Introduction to How New Species Form: Speciation

Framing question: what makes a new species, and how do populations become reproductively isolated?

Speciation is population-level: genetic divergence plus barriers to gene flow, often gradual.

Roadmap: species concepts, reproductive isolation, geographic modes, genetics, evidence, communication.

Why it matters: biodiversity, conservation, and public understanding for students, educators, and enthusiasts.



What Is a Species?

Competing Concepts and Why They Matter

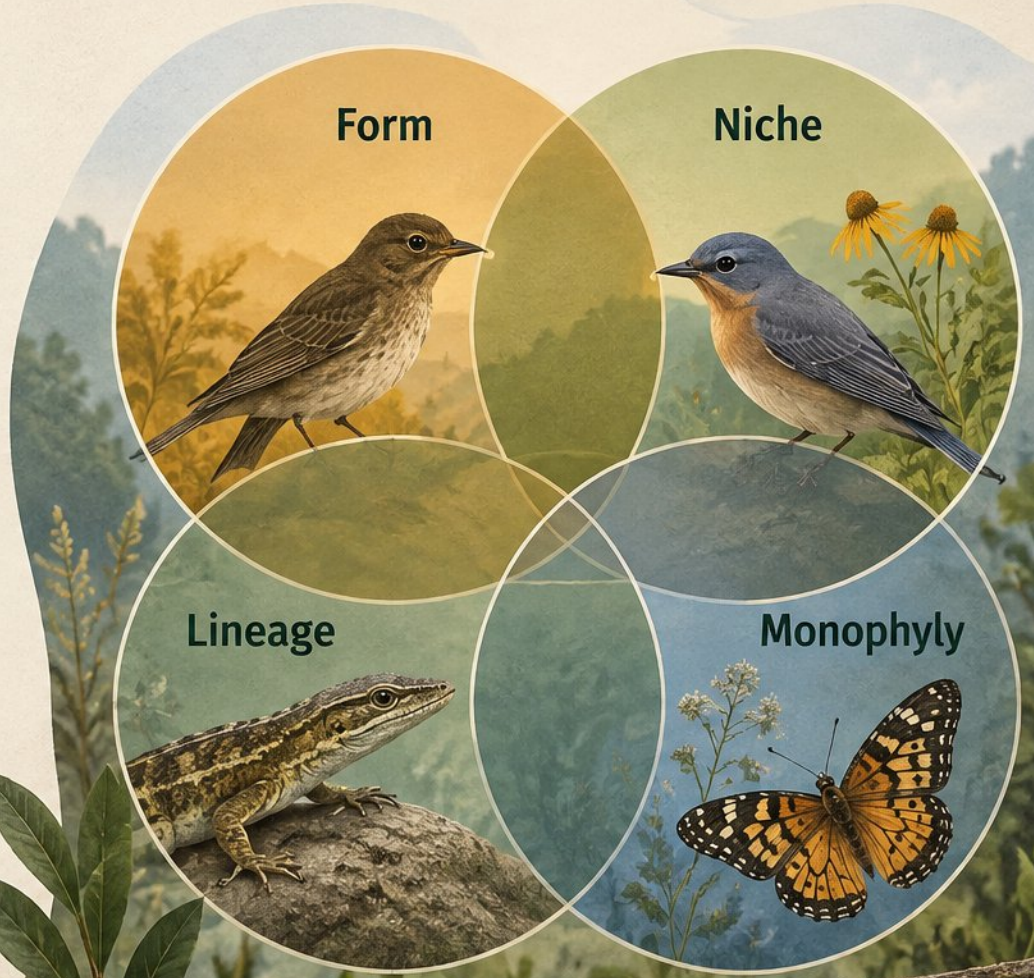
Biological Species Concept:
interbreeding populations, reproductively isolated from others

Limits:
fails for asexuals, fossils, and frequent hybrids

Alternative concepts emphasize
form, niche, lineage, or monophyly

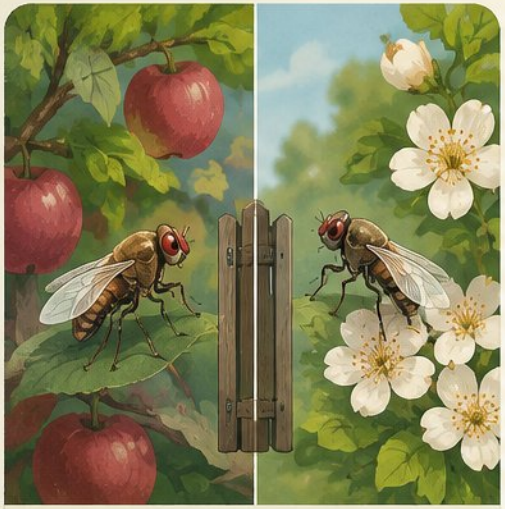
Unifying view:
species are separately evolving metapopulation lineages

For classrooms and museums:
species are hypotheses with graded boundaries



Reproductive Isolation: Prezygotic Barriers

- **Prezygotic barriers block fertilization, preventing hybrid zygotes from ever forming**



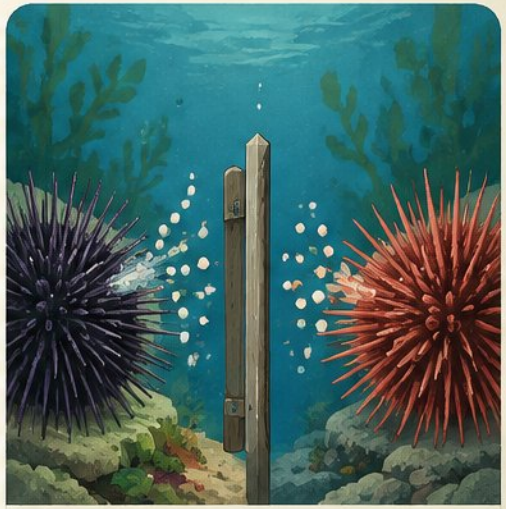
- **Habitat isolation:** populations use different microhabitats in the same area (apple vs. hawthorn flies)



- **Temporal isolation:** breeding or flowering at different times (seasonal frogs; corals spawning at different times)



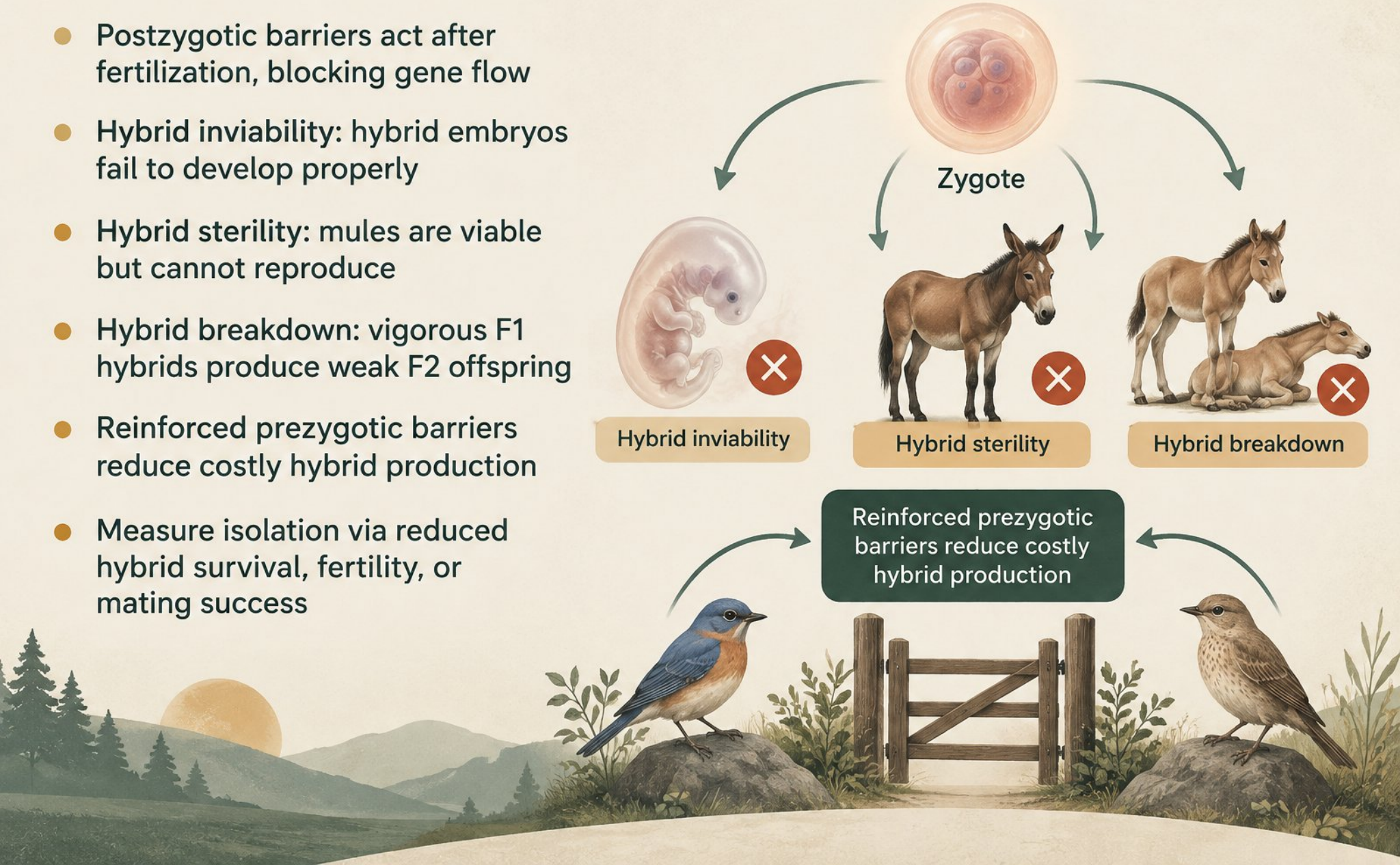
- **Behavioral isolation:** distinct courtship signals and mate recognition (bird songs; firefly flash patterns)



- **Mechanical and gametic isolation:** incompatible reproductive structures or gamete-recognition failure (sea urchin gametes)

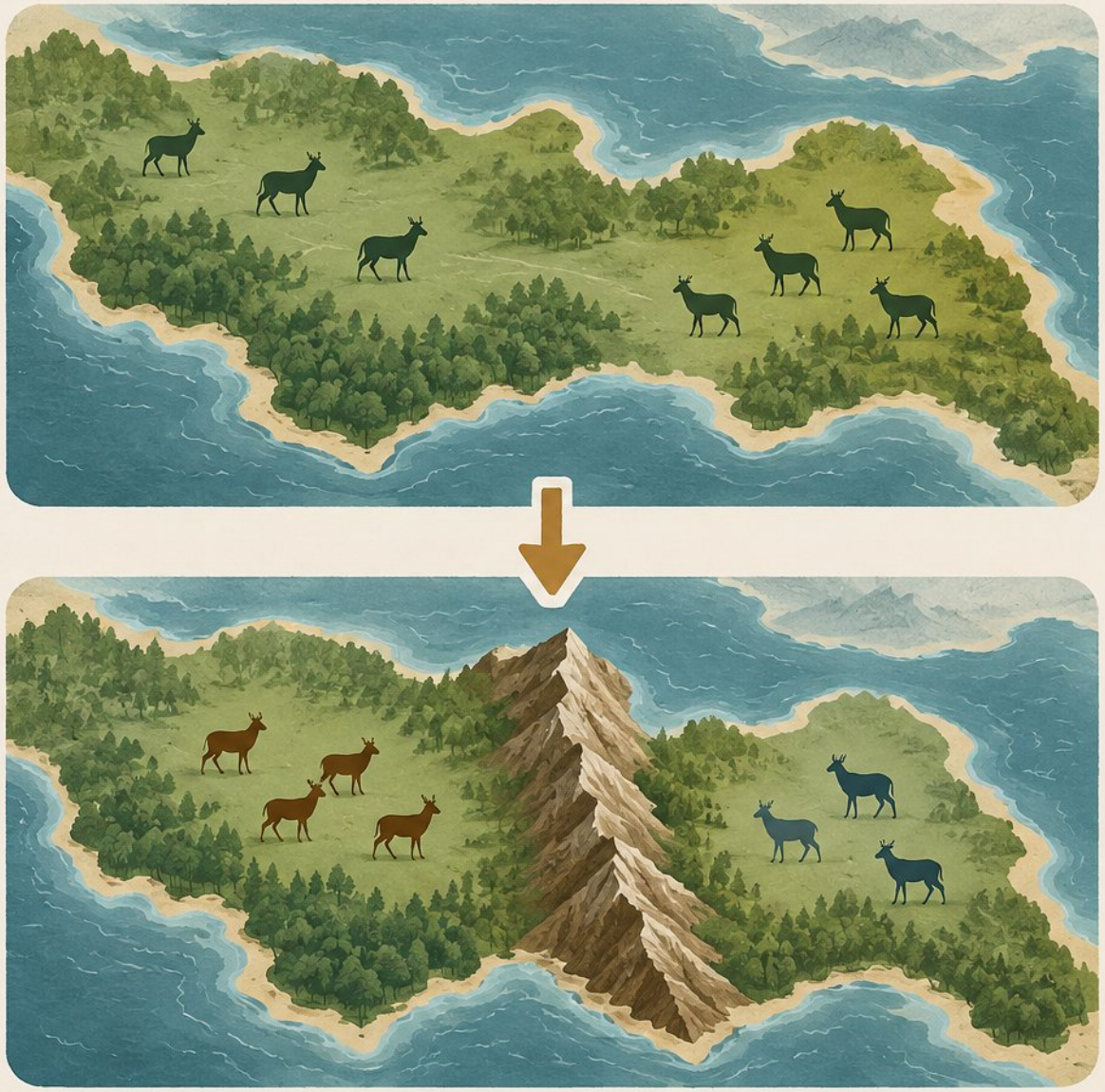
Reproductive Isolation:
Postzygotic Barriers and Reinforcement

- Postzygotic barriers act after fertilization, blocking gene flow
- Hybrid inviability: hybrid embryos fail to develop properly
- Hybrid sterility: mules are viable but cannot reproduce
- Hybrid breakdown: vigorous F1 hybrids produce weak F2 offspring
- Reinforced prezygotic barriers reduce costly hybrid production
- Measure isolation via reduced hybrid survival, fertility, or mating success



Geography of Speciation: Allopatric Divergence

- **Allopatry:** a continuous range is split, blocking gene flow
- Drift, mutation, and divergent selection then accumulate differences
- **Vicariance**: barriers arise im place, e.g., the Isthmus of Panama
- **Dispersal**: organisms cross existing barriers to colonize new areas
- Allopatry alone is not enough—selection and drift drive isolation



Secondary Contact, Hybrid Zones, and Reinforcement

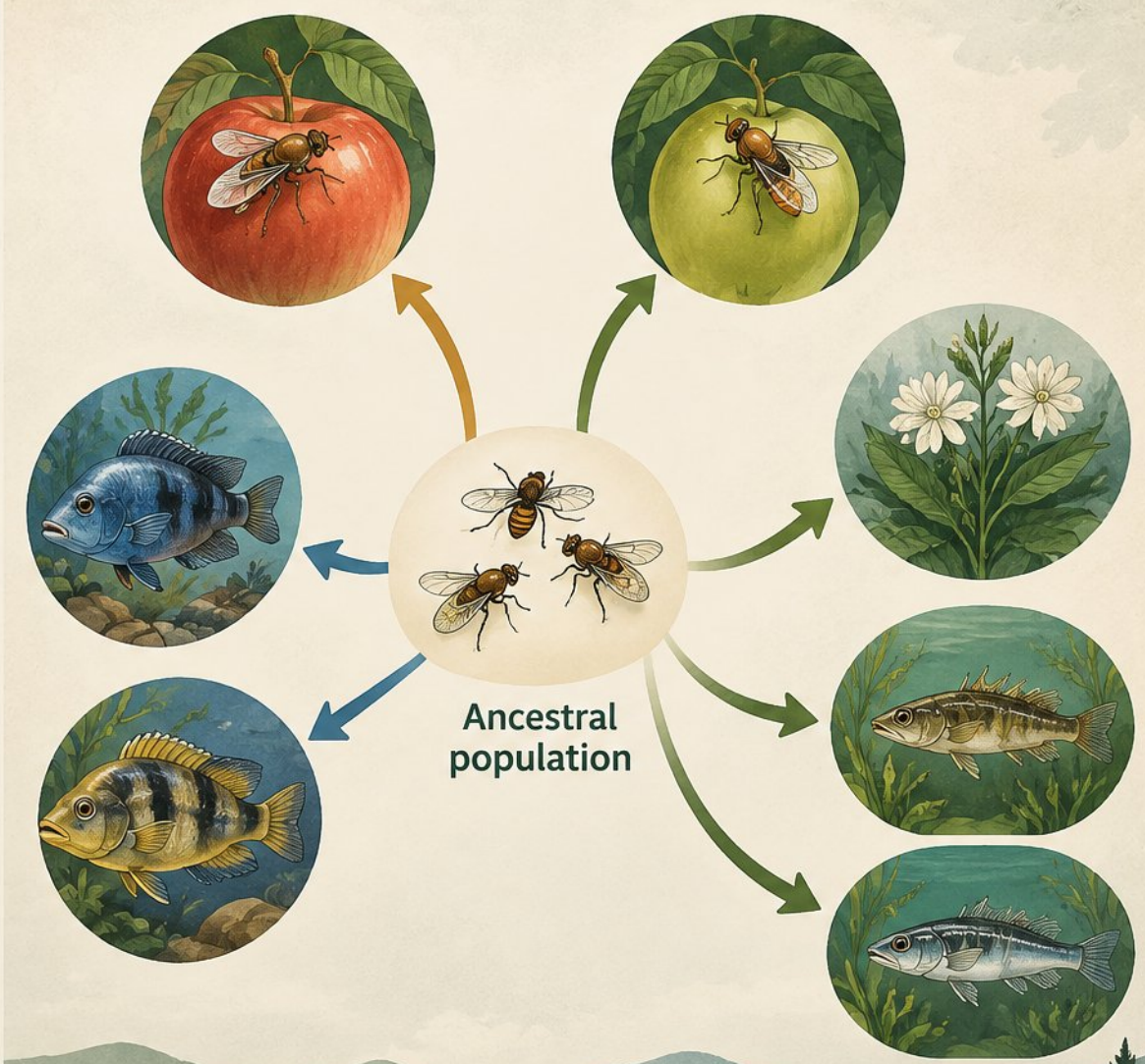
- Diverged populations meet again: fusion, stable hybrid zones, or reinforcement
- Hybrid zones act as natural laboratories: clines reveal genes resisting gene flow
- Barn swallows: sexually selected color and tail traits stay put across hybrid zones
- Low hybrid mating success drives reinforcement of prezygotic barriers
- Hybrid zones make gradual, messy species boundaries visible for museums and classrooms



Sympatric and Parapatric Speciation: Divergence with Gene Flow

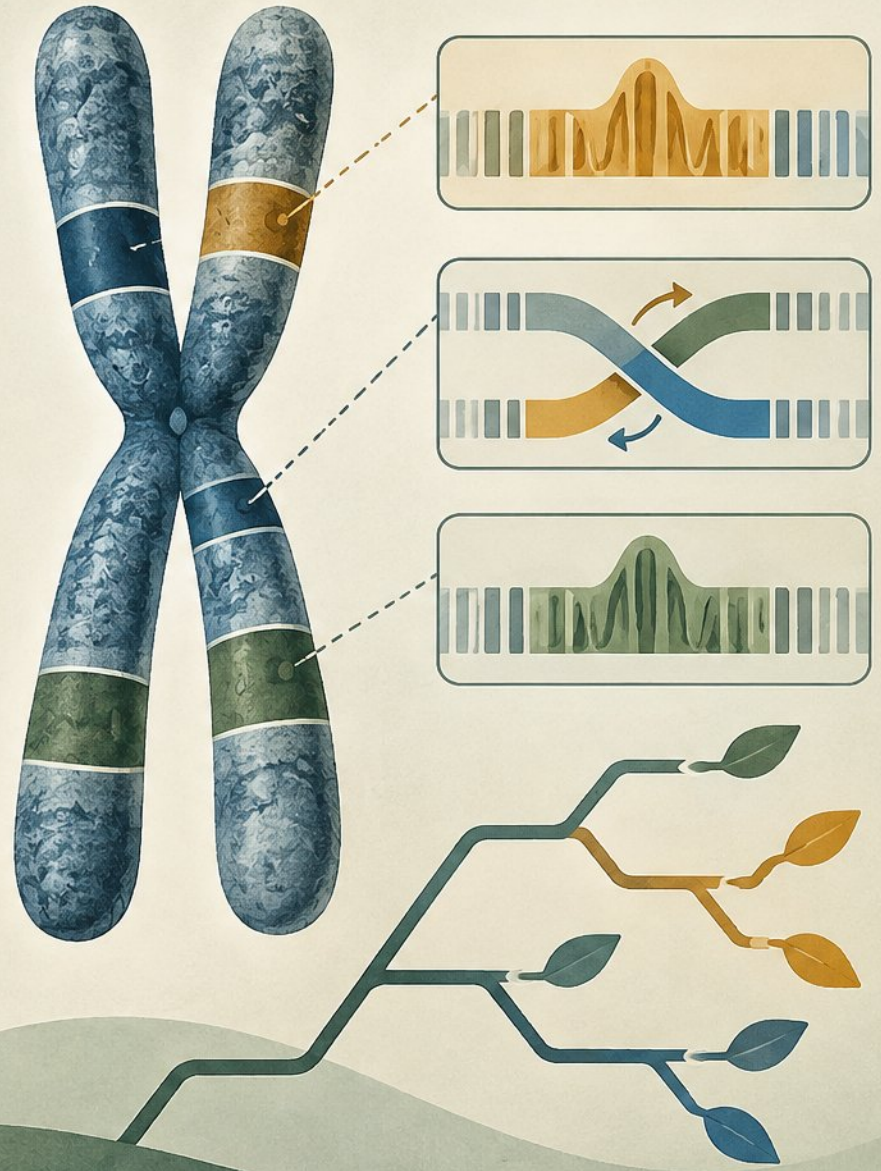
DIVERSITY THROUGH EVOLUTION

- **Sympatric speciation:** divergence without geographic isolation, via host shifts, polyploidy, or sexual selection
- **Parapatric speciation:** divergence along environmental gradients with limited, ongoing gene flow
- **The gene-flow challenge:** divergent selection plus reduced recombination builds genomic islands of differentiation
- **Examples:** apple maggot host races, cichlid radiations, polyploid plants, and stickleback ecotypes
- **Caution:** many celebrated sympatric cases reveal complex histories of allopatric phases plus secondary gene flow



Genetics of Speciation: Genes, Genomes, and Barrier Loci

- Speciation and hybrid incompatibility genes now known in many non-model organisms
- Incompatibility gene count has grown roughly sevenfold since 2010
- Mechanisms: genic incompatibilities, inversions suppressing recombination, intragenomic conflict
- Genomic islands may reflect barrier loci—or linked selection and low recombination
- *Antirrhinum* flower-color loci link selective sweeps to hybrid-zone barriers
- Trait-centered view: many small-effect genes and non-genic inheritance matter



Adaptive Radiation and Ecological Speciation

DIVERSE LIFE
SHARED ORIGINS
THRIVING WORLDS

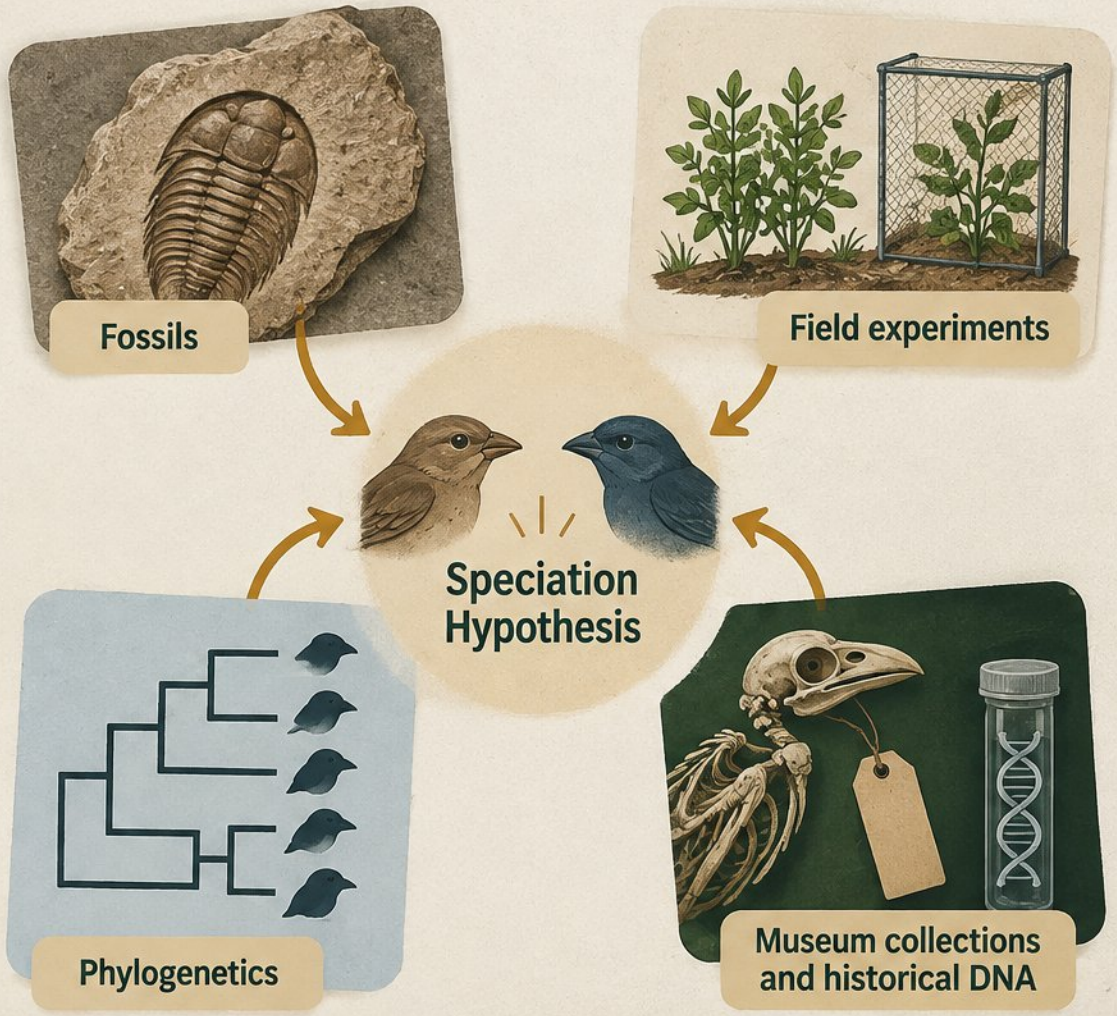
- **Adaptive radiation:** rapid diversification into species occupying diverse ecological niches
- **Schluter's hallmarks:** common ancestry, trait–environment correlation, trait utility, rapid speciation
- **Drivers:** ecological opportunity, key innovations (pharyngeal jaws), competition, sexual selection
- **Classic cases:** Darwin's finches, Anolis ecomorphs, rift-lake cichlids, Hawaiian silverswords
- Ecological and reproductive divergence reinforce each other, generating disparity and richness



DIFFERENT NICHES
BRIGHTER TOMORROWS

Evidence and Methods:
Testing Speciation Hypotheses

- Fossils, phylogenetics, biogeography, field experiments, and experimental evolution
- Experimental speciation manipulates evolution over generations to test reproductive isolation
- Meta-analysis of 34 studies: divergent selection strengthens isolation; plasticity speeds pre-mating isolation
- Museum collections and historical DNA document extinct or declining populations
- Beware convergence, introgression, and incomplete lineage sorting mimicking speciation







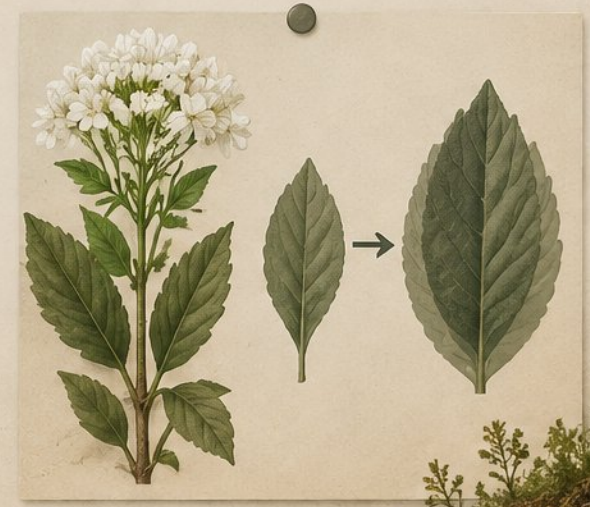
Hybridization, Polyploidy, and Cryptic Diversity

- Hybridization can create species, not just blur boundaries: homoploid and allopolyploid pathways
- Polyploidy drives major speciation in plants and some animals, often causing instant reproductive isolation
- Cryptic species: genetically distinct but morphologically similar lineages revealed by genomic data
- Conservation risk: taxonomy lags evolution, endangering cryptic lineages and hybrid populations
- Iberian rabbit lineages diverged ~2 million years ago, yet are managed as one species









BIODIVERSITY
EVOLUTION
A SHARED TOMORROW

Teaching Speciation: Misconceptions and Strategies

- Common traps: speciation as one event, “missing links,” and evolution as a ladder
- Even researchers can imply misconceptions—model fuzzy boundaries explicitly
- Teach tree-thinking: tree-format cladograms, not linear progressions
- Case studies: Titanoboa, horse evolution, Darwin’s finches
- Learning cycle: elicit preconceptions, explore data, then introduce terminology





Museum and Public Communication:
Making Speciation Tangible

Exhibit narratives:
island radiations, hybrid zones, and museum specimens reveal ongoing speciation

Museum genomics:
historical DNA documents past diversity, extinctions, and hybridization

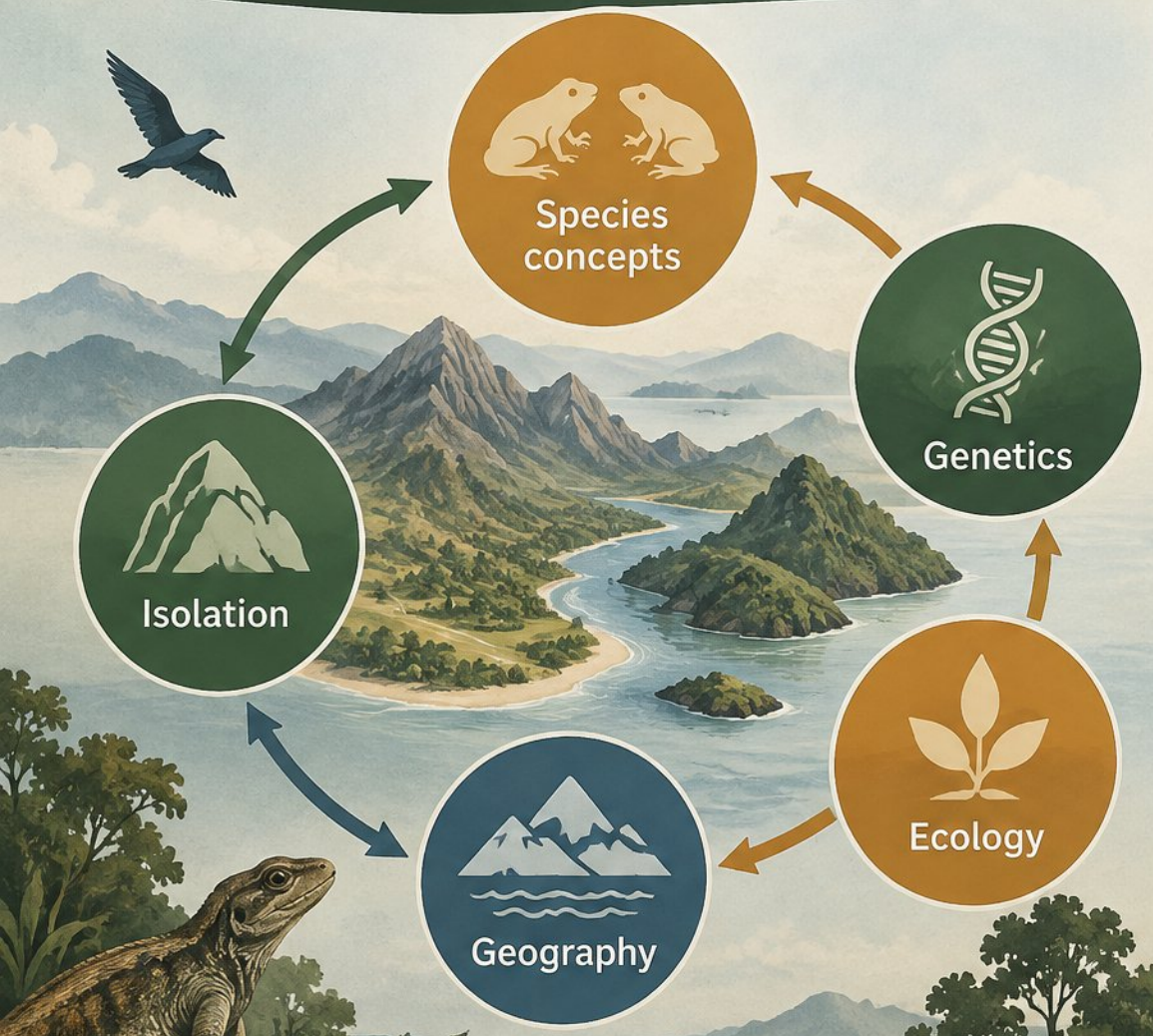
Human relevance:
biodiversity discovery, cryptic species, agriculture, invasive hybridization

Discussion prompts:
Is this one species or two?
What evidence would change your mind?

Assessments:
interpret a phylogeny, classify barriers, design a short exhibit script



Synthesis: Patterns, Processes, and Open Questions



- Species concepts, isolation, geography, genetics, and ecology all interconnect
- Frontiers: how common is speciation with gene flow?
- What genes and traits build reproductive barriers?
- Delimitation affects Red List assessments and cryptic species protection
- Ongoing hybridization challenges the strict isolation view
- Closing: how new species form—and why it matters today

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