Ecological significance of imperfectly synchronized collective behaviors

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School on Community Ecology: from patterns to principles
Population dynamics is an emergent phenomena

Macroscopic pattern

Logistic growth

\[
\frac{dx}{dt} = rx - \delta x^2
\]

Birth, death & competition

Microscopic processes

Prey predator cycles

\[
\frac{dx}{dt} = \alpha x - \beta xy
\]
\[
\frac{dy}{dt} = \delta xy - \gamma y
\]
How do complex microscopic features translate to macroscopic patterns?

Well-mixed

\[ \dot{x} = rx - \delta x^2 \]

Range residency / territoriality

(video from @BoixRichter)

Martinez-Garcia et al. 2019, bioRxiv 712182
How do complex microscopic features translate to macroscopic patterns?

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Self-organized collective behaviors
How do complex microscopic features translate to macroscopic patterns?

Gregarious – solitary transition in the emergence of locust swarms

Calving season in wildebeest
Imperfect \textit{synchronization} is frequent in nature

\textit{Gregarious – solitary transition in the emergence of locust swarms}

Imperfect *synchronization* is frequent in nature

*Calving season in wildebeest*

How do “microscopic” collective behaviors and their features impact “macroscopic”, population-level patterns?

What are the causes of this self-organized process?

What are the consequences of the self-organized structures on the (eco)system?
*D. discoideum*: asynchrony in the transition to aggregative multicellularity
Some cells do not participate in the self-organized collective behavior.
Loners die if exposed to prolonged starvation, but they persist for some time.

Theoretical work predicts selective benefits for loners in stochastic environments

**HYPOTHESIS**

Upon aggregation

\[ \alpha \text{ aggregators} \quad 1-\alpha \text{ loners} \]

Aggregator-loner partitioning is a heritable trait

And coupled with environmental heterogeneity could favor diversity

Spatial heterogeneity

And coupled with environmental heterogeneity could favor diversity

Temporal heterogeneity

Martinez-Garcia & Tarnita, J. Theor. Biology, 2017
Are loners a heritable component of *D. discoideum* life-history?

Rossine*, Martinez-Garcia* et al., (in Press)
Loners are a heritable component of \textit{D. discoideum} life-history?

Rossine*, Martinez-Garcia* et al., (in Press)
Q1: What are the mechanistic causes of loners?

Q2: What are the ecological consequences of the collective behavior?
What are the mechanistic causes of loners?

Proposal: loners are the result of stochasticity in the initiation of a quorum-based aggregation

Rossine*, Martinez-Garcia* et al., (in Press)
What are the mechanistic causes of loners?

Rossine*, Martinez-Garcia* et al., (in Press)
Mechanistic toy-model for loners emergence: infinite signal diffusion

\[ \hat{\lambda} = \begin{cases} 0, & C < \theta \\ \lambda, & C \geq \theta \end{cases} \]

\[ \tilde{v} = \frac{v}{L} \]

\[ \dot{p}(t) = -\hat{\lambda}p(t) \]

\[ \dot{a}(t) = \hat{\lambda}p(t) - \tilde{v}a(t) \]

Pre-aggregating cells, \( P \)

Stochastic quorum-based transition

Aggregating cells, \( A \)

Movement-based transition

Multicellular, \( M \)

Rossine*, Martinez-Garcia* et al., (in Press)
Loners emerge from imperfect synchronization between two time scales

Infinite diffusion and $N \rightarrow \infty$ limit:

$$\rho_L \propto \begin{cases} 
(1 - \frac{\lambda}{\tilde{\nu}}), & \text{if } \lambda < \tilde{\nu} \\
0, & \text{otherwise}
\end{cases}$$

Rossine*, Martinez-Garcia* et al., (in Press)
Different genetic variants differ in partitioning behavior

Rossine*, Martinez-Garcia* et al., (in Press)
What are the ecological **consequences** of the self-organized behavior?

Rossine*, Martinez-Garcia* et al., (in Press)
Effect of mixing on the self-organized process

![Graph showing the effect of mixing on self-organized process](image)

Rossine*, Martinez-Garcia* et al., (in Press)
Effect of mixing on the self-organized process

Rossine*, Martinez-Garcia* et al., (in Press)
Effect of mixing on the self-organized process

Rossine*, Martinez-Garcia* et al., (in Press)
Effect of mixing on the self-organized process

Fraction of strain NC85.2 in the mix

Fraction of the poor aggregator

Rossine*, Martinez-Garcia* et al., (in Press)
Effect of mixing on the self-organized process

Interactions in the developmental process make strains to **DIVERGE** in their aggregation performance

Rossine*, Martinez-Garcia* et al., (in Press)
What are the ecological **consequences** of the self-organized behavior?

Changes in the self-organizing behavior due to mixing have **profound impact on the diversity of the species**

Rossine*, Martinez-Garcia* et al., (in Press)
Further implications

Effect of loners on the integrity of *multicellularity / sociality* against *free-riders*?

Effect of imperfect synchronization on the *persistence of coordinated behaviors*
How do complex microscopic features translate to macroscopic patterns?

**Constant birth-death rates**

Death prob

Individual age

“Traditional” Moran process

**Reproduction vs survival tradeoffs**

Death prob

Individual age

Jairo M. Rojas
How do complex microscopic features translate to macroscopic patterns?

Underlying spatial patterns: from microbes to landscapes
How do complex microscopic features translate to macroscopic patterns?

Underlying spatial patterns: from microbes to landscapes

Martinez-Garcia et al., PLOS Comp. Biol., 2018


Martinez-Garcia et al., in press, 2020

Population clustering

20cm

μm

km

50m

Mussel beds

Martinez-Garcia et al., PLOS Comp. Biol., 2018
Looking for postdocs, PhD and Master students!

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References:
Martinez-Garcia & Tarnita, PLOS Comp. Biol, 2016
Martinez-Garcia & Tarnita, Journal Theoretical Biology, 2017
Martinez-Garcia et al., PLOS Comp. Biol. 2018
Rossine*, Martinez-Garcia*, et al., PLOS Biology (in Press), 2020

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