CAMPBELL
BIOLOGY TENTH EDITION
Reece • Urry • Cain • Wasserman • Minorsky • Jackson

24

The Origin of Species

Lecture Presentation by Nicole Tunbridge and Kathleen Fitzpatrick

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That "Mystery of Mysteries"

- In the Galápagos Islands Darwin discovered plants and animals found nowhere else on Earth

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Figure 24.1

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Figure 24.1a

Galápagos giant tortoise, another species unique to the islands

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Animation: Macroevolution

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- **Speciation**, the origin of new species, is at the focal point of evolutionary theory
- Evolutionary theory must explain how new species originate and how populations evolve
- **Microevolution** consists of changes in allele frequency in a population over time
- **Macroevolution** refers to broad patterns of evolutionary change above the species level

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Concept 24.1: The biological species concept emphasizes reproductive isolation

- *Species* is a Latin word meaning "kind" or "appearance"
- Biologists compare morphology, physiology, biochemistry, and DNA sequences when grouping organisms

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The Biological Species Concept

- The **biological species concept** states that a **species** is a group of populations whose members have the potential to interbreed in nature and produce viable, fertile offspring; they do not breed successfully with members of other populations
- Gene flow between populations holds a species together genetically

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Figure 24.2

(a) Similarity between different species

(b) Diversity within a species

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Figure 24.2a

(a) Similarity between different species

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Figure 24.2aa

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Figure 24.2b

(b) Diversity within a species

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Video: Galápagos Tortoise

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Figure 24.2ba

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Figure 24.2bb

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Figure 24.2be

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Reproductive Isolation

- **Reproductive isolation** is the existence of biological factors (barriers) that impede two species from producing viable, fertile offspring
- **Hybrids** are the offspring of crosses between different species
- Reproductive isolation can be classified by whether factors act before or after fertilization

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Figure 24.3

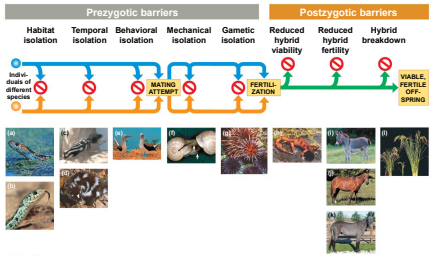

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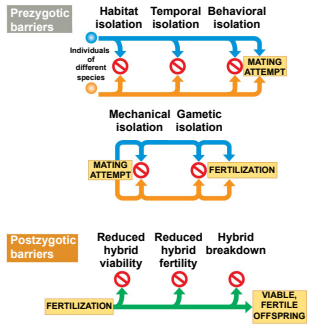
Figure 24.3d



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- **Prezygotic barriers** block fertilization from occurring by
  - Impeding different species from attempting to mate
  - Preventing the successful completion of mating
  - Hindering fertilization if mating is successful

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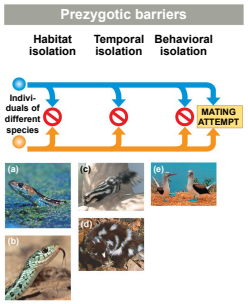
Figure 24.3a



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- **Habitat isolation**: Two species encounter each other rarely, or not at all, because they occupy different habitats, even though not isolated by physical barriers

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Figure 24.3aa

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- **Temporal isolation**: Species that breed at different times of the day, different seasons, or different years cannot mix their gametes

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- **Behavioral isolation**: Courtship rituals and other behaviors unique to a species are effective barriers to mating

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Video: Blue-footed Boobies Courtship Ritual

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Video: Albatross Courtship Ritual

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Video: Giraffe Courtship Ritual

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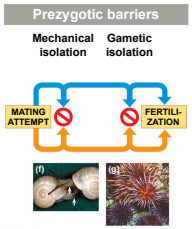
Figure 24.3b



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- **Mechanical isolation**: Morphological differences can prevent successful completion of mating

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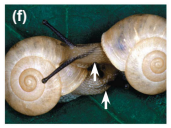
Figure 24.3ba



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- **Gametic Isolation:** Sperm of one species may not be able to fertilize eggs of another species

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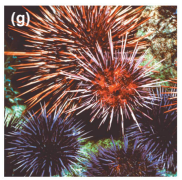
Figure 24.3bb



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- **Postzygotic barriers** prevent the hybrid zygote from developing into a viable, fertile adult
  - Reduced hybrid viability
  - Reduced hybrid fertility
  - Hybrid breakdown

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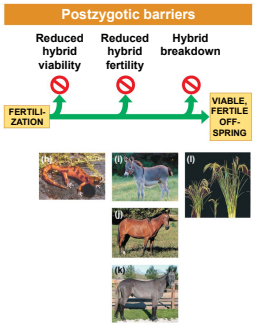
Figure 24.3c



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- **Reduced hybrid viability**: Genes of the different parent species may interact and impair the hybrid's development or survival in its environment

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- **Reduced hybrid fertility**: Even if hybrids are vigorous, they may be sterile

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- **Hybrid breakdown**: Some first-generation hybrids are fertile, but when they mate with each other or with either parent species, offspring of the next generation are feeble or sterile

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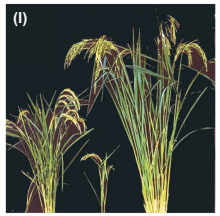
Figure 24.3ce



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Limitations of the Biological Species Concept

- The biological species concept cannot be applied to fossils or asexual organisms (including all prokaryotes)
- The biological species concept emphasizes absence of gene flow
- However, gene flow can occur between distinct species
  - For example, grizzly bears and polar bears can mate to produce "grolar bears"

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Figure 24.4

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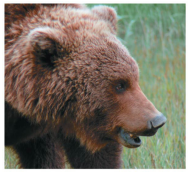
Figure 24.4a



Grizzly bear (*U. arctos*)

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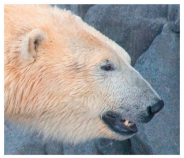
Figure 24.4b



Polar bear (*U. maritimus*)

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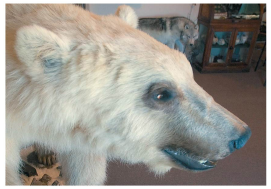
Figure 24.4c



Hybrid "grolar bear"

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Other Definitions of Species

- Other species concepts emphasize the unity within a species rather than the separateness of different species
- The **morphological species concept** defines a species by structural features
  - It applies to sexual and asexual species but relies on subjective criteria

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- The **ecological species concept** views a species in terms of its ecological niche
  - It applies to sexual and asexual species and emphasizes the role of disruptive selection
- The **phylogenetic species concept** defines a species as the smallest group of individuals on a phylogenetic tree
  - It applies to sexual and asexual species, but it can be difficult to determine the degree of difference required for separate species

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Concept 24.2: Speciation can take place with or without geographic separation

- Speciation can occur in two ways
  - Allopatric speciation
  - Sympatric speciation

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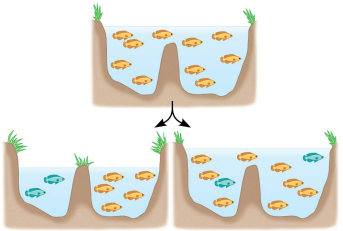
Figure 24.5



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Allopatric ("Other Country") Speciation

- In **allopatric speciation**, gene flow is interrupted or reduced when a population is divided into geographically isolated subpopulations
  - For example, the flightless cormorant of the Galápagos likely originated from a flying species on the mainland

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The Process of Allopatric Speciation

- The definition of barrier depends on the ability of a population to disperse
  - For example, a canyon may create a barrier for small rodents, but not birds, coyotes, or pollen

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- Separate populations may evolve independently through mutation, natural selection, and genetic drift
- Reproductive isolation may arise as a by-product of genetic divergence
  - For example, isolated populations of mosquitofish have evolved reproductive isolation as a result of selection under different levels of predation

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Figure 24.6

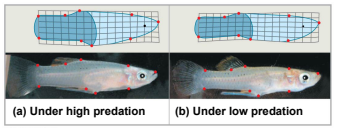

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Figure 24.6a

(a) Under high predation

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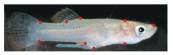
Figure 24.6b



(b) Under low predation

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Evidence of Allopatric Speciation

- Reproductive barriers can develop when laboratory populations are experimentally isolated and subjected to different environmental conditions

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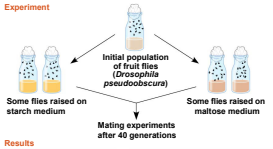
Figure 24.7



Results

		Female	
		Starch	Maltose
Male	Starch	22	9
	Maltose	8	20

Number of matings in experimental group

		Female	
		Starch population 1	Starch population 2
Male	Starch population 1	18	15
	Starch population 2	12	15

Number of matings in control group

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Figure 24.7a

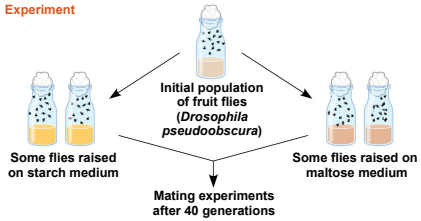

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Figure 24.7b

Results

		Female	
		Starch	Maltose
Male	Starch	22	9
	Maltose	8	20

Number of matings in experimental group

		Female	
		Starch population 1	Starch population 2
Male	Starch population 1	18	15
	Starch population 2	12	15

Number of matings in control group

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- Allopatric speciation can also occur in nature
- Fifteen pairs of sister species of snapping shrimp (*Alpheus*) are separated by the Isthmus of Panama
- These species originated 9 to 13 million years ago, when the Isthmus of Panama formed and separated the Atlantic and Pacific waters

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Figure 24.8

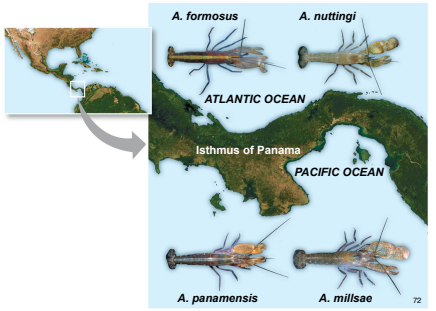

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Figure 24.8a

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Figure 24.8b

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Figure 24.8c

A. formosus

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Figure 24.8d

A. nuttingi

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Figure 24.8e

A. panamensis

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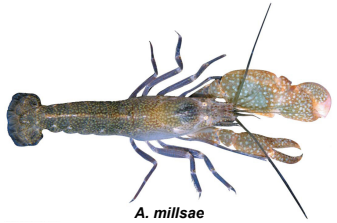
Figure 24.8f



A. millsae

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- Regions with many geographic barriers typically have more species than do regions with fewer barriers
- Reproductive isolation between populations generally increases as the distance between them increases

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- Reproductive barriers are intrinsic to the organisms themselves; physical separation alone is not a biological barrier

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Sympatric ("Same Country") Speciation

- In **sympatric speciation**, speciation takes place in geographically overlapping populations
- Sympatric speciation can occur if gene flow is reduced by factors including
  - Polyploidy
  - Sexual selection
  - Habitat differentiation

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Polyploidy

- **Polyploidy** is the presence of extra sets of chromosomes due to accidents during cell division
- Polyploidy is much more common in plants than in animals
- Polyploidy can produce new biological species in sympatry within a single generation

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- An **autopolyploid** is an individual with more than two chromosome sets, derived from a single species

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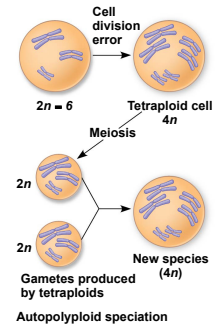
Figure 24.UN02



Autopolyploid speciation

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- An **allopolyploid** is a species with multiple sets of chromosomes derived from different species

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Figure 24.9-1

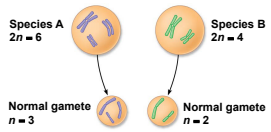

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Figure 24.9-2

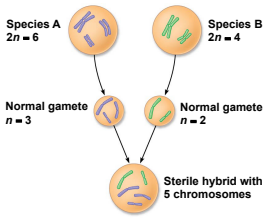

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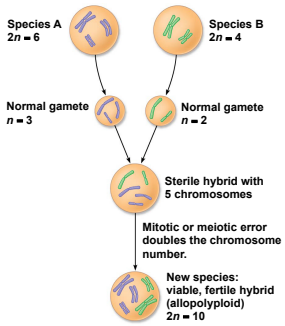
Figure 24.9-3



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- At least five new plant species have originated by polyploid speciation since 1850
  - For example, in the genus *Tragopogon*, two allopolyploid species have evolved from three diploid parent species
- Many important crops (oats, cotton, potatoes, tobacco, and wheat) are polyploids

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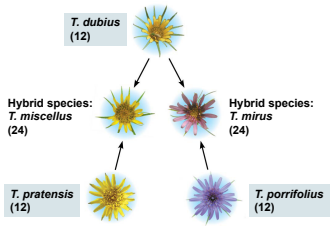
Figure 24.10



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Sexual Selection

- Sexual selection can drive sympatric speciation
- Sexual selection for mates of different colors has likely contributed to speciation in cichlid fish in Lake Victoria

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Figure 24.11

Experiment

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Figure 24.11a

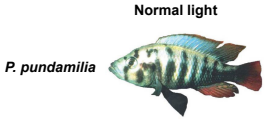

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Figure 24.11b

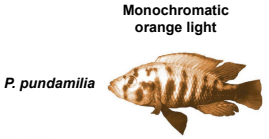

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Figure 24.11c

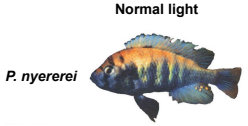

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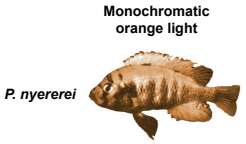
Figure 24.11d



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Habitat Differentiation

- Sympatric speciation can also result from the appearance of new ecological niches
- For example, the North American maggot fly can live on native hawthorn trees as well as more recently introduced apple trees

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Figure 24.UN03

***R. pomonella* feeding on a hawthorn berry**

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Allopatric and Sympatric Speciation: *A Review*

- In allopatric speciation, geographic isolation restricts gene flow between populations
- Reproductive isolation may then arise by natural selection, genetic drift, or sexual selection in the isolated populations
- Even if contact is restored between populations, interbreeding is prevented

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- In sympatric speciation, a reproductive barrier isolates a subset of a population without geographic separation from the parent species
- Sympatric speciation can result from polyploidy, natural selection, or sexual selection

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Concept 24.3: Hybrid zones reveal factors that cause reproductive isolation

- A **hybrid zone** is a region in which members of different species mate and produce hybrids
- Hybrids are the result of mating between species with incomplete reproductive barriers

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Patterns Within Hybrid Zones

- A hybrid zone can occur in a single band where adjacent species meet
  - For example, two species of toad in the genus *Bombina* interbreed in a long and narrow hybrid zone

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Figure 24.12

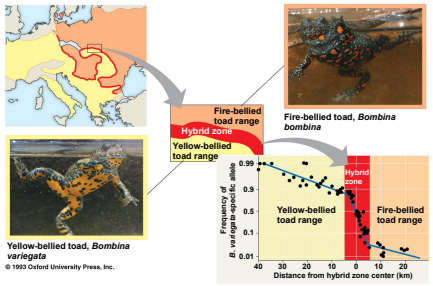

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Figure 24.12a

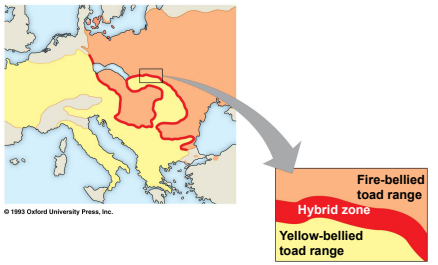

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Figure 24.12b

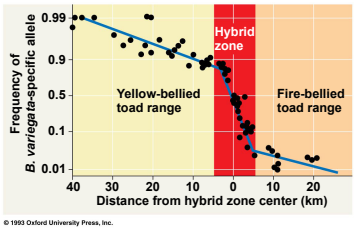

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Figure 24.12c

Yellow-bellied toad, *Bombina variegata*

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Figure 24.12d

Fire-bellied toad, *Bombina bombina*

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- Hybrids often have reduced fitness compared with parent species
- The distribution of hybrid zones can be more complex if parent species are found in patches within the same region

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Hybrid Zones over Time

- When closely related species meet in a hybrid zone, there are three possible outcomes
  - Reinforcement
  - Fusion
  - Stability

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Figure 24.13-1

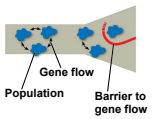

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Figure 24.13-2

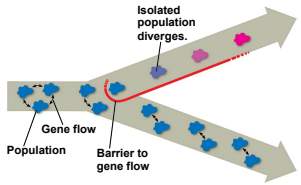

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Figure 24.13-3

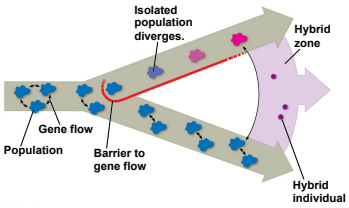

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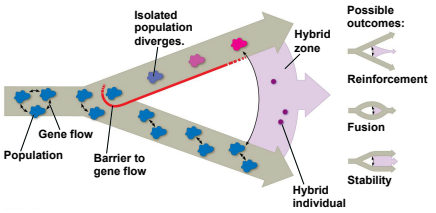
Figure 24.13-4



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Reinforcement: Strengthening Reproductive Barriers

- When hybrids are less fit than parent species, **reinforcement** of reproductive barriers may occur through strong selection for prezygotic barriers
- Over time, the rate of hybridization decreases

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- Where reinforcement occurs, reproductive barriers should be stronger for sympatric than allopatric species
  - For example, in populations of flycatchers, males are more similar in allopatric populations than sympatric populations

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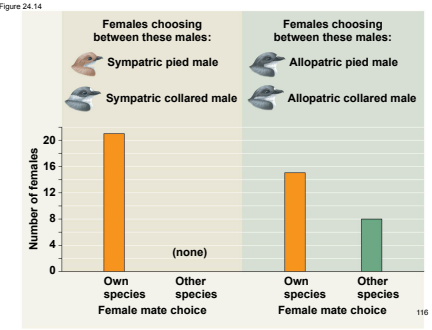
Figure 24.14



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Fusion: Weakening Reproductive Barriers

- If hybrids are as fit as parents, there can be substantial gene flow between species
- If gene flow is great enough, reproductive barriers weaken and the parent species can fuse into a single species
  - For example, pollution in Lake Victoria has reduced the ability of female cichlids to distinguish males of different species

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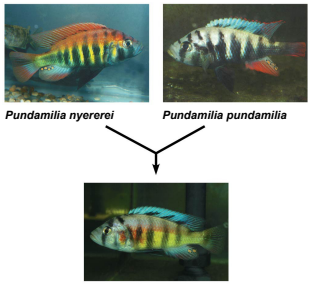
Figure 24.15



Pundamilia "turbid water," **hybrid offspring from a location with turbid water**

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Figure 24.15a

Pundamilia nyererei

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Figure 24.15b

Pundamilia pundamilia

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Figure 24.15c

Pundamilia "turbid water," **hybrid offspring from a location with turbid water**

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Stability: Continued Formation of Hybrid Individuals

- Extensive gene flow from outside the hybrid zone can overwhelm selection for increased reproductive isolation inside the hybrid zone
  - For example, parent species of *Bombina* routinely migrate into the narrow hybrid zone resulting in ongoing hybridization

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Concept 24.4: Speciation can occur rapidly or slowly and can result from changes in few or many genes

- Many questions remain concerning how long it takes for new species to form, or how many genes need to differ between species

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The Time Course of Speciation

- Broad patterns in speciation can be studied using the fossil record, morphological data, or molecular data

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Patterns in the Fossil Record

- The fossil record includes examples of species that appear suddenly, persist essentially unchanged for some time, and then apparently disappear
- Niles Eldredge and Stephen Jay Gould coined the term **punctuated equilibria** to describe periods of apparent stasis punctuated by sudden change
- The punctuated equilibrium model contrasts with a model of gradual change in a species over time

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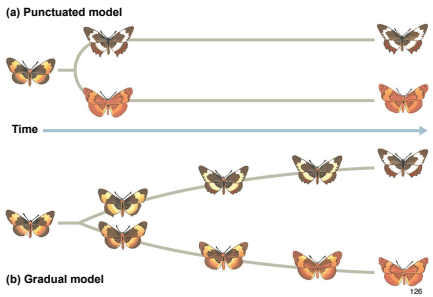
Figure 24.16



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Speciation Rates

- The punctuated pattern in the fossil record and evidence from lab studies suggest that speciation can be rapid
  - For example, the sunflower *Helianthus anomalus* originated from the hybridization of two other sunflower species

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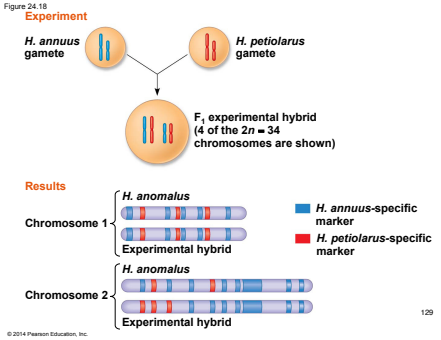
Figure 24.18



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- The interval between speciation events can range from 4,000 years (some cichlids) to 40 million years (some beetles), with an average of 6.5 million years

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Studying the Genetics of Speciation

- A fundamental question of evolutionary biology persists: How many genes change when a new species forms?
- Depending on the species in question, speciation might require change in a single gene or many genes
  - For example, in Japanese *Euhadra* snails, the direction of shell spiral affects mating and is controlled by a single gene

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- In monkey flowers (*Mimulus*), two loci affect flower color, which influences pollinator preference
- Pollination that is dominated by either hummingbirds or bees can lead to reproductive isolation of the flowers
- In other organisms, speciation can be influenced by larger numbers of genes and gene interactions

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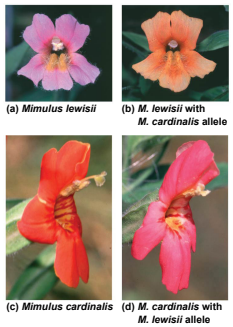
Figure 24.19



(a) *Mimulus lewisii*

(b) *M. lewisii* with *M. cardinalis* allele

(c) *Mimulus cardinalis*

(d) *M. cardinalis* with *M. lewisii* allele

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Figure 24.19a

(a) *Mimulus lewisii*

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Figure 24.19b

(b) *M. lewisii* with *M. cardinalis* allele

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Figure 24.19c

(c) *Mimulus cardinalis*

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Figure 24.19d

(d) *M. cardinalis* with *M. lewisii* allele

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From Speciation to Macroevolution

- Macroevolution is the cumulative effect of many speciation and extinction events

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Figure 24.UN01a

Geographic Distance (km)	15	32	40	47	42	62	63
Reproductive Isolation Value	0.32	0.54	0.50	0.50	0.82	0.37	0.67
Distance (continued)	81	86	107	107	115	137	147
Isolation (continued)	0.53	1.15	0.73	0.82	0.81	0.87	0.87
Distance (continued)	137	150	165	189	219	239	247
Isolation (continued)	0.50	0.57	0.91	0.93	1.5	1.22	0.82
Distance (continued)	53	55	62	105	179	169	
Isolation (continued)	0.99	0.21	0.56	0.41	0.72	1.15	

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Figure 24.UN01b

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Figure 24.UN04

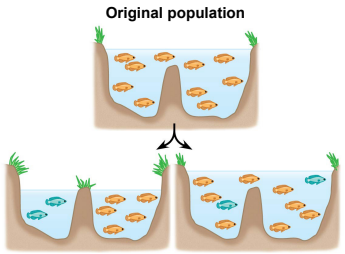

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Figure 24.UN05

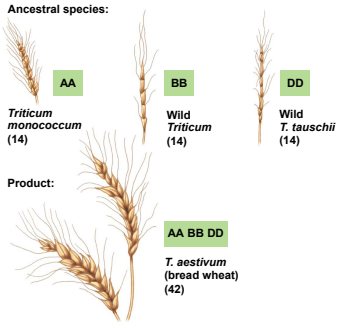

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Figure 24.UN06

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