Lecture 17

Re-cap 1 gene 2 allele model
Complete our ‘cases’
Mendelian selection in nature

6 ‘Cases’ of Selection

Case 1: Equal fitnesses ($w_{11} = w_{12} = w_{22} = 1$)

<table>
<thead>
<tr>
<th>p</th>
<th>q</th>
<th>Generations</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0.25</td>
<td>0.5</td>
<td>50</td>
</tr>
<tr>
<td>0.5</td>
<td>0.5</td>
<td>100</td>
</tr>
<tr>
<td>0.75</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>1.0</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

Case 2: Selection Against Dominant

$w_{11} = 1 - s$  $w_{12} = 1 - s$  $w_{22} = 1$

Early selection: weak
End result: elimination of dominant allele (fixation of recessive)
NOTE: ‘Dominance’ does not imply ‘better’ (in fitness terms)
Case 3: Selection Against Recessive

\[ w_{11} = 1 \]
\[ w_{12} = 1 \]
\[ w_{22} = 1 - s \]

Early selection: strong
End result: difficult to eliminate recessive allele; ‘masked’ in heterozygotes

Case 4 - No dominance

Make a prediction!

<table>
<thead>
<tr>
<th>Case</th>
<th>Genotype</th>
<th>Phenotype</th>
<th>Fitness</th>
<th>Selection coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>A_A_A_</td>
<td>Purple</td>
<td>( w_{11} &lt; w_{12} )</td>
<td>( s_{11} &gt; s_{12} )</td>
</tr>
<tr>
<td>5</td>
<td>A_A_A_</td>
<td>Pink</td>
<td>( w_{12} &lt; 1 )</td>
<td>( s_{12} )</td>
</tr>
<tr>
<td>6</td>
<td>A_A_A_</td>
<td>White</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

(A) \( p \) will decrease, resulting in fixation of \( A_2 \)
(B) \( p \) will decrease, and approach 0 asymptotically
(C) \( p \) will reach an equilibrium between 0 and 1
(D) \( p \) will increase, approaching 1 asymptotically
(E) \( p \) will increase, resulting in fixation of \( A_1 \)

Case 4 - No dominance

\[ w_{11} = 1 - s \]
\[ w_{12} = 1 - 0.5s \]

(Note: can write this way only in the case of a linear array of fitnesses. More generally, \( w_{12} = 1 - s_{12} \) and \( s_{12} > s_{11} \) and \( w_{22} = 1 \))

Early selection: intermediate
End result: fixation of \( A_2 \), but slower than with Case 2
Human Example

Sickle cell anemia in a non-malarial environment.

Case 5 - Heterozygote superiority

<table>
<thead>
<tr>
<th>Case</th>
<th>Genotype</th>
<th>Phenotype</th>
<th>Fitness</th>
<th>Selection coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>A₁A₂</td>
<td>Purple</td>
<td>w₁₁</td>
<td>s₁₁</td>
</tr>
<tr>
<td></td>
<td>A₁A₁</td>
<td>Pink</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>A₂A₂</td>
<td>White</td>
<td>w₂₂</td>
<td>s₂₂</td>
</tr>
</tbody>
</table>

Heterozygote superiority…
Case 5 - Heterozygote superiority

What will happen?

<table>
<thead>
<tr>
<th>Case</th>
<th>Genotype</th>
<th>Phenotype</th>
<th>Fitness</th>
<th>Selection coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>$A_1A_1$</td>
<td>Purple</td>
<td>$w_{11}$</td>
<td>$s_{11}$</td>
</tr>
<tr>
<td></td>
<td>$A_1A_2$</td>
<td>Pink</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>$A_2A_2$</td>
<td>White</td>
<td>$w_{22}$</td>
<td>$s_{22}$</td>
</tr>
</tbody>
</table>

(A) $p$ will decrease, resulting in fixation of $A_2$

(B) $p$ will decrease, and approach 0 asymptotically

(C) $p$ will reach an equilibrium between 0 and 1

(D) $p$ will increase, approaching 1 asymptotically

(E) $p$ will increase, resulting in fixation of $A_1$

Case 5 - Heterozygote superiority

With heterozygote superiority, what is the eventual equilibrium $p$?

Human Example

- Regions without malaria
- Regions with malaria

Fitness

- $Hb^+_p Hb^+_p$
- $Hb^+_p Hb^+_p$
- $Hb^+_p Hb^+_p$

Genotype
Case 5 - Heterozygote superiority

\[ p_{init} = 0.9 \]

\[ w_{11} = 1 - s_{11} \]
\[ w_{12} = 1 \]
\[ w_{22} = 1 - s_{22} \]

End result: Alleles \( A_1 \) and \( A_2 \) remain in the population
An equilibrium \( p \) is reached

Case 5 - Heterozygote superiority
\[ p_{init} = 0.1 \]

Case 5 - Heterozygote superiority
What if \( s_{11} \neq s_{22} \)? Let \( s_{11} = 0.1 \) and \( s_{22} = 0.5 \)

NOTE: This is the ONLY CASE where allelic diversity is maintained!
Case 6 - Heterozygote inferiority

- $W_{11}' = 1 + s'_{11}$
- $W_{12} = 1$
- $W_{22}' = 1 + s'_{22}$

- $S'$ is a selective ‘favor’ coefficient (for this case only) because….

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<table>
<thead>
<tr>
<th>Case</th>
<th>Genotype</th>
<th>Phenotype</th>
<th>Absolute fitness</th>
<th>Oddly relativized fitness*</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>$A_1A_1$</td>
<td>Purple</td>
<td>$W_{11}$</td>
<td>$w_{11}' = 1 + s'_{11}$</td>
</tr>
<tr>
<td></td>
<td>$A_1A_2$</td>
<td>Pink</td>
<td>$W_{12}$ (lowest)</td>
<td>$1$</td>
</tr>
<tr>
<td></td>
<td>$A_2A_2$</td>
<td>White</td>
<td>$W_{22}$</td>
<td>$w_{22}' = 1 + s'_{22}$</td>
</tr>
</tbody>
</table>

(A) p will decrease, resulting in fixation of $A_2$
(B) p will decrease, and approach 0 asymptotically
(C) p will reach an equilibrium between 0 and 1
(D) p will increase, approaching 1 asymptotically
(E) p will increase, resulting in fixation of $A_1$

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Case 6 - Heterozygote inferiority

- What is the eventual fate of alleles $A_1$ and $A_2$?
Case 6 - Heterozygote inferiority

Be Able to Answer These Questions!

- When is the disfavored allele eliminated?
- When does the disfavored allele persist in low frequencies?
- When is allelic diversity preserved?
- When does initial p, q matter?
Real world selection

- Does evolution follow the pattern predicted by the selection equation in the real world?
- Most famous example: *Biston betularia* - peppered moth, of Britain, studied by H. B. D. Kettlewell.

Genetics of Melanism

- One gene, two alleles. M dominant over m. M produces dark pigmentation in dominant homozygote and heterozygote.
- MM=melanic
- Mm=melanic
- mm=typical

Demonstration of Selection

- Clarke and Sheppard (1966) experiment

<table>
<thead>
<tr>
<th>Phenotype</th>
<th>Melanic</th>
<th>Typical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environment</td>
<td>Exposed</td>
<td>Survived</td>
</tr>
<tr>
<td>Dark Background</td>
<td>70</td>
<td>58</td>
</tr>
<tr>
<td>Pale Background</td>
<td>40</td>
<td>24</td>
</tr>
</tbody>
</table>
Which case of selection is this?

(A) Selection against the dominant 
(B) Selection against the recessive 
(C) Heterozygote superiority 
(D) Heterozygote inferiority 

Contrasting Patterns of Selection

Selection acts in opposite directions in the two environments.

Note: Multiple environments: This is an important way in which genetic diversity can be maintained by selection! (in addition to heterozygote superiority)
Sample Selection Problem

Tadpoles with large tails are more effective at resisting predation than tadpoles with short tails. Let’s imagine that large tails are due to a homozygous recessive genotype, \( B^2 B^2 \).

1. Imagine an initial starting population is in Hardy-Weinberg equilibrium and the large-tailed tadpoles represent only 1% of the population. What is the frequency, \( p \), of \( B^1 \) in the population (assume only 2 alleles exist)?

(A) 0.1  
(B) 0.2  
(C) 0.5  
(D) 0.9  
(E) 0.99

Sample Selection Problem

Tadpoles with large tails are more effective at resisting predation than tadpoles with short tails. Let’s imagine that large tails are due to a homozygous recessive genotype, \( B^2 B^2 \).

1. A predator is introduced to the pond containing this species of tadpoles, and small-tailed individuals are at a severe disadvantage. The selection coefficient against small-tailed tadpoles is 0.9! What change in \( p \) will be predicted in one generation as a result of this strong selection?

(A) 0.9000  
(B) 0.8257  
(C) 0.6333  
(D) 0.0743  
(E) 0

Sample Selection Problem

Tadpoles with large tails are more effective at resisting predation than tadpoles with short tails. Let’s imagine that large tails are due to a homozygous recessive genotype, \( B^2 B^2 \).

3. If the predator stays in the pond and continually acts as a selective force, what will the eventual frequency of \( B^2 \) be?

(A) 0  
(B) it will approach 0, but not actually reach it  
(C) 1  
(D) it will approach 1, but not actually reach it  
(E) 0.5
1. A new allele (A₂) is produced via mutation in a bald eagle population that improves the visual acuity of the bird’s eye because the delta crystallin form has better light transmission properties. Heterozygotes (A₁A₂) can see better (and therefore hunt for fish more effectively) than A₁A₁ homozygotes and A₂A₂ homozygotes have the best acuity. Which ‘case’ of selection is this?

Part 2 of Sample Prob 2

2. Over many generations, what would be the outcome of selection in this one gene, two allele system?

Part 3 of Sample Prob 2

3. Which condition in humans most closely resembles the selection that would occur in eagles?
Summary

- With selection in a 1 gene, 2 allele system;
- A. We can quantitatively predict changes in p due to selection using the equation:

\[ p_{t+1} = \frac{w_{11}p_t^2 + 2w_{12}p_tq_t + w_{22}q_t^2}{w_{11}p_t^2 + w_{12}p_tq_t + w_{22}q_t^2} \]

- B. We can predict the qualitative outcome of selection, knowing the whether dominance determines the phenotype, and knowing the relationship between phenotype and fitness.
- C. There are 6 ‘cases’ of selection.

Mendelian selection and Darwin’s model

- If a population has:
  - Phenotypic variation (A_1A_1, A_1A_2, A_2A_2; at least 2 phenotypes)
  - At least some of that variation is heritable (phenotype differences are directly genetic)
  - The phenotypic variation has fitness consequences (not all w=1)

- Then the population will evolve (p_{t+1} \neq p_t)