Introduction to Biological Anthropology: Notes 5

What are species and how do they arise?

- Two ways to look at evolution
  - We can look at it up close
    - as we did with the minor variations in the beaks of finches over just a few generations
    - or even the gradual evolution of the human eye
    - What we see in the close-up, short-term, detailed view is called **microevolution**
      - **Microevolution** = evolution within a species (changes in a population that do not result in a new species)
      - Microevolution usually refers to changes that are often small and not very important in themselves
        - like the beaks of the finches on Daphne Major.
      - microevolutionary changes are often fairly easy to understand in terms of Darwin's theory the process of natural selection
  - or we can step back and look at long-term changes in populations that are visible in the fossil record
    - that is, the kind of evolution that explains why there are many different, distinct kinds of plants and animals
    - What we see in the long-term view is the appearance of new species
      - **Macroevolution** = evolution that creates new species, and groupings of related species (genera, families, etc.)
      - Darwin suggested that the accumulation of a lot of small microevolutionary changes ought to add up to bigger, more obvious differences
        - Eventually, to entirely new species
        - given enough time, the accumulation of microevolutionary changes in many different populations ought to create countless different species with all sorts of different features
      - which is precisely what Darwin originally set out to explain: the profusion of different species of plants and animals, each adapted to its environment

- So let’s now consider macroevolution:
  - that is, the “Origin of Species” that Darwin wrote about

- So, what are “species”?
  - Preliminary definition: **Species** are (usually) easily distinguishable types of organisms (I’ll define this better later)
    - The notion of species has two key parts
      - individuals of the same species are *similar to each other*
      - individuals of one species are *different from* individuals of other species
    - there are (usually) no intermediate types
      - no gradation from one species to the other, but rather a gap
      - no intermediate forms that are hard to classify as one or the other species
      - there are gorillas and there are chimps, but no “gimps” or “chorillas”

- – this is curious
  - – why are there distinct *kinds* of organisms (species), rather than a smooth gradation of characteristics like we see among individuals within a single species?
  - – why are there no chorillas?
- – by and large, species are real categories that exist in nature
  - – unlike many categories used by scientists, species aren't just invented for the sake of convenience
    - – living things really fall into distinct, well-defined categories
- – There are a number of different definitions of species.
  - – amazingly enough, there is actually still a lot of debate about what these distinct kinds of organisms really are
  - – and although they seem easy to observe, in some cases there is still room for disagreement
  - – for a summary of some of this debate, see:
    - – http://www.talkorigins.org/faqs/speciation.html
  - – we will consider just the two most interesting of the leading concepts of species:
    - – the **biological species concept**
    - – the **ecological species concept**

– But first, we need to understand two useful ideas

- – **reproductive isolation**: members of one population do not interbreed successfully with members of another population
- – **gene flow**: the movement of genes among individuals and groups
  - – from parents to offspring, that is, the mixing of genes through mating
  - – or from one population to another, by individuals leaving one group and joining another, or by mating between members different groups

– The **biological species concept**

- – "A species is a group of organisms which interbreed in nature and are reproductively isolated from other groups"
  - – this is by far the most widely accepted species concept, but not the only one
- – according to this view, members of a given species are *similar to each other* because they interbreed
  - – the traits of all members of the species are continually getting mixed together, so the population remains a single, fairly uniform group
- – according to this view, species are *different from other species* because there is no interbreeding between different species
  - – there is no exchange of genes between one species and another, so traits don't get mixed between them
  - – there are no "chorillas" because gorillas and chimps never mate
    - – so there is no way for a gorilla to have offspring with characteristics unique to chimps
  - – each reproductively isolated population is free to evolve in its own direction, leading to big differences between species
- – The biological species concept emphasizes patterns of **gene flow** as the main thing that defines and maintains distinct species

    - according to the biological species concept, there is gene flow *within* species, but *not between* species
    - the gene flow keeps all organisms in one species similar; all reflect more or less the same gene pool
    - while the lack of gene flow between different species means that they remain different, without mixing together
  - a note about reproductive isolation
    - populations may be reproductively isolated in many different, often subtle ways
    - in the most obvious case, they may be so different physically that they simply cannot mate, or that even if they do, the offspring do not survive or are not fertile
    - but isolation is just as complete if they simply do not mate for some other reason
      - for example, if one population is active in the day, and the other at night
      - or if two populations of birds develop preferences for different colors of feathers, and the birds only choose mates of their own type
      - even though they could be made to successfully mate in a lab or on a farm, if they do not actually mate in nature, they are effectively isolated
- The **ecological species concept**
  - "A species is a group of organisms that is genetically distinct from other species because any hybrids between species are much less successful"
    - This is a much less common, somewhat radical view
    - but it is worth looking at
  - according to this view, members of a given species are *similar to each other* due to stabilizing selection
    - stabilizing selection favors the typical type
    - while weeding out any variants
  - according to this view, species are *different from other species* because
    - any hybrids with other species are less successful
    - and are weeded out by natural selection
  - the net result is similar to the biological species concept, but it emphasizes stabilizing selection, rather than gene flow
    - stabilizing selection keeps members of the species similar
    - and weeds out any hybrids, maintaining the difference from other species
  - this explains how even if a species is divided into physically isolated populations and there is no gene flow between them, the two populations often still remain the same
    - because they are experiencing the same stabilizing selection pressures
  - the idea here is that most species are at or near an adaptive "optimum"
    - any change would reduce their fitness, so stabilizing selection keeps the characteristics of each species where they are, and keeps the various species different
  - support for this still somewhat radical viewpoint:
    - 1. Many related species are known to actually hybridize in the wild, yet they don't blend together into one intermediate species
      - because selection weeds out the hybrids?
    - 2. Separate populations of the same species that are isolated from each other by geography often do not diverge

- – something keeps them the same in spite of a total absence of gene flow
- – for example, rainbow trout in different rivers cannot interbreed because they never encounter each other, yet they all remain rainbow trout
- – the populations in the different rivers don't all evolve off in different directions, even though they theoretically could
- – because stabilizing selection keeps them at their adaptive optimum?

– 3. Asexually reproducing organisms are divided into species just like sexually reproducing ones
- – in asexually reproducing organisms, offspring bud or split off a single parent
  - – the offspring is a clone of the parent, genetically identical to it except for occasional copying errors
  - – examples of asexually reproducing organisms: bacteria, fungi, flatworms, many plants under certain circumstances, etc.
- – So there is no mixing up of genes throughout a population, as there is with sexually reproducing organisms
  - – why don't the descendants of each asexual parent each evolve off in their own direction?
  - – why do all the members of the species remain similar to each other?
  - – since there is no mating, there is no gene flow to keep them similar…
  - – yet (asexual) shiitake mushrooms remain shiitake mushrooms wherever they are, generation after generation
- – the likely answer: because stabilizing selection weeds out any variants that arise through errors in reproduction
- – if this were *not* true, then
  - – each lineage of asexual organisms should evolve off in a different direction
  - – this would create a continuous range of variation among asexual lineages
  - – rather than what we actually observe:
    - – many separate lineages of the same kind (species), and no lineages with forms intermediate between species

– Which species concept is correct?
- – undoubtedly both
- – the question is only which processes are more important in a given case
- – in many cases, reproductive isolation (the biological species concept) must play a role
  - – since many species ARE totally reproductively isolated
- – but stabilizing selection must play a role in many cases, too (the ecological species concept)
  - – because gene flow among all members of the species is often minimal or impossible, yet they remain the same species
  - – and many species remain different from each other, even though they do hybridize

– Why do these species concepts matter?
- – Your choice of which process you think is most important in separating and maintaining species in nature affects on how you explain the origin of new species

– Why do species exist at all?

- **speciation:** the development of a new species
- speciation is hard to study
  - it is too *slow* and/or too rare to observe easily in nature
    - most cases of speciation being observed in nature have only "observed" in the sense that new species were seen where they had not existed before; no one happened to be collecting data precisely when it happened
  - and too *fast* and/or too rare to observe in the fossil record
    - usually, fossils of a new species just appear; we generally don't find a nice sequence of fossils leading from one species to the next
      - although there are some known examples of gradual speciation in the fossil record (among marine shellfish, ancestral horses, pigs, and others)
    - this is what we would expect species normally did not change much, and speciation only happened occasionally
      - because the number of individuals involved in the transition would be very few, compared to those involved in the long period of stability
      - so the chance of finding fossils of those few transitional individuals would be low
- Two senses of the concept of speciation: **anagenesis** and **cladogenesis**
  - **anagenesis**: the evolutionary change of a population over time
    - example: say we have a long time to watch a population of rodents
      - they start off the size of mice
      - natural selection favors larger ones for some reason
      - after 5000 generations, they have evolved to the size of house cats
      - we may want to call these a different species
    - if we decide to consider the cat-sized rodents a new species, it would be a **chronospecies** (also called **paleospecies**)
      - **chronospecies**: arbitrary divisions of a lineage of a single population into two or more "species", in order to reflect gradual changes over time
        - because after enough change has accumulated, we don't want to call the later form by the same name as the earlier one, because it is clearly different
    - but chronospecies do not fit the biological species concept
      - we assume that they would not be able to mate with their mouse-sized ancestors, but there is no way to check
        - since the two types never lived at the same time
        - in fact, it is meaningless to discuss reproductive isolation in this case
          - since the first and last generations could not mate with each other regardless of whether they had changed or not; they did not live at the same time
      - also, every generation could presumably mate with the ones just before and just after
        - there is no sharp dividing line between chronospecies
        - but there *are* sharp divisions of reproductive isolation between living species
    - chronospecies do not fit the ecological species concept, either
      - again, the different chronospecies did not live at the same time
        - so there were no hybrids that could have been less successful, and no selection acting on hybrids
    - Chronospecies are just arbitrary categories imposed by scientists

- while species that live at the same time,
- defined by the biological or ecological species concepts,
- are real, distinct categories “out there” in nature
- finally, anagenesis only describes how a population changes over time; it does not explain the increase the number of different populations (species) over time
  - if this were the only process, and life originated on earth just once, there would only ever be one species at a time
- we need to explain how new species are added
  - how species split into multiple descendant species
- **cladogenesis**: the splitting of one species into two (or more) species
  - this is what we usually mean by “speciation”
  - two populations of a species diverge enough that they no longer successfully mate
    - one or both have changed
    - where there was a single species before, now there are two (or more)
    - both populations exist at the same time, but they do not interbreed
  - a **clade** is a descent group of species
    - all the species that descended from a specified ancestral species
    - like a branch of a family tree
    - we’ll get back to clades later in the course
- there are three spatial situations in which speciation (cladogenesis) might occur
  - **allopatric** speciation: “in different territories”
  - **parapatric** speciation: “in adjacent territories”
  - **sympatric** speciation: “in the same territory”
  - these differ mainly in the amount of physical separation they require between the diverging populations
- **allopatric speciation**: speciation that occurs when two populations that are geographically isolated from each other diverge far enough to form distinct species
  - “allopatric”: “in different territories”
    - the two populations are separated by a physical barrier or great distance, like lizards on two different islands, or fish in two different lakes
    - causing them to be reproductively isolated from each other
  - if the selection pressures on the two isolated populations are different, the two populations are free to evolve in different directions
  - if they diverge far enough, they have become separate species
  - this process is especially likely to happen in small, splinter populations
    - because small populations can evolve more rapidly than large ones
    - in large populations, new variants tend to get diluted away by gene flow with the many other individuals
    - while a new variant in a very small population can more rapidly become the common type
  - a hypothetical bird example
    - finches from a wet island get blown to a dry island.

    - selection on the dry island favors deeper beaks, and the bird population evolves deeper beaks
    - eventually they are so different from the parent population that, even if they somehow get back together on a single island,
      - they are reproductively isolated for physiological or behavioral reasons (biological species concept)
      - or the hybrids between the two are not very successful, so the two species don't blend back together (ecological species concept)
    - speciation does not *necessarily* happen when two populations are isolated; it depends on enough evolution occurring in one or both of the populations.
      - if conditions are similar for both populations, the same kind of stabilizing selection acting on both populations may keep them the same
      - then they just remain two populations of the same species
- pretty much everyone agrees that allopatric speciation actually occurs in nature
  - this is the simplest, least controversial speciation process
- The other two spatial patterns of speciation may or may not actually occur
  - they are debated, both theoretically and with field data
  - There is some evidence that parapatric speciation may occur
    - but it is probably rare
  - It is not certain that sympatric speciation can occur at all
    - if it does, it is probably rare
- **parapatric speciation** ("in neighboring territories"): speciation that occurs when two populations that live in adjacent, bordering territories with no barrier between them diverge far enough to become distinct species
  - for example, a population lives both in a forest and in the grasslands next to the forest
    - there is no barrier between them
    - gene flow occurs between the areas, because all are free to mate with each other
    - this should keep their traits all mixed together
  - so how could they diverge into different species?
    - individuals far from the border are more likely to mate with each other that with individuals from the other environment
      - so the two areas are partially isolated
    - the two parts of the population experience selection that favors different characteristics suited to each environment
    - and the limited gene flow between them is not enough to prevent the two parts of the population from diverging somewhat
    - near the boundaries, in the **hybrid zone**, some hybrids will be born
    - if these intermediate types are less successful than the more specialized offspring of parents that are both from the same environment…
      - then natural selection will tend to weed them out
    - leading to two new, different species: speciation
  - in fact, this relatively lower fitness in individuals from hybrid zones is actually observed in many natural cases, so parapatric speciation probably actually occurs

- **sympatric speciation** ("in the same territory"): speciation that occurs when members of a single population occupy different ecological niches in a single area
  - (**niche**: the combination of food, habitat, behaviors, etc. exploited by an organism)
  - such as some living up in the trees, others living on the forest floor
  - the same processes as in parapatric speciation could occur
  - but many biologists doubt that a population could develop two types without some isolation to start with
  - it is not certain that sympatric speciation actually occurs in nature

- An additional useful concept
  - **adaptive radiation**: the rapid divergence of populations of a single species into numerous new species, to take advantage of many newly available ecological options (niches)
    - typically would happen when an organism is first introduced to a new environment, or the environment changes drastically
    - in this new environment, there may be many different adaptations that could work well
    - partially isolated populations of the new organism happen to diverge in many of these different directions
    - leading to numerous new species that are all descended from the original one
    - once most of the available options are taken by new, specialized species, the process of creating new species slows or stops
    - an example that apparently happened on the Hawaiian Islands
      - a small population of one type of finch got to Hawaii, maybe blown in a storm
      - there were no other birds there
      - there were many possible ways for birds to make a living
        - specializing in small, soft seeds; or large, hard seeds, or soft fruits; or hard fruits; or flowers; or insects…
        - and all were available without much competition
      - some or all of the processes of speciation took place (allopatric, parapatric, and/or sympatric)
      - the bird population quickly diverged into many different species, each well adapted to exploit one ecological option (niche)
    - once most or all of the niches are filled, speciation slowed down or stopped
    - we will see that adaptive radiations were important in the evolution of humans