Population Genetics of low-probability transitions

Stephen Proulx UC Santa Barbara





Frequency/Density Dependence

- Alee effect
- Negative Frequency Dependence
- Stochastic selection



Stochastic selection

- Transitions between population states(fixation).
- Can lead to lower than "neutral" transition rates
- In specific models it can also lead to alternative stable states



Small variance approximation

$$E[\Delta p] \approx \frac{p(1-p)}{\mu_1 p + \mu_2(1-p)} \qquad \text{Proulx 2000}$$

$$\left((\mu_1 - \mu_2) + \left(\frac{\mu_1}{\sigma_1^2} - \frac{\mu_2}{\sigma_2^2}\right) \left(\frac{\sigma_1^2 \sigma_2^2}{N(\mu_1 p + \mu_2(1-p))^2} \right) \right) + \text{HOT}$$

$$+ \text{HOT}$$
Stochastic Price Equation
Rice 2007
$$E[\Delta p] \approx \frac{\text{cov}(i, \mu_i)}{H(\bar{w})} - \frac{\text{cov}(i, \sigma_i^2)}{N\bar{w}^2} \qquad \text{Rice 2007}$$

$$= \frac{p(1-p)(\mu_1 - \mu_2)}{H(\bar{w})} - \frac{p(1-p)(\sigma_1^2 - \sigma_2^2)}{N(\mu_1 p + \mu_2(1-p))^2}$$

+ HOT

 $\mu_2 - \frac{\sigma_2^2}{n} < \mu_1 - \frac{\sigma_1^2}{n}$. Gillespie diffusion approx



- Rare strategy is at a disadvantage
- makes transition between states more difficult
- coalescent: (Taylor & Etheridge)

Lottery Competition $p_{t+1} = p_t s_m \xi_t + \frac{p_t n_m}{p_t n_m + (1 - p_t) n_r} \quad (1 - p_t s_m \xi_t - (1 - p_t) s_r \xi_t)$ Surviving pop gen of New empty space from dead adults





Small population size





Large population size



Reg/Coding changes



Ancestral gene functions in two contexts



Mutations can alter coding region



Mutations can alter regulatory region



Both kinds of mutation may affect a single allele

Force et al 1999 The DDC Model Proulx 2012





How many times does the process have to start over before "successful" duplication?

Estimating the Neutral Duplication Time $T_{\rm DDC} = \frac{2N((2\gamma + 1)(2\gamma + 3))}{2\mu} + \frac{4\gamma^2 + 8\gamma + 7}{2\mu}$ High silencing Drift to fixation Higher μ buys rate means the more lottery is slower in large cycle has to be tickets pops repeated

Using the Origin-Fixation framework for gene interaction evolution

- Taking a step towards non-equilibrium dynamics
- Probability of a substitution may depend on an additional process component (mutation selection balance, stochastic tunneling)
- Likewise, a stable polymorphism might be an intermediate state from which further mutations can invade/replace

Example from Proulx 2012

Iwasa et al., 2004b. Stochastic tunnels ...



Weissman et al TPB 2009



Mutation Network



Good combination



N=10⁵ Frequency Dynamics

















Stochastic Tuneling in general

- Cancer: Multiple mutations required, causes a difficult to reverse phase change in the organisms organization
- Invasion of diseases across species boundaries
- Colonization of sink habitats

Feedback through the environment

Dieckmann and Doebeli, 1999, Nature



Thanks!!!

- NSF
- Fred Adler
- Troy Day
- Patrick Phillips
- Kelly Thomasson

Three questions: I'm so confused...

- How can we incorporate analyses of nonequilibrium dynamics *and* be able to make general theory?
- How often do ecological feedbacks results in bistable evolutionary states?