Experimental evolution

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Definition

• The study of evolutionary processes occurring in experimental populations in response to conditions that are defined and controlled by the experimenter (Kawecki *et al.* 2012).

• Study of evolution in real time
  – Adaptations to specific environmental conditions
  – Genetic and physiological mechanisms underlying phenotypic changes
  – Specialization and speciation
  – Evolutionary roles of phenotypic plasticity
  – Testing various evolutionary hypotheses
Laboratory populations – *Acanthoscelides obtectus*

- **Base population 1986.**
  - **host-shift >200 gen.**
  - **plasticity selection >20 gen.**
  - **age-specific selection >250 gen.**

- **E regime**
  - **pop E1 E2 E3 E4**

- **L regime**
  - **L1 L2 L3 pop L4**

- **C**
- **PI**
- **F**

>200 gen.
Age-specific selection  
- *Acanthoscelides obtectus* -

**E regime**

*Procedure*  
- Reproduction for 48h

*Results*  
- Faster larval development
- Lower reproductive activity (40% of mated pairs)
- Female re-mating – 13%
- Lower fecundity
- Smaller beetles
- Shorter life-span

**L regime**

*Procedure*  
- Reproduction without seeds
- Eggs after day 10

*Results*  
- Slower larval development
- Higher reproductive activity (80% of mated pairs)
- Female re-mating – 60%
- Higher fecundity
- Larger beetles
- Extended life-span
Age-specific selection

\[ s(x) = \sum_{y=x+1} e^{-ry} \cdot l_y \cdot m_y \]

Force of selection
Coevolution of the two genomes

- Functionality of mitochondria depends on adequate coupling of subunits in OXPHOS (originated from the mtDNA and nDNA)

- Optimal mito-nuclear allele combinations evolve under diverse environments in each population and over evolutionary time
Genetic differences between E and L

-Nuclear genome: significant differences in allele frequencies on 3 microsatellite loci

-Mitochondrial genome: fixation of one mitochondrial haplotype in L lines that was eliminated from E lines (COI gene)

Stojković B. et al., Evolution, 2017, 71-1: 160–166
Testing the effects of disrupted mito-nuclear epistasis

-repeated introgressive backcrossing-

Results

- **Hypothesis 1**: in EL and LE the activity of ETC complexes should be reduced compared to native EE and LL lines
  - **confirmed for complexes I, III and IV**

- **Hypothesis 2**: EL and LE should have lower fitness than EE and LL lines
  - **confirmed for pre-adult life-history traits**
  - **confirmed for lifespan in reproduced individuals**

Speciation in the lab

- pre-zygotic isolation -
Speciation

• the evolutionary process by which populations evolve to become distinct species

• Reproductive isolation - a set of mechanisms that prevent individuals from one species to breed with members of the other species – to produce fertile offspring.
  – byproduct of of divergent **natural selection**
  – byproduct of divergent **sexual selection**
  – stochastic mechanisms (drift and mutations)
Mating behavior

- **Mate signaling** – the expression of sex-specific phenotypes
- **Mating preference** – propensity of females and males to mate with certain phenotypes

**Mate choice** – active manifestation of mating preference that coevolved with signals of the opposite sex within a population

- **Sexual selection** – intrasexual, intersexual and sexual conflict
  – *(a posteriori)* change in gene or morph frequencies in mated individuals with respect to total population frequencies (Hartl and Clark 1989)
Between populations - isolation

• Evolution of specific mating pattern within each population (A and B)

• Sexual isolation – deviation from random mating between individuals from A and B populations
  – Assortative mating – genotypes/phenotypes from the same population mate more often than expected
  – Disassortative mating – genotypes/phenotypes from the same population mate less frequently than expected
The logic

- **Sexual selection** – change in gene or morph frequencies in mated individuals with respect to total population frequencies
- **Sexual isolation** – mainly caused by mate choice
  - deviation from random mating among mated individuals

Statistics

- **PSS (pair sexual selection)**
  - Expected pair types from mated individuals divided by the expected pair types from total numbers
- **PSI (pair sexual isolation)**
  - Observed pair types divided by the expected pair types from the pool of mated individuals
- **PTI (pair total index)**
  - Observed pair types divided by the expected pair types from total numbers
  \[ \text{PTI} = \text{PSS} \times \text{PSI} \]
\[\begin{array}{ccc}
\text{males} & \text{A} & \text{B} \\
\hline
\text{females} & \text{A} & \text{aa} & \text{ab} & \text{aa} + \text{ab} \\
& \text{B} & \text{ba} & \text{bb} & \text{ba} + \text{bb} \\
& \text{aa} + \text{ba} & \text{ab} + \text{bb} & \text{t} \\
\end{array}\]

\[t - \text{the number of copulating pairs} \quad t = \text{aa} + \text{ab} + \text{ba} + \text{bb} \]

\[T - \text{total number of individuals} \quad T = \text{A} + \text{B} + \text{A}^\prime + \text{B}^\prime \]

\[S - \text{total number of expected pairs from population frequencies} \quad S = (\text{AA}^\prime) + (\text{AB}^\prime) + (\text{BA}^\prime) + (\text{BB}^\prime) \]

**Expected pairs from total numbers**

\[
\begin{array}{ccc}
\frac{\text{AA}^\prime}{S} & \frac{\text{AB}^\prime}{S} & \frac{(\text{aa} + \text{ab})(\text{aa} + \text{ba})}{t} \\
\frac{\text{BA}^\prime}{S} & \frac{\text{BB}^\prime}{S} & \frac{(\text{aa} + \text{ba})(\text{ba} + \text{bb})}{t} \\
\end{array}
\]

**Expected pairs from mates**

\[
\begin{array}{ccc}
\frac{(\text{aa} + \text{ab})(\text{ab} + \text{bb})}{t} \\
\frac{(\text{ba} + \text{bb})(\text{ab} + \text{bb})}{t} \\
\end{array}
\]
More indices

- **W** (cross-product estimator) – fitness estimator of morph A relative to morph B (within each sex)
  \[ W_{AA} = \frac{PSS_{aa} + PSS_{ab}}{PSS_{ba} + PSS_{bb}} \]
  - mating success of one type over the other (e.g. A vs. B males):
    - larger mate propensity of one type of males
    - mate choice favoring one type of males

- **I_{PSI}** (total sexual isolation) – global estimate of pre-zygotic isolation between populations (based on mate choice)
  \[ I_{PSI} = \frac{(n-1) \sum PSI_{jj} - \sum PSI_{ij}}{(n-1) \sum PSI_{jj} + \sum PSI_{ij}} \]
  - n – number of different mating types
  - \( PSI_{jj} \) and \( PSI_{ij} \) – homotypic and heterotypic pair combinations
### A and B populations

<table>
<thead>
<tr>
<th>Females</th>
<th>Males</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>$A'$</td>
</tr>
<tr>
<td>$A$</td>
<td>$aa$</td>
</tr>
<tr>
<td>$B$</td>
<td>$ba$</td>
</tr>
</tbody>
</table>

- $A = 400$, $aa = 130$
- $B = 400$, $ab = 62$
- $A' = 400$, $ba = 74$
- $B' = 400$, $bb = 156$
Empirical example

• **Host-shift experimental lines (P and C populations):**

• **Hypothesis 1:** mating behavior is plastic
  – Environmental variation can influence development of mating signals and their perception
  – Sexual isolation parameters can change due to environmental variation

• **Hypothesis 2:** long-term evolution on two hosts can cause significant sexual isolation
  – Sexual isolation will become independent on short-term host
Design

**Populations**
(1-8)

**Evolution regime**

**Host treatment**

**Crosses:**
- Pp x Pc
- Pp x Cp
- Pc x Cp
- Pc x Cc
- Pp x Cc