Bio 1M: Evolution by natural selection (complete)

1 Evolution

- The theory of **evolution** has replaced the theory of **special creation** in science.

- The theory of special creation asserts that each species is a unique "type", created by God.

- The theory of evolution asserts that species have changed through time (**evolved**).

- Does this mean that scientists don't believe in God?

    - **Answer:** Many scientists do believe in God
    - **Answer:** Scientists learn about the world through experiment and observation
    - **Answer:** Scientists don't treat religious texts as *literally* true

1.1 Change through time

Fossils

- A **fossil** is a physical trace of an organism that lived in the past

- Fossils can be dated using (complicated) radiometric and geological techniques

- Fossils provide information about the history of life

- The **fossil record** refers to the collection of all known fossils

- Chapter 25 (2ndEd 27) for more info about fossils

Extinction

- Many fossils have been left by organisms that are no longer around

    - We say such organisms are **extinct**

- Extinction is one piece of evidence that species are changing

    - In a very limited way
    - How convincing is it as support for the theory that species got here by gradual evolution?

Transitional forms

- When a species disappears from the fossil record, a similar species often appears
    - This often happens in the same geographic area
- Consistent with species evolving: changing through time
- Fig 22.4 (24.4 2ndEd)

Vestigial traits

- A **vestigial trait** is a structure that has no function, but is similar to functioning structures in related species
- Examples?
- Fig. 22.5 (24.5 2ndEd)

Directly observed evolution

- Although much evolution occurs very slowly, some kinds of evolution can be, and have been, observed on faster time scales
    - Tuberculosis
    - Ground finches

1.2   Relationships between species

- If species evolved from a common ancestor, we expect to see evidence that they are related to each other
    - Species fall naturally into groups
        * e.g., mammals, flowering plants
    - Geographic patterns of relatedness
    - Homology

Geographic relationships

- Species in the same geographic area (e.g., nearby islands) often seem to be closely related
- This is what we would expect if these species evolved independently, starting from a common ancestor in the region
- Support for the theory of evolution
- Fig. 22.6 (24.6 2ndEd)

Evolution and similarity

- In nature we observe many, often surprising, similarities between organisms

  – Almost identical developmental genes in fruit flies and people

  – Similar limb bone structure in turtles and people

- The theory of evolution explains these similarities as **homologies**

Homology

- A **homology** is a similarity that is due to common ancestry

  – Similarities apparently due to homology are widespread. This is a strength of the theory of evolution.

Genetic homology

- **Genetic homology** is homology at the level of genetic coding.

- Examples:

  – The genetic code itself is shared (with rare, minor exceptions) by all living organisms

  – Some genes involved in development are very similar all the way from insects to mammals

- Fig 22.7 (24.10 2ndEd)

Developmental homology

- **Developmental homology** is homology in the traits of **embryos** (developing organisms)

  – Embryos of all vertebrates show striking similarities

Structural homology

- **Structural homology** is homology at the level of developed organisms.

  – Tetrapod limbs

Identifying homologies

- How do we know whether similarities are due to common evolution?

  – Homologies assume evolution; how can they be used as evidence for evolution?

- The idea that many similarities are due to homology seems to explain many observed patterns

  – Organisms fall naturally into groups

  – Genetic evidence and morphological evidence often agree

    * We get consistent stories from different lines of evidence, e.g., whale example

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2 Natural selection

- Darwin's big idea was not evolution, but natural selection

- The first real theory of evolution was developed by Lamarck

  - More famous for being wrong about how evolution occurs
  - **Answer:** He thought *acquired characteristics* were inherited

Natural selection drives evolution

- Darwin's theory of natural selection can be explained using four logical steps:

  - **Variation:** The individuals that make a population vary in the **traits** they possess, like size, shape, physiological details.
  - **Heritability:** Some of these differences can be inherited by offspring. For example, tall people may be more likely to produce tall offspring.
  - **Differential *reproductive* success:** In each generation, some organisms leave more offspring than others
  - **Selection:** Reproductive success is not random, but is influenced by differences in traits, including heritable traits

- If all four of these assumptions hold, we expect evolution to occur:

  - Traits associated with good reproductive success will become more common

Natural selection (short version)

- Evolution by natural selection will occur if there is:

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

- Logical consequence?

  - **Answer:** Traits associated with good reproductive success will become more common

Fitness

- "Survival of the fittest" is not a very good name for this process

- **Fitness** in biology, or **Darwinian fitness**, means simply an ability to do well under natural selection

- Fitness is thus *defined* as average reproductive success, given a suite of heritable traits

- Components of fitness:

  - survival, growth, reproduction

Example: Tuberculosis

- What if there were no variation?

  - Where does variation come from?

- What if variation were not heritable?

- What if there were no selection?

Other examples

- Galapagos finches' beak sizes evolve as availability of seed resources changes.

- Squirrels!

Activity

- How would you design an experiment to tell if beak depth is heritable?

  - **Answer:** Raise offspring from different combinations of mothers and fathers, and compare their beaks

    * **Answer:** You might also want to try raising them in different conditions (wet or dry, more or less food available)

  - **Answer:** **Control**. Make all factors except for the beak depths of mothers and fathers as similar as possible

  - **Answer:** **Replicate**. Use many offspring (from different mothers and fathers).

  - **Answer:** **Randomize**. Select individuals to breed at random

    * **Answer:** Maybe less important – but if you do it, you don't have to worry about it

3   The nature of adaptation

Other models

- Natural selection is not the only possible model for how evolution could occur

  - Inheritance of acquired characteristics (Lamarck)

  - Goal-directed evolution

Inheritance of acquired characteristics

- This is the idea that individuals change in response to their environment, and pass those changes on to their offspring

    - Example: giraffes reaching for food

- It is now known that while individuals do often change in response to their environment, such changes are not (usually) passed on to offspring

    - _Comment:_ We even more recently know that sometimes this _can_ happen, but it's not the main way that evolution proceeds
    - https://en.wikipedia.org/wiki/Epigenetics

Goal-directed evolution

- This is the idea that organisms evolve towards specific goals

    - Complex, multicellular organisms
    - Big-brained humans

- If the organism is moving toward a goal, it should move more or less in that direction all the time

Evaluating competing hypotheses

- We challenge hypotheses with experiments and observation

Inheritance of acquired characteristics

- Raise a population of mice in the lab

- Every generation stretch (or chop off) their poor little tails

- Measure natural tail length at the beginning of the experiment, and after 100 generations.

- How could this experiment be improved?

    - **Answer:** Add a control group
    - **Answer:** Use replicate populations (e.g., three control and three experimental populations)
        * **Answer:** Or three "choppy" and three "stretchy" populations
        * **Answer:** Randomize which groups get which treatment

Activity

- What would be the key points of a similar experiment to test whether tail lengths respond to natural (actually, artificial) selection?

  - **Answer:** In each generation, allow mice with longer (or shorter) tails more chances to breed
  - **Answer:** Compare results with a control population.
    * **Answer:** Let them breed how they want?
    * **Answer:** Make couples, and choose 2 offspring from each?

Goal-directed evolution

- There is a great deal of observational evidence against goal-directed evolution:

  - Vestigial traits
  - Bidirectional evolution
    * Finch beaks get larger, then smaller
    * Birds gain, then lose, flying ability
    * Things that become parasites may become much smaller and simpler

Adaptation vs. acclimation

- **Acclimation** is the ability of organisms to respond directly to their environment

  - When organisms **acclimate** this does not affect the traits of their offspring

- **Adaptation** is genetic change that increases the fitness of organisms

  - Adaptation does not occur as a direct response to the environment
  - Adaptation is usually very slow
  - Adaptations are passed on to offspring, and form the basis of evolutionary change

Examples

- If you exercise every day, you will be stronger, but this will not make your children stronger.

  - **Answer:** acclimation

- After swinging through trees for millions of years, chimpanzees have very strongly built arms.

  - **Answer:** adaptation

- Polar bears have thick fur, and thick layers of fat under their skin.

  - **Answer:** adaptation

- Humans raised in hot climates have more sweat glands than those raised in cold climates.

  - **<u>Answer</u>:** acclimation

Acclimation

- Why do we acclimate?

  - **<u>Answer</u>:** It has probably evolved because acclimation is beneficial

- Are responses to changed conditions always good?

  - **<u>Answer</u>:** No. Systems respond in ways that have usually been good through evolutionary time
  - **<u>Answer</u>:** Some forms of severe altitude sickness are probably due to acclimation systems going off track
  - <u>*Comment*</u>: A story about digging holes

Tradeoffs

- Much of adaptation is the result of compromise between conflicting goals

  - Brightly colored individuals are more attractive to mates, and to predators
  - Larger individuals compete more effectively, but are less efficient at reproducing

Historical constraints

- Evolution proceeds by small steps

  - What is possible is guided by what has gone before

- Examples

  - Vestigial traits
  - Blind spot in the vertebrate eye
  - Humans are not well designed to be upright

Evolution by natural selection – Summary

- There is strong evidence that species have evolved through time

  - Fossil record, patterns of relatedness, homologies

- There is strong evidence that this change is driven by natural selection

  - Darwin's logical postulates: heritable variation in traits; differential reproductive success based on traits
  - Direct observations of natural selection (TB, finches, moths)

- Natural selection by (gradual) evolution imposes important constraints

    – Species are not perfectly adapted