Ecology

IF3211 Domain Specific Computation

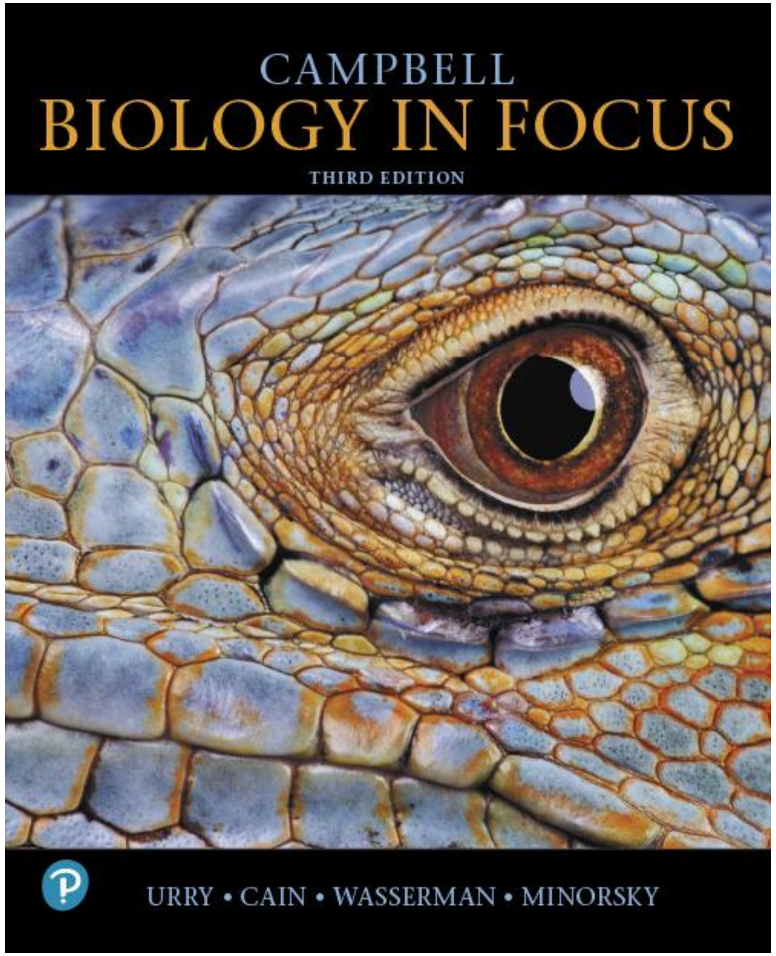
School of Electrical Engineering and Informatics ITB

Content

- Population Ecology and the Distribution of Organisms
- Ecological Communities

Campbell Biology in Focus

Third Edition



Chapter 40

Population Ecology and the Distribution of Organisms

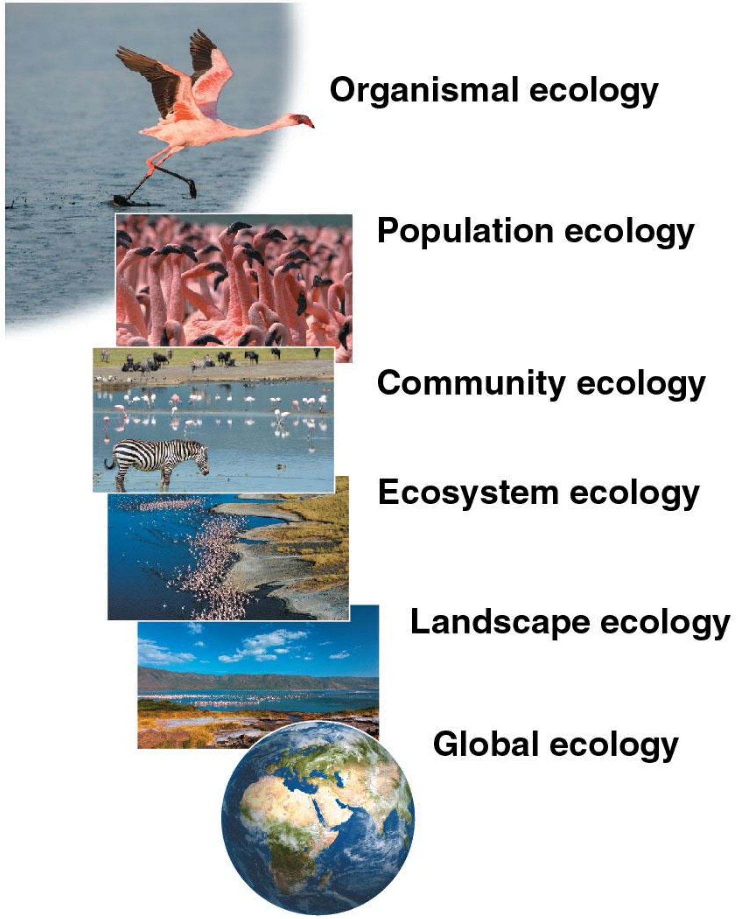
Lecture Presentations by
Kathleen Fitzpatrick and Nicole Tunbridge,
Simon Fraser University

Overview: Discovering Ecology

- **Ecology** is the scientific study of the interactions between organisms and the environment
- Research questions an ecologist might ask following the discovery of a new species of frog include
    - What environmental factors limit the geographic distribution of this species?
    - How do interactions with other species affect population size?

Figure 40.2

Exploring the Scope of Ecological Research

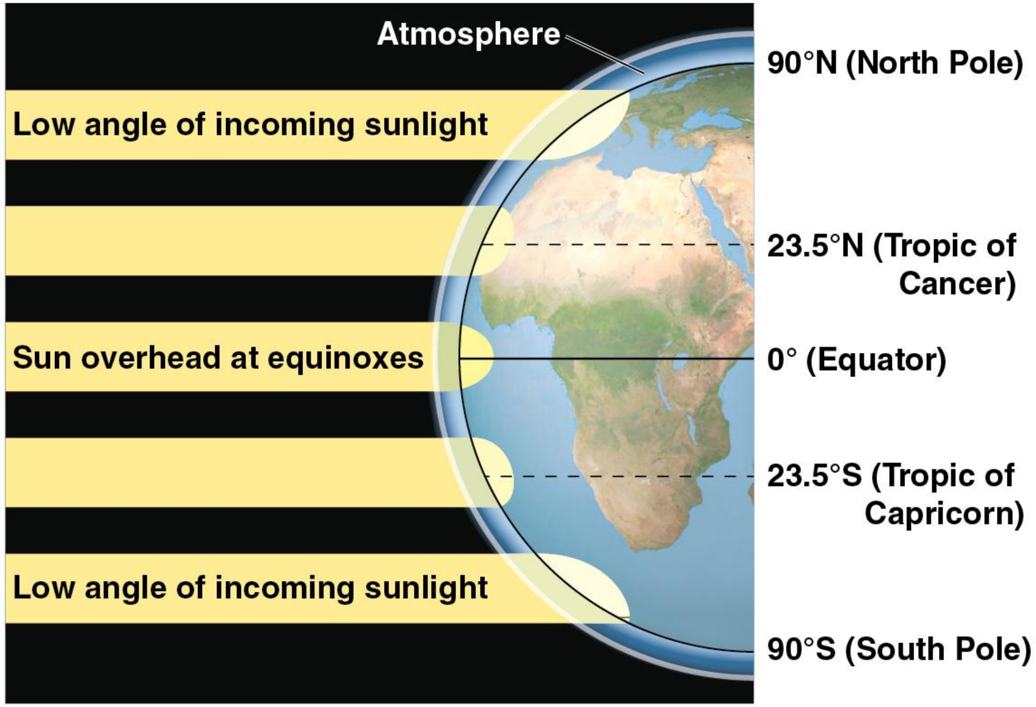


Concept 40.1: Earth's Climate Influences the Distribution of Terrestrial Biomes

- The long-term prevailing weather conditions in an area constitute its **climate**
- Four major physical components of climate are temperature, precipitation, sunlight, and wind

Global Climate Patterns

- Global climate patterns are determined largely by solar energy and the planet's movement in space
- The warming effect of the sun causes temperature variations, which drive evaporation and the circulation of air and water
- This causes latitudinal variations in climate



Latitudinal variation in sunlight intensity

Regional and Local Effects on Climate; Climate is affected by:

- Seasonality: This seasonality is caused by the tilt of Earth's axis of rotation and its annual passage around the sun,
- large bodies of water: Ocean currents influence coastal climates by heating or cooling overlying air masses that pass across the land,
- and mountain ranges: Rising air releases moisture on the windward side of mountains and creates a "rain shadow" as it absorbs moisture on the leeward side

Effects of Vegetation on Climate

- Forests can alter the climate at local and even regional scales
- A forest is relatively dark in color and therefore absorbs more (and reflects less) solar energy than does a desert or grassland, thereby contributing to a warming of Earth's surface in forested areas
- However, evaporative loss of water is much greater in forests than in other ecosystems
- In sum, forests reduce Earth's surface temperature, and they increase precipitation rates in those areas

Figure 40.6X

How cutting down a forest affects regional climate.

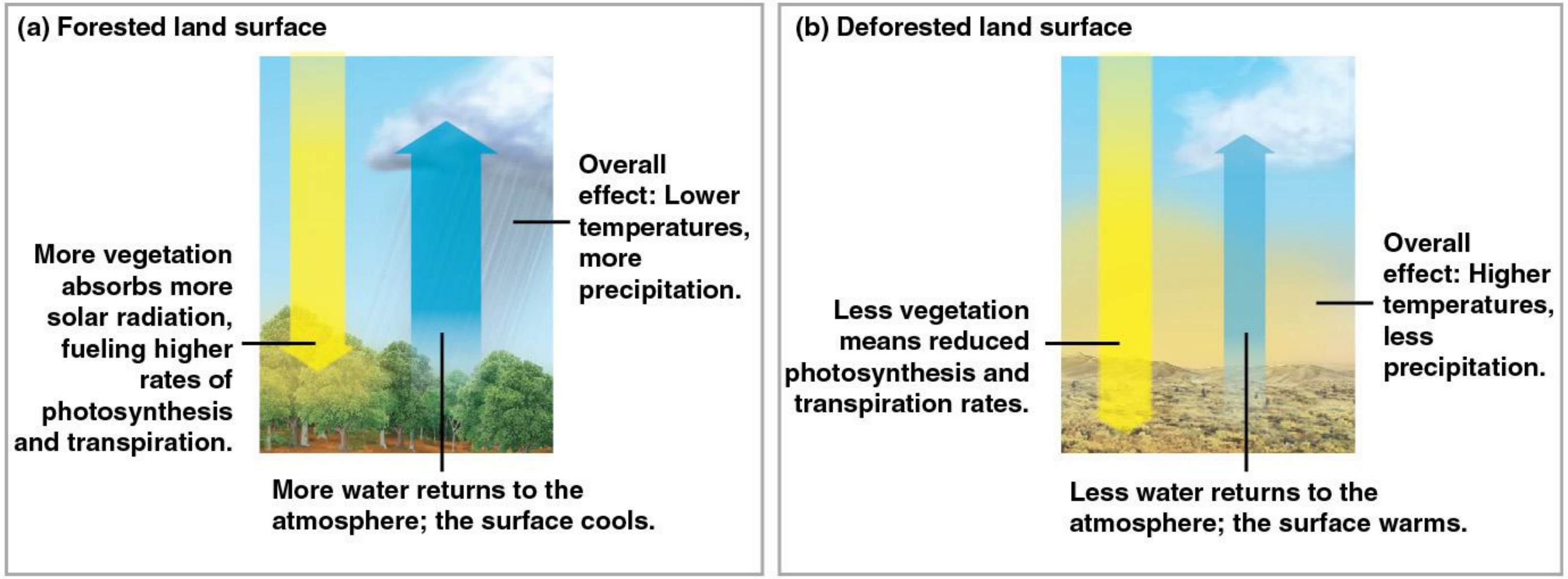
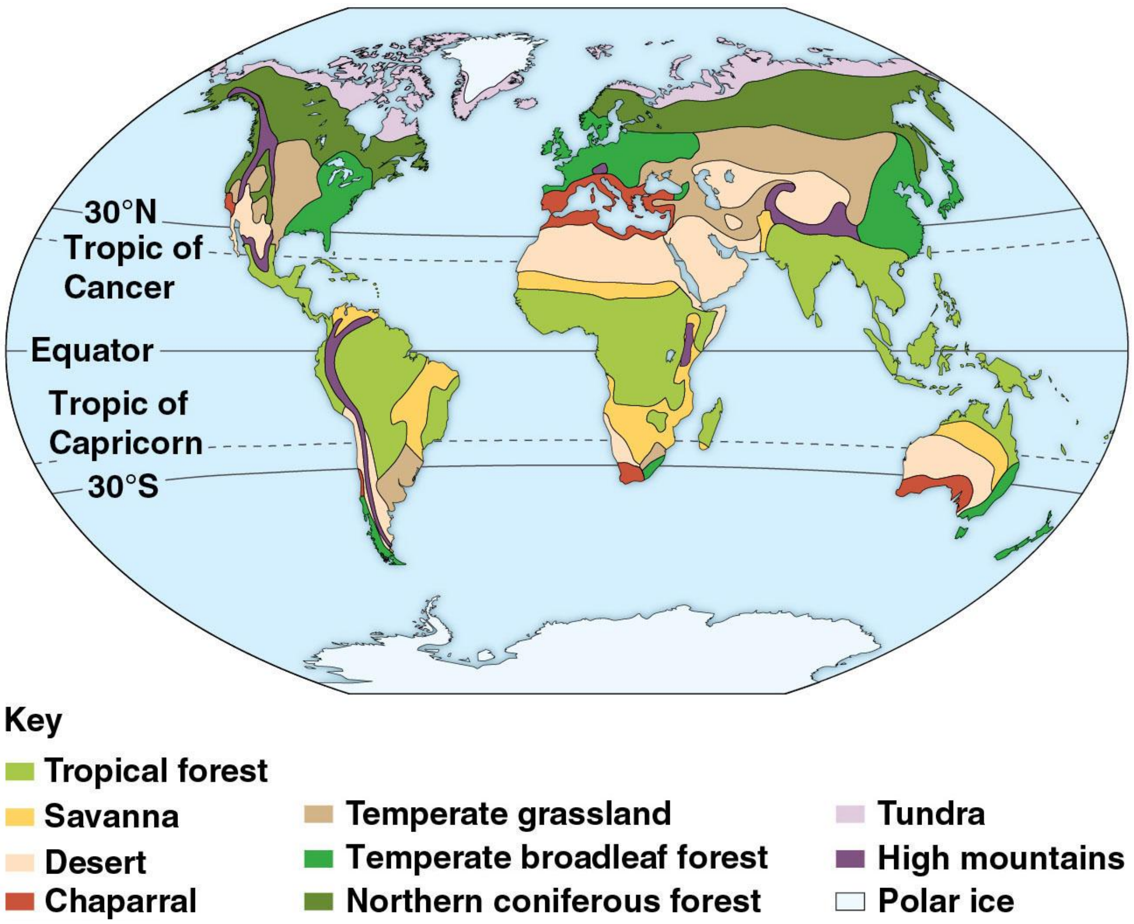


Figure 40.7

The Distribution of Major Terrestrial Biomes



Concept 40.2: Aquatic Biomes Are Diverse and Dynamic Systems That Cover Most of Earth

- Aquatic biomes are characterized primarily by their physical and chemical environment
  - For example, marine biomes have saltwater concentrations that average 3%, whereas freshwater biomes have salt concentrations of less than 0.1%

Concept 40.3: Interactions Between Organisms and the Environment Limit the Distribution of Species

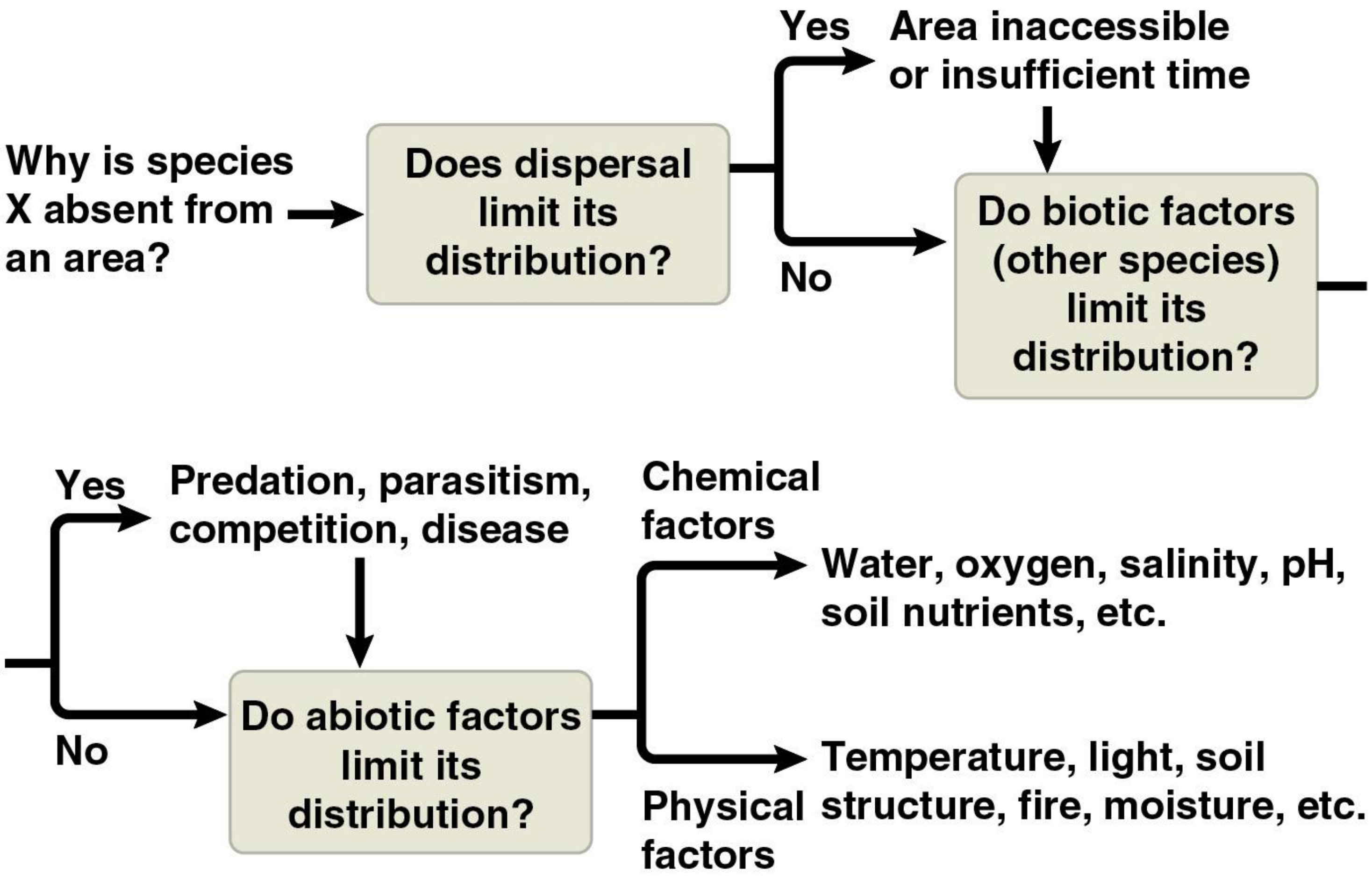
- Species distributions are a consequence of both ecological factors and evolutionary history
- Geographic isolation can result in the evolution of unique lineages restricted to specific areas
  - For example, the kangaroo lineage occurs only on the isolated continent of Australia
  - Ecological factors have prevented kangaroos from dispersing to other continents

Dispersal and Distribution

- **Dispersal** is the movement of individuals or gametes away from their area of origin or centers of high population density
- Dispersal contributes to the global distribution of organisms

Figure 40.12

Flowchart of Factors Limiting Geographic Distribution



Biotic Factors

- Interactions with other species can limit species distributions
- Such biotic factors can include
  - Predation
  - Herbivory
  - Mutualism
  - Parasitism
  - Competition

Abiotic Factors

- Species are not found in areas where physical conditions prevent their survival or reproduction
- Abiotic factors limiting species distributions include
  - Temperature
  - Water
  - Oxygen
  - Salinity
  - Sunlight
  - Rocks and soil

Concept 40.4: Biotic and Abiotic Factors Affect Population Density, Dispersion, and Demographics

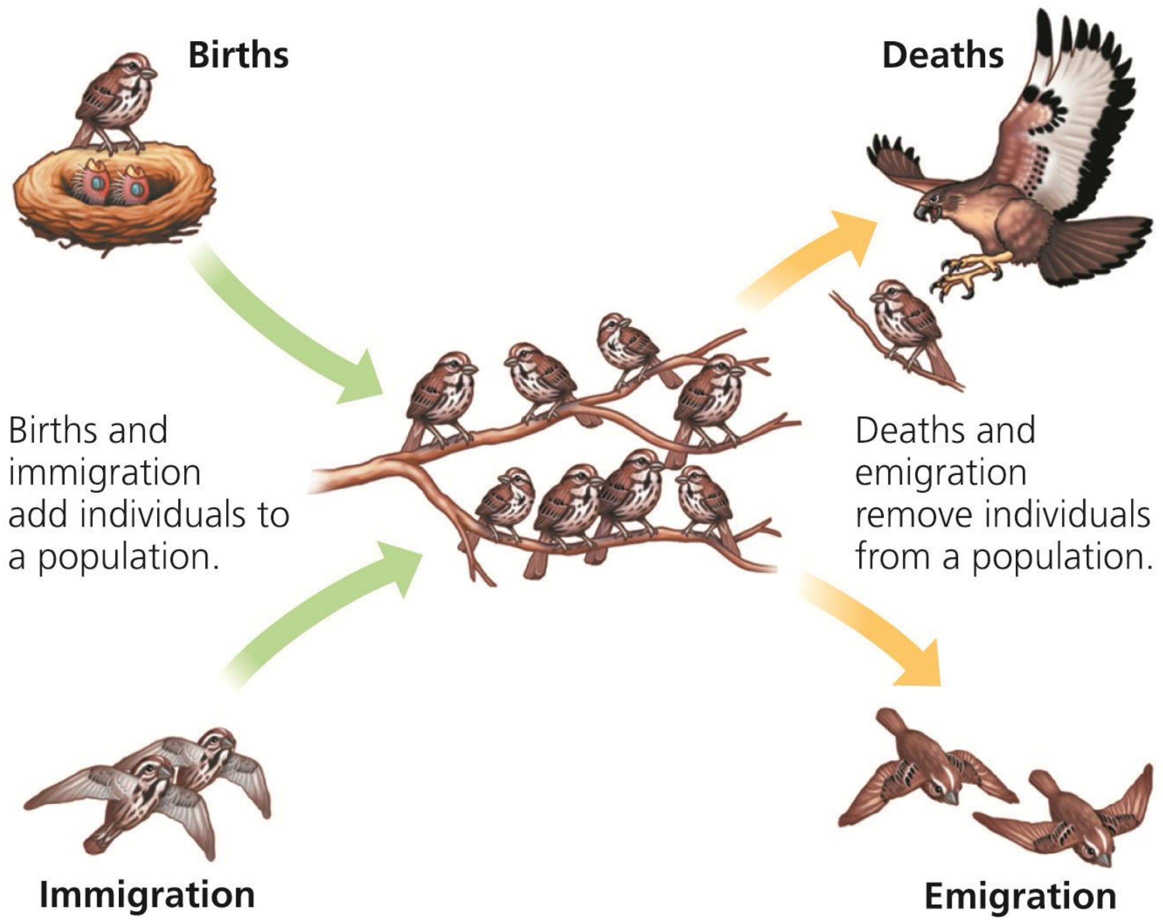
- A population is a group of individuals of a single species living in the same general area
- Populations are described by their boundaries and size
- Population ecology explores how biotic and abiotic factors influence density, distribution, and population size

Density and Dispersion

- **Density** is the number of individuals per unit area or volume
- **Dispersion** is the pattern of spacing among individuals within the boundaries of the population

Figure 40.15

Population Dynamics

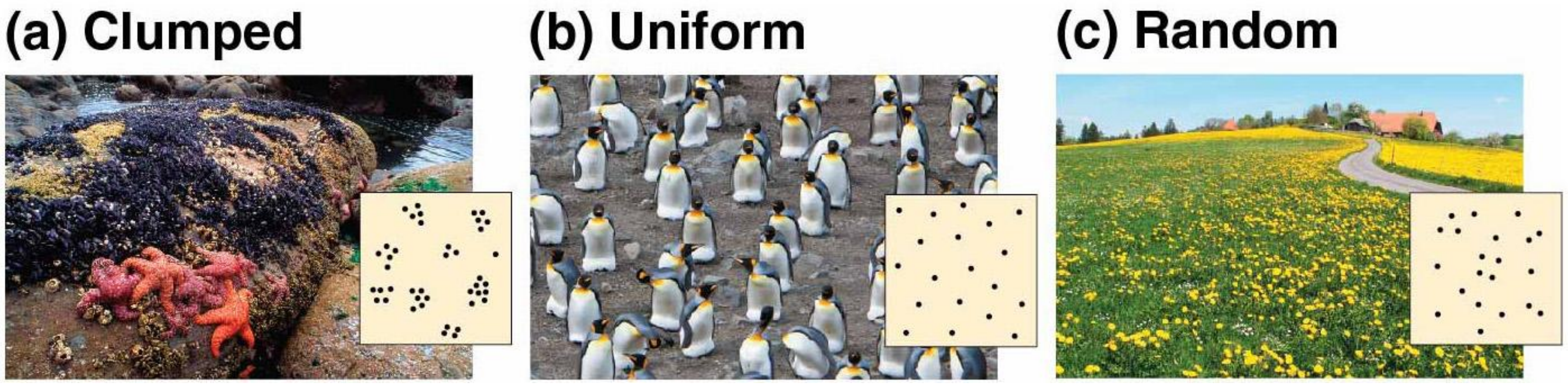


Patterns of Dispersion

- Environmental and social factors influence the spacing of individuals in a population
- The most common pattern of dispersion is clumped, in which individuals aggregate in patches
- A clumped dispersion may be influenced by resource availability, mating behavior, or group predation and defense strategies

Figure 40.16

Patterns of Dispersion Within a Population’s Geographic Range



Demographics

- **Demography** is the study of the births, deaths, and migration rates of a population over time
- This demographic information can be summarized in a life table

Changes in Population Size

- Change in population size can be defined by the equation

$$\text{Change in population size} = \text{Births} + \text{Immigrants entering population} - \text{Deaths} - \text{Emigrants leaving population}$$

- If immigration and emigration are ignored, the change in population size equals births minus deaths

Population Change and Population Density

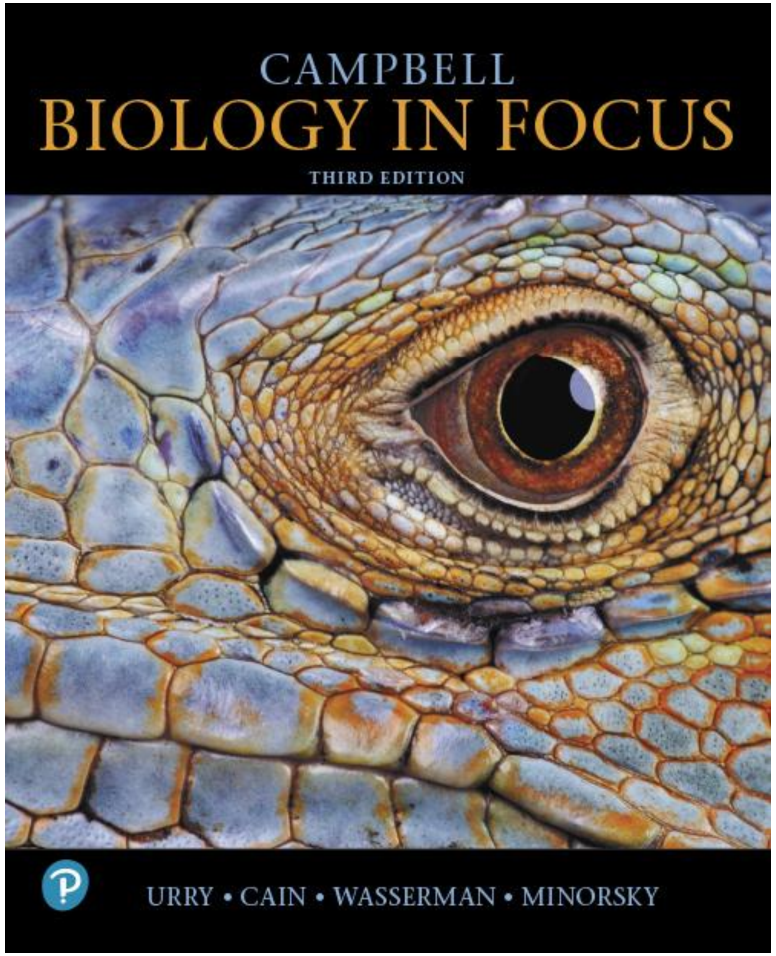
- A birth rate or death rate that is **density independent** does not change with population density
- A birth rate that decreases with population density or a death rate that increases with density is said to be **density dependent**

Immigration, Emigration, and Metapopulations

- **Metapopulations** are groups of populations linked by immigration and emigration
- Local populations occupy patches of suitable habitat surrounded by unsuitable habitat
- If a local population becomes extinct, the patch can be recolonized by immigrants from another local population within the metapopulation

Campbell Biology in Focus

Third Edition



Chapter 41

Ecological Communities

Lecture Presentations by
Kathleen Fitzpatrick and Nicole Tunbridge,
Simon Fraser University

Overview: Communities in Motion

- A biological **community** is an assemblage of populations of different species living in close enough proximity to interact
- Some of these interactions are beneficial to both species involved
  - For example, giant moray eels allow some species of small fish and shrimp to clean their mouths by feeding on the small parasites inside

- Many interspecific interactions are not mutually beneficial; one or both interacting species can experience reduced survival or reproduction

Concept 41.1: Interactions Within a Community May Help, Harm, or Have No Effect on the Species Involved

- Ecologists call relationships between species in a community **interspecific interactions**
- Interspecific interactions are grouped according to whether they have positive (+), negative (–), or no effect (0) on the survival and reproduction of the interacting individuals of each species
- Examples are competition, predation, herbivory, parasitism, mutualism, and commensalism

Competition

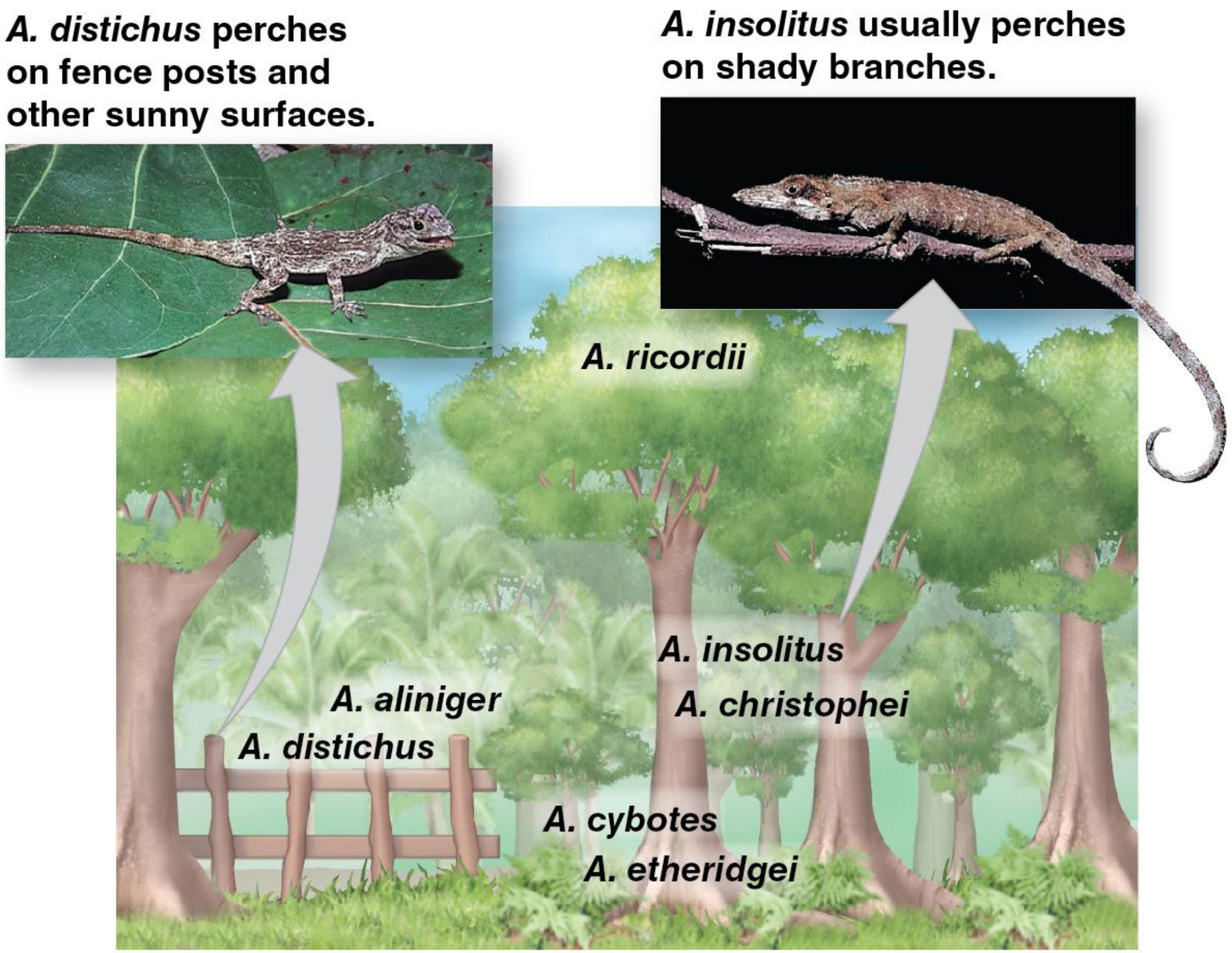
- **Competition** (–/–) occurs when individuals of different species compete for a resource that limits the survival and reproduction of individuals of both species
  - For example, weeds compete with garden plants for nutrients and water
- Species do not compete for plentiful resources
  - For example, terrestrial species do not compete for oxygen
- Strong competition should lead to **competitive exclusion**, local elimination of an inferior competitor

Ecological Niches and Natural Selection

- The specific set of biotic and abiotic resources used by an organism is its **ecological niche**
- Ecologically similar species can coexist in a community if one or more significant differences in their niches arise through time
- The differentiation of niches that enables this coexistence is called **resource partitioning**

Figure 41.3

Resource Partitioning Among Dominican Republic Lizards



Character Displacement

- If character differences between two species are greater when populations are sympatric than allopatric, it is called **character displacement**
- This pattern provides indirect evidence of competition in the past

Exploitation

- **Exploitation** refers to any $+/-$ interaction in which individuals of one species benefits by feeding on (and thereby harming) individuals of another species
- Predation, herbivory, and parasitism are exploitative interactions

Predation

- **Predation** (+/–) refers to an interaction in which an individual of one species, the predator, kills and eats an individual of the other species, the prey
- Predators have acute senses for locating prey, such as the heat-sensing organs used by pit vipers
- Some predator adaptations for capturing prey include claws, fangs, and poison

Herbivory

- **Herbivory** (+ / –) refers to an interaction in which an individual of one species—an herbivore—eats parts of a plant or alga, harming but usually not killing it
- Familiar herbivores include large mammals such as cattle or sheep, but most are small invertebrates
- In marine communities, sea urchins, fish, and some mammals, such as the manatee, are herbivorous

Parasitism

- In **parasitism** (+/–), one organism, the **parasite**, derives nourishment from another organism, its **host**, which is harmed in the process
- Parasites that live within the body of their host are called **endoparasites**
- Parasites that live on the external surface of a host are **ectoparasites**

Mutualism

- **Mutualism** (+ / +), is an interaction that benefits members of both interacting species
- In some mutualisms, members of one or both species cannot survive without the other
  - For example, acacia trees and ants are dependent upon each other for survival and reproduction
- In other mutualisms, members of both species can survive alone

Figure 41.9

Mutualism Between Acacia Trees and Ants

(a) Acacia trees house stinging ants which feed on the trees' nectar and protein-rich swellings (yellow)

(b) Area cleared by ants around an acacia tree

Commensalism

- **Commensalism** (+/0), benefits individuals of one species without harming or helping individuals of the other species
  - For example, wildflowers that grow best in low light benefit from shade provided by forest trees but do not affect the survival and reproduction of the trees

Concept 41.2: Biological Communities Can Be Characterized by Their Diversity and Trophic Structure

- Two fundamental features of community structure are species diversity and feeding relationships
- In some cases, a few species exert strong control on a community's structure

Species Diversity

- **Species diversity** has two components: species richness and relative abundance
  - **Species richness** is the number of different species in the community
  - **Relative abundance** is the proportion each species represents of all individuals in the community

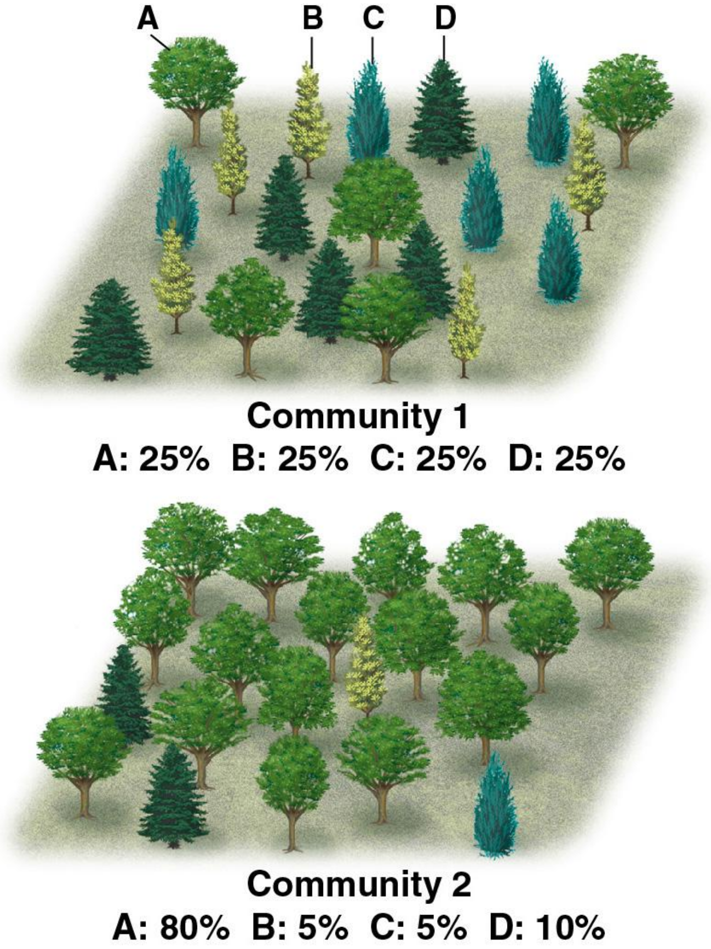
- Diversity can be compared using a diversity index
  - Widely used is the **Shannon diversity index** (H)

$$H = -(p_A \ln p_A + p_B \ln p_B + p_C \ln p_C + \ldots)$$

where A, B, C … are the species, p is the relative abundance of each species, and ln is the natural logarithm

Figure 41.12

Which Forest Is More Diverse?

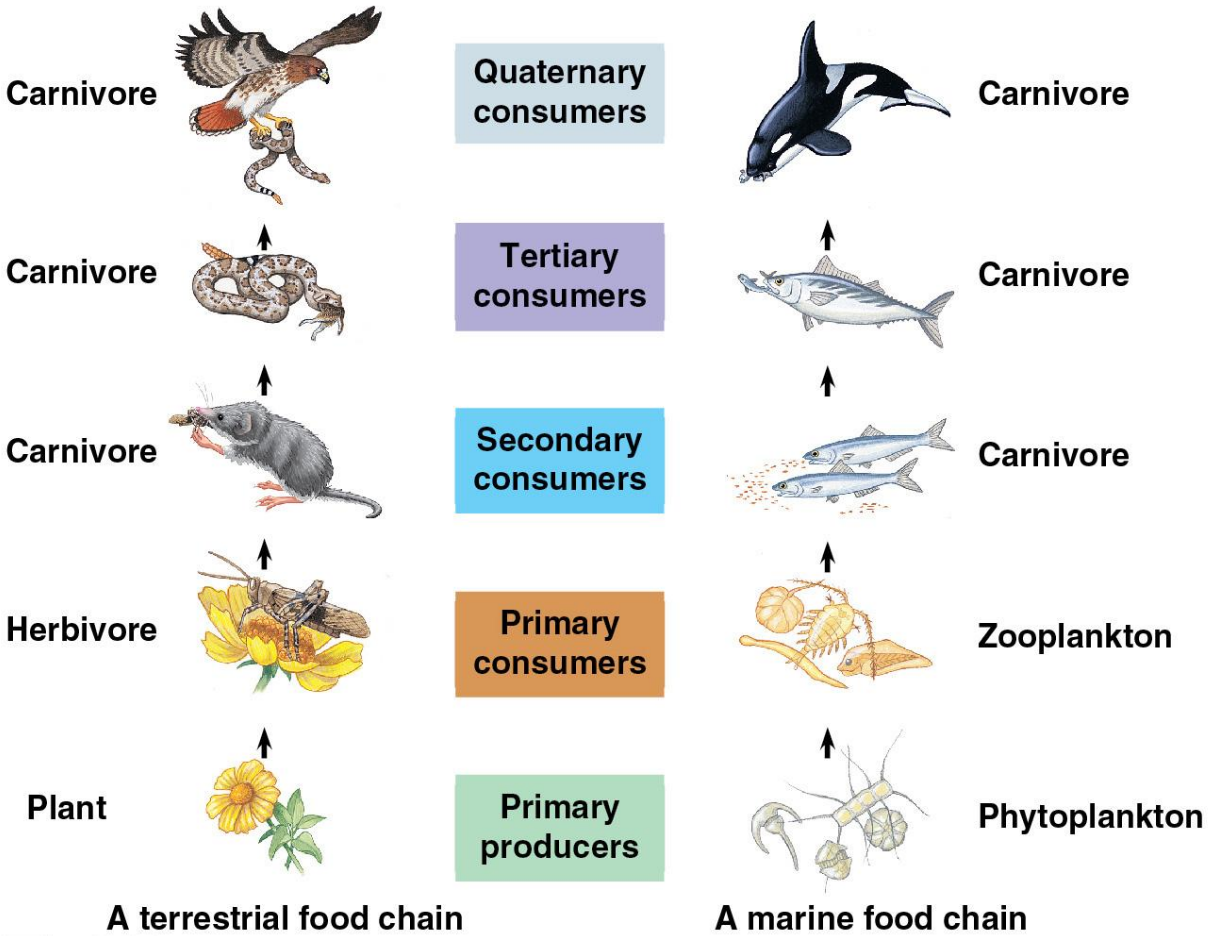


Trophic Structure

- **Trophic structure**, the feeding relationships between organisms in a community, is a key factor affecting community structure and dynamics
- **Food chains** link trophic levels from producers to top carnivores
- The position an organism occupies in a food chain is called its **trophic level**

Figure 41.14

Examples of Terrestrial and Marine Food Chains



Species with a Large Impact

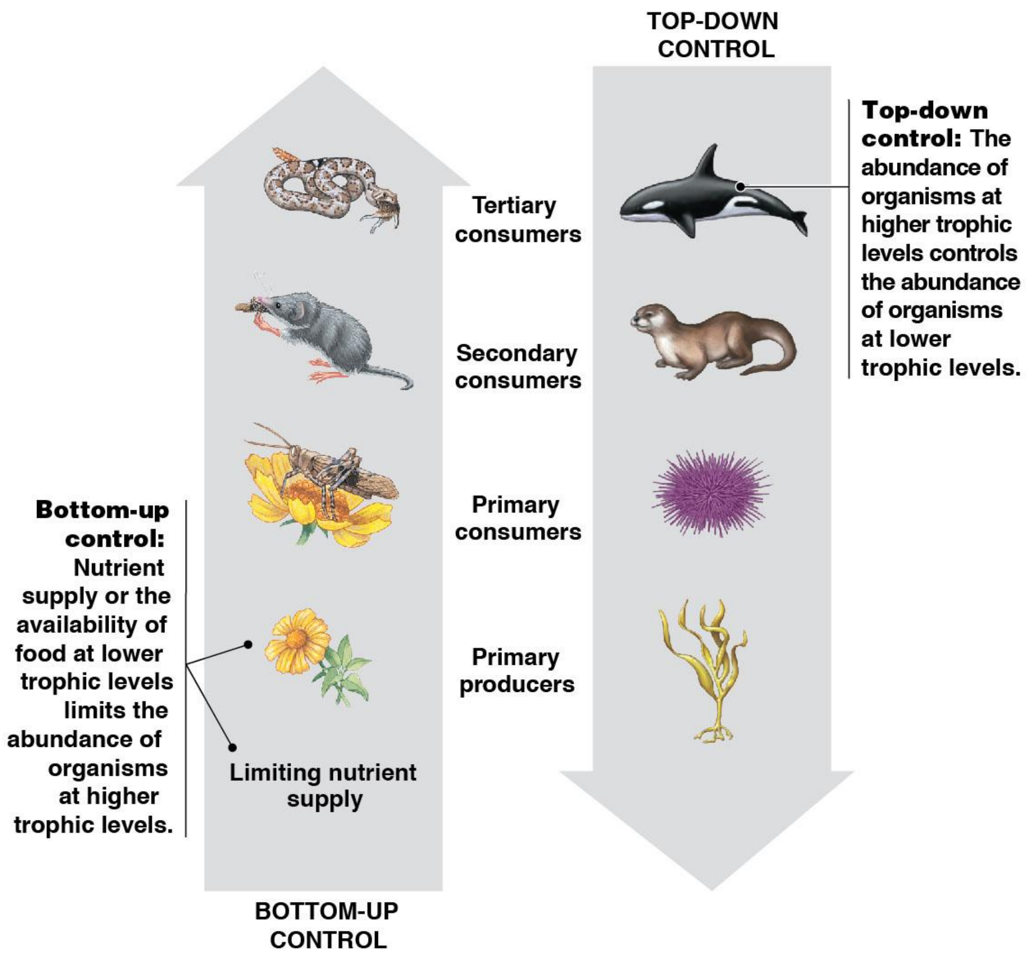
- Certain species have an especially large impact on community structure
- Such species are highly abundant or play a pivotal role in community dynamics
- **Foundation species** are those that have strong effects due to their large size or high abundance
- **Keystone species** exert strong control on a community by their pivotal ecological roles rather than relative abundance
- **Ecosystem engineers** cause physical changes in the environment that affect community structure

Bottom-Up and Top-Down Controls

- The **bottom-up model** of community organization proposes a unidirectional influence from lower to higher trophic levels
- In this case, the availability of mineral nutrients determines the abundance of primary producers
- The abundance of primary producers controls food availability and abundance for all higher trophic levels
- **Biomanipulation** is an application of the top-down model used to improve water quality in polluted lakes

Figure 41.17X

Bottom-Up and Top-Down Control



Ecological Succession

- **Ecological succession** is the sequential change in community composition during colonization following a major disturbance
- **Primary succession** occurs in nearly lifeless areas such as a new volcanic island or the rubble left by a retreating glacier
- **Secondary succession** begins in an area where major disturbance has removed most but not all of the organisms in a community

Human Disturbance

- Human activities represent the strongest disturbances to ecosystems worldwide
- Examples include agricultural development, clear-cutting, overgrazing, and ocean trawling
- Human disturbance to communities is often severe and reduces species diversity

Figure 41.22

Disturbance of the Ocean Floor by Trawling

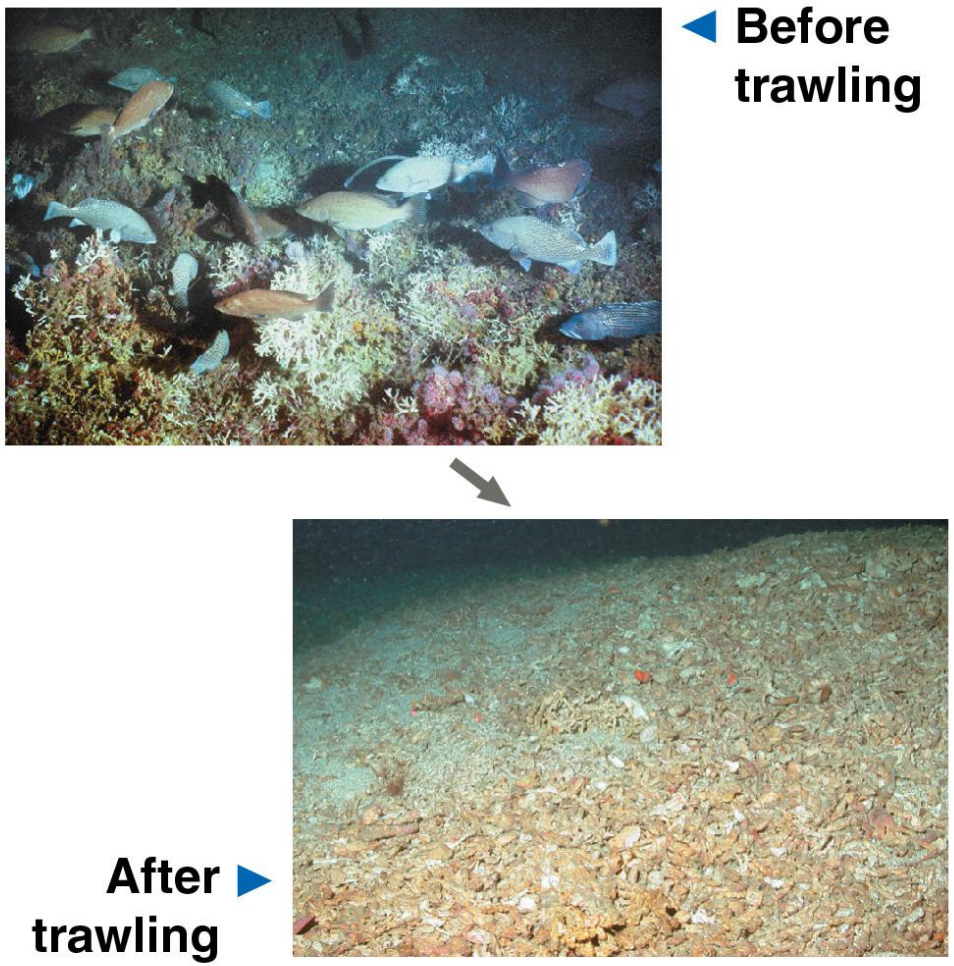
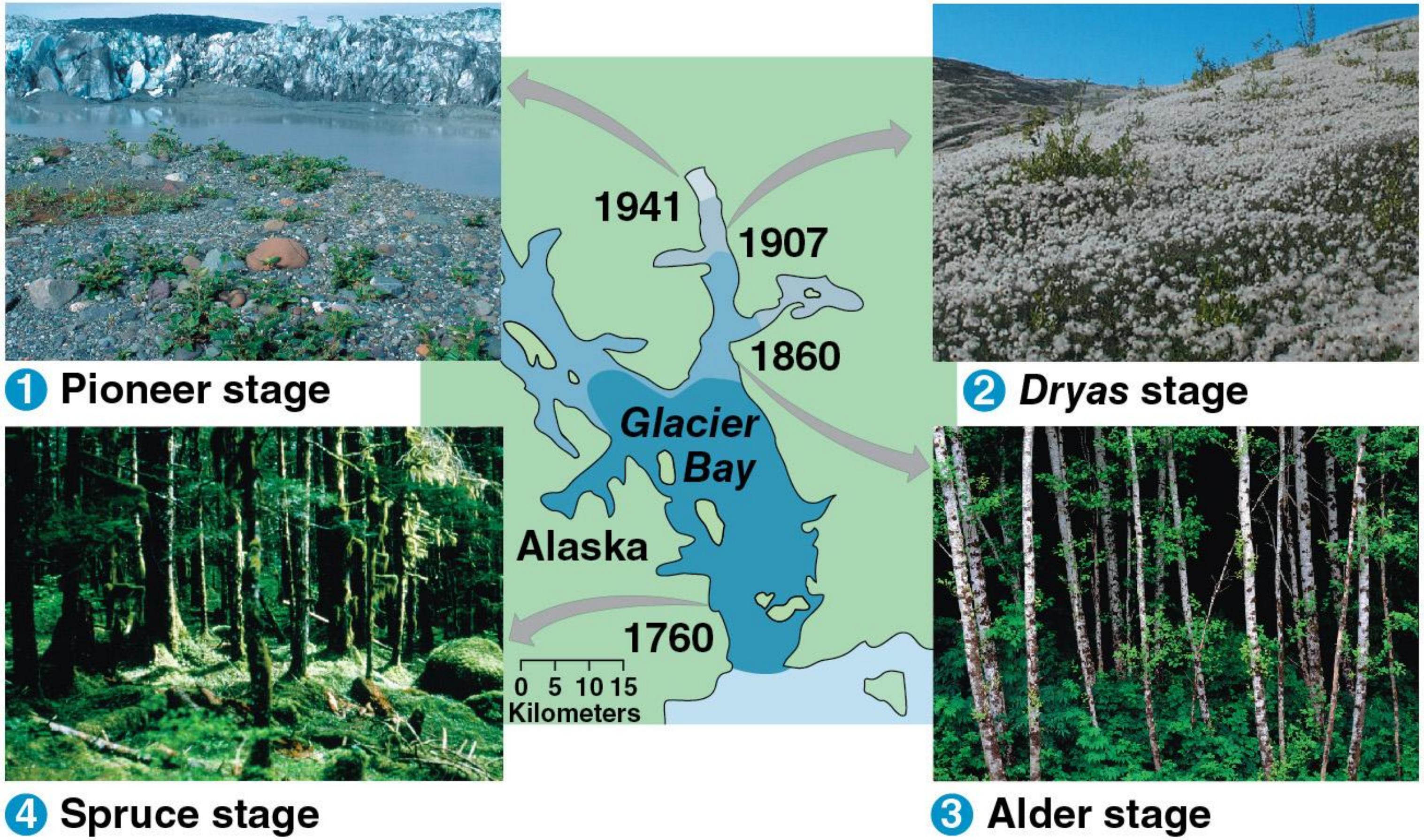


Figure 41.21

Glacial Retreat and Primary Succession at Glacier Bay, Alaska



Concept 41.4: Biogeographic Factors Affect Community Diversity

- Large-scale biogeographic factors such as latitude and area are two key factors that affect a community's species diversity

- Latitudinal Gradients: Two key factors affecting latitudinal gradients are evolutionary history and climate
- The **species-area curve** quantifies the idea that, all other factors being equal, a larger geographic area should have more species

Effects on Community Structure

- Pathogens can have dramatic effects on community structure when they are introduced into new habitats
  - For example, coral reef communities are being decimated by white-band disease
  - Sudden oak death has killed over a million oak trees, reducing the abundance of the bird species dependent on them

Community Ecology and Zoonotic Diseases

- Three-quarters of emerging human diseases are caused by **zoonotic pathogens**, pathogens transferred from other animals into humans
- Pathogen transfer can be direct or through an intermediate species called a **vector**
- Zoonotic vectors are often parasites, including ticks, lice, and mosquitoes

Computational

Modeling Cumulative Effects on Wildlife Populations

- Ecological systems are complex, with multiple interacting factors influencing population dynamics.
- Climate change and human development are major drivers of environmental change, impacting wildlife populations.
- This study uses computational modeling to investigate the cumulative effects of climate and development on moose, wolf, and caribou populations.
- Understanding these interactions is crucial for effective conservation and management strategies.
- Rempel, R.S., Carlson, M., Rodgers, A.R., Shuter, J.L., Farrell, C.E., Cairns, D., Stelfox, B., Hunt, L.M., Mackereth, R.W. and Jackson, J.M. (2021), Modeling Cumulative Effects of Climate and Development on Moose, Wolf, and Caribou Populations. Jour. Wild. Mgmt., 85: 1355-1376. https://doi.org/10.1002/jwmg.22094
  - Tools http://popdyn.com/

Computational Model Overview

- The model integrates climate data (temperature, precipitation), development data (road density, habitat loss), and species-specific parameters.
  - **Moose:** Population growth rate, habitat suitability, vulnerability to climate stress.
  - **Wolf:** Predation rate on moose and caribou, dispersal ability, sensitivity to road density.
  - **Caribou:** Population growth rate, calving success, migration patterns, sensitivity to habitat disturbance.
- The model simulates population dynamics over time, considering interactions between species and environmental factors.

Simulation Results and Management Insights

- Simulations show that climate change and development can have synergistic negative effects on caribou populations.
- Increased road density reduces wolf predation on moose, leading to increased moose populations, which can negatively impact caribou through competition.
- Climate-induced habitat changes can reduce caribou calving success and increase vulnerability to predation.
- The model highlights the importance of integrated management strategies that consider both climate change and development impacts.
- Computational models can inform policy decisions and help prioritize conservation efforts.

Landscape Connectivity

- Landscape connectivity is crucial for species movement, gene flow, and ecosystem resilience.
- Traditional models (patch-corridor-matrix) are limited in capturing real-world complexity.
- Graph theory offers a powerful computational approach to model and analyze connectivity in complex landscapes (used to quantify and analyze the connectivity of habitat networks.).
- Urban, D., & Keitt, T. (2001). Landscape connectivity: A graph-theoretic perspective. *Ecology, 82*(5), 1205–1218
    - https://www.researchgate.net/publication/272504044_Landscape_Connectivity_A_Graph-Theoretic_Perspective

Graph-Theoretic Approach

- **Nodes:** Habitat patches or populations.
- **Edges:** Potential movement pathways (e.g., corridors, stepping stones).
- **Metrics:**
  - **Connectivity:** How well patches are linked. Different species may use the network differently, depending on their movement abilities and habitat requirements.
  - **Centrality:** Importance of a patch in the network.
  - **Shortest Path:** Minimum steps between patches.
- **Applications:** The approach is applied to real-world landscapes, showing how network analysis can identify critical patches or corridors for conservation, and how landscape changes (e.g., fragmentation) affect overall connectivity. The paper highlights the importance of maintaining or restoring connectivity for biodiversity conservation, especially in fragmented landscapes.

Applications and Conservation Implications

- Network analysis identifies critical patches and corridors for conservation.
- Helps predict the impact of habitat loss or fragmentation on connectivity.
- Informs reserve design and restoration efforts to maintain biodiversity.
- Computational analysis is essential due to the complexity and scale of real landscapes.

Managing Invasive Species—A Complex Challenge

- Invasive species threaten biodiversity, ecosystem function, and economies.
- Management is complicated by uncertainty: How effective are control actions? What are the long-term impacts?
- This paper uses computational models to optimize management strategies under uncertainty.
- The paper demonstrates how dynamic programming can be used to optimize decisions about when and how intensively to control an invasive species, balancing costs and ecological benefits. By integrating learning models, the approach allows managers to adapt their strategies as they learn more about the system's response to management.
- Baxter, P. W. J., & Possingham, H. P. (2011). Dynamic programming and learning models for management of a nonnative species. *Ecological Applications, 21*(3), 1049–1057.
    - https://core.ac.uk/download/pdf/6922571.pdf

Dynamic Programming and Adaptive Management

- **Dynamic Programming:** A computational method for finding optimal decisions over time, considering both current and future outcomes.
- **Learning Models:** Adaptive management updates strategies as new information is gained.
- **Framework:**
  - Model system dynamics and management actions.
  - Use dynamic programming to find the best action at each step.
  - Update knowledge and adapt actions as outcomes are observed.

Results and Conservation Implications

- Adaptive strategies (with learning) outperform fixed strategies, especially when system responses are uncertain.
- The approach helps managers allocate resources efficiently and improve outcomes over time.
- **Contribution:** Demonstrates the power of combining optimization and learning for real-world ecological management.

Why Study Pollination Networks?

- Pollination networks are vital for ecosystem function and biodiversity.
- Species extinctions can disrupt these networks, leading to cascading effects.
- This study uses network analysis to assess the robustness of real pollination networks to species loss.
  - the sequential loss of plant and pollinator species and measure the resulting secondary extinctions (i.e., species that go extinct because their mutualists are lost)
- Memmott, J., Waser, N. M., & Price, M. V. (2004). Tolerance of pollination networks to species extinctions. *Proceedings of the Royal Society of London. Series B: Biological Sciences, 271*(1557), 2605–2611
  - https://www.researchgate.net/publication/8114221_Tolerance_of_pollinator_networks_to_species_extinctions

Simulating Extinctions in Networks

- The authors simulate two extinction scenarios:
  - **Random extinction:** Species are removed at random.
  - **Targeted extinction:** Most connected species are removed first.
- They track **secondary extinctions**—species that go extinct because their mutualists are lost.
- Computational network analysis is essential due to the complexity of real-world networks.

Results and Conservation Lessons

- Pollination networks are robust to random loss but fragile if key (highly connected) species are lost.
- Protecting the most connected species is critical for network stability.
- **Contribution:** Demonstrates the value of network analysis for conservation planning and ecosystem management.

Bio-Inspired Algorithms in Machine Learning

- Bio-inspired algorithms mimic natural processes (e.g., animal foraging, evolution, swarming).
- The **Optimal Foraging Algorithm (OFA)** is inspired by how animals maximize food intake while minimizing effort.
- This paper introduces a **Modified OFA (MOFA)** to optimize machine learning models.
  - MOFA mimics animal foraging, balancing exploration (searching new areas) and exploitation (using known good areas).
- Rahman, M. M., & Islam, M. M. (2013). Modified optimal foraging algorithm for parameters optimization of support vector machine. *International Journal of Computer Applications, 61*(19), 1–7.
  - https://www.researchgate.net/publication/322709674_Modified_Optimal_Foraging_Algorithm_for_Parameters_Optimization_of_Support_Vector_Machine

MOFA for SVM Parameter Optimization

- **MOFA Approach:**
  - Represents parameter sets as “food patches.”
  - Agents (foragers) explore and exploit the parameter space.
  - Balances global search (exploration) and local refinement (exploitation).
- **Goal:** Find parameter values that maximize SVM classification accuracy.

Results and Implications

- **MOFA-optimized SVM** achieves higher accuracy and efficiency than grid search, Genetic Algorithm, and Particle Swarm Optimization, in terms of classification accuracy and computational efficiency.
- **Bio-inspired optimization** is effective for complex, high-dimensional parameter tuning.
- **Contribution:** Shows how nature-inspired computation can enhance machine learning performance in real-world tasks for in terms of classification accuracy and computational efficiency for complex parameter optimization, especially where exhaustive search is computationally infeasible.