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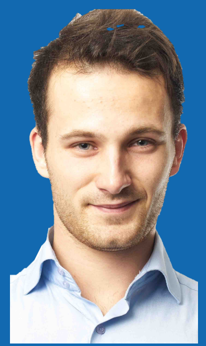
Responses of neutral and adaptive diversity to complex geographic population structure

In preparation



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LANDSCAPE ECOLOGY

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Motivation

The **properties of the landscape** over which populations are structured have a major impact on **differentiation processes**.

In particular, **landscape connectivity** and **habitat heterogeneity** constrain the movement of individuals, thereby promoting **differentiation through drift and local adaptation**.

Research question

How complex connectivity patterns and habitat heterogeneity affect **both neutral and adaptive diversity**?

The model

- We adapt the point process model of Champagnat & al.[1] to a spatial context, where the metapopulation is structured over a trait space $\mathcal{X}$ and a graph with M vertices representing a landscape.

- We study the stochastic process $(Y_t = (Y_t^{(1)}, Y_t^{(2)}, \dots, Y_t^{(M)}))_{t\geq 0}$

where $Y_t^{(i)} = \sum_{j=1}^{N_t^{(i)}} \delta_{x^{(j)}}$ describes the population trait distribution on deme (i).

- The dynamics can be summarized with the infinitesimal generator L defined for all real bounded function ϕ and finite point measure $\nu = (\nu^{(1)}, \nu^{(2)}, \dots, \nu^{(M)})$ as

$$L\phi(\nu^{(i)}) = \sum_{k=1}^{N^{(i)}} b_i(1-\mu)(1-m)(\phi(\nu^{(i)} + \delta_{x^{(i,k)}}) - \phi(\nu^{(i)}))$$

Births

$$+ \sum_{k=1}^{N^{(i)}} b_i\mu(1-m) \int_{\mathcal{X}} (\phi(\nu^{(i)} + \delta_z) - \phi(\nu^{(i)}))\mathcal{M}(x^{(i,k)}, z)dz$$

Deaths

$$+ \sum_{k=1}^{N^{(i)}} \frac{M}{K} N^{(i)}(\phi(\nu^{(i)} - \delta_{x^{(i,k)}})) - \phi(\nu^{(i)}))$$

Migrations

$$+ \sum_{j\neq i} \frac{a_{i,j}}{d_j} \sum_{k=1}^{N^{(j)}} b_i\mu m \int_{\mathcal{X}} (\phi(\nu^{(j)} + \delta_{x^{(j,k)}}) - \phi(\nu^{(j)}))\mathcal{M}(x^{(j,k)}, z)dz$$

$$+ \sum_{j\neq i} \frac{a_{i,j}}{d_j} \sum_{k=1}^{N^{(j)}} b_i(1-\mu)m(\phi(\nu^{(j)} + \delta_{x^{(j,k)}}) - \phi(\nu^{(j)}))$$

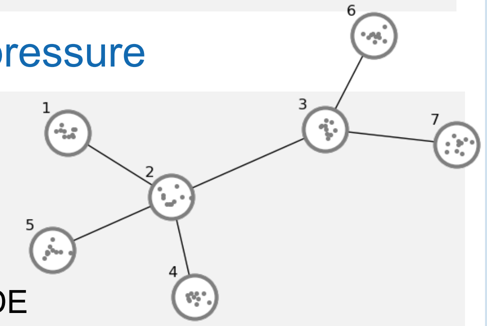
References

1. Champagnat, N., Ferrière, R., & Méléard, S. (2006). Unifying evolutionary dynamics: From individual stochastic processes to macroscopic models. Theoretical Population Biology, 69(3), 297–321. https://doi.org/10.1016/j.tpb.2005.10.004
2. Newman, M. E. J. (2002). Assortative Mixing in Networks. Physical Review Letters, 89(20), 208701. https://doi.org/10.1103/PhysRevLett.89.208701

Diversity partitioning

We are mainly interested in $\boldsymbol{\beta}$ **diversity**, which corresponds to **mean trait variance across the demes.** We distinguish between neutral $\boldsymbol{\beta_u}$ and adaptive $\boldsymbol{\beta_s}$ diversity.

1st scenario: no selection pressure



- Birth coefficient b is constant

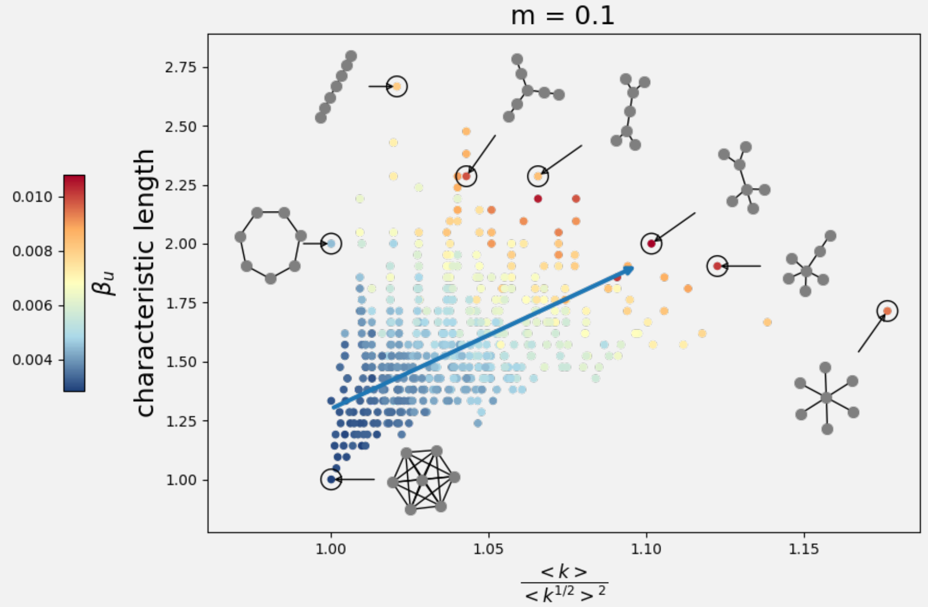
- Population dynamics obeys ODE

$$\partial_t n_i(t) = n_i(t)(1 - \frac{1}{K} n_i(t)) + m[\mathbf{L}n(t)]_i$$

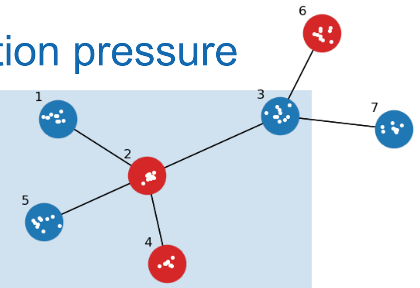
from which one can show that nodes **with high centrality** have relatively **high population size**, therefore experiencing more competition. This impacts $\boldsymbol{\beta}$ diversity.

- Quadratic variations of the neutral trait distribution are not negligible and involve the co-moments of the subprocesses. We thus use **numerical simulations** and relate $\boldsymbol{\beta}$ diversity observed to **topological metrics**

- **Characteristic length and heterogeneity in connectivity** explain best the differences in $\boldsymbol{\beta}$ diversity.



2nd scenario: heterogeneous selection pressure



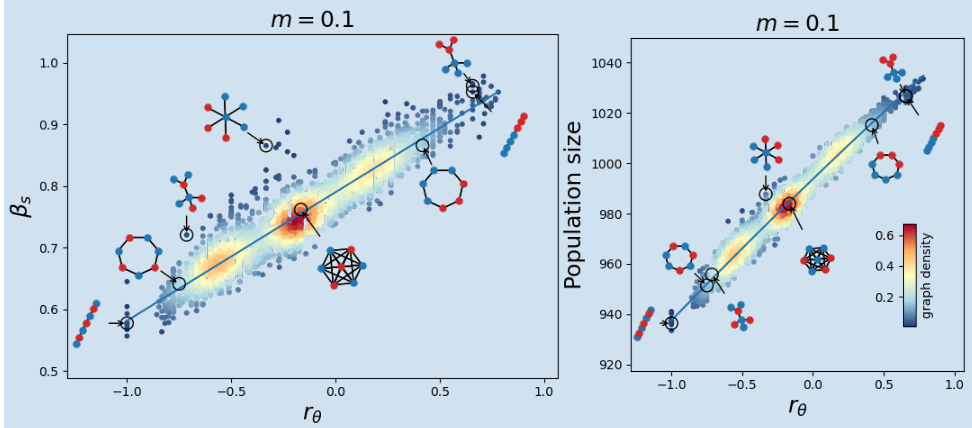
- Individuals are characterized by a neutral and an adaptive trait (u,s) ∈ $\mathbb{R}^2$

$$b_i(s) = \exp\left(-\frac{1}{2}\left(\frac{s-\theta_i}{\sigma_b}\right)^2\right)$$

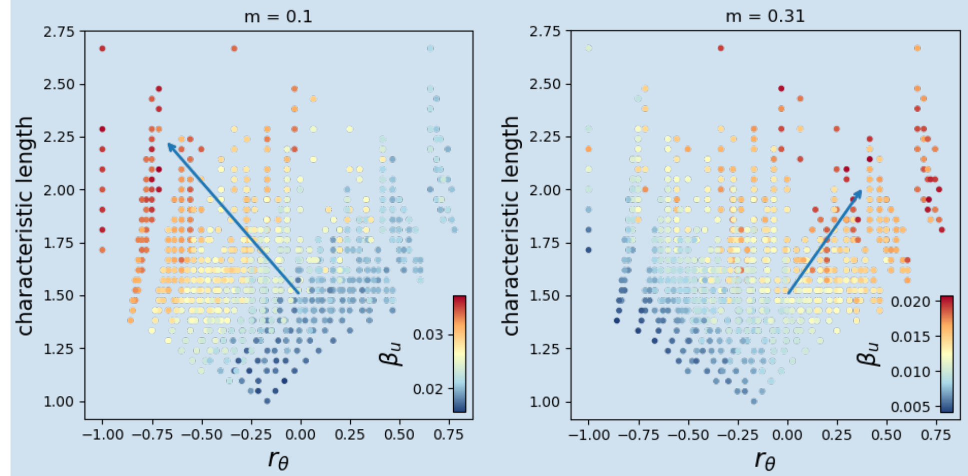
- Adaptive trait distribution can be approximated by a system of M PDEs, which can further be reduced with a mean field approach to a system of 2 PDEs

$$\partial_t u_\circ(t,s) = u_\circ(t,s)\left(b_\circ(s)(1-m) - \int_{\mathbb{R}} u_\circ(t,\mathbf{s})\,d\mathbf{s}\right) + \frac{1}{2}\mu\sigma_\mu^2(\Delta_s b_\circ u_\circ)(t,s)$$
$$+ \frac{m}{2}[(1-r_\theta)b_\bullet(s)u_\bullet(t,s) + (1+r_\theta)b_\circ(s)u_\circ(s,t)]$$

- $\boldsymbol{r_\theta}$ corresponds to the **habitat assortativity** of the graph. It increases adaptive $\boldsymbol{\beta_s}$ diversity.



- r_θ **increases** neutral $\boldsymbol{\beta_u}$diversity **for $m > m_s^*$ but decreases** it for $\boldsymbol{m < m_s^*}$.



Perspectives

- Can we obtain analytical insights on the critical migration $\boldsymbol{m_s^*}$?
- Can we obtain a (stochastic) PDE approximation for the neutral trait dynamics?