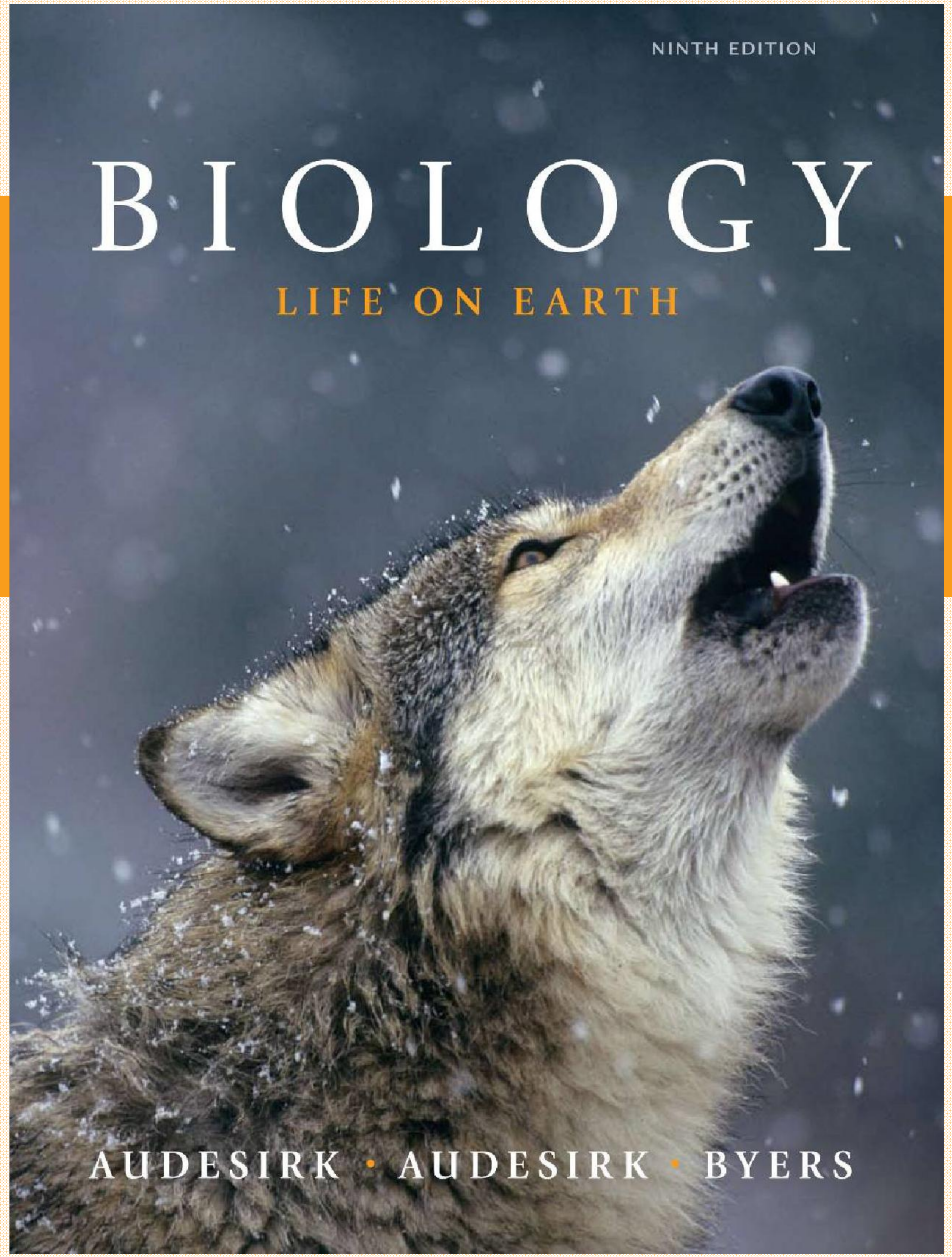

Chapter 16

The Origin of Species

Lecture Outlines by Gregory Ahearn,
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Chapter 16 At a Glance

- 16.1 What Is a Species?
- 16.2 How Is Reproductive Isolation Between Species Maintained?
- 16.3 How Do New Species Form?
- 16.4 What Causes Extinction?

16.1 What Is a Species?

- **Biologists need a clear definition of species**
  - In Pre-Darwinian times, the term “species” referred to different kinds of organisms
  - Species were classified initially based upon appearance

16.1 What Is a Species?

- **Each species evolves independently**
  - Today, a **species** is defined as a group of actually or potentially interbreeding natural populations that are **reproductively isolated (生殖隔离)** from other such groups (the biological species concept)
  - A group that is reproductively isolated is unable to breed successfully outside the group

16.1 What Is a Species?

- **Each species evolves independently (continued)**
  - There are two limitations to the biological species definition
    - Because it is based on the ability to interbreed, this definition cannot be used to determine species identity among asexually(无性地) reproducing organisms or among fossils
    - Also, it is often difficult to observe whether members of two different groups interbreed

16.1 What Is a Species?

- **Appearance can be misleading in determining a species**
  - Organisms of similar appearance sometimes belong to different species
  - The cordilleran flycatcher(一种鹟科小型鸟) and Pacific slope flycatcher are so similar that birdwatchers can't tell them apart
    - These birds were considered to be a single species, but research revealed that they do not interbreed and are in fact two different species
  - A butterfly considered for two centuries to be a single species known as the two-barred flasher butterfly is now known to be 10 separate species

Members of Different Species May Be Similar in Appearance

(a) Cordilleran flycatcher

(b) Pacific-slope flycatcher

Fig. 16-1

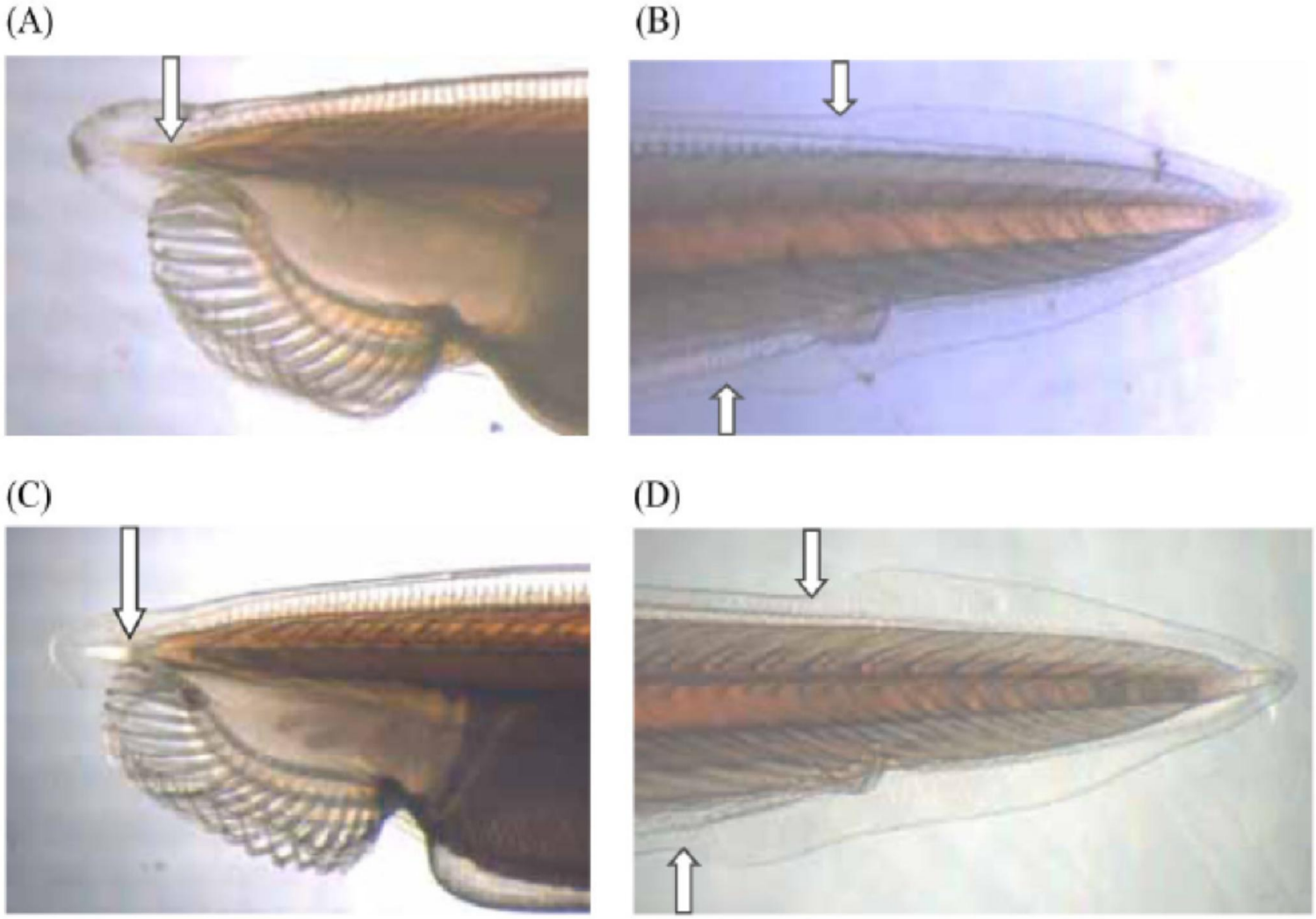
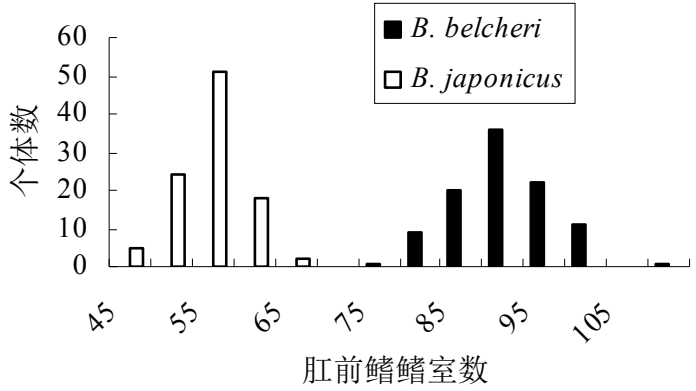


Fig. 2. Head and tail of amphioxus from Oucuo and Huangcuo. (A) Head of Oucuo amphioxus, arrow indicates upward cephalic notochord; (B) Tail of Oucuo amphioxus, arrows indicate obtuse angles; (C) Head of Huangcuo amphioxus, arrow indicates forward cephalic notochord; (D) Tail of Huangcuo specimen, arrows indicate sharp angles.

4、*B. Belcheri*与*B. japonicum*形态上的显著差别

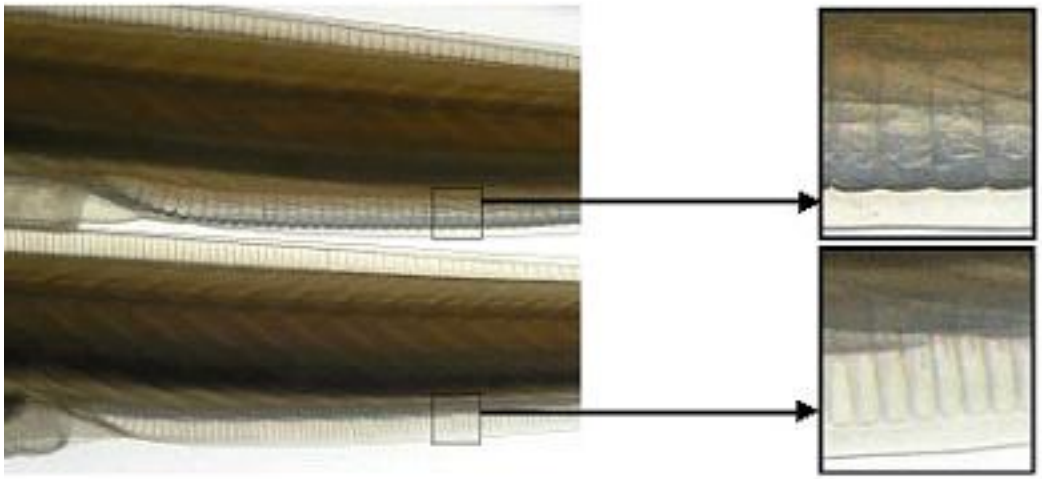
（1）肛前鳍

- 鳍室数
  - ***B. belcheri*: 92.44±5.83(80-103)**
  - ***B. japonicum*: 56.56±3.84(48-64)**

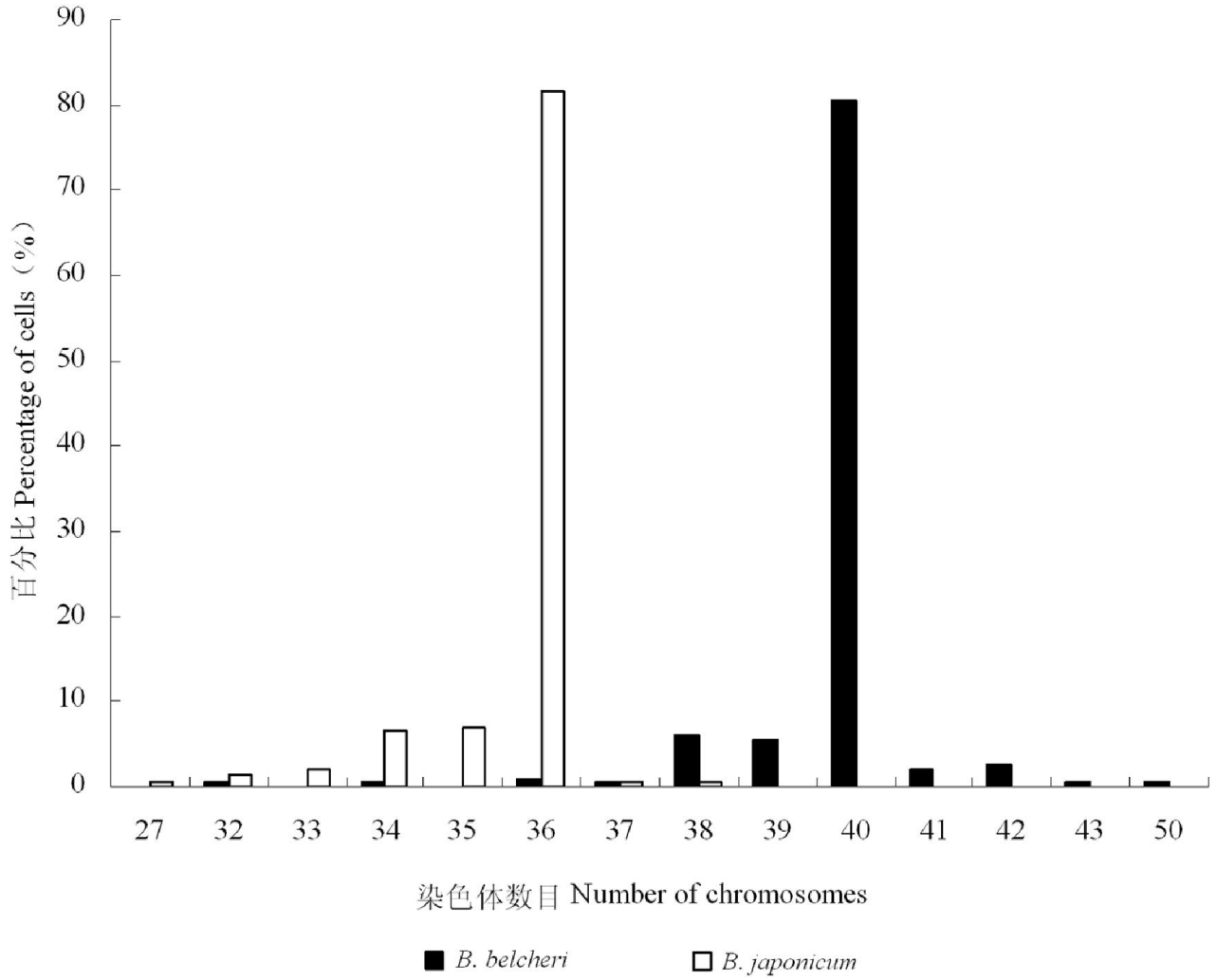


- 鳍室形状

  最高鳍室的高/宽
  - ***B. japonicum*(上) 2.38±0.39(1.67-3.33)**
  - ***B. belcheri*(下) 3.31±0.62(1.75-4.8)**



2种文昌鱼胚胎细胞的染色体计数



16.1 What Is a Species?

- **Appearance can be misleading in determining a species (continued)**
  - Organisms that differ in appearance may belong to the same species
  - The myrtle warbler and Audubon's warbler, which have different throat colors, were listed in bird books as two species in the 1970s
    - It was then discovered that the warblers interbreed where their ranges overlap
    - Today, they are considered a single species

Members of a Species May Differ in Appearance

(a) Myrtle warbler

(b) Audubon's warbler

Fig. 16-2

16.2 How Is Reproductive Isolation Between Species Maintained?

- Traits that prevent interbreeding and maintain reproductive isolation are called **isolating mechanisms**
- Mechanisms that prevent mating between species are called **premating isolating mechanisms(交配前隔离)**
- Mechanisms that prevent formation of vigorous, fertile hybrids between species are called **postmating isolating mechanisms (交配后隔离)**

16.2 How Is Reproductive Isolation Between Species Maintained?

- **Premating isolating mechanisms prevent mating between species**
  - Reproductive isolation occurs when members of one population are unable to interbreed with members of another population
  - For most species, two or more isolating mechanisms interact to prevent the formation of fertile offspring

16.2 How Is Reproductive Isolation Between Species Maintained?

- **Premating isolating mechanisms include the following**
  - Geographical isolation (地理隔离)
  - Ecological isolation (生态隔离)
  - Temporal isolation (时间隔离)
  - Behavioral isolation (行为隔离)
  - Mechanical incompatibility(结构不相容)

16.2 How Is Reproductive Isolation Between Species Maintained?

- **Premating isolating mechanisms (continued)**
  - *Geographical isolation* prevents interbreeding between populations that do not come into contact because they live in physically separated places
  - This type of isolation is usually considered to be a mechanism that allows new species to form rather than one that maintains reproductive isolation between species

16.2 How Is Reproductive Isolation Between Species Maintained?

- Premating isolating mechanisms *(continued)*
  - Geographically separated populations aren't necessarily distinct species
    - The Kaibab and Abert squirrels living in geographically separate areas of the Grand Canyon are physically separated, but still very similar
    - It is currently unknown if the two populations have diverged into two species

Geographic Isolation

(a) Kaibab squirrel

(b) Abert squirrel

Fig. 16-3

16.2 How Is Reproductive Isolation Between Species Maintained?

- **Premating isolating mechanisms (continued)**
  - *Ecological isolation* occurs when species don't mate because they occupy different habitats(栖息地)
    - White-crowned sparrows inhabit fields and meadows, while white-throated sparrows inhabit dense thickets
    - In another example, each species of fig wasp breeds in the fruit of a different species of fig, and the wasps thus do not come into contact with one another

Ecological Isolation

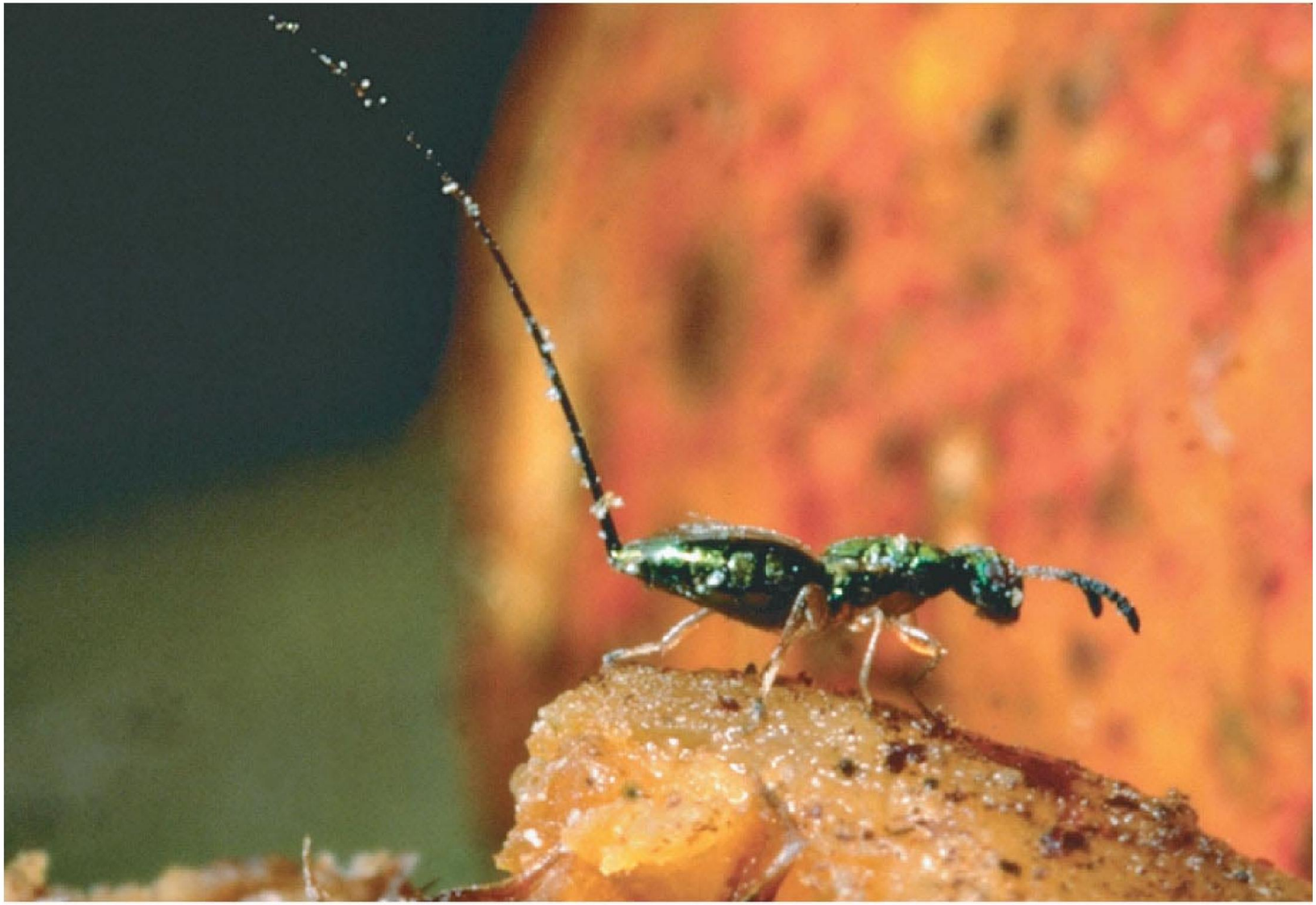


Fig. 16-4

16.2 How Is Reproductive Isolation Between Species Maintained?

- **Premating isolating mechanisms (continued)**
  - *Temporal isolation* occurs when species can't mate because they breed at different times
  - In nature, Bishop pines and Monterey pines do not interbreed
    - Bishop pine pollination occurs in summer
    - Monterey pine pollination occurs in early spring

Temporal Isolation

(a) Bishop pine

(b) Monterey pine

Fig. 16-5

16.2 How Is Reproductive Isolation Between Species Maintained?

- **Premating isolating mechanisms (continued)**
  - *Behavioral isolation* occurs when species can't mate because they have different courtship and mating rituals(求偶和交配仪式)
  - The songs and plumage of male songbirds are species-specific
    - They attract females of the same species
    - Females of other species are unresponsive

Behavioral Isolation

Fig. 16-6

16.2 How Is Reproductive Isolation Between Species Maintained?

- **Behavioral isolation occurs when species can't mate because they have different courtship and mating rituals (continued)**
  - Male frogs embrace any female regardless of species
  - Female frogs encountering males of a different species utter the "release call," which causes the males to let go

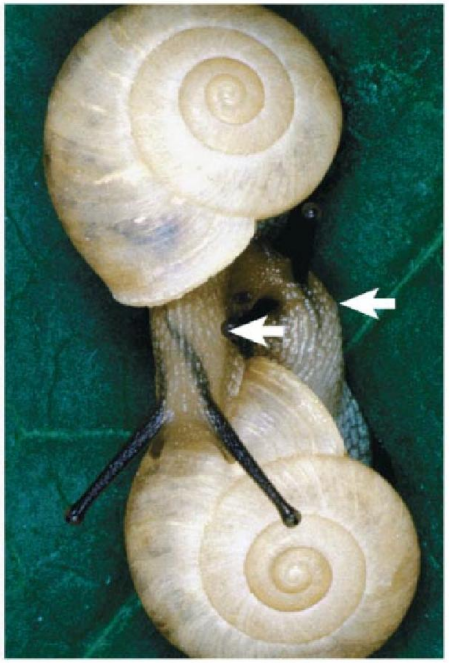
16.2 How Is Reproductive Isolation Between Species Maintained?

- **Premating isolating mechanisms (continued)**
  - *Mechanical incompatibility* occurs when species cannot mate because their reproductive structures are incompatible
  - In animals with internal fertilization, male and female sexual organs may not fit together
    - For example, snails of species whose shells have left-handed spirals may be unable to copulate successfully with snails whose shells have right-handed spirals
  - In plants, differences in flower size or structure may attract different pollinators

Mechanical Isolation

(a) Shells of three snail species

(b) Matching coils



(c) Non-matching coils

Fig. 16-7

16.2 How Is Reproductive Isolation Between Species Maintained?

- **Postmating isolating mechanisms limit hybrid offspring**
  - Postmating isolating mechanisms include the following
    - Gametic incompatibility (配子不相容)
    - Hybrid inviability (杂合子不存活)
    - Hybrid infertility (杂合子不育)

16.2 How Is Reproductive Isolation Between Species Maintained?

- **Postmating isolating mechanisms limit hybrid offspring (continued)**
  - *Gametic incompatibility* occurs when sperm from one species cannot fertilize eggs of another
    - In animals, fluids of the female reproductive tract my weaken or kill sperm of another species
    - In plants, pollen from one species may fail to germinate when it lands on the stigma of another species

16.2 How Is Reproductive Isolation Between Species Maintained?

- **Postmating isolating mechanisms limit hybrid offspring (continued)**
  - Gametic incompatibility may be an especially important isolating mechanism in species such as marine invertebrates and wind-pollinated plants that reproduce by scattering gametes in the water or in the air
    - Sea urchin sperm cells contain a protein that allows them to bind only to eggs of their own species
    - Among plants, chemical incompatibility may prevent the germination(萌发) of pollen from one species that lands on the stigma(柱头) (pollen-catching structure) of the flower of another species

16.2 How Is Reproductive Isolation Between Species Maintained?

- **Postmating isolating mechanisms limit hybrid offspring (continued)**
  - *Hybrid inviability* occurs when hybrid offspring fail to survive to maturity
  - The hybrid may abort early in development or die shortly after birth
  - The hybrid may be unable to reproduce because it displays behaviors that are mixtures of the two parental types
    - Lovebird hybrids have great difficulty learning to carry nest materials during flight and probably could not reproduce in the wild

16.2 How Is Reproductive Isolation Between Species Maintained?

- **Postmating isolating mechanisms limit hybrid offspring (continued)**
  - *Hybrid infertility* occurs when hybrid offspring are sterile or have reduced fertility
    - Mule hybrids (a cross between a horse and a donkey) are sterile
    - Liger hybrids (a zoo-based cross between a male lion and a female tiger) are sterile
  - Infertility is often caused by the failure of chromosomes to pair properly during meiosis, so eggs and sperm never develop

Hybrid Infertility

Fig. 16-8

Table 16-1 Mechanisms of Reproductive Isolation

Premating isolating mechanisms: factors that prevent organisms of two species from mating

- **Geographic isolation:** The species cannot interbreed because a physical barrier separates them.
- **Ecological isolation:** The species do not interbreed even if they are within the same area because they occupy different habitats.
- **Temporal isolation:** The species cannot interbreed because they breed at different times.
- **Behavioral isolation:** The species do not interbreed because they have different courtship and mating rituals.
- **Mechanical incompatibility:** The species cannot interbreed because their reproductive structures are incompatible.

Postmating isolating mechanisms: factors that prevent organisms of two species from producing vigorous, fertile offspring after mating

- **Gametic incompatibility:** Sperm from one species cannot fertilize eggs of another species.
- **Hybrid inviability:** Hybrid offspring fail to survive to maturity.
- **Hybrid infertility:** Hybrid offspring are sterile or have low fertility.

16.3 How Do New Species Form?

- **Speciation(物种形成) is the process by which new species form**
  - Speciation depends on two factors
    - The **isolation of populations(种群隔离)** must prevent gene flow from spreading between them and keeping them similar
    - **Genetic divergence(遗传分化)** of the populations must occur through the evolution of isolating mechanisms, driven by genetic drift or natural selection

16.3 How Do New Species Form?

- **Speciation is the process by which new species form (continued)**
  - Evolutionary biologists group the different pathways to speciation into two broad categories
    - In **allopatric speciation(异域的物种形成)**, the isolating mechanism is a physical barrier
    - In **sympatric speciation(同域的物种形成)**, isolation occurs without geographical separation

16.3 How Do New Species Form?

- **Geographical separation of a population can lead to allopatric(不同地域的) speciation**
  - Allopatric speciation occurs when two populations of a species become separated by a geographical barrier
    - The colonization of remote habitats, such as islands or reefs far out to sea, can lead to separate populations
    - Geological changes caused by such factors as volcanoes, earthquakes, continental drift, and change of course by rivers can lead to the separation of populations

16.3 How Do New Species Form?

- **Geographical separation of a population can lead to allopatric speciation (continued)**
  - Allopatric speciation occurs when isolated populations diverge genetically because of natural selection and genetic drift
  - Allopatric speciation is believed to be the most common type of speciation, especially among animals

Allopatric Isolation and Divergence

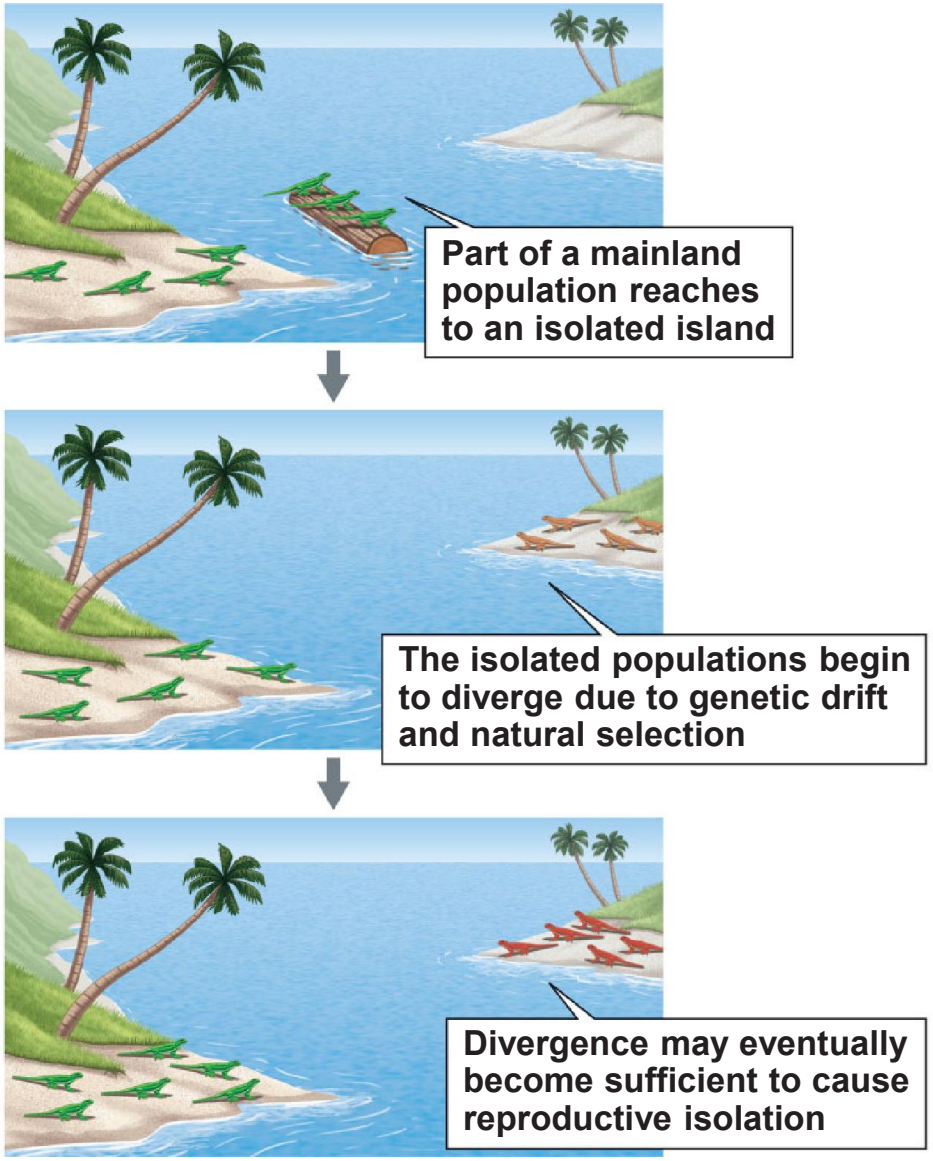


Fig. 16-9

16.3 How Do New Species Form?

- **Ecological isolation without geographical separation can lead to sympatric(同域分布的) speciation**
  - Sympatric speciation may occur when a geographical area contains two distinctly different habitats (ecological isolation)
    - Two populations of a species living in the geographical area may occupy the two habitats
    - Through the action of natural selection, different members of the species begin to specialize in one habitat or the other
    - The two isolated populations may diverge sufficiently genetically so that they can't interbreed and are thus considered separate species

16.3 How Do New Species Form?

- **Ecological isolation without geographical separation can lead to sympatric speciation (continued)**
  - Two sympatric populations of fruit flies (*Rhagoletis pomonella*) may be evolving into two separate species
    - One population lays its eggs in hawthorn fruit, while the other prefers apples
    - The two populations experience very little interbreeding

16.3 How Do New Species Form?

- **Two sympatric populations of fruit flies (Rhagoletis pomonella) may be evolving into two separate species (continued)**
  - Males and females prefer the same type of fruit in which they developed
  - Apples mature two or three weeks later than hawthorn fruit (flies mature and mate at different times)
  - These differences in fruit preference and maturity mean the two varieties of flies have very little chance of meeting and are well on their way to becoming separate species

Sympatric Isolation and Divergence

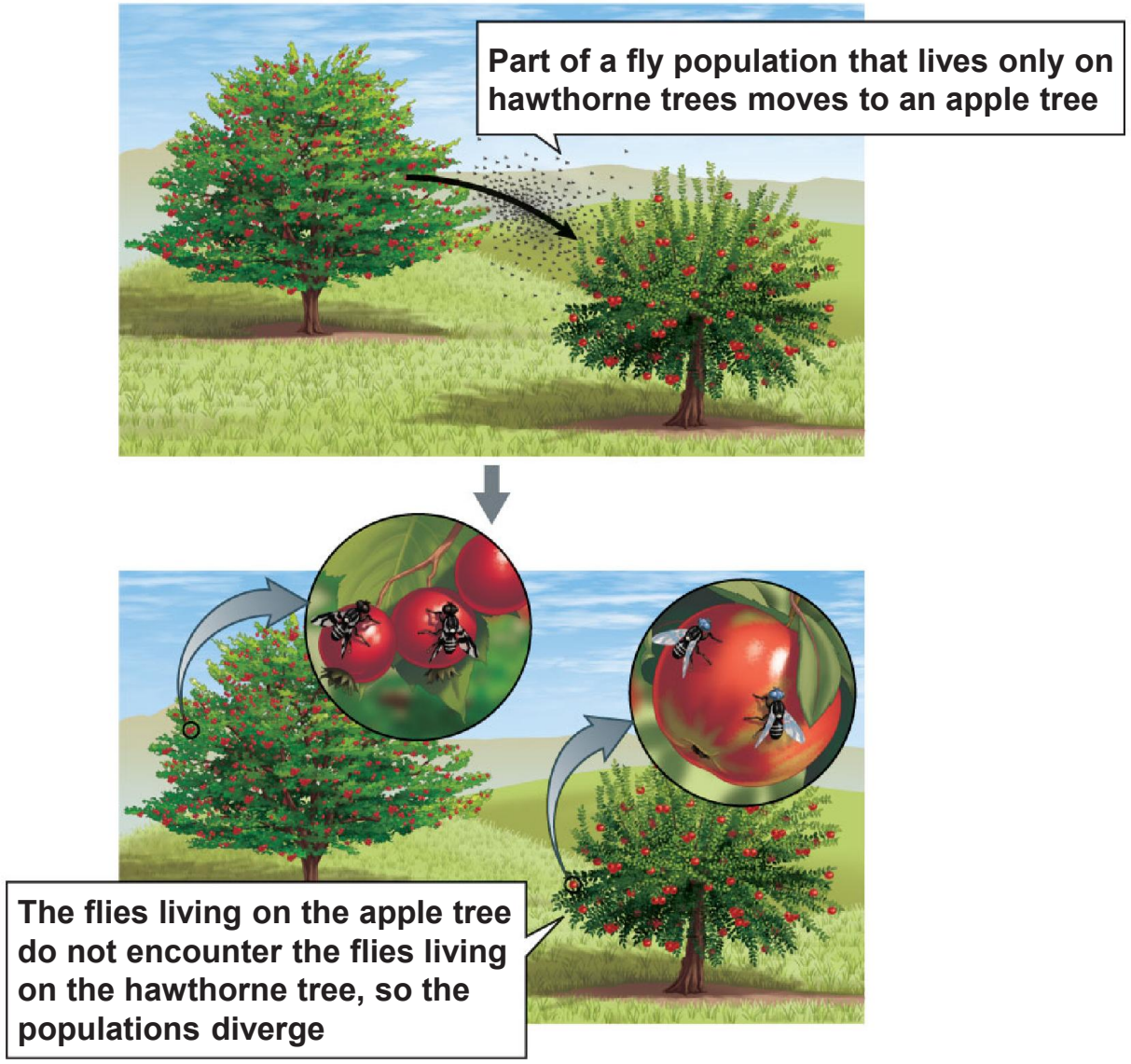


Fig. 16-10

16.3 How Do New Species Form?

- **Mutations can lead to sympatric speciation**
  - New species may arise almost instantaneously as a result of mutations that change the number of chromosomes in their cells
  - The acquisition of multiple copies of each chromosome is known as **polyploidy(多倍体)** and is a frequent cause of sympatric speciation
    - In general, polyploid individuals cannot mate successfully with normal diploid individuals and so are genetically isolated from the parent species
    - Polyploid plants are more likely than polyploid animals to be able to reproduce

Author Animation: Speciation by Polyploidy

16.3 How Do New Species Form?

- **Under some conditions, many new species may arise in a short period of time**
  - The mechanisms of speciation and reproductive isolation lead to forking branches in the evolutionary tree of life, as one species splits into two
  - **Adaptive radiation(适应性分化)** is the rise of many new species over a relatively short period of time

Interpreting Evolutionary Trees

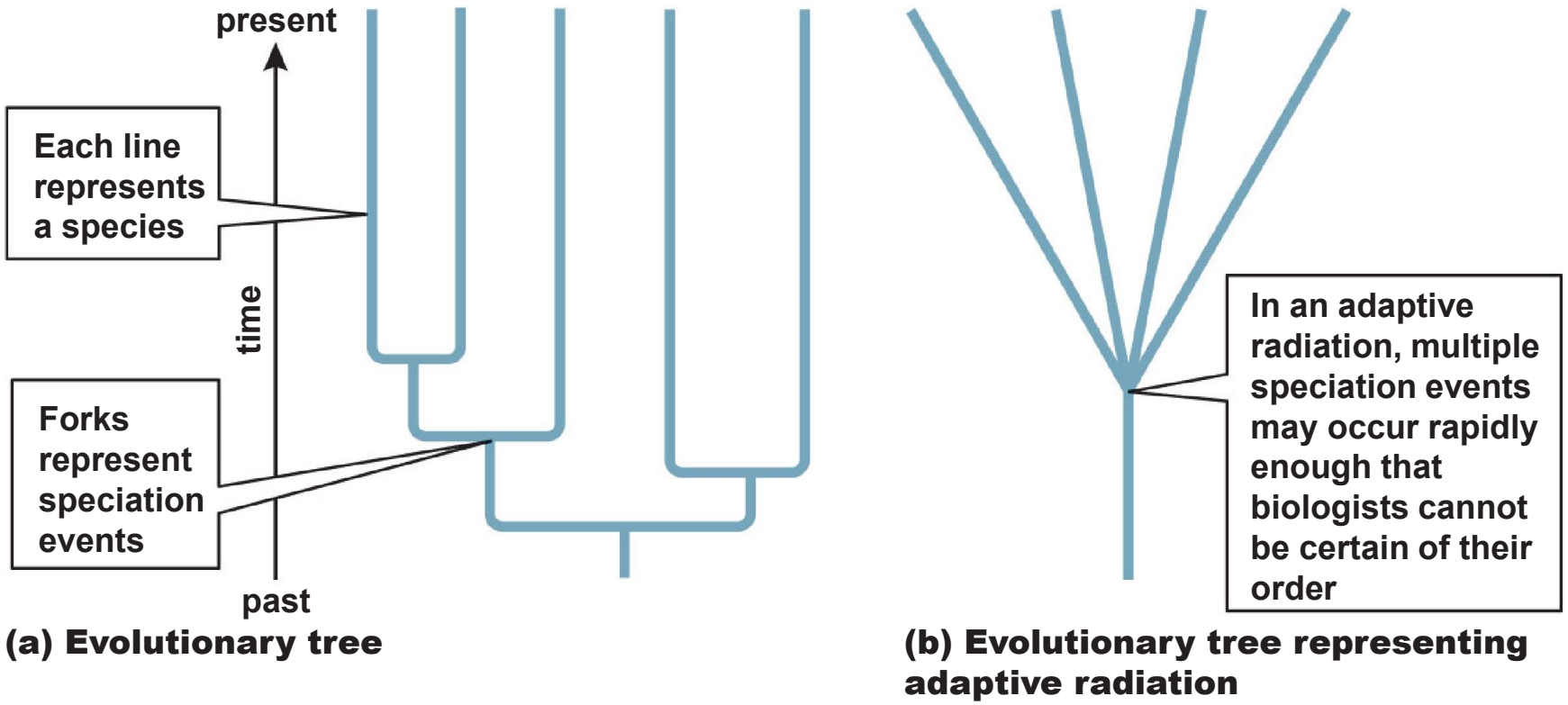


Fig. 16-11

16.3 How Do New Species Form?

- **Under some conditions, many new species may arise in a short period of time (continued)**
  - This process occurs when populations of one species invade a variety of new habitats with few competitors
    - Finch colonization of the Galápagos Islands(加拉帕戈斯群岛) resulted in 13 species
    - Cichlid fish colonization of Lake Malawi resulted in more than 300 species
    - Tarweed plant colonization of the Hawaiian Islands resulted in 30 species

Adaptive Radiation

(a) Ahinahina

(b) Waialeale dubautia

(c) Kupaoa

(d) Na'ena'e 'ula

Fig. 16-12

16.4 What Causes Extinction?

- **Extinction is the death of all members of a species**
- At least 99.9% of all species that ever existed are now extinct
- The immediate cause of extinction is probably always environmental change
  - Environmental changes that can lead to extinction include habitat destruction and increased competition among species

16.4 What Causes Extinction?

- **Localized distribution make species vulnerable in changing environments**
  - Species inhabiting extremely limited ranges may become extinct if the area is disturbed
    - The Devil's Hole pupfish is found in only one spring-fed waterhole in the Nevada desert
  - Wide-ranging species normally do not succumb to local environmental catastrophes

Very Localized Distribution Can Endanger a Species

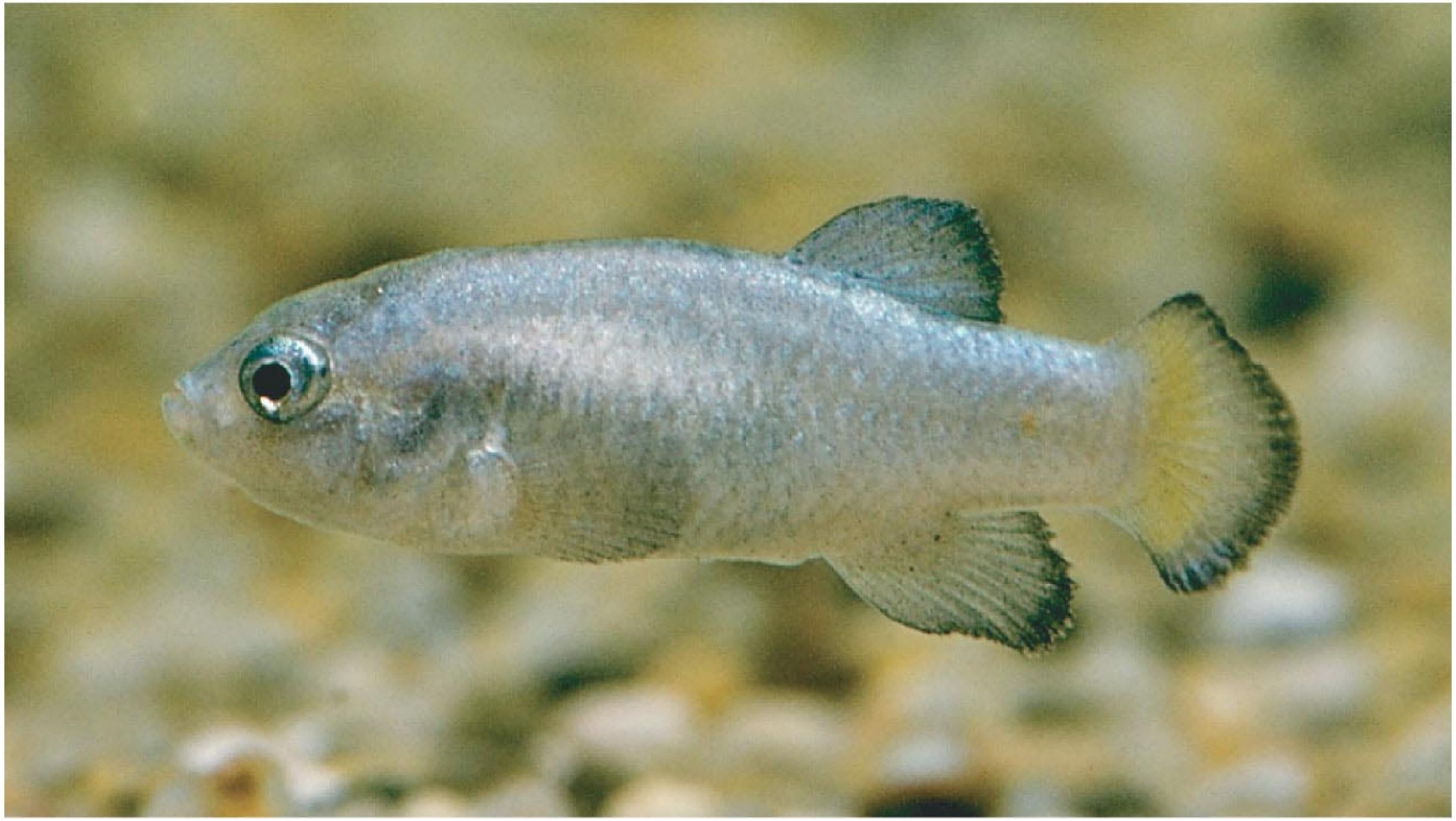


Fig. 16-13

16.4 What Causes Extinction?

- **Overspecialization(过度特化) increases the risk of extinction in changing environments**
  - Species that develop adaptations that favor survival in a specific environment are at risk of becoming extinct
    - The Karner blue butterfly feeds only on the blue lupine plant
    - The habitat of the lupine has been significantly reduced by development
    - Loss of the lupine will lead to extinction of the Karner blue butterfly

Extreme Specialization Places Species at Risk

Fig. 16-14

16.4 What Causes Extinction?

- **Interactions with other species may drive a species to extinction**
  - Species that are unable to exploit resources more efficiently and effectively than their competitors may become extinct

16.4 What Causes Extinction?

- **Interactions with other species may drive a species to extinction (continued)**
  - 2.5 million years ago, a land bridge (the isthmus of Panama) formed between North and South America
  - North American species displaced the vast majority of South American species, many of which became extinct

16.4 What Causes Extinction?

- **Habitat change and destruction are the leading causes of extinction**
  - Extinctions due to prehistoric habitat change have had a significant effect on the evolution of organisms
  - Human activities are the primary cause of present-day habitat destruction
  - Clearing of tropical rainforests could lead to loss of up to half of all current species over the next 50 years