Bio 1M: Evolutionary processes

Evolution by natural selection

- What is the weak link in the story I told last chapter?

  - Heritable **variation** in traits
  - **Selection** (i.e., differential reproductive success) *based on* these traits

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Some genetics

- Our basic traits are determined by **genes**

- A location where a gene can occur is called a **locus** (pl. **loci**)

- A particular version of a gene is called an **allele**

- Complex organisms usually have two alleles at each locus

  - These can be the same, or different

Loci

- Complex organisms usually have two alleles at each locus

  - These can be the same, or different

- An organism with different alleles at a particular locus is referred to as **heterozygous** (adj., n. form heterozygote)

- An organism with two copies of the same allele at a particular locus is referred to as **homozygous** (adj., n. form homozygote)

Two definitions of evolution

- *Lecture*: heritable changes in species traits over time

- *Book*: changes in allele frequencies

- These definitions are consistent; use the one which helps you think clearly

1   Analyzing genotype frequencies — S23.1 (2ndEd S25.2)

Genotypes and phenotypes

- A **genotype** is the collection of an individual's genes

- A **phenotype** is the collection of an individual's physiological and physical traits

  – What we can observe about an individual

  – Phenotype is largely (but by no means entirely) determined by genotype

Example: peppered moths

- Kettlewell's experiment `https://en.wikipedia.org/wiki/Kettlewell%27s_experiment`

- Two different alleles possible at the wing color gene: A_1 and A_2.

  – Individuals with A_1A_1 *genotype* have light-winged *phenotype*

  – Individuals with A_2A_2 *genotype* have dark-winged *phenotype*.

  – Individuals with A_1A_2 *genotype* ???

- If individuals with genotype XY have the same phenotype (on average) as those with XX, we say that X is a **dominant** allele and Y is a **recessive** allele.

- If XY individuals have an intermediate phenotype (between XX and YY, we say X and Y are **incompletely dominant**.

Co-dominance

- Co-dominance means when both phenotypes are expressed. Whatever that would mean.

- Examples?

- a very particular term that should fall under incomplete dominance

- People shouldn't worry about this distinction, and you shouldn't worry about it for this course

  – Notice that it's not in bold

Analyzing genotype frequencies

- We analyze genotype frequencies as follows:

  – Make simple assumptions about how frequencies work

  – Calculate **expected frequencies** under our assumptions

  – Measure **observed frequencies** in the population

  – Look for evidence of systematic (not random) difference between expected and observed frequencies

Making simple assumptions

- Expected frequencies are usually calculated by assuming that alleles assort randomly and independently, like flipping two coins, or rolling two dice

Activity: Coin flipping

- I flip two fair coins (ie., each coin will land heads with probability 1/2).

- What is the probability of:

    - Two heads
    - Two tails?
    - One of each?

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Activity: Professional coin flipping

- A professional gambler can flip a coin so that it lands heads 70% of the time. She flips two coins.

- What is the probability of:

    - Two heads
    - Two tails?
    - One of each?

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Hardy-Weinberg distribution

- The Hardy-Weinberg distribution is the distribution expected if alleles work like coins (random and independent).

- If p is frequency of allele A_1 and q is frequency of allele A_2, then:

    - Frequency of genotype $A_1 A_1$ is p^2.
    - Frequency of genotype $A_2 A_2$ is q^2.
    - Frequency of genotype $A_1 A_2$ is $2pq$.

- Why the 2?

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Example: calculating allele frequencies

- I collect 20 peppered moths from a particular place, and find that 4 have genotype A_1A_1, 8 have genotype A_1A_2, and 8 have genotype A_2A_2.

- What is the observed frequency of each allele?

- What is the expected frequency of each genotype under the Hardy-Weinberg assumptions?

- Is this population in Hardy-Weinberg equilibrium?

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What do we mean by expected?

- If we flip a fair coin 100 times, what is the expected number of heads?

    – What if we flip it 25 times?

- We don't expect to get exactly the expected value.

- The 'expected value' is an average of what is expected under our assumptions

How do you know a coin is perfectly fair?

- You can never be sure that a coin is perfectly fair, you can only evaluate your evidence that it's more or less close to fair.

- Similarly, we never have evidence that a population is exactly in Hardy-Weinberg equilibrium

- We can only evaluate our evidence that it is far from (or close to) equilibrium

- What's another way to think about the evidence?

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Hardy-Weinberg equilibrium

- When do we expect genotype frequencies to behave like coins?

- Alleles selected at random from the previous generation:

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- If these assumptions hold exactly, we expect **Hardy-Weinberg equilibrium**

  - Hardy-Weinberg distribution, with no change in allele frequencies from generation to generation.

- This never happens

Differences from equilibrium

- If we observe large differences from the Hardy-Weinberg equilibrium, this is usually a sign that mating is not random, or that natural selection is operating

- The analysis tells us that something is going on, but not what

- Hardy-Weinberg is a **null model**: it tells us what to expect if complicating effects are absent

- Without a null model, we couldn't start interpreting.

Example: Human blood groups

- MN blood groups in different human populations are very close to Hardy-Weinberg equilibrium — Table 23.1 (2ndEd 25.1)

  - No evidence for non-random mating, or for fitness differences.
  - This *does not* mean it's not happening, but *probably* means that it's small

Activity: Human blood groups at the global level

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Example: Human HLA genes — Table 23.2 (2ndEd 25.2)

- HLA genes are used by the immune system to recognize disease-causing organisms

- Researchers hypothesized that heterozygous individuals may recognize more bacteria and viruses

- Data shows that more people are heterozygous for HLA genes than would be expected under the Hardy-Weinberg assumption

Heterozygous HLA genes

- Why might more people be heterozygous for HLA genes than predicted by Hardy-Weinberg?

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2   Types of natural selection — S23.2 (2ndEd S25.3)

2.1   Directional selection

- **Directional selection** tends to move a population in a particular direction

    – Giraffe necks
    – Human brains

Multi-directional selection

- Directional selection can change through time with the environment

    – Swallows may get larger during extreme cold spells, smaller again during normal weather

        * But we need to know whether the changes we saw were heritable

    – Finch beaks get thicker when food is scarce, and smaller when food is abundant

- Why might small-beaked finches have advantages?

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2.2   Stabilizing selection

- **Stabilizing selection** tends to keep the population where it is

    – Example: human birthweights — Fig 23.4 (2ndEd 25.4)

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Connections between selection types

- What happens if the target of directional selection stays the same for a long time?

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- Examples?

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2.3   Disruptive selection

- Disruptive selection favors phenotypes *different* from the average value — Fig 23.5 (2ndEd 25.5)

  – Black-bellied seedcrackers
  – Animals that get eaten a lot may want to look different from their peers

- Disruptive selection may lead to **speciation** – the formation of new species.

2.4   Balancing selection

- Balancing selection tends to maintain allele diversity

  – When there is no single best allele

- **Heterozygote advantage**: when heterozygotes have higher fitness

- **Frequency dependence**: when rare types have higher fitness

Example: The sickle cell phenotype

- Blood cells that can lose their shape and squash malaria parasites!

  – People heterozygous for this trait get less sick with malaria
  – People homozygous for this trait have too much instability and severe anemia

- This is an example of:

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Example: seedcrackers

- What would happen if almost all of the seedcrackers had large bills?

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- What happens when large-billed and small-billed individuals breed?

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3 Other evolutionary mechanisms

3.1 Genetic drift

- **Genetic drift** is change in allele frequencies due to random sampling:

    – Some individuals have more offspring than others due to chance events
    – Offspring receive certain parental alleles, and not others

- These factors will lead to an accumulation of random changes in allele frequencies

Thought experiment

- Imagine flipping a fair coin 100 times

    – Repeat

- Now imagine choosing 100 alleles at random (with replacement) from a population of 50 A and 50 B alleles

    – Repeat, using new population as a starting point — Fig 23.6 (2ndEd 25.6)

Small populations

- Drift is much stronger in small populations than in large ones (law of averages).

- Even if a population is big now, it may have been small in the past

    – **Founder effects** occur when a new population is started by a small number of individuals
    – **Bottlenecks** occur when a population becomes small, then large again
        * ... or, when a beneficial genetic mutation takes over a population
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Fixation and loss

- An allele may drift to a frequency of 0 (it's **lost**) or of 1 (it's **fixed**)

- Advantageous alleles are often (not always) fixed

- Disadvantageous alleles are usually (not always) lost

- Alleles with **neutral** differences (no selective difference) will be fixed or lost at random

    – This is also true for alleles with small effects

- Drift tends to reduce genetic variation

3.2 Gene flow — S23.4 (2ndEd S25.4)

- **Gene flow** is the movement of alleles from one population to another

    – This happens when individuals move from one population to another and breed

- How we think about gene flow depends on how we choose to define a 'population'

- Gene flow can be an obstacle to speciation; it helps keep populations similar

3.3 Mutation — S23.5 (2ndEd S25.5)

- **Mutations** are heritable errors in copying DNA

- Mutations are rare; *by themselves* they don't cause much evolution

- Mutations are extremely important to evolution, however:

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Types of mutations

- Mutations can occur at many scales:

    – a single DNA base might change
    – chunks of DNA can be added or subtracted
    – whole genes (or whole chromosomes) can be duplicated

- New genetic sequence can come from:

    – copying errors
    – other organisms! **lateral gene transfer**

Mutations are random

- Most mutations are **deleterious** – bad for fitness

- Very rarely mutations are **beneficial** – good for fitness

  - Such mutations are favored by natural selection

Complex organisms

- Can complex organisms arise through random mutations?

  - A central question of biology
  - Large-scale evolution takes a *long* time
  - Beneficial changes can accumulate gradually
  - Much evidence of intermediate forms

- Check out videos of "evolution of the eye"

What about sex?

- Sex does not *directly* change allele frequencies

  - Your book may say this means it's not an "evolutionary process" – don't worry about that

- It does act to bring alleles together (and to split them apart)

- Sex is not a source of new alleles

  - But it is a source of new combinations

- There is still active debate on the advantages and disadvantages of sex in evolution

4   Mating patterns

4.1   Inbreeding

- **Inbreeding** refers to mating between close relatives

- Since relatives will tend to share similar alleles, inbred populations will tend to differ from Hardy-Weinberg equilibrium in what way?

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Inbreeding depression

- In many populations, it is observed that inbred individuals have lower fitness:

    - They are more likely to be homozygous for rare genetic defects
    - They are less likely to be heterozygous for immune-system genes

- Inbreeding depression is a serious concern for conservation

    - As populations get smaller, inbreeding becomes more common

- Wildlife studies show that panthers with both parents from Florida (small population) do not survive well — Fig 23.14

- Human demographic studies show strikingly lower survival for children of first cousins

4.2 Sexual selection

- **Sexual selection** is a form of natural selection

- Occurs when there is heritable variation in traits related to success in obtaining mates

Example: zebra finches

- Males but not females have colorful orange beaks

- Hypothesis: these beaks make males more attractive to females — Fig 23.18 (2ndEd 25.17)

Activity: Zebra finch experiments

- How would you test this hypothesis?

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Results: Zebra finch experiments

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- Why not simply find and use birds whose beaks are naturally more or less orange?

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- What is a possible problem with the conclusion that females prefer birds with orange beaks?

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Why the males?

- Males often have striking traits that females lack, used in courtship, or in battles for mates

    – Sexual **dimorphism** refers to trait differences between males and females

- Why do males more often have these traits than females?

    – Investment in reproduction
    – Variation in reproductive success

Investment in reproduction

- In many species, females invest much more in each offspring than males do

    – Eggs are expensive, sperm are cheap
    – Females are often more involved in caring for offspring

- If females invest a lot in each offspring, they can maximize fitness by *being choosy about mates*

- If males invest little in each offspring, they can maximize fitness by *mating as much as possible*

Testing the theory

- How might we test the theory that males compete more sexually because females invest more in offspring?

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Variation in reproductive success

- Males often have greater variation in reproductive success than females do

- This is a side-effect of the fact that females usually invest a lot in each offspring

    – Reduces potential total number of offspring
    – Makes females desirable to males

- Greater variation in reproductive success means that winning contests is more important to male than female fitness

Example: elephant seals

- Male elephant seals compete for control of breeding beaches

- Huge variation in reproductive success

- Huge size difference between males and females (strong sexual dimorphism) — Fig 23.19 (2ndEd 25.19)

What about people?

- Men and women have pretty clear size differences

- How unequal is child-rearing in people?

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- To what extent do these principles even apply to people?

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Conclusions

- **Mutation** (mistakes!) is the source of new variation

- **Natural selection** drives adaptation: selects variation that allows organisms to thrive in diverse settings

- **Sex** facilitates new combinations, but **sexual selection** can work against adaptation to the environment

- **Genetic drift** and **gene flow** are also non-adaptive drivers of evolution

- The adaptation we see is the result of all of these processes:

    – adaptive, non-adaptive, previously adaptive