Microevolution 2 – mutation & migration
Assumptions of Hardy-Weinberg equilibrium

1. Mating is random

2. Population size is infinite (i.e., no genetic drift)

3. No migration

4. No mutation

5. No selection
An example of directional selection

Let $p = q = 0.5$

Genotype: $A_1A_1$  $A_1A_2$  $A_2A_2$
Fitness: 1  0.95  0.90

\[ w_1 = pw_{11} + qw_{12} = 0.975 \]
\[ w_2 = qw_{22} + pw_{12} = 0.925 \]
\[ \bar{w} = pw_1 + qw_2 = 0.950 \]

\[ p' = p(\frac{w_1}{\bar{w}}) = 0.513 \]
\[ q' = q(\frac{w_2}{\bar{w}}) = 0.487 \]

In ~150 generations the $A_1$ allele will be fixed
Conclusion:

Natural selection can cause rapid evolutionary change!
Natural selection and mean population fitness
Natural selection and mean population fitness

Question: How does $\bar{w}$ change during the process of directional selection?
Natural selection and mean population fitness

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<tbody>
<tr>
<td>Fitness</td>
<td>1</td>
<td>1</td>
<td>0.50</td>
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Here, selection is favoring a dominant allele.
Directional selection always maximizes mean population fitness!

Selection against a recessive allele ($s = 0.5$) and for a dominant allele
Natural selection and mean population fitness

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<tr>
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Here, selection is favoring a recessive allele.
Directional selection always maximizes mean population fitness!

Selection for a recessive allele and against a dominant allele ($s = 0.6$)

Figure 6-17b  Evolutionary Analysis, 4/e  
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Natural selection and mean population fitness

Question: How does $\bar{w}$ change during the process of balancing selection?
Natural selection and mean population fitness

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Results in stable equilibrium point at $p = t/(s + t)$
Natural selection and mean population fitness

Question: How does $\bar{w}$ change during the process of balancing selection?

Example: suppose $s = 0.40$ and $t = 0.60$
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Stable equilibrium point at $p = t/(s + t)$
Natural selection and mean population fitness

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Stable equilibrium point at $p = t/(s + t)$

$= 0.60$
Balancing selection maximizes mean population fitness!

Mean fitness as a function of $p$ for overdominance

Equilibrium

Figure 6-20b Evolutionary Analysis. 4/e
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Balancing selection maximizes mean population fitness!

Mean fitness as a function of $p$ for overdominance

... but is only 0.75!
Conclusion:

Natural selection *always* acts to maximize mean population fitness.
Natural selection and mean population fitness
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- Sewall Wright envisioned populations occupying “adaptive landscapes”.
Natural selection and mean population fitness

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Wright at the University of Chicago in 1925
Natural selection and mean population fitness

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Wright in 1965
Natural selection and mean population fitness

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- These landscapes were covered with multiple adaptive peaks separated by valleys of reduced fitness.
A hypothetical adaptive landscape

Selection usually pushes populations to the top

Fitness

Combinations of genes
Natural selection and mean population fitness

- Sewall Wright envisioned populations occupying “adaptive landscapes”.

- These landscapes were covered with multiple adaptive peaks separated by valleys of reduced fitness.

- His shifting balance theory considered how populations could move from one peak to another.
A hypothetical adaptive landscape

How does a population move among peaks??
Mutation
Mutation

- Let $p$ = frequency of $A_1$ allele
Mutation

• Let $p = \text{frequency of } A_1 \text{ allele}$
• Let $q = \text{frequency of } A_2 \text{ allele}$
Mutation

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Mutation

• Let \( p = \) frequency of \( A_1 \) allele
• Let \( q = \) frequency of \( A_2 \) allele
• Let \( p = q = 0.50 \)
• Let \( \mu = 1 \times 10^{-5} \)

\[
\begin{array}{c}
A_1 \\
\mu \\
A_2
\end{array}
\]
Mutation

• Let $p = \text{frequency of } A_1 \text{ allele}$
• Let $q = \text{frequency of } A_2 \text{ allele}$
• Let $p = q = 0.50$

\[ A_1 \xrightarrow{\mu} A_2 \]

• Let $\mu = 1 \times 10^{-5}$ (and ignore $\nu$)
Mutation

• denoting the change in A2 in one generation as $\Delta q$, 
Mutation

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$$\Delta q = \mu \times p$$
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= (1 \times 10^{-5})(0.5)
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Mutation

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• the $A_2$ allele has increased in frequency to 0.500005.
• it would take another 140,000 generations to reach 0.875
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• the $A_2$ allele has increased in frequency to 0.500005.
• it would take another 140,000 generations to reach 0.875

Conclusion: The rate of change due to mutation pressure is extremely small!
Some comments on mutation

1. Mutation is the “raw material” that fuels all evolutionary change.
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2. Mutations occur randomly!
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1. Mutation is the “raw material” that fuels all evolutionary change.

2. Mutations occur randomly!

3. Mutations occur too infrequently to cause significant allele frequency change.

4. Most mutations are deleterious and experience “purifying selection”.

5. A small (but unknown) proportion of mutations are beneficial and lead to adaptation.
Migration (gene flow)
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- its magnitude is determined by \( m \)

\[
m = \text{the proportion of genes entering a population in individuals (genes) immigrating from a different population.}
\]
Sewall Wright’s Continent-Island model
A simple model of migration
A simple model of migration

• let $p_I = \text{frequency of } A_1 \text{ allele on island}$
A simple model of migration

• let $p_I = \text{frequency of } A_1 \text{ allele on island}$

• let $p_C = \text{frequency of } A_1 \text{ allele on continent}$
A simple model of migration

• let $p_I$ = frequency of $A_1$ allele on island

• let $p_C$ = frequency of $A_1$ allele on continent

• let $m$ = proportion of $A_1$ alleles moving to island each generation
A simple model of migration

• let $p_I = \text{frequency of } A_1 \text{ allele on island}$

• let $p_C = \text{frequency of } A_1 \text{ allele on continent}$

• let $m = \text{proportion of } A_1 \text{ alleles moving to island each generation}$

• let $p'I = \text{frequency of } A_1 \text{ allele on island in the next generation}$
A simple model of migration

- let $p_I$ = frequency of $A_1$ allele on island
- let $p_C$ = frequency of $A_1$ allele on continent
- let $m$ = proportion of $A_1$ alleles moving to island each generation
- let $p'_{I}$ = frequency of $A_1$ allele on island in the next generation

\[ p'_{I} = (1-m)(p_I) + m(p_C) \]
A simple model of migration

• let $p_I = \text{frequency of } A_1 \text{ allele on island}$

• let $p_C = \text{frequency of } A_1 \text{ allele on continent}$

• let $m = \text{proportion of } A_1 \text{ alleles moving to island each generation}$

• let $p'_I = \text{frequency of } A_1 \text{ allele on island in the next generation}$

$$p'_I = (1-m)p_I + m p_C$$

“resident” “immigrant”
A simple model of migration

• let $\Delta p_1 =$ change in frequency of $A_1$ allele on island from one generation to the next
A simple model of migration

• let $\Delta p_I = \text{change in frequency of } A_1 \text{ allele on island from one generation to the next}$

$$
\Delta p_I = p'_I - p_I
$$
A simple model of migration

• let $\Delta p_I = \text{change in frequency of } A_1 \text{ allele on island from one generation to the next}$

$$\Delta p_I = p'_I - p_I$$

$$= (1-m)(p_I) + m(p_c) - p_I$$
A simple model of migration

- let $\Delta p_I = \text{change in frequency of } A_1 \text{ allele on island from one generation to the next}$

\[
\Delta p_I = p'_I - p_I \\
= (1-m)(p_I) + m(p_c) - p_I \\
= m(p_c - p_I)
\]
An example:
An example:

\[ p_c = 0.75 \]
An example:

let $p_c = 0.75$

let $p_l = 0.25$
An example:

\[
\text{let } p_c = 0.75 \\
\text{let } p_I = 0.25 \\
\text{let } m = 0.10
\]
An example:

let \( p_c = 0.75 \)

let \( p_l = 0.25 \)

let \( m = 0.10 \)

let’s ignore back-migration
An example:

\[ \Delta p_I = m(p_c - p_I) \]

let \( p_c = 0.75 \)

let \( p_I = 0.25 \)

let \( m = 0.10 \)
An example:

let \( p_c = 0.75 \)

let \( m = 0.10 \)

let \( p_I = 0.25 \)

\[
\Delta p_I = m(p_c - p_I) = 0.10(0.75 - 0.25)
\]
An example:

let $p_c = 0.75$

let $p_I = 0.25$

let $m = 0.10$

$\Delta p_I = m(p_c - p_I)$

$= 0.10(0.75-0.25)$

$= 0.050$
Now:

\[ p_c = 0.75 \]

\[ p_l = 0.30 \]

let \( m = 0.10 \)
Now:

\[ p_c = 0.75 \]

let \( m = 0.10 \)

\[ \Delta p_I = m(p_c - p_I) \]

\[ = 0.10(0.75 - 0.30) \]

\[ = 0.045 \]
Conclusions
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1. Gene flow can cause rapid evolutionary change.
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2. The long-term outcome will be the elimination of genetic differences between populations!
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1. Gene flow can cause rapid evolutionary change.

2. The long-term outcome will be the elimination of genetic differences between populations!

But… natural selection act to oppose gene flow
Example: Lake Erie water snakes (*Nerodia sipedon*)
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