

# INTERAKSI MIKROORGANISME

## 28. Microorganism Interactions and Microbial Ecology

### Chapter Overview

This chapter focuses on microbial ecology—the study of the relationships microorganisms have with other organisms, each other, and their physical environment. The chapter begins with a discussion of symbiotic relationships, and examples of each type of relationship are presented. This chapter then considers nutrient cycling and the roles of microorganisms in ecosystems. The chapter also includes a discussion of extreme environments and concludes with a discussion of the methods used in microbial ecology.

### Chapter Objectives

After reading this chapter you should be able to:

1. discuss symbiotic relationships
2. give examples of each type of symbiosis
3. describe the roles microbes play in ecosystems
4. discuss the interactions of microorganisms with one another and with nonmicrobial members of ecosystems
5. describe the microorganisms found in extreme environments
6. discuss the various methods used to study microorganisms in the environment

### These are the most important concepts you are learning in this chapter:

1. Symbiosis is the living together in close association of two or more different organisms.
2. Commensalism is a relationship in which one organism benefits while the other is neither harmed nor helped.
3. Mutualism is the living together of two or more organisms in an association in which both members benefit.
4. Gnotobiotic refers to a microbiologically monitored environment or animal in which the identities of all microorganisms present are known or that is germfree.
5. Most microorganisms associated with the human body are bacteria; they normally colonize specific sites.
6. If a symbiont either harms or lives at the expense of another organism, it is called a parasitic organism and the relationship is termed parasitism. In this relationship the body of the animal is referred to as the host.
7. Those parasitic organisms capable of causing disease are called pathogens. Disease is any change in the host from a healthy to an unhealthy, abnormal state in which part or all of the host's body is not properly adjusted or capable of carrying on its normal functions.
8. For a parasitic organism to cause disease, it must be transmitted to a suitable host, attach to and/or colonize the host, grow and multiply within or on the host, and interfere with or impair the normal physiological activities of the host. When a parasitic organism is growing and multiplying within or on a host, the host is said to have an infection.
9. The host's ability to resist infection depends on a continuous defense against parasitic invasion.
10. Resistance arises from both innate and acquired body defense mechanisms. The innate, general, or nonspecific immune mechanisms are those with which a host is genetically endowed and include general, physical, chemical, and biological barriers.
11. Acquired resistance mechanisms are those that the host acquires on contact with either the parasitic organism or its products.

### Study Outline

- I. Foundations of Microbial Ecology
  - A. Symbiosis is an association of two or more different species
  - B. Interactions of organisms with each other and with their physical environment contribute to the functioning of ecosystems
    1. Populations-assemblages of similar organisms within an ecosystem

2. Communities-mixtures of different populations within an ecosystem
  3. Ecosystems-self-regulating biological communities and their physical environment
- C. A major problem in understanding microbial ecology is that most microscopically observable microorganisms cannot be cultured in the lab; however, recent advances in molecular techniques are providing information on the still uncultured microorganisms in ecosystems
- II. Microbial Interactions
- A. Microorganisms can be physically associated with other organisms in a number of ways
1. Ectosymbiosis-microorganism remains outside the other organism
  2. Endosymbiosis-microorganism is found within the other organism
  3. Ecto/endosymbiosis-microorganism lives both on the inside and the outside of the other organism
- B. Physical associations can be intermittent and cyclic or permanent
- C. Mutualism
1. An obligatory association that provides some reciprocal benefit to both partners (some examples are given below)
  2. Protozoan-termite relationship-protozoa live in the guts of insects that ingest but cannot metabolize cellulose; the protozoa secrete cellulases, which metabolize cellulose, releasing nutrients that the insects can use
  3. Lichens-an association between a fungus (ascomycetes) and an alga (green algae) or cyanobacterium
    - a. Fungal partner (mycobiont) obtains nutrients from alga by hyphal projections (haustoria) that penetrate the algal cell wall as well as oxygen for respiration
    - b. Algal partner (phycobiont) is protected from excess light intensity and is provided with water, minerals, and a firm substratum in which it can grow protected from environmental stress
  4. Zooxanthellae-algae harbored by marine invertebrates; reef-building (hermatypic) corals use zooxanthellae to satisfy most of their energy needs; the coral pigments protect the algae from ultraviolet radiation
  5. Sulfide-based mutualisms (e.g., tube worm-bacteria mutualism)
    - a. Tube worm-bacterial relationships occur in hydrothermal vent communities where vent fluids are anoxic, have high concentrations of hydrogen sulfide, and can reach temperatures of 350°C
    - b. Endosymbiotic chemolithotrophic bacteria provide the main energy source in the community through the oxidation of hydrogen sulfide
    - c. The endosymbiotic bacteria are maintained in specialized cells (trophosome) of the tube worm
    - d. The tube worm binds hydrogen sulfide to hemoglobin and transports it to the bacteria; the bacteria use the energy from hydrogen sulfide oxidation to synthesize reduced organic material that is supplied to the tube worm
  6. Methane-based mutualisms-methanotrophs are intracellular symbionts of methane-vent mussels and sponges, which use the bacteria to support their nutritional needs
  7. Microorganism-insect mutualisms-bacterial endosymbionts provide essential vitamins and amino acids to host insects; insect provides a secure physical habitat and ample nutrients to the bacteria
  8. The rumen ecosystem-bacteria in the rumen anaerobically metabolize cellulose to smaller molecules that can be digested by the ruminant; microorganisms produce the majority of vitamins that are needed by the ruminant; methane is also produced in the process
  9. Syntrophism-a mutually beneficial relationship in which each organism provides one or more growth factors, nutrients, or substrates for the other organism; also referred to as cross-feeding or the satellite phenomenon; an important example is interspecies hydrogen transfer, which occurs in anaerobic environments (described below)
    - a. Fermentative bacteria produce low molecular weight fatty acids

- b. Anaerobes such as Syntrophobacter degrade fatty acids, producing hydrogen gas; however, in order for this to provide sufficient energy for Syntrophobacter, the hydrogen produced must be consumed
  - c. Methanogens consume the hydrogen gas during methanogenesis; this promotes further production of fatty acids and hydrogen gas
- D. Protocooperation-a mutually beneficial relationship that is not obligatory (some examples are given below)
  - 1. Degradation of 3-chlorobenzoate by three different microorganisms
  - 2. Linkage of the carbon cycle and the sulfur cycle by the relationship of sulfide-oxidizing autotrophic bacteria and heterotrophic organisms
  - 3. Growth of sulfide-oxidizing bacteria on surface of nematodes; nematodes live at interface of aerobic and anaerobic sulfide-containing sediments, thus providing an appropriate habitat for the bacterial symbionts; bacteria decrease the levels of toxic sulfides and serve as food supply for host
  - 4. Hydrothermal vent communities and cave communities where sulfur-oxidizing bacteria serve as food source for sponges, gastropods, and other organisms
  - 5. Quorum sensing allows microorganisms to communicate as they form associations with plants and animals
- E. Commensalism
  - 1. The microorganism (commensal) benefits, while the host is neither harmed nor helped; often the microorganism shares the same food source with the host
  - 2. Occurs in situations in which waste products of one microorganism serves as the substrate for another; also occurs in situations where one microorganism modifies the environment making it better suited for another microorganism (some examples are given below)
    - a. Nitrification-requires the activity of two different species; one oxidizes ammonia to nitrite and the other oxidizes nitrite to nitrate
    - b. The common nonpathogenic strain of Escherichia coli lives in the human colon; this facultative anaerobe uses oxygen creating an anaerobic environment in which obligate anaerobes (e.g., Bacteroides) can grow; coli derives no obvious benefit or harm
    - c. Succession of microorganisms in an environment-during milk spoilage synthesis of acidic fermentation products by one population stimulates proliferation of acid-tolerant microorganisms; during biofilm formation, the first colonizer makes it possible for others to colonize
    - d. Colonization of surfaces of plants and animals by normal flora-plant or animal produces organic substances, which are used by the normal flora of the host organism
- F. Predation
  - 1. Predator organism engulfs or attacks a prey organism; prey can be larger or smaller than predator; normally results in death of prey
  - 2. Predatory bacteria are known (e.g., Bdellovibrio, Vampirococcus, and Daptobacter); may cause lysis of prey, release of cell contents while attached to surface of prey, or penetrate cytoplasm of prey
  - 3. Ciliates are important microbial predators in aquatic environments and in wastewater treatment facilities
  - 4. Positive outcomes of predation
    - a. Microbial loop-microbial predators mineralize the organic matter produced by autotrophs (primary producers) before it reaches the higher consumers; this returns nutrients to the primary producers and promotes their activity
    - b. Ingestion of prey provides protective environment for the prey
  - 5. Predatory fungi are known (e.g., fungi that trap nematodes)
- G. Parasitism
  - 1. One organism (parasite) benefits from another (host); there is a degree of coexistence between the host and parasite that can shift to a pathogenic relationship (a type of predation)
  - 2. Examples:
    - a. Parasitic fungi and an algal host
    - b. Biocontrol-use of one microorganism to control activity of another

- c. Human diseases (discussed in chapters 38 through 40)
  - H. Ammensalism-organism releases a specific compound that harms another organism
    - 1. Antibiotics
    - 2. Bacteriocins
    - 3. Antibacterial peptides (e.g., cecropins and defensins produce by insects and mammals, respectively)
    - 4. Acidic fermentation products
  - I. Competition
    - 1. Different organisms within a population or community try to acquire the same resources (e.g., nutrients, location, etc)
    - 2. Competitive exclusion principle-if two populations overlap too much in terms of their resource use, then one of the populations is excluded
  - J. Symbioses in complex systems-interactions between two populations lead to the occurrence of feedback responses in the larger biotic community; these feedback responses impact all other parts of the ecosystem and lead to equilibrium of all populations within the community
- III. Nutrient Cycling Interactions
  - A. Biogeochemical cycling (nutrient cycling) involves both biological and chemical processes; oxidation-reduction reactions change the chemical and physical properties of the nutrient
  - B. Carbon cycle
    - 1. Carbon can be interconverted between methane, complex organic matter, carbon monoxide, and carbon dioxide
    - 2. Methane is produced by methanogens; carbon fixation can occur by the activities of cyanobacteria, the green algae, photosynthetic bacteria, and chemolithoautotrophs
    - 3. Degradation of organic matter
      - a. Organic matter varies in terms of elemental composition, structure of basic repeating units, linkages between repeating units, and physical and chemical characteristics
      - b. Degradation of organic matter is influenced by nutrients present in the environment, abiotic conditions (pH, oxidation-reduction potential, O<sub>2</sub>, osmotic conditions), and the microbial community present
      - c. Microbial degradation of complex organic material occurs when microbes use these molecules for growth
        - i. Chitin, protein, microbial biomass, and nucleic acids contain large amounts of nitrogen; the excess nitrogen is released by a process called mineralization
        - ii. Molecules containing only hydrogen, carbon, and oxygen cannot support the growth of microbes; microbes acquire the other nutrients they need for biomass synthesis in a process called immobilization
      - d. Most organic substrates can be degraded in the presence or absence of oxygen; however, hydrocarbons and lignin degradation usually occurs aerobically
        - i. Hydrocarbon degradation usually requires oxygen because the first step involves addition of molecular oxygen to the molecule; recently however, slow anaerobic digestion in the presence of sulfate or nitrate has been observed
        - ii. Filamentous fungi are major lignin degraders and they require oxygen; the need for oxygen has practical implications-wood pilings can be used below the water table where anaerobic conditions are maintained; however, if the water table drops, degradation can take place, thereby weakening the structure
      - e. Presence or absence of oxygen affects the final products that accumulate when organic substances are degraded
        - i. Aerobic conditions-oxidized products are made (e.g., nitrate, sulfate)
        - ii. Anaerobic conditions-reduced end products are formed
        - iii. If end products remain in the environment in which they were formed, they can only serve as sources of nutrients; if they are

moved to other environments, then they can be involved in further energy-yielding reactions

- C. Sulfur cycle-sulfur can be interconverted between elemental sulfur, sulfide, and sulfate forms by the actions of various microorganisms
    - 1. Dissimilatory sulfate reduction produces sulfide, which accumulates in the environment
    - 2. Assimilatory sulfate reduction results in the reduction of sulfate for use in amino acid biosynthesis
  - D. Nitrogen cycle
    - 1. Nitrification-aerobic oxidation of ammonium ion to nitrite and ultimately to nitrate
    - 2. Denitrification-reduction of nitrate to nitrite, nitrous oxide, and gaseous molecular nitrogen
    - 3. Nitrogen assimilation-utilization of inorganic nitrogen and its incorporation into new microbial biomass
    - 4. Nitrogen fixation
      - a. A series of sequential reduction steps to convert gaseous nitrogen to ammonia
      - b. Requires an expenditure of energy
      - c. Can be carried out by aerobes or anaerobes; the actual reduction process must be done anaerobically, even by aerobic microorganisms
      - d. Physical barriers, O<sub>2</sub>-scavenging molecules, and high rates of metabolic activity are used to maintain the anaerobic conditions required for nitrogen fixation
    - 5. Anoxic ammonia oxidation (anammox)-oxidation of ammonia is coupled with the reduction of nitrite to nitrogen gas
  - E. Iron Cycle-iron can be interconverted between ferric iron, ferrous iron, and magnetite
    - 1. Iron oxidation from ferrous iron to ferric iron is carried out by a number of genera under aerobic conditions; some microorganisms can carry out the process under anaerobic conditions using nitrate as the electron acceptor
    - 2. Iron reduction from ferric iron to ferrous iron occurs under anaerobic conditions and is carried out by bacteria that use ferric iron as a final electron acceptor
    - 3. Magneto-aerotactic bacteria reduce iron to magnetite, which is used to construct intracellular magnetic compasses; these bacteria use magnetic fields to migrate to a position in a bog or swamp where the oxygen level is optimal for their functioning
  - F. Manganese cycle-transformation of manganous ion to MnO<sub>2</sub>; occurs in hydrothermal vents and bogs
  - G. Other cycles and cycle links
    - 1. The reduction of a wide variety of metals can decrease toxicity of these metals
    - 2. Microbial transformations of phosphorous primarily involve transformation of phosphorous (+5 valence) to other forms, including polyphosphates
    - 3. Many cycles are linked by using commonly shared oxidants and reductants
  - H. Microorganisms and metal toxicity-metals have varied toxic effects on microorganisms and homeothermic animals; microorganisms modify this toxicity
    - 1. Noble metals (silver, gold, platinum, etc.)-cannot cross the blood-brain barrier of vertebrates, but have distinct effects on microorganisms
    - 2. Metals and metalloids that can be methylated (e.g., mercury, arsenic, lead, selenium, and tin)-methylation enables them to cross the blood-brain barrier and affect the central nervous system of higher organisms; also affect microorganisms; methylated mercury can be concentrated in the food chain (a process known as biomagnification)
    - 3. Metals that occur in ionic forms (copper, zinc, cobalt, etc.) can be directly toxic to microorganisms and more complex organisms; often required as trace elements, but excess is toxic
- IV. The Physical Environment
- A. The microenvironment and niche
    - 1. Microenvironment-specific physical location of a microorganism

2. The fluxes and gradients of oxidants, reductants, nutrients, and waste products create a unique niche (the microorganism, the physical habitat, the time of resource use, and resources available for growth and function)
- B. Biofilms and microbial mats
1. Biofilms-organized microbial systems consisting of layers of microbial cells associated with surfaces
  2. Biofilms can be observed using confocal scanning laser microscopy
  3. Biofilms on living surfaces usually play a role in causing disease; there are numerous advantages to forming biofilms in this situation
    - a. The surface releases nutrients
    - b. The biofilm provides protection from disinfectants
    - c. The biofilm creates a focus for later occurrence of disease
    - d. Release of microbial cells or products from the biofilm can affect the immune system of the host
  4. Microbial mats-large biofilms that have macroscopic dimensions; found in many freshwater and marine habitats
- C. Microorganisms and ecosystems-organisms function as primary producers, consumers, and decomposers; microbes usually function in ecosystems in the following ways:
1. Function as primary producers-synthesize organic matter through photosynthetic and chemosynthetic processes
  2. Decompose organic matter, often with the release of inorganic compounds (mineralization)
  3. Serve as nutrient rich food sources for chemoheterotrophic microorganisms and animals
  4. Modify substrates and nutrients used in symbiotic growth processes and interactions, thus contributing to biogeochemical cycling
  5. Change the amounts of materials in soluble and gaseous forms
  6. Produce inhibitory compounds that decrease microbial activity or limit the survival and functioning of plants and animals
  7. Contribute to the functioning of plants and animals through positive and negative symbiotic interactions
- D. Microorganism movement between ecosystems
1. Microorganisms are constantly moving and being moved between ecosystems by a variety of mechanisms
  2. Fate of microorganisms when moved to another ecosystem is of theoretical and practical importance (e.g., what happens to an animal endosymbiont when it is moved to an aquatic environment)
  3. When microorganisms are moved out of their normal environment, they usually eventually die; the reasons for this are not clear
- E. Stress and ecosystems
1. Factors such as pH, temperature, pressure, salinity, water availability, and ionizing radiation can act as stress factors
    - a. If one or more of these factors is extremely high or low, it creates an extreme environment
    - b. Extremophiles are organisms that survive in extreme environments
  2. Salinity-favors extreme halophiles
  3. High barometric pressure (e.g., deep sea environments) favor barotolerant, moderately barophilic, and extremely barophilic bacteria
  4. Acidity-acidophiles maintain a high internal pH relative to the environment
  5. Alkalinity-alkalophiles maintain a low internal pH relative to the environment
  6. High temperature (up to 113°C) favors thermophiles and extreme thermophiles
- V. Methods Used in Microbial Ecology
- A. Methods in microbial ecology are used to evaluate presence, types, and activities of microorganisms in ecosystems; measurements must span a range of time scales and physical dimensions; methods used include:
1. Microscopic examination
  2. Viable cell counting
  3. Measurement of nutrient cycling
  4. Measurement of organic carbon by biochemical oxygen demand (BOD), chemical oxygen demand (COD), or total organic carbon (TOC)

- B. A major problem for the microbial ecologist is to identify the microorganisms in an ecosystem, especially those that are nonculturable; assessment of microbial community diversity is often done using nucleic acid-based techniques
  - 1. Nucleic acid probe technology can be used to look for specific organisms
  - 2. Gel array microchips (genosensors) containing a mixture of probes can detect small subunit (ssu) rRNA in mixed populations
- C. Recently, techniques for examining single cells in complex microbial communities have been developed (e.g., optical tweezers and micromanipulation)
- D. A summary of methods and their uses in various environments is given in Table 28.8 of the textbook