Unit 2: Introduction to Conservation & Biodiversity

See topic and resource outline for readings, activities

I. Overview: In this unit, we'll introduce some basic issues of conservation biology and discuss the origins of biodiversity. Over the course of the semester, we'll explore each of the conservation issues in more depth, including learning more of the specific biology underlying each one. We'll start a little backwards, with questions about conservation first and the origin of biodiversity second.
   A. What is biodiversity?
   B. How are we doing when it comes to managing the earth's resources and services?
   C. If we're not doing well, what are the problems and their causes?
   D. If we're not doing well, why should we care? What difference does it make to our daily lives if species go extinct or habitats are destroyed?
   E. What, if any, are the solutions?
   F. Where does biodiversity come from? How do species form and how do they go extinct?

II. What is biodiversity?
   A. Simply put, it's the diversity of living resources on the planet.
   B. More specifically, we can identify 3 levels of diversity:
      1. Genetic diversity is variation at the DNA level – among individuals within species and among species.
      2. Species diversity is what we usually think of when we think of biodiversity: it's the number of different kinds of species present on earth.
      3. Ecosystem diversity is the diversity of large-scale networks of organisms (along with the abiotic environment).

III. We're not doing well on any level; for now, we'll focus just on species diversity.
   A. Biodiversity loss: background:
      1. Currently, we've named ~ 1.5 million species of plants and animals; we estimate between 3 and 30 million actually exist

2. Extinction is a natural process
    a. The “average lifespan” of a species is 1-10 million years
    b. Historically, extinctions can be divided into relatively low “background” levels and the “big five” mass extinction events – relatively short (a few million years) periods when huge numbers of species went extinct over very large areas
    c. According to worst-case projections, current extinction rates are 100-1000x the normal background rate; this will qualify as a mass extinction event if continued over the next century or two (but see Sci American article for alternate views)
    d. Note that recovery to normal diversity levels after such an extinction event would take 10-100 million years!
3. What species are at risk? The rarity (hence, vulnerability) of a species is a function of 3 factors:
    a. Geographic range: species with large ranges are at less risk than species with small ranges
    b. Habitat tolerance: species with broad habitat tolerances are at less risk than species with narrow tolerances
    c. Population size: species with large population sizes are at less risk than species with small population sizes
    d. Taken together, get 8 combinations, 7 with at least one form of rarity – so lots of species can be rare!

	Geographic Range			
	large		***restricted***	
Population size	***broad habitat***	***narrow habitat***	***broad habitat***	***narrow habitat***
large population	not rare starlings, "weeds"	1 form red mangrove	1 form Galápagos medium ground finch	2 forms giant redwood
small population (many top predators)	1 form tiger	2 forms Northern spotted owl	2 forms Tasmanian devil	3 forms most lemurs

(1) Species with broad geographic ranges, broad tolerances, and large populations are the only ones not facing potential risk – as we'll see later, these "weeds" are also excellent invasive species.

(2) Everything else faces some potential risk

(3) Most at-risk = "island" endemics: species that live only in one kind of habitat in one restricted place –

(a) a true oceanic island (the Hawaiian islands, e.g., had many species of birds found nowhere else and now extinct), or

(b) an isolated "island" of habitat on a mainland (e.g., some salamander species are unique to individual Appalachian mountain top habitats)

4. What are the ultimate causes of biodiversity loss? "HIPPO" with letters rearranged: **P**opulation growth, **H**abitat loss,**I**ntroduced species, **P**ollution, **O**verexploitation

B. The problems one at a time:

1. Human population growth drives everything else because it drives resource use, habitat exploitation, etc.

   a. For now, the important thing to note is that human populations are growing nearly exponentially, and population growth has slowed only a little and only recently (but size is still growing).
   b. We'll discuss specific patterns and implications in the next unit.
2. Habitat loss is the biggest immediate threat for most species
   a. Habitat is lost as it is converted to, or degraded by, human use
   b. Currently, ~ 50% of the land surface of the earth has been altered by humans
   c. All habitat types are affected, with wetlands hardest-hit globally
   d. Global forest loss is another example – deforestation is a problem in every forest type worldwide
   e. Fragmentation is another form of habitat loss – when habitats are broken into disconnected "islands", less diversity can be supported (even if total area stays relatively large)
3. Introduced species are the second major threat for most species – introduced species disrupt the "normal" interactions of species in natural communities.
   a. The problem arises when new predators or better competitors are introduced into novel habitats – on purpose or accidentally.
   b. Once introduced, successful "invaders" can
      (1) outcompete or overexploit native species
      (2) change the habitat so much that native species can no longer survive
4. Pollution takes many forms and has many effects
   a. Types include toxics (pesticides, industrial waste, etc.), nutrients (from fertilizers), sediments
   b. Effects range from immediate kills to indirect effects on non-target species

c. Biomagnification is a problem for many long-lasting toxics, including toxics that mimic hormones and therefore disrupt important endocrine system functions.

d. We use hundreds of millions of tons of pesticides alone – combined with other toxics and forms of pollution, huge load!

e. "Natural" experiment: what will the effects of pumping contaminated water from New Orleans be on Lake Ponchartrain?

5. Overexploitation = removing resources from the environment faster than they can be replaced. E.g., ~ 75% of world's marine fisheries are fully exploited, overexploited, or severely depleted. Other resources prone to overexploitation include

   a. living resources:

      (1) Forest products (timber, plants)

      (2) Animals for food, ornaments (skins, e.g.), pets (especially birds and reptiles)

      (3) International treaties (especially CITES) protects many species, but consumer demand drives a thriving black market in many products.

   b. non-living resources:

      (1) fresh water (groundwater) is being removed from aquifers faster than it can be replaced; water from rivers, etc. is being diverted to human use, leaving freshwater habitats badly degraded

      (2) fertile soil is lost to erosion, even with good tilling practices, faster than it can be replaced

IV. Why should we care? Many reasons to value biodiversity/ecosystem services:

A. Economic: biodiversity and ecosystem services are critical to human welfare (text 38.2)

1. Ecosystem services:

a. "**Ecosystem services**" are processes that take place in intact, functioning ecosystems and that provide a direct benefit to humans and other organisms

b. Important examples are things we can't live (well) without:

(1) clean air (plants in intact systems clean pollutants from air)

(2) clean water (wetlands, especially, filter water)

(3) fertile soil (intact ecosystems both generate soil and prevent erosion)

(4) decomposition of waste (soil bacteria and insects as well as large decomposers both keep waste from piling up and recycle nutrients)

(5) crop pollination (many economically valuable crops rely on "wild" insect and other animal pollinators)

(6) protection from UV radiation (plants generate oxygen, which generates the ozone layer that protects us)

c. Economists and ecosystem scientists have worked together to try to estimate the dollar value of some of these services – trying to replace those services with "man-made" infrastructure would cost about double the earth's gross economic output ($33 trillion in cost vs. $18 trillion in output in 1997) .

2. Species diversity is important to us independent of ecosystem services for several reasons:

a. Food production: all domestic crops are descended from "wild" species.

(1) The only way we maintain health and vigor in domestic crops is to maintain their genetic diversity – and that means preserving their native "ancestors" in their original habitats.

(2) Where does diversity come from? Wild "ancestors" and

"landraces" = local varieties grown in many different environments for different purposes

(3) Loss of genetic diversity means crops that can fail across entire regions when a genetically uniform monoculture is "attacked" by a disease or pest

(4) e.g. – U.S. corn is genetically very uniform; in 1970, a particularly virulent strain of Southern Corn Leaf Blight (fungus) wiped out much of the corn crop in the southern U.S. – cost about $1 billion in losses! Ancestral corn comes from Mexico; landraces in Central, South America, parts of U.S.

(5) Wild relatives harbor other useful genes: e.g. – Sarah Darwin, great-great-etc. granddaughter of Charles, is working on genetics of Galápagos tomato that seems to have genes for salt tolerance. This could be extremely valuable for farmers with otherwise marginal soils – but the species is being lost via hybridization with introduced garden species.

b. Modern medicine: We depend on "biochemical diversity" of microbes, plants, and animals, especially for modern medicine

(1) Antiobiotics are the chemical defenses soil bacteria and fungi use against one another

(2) In the U.S., ~ 25% of prescription drugs come from plants or synthetics based on plant compounds – including some of the best new chemotherapy agents.

(3) Neurotoxins and other compounds found in toxic/venemous species critical for research into neurology and neurological diseases, pain management, and more

B. Aesthetics & Ethics: Nature in the form of undisturbed landscapes and species diversity has important values beyond the economic.

1. Simplest version: nature is beautiful; we have an ethical responsibility to

preserve that beauty

2. More complex version recognizes set of related arguments that include ethical, aesthetic and social justice values (from Jepson and Canney, 2003, Values-led Conservation. Global Ecology and Biogeography, 12(4): 271):
   a. Because humans have "conquered" nature, we have a moral obligation to protect the other life forms on earth (we are the stewards/caretakers). This view (or similar ones) is integral to many religious faiths as well as being a secular belief.
   b. The wanton consumption/killing of wildlife is uncivilized.
   c. The aesthetic/intellectual contemplation of nature is integral to the well-being of people in many cultures; great works of nature, like great works of art and architecture, should be preserved for their beauty and power to inspire.
      (1) Note that this view stems from individual experiences of nature – from the feelings many of us get from being in natural spaces.
   d. Society has a moral duty to permit traditional peoples inhabiting natural landscapes to choose their own paths to development (or not) in ways that are appropriate to their history, culture, and values – which may require protecting those landscapes.
   e. Finally, for many religions (including the Abahamic religions), nature/natural landscapes have important spiritual value (goes along with #c above).
3. Interestingly, these values are often more compelling for many people than the straight economic arguments – but they're harder to use to implement policy at a time when global economic forces seem to drive everything!

V. What can we do?

A. Education: learn about where the resources we use come from & the consequences of using them; change consumption patterns

B. Regulation: legal and policy changes do work!

C. Preservation: many organizations are developing practical ways to preserve natural resources while improving local economies

VI. *Summary:*

1. *We are not doing a good job of managing our natural resources; the loss of biodiversity and the degradation of ecosystem services are our two most pressing problems.*

2. *We should value ecosystem services and biodiversity for a number of different (but often related) reasons.*

   a. *Economically, we depend on intact ecosystems and a diversity of species for everything from fresh air to pharmaceuticals.*

   b. *Natural landscapes also have aesthetic, social justice, and spiritual values; many believe we have a moral/ethical obligation to protect and preserve them.*

3. *To reverse the current trend, we can educate ourselves and change our consumption patterns, support appropriate legal and policy changes, and support conservation organizations developing practical preservation strategies.*

VII. Overview for the next section on the origin and extinction of biodiversity: In this next section, we'll look at where biodiversity comes from (how new species form) and how it disappears (how species go extinct). These topics fall under the heading of "macroevolution"; to explore them, we'll look at

A. The evidence for descent with modification: how we know that existing species originated from previously existing species.

B. The process of speciation: how new species arise from previously existing species.

C. The process of extinction: from long-term events to the "last gasp" of a species

VIII. Within about 10 years of publishing "The Origin of Species" (published in 1858), Darwin had convinced most of the scientific community that existing species had arisen from pre-existing species. He did this by using, for the first time in an extended argument, the kind of hypothetico-deductive reasoning we discussed earlier.

A. Darwin’s basic approach was to:

1. Establish two competing hypotheses:

   a. **Descent with modification**: existing species are descended from previously existing species and are changed by natural selection over time

   b. **Special creation**: all species were created by a divine creator in a manner consistent with Biblical accounts and designed to “fit” their particular “roles” in the habitats in which they live.

2. Test the competing hypotheses by examining a wide range of evidence against specific predictions of the two hypotheses.

   a. Of course, we would now recognize that special creation is not a scientific hypothesis (why not?) – but the approach is still useful.

   b. Even in Darwin’s time, the evidence overwhelmingly supported descent with modification; to date, no piece of evidence has been found that falsifies it.

3. We don’t have time to look at every piece of evidence, but we can look at most of the major “categories” of evidence – some of which Darwin used and some of which are more recent.

B. Evidence #1: **age of the earth**

1. Predictions

   a. Descent with modification requires lots of small changes over long periods of time; if Darwin’s hypothesis is correct, then the earth must be very old.

   b. Special creation stipulates a young earth – 10,000 years or less, depending on whose version one uses (in Darwin’s time, the young earth was ~ 6000 years old).

2. Evidence from geology: if we apply the principle of uniformitarianism to geological features, we must conclude that the earth is old (this conclusion was reached in the 1700's, even before Darwin)
   a. We can measure how long it takes specific geological processes to produce specific kinds of geological features (e.g., how long it takes sediment to erode from a mountain; how long it takes volcanoes to form; etc.)
   b. The principle of uniformitarianism states that these same processes must have operated the same way in the past.
   c. When we measure existing geological features against known rates, we must conclude that the earth is very old: 2 examples
      (1) Erosion of the Grand Canyon by the Colorado River estimated at ~ 6 million years (rocks are several hundred million years old, though!)
      (2) Deposition of chalk cliffs in England: chalk is accumulated skeletons of microscopic organisms; age of cliffs estimated at ~ 70-100 million years old
3. Evidence from chemistry/physics = radiometric dating also relies on uniformitarianism in the behavior of atoms
   a. Radiometric dating relies on understanding how the nuclei of atoms change over long periods of time
   b. Many different kinds of atoms “decay” (change), and they change over different time scales – e.g.
      (1) the most common form of carbon changes over a time scale of 10's of thousands of years
      (2) a common form of uranium decays to a form of lead over 100's of millions of years
      (3) other elements decay over time scales of billions of years
   c. By comparing the ratios of “parent” to “daughter” elements in rocks

and other structures, we can estimate their ages

d. Innumerable tests of many different kinds of rocks and meteorites using many different elements confirm that the earth is about 4.5 billion years old

4. Conclusion: the earth is very old, as predicted by descent

C. Evidence #2: the **fossil record** reveals several patterns predicted by descent but not by special creation

1. Special creation predicts, at best, a single extinction event (the Noachian Flood); descent predicts long process of extinction and change over time

   a. The fossil record documents huge number of extinctions over long periods of time

   b. so the simple fact that we can document an enormous number of species that have gone extinct over hundreds of millions of years supports descent over special creation

2. Descent predicts that fossils will be found in a specifically ordered historical sequence:

   a. prediction = most recent fossils will most closely resemble modern (extant) species; differences will be greater as we go further back in time.

   b. prediction is met in every group – e.g., horses (see figure 14.13 p. 304)

3. Descent predicts that fossils within a single geographic region will resemble modern species in that region more than they do modern species elsewhere (because the modern species are descended from the older species)

   a. e.g., Darwin studied armadillos in Argentina, found they were more similar to fossils (glyptodonts) from the same region than to living or fossil organisms from anywhere else

4. Descent predicts that the fossil record will include transitional species =

organisms with characteristics of both "ancestral" and "descendant" forms

a. not predicted at all by special creation, but predicted by descent with modification

b. examples are very numerous, especially in vertebrates – we have well-documented transitional forms, e.g.:

(1) between fish and amphibians

(2) between amphibians and reptiles

(3) between reptiles and birds

(4) between reptiles and mammals

c. one fairly recent e.g. = transitional whale fossils showing change from terrestrial to fully aquatic form

D. Evidence #3: Patterns of **biogeography** (the geographic distribution of species) meet the predictions of descent, not special creation

1. special creation predicts that organisms will be most similar in habitats with similar environments (think why)

2. descent with modification predicts that organisms will be most similar in regions representing places of origin and subsequent dispersal

3. evidence supports descent.:

a. Plants and animals on the same continent are more similar to each other, even when their environments differ, than they are to species on other continents whose environments differ – e.g.:

(1) special creation predicts that organisms in African tropics will be more similar to organisms in SA tropics than they will to organisms in African deserts (because of similarities/differences in environment)

(2) descent with modification predicts that organisms in African tropics will be more similar to organisms in African deserts than to organisms in SA tropics – because they are more likely to share a

common ancestor

(3) In fact, African organisms are more similar to each other, as are SA organisms (Darwin observed this and similar patterns)

b. Plants and animals on islands are more similar to those on the nearest mainland (the source populations) – even when the environment is different – than they are to distant islands with similar habitats – e.g.:

(1) Darwin noticed that plants, animals on the Galápagos islands were similar to those on SA mainland, even though the environment was very different

(2) African islands with environments similar to Galápagos still had plants/animals resembling those on African mainland, not Galápagos

E. Evidence #4: patterns of comparative anatomy are best predicted by descent, not special creation

1. To understand this type of evidence, we need to introduce the concept of **homology** = features of organisms that share fundamental similarities in terms of the number, kind, and arrangement of structural components, even when

a. structures superficially different and

b. structures have different functions

2. Examples of homology include:

a. homology in the bones of vertebrate forelimbs

b. homology of plant parts (e.g., flowers, climbing tendrils, and leaves are homologous structures)

c. We also have many, many examples of biochemical homology, with more being uncovered nearly daily due to advances in molecular genetics

3. Special creation doesn't explain homology well: if organisms are specially created to "fit" their function/role in the environment, then predict

fundamental differences in development and structure when functions are vastly different (e.g., digging vs. flying vs. swimming vs. running)

4. In contrast, descent with modification predicts two important patterns that have been widely documented across every group of organisms:
    a. The presence of homologies themselves: descent predicts organisms descended from a common ancestor will inherit fundamental characteristics; superficial differences are due to natural selection adapting them to different situations
    b. concordance of patterns produced by different homologies:
        (1) We can examine the homologies in one characteristic – say, skeletal structure – in a group of organisms and use them to create a "genealogy" of the organisms: the organisms with the most homologies in common are the most closely related
        (2) We can then examine another homology – say, protein structure – in the same group of organisms
        (3) Special creation predicts no relationship between the two types of characteristics
        (4) Descent predicts that both will produce the same pattern, since both are produced by the same process (descent with modification).
        (5) In fact, we find that different types of homologous structures produce very similar patterns of genealogy, again supporting descent.

F. Evidence #5: **Vestigial structures** (more evidence from comparative anatomy)

1. Vestigial structures = functionless or rudimentary version of a body part that has an important function in closely related species
2. We know of many, many examples of these, including:
    a. reduced or absent eyes in cave-dwelling animals (fish, salamanders, insects, crustaceans)

b. reduced wings in flightless birds, insects

c. human tail bones, "ear wiggling" muscles, appendix

d. vestigial legs in snakes

e. pseudogenes = lengths of DNA that don't code for functional proteins

f. developmental vestiges – e.g., notochords, pharyngeal pouches in humans

3. Special creation predicts that vestigial structures shouldn't happen at all because species are intelligently designed for specific functions

4. Descent with modification predicts vestigial structures as features inherited from a common ancestor and changed over time as their use changes.

G. Summary:

1. Within about 10 years of publishing "The Origin", Darwin had convinced the scientific community that descent with modification was true beyond a reasonable doubt. We now accept as fact that

a. All living things are related by descent in an unbroken chain back to the first living things.

b. Organisms have changed over time (via natural selection).

2. Darwin convinced his contemporaries using hypothetico-deductive reasoning, showing that descent with modification predicted many patterns in nature that special creation could not. We now include among those patterns

a. the age of the earth;

b. the fossil record;

c. biogeography;

d. homology;

e. vestigial structures.

IX. Speciation is the process by which one species gives rise to one or more "daughter" species. Over the last 3.5 billion years, speciation combined with change has produced the diversity of life on earth.

A. To understand speciation, we need first to define what we mean by "species."

1. This is actually a complex question that we will simplify – it's complex because organisms are complex and don't all "work" as simply as we'd like!

2. To simplify, we'll use only one of many possible definitions based on the biological species concept (BSC): ***A species is a group of actually or potentially interbreeding natural populations reproductively isolated from other such groups.***

3. This definition includes two important components:

a. A species almost always consists of more than one population whose members interbreed with one another.

(1) In genetic terms, interbreeding means that genes are exchanged among populations.

(2) We call the exchange of genes via interbreeding **gene flow** – as we'll see, it's an important process for more than just speciation.

b. The populations of a species interbreed with one another, but not with populations of other species.

(1) This means that novel traits that arise in one species AREN'T shared with others.

(2) That, in turn, means that species will change over time independently of one another – they will diverge and become more different as they continue to evolve.

B. Speciation is a three-step process – these steps are always necessary, even though the mechanisms for each step to gen may vary

1. The establishment of a **barrier to gene flow** leads to genetic isolation among populations

2. Disruption of gene flow leads to the genetic (and consequently morphological, behavioral, ecological, etc.) **divergence** between species.

a. In general, isolated populations face different selection pressures, so different traits are favored in each one.

b. Because they can't exchange genes, traits arising in one set of populations aren't shared with the others – so each group of populations changes in its own way.

3. If divergence continues long enough, populations will become **reproductively isolated** – i.e., won't be able to interbreed even if members come into contact.

4. Once reproductive isolation is achieved, speciation has occurred.

C. Many different mechanisms of speciation have been identified based on how the original barrier to gene flow is established. We'll look just at one of the most widespread: **allopatric ("different country") speciation**

1. In **allopatric speciation** , the barrier to gene flow is geographic/climatic (e.g., mountain range, river, desert, etc.) = physical isolation

2. barriers may arise via one of two processes – **dispersal** or **vicariance**:

a. **dispersal** = movement of individuals to previously unoccupied habitat; the classic e.g. = organisms colonizing new islands

(1) e.g., fruit fly radiations in Hawaiian islands

(a) over 500 named species + ~ 350 still waiting to be formally described; huge ecological variation among species

(b) leading explanation for extreme diversity is that islands (and habitats within islands) were successively colonized by small founding populations, each of which was then physically isolated from its source

(2) e.g., Darwin's finches on the Galápagos islands

(a) 14 different species occupying a range of habitats and using a variety of different types of food

(b) All descended from a small population from the South American with speciation driven by isolation following colonization of different islands.

b. **vicariance** (don't worry about the term) = geologic and/or climatic events that create physical barriers to gene flow (e.g., mountain uplift; climate change; rise in sea level; etc.)

(1) Examples of vicariant events include geologic events such as:

(a) Establishment of the isthmus of Panama separated marine organisms into Caribbean and Pacific populations

(b) Splitting up of supercontinent Gondawanaland separated South America, Africa, Australia, and Antarctica

(2) They also include climate events, such as climate change during the Miocene

(a) This caused the central U.S. to become much warmer and drier and converted woodland to arid grassland

(b) This, in turn, isolated organisms requiring cooler, moister habitats – they "retreated" up mountains and became isolated on mountaintops

3. Whatever the barrier, the result is the same: physical isolation disrupts gene flow among populations – this permits divergence and reproductive isolation to evolve.

4. Note that this all takes a long time – many hundreds of generations at a minimum; longer in most cases – so we can see examples of groups of populations in which the process is incomplete.

D. Reproductive isolation: for speciation to be complete, divergence must eventually lead to mechanisms that prevent gene flow even when groups come back into contact.

1. For our purposes, "successful interbreeding" means producing fertile, viable offspring – reproductive isolation prevents that

a. e.g. – horses can breed with donkeys, but mules are sterile. So even though they have healthy offspring, they aren't really interbreeding

2. We currently divide mechanisms of reproductive isolation based on whether or not hybrid fertilization takes place.

   a. **Pre-zygotic isolating mechanisms** prevent mating or fertilization:

      (1) **Habitat isolation**: different populations may live and/or breed in the same general area, but not the same specific places – so they don't tend to "find" one another to interbreed.

         (a) e.g., subway mosquitoes in chapter opening essay

         (b) e.g., terrestrial vs. aquatic garter snakes

         (c) e.g., parasites confined to a single species of host plant or animal

      (2) **Temporal isolation:** breeding (mating or flowering) occurs at different times of the day or during different seasons

         (a) e.g., some flowering plants only open their flowers at night; others open during the day

         (b) e.g., many species of salamanders and frogs breed in the same ponds, but at different times of the year

      (3) **Behavioral isolation**: behavioral differences prevent individual of one species from "recognizing" or being attracted to individual of another species

         (a) e.g., many species of birds, insects use elaborate "courtship rituals" that differ among species; the correct ritual is necessary for breeding

         (b) Odor cues, like female pheromones, also fall into this category.

      (4) **Mechanical isolation**: anatomy of genitalia or flowers prevents copulation or pollen transfer

         (a) This is common in plants, especially those whose flowers are adapted for pollen transfer by only one species of animal

(5) **Gametic isolation**: gametes can't unite to form a zygote (fertilized egg). This generally happens because

(a) recognition proteins on sperm, egg, incompatible

(b) sperm are inviable in female reproductive tract (animals) / pollen is incompatible with style tissue (plants)

b. **Post-zygotic isolating mechanisms** prevent viable, fertile adults from developing. In these cases, a hybrid zygote forms, but has reduced fitness at some stage of development (because its parental genes are fundamentally incompatible). We divide these mechanisms based on when the hybrid stops "fuctioning" properly:

(1) **Hybrid inviability**: the zygote dies before adulthood (sometimes before birth)

(2) **Hybrid sterility**: the hybrid develops into adulthood, but is infertile

(3) **Hybrid breakdown**: hybrids themselves are fertile, but their offspring are extremely weak or infertile

E. When reproductive isolation fails: a problem with plants

1. Hybrids with relatively high fitness are common in plants for some reason – gardeners and horticulturalists take advantage of this when developing new ornamental and crop plants.

2. But this trait also leads to a major concern over use of genetically modified crop plants: what happens if engineered genes "escape" from crop species to weed species via hybridization? (Think about what the mechanism would be . . .)

a. Genetically modified crops are plants that have had genes from other species "added" to their DNA.

b. Many commercial crop species are grown in areas that also support native "weedy" relatives – the mechanism would be that pollen from the modified crops would "transport" new genes to the weeds and form modified hybrids.

c. Two plant scientists, Arriola and Ellstrand, demonstrated this possibility using sorghum (important crop) and johnsongrass (a close relative and major weedy "pest")

(1) First they sowed an experimental field with sorghum that had a unique genetic marker (not anything dangerous – just a form of a gene that would allow them to identify the sorghum as the parent of a sorghum/johnsongrass hybrid) – this "mimics" a genetically engineered crop.

(2) Then they planted seedlings of johnsongrass at various distances from crop field.

(3) Finally, they harvested johnsongrass seeds and raised the offspring.

(a) Hypothesis: Hybridization will allow "engineered" genes to flow from the crop to the weed.

(b) Prediction: genetic marker will be present in the offspring of seeds produced by the johnsongrass (because the seeds will have formed when sorghum pollen fertilized johnsongrass ovules)

(c) Independent variable = pollen source

(d) Dependent variable = presence/absence of sorghum genes in johnsongrass offspring

(4) When they tested offspring for presence of of the genetic marker, they found significant crop-to-weed gene flow via hybridization

3. Question: what would happen if, instead of a neutral genetic marker, crop-to-weed gene flow involved engineered genes for resistance to pests or pathogens? Could get "superweeds" – a major concern for many.

F. Summary:

1. Over billions of years, speciation and divergence have produced the millions of species alive today (and the many more that have gone extinct).

2. *For our purposes, a species is a group of actually or potentially interbreeding natural populations reproductively isolated from other such groups.*
   a. *New traits (adaptations) can spread within a species, but not among species.*
   b. *Reproductive isolation means that, over time, species will diverge from one another.*
3. *Speciation requires three steps: the formation of a barrier to gene flow; genetic divergence; and reproductive isolation.*
4. *A common mode of speciation is allopatric speciation, in which geographic or climatic barriers separate populations.*
5. *Reproductive isolation is achieved by a variety of mechanisms. Pre-zygotic isolating mechanisms prevent mating, fertilization, or pollination. Post-zygotic isolating mechanisms prevent a fertilized hybrid zygote from developing into a fertile, viable adult.*
6. *Plants often hybridize readily, leading to concerns over the long-term impact of genetically modified crops on weedy "pest" species.*

X. Extinction is the ultimate fate of all species. Here we'll examine extinction from several perspectives.

A. First some vocabulary. Remember that a species is a group of populations. Ultimately, the fate of the species is the sum of the fate of the populations.

1. When a single population is eliminated (no more individuals remain), we call that a **local extinction**.
2. What we normally think of as extinction happens when all individuals in all populations die – that's technically referred to as a **global extinction**, but we'll just refer to it as a "true" extinction or just extinction.

B. To understand how species become globally extinct, it's helpful to think first about how they persist.

1. A population will persist as long as individuals are added at the same rate

at which they're removed.

a. Individuals are added by birth within the population and immigration from other populations.

b. Individuals are removed by death within the population and emmigration to other populations.

2. So, an individual population will persist as long as birth + immigration $\geq$death + emmigration.

3. Turning this around, then, populations become locally extinct when individuals are lost more rapidly than they're replaced: birth + immigration $<$ death + emmigration.

C. Ultimately, extinction happens through a "divide and conquer" process: species are broken up into increasingly small, isolated populations – and those populations die off until the species is extinct.

D. Several different processes may lead to extinction.

1. In a sense, the root of all of them is a failure of a species to adapt to something new.

2. Remember that individuals of every species are adapted for a limited range of environmental (biotic and abiotic) conditions.

a. Remember that natural selection takes a long time.

b. Changes may take place too quickly for selection to respond.

3. The kinds of changes that have been implicated in extinction events include:

a. Long-term climate and other environmental change may reduce habitat suitable for a species.

b. New species may outcompete older species by being better adapted to exploit food, shelter, etc. The new species will "take over" their habitat and driving them to extinction. (We'll talk more about competition when we talk about invasive species and community interactions).

c. New predators may evolve to which existing species aren't adapted – they don't have appropriate defenses.

E. Background vs. mass extinctions

1. When we look at the fossil record, we can see that during a normal 100-200 million year interval
   a. 10-20% of species will go extinct
   b. the rate of extinction will be fairly even
2. This rate of extinction is called the background rate, and accounts for ~ 96% of extinctions over evolutionary history.
3. At five major times in the earth's history, we've seen mass extinction events. These differ from background events in that
   a. they are global in scope – they affect species in all regions and many different habitats;
   b. they affect many different groups of organisms
   c. they are rapid relative to the expected "life span" of the affected species (i.e., a large fraction of species will go extinct in a matter of a few million years).
4. We don't know all the causes of all mass extinction events.
   a. Evidence is now pretty solid for an asteroid impact causing the Cretaceous/Tertiary extinction (the one that killed the last of the dinosaurs) – with a 10-km diameter asteroid, the impact would have created a massive change in global climate as well as many other large-scale disturbances.
   b. Other kinds of global changes that may be involved in mass extinctions include continental drift and large-scale climate cycles. This is an area of vigorous research – especially as it relates to the potential impact of global climate change.
   c. Chance may also play a role – over evolutionary time frames, we should expect that chance alone would produce the occasional

episode in which many species just happen to go extinct at the same time, even though the cause of each one is different (just like, every once in a while, 3 hurricanes hit Florida within a single season . . .!).

5. Mass extinctions have had important consequences for current biodiversity:
   a. During each of the "big 5" mass extinctions, one or more dominant groups of organisms has gone extinct.
   b. This has opened up new ecological niches for species that didn't go extinct, and often led to their diversification in ways that probably wouldn't have happened otherwise.
   c. E.g., the final demise of the dinosaurs and other large reptiles at the end of the Cretaceous opened up new evolutionary opportunities for mammals, leading to our diversification (and eventually the presence of humans).
   d. We need to remember, though, that the recovery of biodiversity after a large-scale extinction event takes millions and millions of years. That's an "eyeblink" in evolutionary time, but not in human terms!

F. Summary:

1. *Extinction is the counterpart to speciation; it leads to the loss of biodiversity.*
2. *A true global extinction occurs when all populations of a species become locally extinct.*
3. *Local extinctions happen when populations consistently lose more individuals through death and emmigration than they gain through birth and immigration.*
4. *Global extinction happens when a species is divided into increasingly few, small, isolated populations, which then go locally extinct.*
5. *The causes of extinction can all be considered a "failure to adapt" as environmental conditions change more rapidly than natural selection can*

keep up with. Changes may involve abiotic conditions (climate, e.g.) or biotic factors (the evolution of new competitors, new predators).

6. *Over evolutionary time, extinctions tend to fall into two categories.*
    a. *Background extinctions happen at a fairly steady rate over time.*
    b. *Mass extinctions cause the relatively rapid loss of many groups of organisms in many different places and habitat types.*
    c. *The causes of most mass extinctions are unknown.*
7. *Mass extinctions have led to the diversification of many kinds of organisms (including mammals), but the recovery of biodiversity after a mass extinction event takes millions of years.*