PhD Workshop 2012

Formalisms for ecological applications

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Population Ecology

Naturalists and biologists need to model and simulate large populations of interactive animals.

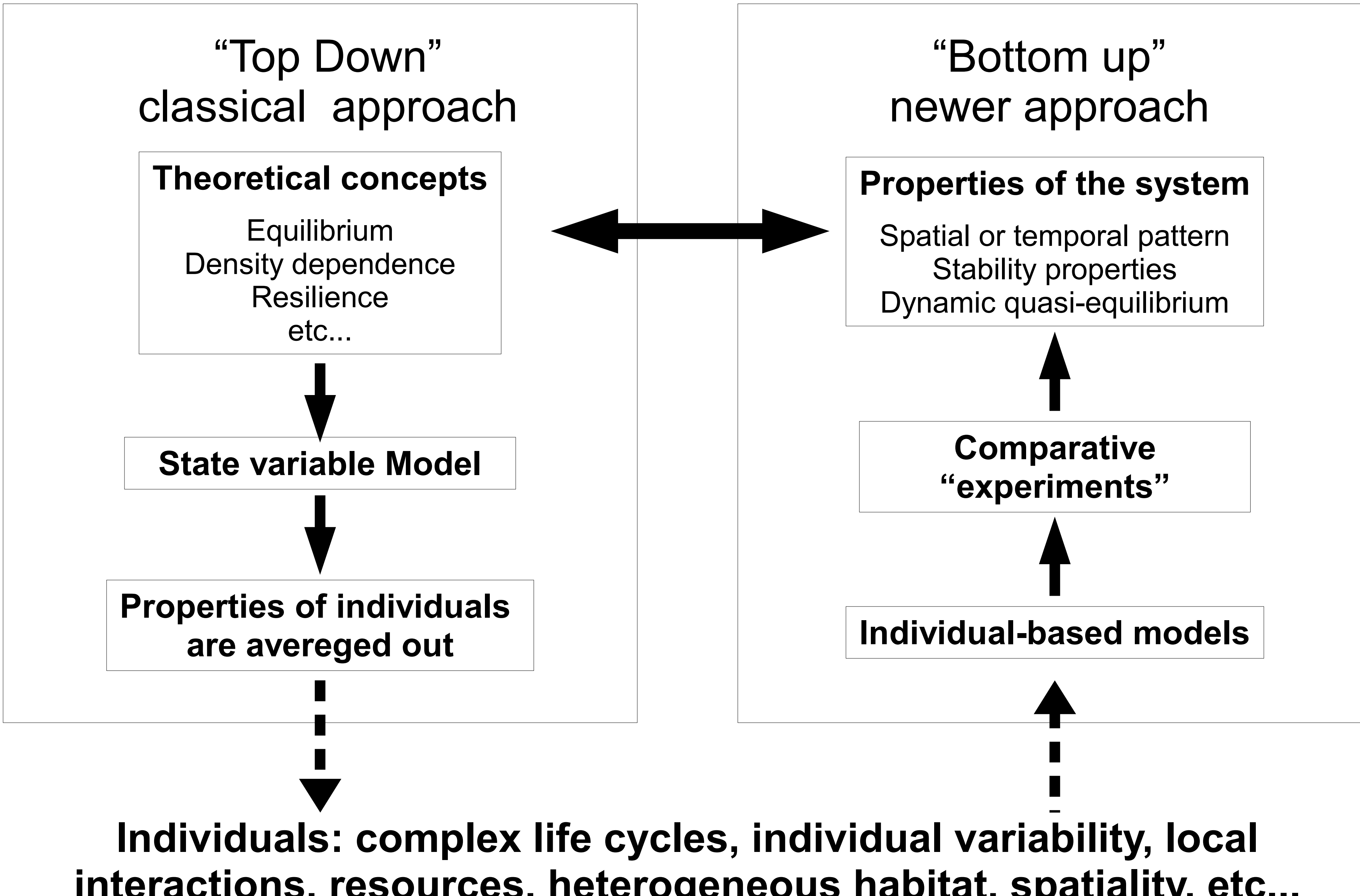
Two possible roads

- classical: differential equations
- modern: individual-based models

Motivation matters:

Pragmatic: use the model as a tool	vs	Paradigmatic: search for the overall meaning and the theory

Approaches in ecological modelling



Classical approach

- No reference to behavior
- Everything is reduced to population growth

Successful in devising and demonstrating concepts such as density dependence and intra- and inter-specific competition.

Limited success in being predictive: they can produce understanding of the observations but the predictions are not testable

Individual-based models

PROS	CONS
Can determine what individual properties and what elements are essential to the overall population dynamics.	Difficulties in the determine the right resolution and to have the same one in the whole model.
Can include spatial dynamics and abiotic factors.	Only partial knowledge is available at small resolutions
Supposedly more testable as closer to reality.	But closer to reality means more parameters which in turn means more effort to determine them.

Moreover, the search for the theory behind the model is more difficult since overall properties must emerge (and be recognized) from the details.

Case Study: *Emys orbicularis*

E. orbicularis is a freshwater european turtle with a wide western distribution, from Portugal to Kazakhstan, from Denmark to southern Italy.

The European pond turtle is inserted into the Habitat Directive (EU) and is classified as "near threatened".

Yet, it suffers from inadequate protection and management rules mostly because comparative approaches on different populations are still scarce.

Automata – Syntax

Species are represented by automata with distinct names

$$\text{Species } S \ ::= \ \langle \text{Names}_S \ , \ \text{States}_S \ , \ \sigma_S \in \text{States}_S \ , \ \mathcal{F}_S \subseteq (\text{States}_S \cup \text{Nil}) \ , \ \text{Table}_S \rangle$$

$$\text{Table}_S \subseteq \text{States}_S \times \text{Trans}_S \times (\text{States}_S \cup \text{Nil})$$

$$\begin{aligned}\text{Trans}_S \ ::= \ & @r \mid \downarrow (n, S, p_r)@r \mid \uparrow (n, S, p_r)@r \\ & \mid \text{consume}(n, S, p_r)@r \mid \text{emit}(n, S, p_r)@r \\ & \mid !(\text{new}(S), S, p_r)@r \\ & \mid \text{up}@r \mid \text{down}@r \mid \text{left}@r \mid \text{right}@r\end{aligned}$$

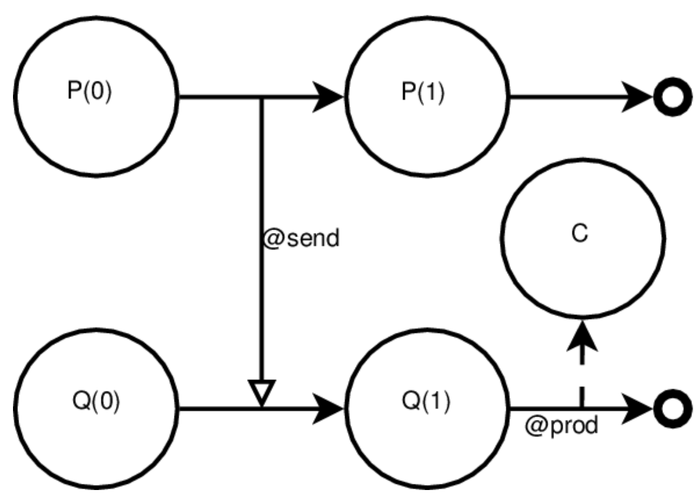
with $S \in \text{Species}$, $n \in \text{Names}_S$, $p_r \in \mathbb{N}$, $r \in \mathbb{R}^+$
and $\text{new}(S)$ returns a fresh name from $\text{Names}_S \subseteq \text{Names}$

Automata – Syntax (cont)

Individuals are

- named automata
- in a certain position
- of a given species
- and with a current state

$$\text{Individual } I \quad ::= \quad \langle n \in \text{Names}_S \ , \ p \in \mathbb{N}^2 \ , \ s \in \text{States}_S \ , \ S \in \text{Species} \rangle$$



Name Convention

The set of Names used can be any infinite set of distinct strings.

These are built by justaxposing strings from different Ranks, set of unique strings whose only intersection is the “don't care” symbol.
These Ranks mimic the hierarchical structure for names typical of species classification (Species, Genus, etc...).

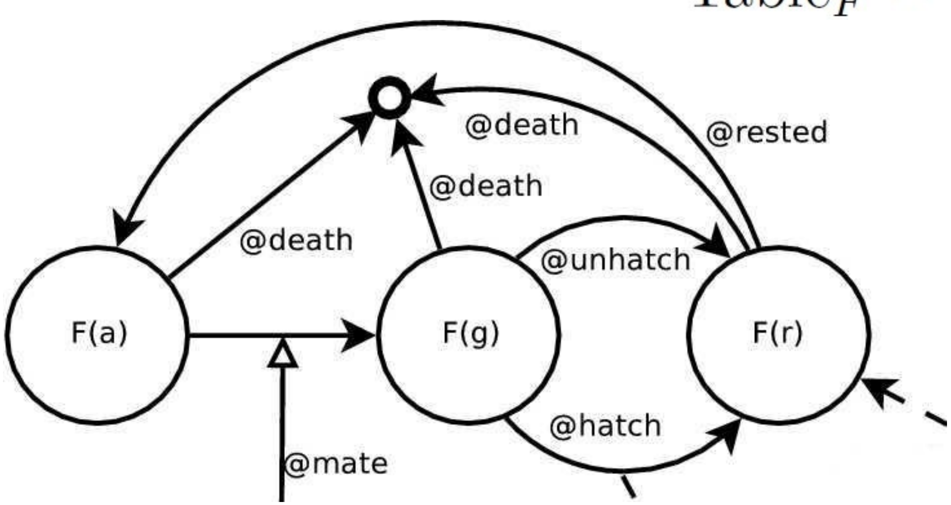
$$\text{Names} = \{n_1.n_2.\cdots.n_m \mid m > 0, n_i \in \text{Rank}_i\}$$

$$\text{with Rank}_i \;=\; \{N_j \mid N_j \neq N_k \text{ if } j \neq k\} \cup \text{'-' ('don't care' symbol)}$$

$$\text{and where Rank}_i \cap \text{Rank}_j = \{\text{'-'}\},\; \forall i, j, i \neq j$$

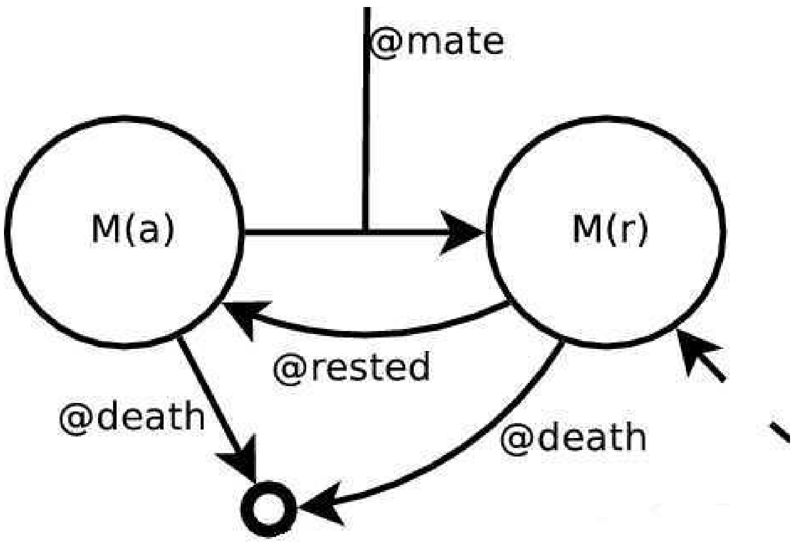
Example: *E. orbicularis* Reproduction Cycle

$$\text{Species } F = \langle\ \text{Names}_F = \{*\text{.female.turtle}\},$$
$$\text{States}_F = \{F_a, F_g, F_r\},$$
$$\sigma_F = F_r,$$
$$\mathcal{F}_F = \{Nil\},$$
$$\text{Table}_F = \left\{ \begin{array}{l} (F_a, \text{@death}, Nil), \\ (F_a, \downarrow(\text{-.male.turtle}, M, 1)\text{@mate}, F_g), \\ (F_g, \text{@death}, Nil), \\ (F_g, \text{@unhatch}, F_r) \\ (F_g, !(\text{New(N)}, N, 1)\text{@hatch}, F_r), \\ (F_r, \text{@death}, Nil), \\ (F_r, \text{@rested}, F_a) \end{array} \right\}$$



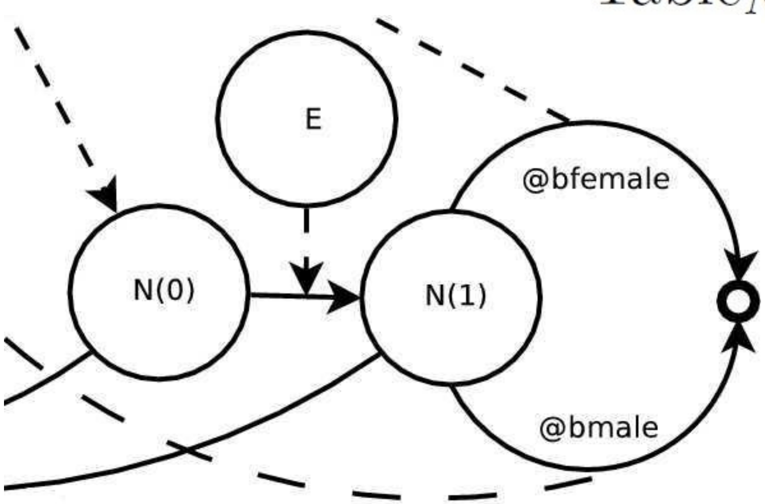
Example: *E. orbicularis* Reproduction Cycle

$$
\begin{aligned}
\text{Species } M \; = \langle\; & \text{Names}_M = \{\text{*.male.turtle}\}, \\
& \text{States}_M = \{M_a, M_r\}, \\
& \sigma_M = M_r, \\
& \mathcal{F}_M = \{Nil\}, \\
& \text{Table}_M = \left\{ \begin{array}{l} (M_a, \text{@death}, Nil), \\ (M_a, \downarrow (\text{-.female.turtle}, F, 1)\text{@mate}, M_r), \\ (M_r, \text{@death}, Nil), \\ (M_r, \text{@rested}, M_a) \end{array} \right\}
\end{aligned}
$$

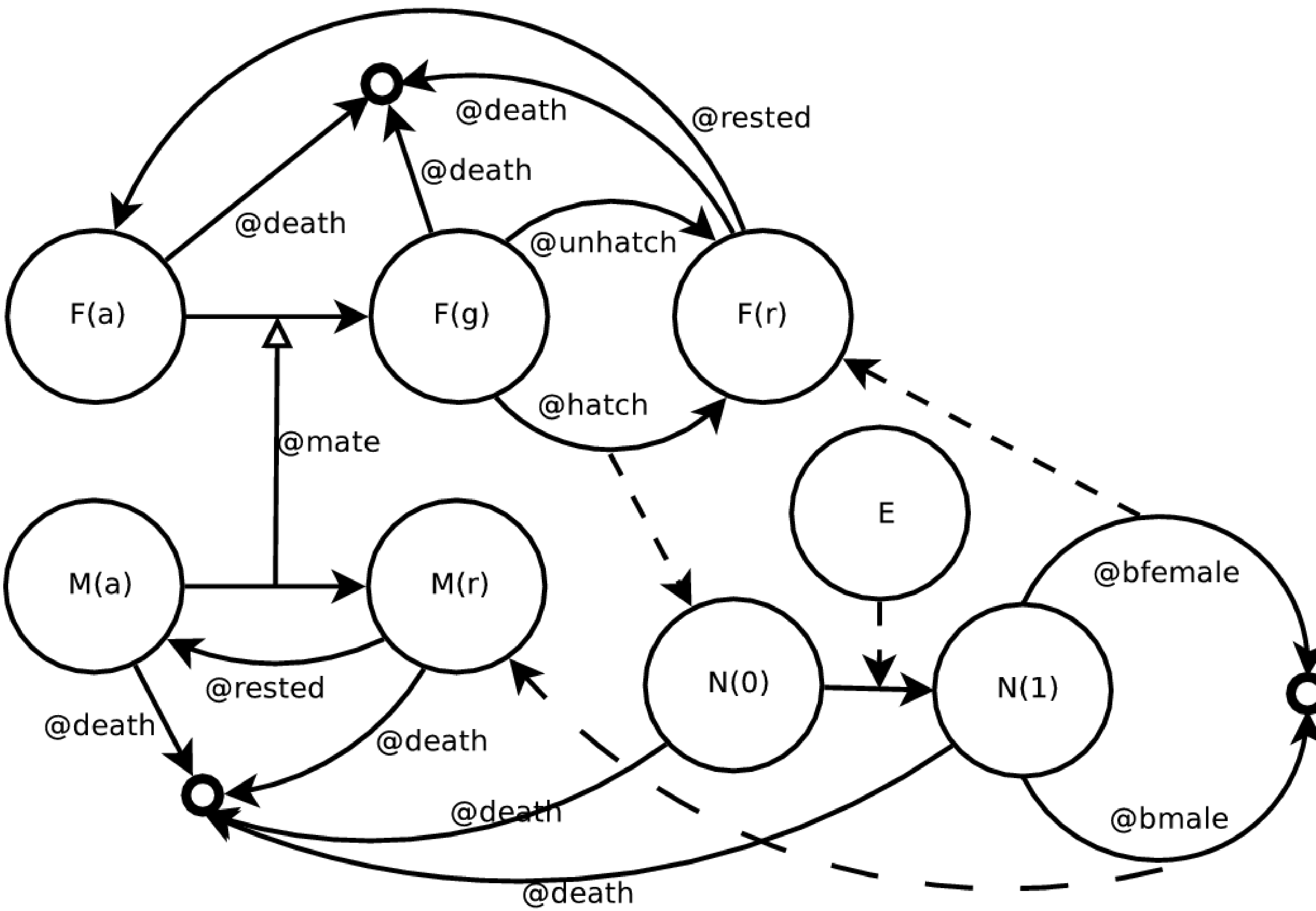


Example: *E. orbicularis* Reproduction Cycle

$$
\begin{aligned}
\text{Species } N \;=\langle\; & \text{Names}_N = \{\text{*.nest.turtle}\}, \\
& \text{States}_N = \{N_0, N_1\}, \\
& \sigma_N = N_0, \\
& \mathcal{F}_N = \{Nil\}, \\
& \text{Table}_N = \left\{ \begin{array}{l}
(N_0, \text{@pred}, Nil), \\
(N_0, \downarrow(\text{environment}, E, 0)\text{@mate}, N_1), \\
(N_1, \text{@pred}, Nil), \\
(N_1, !(\text{New(M)}, M, 1)\text{@bmale}, N_1), \\
(N_1, !(\text{New(F)}, F, 1)\text{@bfemale}, N_1), \\
(N_1, \text{@end}, Nil)
\end{array} \right\}
\end{aligned}
$$



Example:
E. orbicularis Reproduction Cycle



Case Study: *Tropheus moorii* (tropical cichlid)

These little colored fishes, natives of african central lakes (lake Tanganyika) with over 40 different morphs distributed throughout the lake.

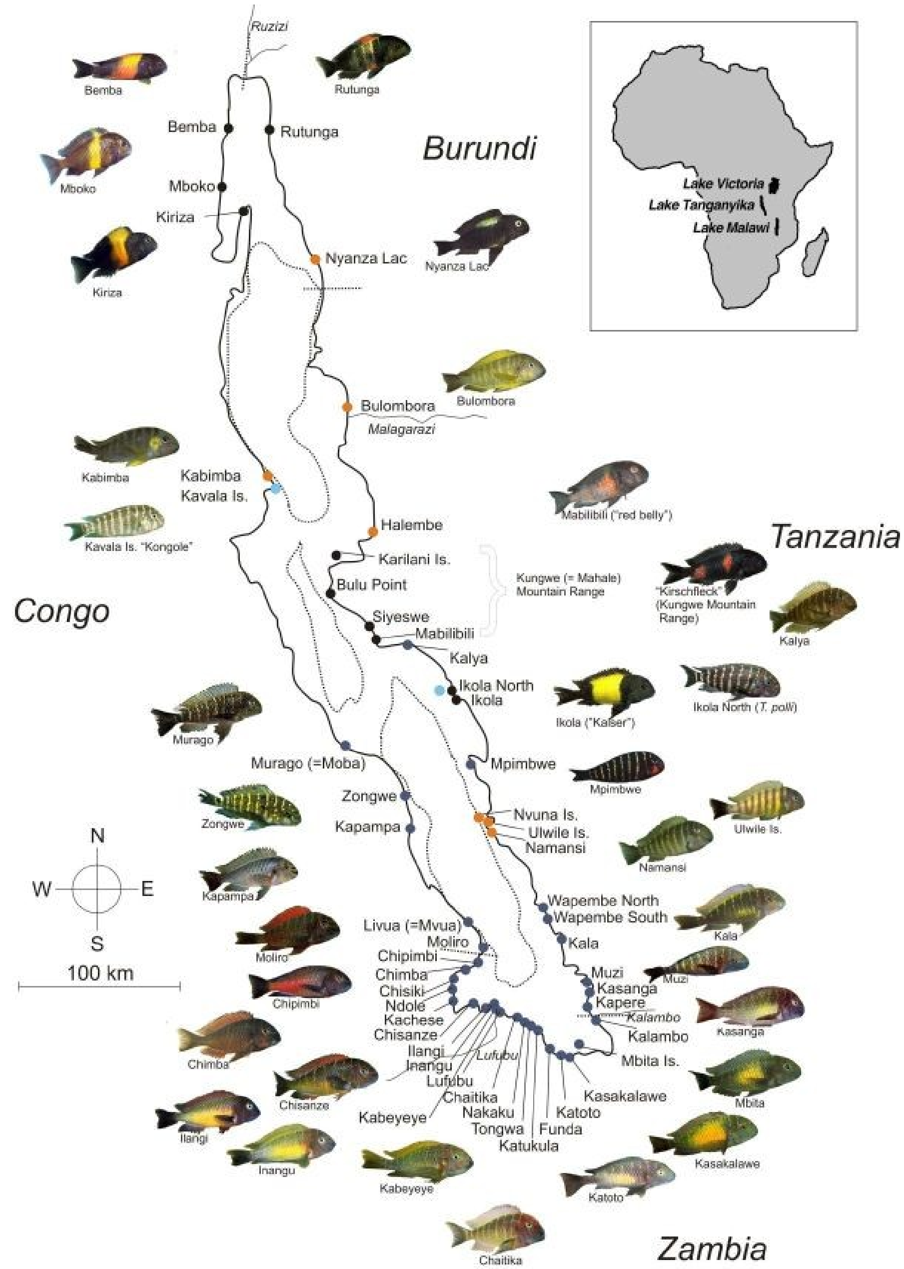
This form of peripatric speciation (speciation with loosely interconnected habitats) is quite difficult to explain given the existing models.

Cyclid in Lake Tanganyika

Fishes that lives in nearby communities have different colors.

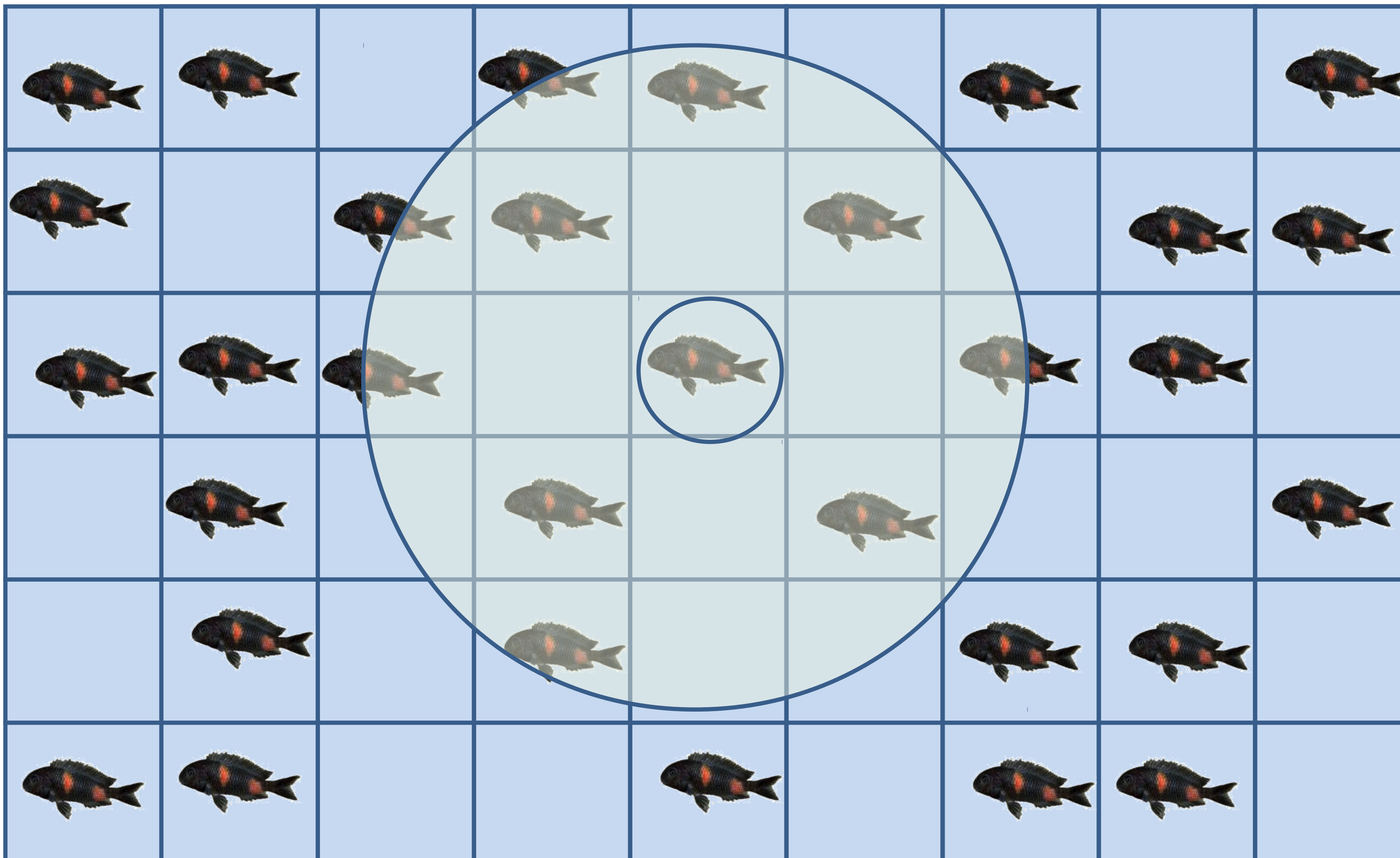
There are color morphs (i.e. *T. polli* and *T. moorii Bulu Point*) that live along the same cost line but at different depth.

Question: is ecological trait differentiation enough to induce morph separation through sexual selection?



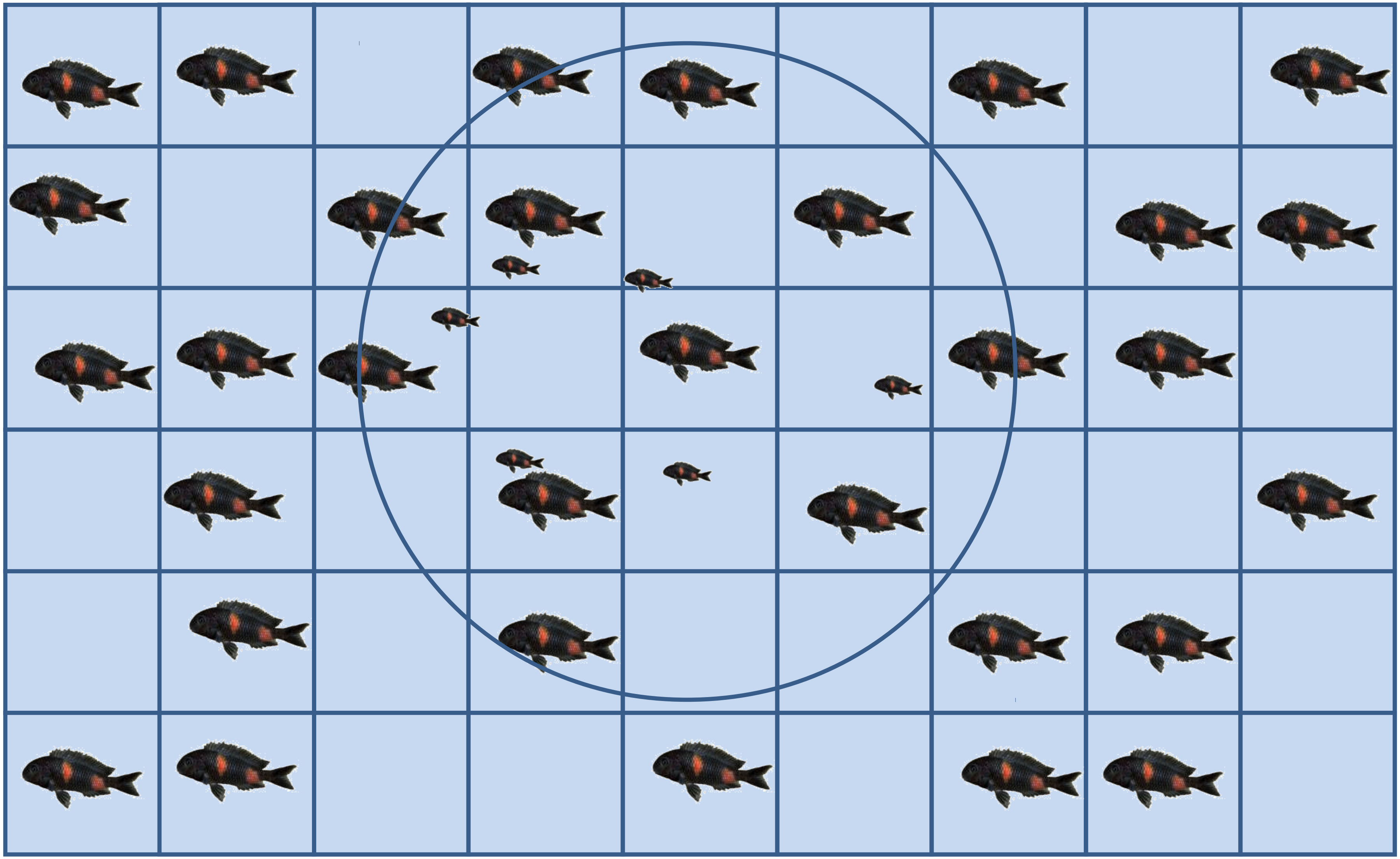
Local Behaviour

Radius of selection for females (depends on the density)



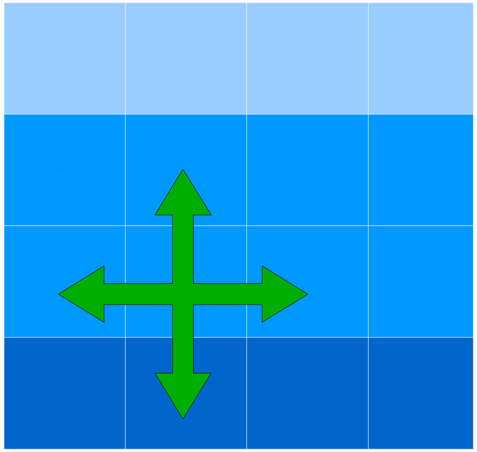
Local Behaviour

Release of juveniles is local



Syntax : Space

$$\text{Cell } C \ ::= < p \in \mathcal{N}^2 \ , \ Rules >$$



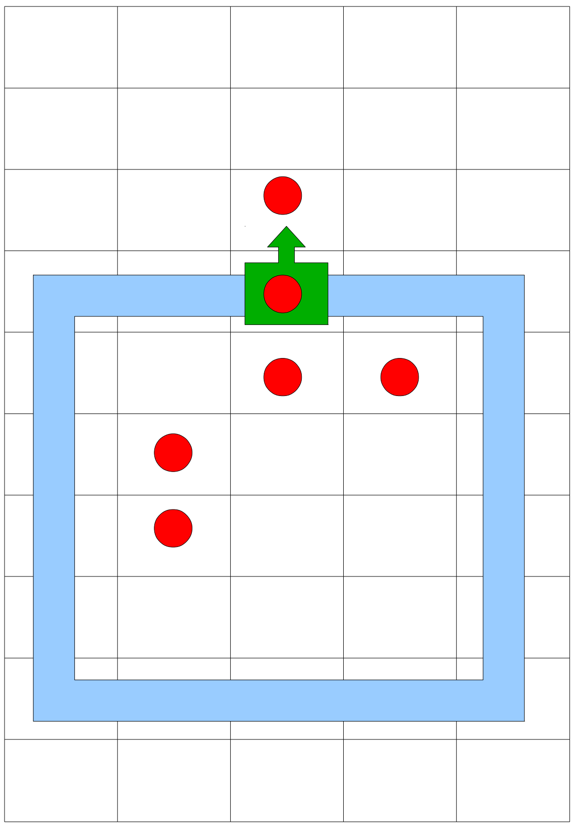
$$\text{Rules} \ \subset \ \{\langle N \subset \text{Names} \ , \ d \in \text{Dir} \ , \ r \in \mathcal{R}\rangle\}$$

$$\text{Dir} = \{(0,1) \ , \ (0,-1) \ , \ (1,0) \ , \ (-1,0) \ , \ (0,0)\}$$

Features

With this explicit notion of space we can:

- create barriers/containers
- create gateways/receptors
- specify direction-wise permeability rules
- calculate occupation and radius of interaction



Diffusion time proportional to density comes for free.

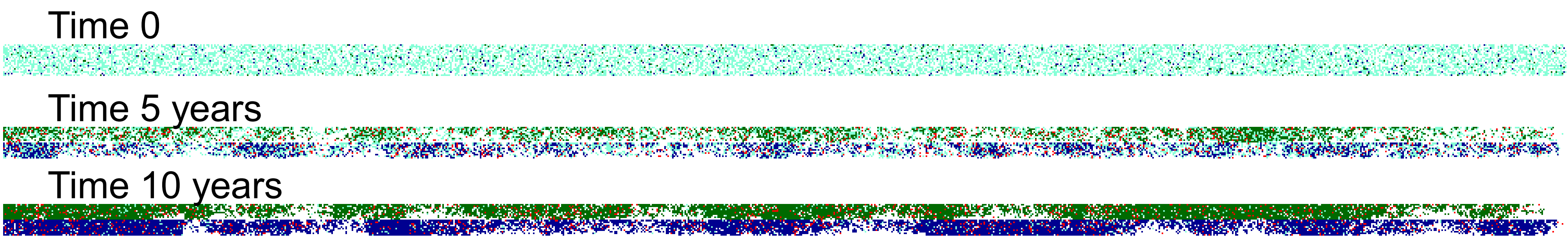
Different travel speed for different agents/particles.

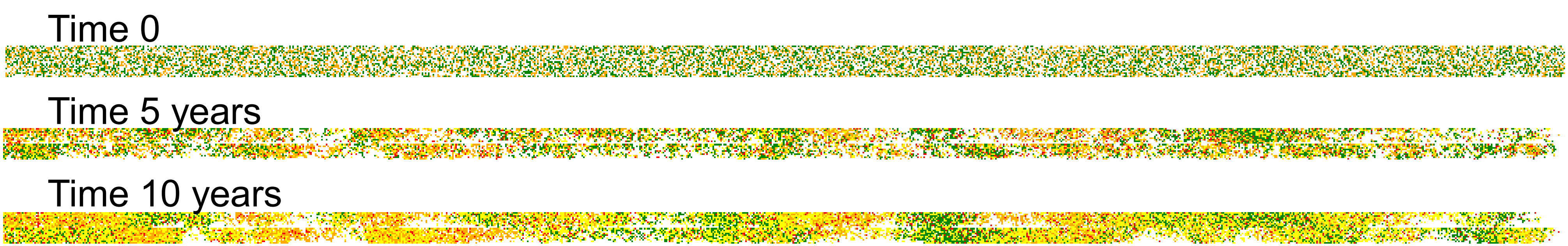
Results

Simulation of a <u>dense population</u> of two different morphs of the same species of fishes.

The two morph are interbreeding.

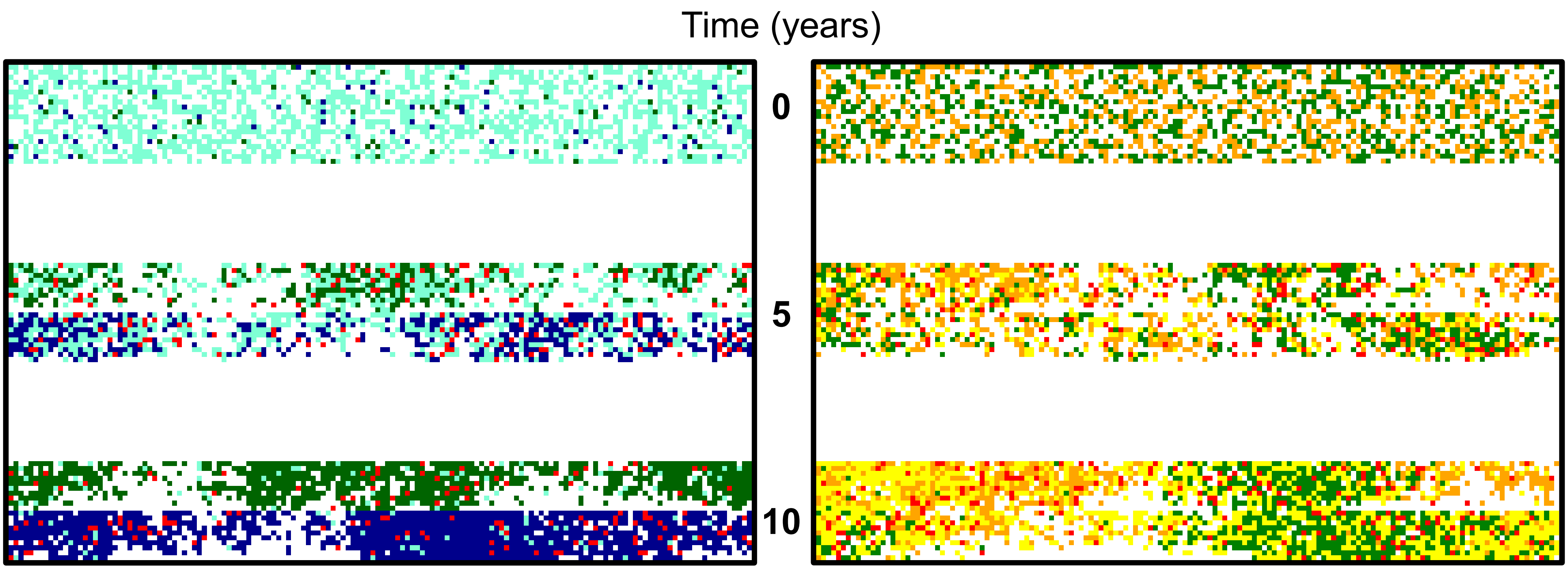
Change of ecology trait and phenotype in time.



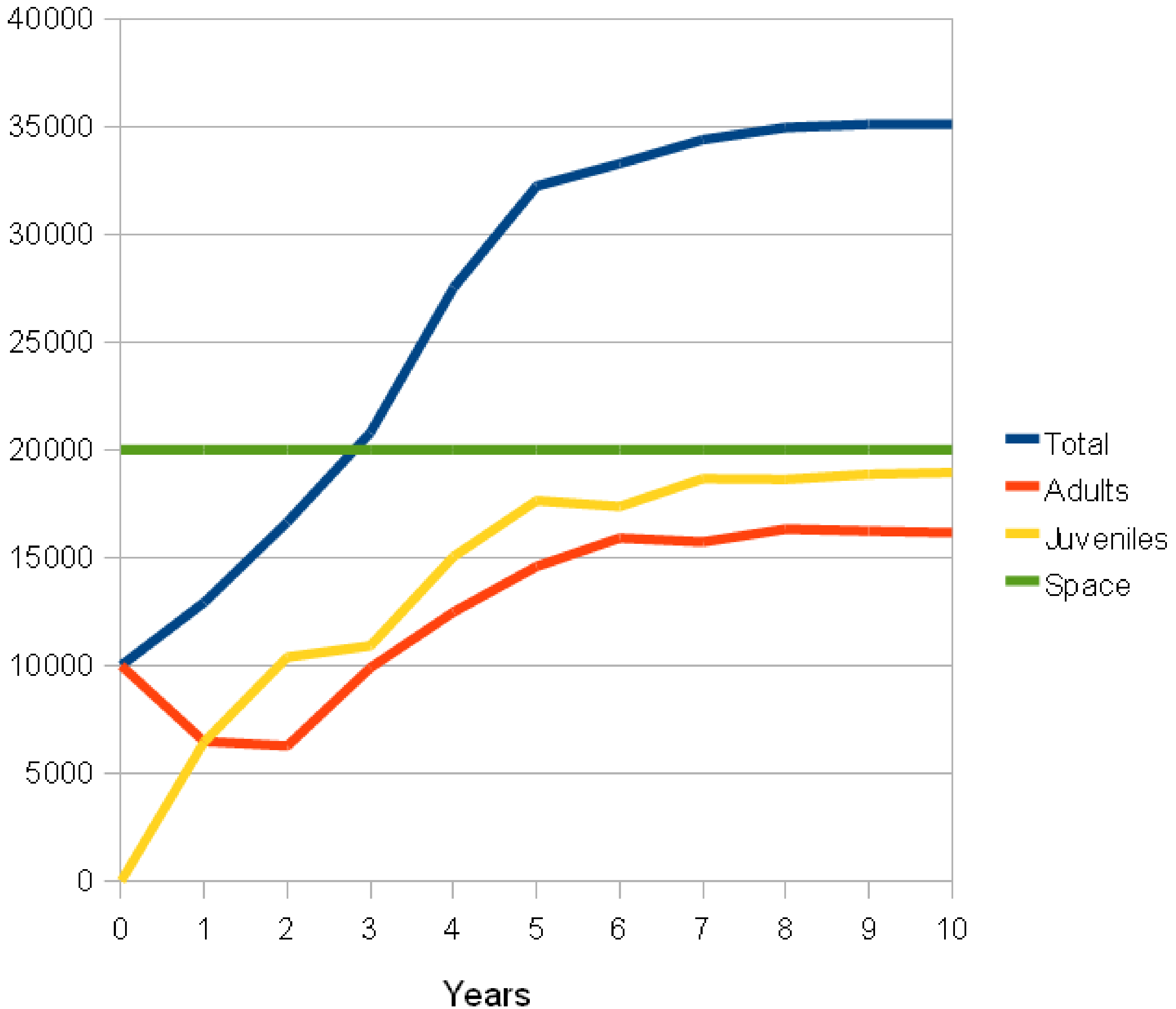


Results: Zoom-in

Change of ecology trait and phenotype in time.



Results: Population



Nicely simulated:

Population growth to environment limits

Dynamic stabilization

Juveniles over adults ratio

Still missing and future work

Promoters and inhibitors (Turing equivalence?)

Time intervals (Time scalability)

Creation and destruction of barriers →
Cell properties modified by agent's rules

Modelling and simulating tools

Main references

Ambients
• Cardelli - Artificial Biochemistry
• Cardelli, Gordon - Mobile Ambients

Automata
• Lynch, Attie - Dynamic Input-Output Automata
• Lanotte, Maggiolo - Dynamic Hierarchical Machines
• Barbuti et al. - Timed P Automata

Population
• Grimm - Ten years of individual-based modelling in ecology
• Dunning Jr, et al. - Spatially Explicit Population Models

Speciation
• Gavrilets - Models of speciation
• Gavrilets, Salzburger, et al. - Case studies and mathematical models of ecological speciation

Tropheus
• Salzburger, Sturmbauer et al. - Colour-assortative mating among populations of *T.moorii*
• Salzburger, Sturmbauer et al. - Lake Level Fluctuations Synchronize Genetic Divergences [...]

Publications

Barbuti, Mautner, Carnevale, Milazzo, Rama, Sturmbauer
“Population dynamics with a mixed type of sexual and asexual reproduction in a fluctuating environment”, submitted, 2011

Zuffi, Rama, Barbuti, Maggiolo Schettini, Milazzo
“Headstarting in the European pond turtle, Emys orbicularis”, submitted, 2011

Barbuti, Lepri, Maggiolo-Schettini, Milazzo, Pardini, Rama
"Simulation of Kohn's Molecular Interaction Maps Through Translation into Stochastic CLS+" in LNCS 5947, 2010

Barbuti, Maggiolo-Schettini, Milazzo, Pardini, Rama
"A Process Calculus for Molecular Interaction Maps" in EPTCS-11, 2009

Thank you