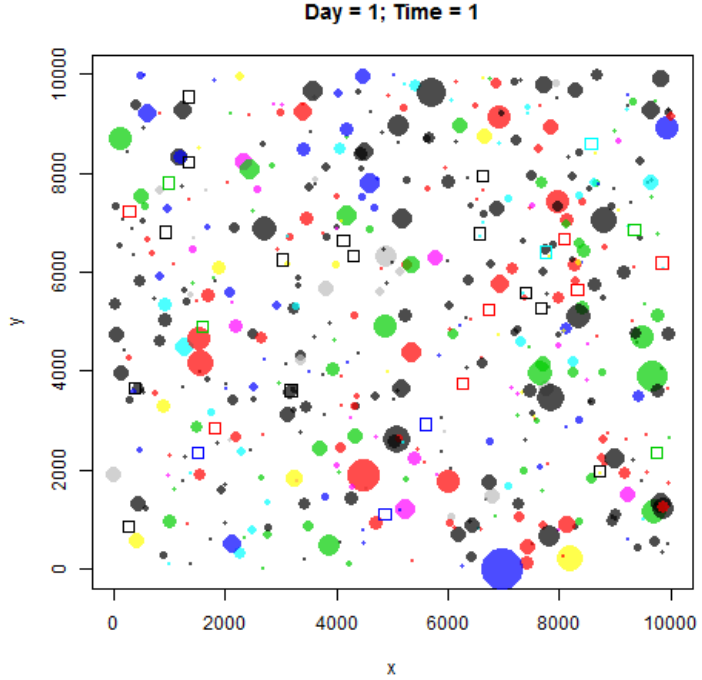
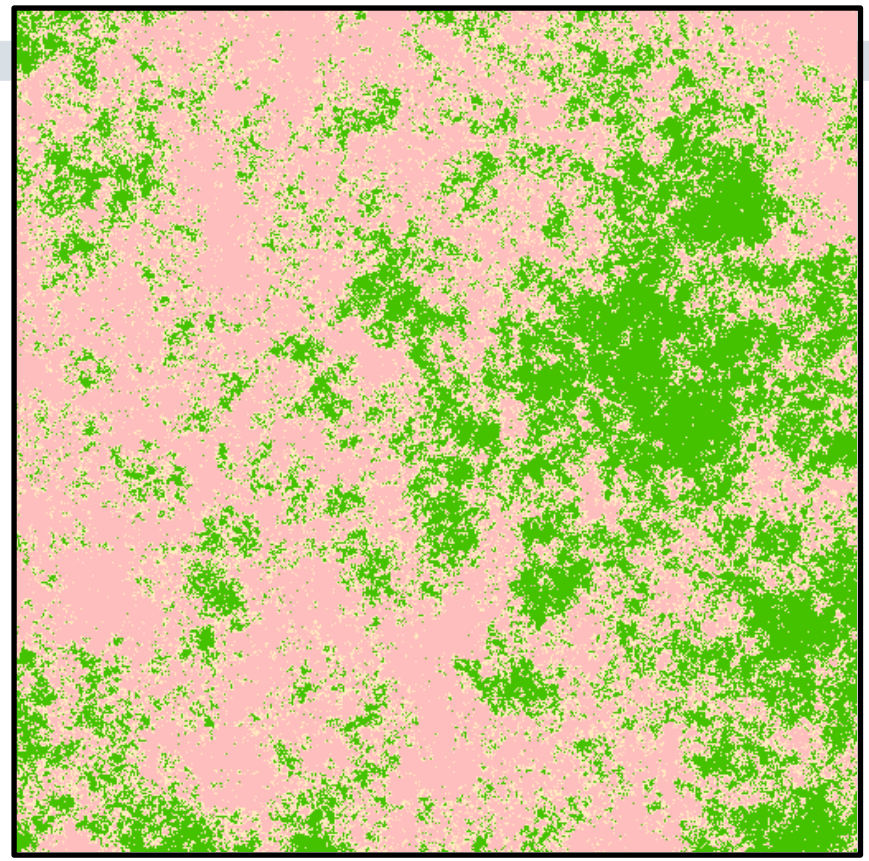

Day = 1; Time = 1
y
x
0
2000
4000
6000
8000
10000





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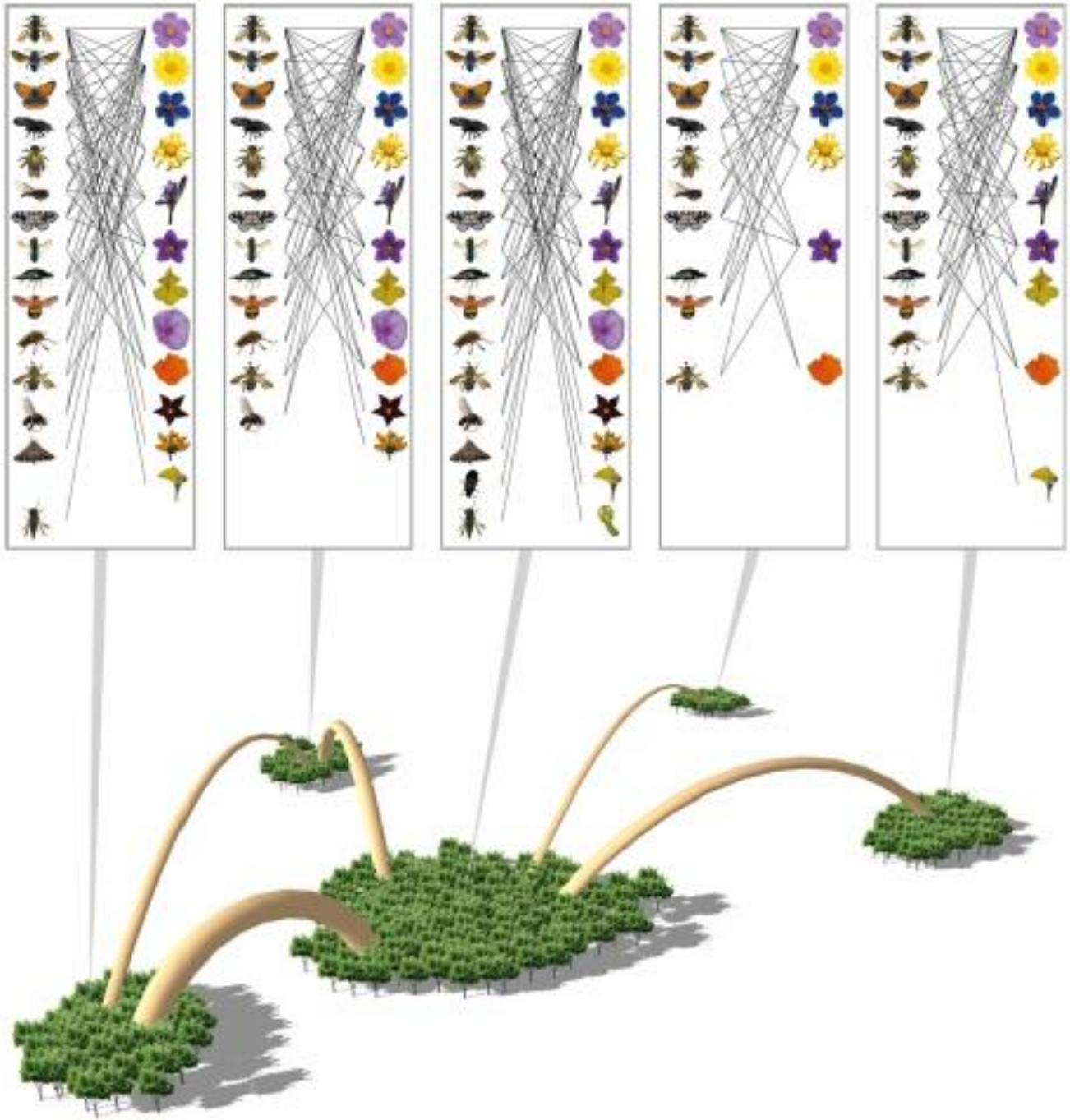

Hagen et al. 2012
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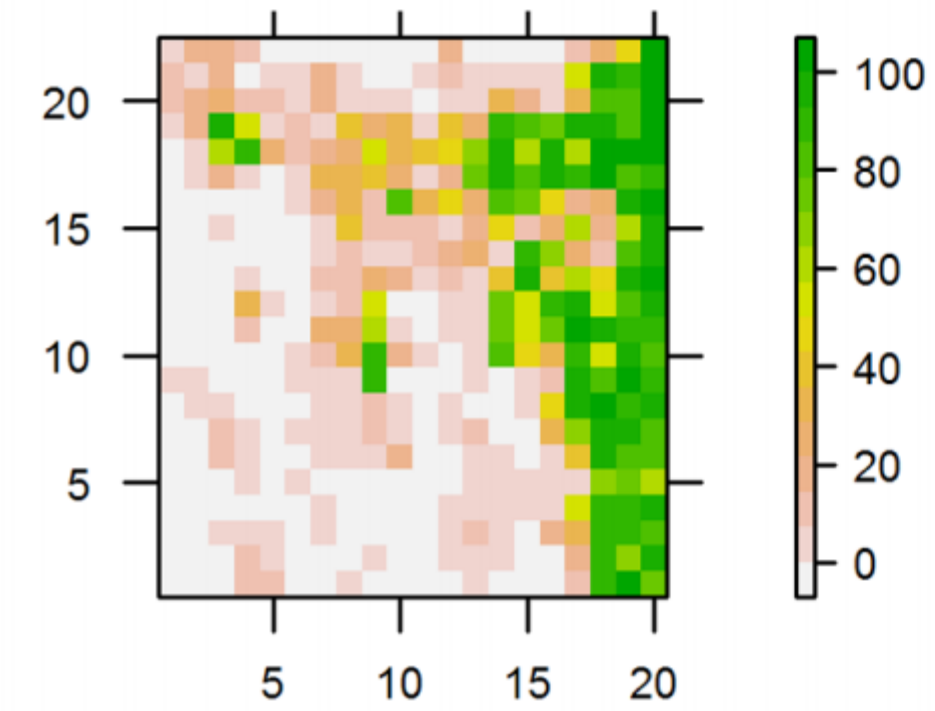
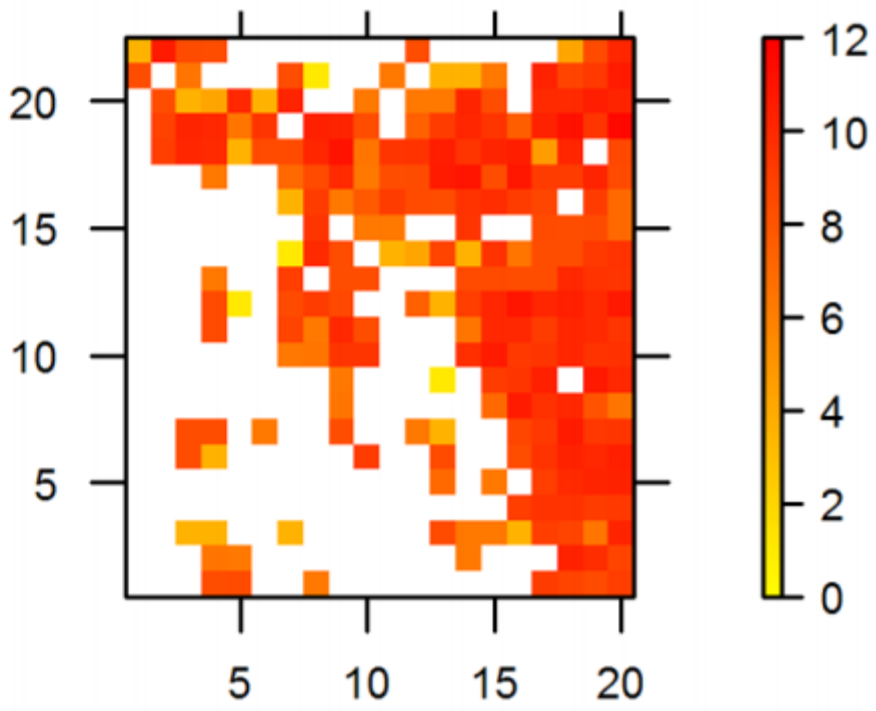
Frugivore Behavioural Details Matter for Seed Dispersal: A Multi-Species Model for Cantabrian Thrushes and Trees

Juan Manuel Morales[1]*, Daniel García[2], Daniel Martínez[2], Javier Rodriguez-Pérez[2], José Manuel Herrera[2¤]





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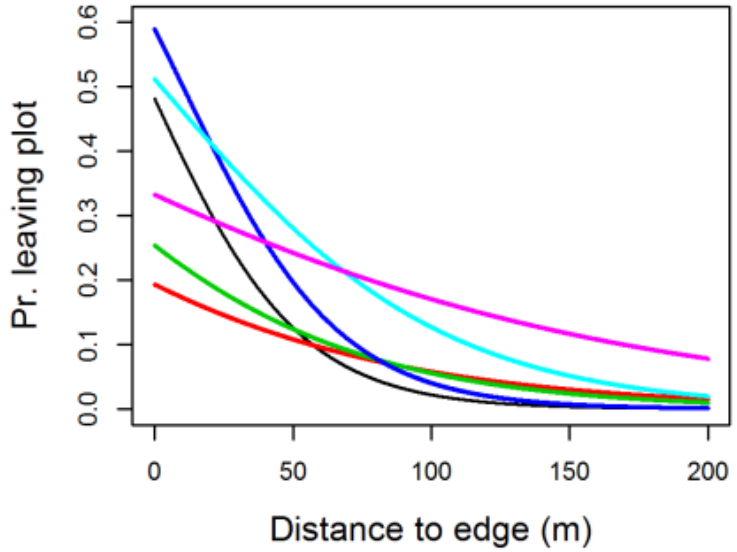

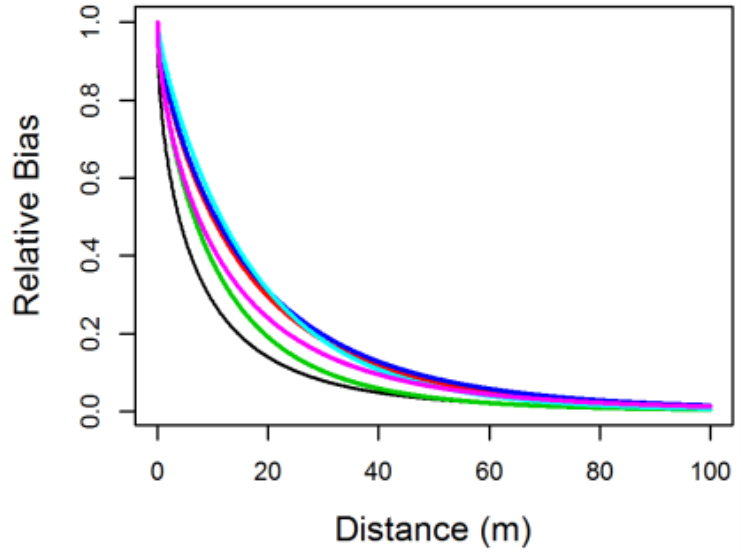

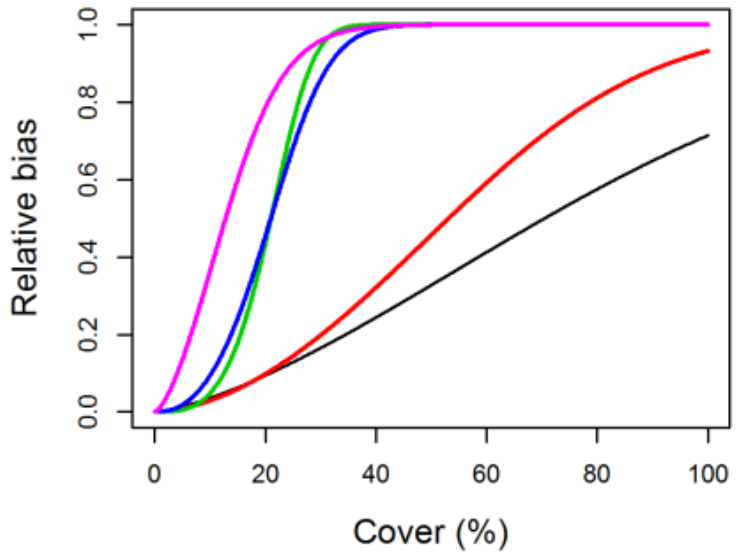

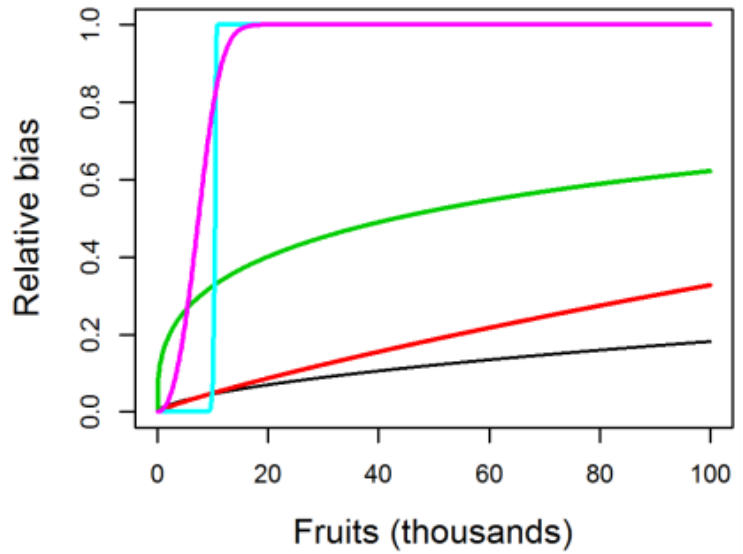

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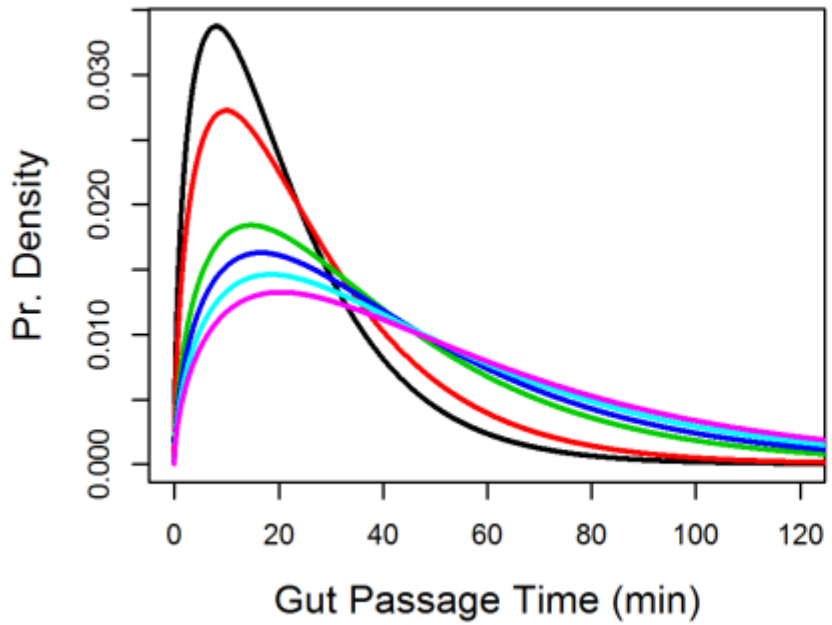

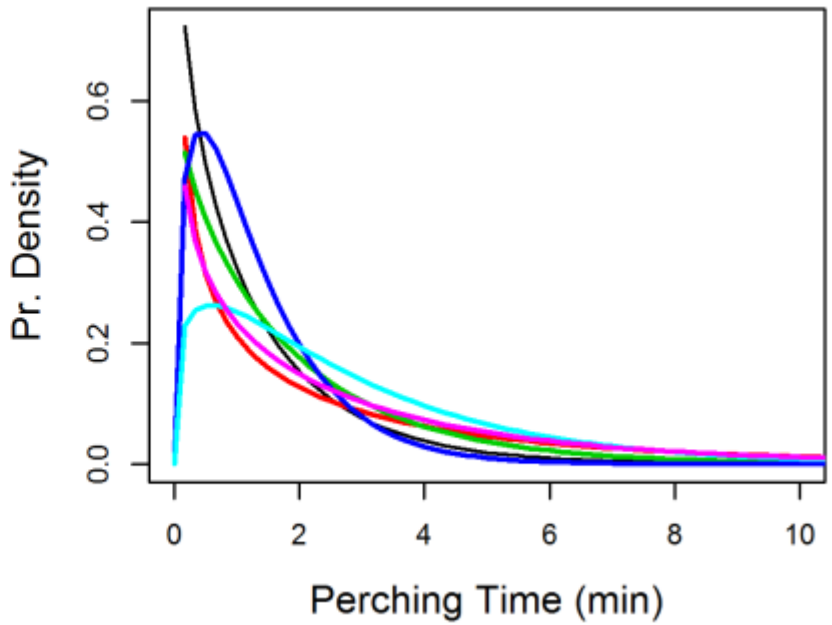

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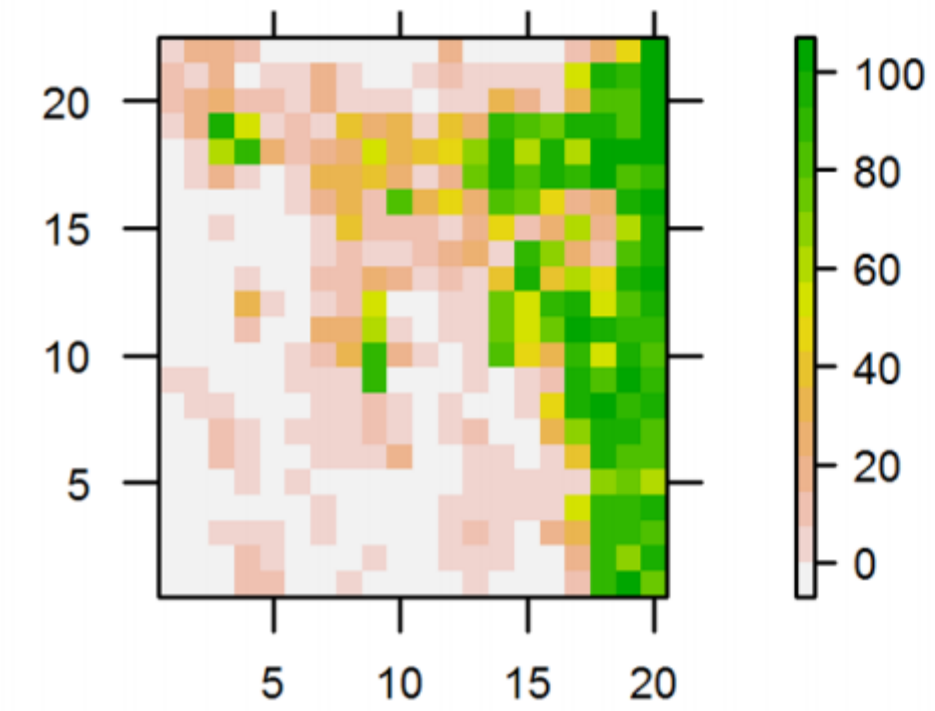

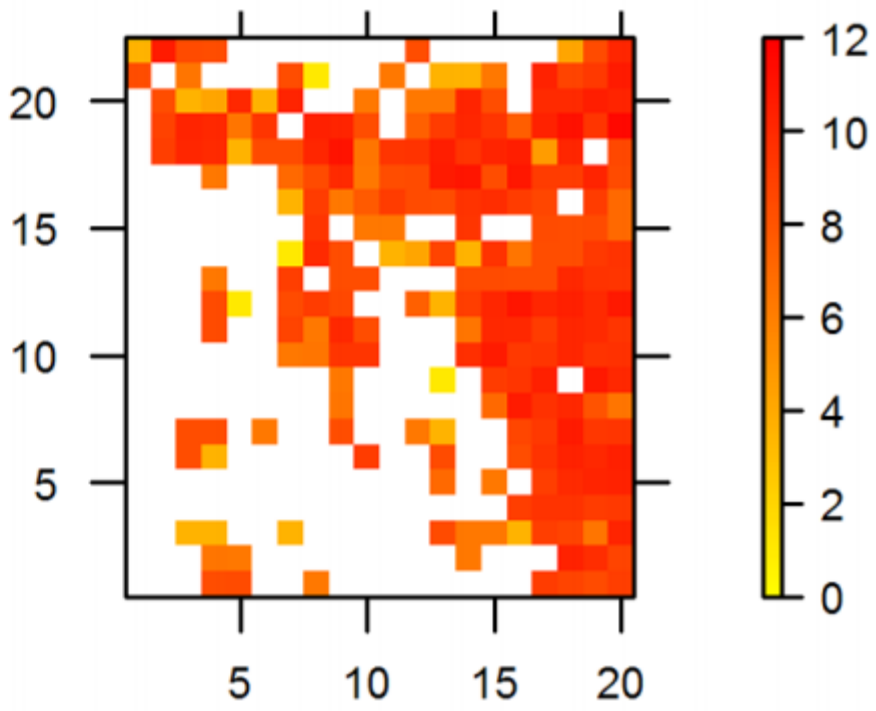

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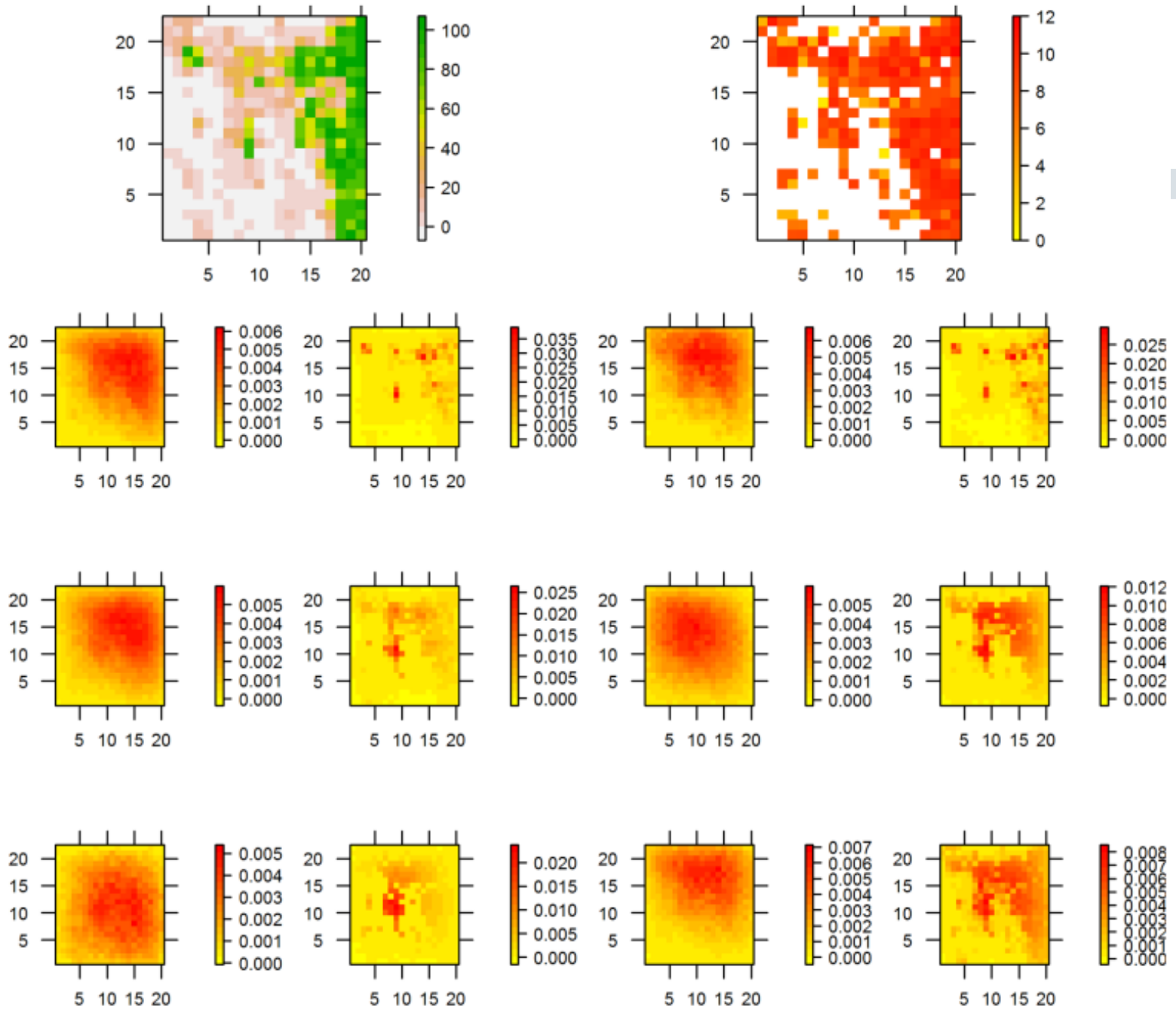
Frugivore Be
A Multi-Spec

Juan Manuel Morales[1]
Manuel Herrera[2¤]



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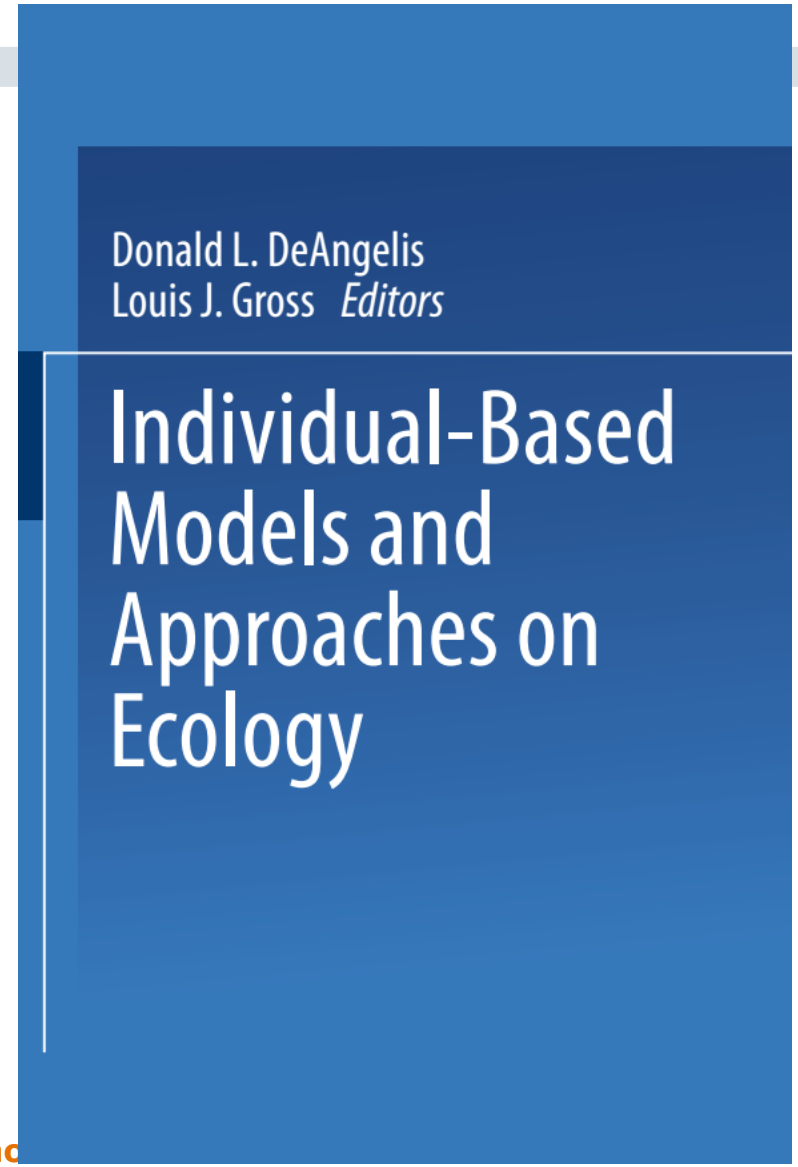
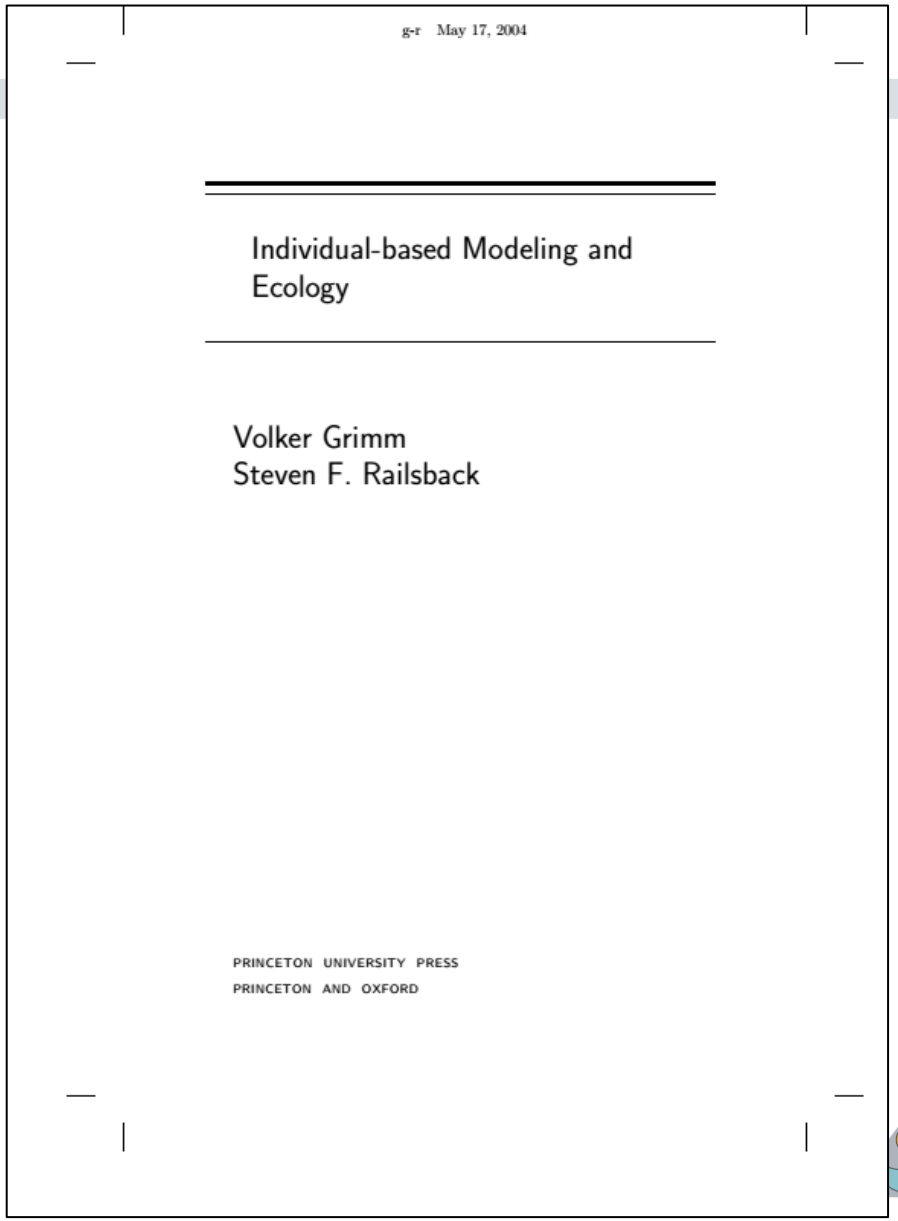
Literature





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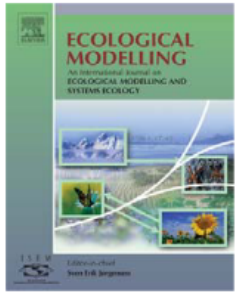

A standard protocol for describing individual-based and agent-based models

Overview	Purpose
	State variables and scales
	Process overview and scheduling
Design concepts	Design concepts
Details	Initialization
	Input
	Submodels

Question!

Entities, time and spatial scales

What variables will be registered?

Summary of “rules”

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Tools

- NetLogo
- R:
  - SiMRiv: An R package for simulation and analysis of spatially-explicit individual multistate (animal) movements in any landscape
  - abmAnimalMovement: An R package for simulating animal movement using an agent-based mode
  - aniMotum: an R package for animal movement data: Rapid quality control, behavioural estimation and simulation
    - amt: `redistribution_kernel()` and `simulate_path()`
    - moveHMM: `simData()`

Cooperation and expertise for a sustainable future

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bernardo.brandao@nina.no

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