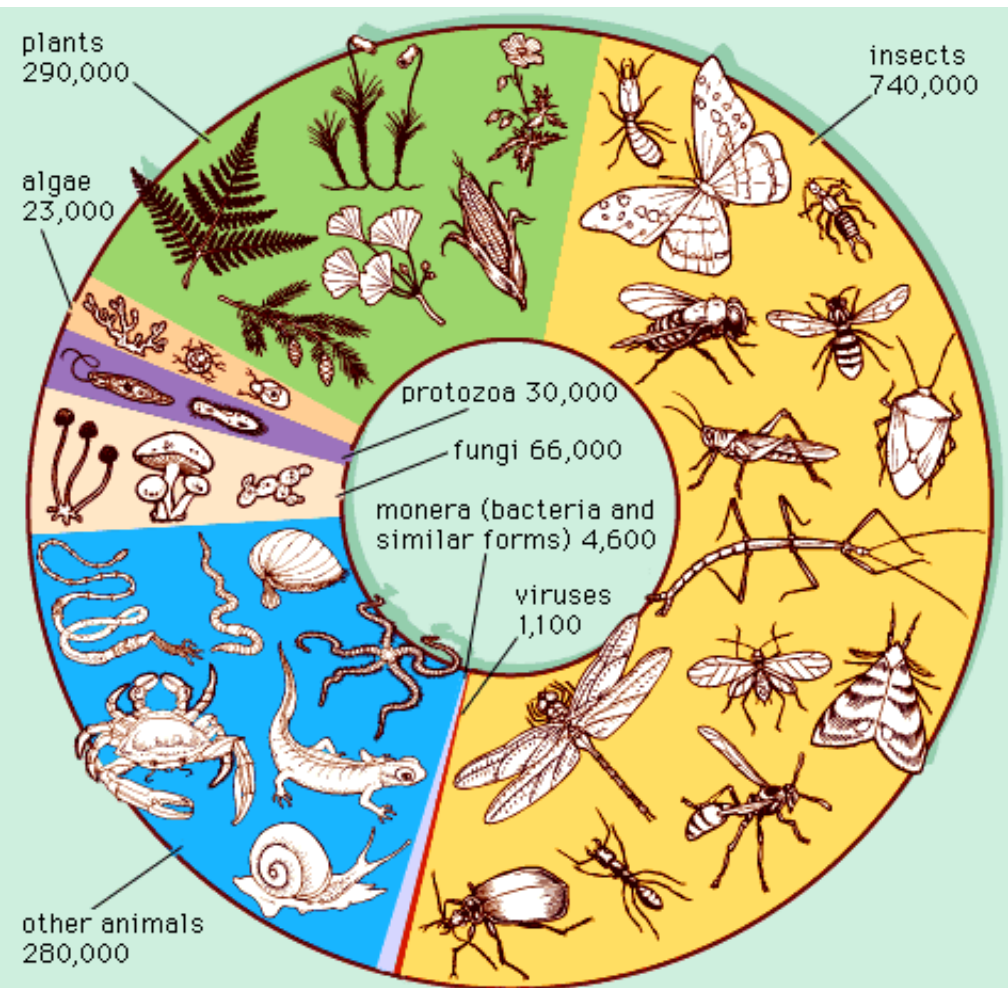


On the origin of species, Really

Mohamed Noor
Duke University



Life on our planet is highly diverse



- ... but that life seems to exist in discrete “clusters” at multiple levels...

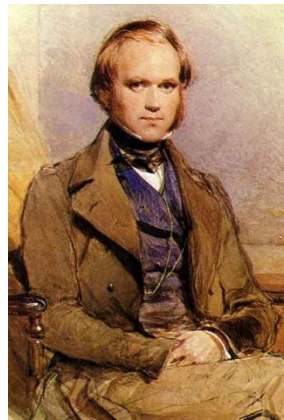
We readily recognize these clusters and see as “natural”



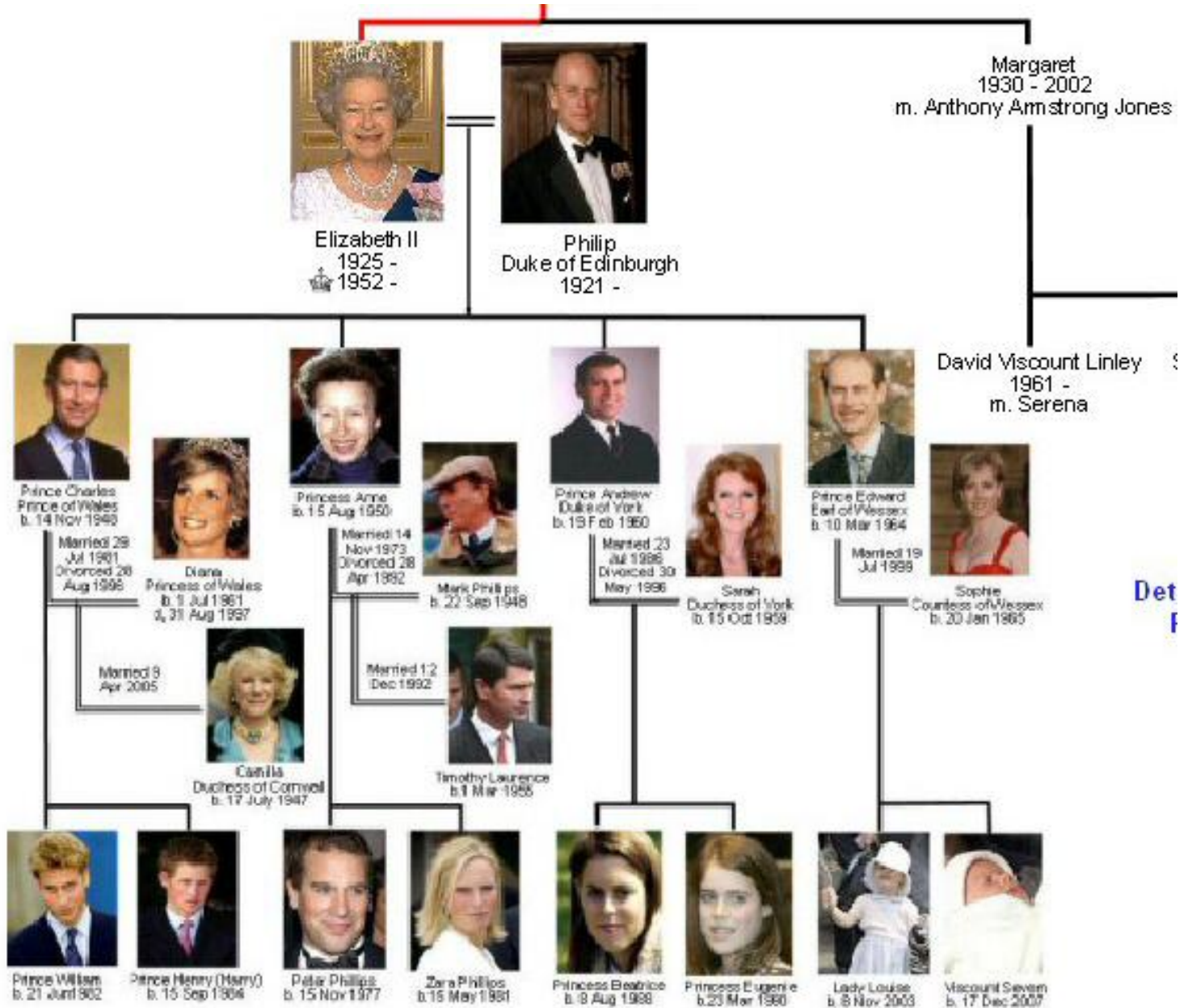
- Can see which “is not like the others” based on DNA or appearance.
- How did these clusters come about?

Common descent

- Darwin argued in 1859 book for “universal common descent” of all life- this explains the natural clustering we see
- Since then, the evidence for this idea has expanded greatly, particularly with growth of genetics

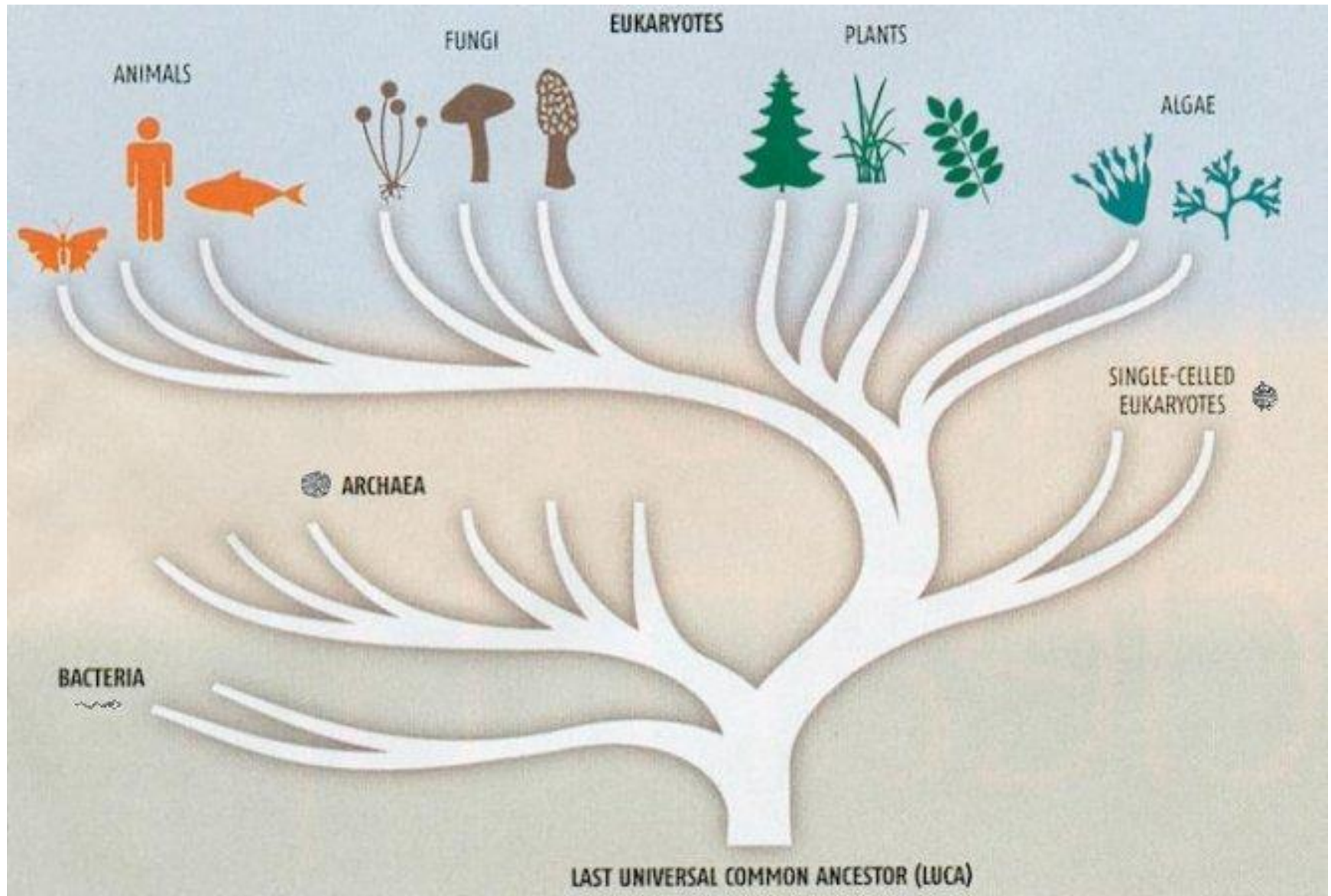


Common descent of families

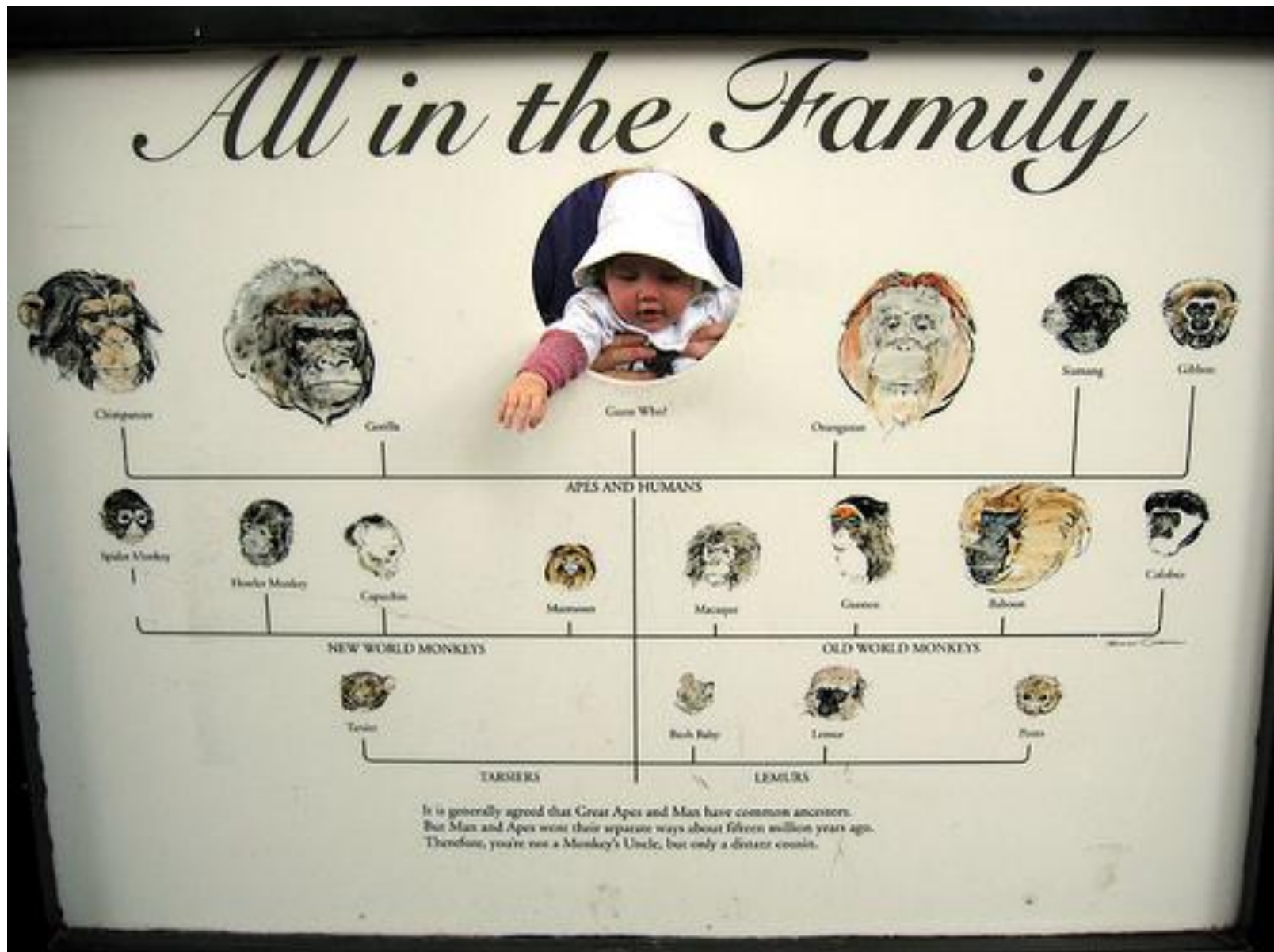


Det
F

Common descent of life



Common descent at finer scale



Kirk Cameron on evolution

"There is something called microevolution- this is very different. Microevolution is adaptation within a species. Look at dogs- you've got the tiny chihuahua and the great dane. They're very different, but they're both dogs. Or horses. You've got zebras and donkeys ... very different, but they're horses. Horses produce horses, and dogs produce dogs. Adaptation within a species is totally different than man evolving from an entirely different species."

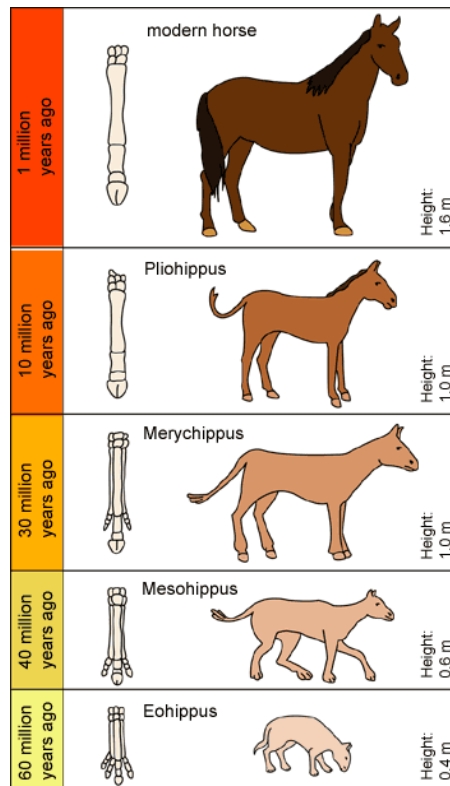


In reality, EVOLUTION has two fundamental processes

- Change within a lineage
- Formation of new lineages (associated with split of existing lineage)


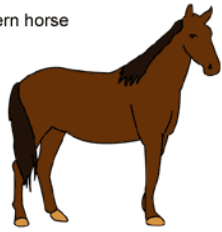

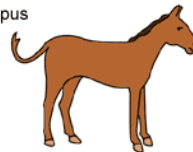

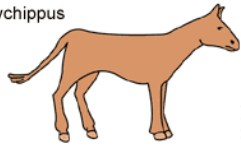

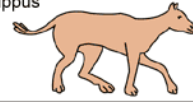


In reality, EVOLUTION has two fundamental processes

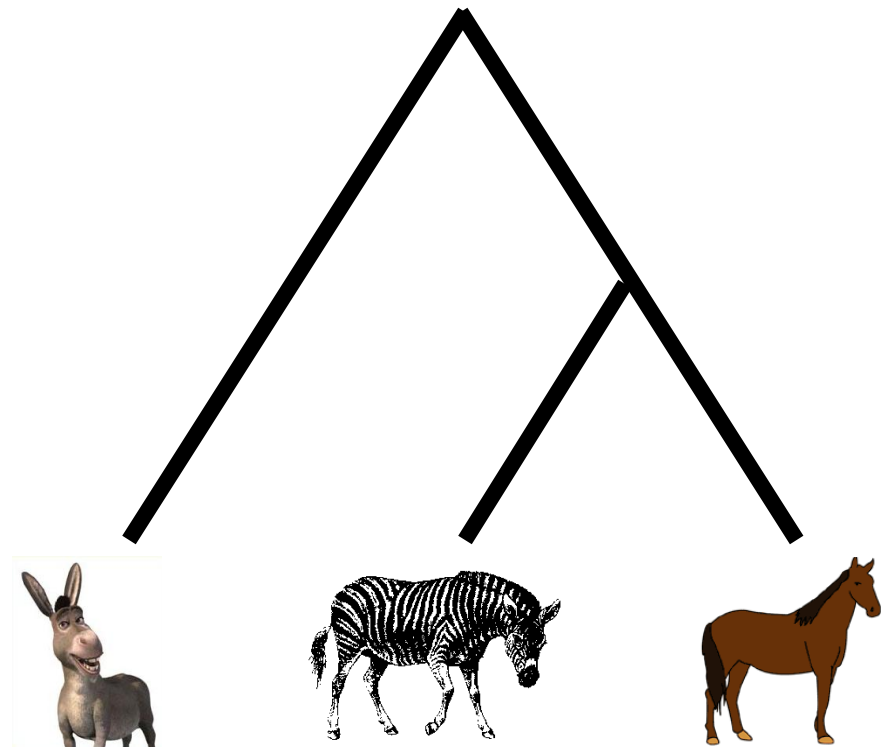
- Change within a lineage
- Formation of new lineages (associated with split of existing lineage)



In reality, EVOLUTION has two fundamental processes

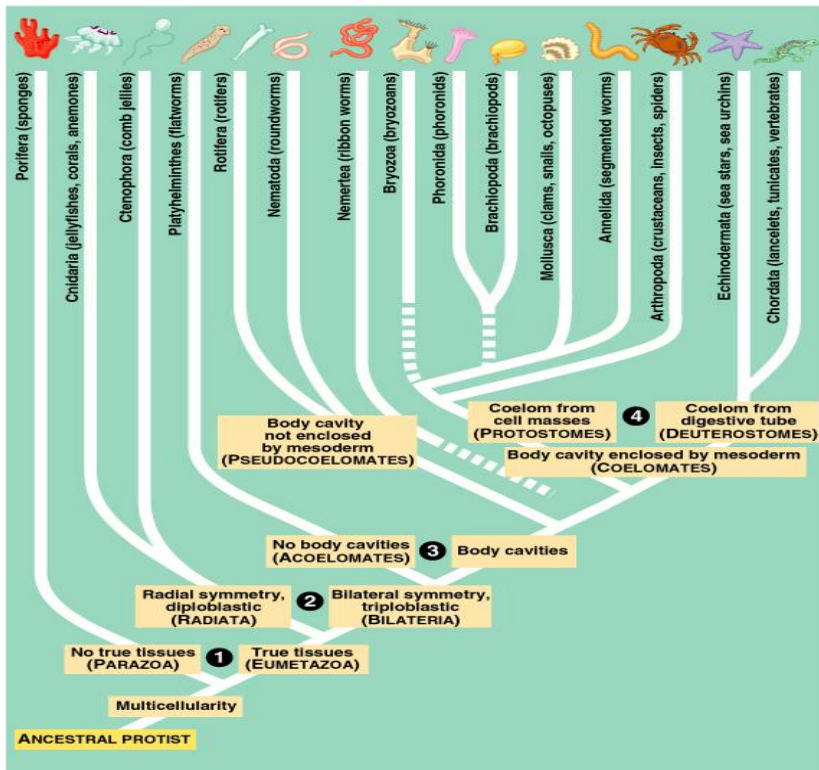
- Change within a lineage
- Formation of new lineages (associated with split of existing lineage)

1 million years ago	 modern horse	 Height: 1.6 m
10 million years ago	 Pliohippus	 Height: 1.0 m
30 million years ago	 Merychippus	 Height: 1.0 m
40 million years ago	 Mesohippus	 Height: 0.6 m
60 million years ago	 Eohippus	 Height: 0.4 m



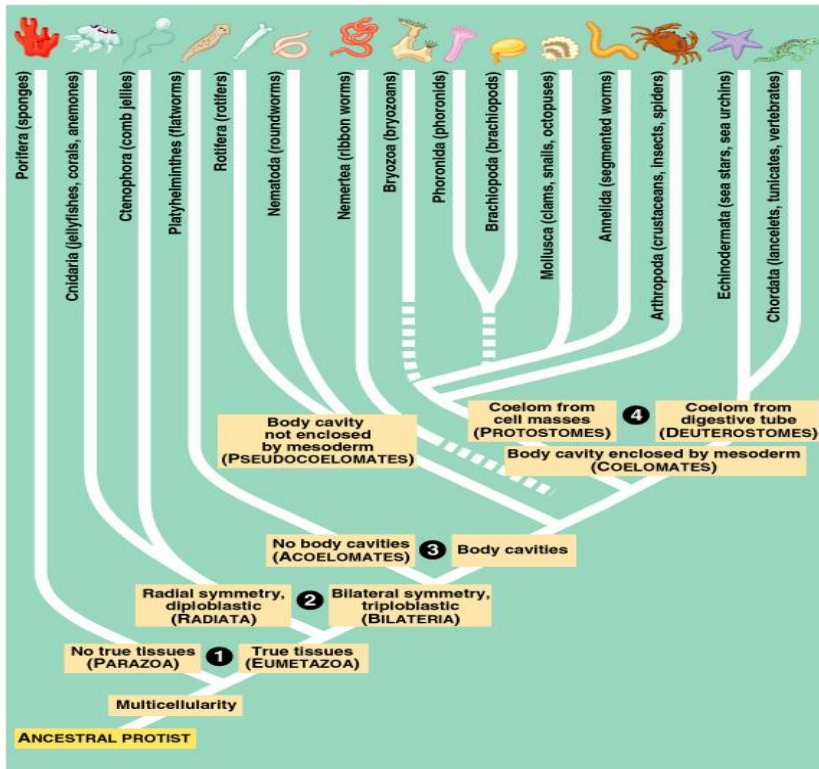
New lineage formation leads to the diversity of life on Earth

Tree of animal life



New lineage formation leads to the diversity of life on Earth

Tree of animal life



Twig of animal life



How do new forms persist as new species?

- Organisms exist in discrete clusters- don't observe in nature all intermediate forms...
- Darwin addressed this only indirectly- considered species and genera to be extension of “varieties”



How do new forms persist as new species?

- Organisms exist in discrete clusters- don't observe in nature all intermediate forms...
- Darwin addressed this only indirectly- considered species and genera to be extension of “varieties”

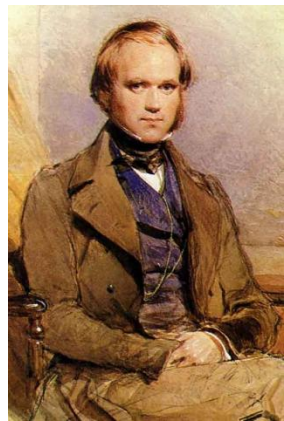


Some big questions on origin of species

- **What keeps these clusters separated?**
- What evolutionary processes cause the clusters to form in the first place?
- What is the genetic basis of species formation?



Today's talk



What is a “species” anyway???

On a practical level, decide based on appearance... but how different do you have to be?

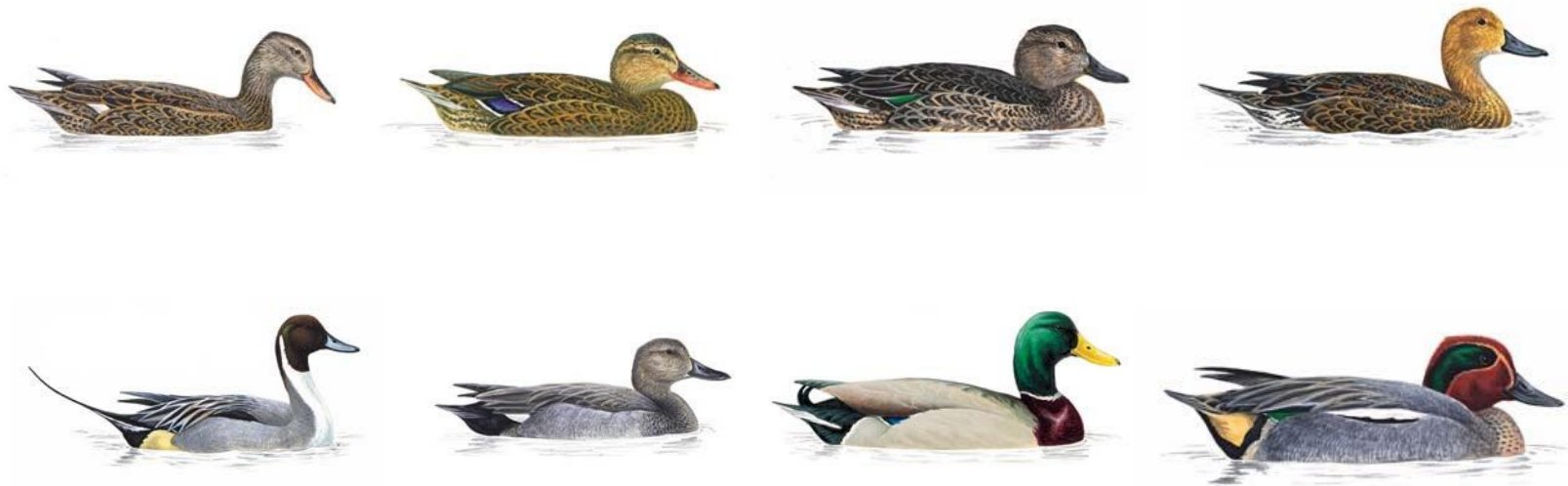
What is a “species” anyway???

On a practical level, decide based on appearance... but how different do you have to be?



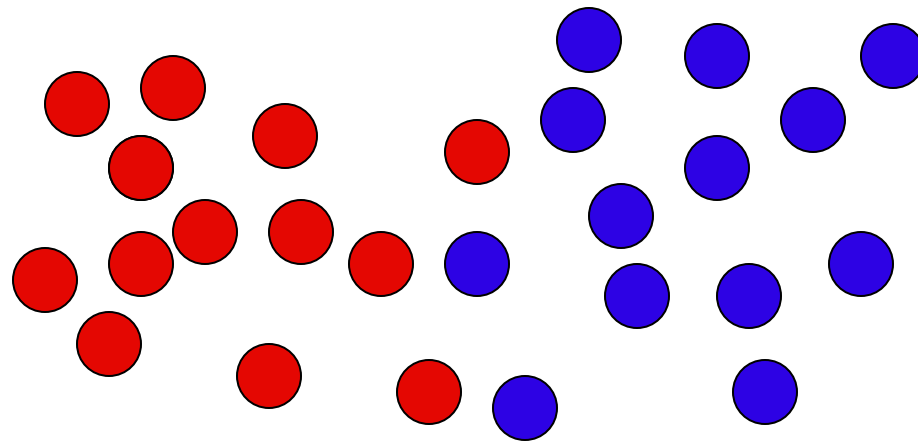
What is a “species” anyway???

On a practical level, decide based on appearance... but how different do you have to be?



Most widely used concept: “gene pools”

- Groups of interbreeding natural populations that do not exchange genes with other such groups
 - Termed the “Biological Species Concept”



“Barrier traits” separate gene pools in two ways

1) Interbreeding doesn't happen at all

- Live in different parts of common environment
- Breed at different times of day or different seasons
- Just not attracted to each other

“Barrier traits” separate gene pools in two ways

- 1) Interbreeding doesn't happen at all
 - Live in different parts of common environment
 - Breed at different times of day or different seasons
 - Just not attracted to each other



“Barrier traits” separate gene pools in two ways

- 2) Whoops! Well, interbreeding does not result in gene exchange for other reasons
- Sperm don't fertilize eggs of other species
 - Hybrids die early in life
 - Hybrids live but are sterile (dead-ends)

“Barrier traits” separate gene pools in two ways

- 2) Whoops! Well, interbreeding does not result in gene exchange for other reasons
- Sperm don't fertilize eggs of other species
 - Hybrids die early in life
 - Hybrids live but are sterile (dead-ends)



Example: habitat differences

- ***Rhagoletis* fruit flies**
 - Two races in North America: breed exclusively on apple or hawthorn berries
 - Survival & reproduction better on “own” host
 - Genetic differences



Example: habitat differences

- ***Rhagoletis* fruit flies**
 - Two races in North America: breed exclusively on apple or hawthorn berries
 - Survival & reproduction better on “own” host
 - Genetic differences
 - Apple race JUST formed in last 120 years- before 1600s, no apple trees in USA



Example: timing differences

- **Cicadas- some species emerge every 13 years, and some every 17 years**
 - **Until that time, burrow underground and eat off tree roots**
 - **Then emerge, drop exoskeleton, and call**
 - **Only overlap once every 221 years!**



Example: preference differences

- North American fruit flies *Drosophila pseudoobscura* and *D. persimilis* co-occur & look identical, but “sing” different songs
 - Females reject males singing wrong song



Example: fertilization specificity

- Red and pink abalone spawn at similar times, but sperm only fertilize females of same species
 - Molecular genetic studies have identified several of the proteins (on sperm and egg) mediating this species-specific interaction



Example: fertilization specificity



- Red and pink abalone spawn at similar times, but sperm only fertilize females of same species
 - Molecular genetic studies have identified several of the proteins (on sperm and egg) mediating this species-specific interaction



Example: hybrid sickly/ dead

- Intertidal copepods from northern and southern California produce sickly hybrids
 - This inviability is associated with defects in their mitochondrial electron transport system—their means of getting energy
 - Specific genes known



Example: hybrid sterile

- Liger- hybrid of lion father and tiger mother. Probably doesn't happen in nature since don't overlap ranges. Males usually sterile.
- Zonkey- usually hybrid of zebra father and donkey mother. Found in South Africa. Usually sterile (especially males).



Barrier traits act together

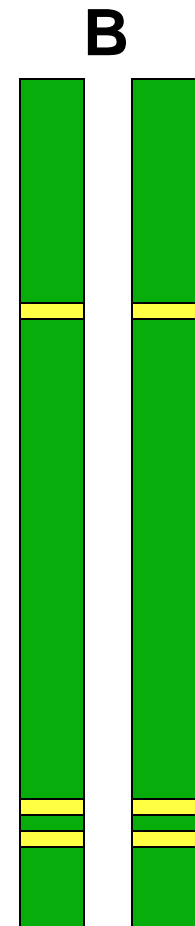
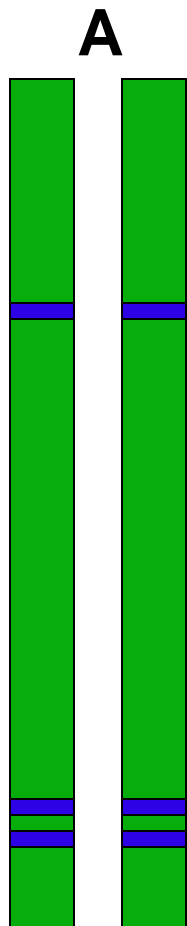
- *Very few cases where one looks at two species and only sees a single barrier trait separating them.*
- Still debated among some evolutionary biologists whether some barrier traits are more common “earlier” in divergence process.
- BUT, since 1930’s, genetic studies of species formation have focused on studying these traits.



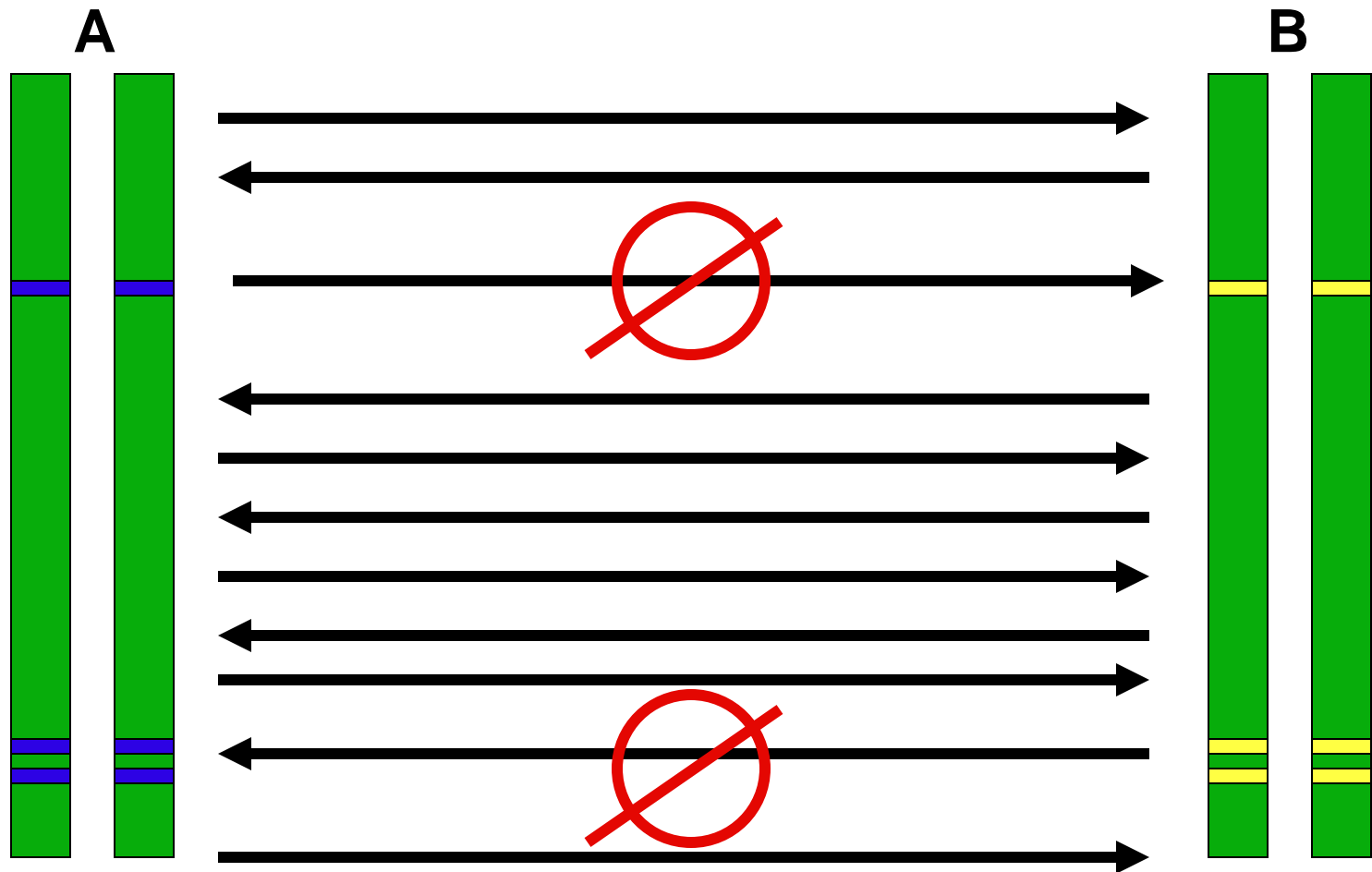
... and these barriers are not always perfect...

- Estimates suggest 10-25% of species hybridize with other species, and most of these exchange some genes
- This does **NOT** undermine their usefulness or their effect- still keep parts of genome “distinct” into clusters

Hybridizing species can exchange some genes but not others

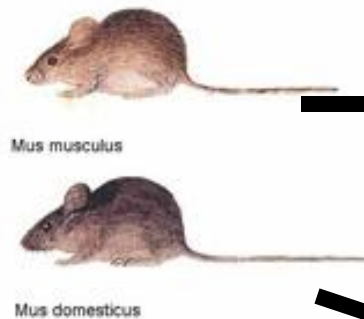


Hybridizing species can exchange some genes but not others



Some “hybrid zones” have persisted for thousands of years

- Diagnosable clusters persist despite many generations of gene exchange
- **Example:** house mouse hybrid zone in SE Europe estimated ~6000 years old
- Some genes more freely across zone, others don't



-- Tricky areas --

- What if geographically separated?
- What if the groups are asexual?
- “How much” gene exchange is too much?



Quick recap:

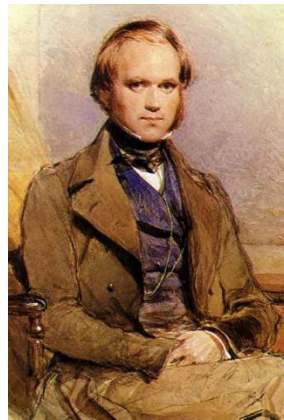
- Species defined as diagnosable groups that don't exchange genes
- Gene exchange prevented by (one or) multiple “barrier traits”
- Gene exchange need not be reduced to zero for groups to be “species”, but need to be diagnosable

Some big questions on origin of species

- What keeps these clusters separated?
- **What evolutionary processes cause the clusters to form in the first place?**
- What is the genetic basis of species formation?

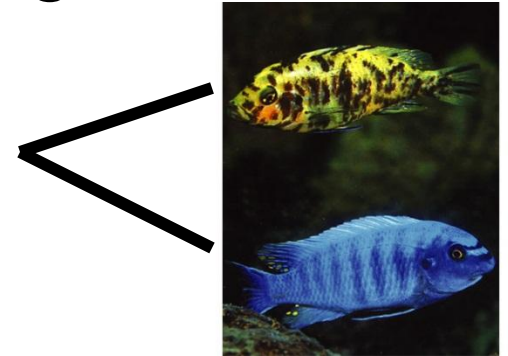


Today's talk



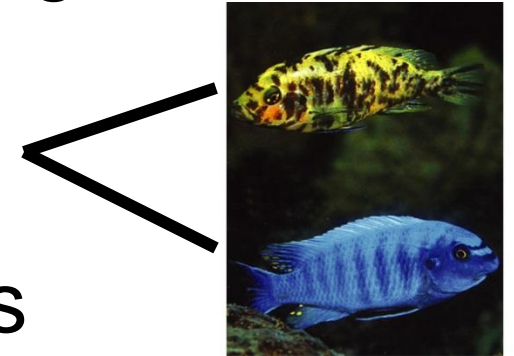
What makes new species evolve?

- Formation of barrier traits
- Cordoning off of some or all of genome from gene exchange



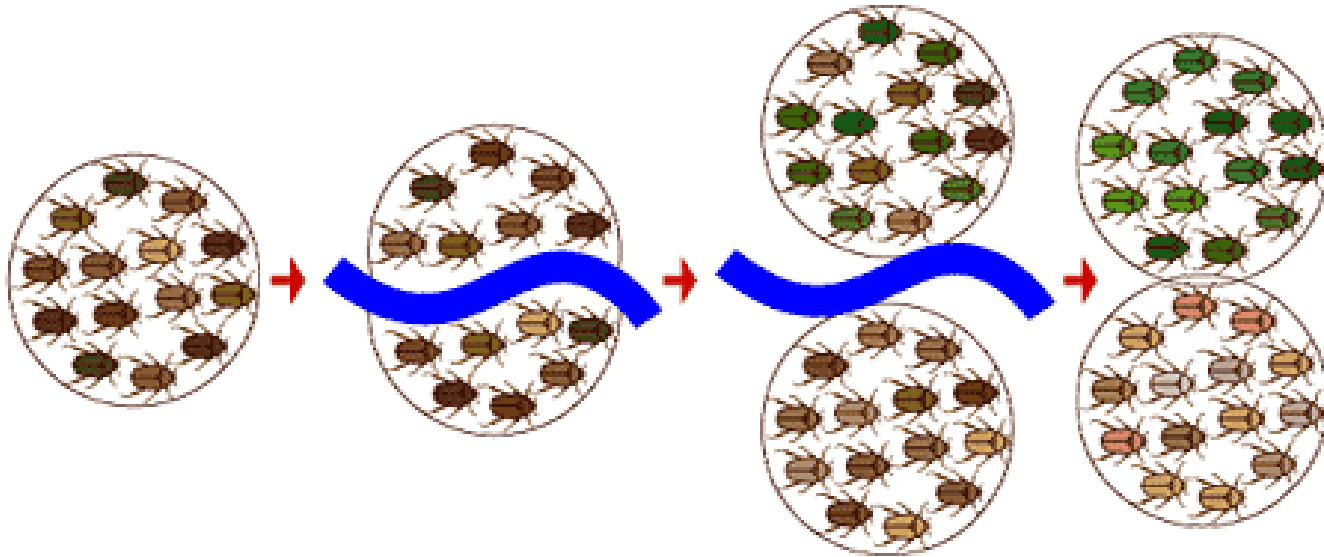
What makes new species evolve?

- Formation of barrier traits
- Cordoning off of some or all of genome from gene exchange
- Random/ stochastic processes
- Natural selection acting *directly* on traits to prevent gene exchange
- Natural selection incidentally forming traits



Models of species formation

1. Geographic isolation



- A) One population
- B) Become separated by mountain range or stream
- C) Changes happen within populations on opposite sides
- D) Come back into contact but now different

What made these “changes”



happen?



- New, random mutations arose in one population but not the other
- Environment different on the two sides, so different gene forms were favored by natural selection
- **NOT** selection for barrier effect specifically

Concept

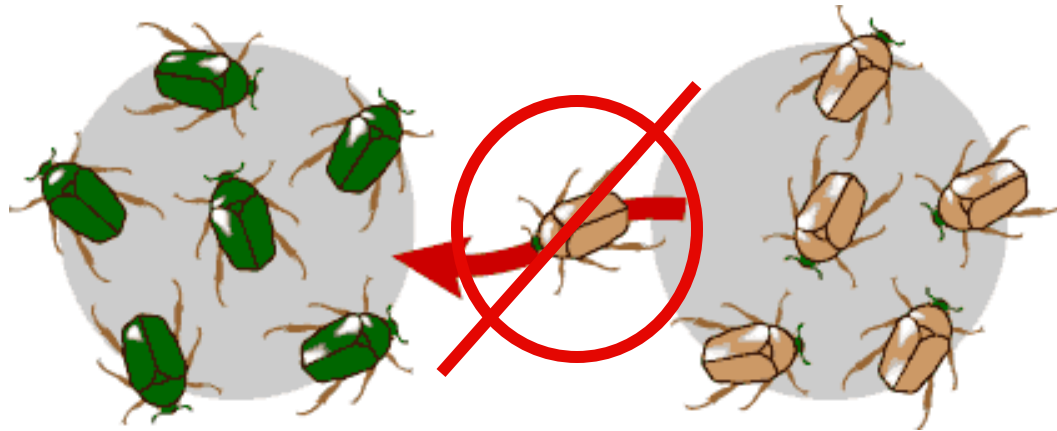
- Gene exchange is a “homogenizing force” in evolution



- If have long period of time with NO gene exchange, easier to diverge into two differentiated populations

Concept

- Gene exchange is a “homogenizing force” in evolution



- If have long period of time with NO gene exchange, easier to diverge into two differentiated populations

Evidence

- **Many species boundaries match geographic barriers (past or present)**
 - *Point Conception, CA*: 21 species of snails, algae, and barnacles have ranges ending there, and close relatives on other side



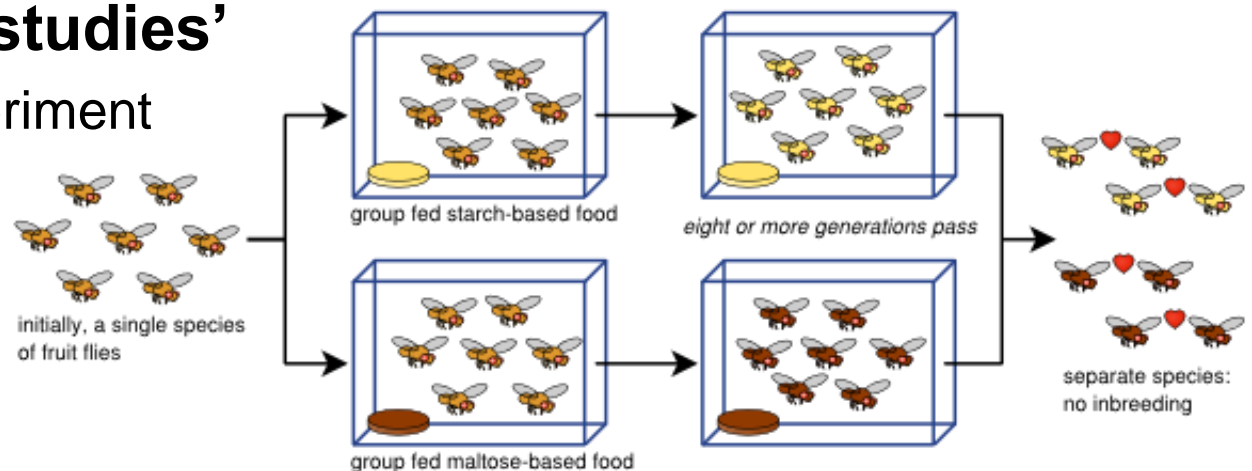
Evidence

- **Many species boundaries match geographic barriers (past or present)**
 - *Point Conception, CA*: 21 species of snails, algae, and barnacles have ranges ending there, and close relatives on other side



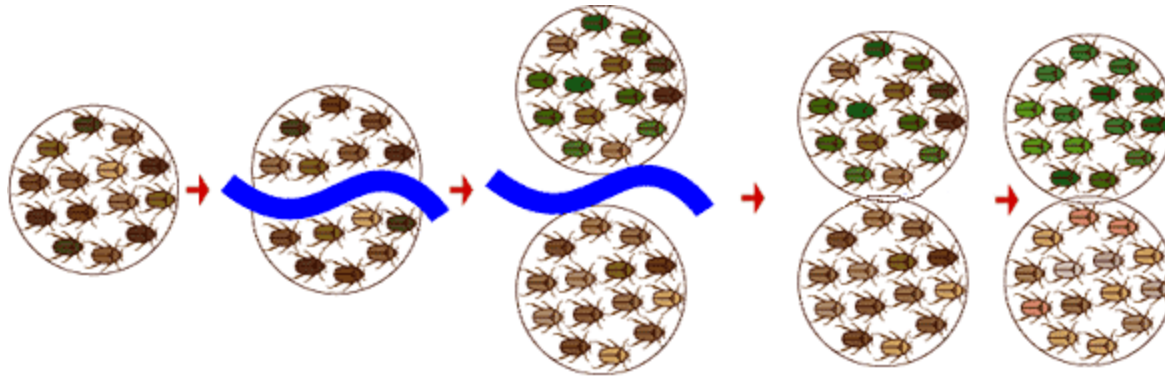
- **Experimental studies'**

- Selection experiment



Models of species formation

2. Geographic isolation, but regain contact before speciation



- A) One population
- B) Become separated by mountain range or stream
- C) Changes happen within populations on opposite sides
- D) Come back into contact but now a little different
- E) Continued divergence and formation of barrier traits

Making hybrids is “bad”

- Anything that helps animals pass on their genes favored by selection
- Species hybrids often sterile
- Producing sterile species hybrids costly
 - Genes not passed on in sterile hybrids
 - Waste gametes and parental efforts



Making hybrids is “bad”

- Selection favors individuals who mate with their own type
 - Reduces breeding with other species ‘cuz bad



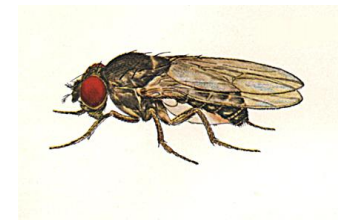
Making hybrids is “bad”

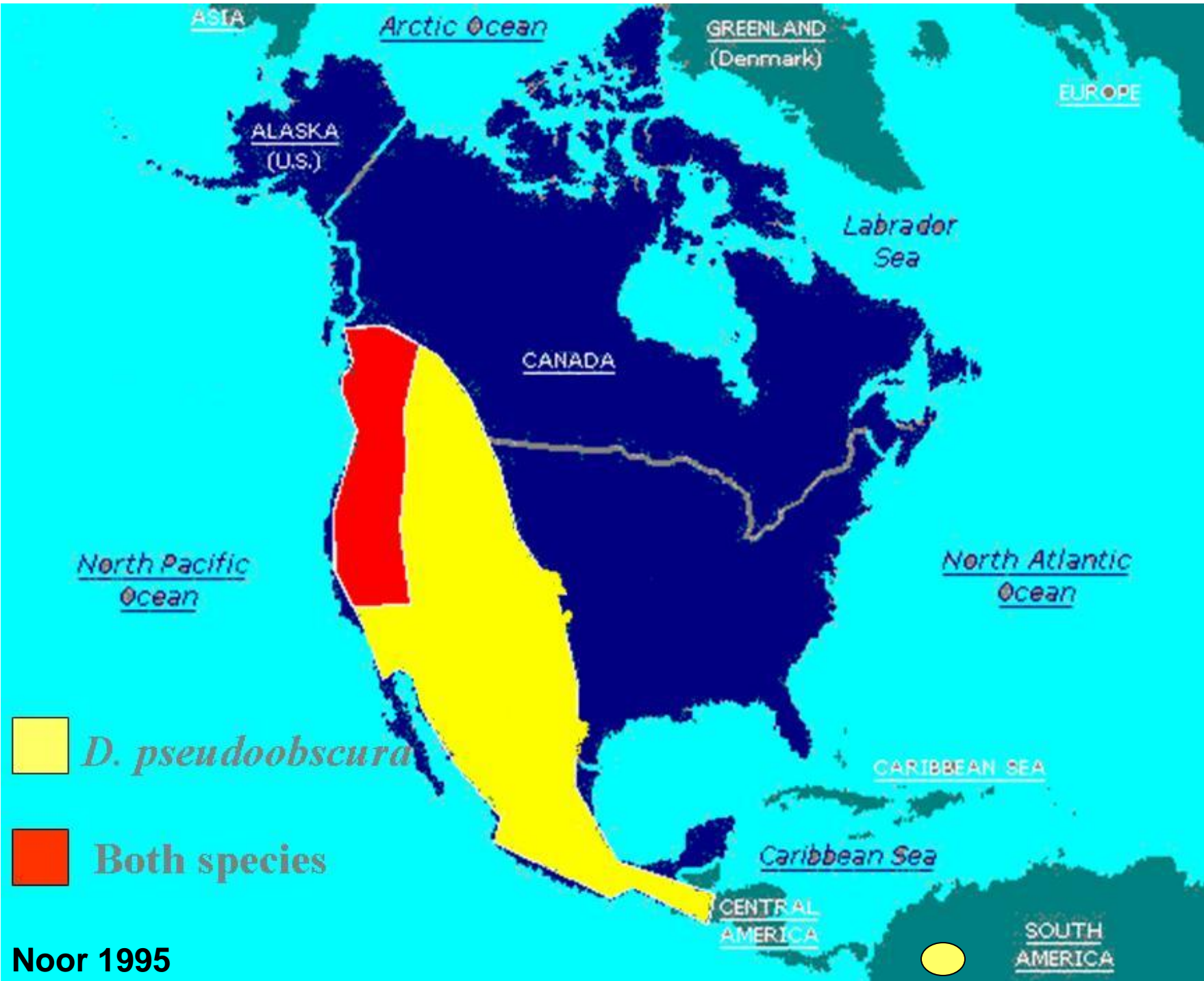
- Selection favors individuals who mate with their own type
 - Reduces breeding with other species ‘cuz bad
- This selection only operates in populations where you CAN mate with the other species



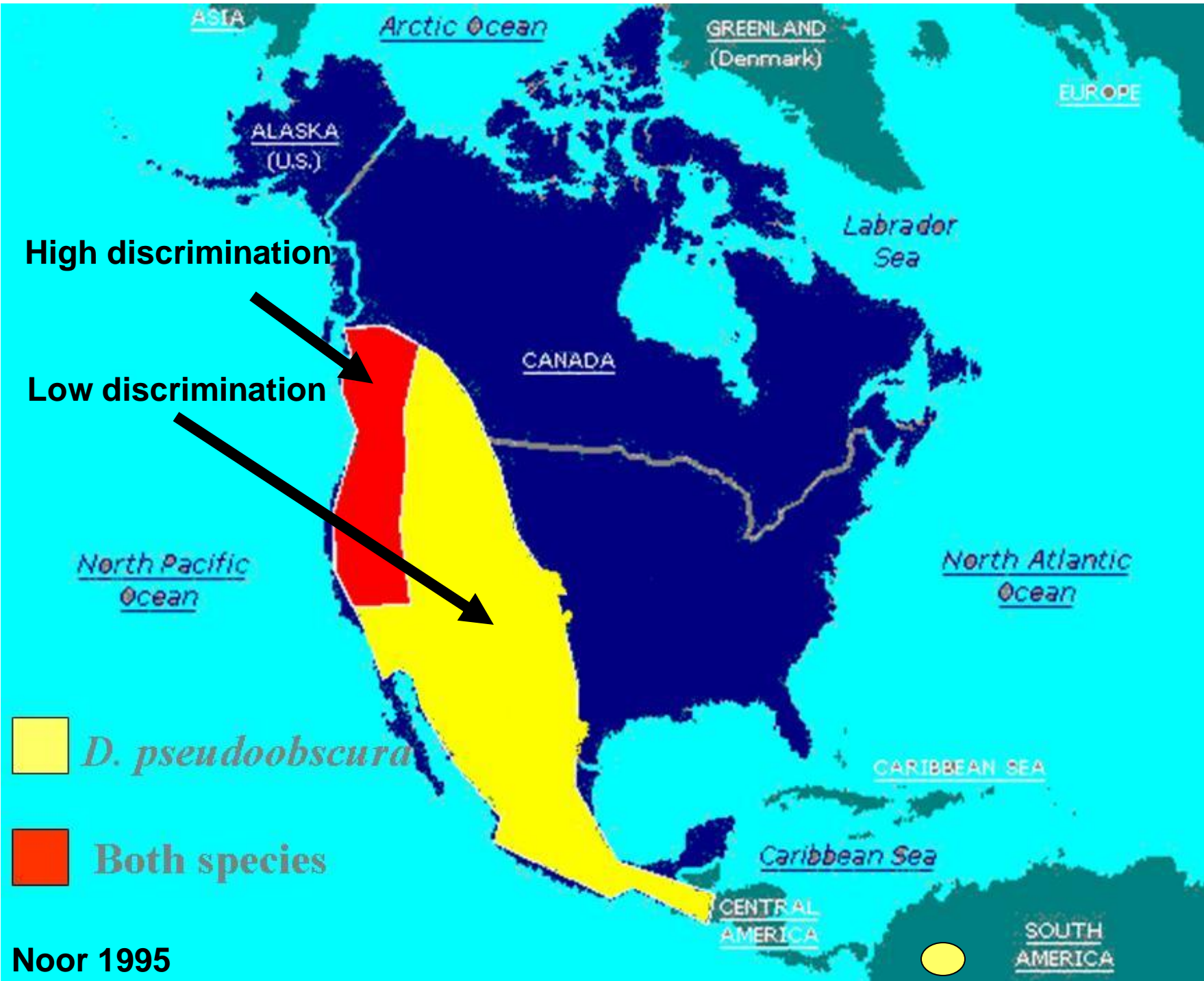
Noor's PhD study (1995): *Drosophila pseudoobscura* *D. persimilis*

- Species that look exactly alike
- Hybrid males sterile (so bad at passing on genes), hybrid females fertile
- Mate in nature, though not very much
- Native to North America and co-occur in some areas





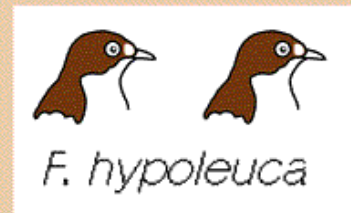
Noor 1995



More Evidence

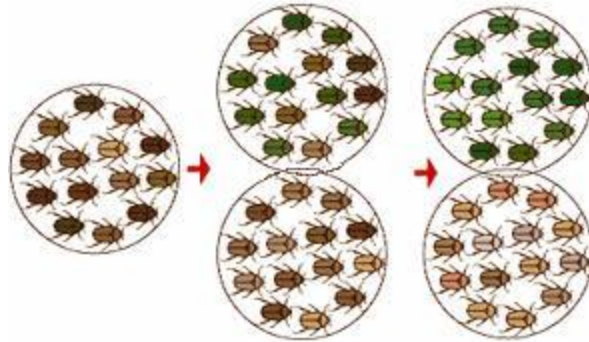
- Differences in sexually-preferred characters in areas enhanced where species overlap

– Pied & collared flycatcher



Models of species formation

3. No geographic isolation



- A) One population
- B) See partitioning into distinct types, interbreeding reduced
- C) Continued divergence and formation of barrier traits

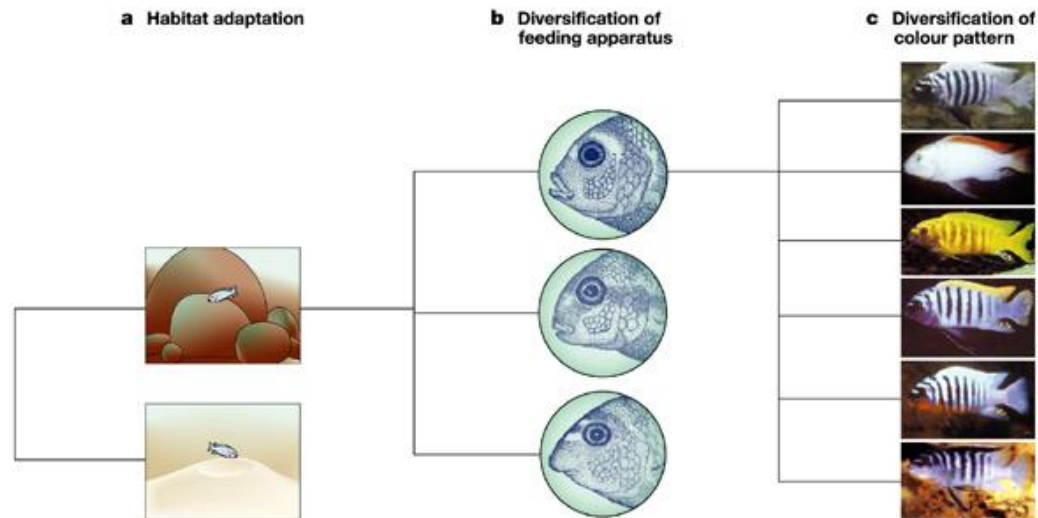
Why split?

- Distinct niches, filled by types in which intermediates (or switchers) are less fit.
 - Trade-offs in adaptation.
- Requires strong natural selection.



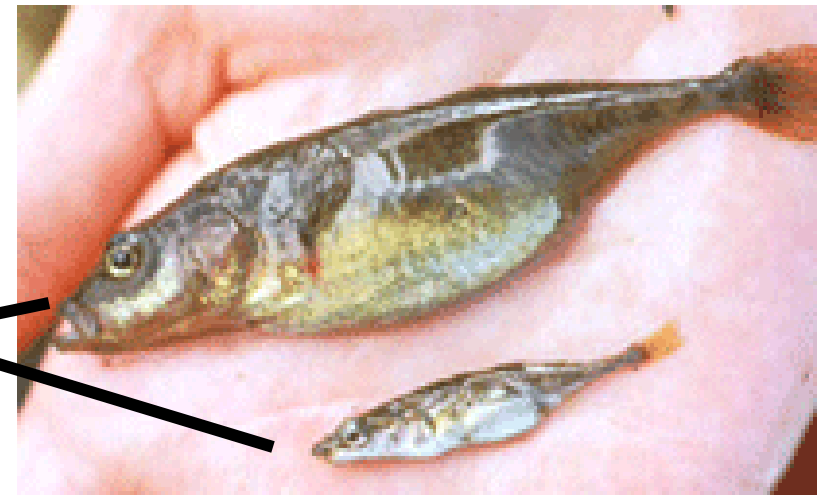
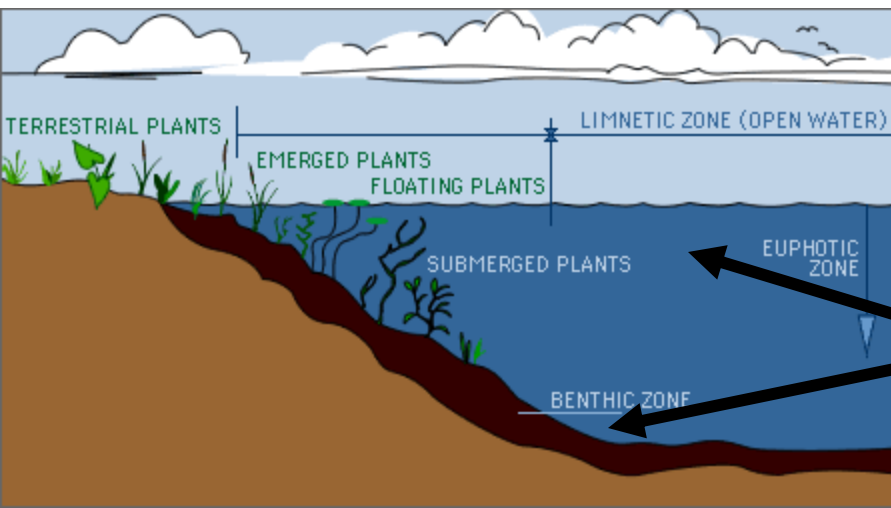
Evidence

- Crater lake cichlids
 - Lakes isolated historically
 - Diverse niches within
 - Nearest relatives all in same lake



Evidence 2

- Lake stickleback forms
 - Open water vs deep forms
 - Distinct niches – hybrids ecologically inferior
 - Preferentially mate with their own type
 - *2 forms evolve repeatedly in different lakes*



Diversity of answers...

- Can have natural selection incidentally cause new species
- Can have natural selection directly drive formation of new species
- Random processes can contribute
- How often each???



Quick recap:

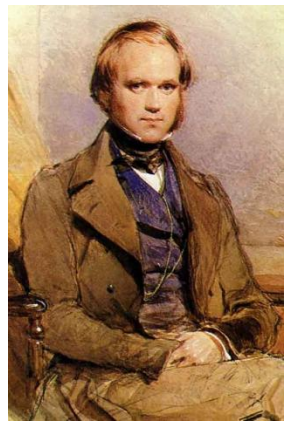
- From geographic patterns, can infer evolutionary processes causing species splits
- Evidence for diverse modes of species formation, and diverse roles of natural selection or random processes
- Frequency uncertain- that's the big question now.

Some big questions on origin of species

- What keeps these clusters separated?
- What evolutionary processes cause the clusters to form in the first place?
- **What is the genetic basis of species formation?**

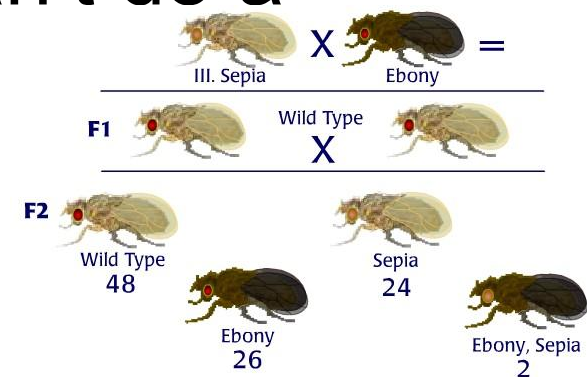


Today's talk



Genetics of species formation = genetics of barrier traits

- By knowing genetic differences between species causing barrier traits, can see genetics of species formation
- ... but can't do genetics between species (easily) since, by definition, can't do a "genetic cross" ...



Get around this problem using incompletely separated species

- Again, barriers are not always “perfect”, and sometimes weaker in lab than in nature
- Often **one** sex is sterile/ dead (XY), and can study the genetic basis of this by crosses to the other sex



Why are hybrids sterile???

- Hybrids only have the genes of their parent species: rarely “new” genetic material
- No gene “functions” to cause sterility
 - More likely disruption of a normal function
- Likely interactions between genetic material from one species with genetic material from the other
- Can map sterility within the genome through **genetic crosses**



- Genetic mapping by crosses seeks to associate **differences in “letters”** between individuals with traits (e.g., eye color)

Individual 1



AGGATCAGCAGCGACGACGCGGGACATCGAG**C**GA

Individual 2

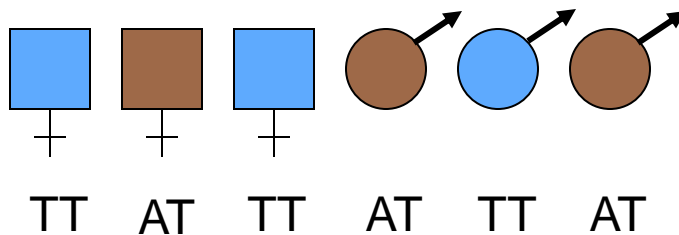
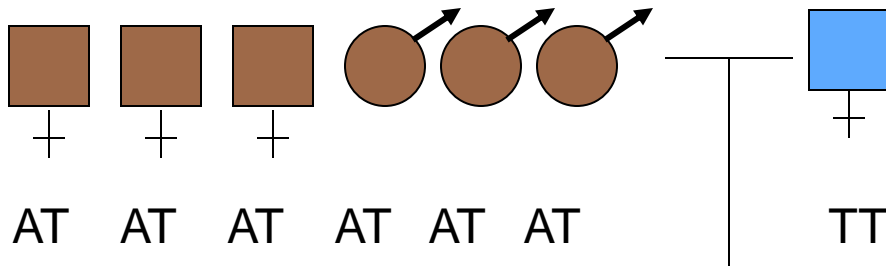
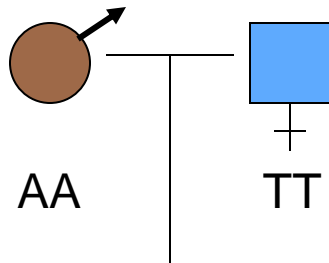


ATGGATCAGCAGCGACGACGCGGGACATCGAG**G**GA



Genetic mapping – like a family tree

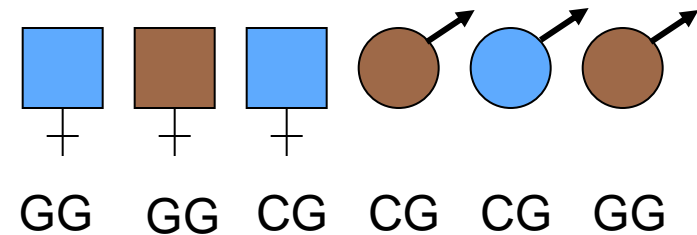
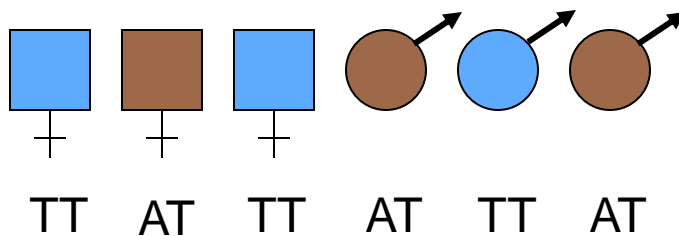
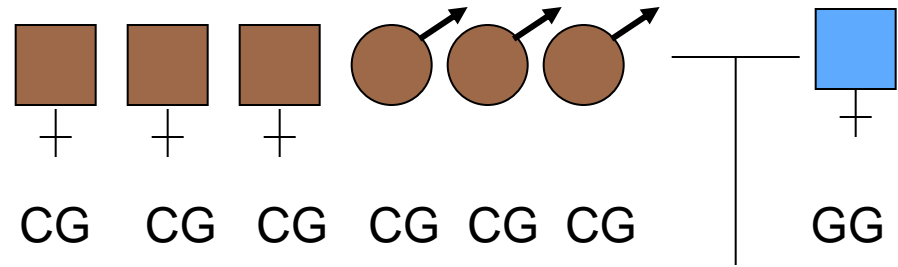
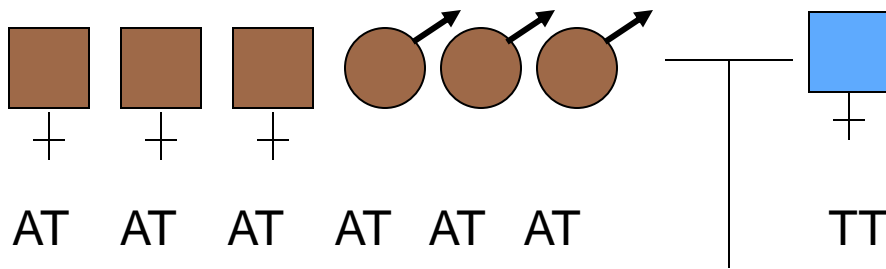
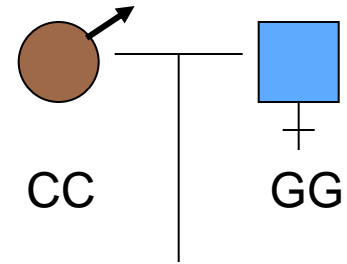
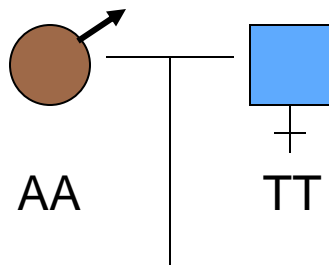
Let's look at eye color... if see right gene,



Genetic mapping – like a family tree

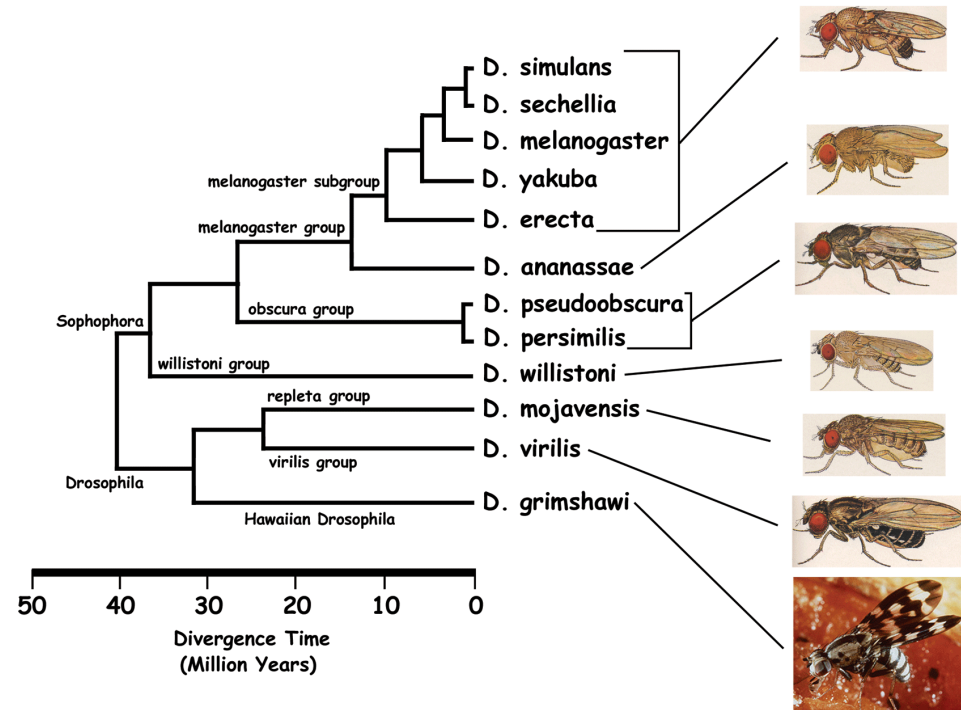
Let's look at eye color... if see right gene,

... for a gene far from the eye color...



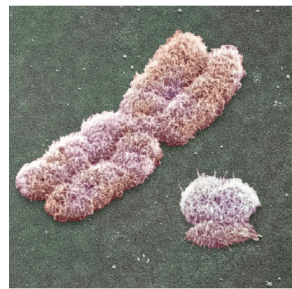
Workhorses of genetics: Drosophila fruit flies

- Thousands of species, including many recently diverged
- Genome sequences
- Easy to rear/ cross



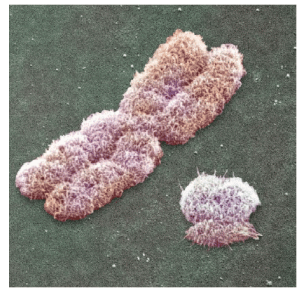
Some results!

- Sterility often results from an **interaction** between genes on the “X” and genes elsewhere.
- The bad interaction from genes on the “X” is recessive (like blue eyes)- that’s why males (**Xy**) are more often sterile than females (**XX**).



Some results!

- Sterility often results from an **interaction** between genes on the “X” and genes elsewhere.
- The bad interaction from genes on the “X” is recessive (like blue eyes)- that’s why males (**Xy**) are more often sterile than females (**XX**).
- Underlying genes unusually different in DNA sequence between species: suggests changes driven by **natural selection**.



Darwin was right!

- Hybrid sterility “is not a specially endowed quality, but is incidental on other acquired differences,” (p. 245) and is caused by a hybrid's “organization having been disturbed by two organizations having been compounded into one” (p. 266).
- Natural selection appears to be a major contributor.
- Also a major contributor to other barrier traits.



Quick recap:

- Sterility often results from an interaction between genes on the “X” and genes elsewhere.
- Natural selection seems to be involved in driving these gene forms.

IMPLICATIONS:

- Human-induced habitat destruction is reducing the number of species worldwide
 - Bad for humans in part because increases vulnerability to flood & drought, crop failure, spread of disease, and water contamination
- This research looks at the other end of the process: species formation -> extinction

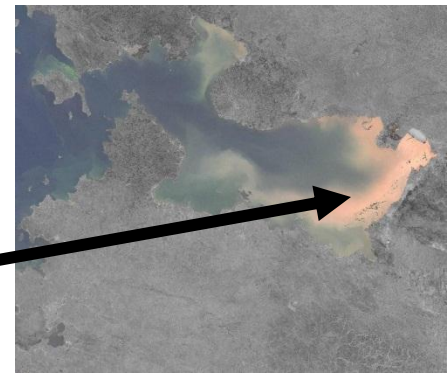


IMPLICATIONS:

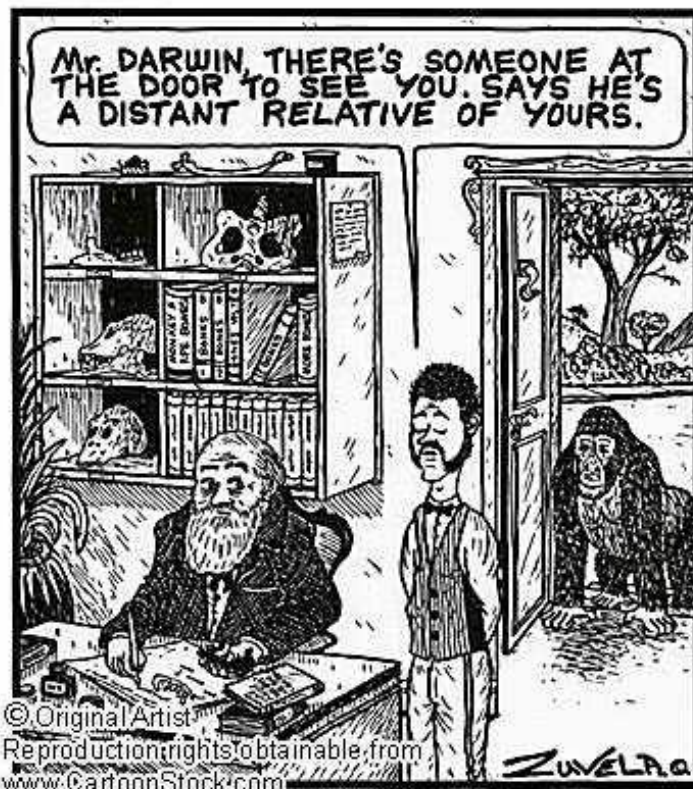
- Not just losing existing species, but losing species that were “just beginning to form”
 - Lake Victoria cichlids choose mates by coloration
 - Turbidity (human-induced) in water reducing mate choice, so now mating more at random
 - Species that would have formed, now won't...



Cyanobacteria,
Algal blooms, etc.



... and we strive to continue to understand and explain...



THANK YOU!

**And see related talk by Dr. Michael Benton
Friday, October 7, 6:30pm
“Origins of Modern Biodiversity”**