

# The Impact of Microbes on the Environment and Human Activities

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## Microorganisms - Beneficial Effects on Organisms & Environments

Microbes are everywhere in the biosphere, and their presence invariably affects the environment that they are growing in. The effects of microorganisms on their environment can be beneficial or harmful or inapparent with regard to human measure or observation. Since a good part of this text concerns harmful activities of microbes (i.e., agents of disease) this chapter counters with a discussion of the beneficial activities and exploitations of microorganisms as they relate to human culture.

The beneficial effects of microbes derive from their metabolic activities in the environment, their associations with plants and animals, and from their use in food production and biotechnological processes.

## Nutrient Cycling and the Cycles of Elements that Make Up Living Systems

At an elemental level, the substances that make up living material consist of carbon (C), hydrogen (H), oxygen (O), nitrogen (N), sulfur (S), phosphorus (P), potassium (K), iron (Fe), sodium (Na), calcium (Ca) and magnesium (Mg). The primary constituents of organic material are C, H, O, N, S, and P. An organic compound always contains C and H and is symbolized as  $\text{CH}_2\text{O}$  (the empirical formula for glucose). Carbon dioxide ( $\text{CO}_2$ ) is considered an inorganic form of carbon.

The most significant effect of the microorganisms on earth is their ability to recycle the primary elements that make up all living systems, especially carbon (C), oxygen (O) and nitrogen (N). These elements occur in different molecular forms that must be shared among all types of life. Different forms of carbon and nitrogen are needed as nutrients by different types of organisms. The diversity of metabolism that exists in the microbes ensures that these elements will be available in their proper form for every type of life. The most important aspects of microbial metabolism that are involved in the cycles of nutrients are discussed below.

**Primary production** involves photosynthetic organisms which take up  $\text{CO}_2$  in the atmosphere and convert it to organic (cellular) material. The process is also called  $\text{CO}_2$  fixation, and it accounts for a very large portion of organic carbon available for synthesis of cell material. Although terrestrial plants are obviously primary producers, microorganisms such as planktonic algae and cyanobacteria account for nearly half of the primary production on the planet. These unicellular organisms which float in the ocean are the "grass of the sea", and they are the source of carbon from which marine life is derived.

**Decomposition** or **biodegradation** results in the breakdown of complex organic materials to forms of carbon that can be used by other organisms. There is no naturally-occurring organic compound that cannot be degraded by some microbe, although some synthetic compounds such as teflon, styrofoam, plastics, insecticides and pesticides are broken down slowly or not at all. Through the metabolic processes of fermentation and respiration, organic molecules are eventually broken down to CO<sub>2</sub> which is returned to the atmosphere.



**Waste management, whether in compost, landfills or sewage treatment facilities, exploits activities of microbes in the carbon cycle. Organic (solid) materials are digested by microbial enzymes into substrates that eventually are converted to a few organic acids and carbon dioxide.**

**Nitrogen fixation** is a process found only in some bacteria which removes N<sub>2</sub> from the atmosphere and converts it to ammonia (NH<sub>3</sub>), for use by plants and animals. Nitrogen fixation also results in replenishment of soil nitrogen removed by agricultural processes. Some bacteria fix nitrogen in symbiotic associations in plants. Other Nitrogen-fixing bacteria are free-living in soil and aquatic habitats.



**Some habitats like this cactus community in the Sonoran Desert, rely on nitrogen-fixing bacteria at the base of the food chain as the source of nitrogen for maintenance of cell material. Every plant in this scene depends ultimately on biological nitrogen fixation.**  
<http://helios.bto.ed.ac.uk/bto/microbes/nitrogen.htm>

**Production of Oxygen** - Photosynthesis occurs not only in plants, but in microorganisms like algae and cyanobacteria. Photosynthesis results in the production of O<sub>2</sub> in the atmosphere. **At least 50 percent of the O<sub>2</sub> on earth is produced by photosynthetic microorganisms (algae and cyanobacteria)**, and for at least a billion years before plants evolved, microbes were the only organisms producing O<sub>2</sub> on earth. O<sub>2</sub> is required by many types of organisms, including animals, in their respiratory processes.



**The cyanobacterium, *Synechococcus*, is a primary component of marine and freshwater plankton and microbial mats, The unicellular prokaryote is involved in primary production, nitrogen fixation and oxygenic photosynthesis and thereby participates in the cycles of carbon, nitrogen and oxygen. *Synechococcus* is among the most important photosynthetic bacteria in marine environments, estimated to account for about 25 percent of the primary production that occurs in typical marine habitats.**  
 Thomas D. Brock.

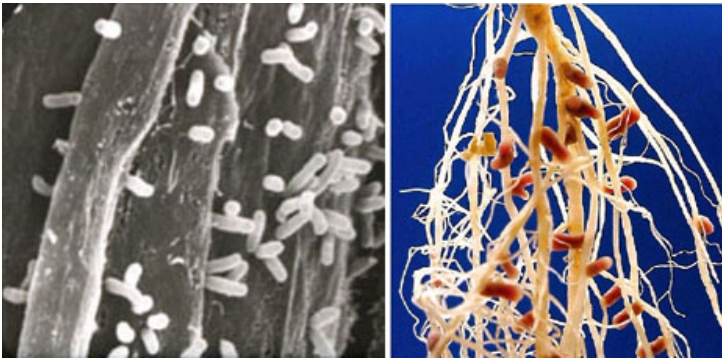
## Symbiosis with Animals and Plants

Microbes invariably enter into beneficial, sometimes essential, associations with all higher forms of organisms, including insects, invertebrates, fish, animals and plants. For example, bacteria and other microbes in the intestines of animals and insects digest nutrients and produce vitamins and growth factors. In the plant world, leguminous plants (peas, beans, clover, alfalfa, etc.) live in intimate associations with bacteria that extract nitrogen from the atmosphere and supply it to the plant for growth.

The microbes that normally live in associations with humans on the various surfaces of the body (called the normal flora), such as *Lactobacillus* and *Bifidobacterium*, are known to protect their hosts from infections, and otherwise promote nutrition and health.



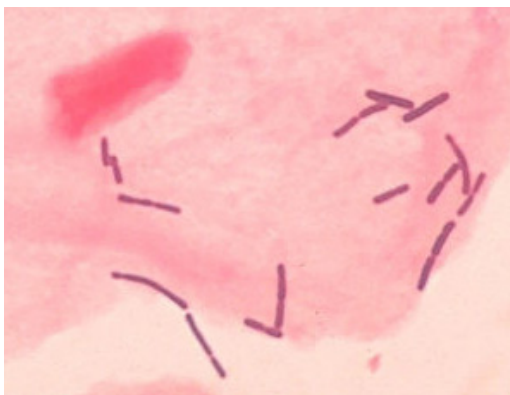
Microbes in the rumen (forestomach) of cows, sheep and other ruminant animals are responsible for the initial digestion of nutrients (primarily cellulose), and they provide not only a source of carbon for their host, but also a source of protein and vitamins.



The mutualistic association between nitrogen fixing bacteria and leguminous plants.

Left. Nitrogen-fixing *Rhizobium* bacteria colonized on the root hairs of clover plants.

Right. Nodules containing *Rhizobium* bacteria on the plant roots. In the nodule, the bacteria fix nitrogen which they share with the plant. In exchange, the plant supplies the bacteria with a source of carbon and energy for growth.



*Lactobacillus acidophilus* and a vaginal squamous epithelial cell. CDC. *L. acidophilus* (informally known as Doderlein's bacillus) colonizes the vagina during child-bearing years. As a lactic acid bacterium, the organism creates a low pH (acidic environment) on the tissues which prevents colonization by potentially harmful yeast and other bacteria.

## Production of Foods and Fuels

In the home and in industry, microbes are used in the production of fermented foods. Yeasts are used in the manufacture of beer and wine and for the leavening of breads, while lactic acid bacteria are used to make yogurt, cheese, sour cream, buttermilk and other fermented milk products. Vinegars are produced by bacterial acetic acid fermentation. Other fermented foods include soy sauce, sauerkraut, dill pickles, olives, salami, cocoa and black teas. Yeast are also involved in fermentations to convert corn and other vegetable carbohydrates into ethanol to make beer, wine or gasohol, but bacteria are the agents of most other food fermentations.



A variety of fermented foods and beverages produced by microorganisms.

## Medical, Pharmaceutical and Biotechnological Applications

In human and veterinary medicine, for the treatment and prevention of infectious diseases, microbes are a source of antibiotics and vaccines.

**Antibiotics** are substances produced by microorganisms that kill or inhibit other microbes which are used in the treatment of infectious disease. Antibiotics are produced in nature by molds such as *Penicillium* and bacteria such as *Streptomyces* and *Bacillus*.

**Vaccines** are substances derived from microorganisms used to immunize against disease. The microbes that are the cause of infectious disease are usually the ultimate source of vaccines. Thus, a version of the diphtheria toxin (called toxoid) is used to immunize against diphtheria, and parts of *Bordetella pertussis* cells are used to vaccinate against pertussis (whooping cough). The use of vaccines such as smallpox, polio, diphtheria, tetanus and whooping cough has led to virtual elimination of these diseases in regions of the world where the vaccines have been deployed.



Various antibiotics used in veterinary medicine.

**Biotechnology** - Microbiology makes an important contribution to biotechnology, an area of science that applies microbial genetics to biological processes for the production of useful substances. Microorganisms play a central role in recombinant DNA technology and genetic engineering. Important tools of biotechnology are microbial cells, microbial genes and microbial enzymes.

The genetic information for many biological products and biological processes can be introduced into microbes in order to genetically engineer them to produce a substance or conduct a process. The genes can come from any biological source: human, animal, plant or microbial. This opens the possibility for microbial production of foods, fuels, enzymes, hormones, diagnostic agents, medicines, antibiotics, vaccines, antibodies, natural insecticides and fertilizers, and all sorts of substances useful in our civilization and society. Also, the microbial genes that encode for these substances, most of which are unknown, are a tremendous resource of information for application in medicine, pharmacy, agriculture, food science and biotechnology.



**Streptokinase for dissolving blood clots. Made by recombinant DNA technology. Other medical products include hormones, vitamins, vaccines, antigens, antibodies, cytokines, antibiotics and diagnostic agents.**



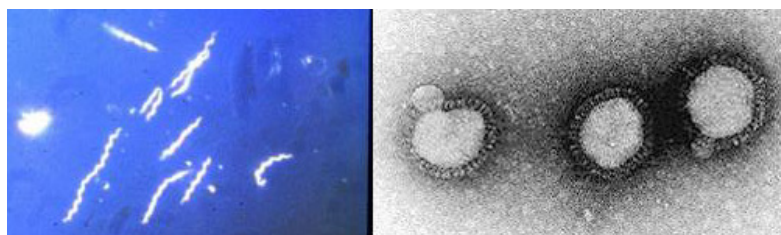
Human insulin for treatment of diabetes.

## Microorganisms - Harmful Effects on Organisms & Ecosystems

The primary harmful effects of microbes upon our existence and civilization is that they are an important cause of disease in animals and crop plants, and they are agents of spoilage and decomposition of our foods, textiles and dwellings.

### Microbes Cause Infectious Disease

A microbe which is capable of causing infectious disease in an animal or plant is called a pathogen. Four groups of microbes contain pathogens: bacteria, fungi, protozoa and the viruses. Only the archaea and algae are lacking pathogens. Pathogens are the cause of infectious diseases.



(L) *Borrelia burgdorferi*, the spirochete that causes Lyme Disease. (R) Influenza virus, cause of flu. CDC.

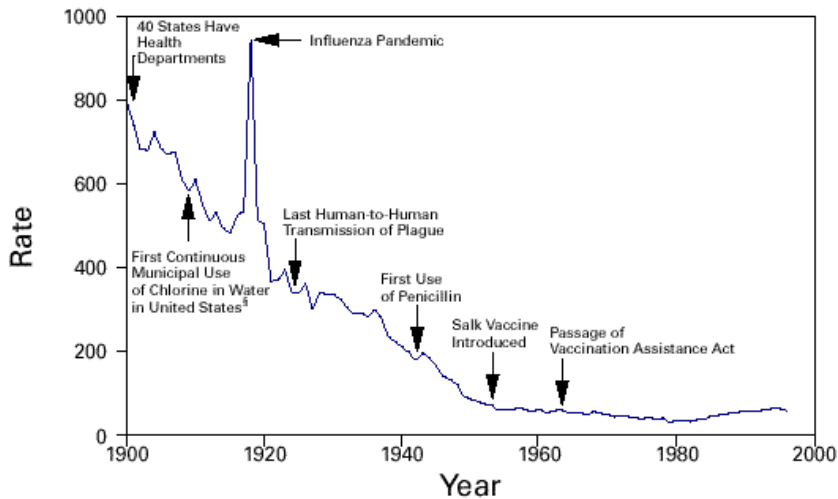
Historically, infectious diseases are the most significant cause of death in humans. Until the beginning of the Twentieth Century, it is estimated that more than half the people who ever lived died from smallpox, caused by a virus, or malaria, caused by a protozoan. Bacteria, too, have been the cause of some of the most deadly diseases and widespread epidemics of human civilization. Bacterial diseases such as tuberculosis, typhus, plague, diphtheria, typhoid fever, cholera, dysentery and pneumonia have taken a huge toll on humanity.

Deaths from infectious diseases declined markedly in the United States during the 20th century. This contributed to the nearly 30-year increase in life expectancy during this period. In 1900, the three leading causes of death were pneumonia, tuberculosis (TB), and diarrhea and enteritis, which (together with diphtheria) caused one third of all deaths. In 1997, heart disease and cancers accounted for 55% of all deaths, with 4.5% attributable to pneumonia, influenza, and human immunodeficiency virus (HIV) infection. However, one of the most devastating epidemics in human history occurred during the 20th century: the 1918 influenza pandemic that resulted in 20 million deaths, including 500,000 in the United States in less than 1 year - more than have died in as short a time during any war or famine in the world.

HIV infection, first recognized in 1981, has caused a pandemic that is still in progress, affecting 33 million people and causing an estimated 13.9 million deaths. This illustrates the volatility of infectious disease and the unpredictability of disease emergence and points us to the challenges ahead.

Progress in the 20th century is based on the 19th century discovery of microorganisms as the cause of many serious diseases (e.g., cholera and TB). Disease control resulted from improvements in sanitation and hygiene, the discovery of antibiotics, the implementation of universal childhood vaccination programs, and technological advances in detecting and monitoring infectious disease.

Crude death rate\* for infectious diseases — United States, 1900–1996†



\*Per 100,000 population per year.

†Adapted from Armstrong GL, Conn LA, Pinner RW. Trends in infectious disease mortality in the United States during the 20th century. JAMA 1999;281:61–6.

‡American Water Works Association. Water chlorination principles and practices: AWWA manual M20. Denver, Colorado: American Water Works Association, 1973.

**Incidence of infectious disease as a cause of mortality 1900 to 1996. CDC.**

Water purification, immunization (vaccination), and modern antibiotic therapy (all developments in the field of bacteriology) have dramatically reduced the morbidity and the mortality of infectious disease during the Twentieth Century, at least in the developed world where these are acceptable cultural practices. However, many new microbial pathogens have been recognized in the past 30 years and many "old" bacterial pathogens, such as *Staphylococcus aureus* and *Mycobacterium tuberculosis*, have emerged with new forms of virulence and new patterns of resistance to antimicrobial agents.

Microbes are also the cause of many diseases in plants, which, if crop plants or forest resources, may have important economic or social consequences.

## Microbes Cause Food Spoilage and Decomposition

Microbes are the agents of food spoilage and decomposition of clothing and sheltering materials. The factors that allow microbes to accomplish biodegradation and carbon cycling are at work on everything organic, which includes foods and grains stored in granaries, supermarket or refrigerator, as well as natural structural materials and textiles used for our shelters and clothing. Nothing lasts forever, and the microbial decomposition of everything organic will occur in time. Fungi and bacteria are the major microbial agents of decomposition in aerobic environments. Bacteria take over in environments that lack oxygen.

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