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Disease Emergence and Resurgence: The Wildlife-Human Connection

Milton Friend
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Prepared by the USGS National Wildlife Health Center
in cooperation with the U.S. Fish and Wildlife Service

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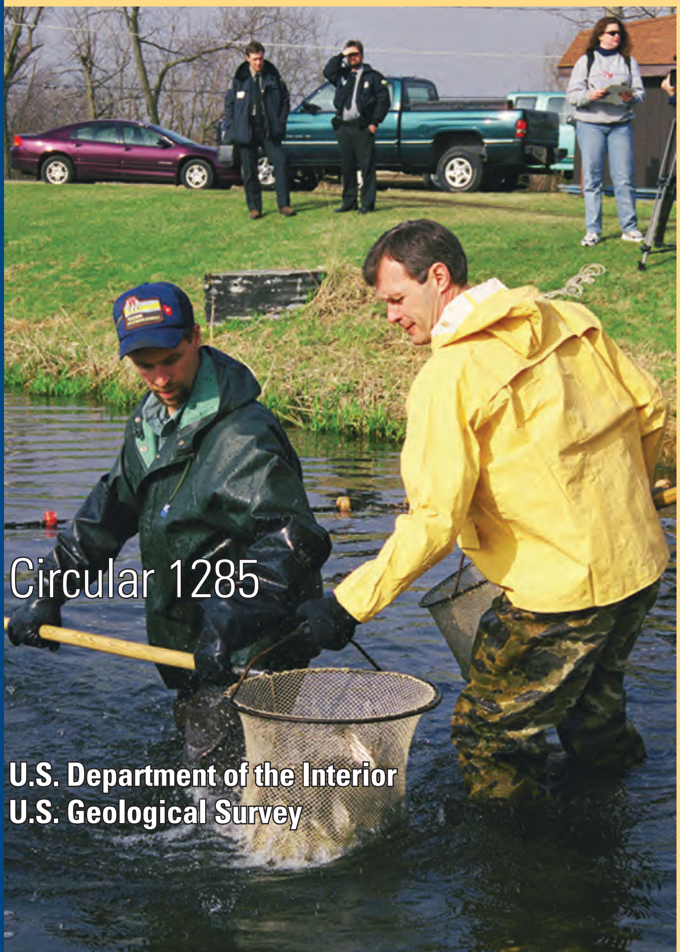

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By Milton Friend
With contributions from James W. Hurley, Pauline Nol, and Katherine Wesenberg

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Foreword

"Given the conspicuous role that diseases have played, and in many parts of the world continue to play, in human demography, it is surprising that ecologists have given so little attention to the way diseases may affect the distribution and abundance of other animals and plants." (May)[1]

In 2000, the Global Outbreak Alert and Response Network (GOARN) was organized as a global disease watchdog group to coordinate disease outbreak information and health crisis response. The World Health Organization (WHO) is the headquarters for this network.[2] Understandably, the primary focus for WHO is human health. However, diseases such as the H5N1 avian influenza epizootic in Asian bird populations demonstrate the need for integrating knowledge about disease emergence in animals and in humans.[3,4]

Aside from human disease concerns, H5N1 avian influenza has major economic consequences for the poultry industry worldwide.[5] Many other emerging diseases, such as severe acute respiratory syndrome (SARS), monkeypox, Ebola fever, and West Nile fever, also have an important wildlife component. Despite these wildlife associations, the true integration of the wildlife component in approaches towards disease emergence remains elusive. This separation between wildlife and other species' interests is counterproductive because the emergence of zoonotic viruses and other pathogens maintained by wildlife reservoir hosts is poorly understood.[6]

This book is about the wildlife component of emerging diseases. It is intended to enhance the reader's awareness of the role of wildlife in disease emergence. By doing so, perhaps a more holistic approach to disease prevention and control will emerge for the benefit of human, domestic animal, and free-ranging wildlife populations alike. The perspectives offered are influenced by more than four decades of my experiences as a wildlife disease practitioner. Although wildlife are victims to many of the same disease agents affecting humans and domestic animals, many aspects of disease in free-ranging wildlife require different approaches than those commonly applied to address disease in humans or domestic animals. Nevertheless, the broader community of disease investigators and health care professionals has largely pursued a separatist approach for human, domestic animal, and wildlife rather than embracing the periodically proposed concept of "one medicine."[7] We especially need to embrace this concept as the human population increases because there will be more contact, direct and indirect, among humans, domestic animals, and wildlife. An "Ecology for a Crowded Planet"[8] will be an even more pressing concern, and that includes increasing our understanding of disease ecology, especially that of the zoonoses.[9]

Milton Friend

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Acknowledgments

This publication is the culmination of a fulfilling career far beyond anything I had envisioned. Contributions to my professional development by family and mentors deserve special recognition along with contributions by others because they have provided the foundation for me to undertake such a project. The encouragement, support, and sacrifices by my parents, Leo and Fannie, resulted in my transition from a laborer into the intriguing world of science. My wife, Jacki, enriches my life, provides the love, encouragement, and support that allowed me to experience a career that seems more like a wonderful “fairy tale” rather than reality.

Three of my many mentors also deserve special mention. Professor J. Franklin Witter (Animal Pathology, University of Maine), kindled my interests in diseases of wildlife and started me down the path that I would eventually follow. Dr. Donald J. Dean (Director, Division of Laboratories and Research, New York State Department of Health), introduced me to the challenges of zoonotic disease and encouraged my pursuit of advanced training. Professor Daniel O. Trainer, Jr. (University of Wisconsin) provided a highly stimulating advanced education and learning experience and greatly contributed to my professional development. Collectively, their friendship, guidance, and technical expertise enhanced my knowledge base, technical capabilities, perspectives, and vision. Their patience, understanding, and other traits made them excel as role models and I am forever grateful to have worked with and learned from these outstanding individuals.

I also am sincerely grateful to the many individuals who have contributed to the completion of this project through their time, efforts, and thoughtful comments. Ms. Danielle Lohaus and Ms. Melissa Lund typed the draft manuscripts, making countless adjustments to the drafts, organized some of the tables, and assisted in many other ways. A smile was always part of their efforts despite often trying conditions and frequent requests for rapid completion of material. Dr. Margaret Fleischli meticulously checked the numerous citations within the chapters and organized them into numerical lists, compiled the draft lists of scientific names and the glossary of technical terms, and drafted several of the Appendices. Her contributions were invaluable. Ms. Karen Cunningham and Ms. Kathryn Cleary provided searches and tabulations of information from the National Wildlife Health Center (NWHC) databases that were used in various graphics and tables. Ms. Kathy Wesenberg and Ms. Christine Marsh provided invaluable library support though searches and document acquisition that provide the foundation for much of the information presented in this publication. Ms. Carol Williams provided endless photocopy services needed for project operations and assisted with the library support efforts in other ways. Ms. Barbara Littlewood indexed the manual. Ms. Frances J. Bergmann, Ms. Jennifer Rodriguez, and Ms. Rosemary Stenback provided cartography and illustration support, and Ms. Kelly Conrad provided data and information search support. Many NWHC scientific staff and others also deserve special recognition: Dr. David E. Green for his contributions on infectious diseases of amphibians; Dr. Rebecca Cole for her counsel on parasitic diseases; Drs. Kathy Converse, Grace McLaughlin, Joshua Dein, and Rex Sohn for data and counsel involving wildlife mortality events and agency wildlife disease programs; Mr. Doug Docherty for assistance with the taxonomy of viruses; Dr. Frank Panek of the USGS Leetown Science Center for his information on emerging fish diseases; and Drs. Louis N. Locke (retired), David Blehert, Kathy Converse, Kimberly Miller, Bryan Richards, Mr. Bob Dusek, and Mr. Paul Gertler of the U.S. Fish and Wildlife Service also deserve special recognition for their laborious manuscript reviews and helpful comments. I am also greatly appreciative of the support, manuscript reviews, other assistance, and great patience and forbearance afforded me in the completion of this project by Dr. Leslie Dierauf, Director of the NWHC, and Deputy Director, Ms. Christine Bunck. I apologize for any omissions in acknowledgment of individual contributions that may have been made by others over the extended period of time required for project completion.

Milton Friend

Preface

"Scientists need to think beyond traditional disease research and consider the possible roles played by climate change, air travel, and the growth of cities…" (Dr. François-Xavier Meslin, World Health Organization)

Because of the increasing human population worldwide, and the greater number of people traveling globally, infectious diseases are spreading more rapidly than in previous decades. Nevertheless, any outbreak, whether zoonotic or another infectious disease, is a local event. Recently, a reporter contacted the National Wildlife Health Center (NWHC) and asked us to predict the next five deadliest diseases that could affect the nation. His urgent request asked us to provide him with every bit of information possible, so he could inform the public about how best to get ready for the next epidemic, be it in wildlife, domestic animals, or people. This is not the first time people or agencies inside or outside the federal government have asked scientists at the NWHC to predict what disease will next rear its ugly head. "What will be the next disease *du jour*?" "What do you see in your crystal ball?"

Even though many scientists worldwide are investigating emerging and resurging diseases, no one is able to predict the future, at least not at this time in the fields of wildlife and/or zoonotic diseases. We cannot yet say that on this date, in that location, at this time, disease X will break out in a particular species and from a specific source. Nevertheless, on several occasions NWHC scientists in the field have identified environmental situations prone to disease emergence prior to disease eruptions occurring in wildlife. They have also developed models of environmental factors associated with avian botulism.[1] Ecological investigations of diseases by NWHC scientists and others are enhancing our ability to "read the landscape" relative to disease risks. The time is coming soon though, when we will be able—at the very least—to forecast the next occurrence, perhaps based on climate change predictions, or changes in habitat, or other environmental or ecosystem factors. For example, the altitudinal spread of avian malaria and avian pox in Hawaiian forest birds is a possible outcome of increasing global temperatures.[2]

Enhanced understanding of the ecology of diseases of wildlife has direct importance for combating many infectious diseases of humans. According to Dr. Mark Woolhouse from the University of Edinburgh (Scotland), humans are plagued by 1,709 known pathogens, 832 of which are zoonotic (49 percent). Of the156 of these diseases that are considered "emerging," 114 are zoonotic (73 percent).[3] On the list of high-priority agents of concern for bioterrorism activities from the Centers for Disease Control and Prevention (CDC), nearly 80 percent are zoonoses (CDC A and B lists). Therefore, the wildlife-human-domestic animal connections are nearly impossible to ignore when investigating wildlife disease. Emerging diseases can be novel or exotic, with either expanded geographic range, emerging in species not previously considered susceptible or spreading in novel ways and to unusual locales and communities. For example, the National Center for Infectious Diseases states "Many emerging or reemerging diseases are acquired from animals or are transmitted by arthropods. Environmental changes can affect the incidence of these diseases by altering the habitats of disease vectors."[4]

Who are the players, and what are their roles in infectious, emerging, and resurging diseases? The short answer is everyone and everything. The long answer is those scientists who study/investigate wildlife, domestic animal, and vector-borne public health and disease, those with interests in conservation, environmental and ecosystem health, and those who believe that public education, politics, and science-based policy are essential components of any process or program related to public health and safety. For truly novel diseases, like SARS and Hendra virus infection, preventing establishment in new geographic areas and host populations should be a primary focus. Triage in each and every outbreak involves these steps:

1. Determine whether or not an outbreak is occurring;
2. Assess the risk level (high, medium, low) of that disease being caused by a zoonotic or other infectious agent;
3. Determine whether exposure to that disease agent will lead to catastrophic losses/impacts and/or mortality/morbidity;
4. Gather data on incidence and exposure routes and rates;
5. Understand prevalence of the particular disease outbreak agent;

6. Implement a consistent contingency response to prevent, control, treat and/or manage the risk of contracting that disease; and,

7. Ensure that science-based decisionmaking and policy development take place.

Due to the complex nature of information needed to address each of these steps, I believe the future of wildlife disease investigation and study, especially of zoonoses, lies in collaborative and coordinated efforts, undertaken by multi- and inter-disciplinary teams of highly motivated individuals, to promote and spread the word of scientific discovery. May this publication make a difference in all you do and motivate you to participate in studies involving the wildlife-human-domestic animal connections related to zoonotic and other infectious diseases.

Leslie A. Dierauf, V.M.D.
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Biographies

Milton Friend is an emeritus biologist at the U.S. Geological Survey's National Wildlife Health Center (NWHC) in Madison, Wisconsin. He developed the concept document for the Center and served as the director from its inception in 1975 until 1998. In 1999, he accepted an appointment by the Secretary of the Interior to develop and oversee a science program for the restoration of California's Salton Sea. He served as chief scientist for that program until early 2002, and then returned to the NWHC to work on this publication. Previous employment includes research on environmental contaminants for the U.S. Fish and Wildlife Service, serving as the wildlife disease specialist for the New York Department of Environmental Conservation, and positions with the Vermont and the Massachusetts Departments of Fish and Game. He received a B.S. in wildlife conservation from the University of Maine (forestry minor), M.S. in wildlife management from the University of Massachusetts (epidemiology minor), and joint Ph.Ds (veterinary science and wildlife ecology) from the University of Wisconsin (epidemiology minor) where he is an adjunct professor of Animal Health and Biomedical Sciences. His teaching at the University of Wisconsin is focused on diseases of wildlife. Among his numerous publications are the *Field Guide to Wildlife Diseases* published in 1987 and a greatly expanded and updated 1999 revision co-authored with J.C. Franson, *Field Manual of Wildlife Disease, General Field Procedures and Diseases of Birds.*

Dr. James W. Hurley is a family practice physician in Madison, Wisconsin. He received a B.S. in Zoology from the University of Wisconsin–Madison in 1965 and an M.D. degree from Tulane University in New Orleans in 1969. He completed his internship and residency in California (UC San Diego and UC Davis). For many years, Jim lived in California, where he practiced at the Truckee-Tahoe Medical Clinic in California. His appreciation of the outdoors, wilderness medicine, and domestic and foreign travel shapes his perspectives on zoonotic and infectious diseases. In working to help the public and other physicians become more aware of appropriate precautions, he believes that awareness leads to prevention.

Pauline Nol is a research scientist at the U.S. Department of Agriculture's National Wildlife Research Center in Fort Collins, Colorado, developing vaccines against brucellosis and bovine tuberculosis in wild ungulates. From 1999 to 2003, she worked at the U.S. Geological Survey's National Wildlife Health Center as a graduate student and a post-doctoral researcher, studying avian botulism in fish-eating birds and sylvatic plague in black-footed ferrets and black-tailed prairie dogs. She received a B.S. in Zoology and a D.V.M. from the University of Florida, and an M.S. in Veterinary Science at the University of Wisconsin.

Katherine Wesenberg is the librarian at the U.S. Geological Survey's National Wildlife Health Center. Previous to 1992, when she began at NWHC, she was the librarian for Anaquest Corporation, a pharmaceutical firm. In 1995, she produced a literature review concerning the investigation of avian mortality in the Playa Lakes region of New Mexico. In 1997, she authored a chapter titled "The Effects of Pollutants on Wildlife" in *Information Sources in Environmental Protection* (Bowker Saur, 1997). Between 1999 and the present, initiatives involving West Nile virus (WNV) and Chronic Wasting Disease (CWD) have been her major focus. She received her M.S. in Library Science and Information Studies from the University of Wisconsin.

John M. Evans is the graphics subunit chief and senior illustrator with USGS, Denver, Colorado. After attending Eastern New Mexico University, John served four years as a Navy Lithographer/Artist (1968–1972). John has worked in publications design, created artwork for textbooks, and has provided illustrations and design support to numerous agencies. While working as a supervisory visual information specialist with the Bureau of Reclamation (1979–1981), John received an Award of Excellence from the Society for Technical Communication for his scientific field guide illustrations. From 1981 to 1989, John developed course artwork and graphic design for the Office of Personnel Management. His work has appeared in many USGS publications including the National Ground Water Atlas, National Water Summary, and a State Department presentation for the Middle East Peace Process. He has also produced artwork for the Colorado Division of Wildlife, National Oceanic and Atmospheric Administration, and for numerous college geology textbooks.

Elizabeth Ciganovich is a technical editor with the U.S. Geological Survey, Water Resources Discipline, in Madison, Wisconsin. She served on the editorial and design teams for U.S. Fish and Wildlife Service wetland status publications and for the USGS technical report templates, the *Field Manual of Wildlife Diseases, General Field Procedures and Diseases of Birds*, the National Water Summary series, and the National Ground Water Atlas. She has a degree in journalism from the University of Wisconsin and is a member of the Association of Earth Science Editors.

Gail Moede Rogall is a technical editor and information specialist with the U.S. Geological Survey's National Wildlife Health Center. She has worked at the NWHC since December 1999. Previously, she worked as a technical editor for the USGS Water Resources Discipline in Wisconsin and Massachusetts. Gail received her B.S. in Landscape Architecture and her M.S. in Life Sciences Communication from the University of Wisconsin.

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Introduction

"The scourge of epidemic disease retains an important place in the history of humanity." (Kohn)[1]

Humans have been affected by and have contributed to the eruption and spread of disease since antiquity.[1–3] This connectivity is such that disease in the Americas was one of the five Seeds of Change addressed by the National Museum of Natural History's commemoration of the Columbus Quincentenary. As for the other Seeds of Change, diseases "…sent ripples around the globe, affecting the people as well as the flora and fauna of both the New World and the Old."[4] During recent decades, these ripples have become waves that are likely to intensify, swelled by human population growth, civil strife, and other factors. Similar to the Columbus voyages of discovery, disease emergence involves the processes of encounter and exchange resulting in both deliberate and accidental introductions.[4] Biowarfare was the primary purpose for past deliberate disease introductions in the Americas (e.g., smallpox during the French and Indian Wars). Bioterrorism is the primary focus for current introductions (e.g., post-9/11 anthrax letters).[5]

Ecosystem alteration is a human hallmark with direct and indirect consequences for disease,[6–12] especially for zoonoses. Large-scale landscape alteration will continue to occur due to human population growth and technological advancement.[13,14] These transformations not only enhance the processes of encounter and exchange between organisms as a factor for disease emergence, but they also can greatly accelerate evolutionary changes, especially in disease organisms.[11]

Clearly, disease continues as an important "seed of change" sowed by human actions that result in the emergence of new global challenges for society. The context for this book focuses on providing an understanding that disease emergence and spread often are outcomes of human actions, rather than the result of events for which society has no control.

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Chapter 1

Why This Book?

"...diseases entrenched in natural foci are old in nature and 'new' only in relation to the time and conditions of their appearance in man and still more 'new' when one considers the time at which the physician learned to diagnose correctly."(Pollitzer)[1]

Photo by Milton Friend

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Chapter 1

Why This Book?

Overview

The appearance and diagnosis in humans of various infectious diseases is a dynamic situation involving “new” diseases that continue to arise and challenge humankind, along with fluctuating levels of established diseases. Some of the agents causing these diseases originate in humans and others in animals. As a group, the **zoonoses** (diseases transmissible between animals and humans) are of special concern because of the close associations people have with domesticated species and **free-ranging wildlife**. In many areas of the world, those associations with wildlife have become greater during recent years, especially as the increasing human population results in wildlife and people sharing more of the same space (Fig. 1.1). In addition, the popularity of outdoor recreation and **ecotourism** results in millions of humans entering “wild places” (Fig. 1.2). During 2001, 39 percent of the USA population 16 years old and older participated in activities related to fish and wildlife. These activities generated 1.1 percent of the Nation’s gross domestic product ($110 billion).[2] Because of these factors, zoonoses are the dominant type of infectious disease in the current era of disease emergence and reemergence, a situation that is likely to continue for the foreseeable future (see Chapter 2). Not only can humans contract diseases from wildlife (Fig. 1.3), but humans can introduce diseases that jeopardize wildlife.[3,4] Wildlife populations that become infected by **pathogens** typically considered to cause human disease may then become **enzootic** foci for those infections. Recent infection of African wildlife with the human strain of tuberculosis (*Mycobacterium tuberculosis*) has been attributed to the expansion of ecotourism and is but one example of disease introduced into wildlife populations associated with human encroachment into remote areas.[4–7]

Photo by Milton Friend

Figure 1.1 Urban and suburban environments are important habitats for some wildlife. The potential for transfer of zoonotic diseases amplifies the need to actively manage the health of wildlife populations within human environments.

Three basic factors can minimize the potential for diseases present in nature, such as **AIDS**, from becoming established as new diseases of humans, and can help to protect humans from long established zoonoses, such as rabies: 1) knowing the natural history of animal diseases transmitted to humans, 2) raising public awareness about the diseases they may encounter, and 3) implementing sound practices and public policy to address those diseases. Minimizing the introduction

Photos by Milton Friend

Figure 1.2 Outdoor recreational visitor use associated with USA parks and forests in 2000 (data from T. Jordan, National Park Service; L. Warren, National Forest Service; D.D. McLean, Indiana State University).

Figure 1.3 Examples of diseases potentially acquired from various wildlife species groups.

of typically human infections into wildlife populations is complicated because less is known about disease **transmission** from humans to free-ranging wildlife. A better understanding of the dynamics involved is essential for identifying mechanisms for limiting wildlife exposures to those infections.[4] In addition to human illness and death, zoonoses are a threat to the sustainability of wildlife populations and impose heavy economic, social, and institutional costs.

Background

Another Emerging Diseases Publication

Many published works have addressed emerging diseases; however, these publications often are directed towards scientific audiences within the human and animal health fields (Box 1–1). Nondisease specialists and the general public are also in need of information about these diseases, thus this book is directed towards them. In contrast to the previous "Field Manual of Wildlife Diseases,"[8] also developed by the National Wildlife Health Center, this publication does not address the pathology, ecology, and control for specific diseases. Instead, the focus is on concepts associated with disease emergence in wildlife, the general importance of wildlife as sentinels for disease emergence, and the importance of wildlife as sources for **zoonotic** disease. Forthcoming publications will provide in-depth coverage for many of the diseases identified here. The extensive literature citations in this publication expand the information base for disease specialists and others by providing scientific literature sources about specific diseases and associated subject areas. Noninfectious diseases and the full spectrum of infectious diseases are not addressed here.

Compared with general knowledge about diseases transmitted to humans by **domestic animals**, the public knows less about acquiring diseases from wildlife populations, especially diseases associated with the changing pattern of wildlife/human interactions. Because of this lack of knowledge, response to zoonoses transmitted by wildlife is often crisis-oriented rather than based on preventive strategies. Our intent is to enhance the basic understanding about disease ecology and disease transmission from wildlife to humans, especially those who are more at risk because of their contact with wildlife (Fig. 1.4). We also highlight the human role in disease emergence in wildlife.

Disease Emergence in a Changing World

Many factors associated with disease emergence and resurgence (see Chapter 2), such as human-induced landscape and seascape changes, worldwide travel, urbanization, changing environmental conditions, and changes in human behavior, provide new opportunities for **microbes** and parasites to infect humans, animals, and arthopod vectors of disease. Evolutionary processes favor the disease agents[9] and are providing an increasing number of "wake-up calls" in response to human ignorance and arrogance towards disease processes.[10] **HIV** infection is a well-known consequence of human behavior and conveys lessons relative to how human/wildlife interactions, in combination with human mobility and behavior, can result in the establishment of new disease foci.[11] Therefore, it is prudent to consider diseases of wildlife from a global perspective rather than from just a local, regional, or even national perspective (Box 1–2).

Disease Ecology

By examining the history of long-standing diseases and how their ecology has changed in response to changes in environmental conditions and human behavior, we can understand more about current and future disease risks. For example, the history of rabies, a long-standing **zoonosis**, is lost in antiquity. The first recorded presence for this disease is from the days of the **Asclepiadae**, 124 – 40 BC .[12] Despite this extended history, "with few exceptions, the disease is no less a worldwide problem than it was centuries ago".[13] In part, the stature of rabies as a dreaded disease has been maintained by its diverse ecology. Rabies transmitted to humans by nonvampire bats has provided new dimensions for this disease within North America since the early 1950s.[14] However, rabies virus in a nonvampire **bat** was first identified in 1916 in a Brazilian fruit-eating bat. Since then, rabies in nonvampire bats has also been documented in Europe and Asia in addition to South and North America.[15] Several different strains of rabies associated with specific wildlife species have been recognized, leading to a greater understanding of rabies ecology. The ecology of **arthropod**-vectored disease, such as West Nile fever and dengue fever, can be even more complex than that of rabies.

Humans can become infected and contract the same zoonoses through multiple routes (Fig. 1.5). Therefore, to prevent exposure to pathogens, it is important to know the different routes of exposure (Table 1.1) and to be aware of other factors, such as the environmental persistence of the causative agents. For example, animal hides with hair have been the source of human cases of anthrax from curios purchased by tourists.[16] Fish and wildlife law-enforcement personnel involved with port-of-entry inspections and other activities may encounter animal hides and other materials imported illegally. Safeguards against the transport of pathogens from the country of origin have been compromised in those situations and the law-enforcement personnel must quickly evaluate potential risks and deal with the situation without compromising their health or that of others. Important factors to consider are knowledge of the types of disease agents that might be encountered in animal hides and products made from them, the countries that pose substantial risks from those diseases, and routes for human exposure (e.g., aerosol vs. contact).

Postmortem photo by James Runningen; cave photo by William Zarwell; other photos by Milton Friend

Figure 1.4 Enhanced contact with animals and animal components associated with some types of work-related and recreational activities results in increased potential for exposure to zoonotic diseases. Recognition of inherent risks provides a basis for actions to minimize risks that may exist.

Infectious Disease Publications: Past and Present *Box 1–1*

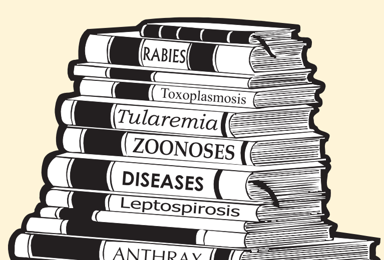
Keeping up with the continual publication of new scientific literature can be a challenge. An unfortunate result of focusing primarily on the newest literature is that the historic literature is often forgotten. Consequently, insights that might spring from reexamining past perspectives along with present knowledge do not emerge. Also, for some, the historic literature may hold greater interest than current literature because of the richness of concepts, discovery, and insights of early investigators prior to the development of current technologies and expanded knowledge of specific diseases.

- Before modern theories and technology were highly developed, publications on diseases were rich in descriptive detail of the observations being made at the gross level and the conclusions being drawn from those observations. The general wisdom and powers of deduction displayed, despite the technical limitations of those times, are impressive (see quote from **Hippocrates** on page 11).

- Descriptive epidemiology provides a foundation for many correlations and hypotheses that have been converted to important scientific discovery with the advent and application of enhanced technology and scientific methods. A classic example of descriptive epidemiology leading to disease control is John Snow's quantitative investigation of cholera in London during 1854, many years prior to the 1883 identification of the causative agent. He determined that the mortality rates in houses supplied by a specific water company were between eight and nine times greater than those in homes supplied by another water company, and also were much greater than in the remainder of London. Those findings, along with his investigation of the Broad Street Pump cholera **epidemic**, resulted in his inference of the existence of a "cholera poison" transmitted by polluted water, and led to legislation mandating that all of the water companies in London filter their water by 1857.[18] Numerous other diseases have been described as distinct clinical entities and the primary sources for human infection correctly identified prior to the isolation and identification of the causative agents.

- The historic accounts of disease are also an important part of the history of human civilization because the two are so intimately intertwined (see Chapter 2). For example, it has been suggested that **domestic pigs** brought to the New World in 1539 by the Spanish explorer Hernando de Soto were the source of epidemic disease that decimated Native American populations in the Mississippi Valley following disease transfer from the pigs to wildlife.[19] Historic publications on **epizootics** affecting wildlife that involve zoonoses often provide a wealth of information about animal populations, habitat conditions, environmental changes, and human activities during the time period of the publication. The "descriptive naturalist" approach by some of the field biologists conducting those investigations provides an enhanced vision of the field conditions associated with the specific disease events.

Current knowledge about infectious diseases is essential for combatting these diseases. Nevertheless, there will always be value in taking the time to "dust off" historic accounts of disease to appreciate the contributions made, and perhaps, to gain some new insights from the wisdom of past investigators. Chapter 7 (*How to Find and Access Published Information on Emerging Infectious Diseases*) provides guidance for access to historic and current information on emerging infectious diseases.



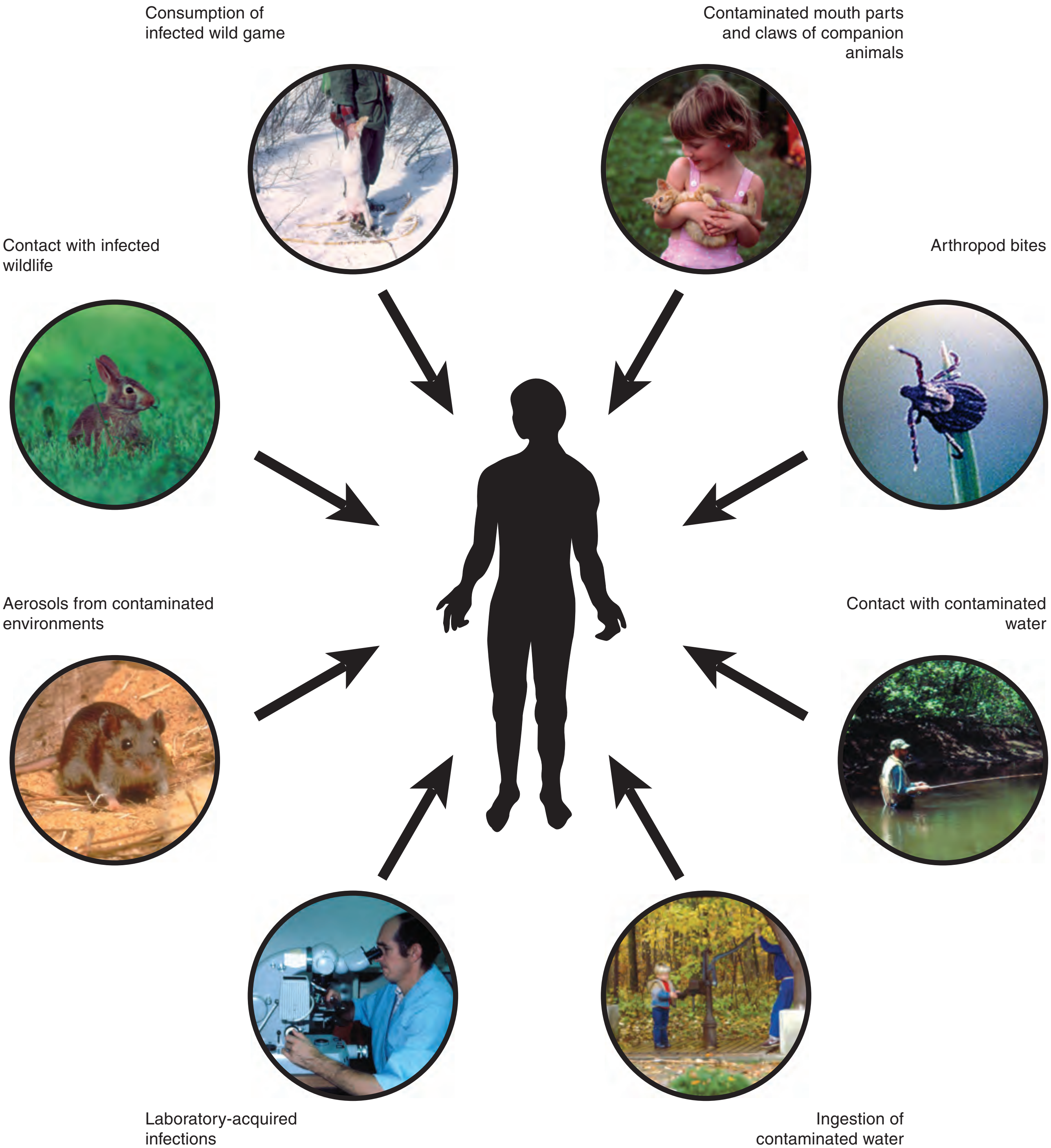


Figure 1.5 Principal routes of human exposure to infectious agents. (Mouse and tick photos courtesy of the Centers for Disease Control; microscope photo by James Runningen; other photos by Milton Friend.)

Although zoonoses are diseases transmitted between animals and humans, humans are not essential for the maintenance of most zoonotic disease agents. In many instances, the disease is not transmissible from human to human nor do human cases of the disease result in the transfer of the disease to other species. In those situations, humans are a "dead-end host," regardless of whether disease culminates in death. Nevertheless, humans greatly influence the establishment, maintenance, and occurrence of many zoonoses and other diseases. Serious consequences can arise from instances where significant human diseases are introduced into wildlife populations, which then serve as reservoirs for human infections. This dimension of disease emergence has received little attention.

Regardless of the disease, three basic factors are involved for disease to occur. Environmental conditions must be such that the disease agent can exist in a viable state; **hosts** must be susceptible to that agent; and the host and agent must have sufficient interaction for disease to occur (Fig. 1.6). Environmental conditions are often the driving force that cause host-agent relations that result in disease.

The basic disease cycle of host, agent, and environment has many permutations. These differences are primarily associated with how various types of infectious disease agents (Table 1.2) are maintained in nature and transmitted to susceptible hosts (Fig. 1.6). Understanding these processes can help minimize the potential for exposure to the pathogens that cause infectious disease. This aspect of "landscape ecology" is not a new concept.

Many people move freely and rapidly between cities, nations, and continents "in which we are a stranger." Also, our love for nature frequently takes us into environs that are even less familiar. Familiarity with disease risks before we visit a place can help guard against the diseases that may be present in those places. For example, multiple reports of outbreaks of acute **schistosomiasis** have been documented since 1975 among European and American tourists returning from various African countries.[17] In addition, a greater understanding of the potential that humans, **companion animals**, and agricultural activities have for introducing disease into wildlife populations can help in minimizing the establishment of those diseases.

This Book in Perspective

This book provides a foundation for why diseases of wildlife deserve greater attention and how lack of attention can in some instances result in those diseases becoming important zoonoses. *Disease Emergence and Resurgence* (Chapter 2) discusses the current state of emerging and reemerging diseases of wildlife and humans. *The Wildlife Factor* (Chapter 3) discusses the changing patterns of wildlife–human interactions and how those changes affect the potential for disease emergence and resurgence. *Zoonoses and Travel* (Chapter 4) provides information to expand awareness about zoonoses that may be encountered during travel and useful information for interacting with the medical community. *Is This Safe to Eat?* (Chapter 5) provides general commentary on the consumption of fish and game and addresses some of the questions commonly asked of wildlife disease specialists. *Biowarfare, Bioterrorism, and Animal Diseases as Bioweapons* (Chapter 6) focuses on the concepts, concerns, and potential for utilizing wildlife as vehicles for the introduction and transmission of infectious disease. *How to Find and Access Published Information on Emerging Infectious Diseases* (Chapter 7) provides insights and guidance for negotiating the information maze of scientific literature and staying current with advances in knowledge. Following the chapters, supplemental information ranging from a glossary of terms, scientific names of species, and other useful data are included. Literature citations provide sources for further exploration. In some instances, historical or other interests are the basis for the citation. Collectively, the contents of this book provide a wealth of information in a format that should be highly readable and informative for individuals with different levels of interest and knowledge in zoonoses and other infectious diseases of wildlife.

Milton Friend

Centuries ago, Hippocrates, in his treatise *On Airs, Waters, and Places*, c. 400 B.C., noted the linkage between environmental conditions and disease prevention and control in humans.

"When one comes into a city in which he is a stranger, he ought to consider its situation, how it lies as to the winds and the rising of the sun; for its influence is not the same whether it lies to the north or to the south, to the rising or to the setting sun. These things one ought to consider most attentively, and concerning the waters which the inhabitants use, whether they be marshy and soft, or hard and running from rocky elevations, and then if saltish and unfit for cooking; and the ground whether it be naked and deficient in water, or wooded and well-watered, and whether it lies in a hollow, confined situation, or is elevated and cold.... From these things he must proceed to investigate everything else. For if one knows all these things well, or at least the greater part of them, he cannot miss knowing, when he comes into a strange city, either the diseases peculiar to the place, or the particular nature of the common diseases, so that he will not be in doubt as to the treatment of the diseases, or commit mistakes, as is likely to be the case provided one had not previously considered these matters. And in particular, as the season and the year advance, he can tell what epidemic disease will attack the city, either in the summer or the winter, and what each individual will be in danger of experiencing from the change of regimen."

Box 1–2 Human Activities and Zoonoses

Humans interact with wildlife in many ways including cultural and subsistence use by native peoples, recreation, economic pursuits, and as a result of employment activities. Too often, the potential for disease transfer is either not considered or inadequately addressed (see Chapter 2). Increased consideration of disease can reduce human risks and still provide for the continued enjoyment and traditional uses of wildlife.

All photographs by Milton Friend

- Ecotourism—Increasing numbers of people visit “exotic places” and enter into habitat that may expose them to microbes and parasites not present in their home environment. Physical contact with wildlife often is not required because arthropod vectors, contact with contaminated waters, or cultural food habits may be the primary means for disease transmission. For example, about one-third of 26 members of a whitewater rafting expedition in Costa Rica contracted leptospirosis from the river water during their expedition.[20] Another example involves a cluster of African trypanosomiasis (sleeping sickness) in travelers to Tanzanian National Parks. Those cases are thought to represent a change in the local epidemiology of this disease.[21] Travelers can minimize their potential exposure to disease agents by learning about the status of significant diseases and taking appropriate precautions.

- **Companion Animals**—An estimated 68 million **dogs** and 73 million cats are kept as pets in the USA.[22] While outdoors, the dog or **cat** may encounter and consume wildlife such as small **rodents** that are either diseased or **carriers** of disease agents that cause zoonoses. They may also encounter **ticks** and other arthropods infected with disease agents.

  Many people also have wildlife as companion animals. Several cases of rabies resulting in substantial numbers of human exposures within the USA have been associated with pet skunks.[23] Salmonellosis has often been contracted from pet **turtles**, and Easter ducklings and chicks[24,25] and during recent years unusual *Salmonella* **serotypes** (strains) have been isolated from people having direct or indirect contact with lizards, **snakes**, or turtles.[26] Ornithosis (chlamydia) outbreaks originating from pet shops[27] and human cases associated with **birds** kept in the home[28] are other examples of zoonoses acquired from companion animals.

- **Wildlife Rehabilitation**—The strong bonds that exist between many people and wildlife have resulted in increasing involvement in efforts to save and rehabilitate injured and diseased wildlife, such as the cleaning of wildlife coated with spilled oil. In many instances, the individuals involved are not specialists in animal disease, and the clinical signs in the affected animals are too general to identify the presence of serious zoonoses. Also, the facilities where the animals are cared for, and the management of animals within them, are rarely adequate to minimize the potential for disease transmission among animals or between the animal patients and humans. For example, an attempt to assist a sick wild baby **rabbit** resulted in tularemia affecting an eye (Parinaud's oculoglandular syndrome) of the individual attempting to provide assistance.[29] As more wildlife rehabilitators become aware of particular zoonoses and gain more knowledge about species that are likely to harbor disease agents, they will be able to better judge risks involved with individual animals brought into the rehabilitation facility (chlamydiosis and West Nile fever are two **avian** diseases of increasing importance). To reduce risks from disease, training for individuals and certifying wildlife rehabilitation facilities is essential.

- Wildlife Harvests—Many people hunt, trap, and fish; these activities result in humans having direct contact with a broad spectrum of wildlife. Nevertheless, those involved in the harvest of wildlife may have little knowledge of what disease agents may be harbored by the species they are pursuing or how humans become infected by those agents. Trichinosis infections of individuals consuming wild game meat[30,31] and a recent case of *Escherichia coli* O157:H7 from **deer** meat[32] are examples of diseases generally associated with **livestock**. Unlike domestic animals, there are no health inspections for wildlife harvested for personal consumption. Timely, objective information on wildlife diseases should be fully integrated within the framework for licensing, methods for take, and promotion of these activities. However, to better inform the public about disease risks, more wildlife-disease surveillance is needed.

- Other—Numerous other human activities have the potential to result in exposure to zoonoses. For example, 9 members of a 34-person humanitarian group from Oregon that traveled to Swaziland to participate in a construction project returned to the USA with African tick-bite fever.[33] Similar humanitarian activities in Mexico have resulted in church group members from Pennsylvania and from Washington State returning with cases of the fungal disease coccidioidomycosis.[34] People have commonly acquired Lyme disease from ticks while hiking, and have become infected with hantavirus from exposure to contaminated environments while camping.

Trapping photo courtesy of the Centers for Disease Control; all others by Milton Friend

These examples are not reasons for avoiding the activities noted. Instead, they indicate the need for greater awareness of zoonotic diseases so that people can minimize their potential risks. For example, because of the potential contact with bats, since the 1960s it has been recommended that cavers receive rabies vaccination. Nevertheless, a recent survey of cavers indicated a general under-appreciation of the risk for rabies from bat bites.[35] Similarly, recent fatal cases of yellow fever in unvaccinated travelers to the Amazon also reflect under-appreciation of the risks involved from this disease.[36,37]

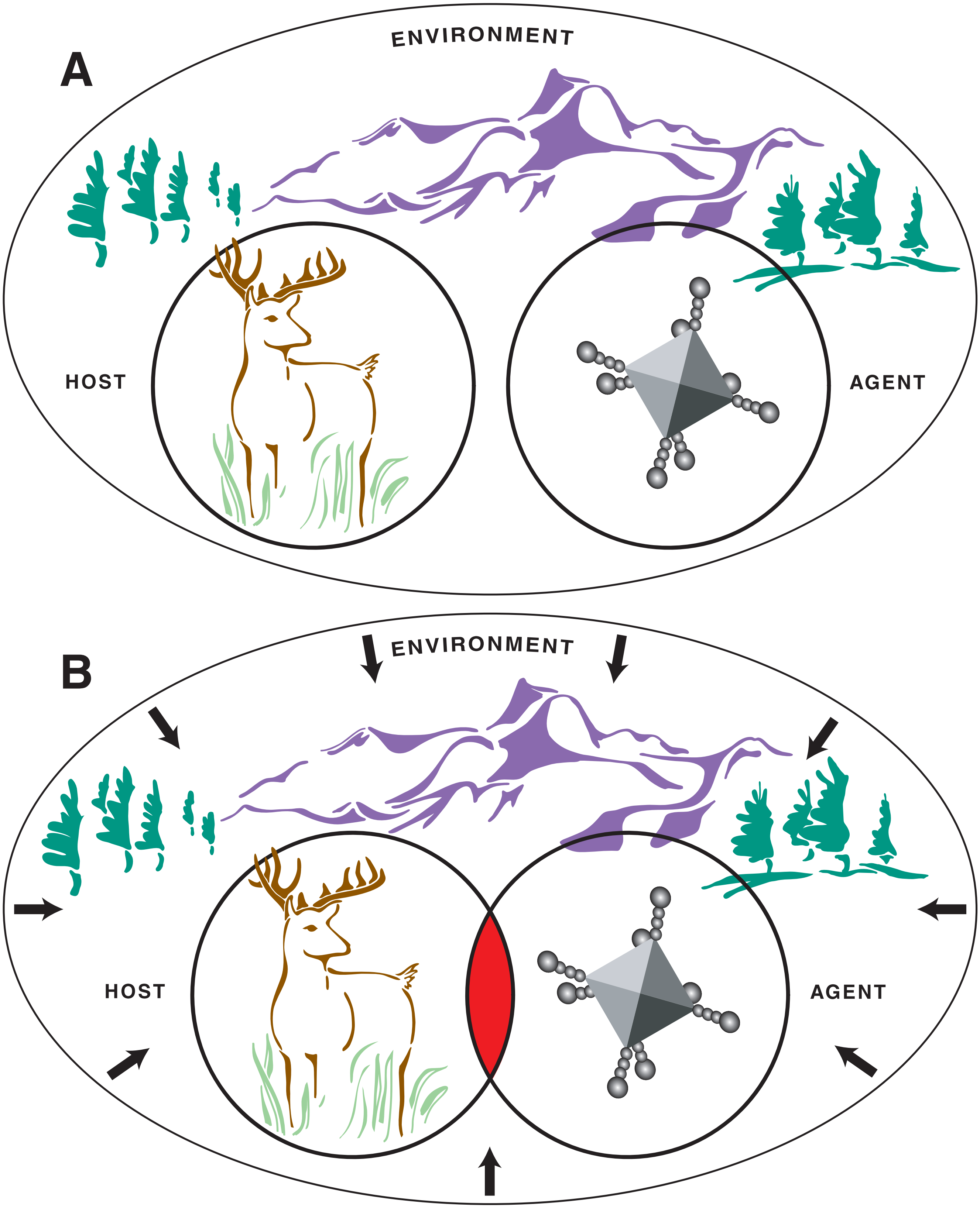


Illustration by Jennifer Rodriguez and Frances J. Bergmann

Figure 1.6 (A) Primary factors involved in the occurrence of disease: susceptible hosts; agents capable of causing disease; environmental conditions that facilitate the presence of disease agents; (B) Environmental conditions facilitate host-agent interactions in a manner that results in disease.

Table 1.1 Routes for human exposure to infectious disease agents harbored by wildlife.

Route of exposure	General circumstances (examples)
Animal bite	• Diseased animal has agent present in saliva and inoculates human through a bite wound (rabies). • Healthy animal commonly has agent present in mouth and transfers the agent through a bite wound (pasteurellosis). • Healthy animal has contaminated mouthparts from recent feeding on diseased animal and transfers the agent through a bite wound (tularemia).
Direct contact	• Individual harvesting, processing, or handling wildlife with bare hands, contact with infectious agents present within animal tissues, organs, and fluids, and in some instances on contaminated body surfaces (tuberculosis). Contaminated hands may also transfer agent to eyes (tularemia).
Indirect contact	• Swimming or otherwise immersing bare body parts in waterbodies contaminated by infectious agents able to survive within those environments. Entry of the pathogen is through small abrasions in the skin, conjunctiva of the eye, or by invasion of infectious parasites ("swimmers' itch"). • Contact with soil and other components of the terrestial environment that have been contaminated with infectious agents by rodent feces and urine (hantavirus).
Arthropod bite	• Arthropods that either become infected and harbor those infectious agents or have contaminated body parts and fluids as a result of recent feeding on an infected host transmit the disease agent when feeding on humans (West Nile fever).
Aerosol	• Individuals investigating various aspects of infectious diseases in confined areas (scientists and other laboratory workers), workers processing animals and crop harvests in production facilities, and individuals cleaning animal facilities have become infected by a variety of infectious agents present in the animals, their body discharges, or by water contaminated at other locations. The infectious agents become airborne in water sprays and by other means, are inhaled, and establish infection with the human host. In some instances, entry may occur through the conjunctiva of the eye (Newcastle disease). • Contaminated hides used for curios for the tourist trade and hides processed for the leather industry and other purposes have been a source for human infections. The infectious agents become airborne during handling and are inhaled (anthrax). • Fungal spores present in soil and in bird and bat guano become airborne when soil is disturbed. Human exposure to the fungal pathogens results from inhalation (histoplasmosis).
Ingestion	• Healthy-looking infected wildlife (including fish) are harvested and consumed without being cooked long enough or at a sufficiently high temperature to kill disease agents present (trichinosis). In some instances, the wildlife (especially fish) is consumed raw (anisakiasis).

Table 1.2 Types of infectious disease agents causing zoonoses.

Agent type (examples)	Characteristics
Virus Rabies (RNA virus); herpesvirus infections (DNA viruses)	• Organisms usually too small to be seen by light microscopy • Use the functions of living host cells of other species to replicate • Able to reproduce with genetic continuity and the possibility of mutation • Virus particle, or virion, primarily consists of either a DNA or an RNA (nucleic acid) core enclosed within a protein shell or capsid
Bacteria Salmonellosis	• Unicellular organisms, other than blue-green alga, visible by light microscopy; reproduction is commonly by cell division • Typically, the bacterial cell is contained within a cell wall
Rickettsia Rocky Mountain spotted fever	• A specialized type of bacteria that typically occurs within the cytoplasm of cells or within the gut of insects that transmit these organisms to vertebrates, including humans
Chlamydia Chlamydiosis (ornithosis, psittacosis)	• Another specialized type of bacteria that is classified as a separate group • Reproduction is only within the cytoplasm of vertebrate host cells • Reproduction is by a unique, complex developmental cycle involving attachment and penetration of the host cell by infectious elementary bodies, which undergo further transformations before developing into additional elementary bodies that are released when the dead cell is ruptured as part of the reproductive process • Do not have a cell wall
Fungi imperfecti Histoplasmosis	• Heterogeneous group of fungi with a body not differentiated into discretely recognized components for reproduction and other functions; some develop into two forms depending on the conditions for their growth (dimorphic); budding is a common form of growth • Systemic mycoses are the group most commonly involved in zoonoses of concern and are generally pulmonary in origin
Protozoa Toxoplasmosis	• “Animal-like” unicellular organisms that range in size from submicroscopic to macroscopic • Approximately 10,000 of the 35,000 species within this group are parasitic • Reproduction typically involves asexual and sexual stages
Metazoan parasites Hydatid disease (echinococcosis)	• Multicellular parasitic organisms with a body composed of cells differentiated into tissues and organs; usually with a digestive cavity lined with specialized cells • Generally macroscopic, but some are microscopic • Life cycles often involve different host species for each of the developmental stages of the parasite; a mixture of invertebrate and vertebrate intermediate (developmental) hosts is common for completion of the life cycle
Prions “Mad cow disease”	• An aberrant form of the normal cellular prion protein; causes neurodegenerative disease • An emerging disease issue about which too little is known to clearly understand the processes involved in transmission or zoonotic status

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Chapter 2

Disease Emergence and Resurgence

"Ingenuity, knowledge, and organization alter but cannot cancel humanity's vulnerability to invasion by parasitic forms of life. Infectious disease which antedated the emergence of humankind will last as long as humanity itself, and will surely remain, as it has been hitherto, one of the fundamental parameters and determinants of human history." (McNeill)[1]

Photo by Milton Friend

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Chapter 2

Disease Emergence and Resurgence

A profusion of emerging diseases has affected humans since the early 1980s, and pathogens of animal origin or products of animal origin cause many of these.[2] Some of these diseases had not been established previously, such as AIDS, and others are a resurgence of diseases thought to have been controlled, such as tuberculosis in developed nations. This change in the status of diseases affecting humans has resulted in emerging infections becoming a focus for national and global attention (Box 2–1).

Emerging and reemerging diseases have generally been defined as infectious diseases of humans whose occurrence during the past two decades has substantially increased or threatens to increase in the near future relative to populations affected, geographic distribution, or magnitude of impacts.[3–5] This concept has been expanded to also include other species and noninfectious diseases.[6–8] Disease emergence and reemergence are affecting a wide variety of species on a global scale. An overview of the scope of this problem is provided to increase awareness of the role of wildlife in the ecology of emerging/reemerging diseases and to explore some of the primary factors involved.

Concepts

What is Disease?

For general purposes, disease is broadly defined as any departure from health[9] resulting in bodily dysfunctions. Impairments to health caused by conditions such as arthritis, major depression, reproductive sterility, dementia, and Parkinson's disease are common, in addition to clinical illness from infections, such as influenza and death due to cancers and cardiac failure. For wildlife, disease primarily impairs populations by reducing offspring (e.g., brucellosis) or by reducing the probability for survival of individuals (e.g., plague). If enough individuals are affected, the collective effects can reduce the sustainability of the population.[8] Recent appearances of chytridiomycosis in **amphibian** populations have raised great concern about the sustainability of affected populations, especially those already in threatened and endangered status.[10–12]

Disease Agents

Disease can result from exposure to a variety of infectious agents and also can be an outcome from other factors (Table 2.1). Infectious disease has been the human health focus for disease emergence and reemergence and is the primary orientation here. That is, the focus is on organisms that invade live hosts in a manner that generally involves multiplication of the organism within the host as a prerequisite for an outcome of disease. Noninfectious diseases such as botulism, other diseases involving natural (i.e., algal, fungal, etc.) and synthetic toxins (i.e., pesticides) that may be acquired from the consumption of food items and allergic responses are, in general, not addressed here. However, diseases caused by biotoxins (natural toxins) are noted for circumstances of special concern.

For wildlife, noninfectious diseases of microbiological origin have been a prominent component of disease emergence and reemergence. For example, type C **avian** botulism, *Clostridium botulinum*, is a "food poisoning" of wild birds and occasionally some other species (humans are resistant to type C toxin but not to most other types of botulinum toxin). This disease has evolved from being a problem in Western North America to becoming the greatest known cause of disease affecting free-ranging **waterbirds** throughout the world. Avian botulism was essentially limited to areas west of the Mississippi River prior to 1940 (Fig. 2.1),[13] and prior to 1960, had very limited occurrence outside of North America (Fig. 2.2). In addition to greatly expanding its geographic distribution within the USA since the mid-1970s (Fig. 2.1), unique epizootics have appeared since the mid-1990s at the Salton Sea in southern California. The type C botulism outbreaks in white **pelicans** and brown pelicans at the Salton Sea are the largest die-offs of pelicans ever reported from any cause and the first to be associated with fish.[14]

The occurrence of epizootics of type E botulism during 2000 and 2002 in Lake Erie of the North American Great Lakes system also is of significance because humans are highly susceptible to type E toxin.[15] An estimated 8,000 birds died during the summer outbreak of 2000, and more than 25,000 during the 2002 epizootic. Ring-billed **gull**, red-breasted merganser, common loon, and long-tailed **duck** were the primary species affected.[16] These epizootics are the largest mortalities recorded for birds due to type E botulism. The first wild **bird** epizootic from this toxin was in 1963 and involved extensive mortality of gulls and common loons in Lake Michigan, another of the Great Lakes, where periodic outbreaks have persisted.[17,18]

Little is known about the ecology of type E botulism in nature. Fish are susceptible to type E toxin and they may be the source of the toxin killing some fish-eating birds. Human cases of type E botulism acquired from commercial smoked fish from the Great Lakes resulted in changes in regulations governing the commercial preparation of smoked fish.[19,20] However, recreational fishermen sometimes smoke the fish

Box 2–1 Infectious Disease: A Continuum of New Challenges and Opportunities

"Infectious disease is one of the few genuine adventures left in the world" (Zinsser).[291]

Time has vividly etched how infectious disease has influenced human life as evidenced by cultural mores, religious beliefs, the demography of peoples, the outcomes of wars and colonization attempts, economic status, and life-expectancy.[1,289–291,337] Thus, there is a foundation of self-interest involving personal health and economic well being in the current resurgence by the developed nations of the world to increase efforts for addressing infectious disease after decades of neglect. In addition, bioterrorism has become an increasing concern due to world change initiated by the infamous events of September 11, 2001, and by the anthrax-contaminated letters sent in the months that followed. As a result, previous reductions in resources for infectious disease programs are being restored[28] and enhanced.

Photo courtesy of the Centers for Disease Control

People grieve by the NAMES Project AIDS Memorial Quilt

Our globally interactive society results in the need for a global perspective in combating infectious disease because:

> "It is not possible to adequately protect the health of our nation without addressing infectious disease problems that occur elsewhere in the world.... Left unchecked, today's emerging disease can become the endemic disease of tomorrow" (CDC).[255]

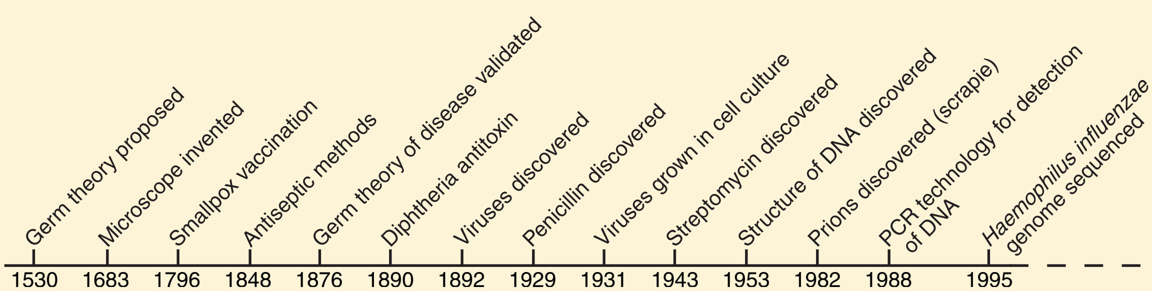
International collaboration, as in the 2003 onset of severe acute respiratory syndrome (SARS),[338] is essential for minimizing the potential impacts from emerging disease because pathogens are often hidden hitchhikers associated with commerce and human travel. Proactive rather than reactive efforts are needed to meet the challenges posed by:

> "…those ferocious little fellow creatures, which lurk in the dark corners and stalk us in the bodies of rats, **mice**, and all kinds of domestic animals [and wildlife]; which fly and crawl with the insects, and waylay us in our food and drink and even in our love" (Zinsser).[291]

These challenges are eternal because of the great adaptive capabilities of "those ferocious little fellow creatures"[22] and new opportunities continually provided to them by the periodic folly of human behavior and actions.

A recent editorial spoof, "New World Pathogen Strategy Disclosed,"[339] exploits pathogen adaptability and human frailties by taking the reader into a mythical convention of pathogens in which they are discussing the topic "Our Infective Future: The New Agenda." The keynote speaker, a contemporary prion, in addition to giving plaudits to HIV, the tuberculosis bacillus, and to the viruses Ebola, Hanta, Lassa, and Marburg for gains they have made, notes that:

> "*Homo [sapien]* is remarkably hospitable to us… And they are recklessly changing the climate, releasing many of us from our historical geographic costraints… Although they themselves deny that there is such a thing as a free lunch, we know better. There is a free lunch, and it is them."



Disease and Discovery

(adapted from Lederberg)[22]

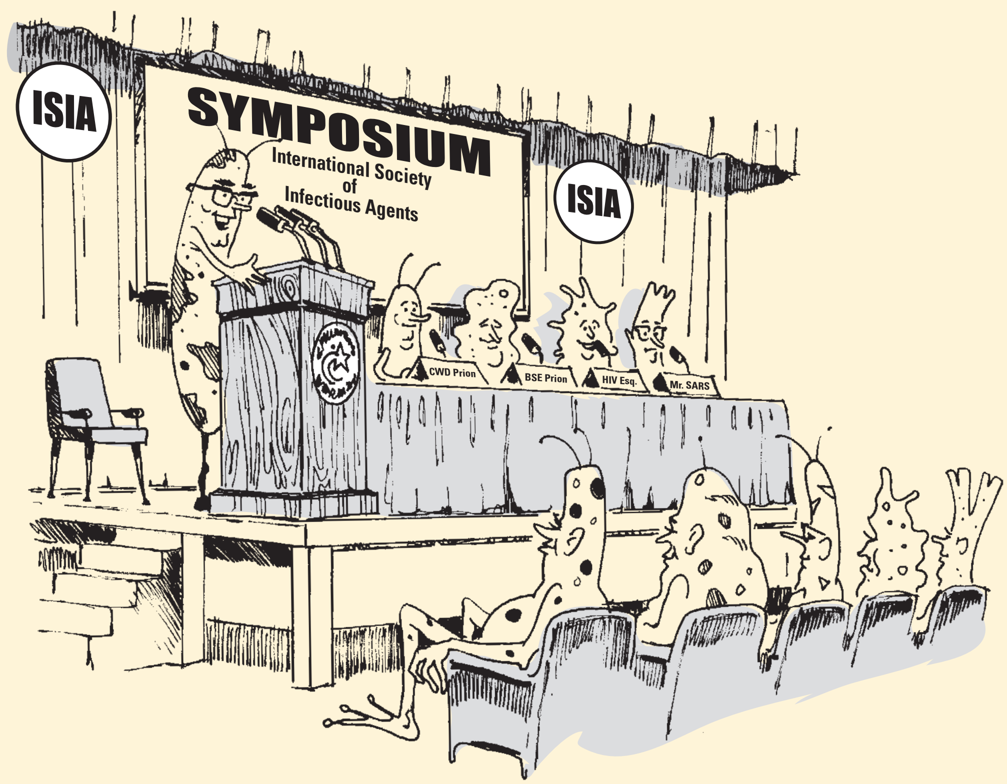


Illustration by John M. Evans

Human actions have always created new opportunities for pathogens, while disease emergence continues to provide new opportunities for humans to gain a better understanding of the ecological, behavioral, and social conditions that result in disease. The need to aggressively apply this knowledge is facilitated by a more informed public and collaboration among agencies, governments, and scientists that spans disciplines and political boundaries.

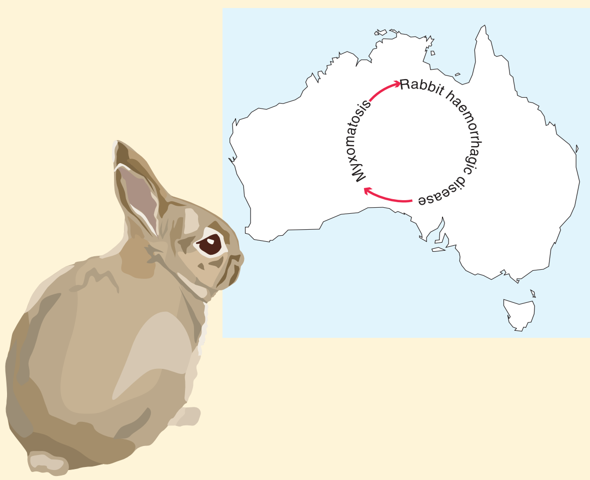
Numerous scientific conferences, workshops, other regional, national, and international meetings, and other actions are focusing on emerging infectious disease. Notable actions include:

- 1995—The Centers for Disease Control and Prevention (CDC) of the United States Department of Health and Human Services, Public Health Service initiates publication of "Emerging Infectious Diseases," a scientific journal for tracking and analyzing disease trends.
- 1996—The White House issues a "Presidential Decision Directive on Emerging Infectious Diseases," which establishes a national policy and implementation actions to address the threat of emerging infectious disease by improving domestic and international surveillance, prevention, and response measures.[340]
- 1998—CDC issues an emerging disease strategy document, "Preventing Emerging Infectious Diseases: A Strategy for the 21st Century."[341]
- 2002—CDC issues a mission-oriented document addressing approaches for the improvement of global capacity for disease surveillance and outbreak response, "Protecting the Nation's Health in an Era of Globalization: CDC's Global Infectious Disease Strategy."[342]
- Numerous global health Web sites focusing on emerging diseases are developed as well as numerous regional and disease-specific surveillance networks (see CDC Appendices A and E).[342]

The actions noted are but the tip of the proverbial iceberg of current response to emerging infectious disease. Major investments are also being made in the development of high level biosecurity facilities where studies can be carried out on the most hazardous pathogens. Advances being made have been greatly assisted by the reporting from all aspects of the news media including newspapers and weekly news magazines to television news shows and documentaries, and by the Hollywood spotlight that has made millions of people aware of emerging infections [e.g., "The Philadelphia Story" (AIDS) and "Outbreak" (Ebola)]. Therefore, it is fitting that the author of the book, "The Coming Plague: Newly Emerging Diseases in a World Out of Balance"[343] earned a Pulitzer Prize for journalism.

Australia, Myxoma Virus, and the European Rabbit

Myxomatosis in Australia is a classic example of host-pathogen adaptation for the benefit of both parties.[26] Highly virulent strains of myxoma virus were introduced into European rabbit populations in an attempt to rid Australia of this introduced species. The biological control program depended upon mosquitoes to vector the disease and spread it among the rabbit population. After several failed introduction attempts, the virus established an epizootic foothold, causing a case-fatality rate of over 99 percent during the summer of 1952.[27] However, instead of dying out during the winter as expected, some virus survived and established enzootic foci for the disease. Those foci produced mutant strains of virus with reduced virulence, as evidenced by longer survival times for infected rabbits (weeks rather than days). Because of the longer survival times, the probability for mosquitoes to acquire and transmit the attenuated virus strains was far greater than that for the highly virulent strains. Within 3 years, this selective process resulted in the attenuated mutant viruses (70-percent to 90-percent case-fatality rate) becoming the predominant strains of myxoma virus in Australia.[27,28]



Drawing by Erinn Dornaus

In addition to virus mutations, genetic selection for survival was also occurring within the rabbit population. Within 7 years, the susceptibility of the rabbits to the original virulent virus when tested in the laboratory had fallen from 90 percent to 25 percent. Thus, attenuation of the myxoma virus and genetic selection for resistance to myxoma virus by the rabbit population has resulted in host-pathogen adaptation that prevents the virus from killing all of the hosts that sustain its presence. While some rabbits still die in Australia from myxomatosis, many survive infection to produce young. The European rabbit remains a pest species in Australia, but populations are at levels considerably reduced from those that existed prior to the establishment of myxomatosis.[26–29]

A biological postscript is currently being written to the myxomatosis story. Rabbit hemorrhagic disease virus escaped from experimental studies on an offshore island, reached mainland Australia in October 1995, and rapidly spread. Rabbit hemorrhagic disease (RHD) has decreased long-term average numbers of rabbits by 85 percent in some arid areas. In the coastal areas, the numbers of rabbits were reduced by 73 percent in the first year, but gradually recovered to only 12 percent below pre-RHD numbers in the third year.[30] As for myxomatosis, biological adjustments are occurring, although, now as a three-party interaction of RHD, myxomatosis, and rabbits.

The appearance of RHD has changed seasonal patterns of rabbit recruitment, rabbit abundance, and myxomatosis activity. RHD generally has a severe impact on rabbit populations through the breeding season, but compensatory recruitment after RHD activity declines allows rabbit numbers to recover somewhat. Because of the loss of susceptible rabbit hosts, the seasonal peak in myxomatosis activity is slightly delayed. RHD is outcompeting myxomatosis because it kills most rabbits (2 days for viremia) before they become infective for myxomatosis (8–10 days for viremia).[30] The final outcome from this competition remains to be learned.

they catch. Public education has been helpful in informing the public of proper temperature and time required at that temperature to destroy toxins that may be present.

It is likely that the recent bird mortalities on Lake Erie are an indicator of environmental changes that are resulting in increased levels of type E botulinum toxin within the food chain of this lake, creating potentially severe ramifications for human and wildlife health. Similar to type C botulism in pelicans at the Salton Sea, exotic species also appear to be a major factor in toxin production within the food chain of Lake Erie. Tilapia, an introduced fish species, is a primary source for toxin production at the Salton Sea. Other introduced species, such as the round goby fish, zebra mussel, and quagga mussel, are believed to be involved in toxin production or transport within Lake Erie.[21]

Evolutionary Considerations

In considering disease emergence and reemergence, one must recognize that disease is an outcome, not a cause; an outcome that can be viewed as a state of instability among coinhabitants of Earth due primarily to two associated instabilities, one of which is ecological and the other evolutionary.[22] The dynamic nature of these factors challenge the common belief that, "Given enough time, a state of peaceful coexistence eventually becomes established between any host and parasite."[23] Some notable evolutionary biologists challenge the concept of benign coexistence between parasites (including microbes) and their hosts as being at odds with the fundamental principles of evolution on which they are based.[24] Nevertheless, the long-term trend towards coadaptation between hosts and pathogens is to the advantage of both because very severe impacts may result in the elimination of both species.[25]

Coadaptation does not necessarily equate to benign coexistence. Mortality of the host may be replaced by disease that has less severe outcomes as pathogens mitigate their **virulence** in ways that do not compromise their continued existence, but may still negatively impact their hosts.

Infectious pathogens have great capability to make adjustments that provide them with suitable hosts (e.g., cross species barriers) and to sustain their invasiveness and spread (e.g., antibiotic resistance). Their superiority in numbers, species, and capability for genetic change allow pathogens to adapt to changing environmental and host conditions at a pace greater than humans can counteract in the short term.[25,31] The continual need to develop vaccines against the latest strain of influenza virus and the growing problem of resistance to antibiotics long used to successfully combat serious human illness are familiar examples of the ability of microbes to make adaptive changes that sustain their infectivity for humans despite our technological capabilities.

Table 2.1. Some of the many sources of human disease.

Infectious agents	Zoonotic examples
Viruses	Rabies, West Nile fever
Bacteria	Tuberculosis, Lyme disease
Rickettsia	Rocky Mountain spotted fever, Q fever
Fungi	Coccidioidomycosis (valley fever), histoplasmosis
Metazoan parasites	Echinococcosis (hydatid disease), trichinosis
Protozoan parasites	Toxoplasmosis, giardiasis
Prions	Bovine spongiform encephalopathy (BSE)
Noninfectious agents	**Disease examples**
Microbial toxins	Botulism, enterotoxemia
Algal toxins	Domoic acid poisoning, saxitoxin (contaminated shellfish)
Plant toxins	Aflatoxicosis (contaminated peanuts), mushroom poisoning (*Amanita* spp.)
Synthetic chemicals	Pesticide poisoning, drugs
Heavy metals	Lead poisoning, mercury poisoning
Oil spills	Skin irritation from contact; liver disease from inhalation
Other causes	**Examples**
Neoplasia	Cancers
Genetic disorders	Down’s syndrome, hemophilia
Diseases of immunity	Autoimmune disease, Chédiak-Higashi syndrome
Systemic diseases	Diabetes, gout
Deficiency diseases	Malnutrition, vitamin deficiencies
Psychoses	Depression, post-traumatic stress syndrome
Physiological disorders	Endocrine disruption, hypothermia
Trauma	Blunt impacts, gunshot

The Human Influence

The instability of ecological conditions encountered by pathogens is primarily a result of human actions that alter the physical and biological environment, the microbial and animal tenants (humans included) of these environments, and human interactions (including hygienic and therapeutic interventions) with pathogens.[22] The magnitude of human impacts contributing to this ecological instability is such, "…that humans may be the world's dominant evolutionary force."[32] Landscape disruption alone grossly reflects the magnitude of environmental change. About 40 to 50 percent of land on the Earth has been irreversibly transformed or degraded by human actions. An additional one-third of global land cover will be transformed over the next century.[33] Changes in biotic diversity and alterations in the structure and function of ecosystems are the two most dramatic ecological trends of the past century.[34] Disease emergence and reemergence should be expected as continuing outcomes from this accelerated magnitude of ecological instability and associated changes in species abundance, presence, and interactions.

Perspectives

> **"Most of the infectious diseases…have now yielded up their secrets…. Many illnesses…had been completely exterminated; others had [been brought] largely under control…." (Sigerist, 1931, cited by Cohen)[35]**

The Mirage of Health

Human experiences with infectious disease have stimulated pursuit of a world free from the debilitation, suffering, and death that disease causes. Economic and other costs of disease stimulate this utopian vision, in addition to impacts on the personal health of individuals, families, and populations. Notable accomplishments in this quest during the 20th century include the global **eradication** of smallpox and major advances in the elimination of polio in much of the world.[36] Infectious disease mortality within the USA declined from 797 deaths per 100,000 individuals in 1900 to 36 deaths per 100,000 in 1980.[37] These and other accomplishments have resulted in overoptimistic perspectives regarding human dominance over infectious pathogens (Box 2–2).

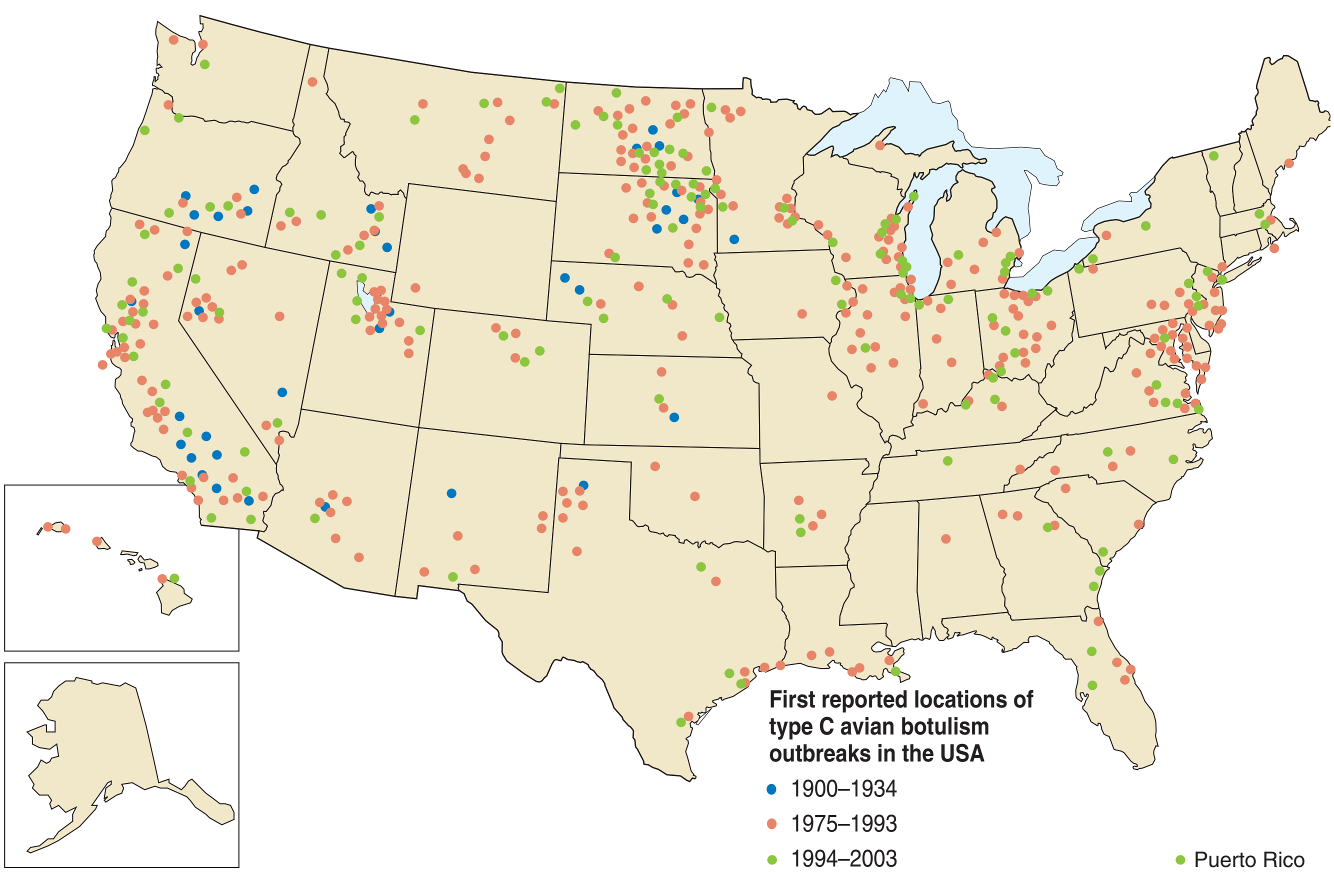


Figure 2.1 Locations of type C avian botulism outbreaks in the United States.

The euphoria associated with accomplishments in the conquest of infectious disease is based on reflections from a mirage rather than images of lasting substance. Those perspectives and the prediction that the history of human infection will progress steadily toward virtual elimination of infectious disease were replaced during the 1980s by a resurgence of human infections occurring on a global scale.[3,38–40] Instead of infectious disease being conquered by the end of the 20th century, the last two decades of that century initiated the start of an era of emerging and reemerging diseases of humans that, once again, reflects humanity's vulnerability to invasion by parasitic forms of life.[1] As we enter the third millennium, microbial diseases remain as the most frequent cause of human mortality worldwide.[41]

The Process of Living

> **"Complete freedom from disease and from struggle is almost incompatible with the process of living" (Dubos).[42]**

Human impacts result in a continuum of environmental changes, ecological disturbances, and adjustments by microbes and parasites to survive and flourish as part of these changing conditions. The current lesson being relearned from history, as evidenced by the more than 30 diseases of humans that have emerged during the past quarter century, is that environmental change leads to the continual emergence of infectious disease.[7,35,43,44] Society is not only subject to diseases of antiquity, such as rabies and tuberculosis, but we have also facilitated the establishment of a host of new diseases, including some such as Legionnaires' disease and toxic shock syndrome that are products of technological advances.

The Devil's Cauldron

It is increasingly evident that the human pursuit of the "good life" is tainting the elixir of life with a potpourri of ingredients that enhance disease emergence. In some respects it seems as if that elixir is being brewed in the "devil's cauldron" and that its consumption is a major factor leading to human disease. The number of infectious agents causing disease in humans is increasing and substantial, but difficult to quantify because of differences in the way disease agents are categorized and enumerated. For example, bacteria of

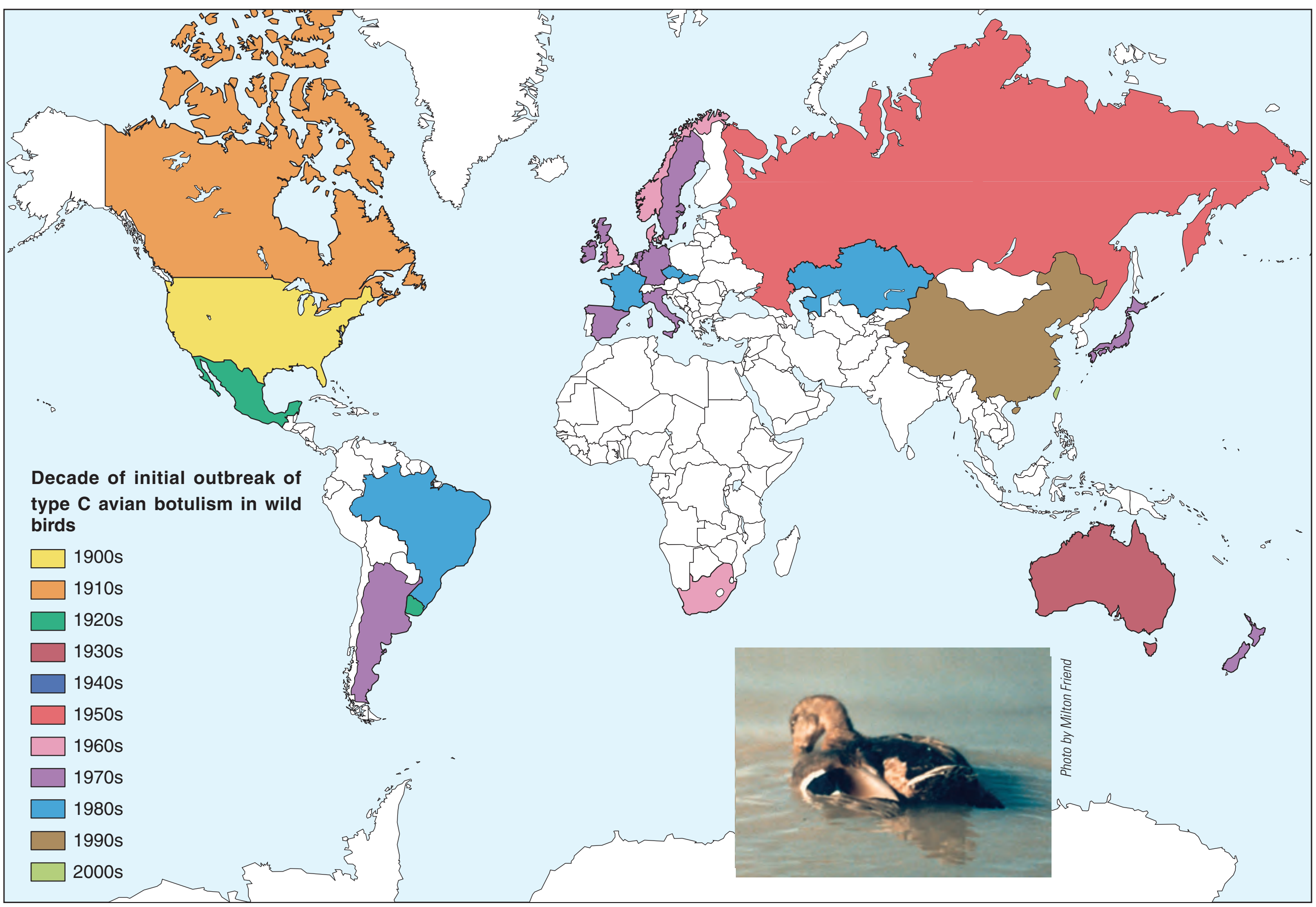


Figure 2.2 Countries where type C avian botulism has occurred in wild birds (through 2003).

Box 2–2 Humans and Disease: From Despair to Optimism and a Return to Reality

Illustration by John M. Evans

The historic impacts of infectious disease on human society are incomprehensible for most individuals living in the developed nations of the world. Epidemics of early times reflect a world that illustrates the German term Durchsevchung, which means thorough saturation of a population with infection.[291] About 25 percent of the entire population of Europe was destroyed by the first waves of plague (*Yersinia pestis*) that swept through that continent. It is estimated that nearly 70 percent of the population was affected by the epidemic that began in 1348, with most infected individuals dying. Very few of those infected by another epidemic in 1361 survived, but only about 50 percent of the population was affected. In the Americas, one infected individual who came ashore from the ship of an expedition introduced smallpox into native populations, resulting in a death toll of over 3 million. Epidemics from diseases such as plague, smallpox, measles, typhoid fever, and typhus were common events associated with global developments of earlier times and took a high toll on human life throughout the world.[289]

Modern medicine and its associated technology, along with greater understanding of the ecology of infectious disease, has helped to combat many of the diseases that have had the greatest impacts on human health. Impressive accomplishments in reducing human cases of deadly and debilitating infectious diseases created hope and optimism that became translated into optimistic public statements by notable individuals. Especially noteworthy is the statement by medical historian Henry Sigerist[35] (p. 26) and those below by Nobel laureate Dr. Frank MacFarlane Burnet, and Dr. William Stewart, former U.S. Surgeon General of the USA.

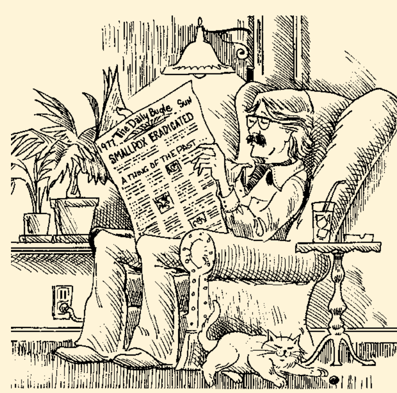


Illustration by John M. Evans

Time period

1 AD
- Plague
- Smallpox

1000
- Typhus

1500
- Yellow fever
- Measles

1700
- Yellow fever
- Flu

1800
- Cholera
- Smallpox

1900
- Plague
- Flu

1925
- Typhus

1950
- Dengue fever

1975 to today
- Lyme disease
- Legionnaire's disease
- HIV
- Ebola
- "Mad Cow"
- West Nile virus
- SARS

"One can think of the middle of the 20th century as the end of one of the most important social revolutions in history, the virtual elimination of the infectious disease as a significant factor in social life."(Burnet)[344]

"…it is time to 'close the book on infectious diseases.'" (Stewart)[345]

"During the last 150 years the Western world has virtually eliminated death due to infectious disease."(Stewart, 1975, cited by Cairns)[346]

Similar statements were made by numerous other learned individuals of those times. These statements reflect general beliefs at the time they were made and a growing need to address a variety of disease conditions that, for the most part, do not involve infectious pathogens (e.g., heart disease and most cancers).

The resulting redirection from infectious disease to other human health issues has caused us to relearn two important lessons of history noted by Zinsser:[291]

- "Infectious disease is one of the greatest tragedies of living things—the struggle for existence between different forms of life…Incessantly, the pitiless war goes on, without quarter or armistice—a nationalism of species against species."

Consider for example that World Health Organization figures for 1990 indicate human annual deaths from acute respiratory infections of 4.3 million, diarrheal diseases due to bacterial or viral infections of 3.2 million, 3 million deaths from tuberculosis, and millions of additional deaths from a variety of other infectious diseases.

- "Swords and lances, arrows, machine guns, and even high explosives have had far less power over the fates of the nations than the typhus louse, the plague flea, and the yellow-fever mosquito."

During the Spanish-American War, typhoid fever was a major factor contributing to death from infection causing seven times the number of fatalities as battle wounds.[347] During the Civil War of the USA, infectious diseases, such as typhoid fever, malaria, smallpox, and diseases of dysentery and diarrhea killed three times as many soldiers as died from battle wounds.[289] Infectious disease has remained a formidable enemy in times of war and peace.

If these thoughts are viewed as simply reflections of the past, one should consider the reality of AIDS on the African continent; the 50–100 million annual cases of dengue fever, many of which occur in the Americas; preparation being undertaken to protect humans against the potential reappearance of smallpox; and the 2003 pandemic of severe acute respiratory syndrome (SARS)[338] that exemplifies:

"Mother Nature is by far the worst bioterrorist out there." (Marjorie Pollack)[338]

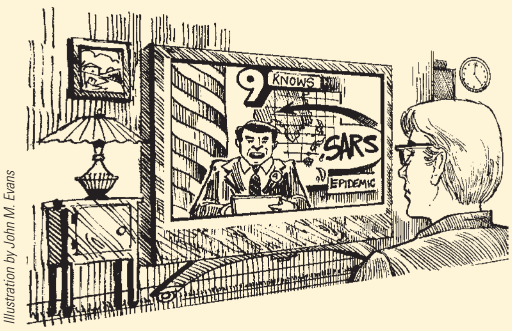
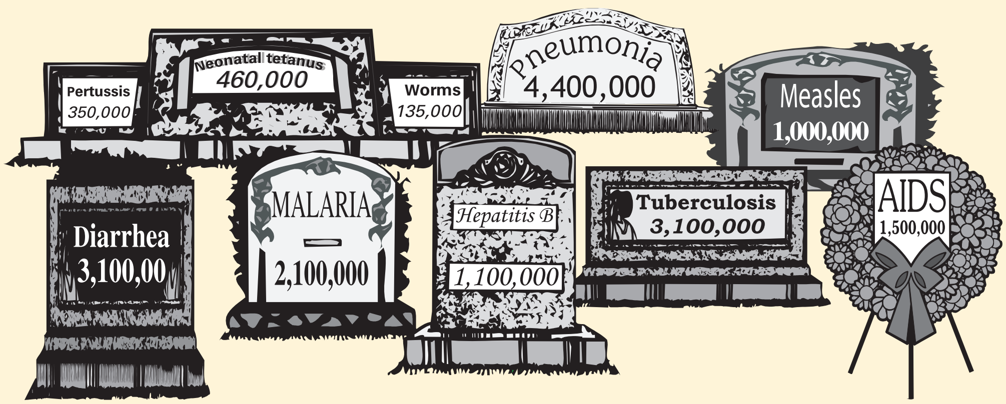


Illustration by John M. Evans



Mortalities from the 10 most infectious global diseases (Johns Hopkins University).

the genus *Salmonella* cause the disease salmonellosis. That genus contains more than 2,300 variants (serotypes) of *Salmonella* spp. and each **serotype** causing disease could be individually enumerated. Alternatively, salmonellosis might be considered a single disease, or different forms of the disease might each be enumerated separately. Therefore, one evaluation places the number of zoonoses among infectious diseases to be between 100 to 3,000 depending on the methods for enumeration. The lower figure is about 59 percent of the diseases listed in a particular book on communicable diseases in humans.[45] Another evaluation identifies 1,415 species of infectious agents as having been reported as causes of disease in humans. Of those, 61 percent are known to be zoonotic.[46]

On a percentage basis, diseases of bacterial or **rickettsial** origin are the predominant types of infectious diseases. Zoonoses are most commonly caused by helminthes (parasitic worms) and bacterial or rickettsial disease agents. However, helminthes are by far the group of pathogens most associated with zoonoses. About 95 percent of helminth species pathogenic to humans are known to be zoonotic compared with 50 percent of bacteria and rickettsia (Fig. 2.3).

Zoonoses and Disease Emergence

Zoonoses are a prominent aspect of disease emergence. Over the past decade more than two-thirds of emerging diseases have animal origins,[47] an outcome that results in emerging zoonotic diseases being among the most important public health threats today.[48] Human exposure to zoonoses is not restricted to direct interface between humans and nature (Table 2.2). The emergence of numerous foodborne diseases is particularly noteworthy. Increased globalization of food supplies and "novel dining experiences" associated with human travel are presenting new opportunities for pathogens to encounter naive hosts. The associated costs to society from emerging diseases go beyond illness and death by altering our way of life and causing major economic burdens (Box 2–3).

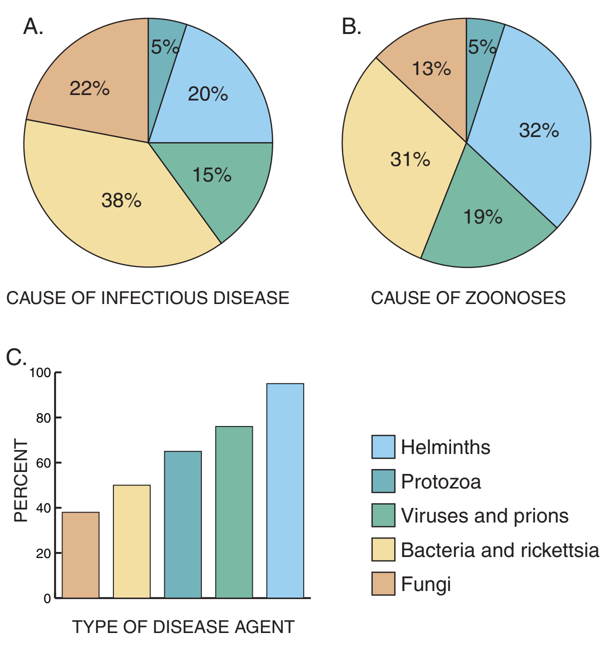


Figure 2.3 (A) The percentage of infectious diseases caused by different classes of disease agents, (B) the percentage of agents within those classes causing zoonoses, and (C) the percentage of infectious agents known to be pathogenic for humans that are also zoonoses. (Adapted from data from Taylor et al.[46])

Many of the zoonoses affecting humans are of wildlife origin or wildlife have a role in their maintenance, transmission, and/or geographic spread. A recent analysis of the probability of known infectious agents becoming emerging diseases of humans disclosed that those agents infecting wildlife were twice as likely to become emerging diseases as those without wildlife hosts,[49] which suggests that wildlife are an important aspect of the resurgence of infectious disease in humans. Therefore, it is noteworthy that disease emergence in humans has been accompanied by disease emergence and geographic spread in free-ranging wildlife populations. **Companion animals**, primarily cats and dogs that come into contact with infected wildlife, can provide a "bridge" for transporting zoonoses of wildlife into households, veterinary clinics, boarding kennels, and animal shelters. Disease transmission to humans from companion animals often involves mechanical processes (i.e., contaminated mouth parts) and transfer of infected arthropod vectors (i.e., ticks) rather than infections acquired from a clinically ill dog or **cat**.

The current magnitude of disease emergence in wildlife populations is unprecedented and appears to have begun about a decade earlier than that for humans. In general, wildlife have a greater intimacy with the environment than humans and that intimacy may provide enhanced sensitivity to environmental changes that are important indices for disease emergence. Therefore, disease surveillance in free-ranging wildlife populations may provide an early warning system.[50] This concept has been selectively applied for monitoring arboviruses, influenza, and some other diseases. For example, virus activity in birds has been the most sensitive index for the presence of West Nile virus. A greater focus on monitoring wildlife diseases may be especially valuable for protecting human health in natural areas with expanded human presence and for protecting economic interests associated with the domestic animal industry.

Wildlife and Zoonoses

Contact with wildlife, including animals being handled, animal bites, and the consumption of animals, all provide opportunities for the direct transmission of zoonoses. However, wildlife often have other roles in the ecology of diseases affecting humans (Box 2–4). Especially noteworthy are the ability of infectious disease agents to cross species

Table 2.2. Common routes for human exposure to zoonoses.

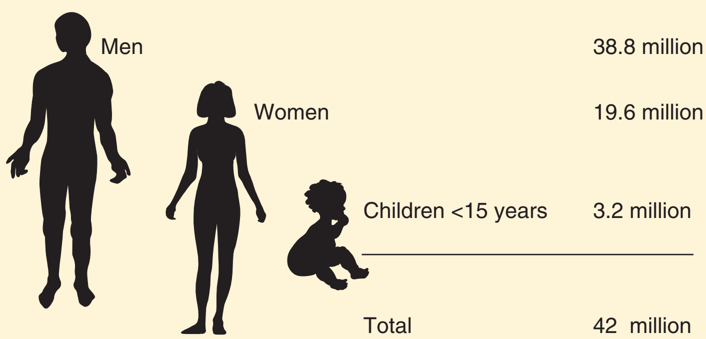
Type of exposure	Activity examples	Wildlife and zoonoses examples
Direct contact with infected animals	• Handling infected organs and tissues when processing carcasses for consumption	Rabbits, muskrats, and tularemia
	• Handling infected live animals for biological, clinical, and other purposes	Migratory birds and chlamydiosis
	• Processing carcasses for scientific study	Staphylococcal and *Erysipelothrix* infections from deer and migratory birds
	• Bite by infected animal	Carnivores, bats, and rabies
Consumption of infected animal meat and other products	• Preparation of smoked fish at temperatures too low to destroy potential pathogens	Salmonids, whitefish, and type E botulism
	• Preparation of game sausage contaminated with parasites	Cougar jerky and trichinosis
	• Inadequate cooking of infected meat	Deer and *Escherichia coli*
	• Raw consumption of parasite-laden foods	Cod and cod worm
Bites by infected or contaminated vectors	• Outdoor activities that provide exposure to ticks, mosquitoes, and other arthropods	Birds and West Nile fever
Contact with contaminated environments	• Skin contact in infested environments	Waterfowl, rodents, snails, and swimmers itch
	• Aerosol exposure caused by disturbing soils and other substrates heavily laden with infectious agents	Insectivorous bats, blackbirds, and, histoplasmosis
Ingestion of contaminated water	• Drinking untreated water from naturally flowing surface waters and lakes	Aquatic rodents and giardiasis
Companion animal bridge	• Contact with pets that have consumed diseased wildlife	Cats, prairie dogs, and plague
	• Bites from infected ticks that transfer from wildlife to pets and their humans	Cats, rodents, and tularemia

Box 2–3

Social Impacts of Emerging Infectious Disease

The definition of disease in medical dictionaries spans many pages to provide succinct generalizations of disease conditions from A (i.e., Acosta's disease or acute mountain sickness) to Z (i.e., zymotic disease or a disease due to the action of an enzyme…).[349] In contrast, the definition of disease in a standard dictionary, while still focusing on impacts on organism form and function, is brief and includes an added dimension, "…a harmful development (as in a social institution)."[350] Disease affects our economy, behavior, and governmental regulations. Thus, emerging infectious diseases often have impacts that extend far beyond the clinical manifestations of specific diseases on individuals, the economic costs for diagnosis and treatment, and those collective costs on individuals, families, and populations. AIDS is but one of many examples.

Number of people living with HIV/AIDS in 2002



The emergence of AIDS has been accompanied by social stigma for individuals testing positive for HIV, regardless of whether or not they have clinical disease. Various forms of discrimination have appeared in the work place and in other components of society as a response to beliefs, perspectives, and fear of AIDS. A variety of regulatory and procedural changes have been implemented that impact health-care providers, blood banks, and education processes. Other adjustments in human behavior, our activities, and our way of life have also resulted from the emergence of this disease. Clearly, the burden of AIDS extends far beyond the pathogenesis of the causative virus. Similar broad-based responses are often associated with wildlife species that harbor diseases of concern.

Chronic Wasting Disease

Deer hunting is a traditional activity for millions of Americans and in many rural areas it remains an important social activity with significant economic ramifications for communities. This activity also has significance for wildlife management agencies. For example:

- In 1996, hunters spent $897 million within Wisconsin in pursuit of their hunting activities. Those expenditures support a great deal of employment and provide a foundation for wildlife programs such as land acquisition and management, wildlife education, and research.[351]
- During recent years, more than 600,000 Wisconsin deer hunters have been spending nearly $500 million annually in pursuit of their sport.[352]
- Deer hunting licenses in Wisconsin contribute $21 million, or about one-third of the Wisconsin wildlife management budget.[353]

As with AIDS, public perceptions and fear about chronic wasting disease (CWD) are causing major adjustments in human behaviors, regulatory processes, agency and scientific priorities, and resource allocations. The general basis for human concern about CWD lies in the causative agent being a prion, the same type of agent responsible for bovine spongiform encephalopathy (BSE) or "mad cow disease." Transformation of that agent has resulted in a

Photo by Christina Sigurdson

variant Creutzfeldt-Jakob agent that has caused approximately 100 human fatalities.[354] Public concern is that a similar variant may evolve from prions associated with CWD. Agriculture agencies also are concerned because several captive elk and deer herds associated with game ranching and commerce have been infected by CWD. Another concern is that a high prevalence of CWD in wild cervids may enhance the potential for a variant to evolve and infect livestock.

Because of CWD's negative impacts on deer and elk health and survival, and the social and economic importance of these species, wildlife conservation interests also are involved. The focus for wildlife agencies is eradication of CWD where possible and preventing its spread to other states where this disease does not already exist. The result of these concerns is an unprecedented effort focused on combating a disease affecting free-ranging wildlife.

- A multiagency plan involving the collaboration of 9 federal agencies, 14 state agencies, 4 universities, the International Association of Fish and Wildlife Agencies, and others was developed to guide a coordinated effort to combat CWD.[348]

- CWD has been present in Colorado for several decades and recently the Colorado Division of Wildlife completed a 5-year Strategic Plan that establishes disease management and elimination as one of its highest priorities.[355]

Fiscal support for many state wildlife agencies is highly dependent upon license sales. Concern about consuming deer meat reduced Wisconsin deer license sales, which negatively impacts fiscal resources for carrying out deer and other wildlife conservation responsibilities. During 2001, the Wisconsin Department of Natural Resources sold over 688,000 licenses to hunt deer. Survey results indicated a 10 to 20 percent reduction during 2002.[352,353] This relatively small percentage reduction results in a substantial loss of revenue and is compounded by the costs to combat CWD.

The 2002 appearance of CWD in white-tailed deer in Wisconsin has been costly. The resources required to combat CWD, even with supplemental funding, burdens agency capabilities by redirecting funds and agency staff, thereby, compromising the ability to address other needs.

- An intensive surveillance and testing program was implemented to determine the geographic distribution of CWD in Wisconsin. Hunter participation is a major component of these types of programs and the testing provides hunters with evaluations of the deer they harvest.

- Construction of a state facility was required to process the estimated 40,000 Wisconsin deer heads for sample extraction during 2002. Also, many people were needed to collect the deer heads in the field, to process them for sample extraction, and to do laboratory evaluations.

There also are general community costs associated with CWD. For example:

- The projected net loss to Wisconsin's economy as a whole from reduced spending by nonresident deer hunters alone was estimated to be approximately $5 million to $10 million for 2002.[352]

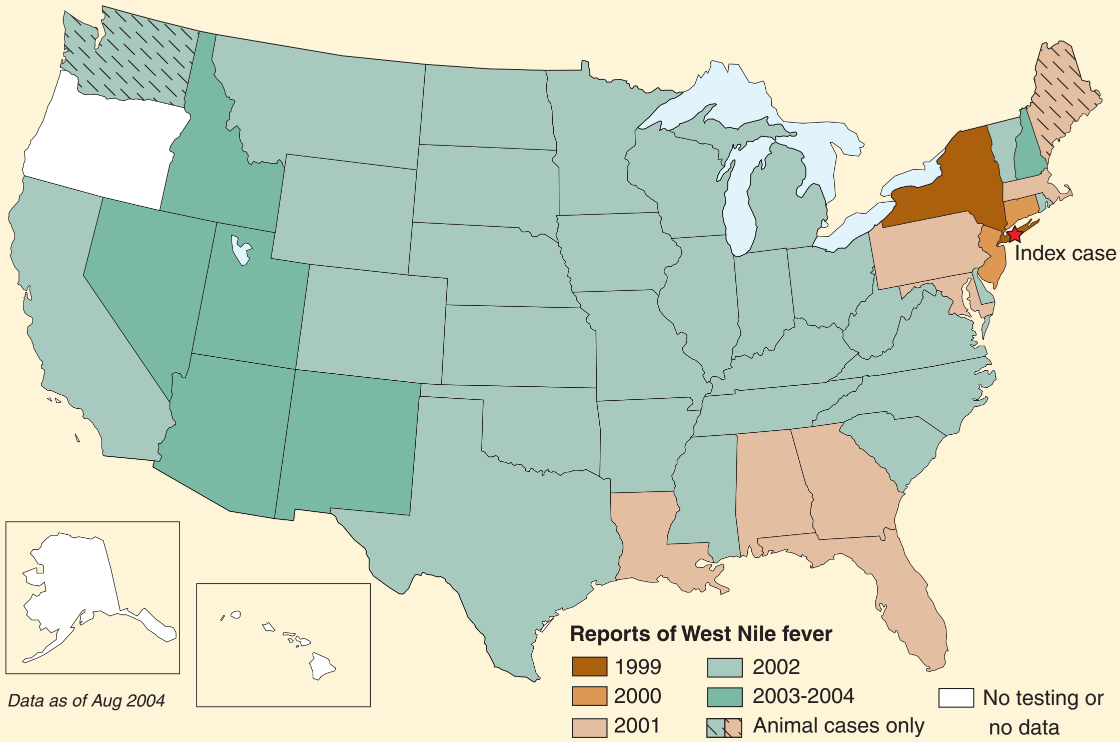
Photo by Milton Friend

- A variety of regulations promulgated in response to CWD and the processes for their enforcement impose still other costs, including adjustments in human activities. Those regulations establish inter- and intrastate conditions for the movement of live elk and deer, their carcasses, and components of those animals that have been harvested by hunters and commercial activities.[351,354–357]

- CWD in North America has resulted in the suspension by South Korea and Japan of the importation of deer, elk, and their products from the United States and Canada.[356]

- Indemnity payments are provided by the United States Department of Agriculture (USDA) for the voluntary depopulation of captive **cervid** herds within the United States that are infected with CWD.[356]

- Small business operations such as taxidermists, processors of elk and deer, and a variety of other services provided to deer hunters also are negatively impacted, as are deer and elk farms found to be positive for CWD.



Impacts from CWD are most notable in rural areas where deer hunting is a popular activity and are felt by those communities in many ways.

- Motels, restaurants, gas stations, and a number of other local businesses in rural areas are quite dependent upon deer hunting to bring business to their community during deer season.
- The revenue for a small, rural Wisconsin feed store in an area removed from the CWD focal area fell by tens of thousands of dollars due to the 2002 statewide ban on deer feeding, one of the disease-control actions initiated. A large business operation projected a reduction of $300,000 in revenue due to that ban.[353]
- A small business that sells archery equipment suffered a reduction of more than 50 percent of normal sales because of reduced deer-hunting activity.[353]

Clearly, the economic impacts in Wisconsin associated with CWD have substantial ramifications. Impacts of this disease outbreak on agencies and local communities are striking, especially considering the absence of a single documented human or livestock case of disease attributed to CWD during the more than two decades that this disease has been present in limited areas of the Western United States.

West Nile Fever

The 1999 appearance in North America of West Nile fever (WNF) is another vivid example of human impacts associated with disease emergence in wildlife. Unlike CWD, WNF is clearly a zoonosis. Its appearance was first detected because of a cluster of human cases, including several deaths, in the New York City area. The human cases occurred along with a cluster of bird deaths, primarily **crows**. Since 1999, this disease has spread across the USA and into Canada. The host range for WNF includes horses as well as other domestic animals, a broad array of wildlife species (primarily birds), and humans. Thus, like CWD, attempts to combat WNF have an interagency orientation and are multifaceted.

- Shortly after the diagnosis of WNF in New York City, the Centers for Disease Control and Prevention (CDC) and the USDA cosponsored a workshop and developed guidelines for disease

Photo from USGS files

Photo by Milton Friend

surveillance, prevention, and control. Experts from federal, state, and city agencies joined members of the academic community and the private sector in that undertaking.[358]

- National guidelines developed for the control of West Nile virus (WNV) place a high priority on monitoring for the virus and providing guidance for the timing of that activity based on geographic regions in the USA.[358]

- Training workshops, protocols for diagnostic and surveillance activities, and data management are some of the integrated efforts established to combat WNV.

Many agencies are incurring substantial costs for the surveillance and testing programs needed for guiding actions to protect human health. In addition, because of the risks to human health, mosquito abatement activities have increased, as well as the level of protective measures required for processing wildlife in disease diagnostic laboratories.

- In early December 2000, the CDC provided 16 States and local health departments along the East Coast of the USA with $2.5 million to enhance their surveillance for WNV and to develop local measures to prevent outbreaks. Pennsylvania anticipated it would spend $9.8 million in addition to CDC funds to develop internal mosquito-control and surveillance plans.[360]

- During the spring of 2001, New York received a $3.9 million grant from CDC to combat WNV, in addition to the $21.9 million for local virus control activities proposed by the Governor in the State budget to cover 2000–2001 costs.[359]

- During 2000 and 2001, the CDC provided more than $58 million to State or local health departments to develop or enhance epidemiologic and laboratory capacity for WNV and other mosquito-borne diseases. In fiscal year, 2002, approximately $35 million in federal funds were awarded by the CDC to these agencies to address the continued spread of the virus.[361]

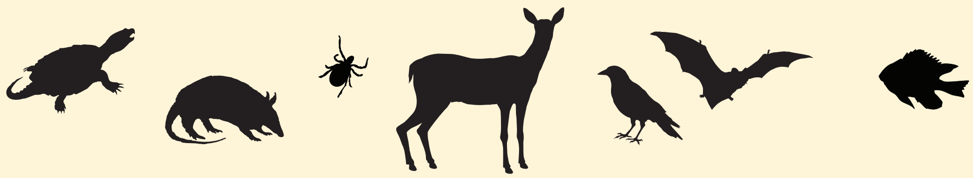
- Other societal costs include major investments in research on disease ecology and evaluation of vaccination as a means for combating WNF.

WNF also has ramifications for wildlife conservation and education programs. Many thousands of birds have died from this disease. Also, the specter of WNF looms as an ominous shadow over wildlife rehabilitation. The rehabilitation of sick and injured wildlife is a popular activity and one that is primarily carried out by the private sector rather than by government agencies. Thousands of individuals participate, the majority as volunteers that have very limited training and knowledge of animal diseases. In general, the facilities where these activities are conducted are inadequate for the containment of WNF in the event of an outbreak. Also, protective measures for people are seldom adequate to prevent disease exposure in the event infectious disease is brought into the facility. The emergence of WNF calls for additional knowledge of disease risks within wildlife rehabilitation programs and adjustments in how rehabilitation programs are conducted. WNF has also struck zoos, causing many bird deaths, and threatens captive breeding programs that enhance the populations of endangered avian species.

CWD and WNF are but two of the multitude of emerging and reemerging infectious diseases confronting society. Human activities and behavior are major factors contributing to disease emergence. Hopefully, greater appreciation of the effects of these diseases on our way of life and things that we value will result in behavior that reduces the spread of pathogenic microorganisms.

Box 2–4

Wildlife and Zoonoses: Different Roles for Different Diseases



Wildlife may contribute to zoonoses in ways other than direct transmission between wildlife and humans. For influenza, the greatest wildlife contribution is the transfer of genetic material between influenza viruses that leads to disease emergence in humans, not direct contact between humans and wildlife. For some diseases, such as Lyme disease and ehrlichiosis, the major role for wildlife is disease maintenance in nature; for other diseases such as giardiasis, the primary role is environmental contamination by wildlife (e.g., shedding infectious agents into surface waters) leading to human infections. Birds infected with West Nile virus serve as a source for infection of mosquitoes that then infect humans, and the disease spreads through the movements of infected birds. The following examples highlight some of the major roles wildlife have in the ecology of zoonoses, besides direct contact transmission of the disease.

Tick Production

Lyme disease is typically contracted from the bite of infected ticks and not from contact with wildlife that may harbor the causative spirochete bacterium. Tick populations are dependent upon having adequate numbers of hosts to feed on as their growth and reproduction requires blood meals to provide the necessary nourishment. Typically, when larvae emerge from the egg, they feed on small rodents, such as mice; nymphs and adults feed on larger mammals. Thus, mice and white-tailed deer are the species that contribute to the maintenance of tick populations, and through that contribution, to the transmission of Lyme disease.

Photo by Milton Friend

Gene Pool Contributions

Migratory birds, especially shorebirds, are an important source of influenza viruses but rarely suffer clinical illness or mortality from those viruses. However, recombination is a characteristic of influenza viruses, and involves the transfer of genetic material between different influenza viruses to produce new virus strains. These exchanges involve mammals, especially swine, as well as birds and are the source of virus variants that are lethal for poultry and other variants that cause disease in humans.

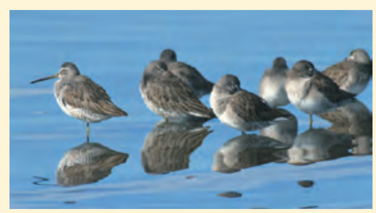


Photo by Milton Friend

Developmental Hosts

Many metazoan parasites require one or more wildlife hosts for the parasite to become pathogenic for humans. For example, wildlife species such as red foxes and coyotes are definitive hosts for the tapeworm *Echinococcus multilocularis*, the cause of hydatid disease; they are essential components of the disease cycle. Infected wild carnivores imported into areas where this parasite is not yet established pose a significant threat to human health by introducing the parasite into the wildlife populations of the new area.

Photo by Milton Friend

Photo by Elizabeth Ciganovich

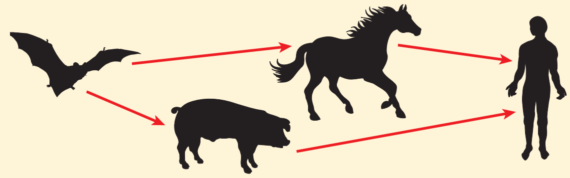
Environmental Contamination

Giardiasis is a common waterborne disease of humans. Cysts of the protozoan parasite that cause this disease are shed in the feces of infected animals, such as beaver, and are immediately infective. Surface waters become contaminated in this manner and unless adequately treated, become a source for human infections.

Amplification Hosts

The ability of arthropods to become infected (biological transmission) or for their mouth parts and excretions to be contaminated at levels sufficient for mechanical disease transmission is a function of the number of organisms present in the blood meal taken by the arthropod. The rapid spread of West Nile fever in North America has been facilitated by the high level of viremia in infected crows and some other bird species. Mosquitoes feeding on these birds become infected and continue the transmission cycle when they take their next blood meal from another susceptible host.

USGS file photo



Interspecies Transfers

Wildlife often harbor microbes and parasites that are not pathogens for them, but become disease agents for other species that interface with those wildlife or environments contaminated by them. Human infections occur as a result of contact with other species, not with the wildlife host. Among numerous examples are the recent emergence of Nipah and Hendra virus infections. Both involve domestic animals as the source of human infections and fruit bats as the wildlife reservoir hosts.[48]

Photo by Milton Friend

Spread of Infection

The movement patterns of wild birds have long been associated with the spread of infectious disease, including zoonoses.[362–367] Arthropod vectors often are “hitchhikers” that transfer to new environments and geographic areas during bird and other wildlife movements. These arthropods may provide means for transmission of indigenous pathogens or they may be infected with diseases new for the environments they enter. Infected wildlife also may serve as a source for infection of local arthropod populations as occurs for mosquitoes and West Nile fever. Earlier studies have suggested that infected migrating birds are the source for repeated West Nile virus (WNV) introductions in the central highlands of South Africa. Also, experimental studies and isolations from nature indicate that WNV can adapt to ticks and may be transferred by tick bite.[363]

barriers. Recent examples include HIV-1 and HIV-2, Hendra and Nipah viruses, *Streptococcus iniae*,[51] and other disease agents, suggesting that this ability may be more important than was recognized previously.[48] Also, the natural movements of wild birds can contribute to zoonoses by introducing arthropod vectors, by transporting disease agents, and by other means.[52–55] This multiplicity of roles is interactive with environmental conditions. Therefore, the dynamics of environmental disruptions and change can greatly influence the role of wildlife in the ecology of zoonoses.

Disease Emergence in Wildlife

> **"Pathogens that infect wildlife are twice as likely to become emerging diseases of humans as pathogens without wildlife hosts" (Cleaveland et al.).[49]**

More noteworthy disease events have affected free-ranging wildlife during the 20th century than have been collectively reported previously. Currently, infectious disease has become established as a prominent cause of mortality for wild birds, some **enzootic** diseases have increased in frequency of occurrence and geographic distribution, and rare or previously unreported diseases have taken a large toll on wildlife. The large number of avian mass mortality events in the USA and Canada stands as testimony to the toll of wildlife affected by disease (Fig. 2.4). Large numbers of other types of wildlife from amphibians to fishes to **mammals** are also victims of disease. Not all of these diseases are zoonoses, but in many instances there is no clear distinction between zoonoses and diseases that are not,[56] because host susceptibility is mediated by a number of factors.[52] Impairment of the immune system, such as from HIV infections, poor nutrition, and other means, can result in disease from organisms generally of low virulence for humans.[57–59] Tuberculosis due to human infection with avian strains of *Mycobacteria* in AIDS cases is an example.[60]

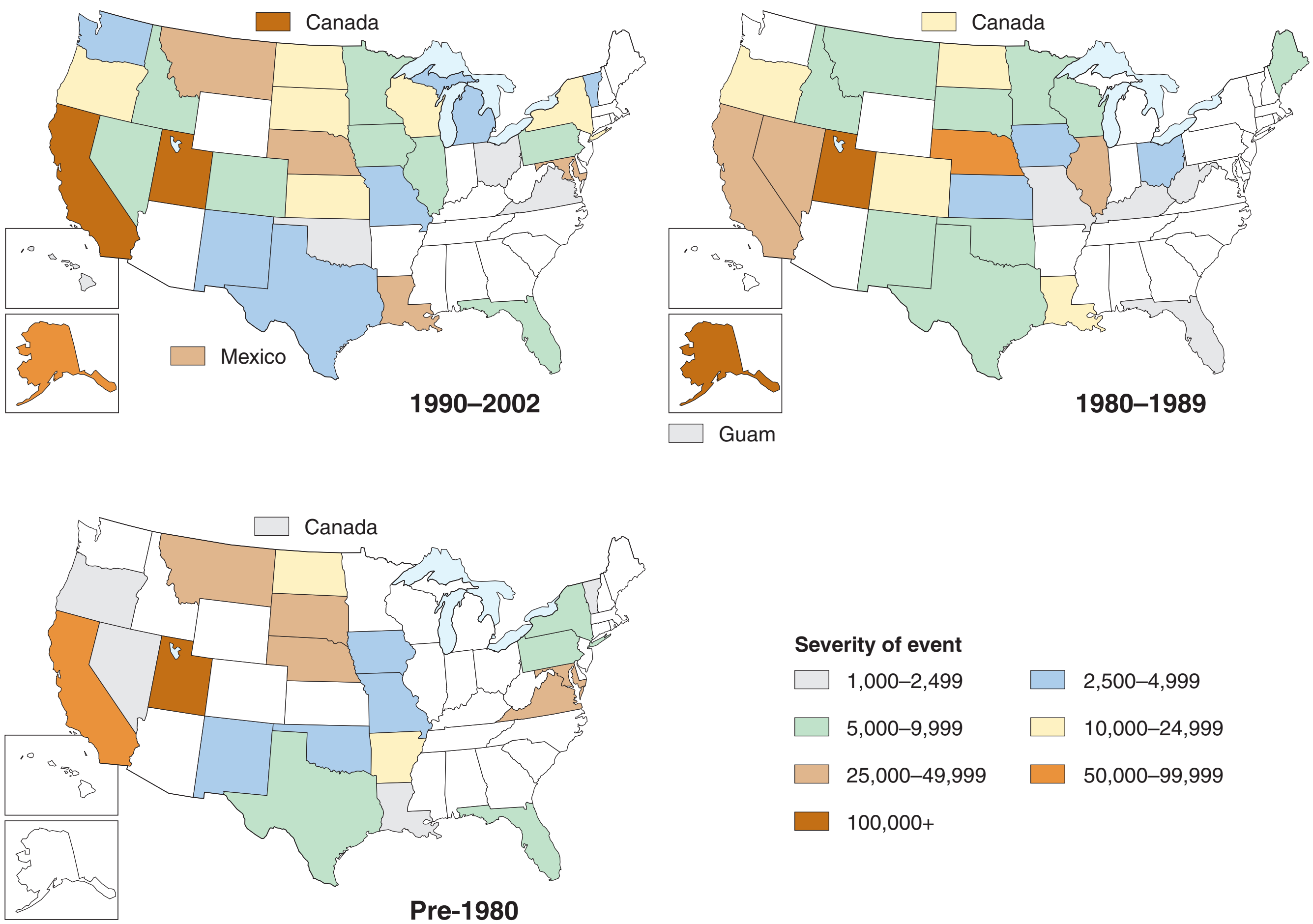


Figure 2.4 Avian mass-mortality events within different time periods in the United States.

Marine Environment

> **"Of the natural factors that influence abundance of marine organisms, few are more spectacular or less understood than disease" (Sinderman).[61]**

Human actions are increasingly challenging the oceans' capabilities to sustain the abundance and diversity of life. Introductions of nonindigenous pathogens and other aquatic organisms from discharges from land, ballast water, and other means are altering ocean ecosystems, degrading the quality of the marine environment, and contributing to disease emergence in a wide variety of nearshore and offshore marine species (Fig. 2.5). Human health and well-being also are jeopardized by disease emergence and reemergence in those species as a result of:

- Consumption of **finfish** and **shellfish** contaminated by biological toxins (e.g., "red tides"), toxic chemicals, and microorganisms;
- Reductions of fish stocks by disease, placing further stress on already overharvested fish populations that are important as a source of food for many people;
- Increased risk for exposure to pathogens when swimming in contaminated waters;
- Direct exposure to "red tides" causing serious illness; and
- Economic impacts associated with contamination of beaches, shellfish beds, and finfish.[62]

The frequency of infectious disease events in marine ecosystems and the broad spectrum of marine species affected are unprecedented and have far-reaching implications for the integrity of those ecological systems and the biological services they provide. Therefore, it is not surprising that disease emergence in the marine environment was the focus for two international meetings in 1999 in which direct linkage between human disease and the marine environment were explored.[63] The contributions of the marine environment to the maintenance and spread of cholera was one of the topics considered (Box 2–5).[335]

Plant Communities

Seagrass beds, such as eelgrass and turtlegrass, that serve as important habitat for a variety of **waterfowl**, **shrimp**,

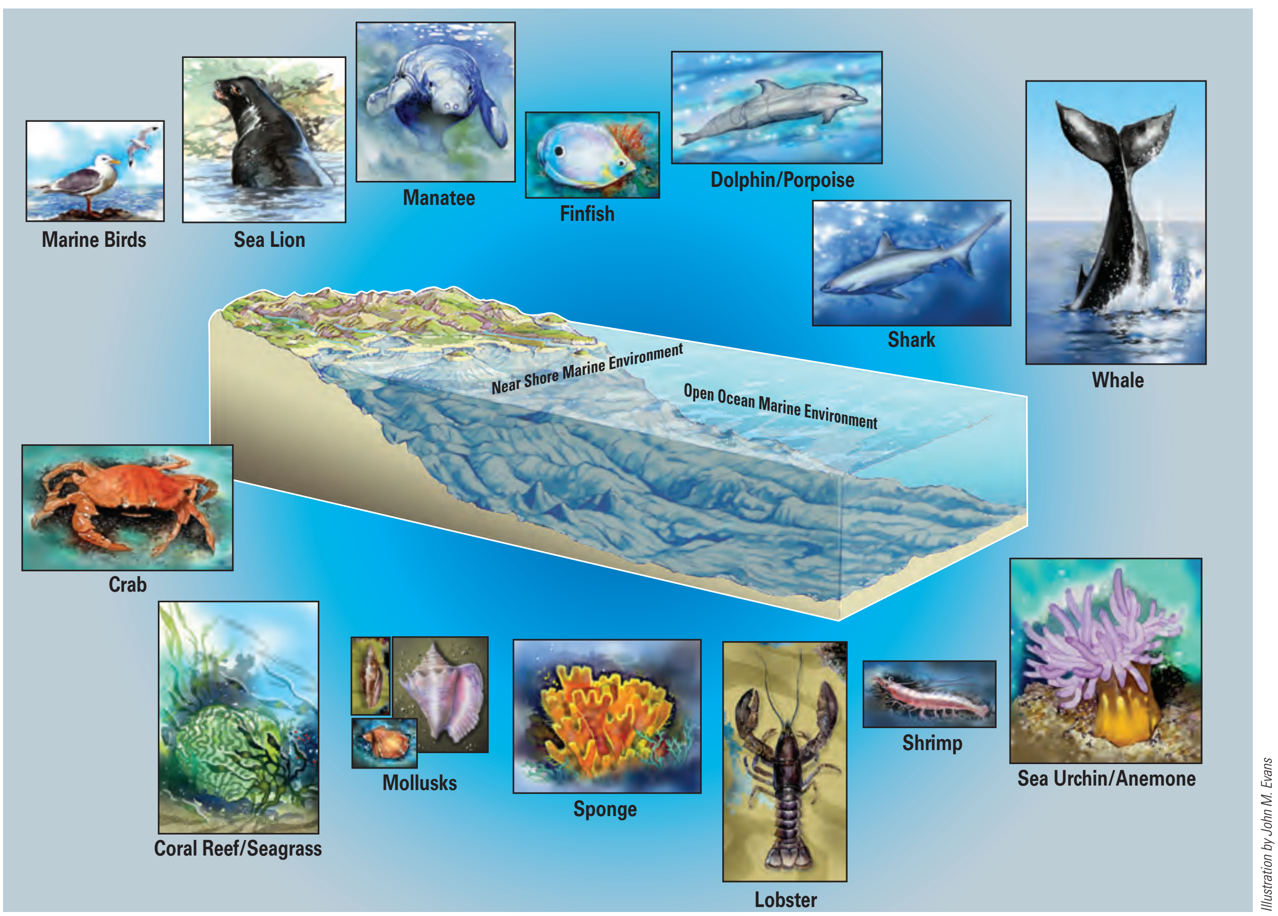


Figure 2.5 Examples of species affected by disease emergence in the marine environment.

Box 2–5

Cholera and the Marine Environment

Illustration by John M. Evans

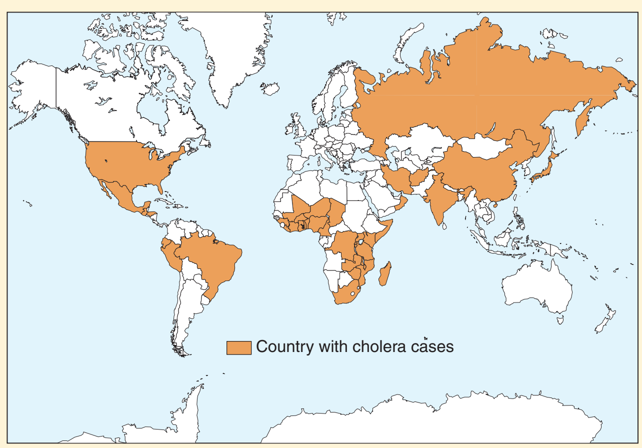
Cholera (*Vibrio cholerae*) is an ancient "voyager" whose capacity to result in pandemic spread has left many footnotes to the story of civilization.[289,291] Despite great advances in the control of many infectious diseases, cholera remains as an epidemic disease claiming hundreds of thousands of lives each year. The seventh pandemic is ongoing and includes noteworthy epidemics that began in 1991 in India, Bangladesh, and the Americas.[368]

The continuing challenges posed by cholera, one of the most feared infectious diseases of humans, are integrally linked to marine environments.[369]

- "Historically, most of the major epidemics or outbreaks of cholera around the world have originated in coastal regions…There is compelling evidence that *V. cholerae* always is present in the aquatic environment and proliferates under non-epidemic conditions while still attached to, or associated with eucaryotic organisms…**Zooplankton** play a significant role as a reservoir of *V. cholerae* in the environment."[369]
- Cholera eruptions appear to be stimulated by global changes taking place, including ecosystem alterations resulting from human actions.[369]
- Cholera was reintroduced into South and Central America during 1991–92 following over more than 100 years of absence.[370] By the end of August 1992 more than 600,000 cases and 5,000 deaths were reported from 20 countries.[371] From January 1, 1991 to September 1, 1994, more than 1 million cases, including 158 cases in the USA, and nearly 10,000 deaths occurred in 21 countries in the Western Hemisphere.[372]
- Since 1991, approximately 120 countries worldwide have reported indigenous cases of cholera and in nearly half of them cholera has been a recurring problem.[369]

The marine environment is the natural habitat of *V. cholerae*; crustaceans and copepods are natural hosts for sustaining this organism. Linear correlation exists between the growth of *V. cholerae* and increased sea-surface temperature. Plankton blooms are dependent on warm ocean temperature. Cases of cholera are correlated with the response of phytoplankton to increased temperature and the subsequent appearance of the zooplankton blooms that harbor the cholera organisms. Other factors also are involved but the relations just noted illustrate the importance of the marine environment for sustaining *V. cholerae*.[368]

The occurrence of the cholera bacterium in coastal waters of the USA has been well documented. However, despite the environmental presence of *V. cholerae* there is a paucity of cholera cases obtained from these waters because of the advanced sanitation practices and facilities that prevent the secondary spread of *V. cholerae* through drinking-water contamination.[373] While these safeguards have served the people of the USA well, it is sobering to recognize that *V. cholerae* is present in our coastal waters, patiently waiting for an opportunity to mount a successful invasion. It is also sobering to recognize that modern technology does not provide an invincible shield against waterborne diseases such as cholera. The 1993 invasion of cryptosporidiosis that resulted in 403,000 infections via the drinking water for Milwaukee, Wisconsin[336] should be considered a "wake-up call."



Adapted from the World Health Organization

scallops, fish, and other aquatic species have been severely degraded in many areas and essentially eliminated in some. Many factors are involved, including the fungal pathogen, *Labyrinthula zosterae*. This marine slime mold is responsible for "seagrass wasting disease" along the Atlantic coast of the USA. Outbreaks of this disease off the coast of New England have most recently occurred during the 1980s and again in 1997. Mass mortality of turtlegrass in Florida Bay is also associated with *Labyrinthula*.[62]

Disease in **seagrass communities** is noted to illustrate the pervasive nature of infectious disease occurring within natural biological systems. Because **plant communities** are a fundamental building block for biological communities, disease impacts on plant species can have far-reaching ecological impacts. For example, the seagrass community of Florida Bay supports over 100 species of finfish and over 30 crustacean species, including both permanent residents and species that temporarily occupy this habitat as a major nursery.[64] Seagrasses not only provide habitat for many species but they also are an important part of the food web for some species. Nutritional degradation of food webs can negatively impact immunocompetency in animals just as poor nutrition affects immunocompetency in humans.

Seagrass wasting disease is not a new disease. In the 1930s, a similar disease of unknown etiology almost eliminated eelgrass in the North Atlantic. That disease decimated eelgrass beds along the Atlantic coast from North Carolina (USA) to Nova Scotia (Canada). However, healthy eelgrass populations were reestablished by the 1960s over most of the affected area. Reappearance of the same, or a similar disease, occurred in 1987[65] in eelgrass beds on the border of New Hampshire and Maine (USA) and that same year in turtlegrass beds of Florida Bay.[64] Seagrass epizootics that began in the 1930s and again in 1987 were not limited to the eastern seaboard of North America. Seagrass mortality during both time periods also occurred in Europe and along the Pacific coast of the USA.[65]

Coral Reef Communities

Coral reefs also sustain higher forms of life. Not only are coral reefs one of the world's most spectacular ecosystems, they also are a critical resource for millions of people and are inhabited by between one-half million and 2 million species, if not more.[66] Coral reefs are home to about 25 percent of all marine species[67] and recently have become a focus for investigations because of the emergence of diseases and other factors impacting reef viability. Disease has caused a dramatic loss of coral reef species and degradation of coral reefs in many areas of the world (Fig. 2.6). The magnitude of loss that has occurred is unprecedented in recent geologic history.[68]

During the late 1980s, white-band disease almost eliminated the dominant coral-space occupier in lagoonal reefs in Belize.[69] On a regional scale, white-band disease has probably been the most significant factor in reducing populations of elkhorn and staghorn corals. Elkhorn coral, previously one of the most important and most common species of coral in the Caribbean, is now rare. The abundance of corals in Jamaica declined from a mean of 52 percent coral reef habitat along the coastline from 1977 to 1980 to 3 percent from 1990 to 1993.[70,71]

The continuum of new diseases and reef species being affected (Box 2–6) suggests that the coral reef systems are badly stressed and that additional diseases will continue to emerge. For example, in 1997, "rapid-wasting disease" appeared as a new pathology affecting the massive *Montastraea* and *Colpophyllia* corals of Caribbean reefs. Coral reefs of Florida vividly illustrate that disease impacts are increasing relative to the number of species being affected and geographic distribution of diseased coral. A 1999 evaluation found 82 percent of all reef study locations were affected, which is a 404-percent increase over 1996 and that 85 percent of all reef corals were affected, a 218-percent increase over 1996.[63]

In addition to disease affecting hard corals, **soft corals** such as sea fans, along with **sponges** and **sea urchins** also have been affected by emerging diseases. The rapid spread since the 1980s by the variety of novel pathologies of reef organisms suggests that disease agents are entering naive populations that have little ability to reject their invasion.[72] The effects from these diseases threaten the viability of many reef systems. For example, a bright orange bacterial pathogen

Figure 2.6 Locations of of coral disease. (Compiled from Spalding and Green[66] and the World Conservation Coral Disease Monitoring Center—NOAA coral disease database.)

Box 2–6 Emerging Disease and Coral Reefs

Coral reefs throughout the world have been severely degraded during recent decades. Emerging diseases are a major factor in this degradation, primarily through the destruction of **scleractinian** stone-like corals that provide the basic framework for reefs. Initial reports of disease affecting reef-building corals appeared during the early 1970s and were viewed at that time as unique situations. Today, disease has been observed in more than 100 coral species (primarily **hard corals** but also some soft corals) on reefs in more than 50 countries.[66] The areas involved include popular diving locations such as the Caribbean islands, Fiji, the Red Sea, and the Great Barrier Reef of Australia. However, the prevalence and diversity of coral disease appears to be greatest in the tropical western Atlantic,[374] primarily within the Caribbean.[66] The number of distinct diseases being observed within this area, as well as globally, has increased substantially since the 1970s.

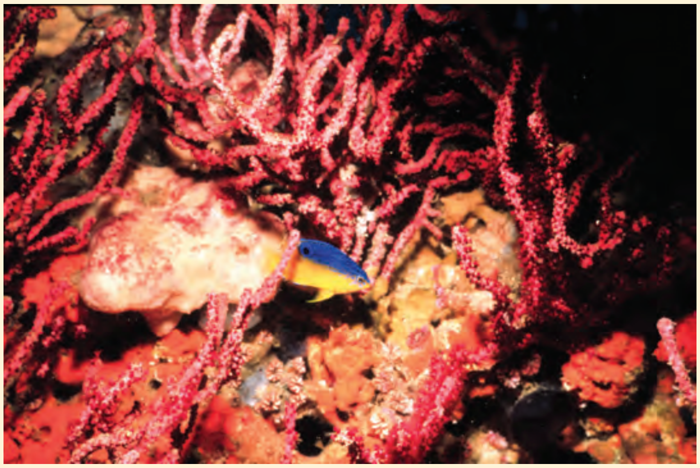


Photo courtesy of the National Oceanic and Atmospheric Administration

Coral reef and tropical fish off of the coast of North Carolina.

Disease of Scleractinian Corals

Black-Band Disease

Black-band was the first disease reported to affect scleractinian corals and was first described in 1973 from Belize. Subsequently, reports followed during the 1970s from reefs off Bermuda and the Florida Keys.[374] Black-band disease is now known to exist throughout the Caribbean, in reefs of the Indo-Pacific (Philippines, Fiji), the Red Sea, and the Great Barrier Reef.[374–376] Hard corals such as star coral, fire corals, and soft corals such as **gorgonians** (sea fans) are affected. **Acroporids** (branching corals) have been found infected on the Great Barrier Reef.[377] Significant mortality from black-band disease has occurred in at least 13 species of coral[378] and it is a major factor in the recent decline (1990s) of hard corals on reefs off Jamaica.[375]

Black-band disease is caused by a microbial mat consisting of a complex of organisms. The most dominant species are the cyanobacterium *Phormidium corallyticum* and bacterium of the genus *Beggiatoa*. Other species in the mat complex include numerous heterotrophic bacteria (organisms that derive energy from consumption or absorption of other organisms), marine fungi, and bacteria of the genus *Desulfovibrio*.[379,380]

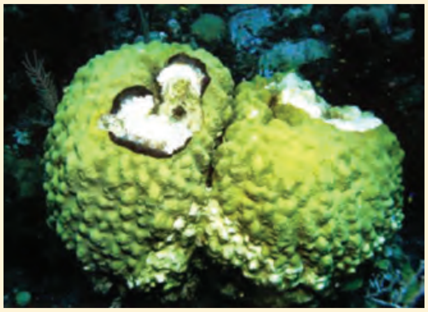


Photo courtesy of the National Oceanic and Atmospheric Administration

Black-band disease.

Red-Band Disease

Red-band infections of corals were first noted during the early 1980s and thought to be a variant of black-band disease infecting sea fans off Belize,[374] but was described as a separate disease based on observations made during 1991 at a site southwest of Bimini in the Bahamas.[381,382] This disease is also known to be present on the west coast of Puerto Rico and in the Florida Keys[383] and may be present as brown-band disease on the Great Barrier Reef. Infections have occurred in 20 coral species in five scleractinian families.[374]

A microbial mat similar to that for black-band disease is involved but differs in species composition, migration across the coral, and daily activity.[381] Red-band disease is associated with a cyanobacterium of the group *Oscillatoria* spp. but the primary cyanobacteria present in the red-band may differ between geographic locations. Other organisms known to be part of the mat complex are other cyanobacteria, the bacterium *Beggiatoa*, heterotrophic bacteria, and the nematode *Araeolaimus*.[374,383]

White-Band Disease

Acroporid corals from St. Croix, U.S. Virgin Islands, were first reported infected with white-band disease in the 1970s. Massive mortality of elkhorn corals occurred in 1977 on the reefs of Buck Island and Tague Bay and was part of a progressive destruction of the majority of Caribbean *Acropora* during the late 1970s and early 1980s.[374,383] This disease is widespread, occurring in reefs throughout the Caribbean from the Florida Keys to Panama and Nicaragua. It is also present in reefs of the Philippines, the Red Sea, the Gulf of Oman (Arabian Sea), and the Great Barrier Reef.[374] White-band disease attacks multiple species of scleractinian corals but has been most destructive of branching corals.

The original form of white-band disease that emerged in the 1970s is referred to as Type I. Type II, a more aggressive form relative to the speed of disease progression in infected coral, emerged during the early 1990s,[377,383] and has only been found in the Bahamas. Both diseases appear to be due to bacterial infections. Bacterial aggregates have been identified in some, but not all cases of Type I disease. Specific species of bacteria have not been identified as the cause for this disease. Bacteria similar to *Vibrio carchariae* have been identified as a probable agent for Type II disease.[384]

Yellow-Band Disease (Yellow-Blotch Disease)

Some authors refer to this disease as yellow-blotch disease in the Caribbean and yellow-band disease in the Arabian Gulf. Yellow-band disease was first reported as ring bleaching in the 1970s.[385] In 1990 it was first associated with bleached corals in the Cayman Islands,[386] and in 1994 it was first noted as an independent disease in the lower Florida Keys.[374] Yellow-band disease is now known to occur in many Caribbean reefs.[383] Recent transect studies (1997–1998) revealed that this disease affects as much as 90 percent of star coral.[385] It is the latest coral disease in Colombian waters (observed in April 1998) and the cause of a major epizootic affecting several coral species.[387] Yellow-band disease has also been observed in pristine reefs in San Salvador waters[377] and in the Arabian Gulf at Jebel Ali in Dubai, United Arab Emirates.[388]

Yellow-band disease affects star coral in the Florida Keys and in the Netherlands Antilles, but different species

Photo courtesy of the National Oceanic and Atmospheric Administration

Red-band disease.

Photo courtesy of the National Oceanic and Atmospheric Administration

White-band disease.

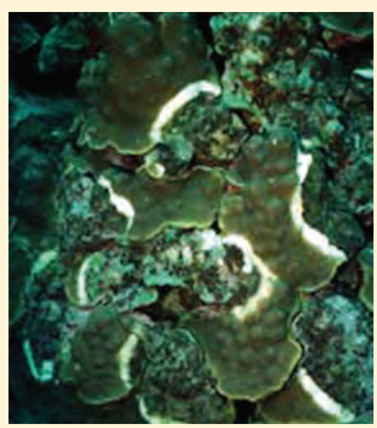


Photo courtesy of the National Oceanic and Atmospheric Administration

Yellow-band disease.

including branching corals are affected in the Arabian Gulf. Prior to its appearance in Colombian waters, this disease had only been known to affect two species of corals (star coral and mountainous star coral). An additional seven coral species were found affected in Colombia.[387] The cause of this disease is unknown, but may be of bacterial origin.[374]

Rapid Wasting Disease

This disease syndrome was first noted in Bonaire, Netherlands Antilles during late 1996. It is a rapidly spreading new condition that exists throughout the Caribbean affecting star coral and brain coral, two of the major reef builders of this region.[377,383] A filamentous fungus and a ciliate (protozoan) parasite associated with the fungus were originally thought to be responsible for rapid wasting disease.[72,383,389] However, recent observations indicate that **parrotfish** feeding on the coral may be the primary cause of this syndrome.[388]

Dark-Spot Disease

First observed in 1990, this disease affects massive starlet coral and some other star corals throughout the Caribbean. Transects during 1997–1998 disclosed up to 56 percent of those species of corals to be affected.[383,385] Dark-spot disease was the first record of a coral disease in Colombia (1990 at the Rosario Islands) and has affected 10 coral species in reefs of that country.[387] The pathogen involved is unknown.

White Pox Disease

Elkhorn coral was found affected by white pox disease around 1995 in the Florida Keys. Rapid geographic expansion has followed and this disease now occurs throughout most of the Caribbean. An unknown infectious agent is believed to be the cause for this disease.[72,383]

Coral (white) Plague

There are two distinct forms of white plague. Type I is a slowly progressing infectious disease and was first reported in 1977 on Alligator Reef in the Florida Keys. It has been documented for several species of nonbranching corals such as brain coral and fleshy coral. Type II white plague was also first observed in Alligator Reef (1995), but in contrast to Type I, is a rapidly spreading disease.[377,383] The 17 scleractinian coral species infected is the greatest number of these corals ever reported for any disease in the Caribbean region. Only nonbranching corals are affected. Type II white plague is the first known disease of elliptical star coral, the primary species affected during epizootics.[390]
Three major epizootics of Type II white plague have occurred in different reef areas of south Florida: the middle Keys in 1995; the southern Keys and Dry Tortugos during 1996; and reefs north of Miami during 1997. White plague (Type I and Type II combined) was first reported in Colombian reefs in 1994 affecting only one species (*Montastraea cavernosa*). It is now widespread and has affected 21 hard coral species.[387] A single dominant bacterium associated with the disease line has been isolated and shown to be contagious under experimental conditions. This organism is most closely related to *Sphingomonas*.[390]

Disease of Other Reef Organisms

Coralline Algal Disease [Coralline Lethal Orange Disease (CLOD)]

The orange-yellow growth of an unidentified bacterium that attacks coralline algae (*Porolithon* spp.) gives this disease its name.[383] Initially observed in June 1993, coralline algal disease has spread over 10,000 km, affecting

Photo courtesy of the National Oceanic and Atmospheric Administration

Dark-spot disease.

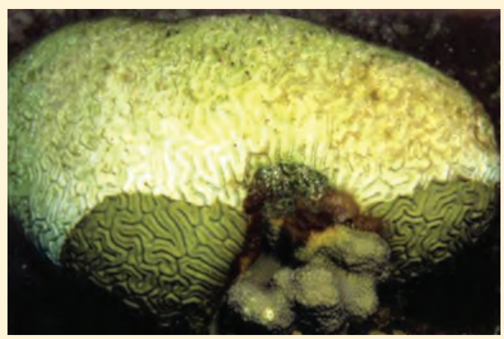


Photo courtesy of the National Oceanic and Atmospheric Administration

Coral (white) plague.

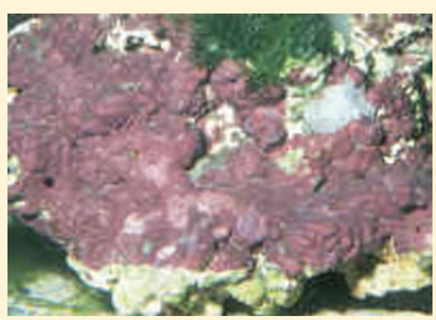


Photo courtesy of the National Oceanic and Atmospheric Administration

Coralline algae disease.

South Pacific reefs from the Cook Islands to the Mariana Islands.[391] In 1996, a new condition that attacks these algae but has a different appearance appeared in the Caribbean. Between 25 to 75 percent of the coralline algae has been killed at some Caribbean sites.[383]

Sea Fan Disease

Sea fans are soft coral life forms. Mass mortality events involving these species were first reported in the Caribbean during the 1980s: Trinidad (1981/82); Costa Rica (1982/83); Panama (1982/83); Colombia and San Andrea Island (1986/88). The causative agent, although unknown, was highly virulent, resulting in almost total mortality. Disease appeared to be restricted to the Caribbean continental coasts. A second, less virulent, epizootic wave, extending at least 2,500 km, began in January 1995. This event reached at least from Trinidad westwards to the Panama/Colombia border in the southern Caribbean, and northwestwards to the Bahamas and the Florida Keys in the northern Caribbean.[392] This latest event has been shown to be caused by a fungus (*Apergillus sydowii*).[393-395]

Sponge Disease

Die-offs of barrel sponges have been reported from the Florida Keys since the 1980s. In 1996, mass mortality

Photo courtesy of the National Oceanic and Atmospheric Administration

Sea fan disease.

(40–50 percent) affected the barrel sponge population in reefs along Palm Beach, Florida. The previous year mortality occurred off Key Largo in the Florida Keys.[396] Mortality is caused by a rotting disease that leaves holes in the sponge frame.

A rapidly spreading disease of large barrel sponges *(Xestospongia muta)* appeared in the Belize Barrier Reef Tract during 1996 and spread to Curacao, Tobago, and Panama. Several different species of sponges were affected in Panama and a different species of barrel sponge in Tobago.[383] The pathogen involved has not been identified for any of the sponge disease events.

Sea Urchin Disease

During 1983 and 1984 the black long-spined sea urchin suffered mass mortality from disease throughout its entire geographic range. That initial epizootic is thought to be the most widespread epizootic ever recorded for a marine **invertebrate**.[397,398] Approximately 3.5 million square km (not counting Bermuda) were impacted by this event.[398] In 1983, Jamaican reefs alone lost about 100 million sea urchins during an 8-week period.[71] A second epizootic followed in 1984, further stressing any survivors from the previous event.[397] Densities of this species in Jamaica were reduced by 99 percent from pre-die-off estimates and have remained suppressed.[71] A similar die-off struck the Florida Keys during May 1991.[569] Additional mass mortalities from 1995–1997 affected sea urchins in Puerto Rico, Antigua, Aruba, Jamaica, and Curacao.[383] Mass mortalities from 1980 to 1982 reduced green sea urchin populations in Nova Scotia by about 90 percent.[62] The pattern of mortality associated with sea urchin die-offs is consistent with infectious disease, but the causative agent(s) have not been determined. An amoeboid protist, *Labyrinthula* spp., is thought be the cause of the Nova Scotia die-off.

Numerous other maladies have also appeared as diseases of reef organisms during recent years. For example, in 1996 an unnamed new disease appeared in Brazil in a colonial benthic (bottom dwelling) organism, commonly found on shallow reefs in the western Atlantic. Bacteria are thought to be the primary pathogens, and fungi and other organisms are most likely secondary invaders; it is widespread along the Brazilian coast but not seen elsewhere.[399]

Noted reef biologists are obviously quite concerned about the magnitude of disease:

"The spread of coral reef diseases has become so commonplace, and with such intensity, that they have become the major cause of accelerating coral mortality in many locations and are likely to become far more prevalent in coming years" (Goreau et al.).[383]

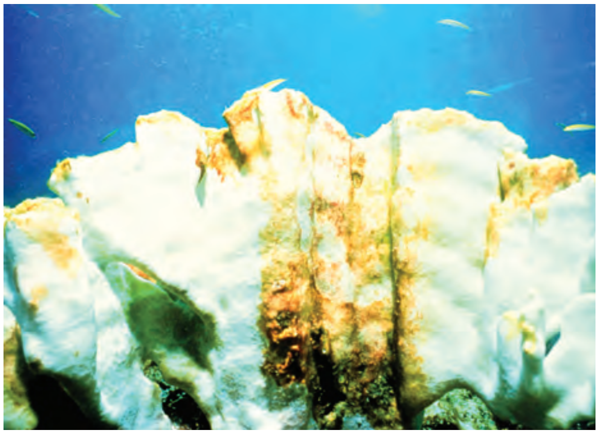


Figure 2.7 Bleached coral.

Photo courtesy of S. Miller, OAR/National Undersea Research Program (NURP), University of North Carolina at Wilmington

that is lethal to coralline algae, living organisms that cement dead corals together to make reefs, was first recorded in the Cook Islands of the Pacific Ocean in June 1993. Within a year, this disease had spread over a distance of at least 6,000 kilometers. In 1992, coralline lethal orange disease (CLOD) was nonexistent at Great Astrolabe Reef sites in Fiji, but by 1993, it was present in 100 percent of the reefs. Because coralline algae play critical roles in forming reef rims throughout the Indo-Pacific region, CLOD may significantly affect reef ecology and reef building processes.[73]

Coral bleaching is an additional pathology of reef systems that is occurring over broad geographic areas. This malady (Fig. 2.7) is seen as a whitening of corals due to loss of symbiotic algae and/or their pigments.[74] The first description of coral bleaching was in 1984, but scientists in French Polynesia made the first observations 11 years earlier. Coral bleaching occurs regularly in the Indian and Pacific Oceans and the Caribbean Sea, and is now common at many sites.[74] A major coral bleaching event occurred throughout the Caribbean in late 1995 (Table 2.3). For some places, such as Mexico, Cuba, Honduras, and Belize, this was the first occurrence. Bleaching was most evident in the western, central, and southern Caribbean.[75]

The most geographically extensive and severe mass bleaching event occurred during 1998[66] (Fig. 2.8). High sea surface temperatures associated with El Niño were among the factors responsible for coral bleaching.[69,76] This pathology has long-term impacts because of the magnitude of mortal-

Table 2.3. Relative severity of coral bleaching[a] within different areas of the Caribbean during a 1995 bleaching event.[7,75]

Unremarkable	Slight	Highly evident	Severe
Tobago	Barbados	Bahamas (San Salvador)	Bonaire
	Bermuda	Belize[b]	Cayman
	Costa Rica	Colombia	Curacao
	Saba	Cuba[c]	Jamaica
	St. John	Dominican Republic	Venezuela
		Honduras[b]	Mexico[b]
		Puerto Rico	

[a]Unremarkable=percentage of coral affected too little to be noticeable; slight=bleaching of some coral evident but only a low percentage of coral affected; highly evident=bleaching readily visible because of the moderate to high amount of coral affected; severe=bleaching widely occuring and affecting most of the area.

[b]Bleaching was a minor occurrence previous to this event.

[c]First bleaching event

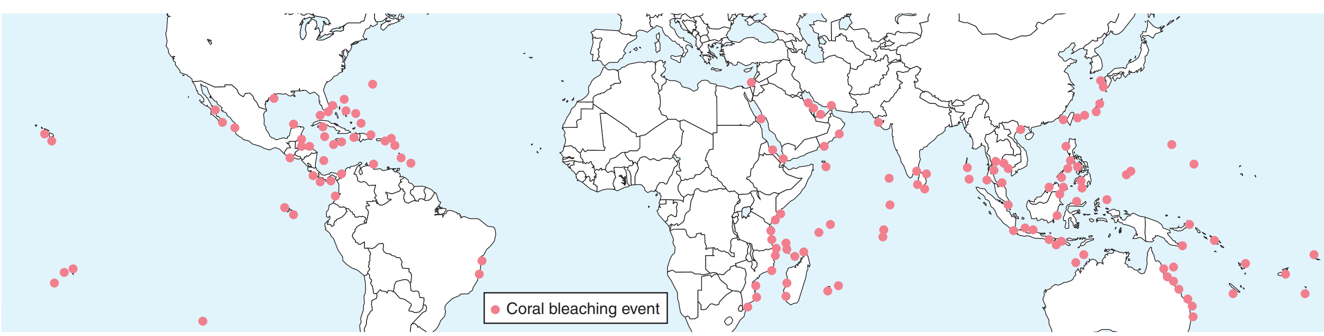


Figure 2.8 Locations of coral bleaching, 1998. (Data modified from Spalding and Green[66] and the World Conservation Coral Disease Monitoring Center—NOAA coral disease database.)

ity[76] and the damage to the coral's reproductive capacity that persists beyond the period of stress from elevated water temperatures.[77] Also, coral bleaching is often followed by the appearance of infectious disease. It is not clear whether the damage caused by bleaching results in invasion by infectious disease or whether the physical appearance of bleached corals masks the observability of lesions from some infectious diseases that already may be present.

Finfish and Shellfish

Infectious disease emergence and reemergence in fish is a worldwide concern[78] because of impacts being experienced by wild stocks of shellfish and finfish and those affecting **mariculture**, shrimp farming, and other forms of **aquaculture**. Several diseases of marine species that are caused by biotoxins also are noted because of the implications for human and wildlife health (Box 2–7).

Marine **mollusks**, such as **oysters**, **clams**, and **abalone**, and **crustaceans**, such as shrimp, have experienced increasing numbers of mass mortality events during recent years. These events have been caused by a growing number of infectious agents and by other factors.[79–81] Many recognized infectious diseases are associated with the commercial farming of these species. Pathways for pathogens to move between wild and commercial stocks of marine shellfish exist because of the close associations between these populations. Wild populations are the broodstock for some of these species and aquaculture often occurs within estuarine areas. The greater surveillance of cultured stock and the interface that often exists with wild stock can obscure the origin (wild vs. cultured stock) of diseases. Also, these relations make it difficult to separate the natural geographic distribution of the causative agents from distribution caused by industry movement of broodstock and commercial shipment of products (Box 2–8).

Infectious disease also is occurring more frequently and in greater numbers of species of marine finfish than previously reported.[78,82] Like shellfish, these diseases most often are first detected among captive populations of finfish, especially those raised in aquaculture facilities. Like shellfish, **salmon** and some other finfish are reared in estuarine environments that can provide a water corridor for disease transfer between wild and cultured stocks of finfish (Fig. 2.9). Two situations regarding infectious disease in shellfish and finfish are likely: aquaculture may be the probable source for many of the emerging infectious diseases being encountered (Table 2.4) and/or aquaculture simply facilitates the detection of infectious agents present in wild populations.

Photo courtesy of the National Oceanic and Atmospheric Administration

Figure 2.9 An aquaculture net pen offshore of Catalina Island, California, 2000. The walkways provide access for commercial fish feeding and pen maintenance.

Egtved disease, or viral hemorrhagic septicemia (VHS), is an example of how the interface between farmed and wild fish stocks can result in the emergence of highly virulent pathogens. This disease is caused by infection with viral hemorrhagic septicemia virus (VHSV). Different strains of VHSV exist in Europe and North America. The European strain is highly virulent for **salmonids**, causing mortality in juvenile fish that has approached 100 percent and up to 25–75 percent in adults. In contrast, the North American strain is relatively avirulent for the salmonids evaluated, but causes occasional self-limiting epizootics in its Pacific herring **reservoir host**. The high virulence of the European strain of VHSV is thought to be the result of a mutant strain evolving from infection of rainbow **trout**.[83]

VHS is the most serious viral disease of farmed rainbow trout and occurs widely in mainland Europe.[84] Rainbow trout were imported from North America into Europe in the late 1800s. Later infection by VHSV may have resulted in contaminated water from cultured fish infecting ocean salmon.[83] Recent findings suggest that rainbow trout initially became infected from a marine source rather than vice versa and that Atlantic herring fed to farmed fish may have been the original source for infection.[85]

VHSV was first isolated in North American salmon in 1988 and recommendations have been made to eradicate VHSV-infected **hatchery** stocks to reduce the possibility of the North American strain evolving into a more virulent salmonid virus.[83] The 1994 appearance of VHS in Scotland was the first in the British Isles and occurred in tank-reared turbot. All of the fish on the infected farm were destroyed to combat this infection.[84]

Among the viral diseases infecting marine finfish, the nodaviruses and the iridoviruses are the most prominent emerging diseases because of the frequency of disease events and the number of different fish species affected. Nodaviruses cause behavioral abnormalities prior to death because of their predilection for nerve tissue. This group of viruses has infected over 20 species of marine fish that belong to 11 different families; infections have been found throughout much of the world, except for the Americas and Africa.[86] Atlantic salmon, sea bass, grouper, and Atlantic halibut are among popular food fish being infected.[78] Red sea bream iridoviral disease is a major representative of the iridoviruses and first appeared in cultured red sea bream in Japan in 1990. Since

Box 2–7 Biotoxins and Disease Emergence

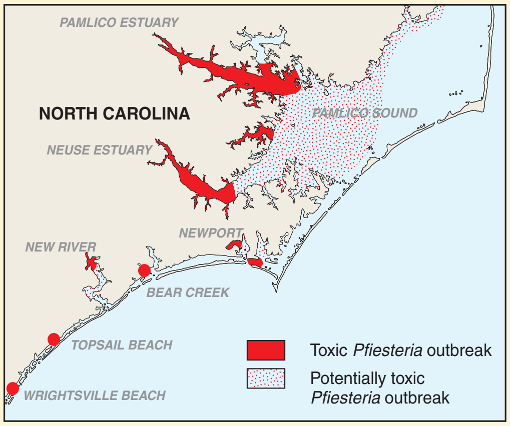
Photo by Milton Friend

Large-scale algal blooms in marine environments have become an increasing focus for concern and study since the 1970s because of the potential for toxic side effects. Referred to as harmful algal blooms (HABs), these events include such conditions as red tides, brown tides, and cyanobacterial blooms. Wildlife die-offs,[327,400] especially those involving fish,[401,402] contamination of shellfish beds, and human illness have all been associated with HABs.[62,402] During the past decade, *Pfiesteria* has become a high-profile disease because of large-scale fish kills and a reported association with human illness.

Pfiesteria piscicida is the representative species for a novel group of **dinoflagellates** (single-celled, plantlike organisms) first discovered in the 1980s.[403] Association of these organisms with HABs was first described in 1992[401] and the taxonomy for dinoflagellates was resolved in 1996.[404] An estimated loss attributed to *Pfiesteria* of more than 1 billion fish in 1991 occurred in the Neuse and Pamlico Estuaries of the Albemarle Pamlico System of North Carolina (USA).[62] This System is the second largest estuary on the USA mainland and has been the site of numerous *Pfiesteria*-related fish kills between 1991 and 2000.[405] *Pfiesteria* was first linked to mortality in these fish by assays of water samples from a mass mortality site of Atlantic menhaden.[401] *Pfiesteria* has also been implicated as the cause of mortality in a variety of other **estuarine fish** along the Atlantic coast.[405,406] Blue crab also have been killed by *Pfiesteria* in some of those events. Laboratory studies have disclosed that a broad range of finfish (at least 33 species) and four species of estuarine invertebrates are susceptible to *P. piscicida* and *Pfiesteria*-like dinoflagellates.[403]

Initially, it was thought that the open sores in Atlantic menhaden were caused by *P. piscicida*. However, skin and muscle ulcers in fish can result from numerous causes, are commonly associated with fungi, and, in general, are referred to as ulcerative mycosis.[407,408] In one study, a highly pathogenic fungus, *Aphanomyces invadans*, not *Pfiesteria* toxins, was found to cause skin ulcers in menhaden.[408]

Whether or not *Pfiesteria* is a threat for human health and to what extent is controversial. The first association between human illness and exposure to *Pfiesteria* was reported among laboratory personnel working with the organism during the early 1990s.[409] In 1997, additional cases of human illness were associated with exposure to waterways where the dinoflagellate was present.[410] These and other reports suggest that chronic or recurrent high-level exposure to *Pfiesteria* toxin may result in a



Adapted from Glasgow et al., 2001[405]

distinctive clinical syndrome characterized by difficulties in learning and memory.[411] However, the general conclusion reached during the *National Conference on Pfiesteria: From Biology to Public Health*[412] is that, "The consequence of human exposure to *Pfiesteria* toxin and the magnitude of the human health problem remains obscure."[403] Because of environmental conditions present, the states of Delaware, Florida, Maryland, North Carolina, South Carolina, and Virginia are most likely to be affected by the presence of *P. piscicida* in their estuaries.[413] The high density of the human population along the eastern seaboard of the USA, the recreational use of estuarine areas of that region, and the commercial importance of those areas for finfish and shellfish ensures that *Pfiesteria* will remain a focus for intensive investigations until questions of human health risk are resolved.

In 1996, another type of dinoflagellate resulted in an unprecedented epizootic that killed approximately 150 West Indian manatees along the southwest coast of Florida. A red tide dinoflagellate bloom (primarily *Gymnodinium breve*) that produced brevetoxin was identified as the cause of that epizootic, the largest reported disease event affecting this species. The estimated population of West Indian manatees is only 3,000 animals;[414] it is one of the most endangered marine mammals in the coastal waters of the USA.

Photo courtesy of the Florida Marine Research Institute

Manatee postmortem exam.

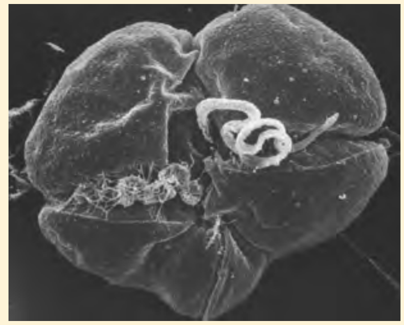


Photo courtesy of the Florida Marine Research Institute

Gymnodinium breve.

Red tide blooms are common on Florida's west coast, thereby providing the potential for manatees to periodically become exposed to brevetoxin. The infrequency of **manatee** mortality from this cause suggests that brevetoxicosis may be cumulative and require prolonged exposure and/or high dose exposure to this toxin.[414] Retrospective analysis of tissues from a smaller 1982 epizootic[415] support the involvement of brevetoxin as a component of that event.[414]

A bloom of *G. breve* is also believed to have been the cause of an epizootic involving lesser scaup in the Tampa Bay area on the west coast of Florida. Several thousand birds died during that event.[326,327] Another type of biotoxin, domoic acid (DA), caused the mortality of about 300 birds in Santa Cruz, California (USA) in 1991. Brown pelicans and Brandt's cormorants were the primary affected species. The toxin was associated with a bloom of the diatom *Pseudonitzschia australis*. That event was the first reported incident of DA poisoning in free-ranging wildlife, the first documentation of DA in finfish (northern anchovy), the first report of DA being produced by the diatom *P. australis*, and was the first report of DA outside of Canada's Atlantic Coast.[416] Previously, the only documented case of DA poisoning had occurred in 1987 on Prince Edward Island, Canada. More than 100 human cases, including three deaths resulted from the consumption of cultured blue mussels.[259] Shortly after the bird event in California, DA was found in clams and **crabs** harvested in Washington and Oregon, and human cases may have resulted from ingestion of clams.[320]

Poisoning of humans by DA is known as amnesic shellfish poisoning because of memory loss that sometimes occurs. DA has joined several other types of shellfish poisoning and ciguatera fish poisoning as examples of diseases caused by biotoxins that appear to be increasing.[252,259,320] These diseases are associated with coastal marine ecosystems. The general increase in their occurrence in humans is associated with degradation of the marine environment.[62,320] Human exposure to these toxins is not limited to consumption of contaminated foods. Aerosol exposure from contaminated environments has resulted in respiratory entry and disease. Therefore, HABs affect recreation (e.g., swimming) and food consumption along with the attendant economic consequences that often result.

Table 2.4. Examples of important emerging and reemerging diseases of marine finfish in North America (contribution of F. Panek, U.S. Geological Survey).[a]

Disease	Type	Period of emergence	Geographic area	Comments
Damselfish neurofibromatosis (DNF)	Virus-like agent	1980s	Florida and Caribbean coral reefs	• Transmissible cancer affecting bicolor damselfish.[462] • Exhibits many traits in common with neurofibromatosis type-1 in humans, including multiple plexiform neurofibromas and areas of hyperpigmentation.[463]
Infectious salmon anemia virus	Orthomyxo-like virus	Late 1990s	Maine and New Brunswick, Canada	• Highly infectious disease of Atlantic salmon. First reported within Norwegian aquaculture facilities.[464] • First case confirmed in Maine net pens mid-February, 2001.
Streptococcus iniae	Bacteria	1970s	USA Atlantic and Gulf coast waters and coral reefs	• Worldwide distribution and usually associated with poor water quality or environmental conditions • Well-known in fish culture since the 1950s; epizootics associated with wild fish since 1970s; most recently implicated as cause of mass mortalities of coral reef fishes.[465] • Recent human cases associated with processing fish.[51]
Mycobacteriosis	Bacteria	Mid-1990s	Coastal waters	• A subacute to chronic wasting disease known to affect 167 species of freshwater and saltwater fishes. • Occurs in all coastal waters of the USA. • *Mycobacterium marinum* is primary agent although seven *Mycobacterium* species may be involved.[466] • Causes "fish-handler's" disease in humans
Epizootic ulcerative syndrome	Fungus (oomycete)	1984	Coastal waters	• Widespread disease in estuarine fish along the USA Atlantic coast; first recognzed in this area in North Carolina estuaries. • High incidence of ulcerative lesions (see Box 2–7) in Chesapeake Bay and Florida. Atlantic menhaden young-of-year are highly susceptible.[467]

[a] National Fisheries Research Center, U.S. Geological Survey.

then, it has been reported in 20 species of cultured marine fishes and it has become one of the most threatening viral diseases for several of those species, such as red sea bream, yellowtail, sea bass, and Japanese parrot fish.[87]

Piscirickettsiosis, an emerging rickettsial disease of salmonid fish, is caused by infection with the rickettsia-like organism *Piscirickettsia salmonis* and has been found in four different species of salmon and in rainbow trout reared in oceanwater. This disease has also appeared in freshwater-reared coho salmon and rainbow trout.[82] Rickettsia were not recognized as important pathogens of fish prior to 1989, but that year large-scale die-offs due to *P. salmonis* occurred in coho salmon reared in seawater net pens in southern Chile. This disease was then found during 1992–1993 in salmonids on the west coasts of Canada, Norway, and Ireland,[88] and since has been found on the east coast of Canada.[86] Subsequently, several unidentified rickettsia-like organisms have also emerged as causes of fish mortality. Perhaps the most significant is the organism causing mortality in several species of tilapia in Taiwan where mortality has reached 95 percent at some sites.[88,89]

Explosive epizootics also have appeared in wild fish without an association with fish culture. Beginning in March 1995 and ending in September of that year, a mass mortality due to a herpesvirus infection spread around the coasts of Australia and New Zealand. At least 10 percent of the pilchard population in Western Australia died. No other species were affected. This epizootic was the first large-scale pilchard mortality event reported for Australian and New Zealand waters. The characteristics of the disease pattern (focal origin, high mortality, and rapid spread) are indicative of an infectious agent entering a naive host population.[90] The source of this pilchard herpesvirus epizootic is unknown. This event provides an example of the vulnerability of wild fish stocks to large-scale mortality from disease even under the unconfined conditions of the ocean environment.[91]

A substantial number of other diseases of marine finfish have been recognized in association with the expansion of species being cultured and the increasing magnitude of fish farming to meet human demands. Not addressed in the examples provided is the myriad of bacterial diseases that have appeared as expanding or previously unreported diseases of marine and freshwater finfish; nearly half of the unreported taxa involved have appeared in only two countries, Spain and the USA. The most dramatic increase of fish-pathogenic taxa is in the number of **vibrios** causing disease.[92]

Disease emergence is not an unexpected outcome of fish farming. The environmental conditions of intensive aquaculture facilitate the transmission and expression of infectious agents present within the farmed species and any infectious pathogens that enter these populations. The broad spectrum of wild and farmed fish species affected confirms the need for sound surveillance programs and aggressive management of diseases that appear.

Turtles

Fibropapillomas (Fig. 2.10) have become an important emerging disease of **sea turtles** since the early 1980s. This disease was first identified in green turtles in 1938 near Key West, Florida, USA,[93] but it was rarely observed until the 1980s.[94] By late 1985, more than 50 percent of the green turtles in Florida's Indian River Lagoon had external tumors.[95] This disease has now been reported in green turtles in every major ocean where this species exists[94] and has also appeared in other species of marine turtles.[96] The prevalence of tumors in some populations sampled has exceeded 90 percent.[94,97] These tumors are believed to be of viral etiology.[98,99,573] Several other diseases also have been recently identified in marine turtles, but too little information is available to determine whether or not these are emerging as new sources of mortality.

Three bacterial diseases (ulcerative stomatitis, obstructive rhinitis, and pneumonia) and associated complexes of disease were found to cause mortality rates of up to 70 percent in farmed and oceanarium-reared 3- to 52-week-old green and loggerhead turtles. Researchers concluded that obstructive rhinitis appears to be a new disease in sea turtles as is the disease complex of the three primary conditions observed. *Vibrio alginolyticus*, *Aeromonas hydrophilia*, and *Flavobacterium* spp. were commonly isolated from turtles with ulcerative stomatitis and obstructive rhinitis, and from the trachea and bronchi of turtles with bronchopneumonia. These findings differ from those of other investigators that attributed pneumonia in farmed sea turtles to a herpesvirus infection and ulcerative stomatitis to a protozoan infection.[100]

Marine Mammals

Marine mammals worldwide have been affected by emerging disease during recent years.[101–108] At least 20 species of **cetaceans** (**whales**, **dolphins**, and porpoises) and 15 species of **pinnipeds** (**seals**, sea lions, and walruses) have been victimized by more than 30 different emerging and reemerging disease agents and disease conditions.[106]

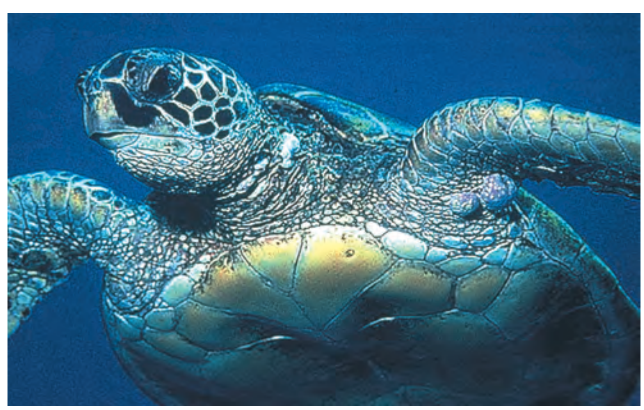


Photo by Thierry Work

Figure 2.10 Fibropapillomas, or tumors, are an emerging disease of marine turtles.

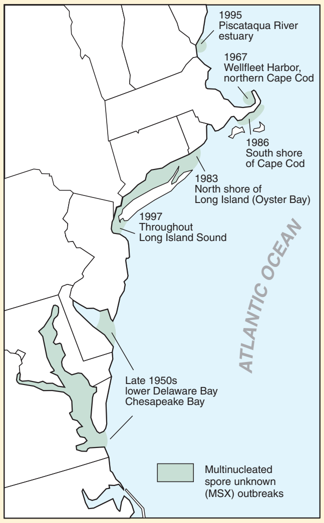
Box 2–8 Disease Emergence and Resurgence in Shellfish

A wide variety of marine shellfish are being affected by an equally diverse array of pathogens, many of which are the causes of emerging and reemerging diseases.[80,81] These diseases cause substantial economic impacts because of the high commercial values of mollusks and crustaceans as food products. The following examples are drawn from a more extensive list of pathogens affecting shellfish.

- MSX (Multinucleated Spore Unknown) is a protozoan disease (*Haplosporidium nelsoni*) of the eastern (American) oyster. MSX, or haplosporidiosis, was first recognized in the late 1950s as the cause of 90 to 95 percent mortality of the oysters in lower Delaware Bay (USA).[417] The initial appearance of this disease in nearby Chesapeake Bay in 1959 was followed by an epizootic killing 45 to 55 percent of the oysters on some bars for several years.[418] MSX rarely was found outside of the Delaware and Chesapeake Bay areas until the 1980s. MSX then reached the north shore of Long Island, New York in 1983, the south shore of Cape Cod, Massachusetts in 1995, the Maine-New Hampshire border in 1995, and by 1997 was found throughout Long Island Sound.[417] This disease is one of the five shellfish pathogens whose appearance is notifiable to the Office International des Epizooties (OIE) by member countries because of the high level of infectiousness and serious economic consequences associated with epizootics.

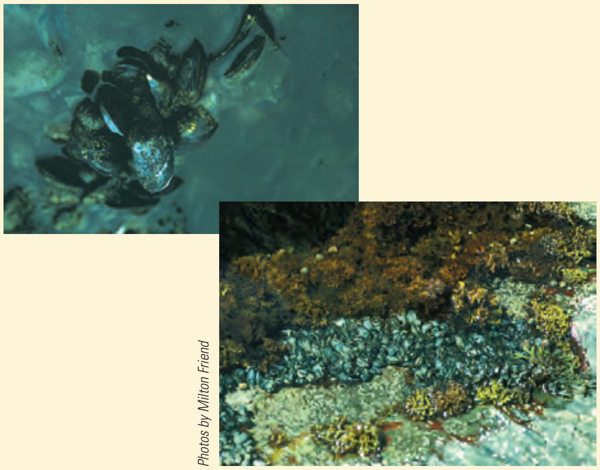
- Withering syndrome (WS) was first detected in abalones in the California Channel Islands in 1985, spread throughout those islands, and by 1992 black abalone were extirpated from six of the eight Islands. The fishery for this species was closed in 1993.[421] Mortalities of over 95 percent when water temperatures are 18–20°C are associated with this disease. The WS disease agent appears to be a rickettsial-like infection that is interactive with warm water conditions.[81,420,421] However, the role of rickettsia has not been firmly established.[420] Red abalone farms exhibited severe economic losses from WS in 1997–1998.

Photo by Milton Friend



- Quahog parasitic unknown (QPX) is an important new disease of **hard clams** or quahogs (quahaugs) in the Northeastern USA. The causative organism is an unnamed microscopic parasite within the subkingdom Protozoa.[422] This parasite was first reported in a limited population of clams in New Brunswick, Canada, during the early 1960s, and later that decade in a shellfish hatchery on Prince Edward Island (PEI), Canada. QPX reappeared at the PEI hatchery in 1989 and has been a persistent problem since, causing significant mortality among hard clams. The extent of hatchery losses raised concern about QPX as a mortality factor in wild populations of hard clams.[423] During 1995, QPX struck two locations on the coast of Massachusetts, causing high morbidity and mortality of hard clams. Anecdotal reports for the Provincetown site indicated nearly 90-percent mortality. However, scientific evaluations using random core samples averaged 30-percent mortality. Microscopic evaluations of nongrowing hard clams indicated 90-percent prevalence of infection. Also, retrospective analyses of archived hard clam tissues identified QPX as being present in a 1993 mortality event in Chatham, Massachusetts, and in a major mortality event in Barnegat Bay, New Jersey, in 1976.

- Juvenile oyster disease (JOD) is another major disease of eastern oysters. Since 1988, recurrent and widespread mortalities from this disease have affected nursery-reared oysters throughout the Northeastern USA. Total mortalities have ranged from 50 percent to nearly 100 percent of total nursery-reared stocks.[424] The causative agent remains elusive. Some investigators present data that a microscopic protistan parasite is the cause and



Photos by Milton Friend

reject a bacterial etiology;[425] others present data supporting a link between infection by a strain of *Vibrio* bacteria and JOD.[424]

- Disseminated neoplasia (DN) emerged during the 1980s and was first described in New England (USA) in **soft-shelled clams** and causing losses in Chesapeake Bay in 1983–1984.[426] DN has been compared to vertebrate leukemia as a disease process. The causative agent and transmission in nature are unknown.[437]

- Mikrocytosis is caused by a microcell parasite (*Mikrocytos mackini*) and is another of the five shellfish pathogens notifiable to OIE. This disease was first confirmed in the USA in New Dungess Bay, Washington, as an infection of Pacific oysters in 2002. The source of the parasite and potential impacts are unknown.[428] Mortalities of Pacific oysters in British Columbia, Canada, were reported from this disease in 1960.[429]

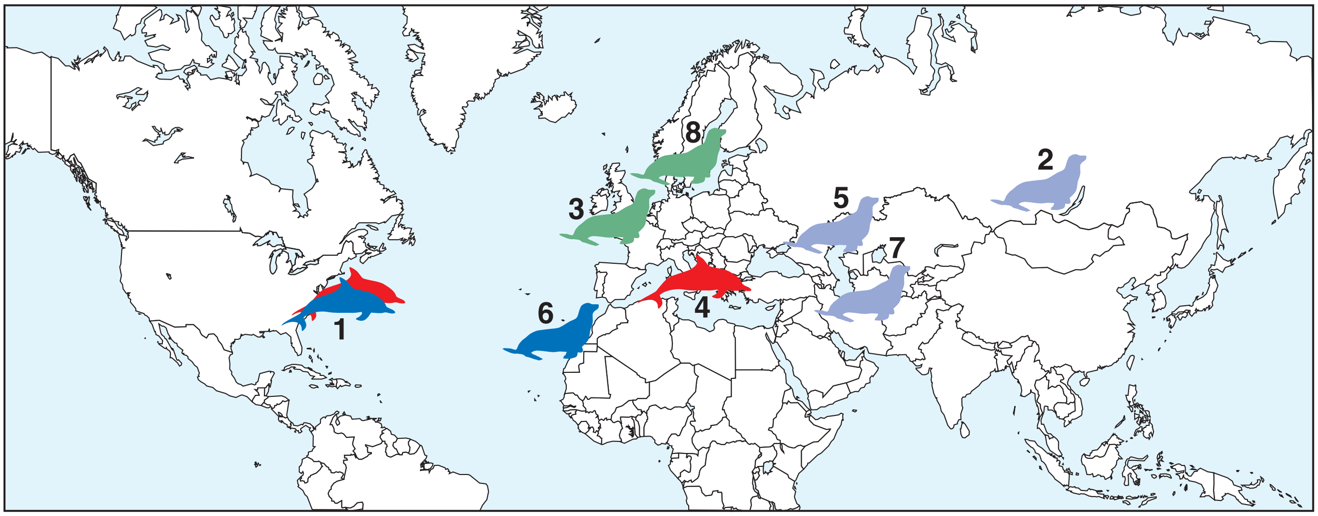
- Dermo disease is another of the five shellfish pathogens notifiable to OIE. The protozoan parasite (*Perkinsus marinus*) causing this disease is a significant pathogen of cultured and wild oysters along the Gulf Coast and East Coast of the USA. The oyster industry along the Gulf Coast of Mexico suffers 50-percent losses annually and this parasite has decimated oyster populations in Chesapeake Bay along the East Coast.[430] This pathogen has likely been present along the Gulf Coast since the early 1900s and in Chesapeake Bay since at least the 1940s. However, since the 1980s, the observed distribution of this disease has changed greatly by expanding northward along the East Coast. Major epizootics have been part of the range extension of more than 500 km north of Chesapeake Bay.[431]

- White spot syndrome virus (WSSV) emerged in 1995 as a serious disease in penaeid shrimp culture. This viral disease was first observed in East Asia in 1992–1993 and spread to the Western Hemisphere causing mass mortality in farmed shrimp in Texas and South Carolina in 1995–1997. Most recently, WSSV has erupted in the shrimp cultures of Central and South America.[432]

- Taura Syndrome disease (TS) emerged in 1991 as a major epizootic disease of panaeid shrimp and spread rapidly during 1992–1993 from Ecuador to other regions of Latin America and to Mexico. TS subsequently occurred in Hawaii and Florida and by mid-1996, had expanded its distribution to include virtually all of the shrimp farming regions of the Americas, including Texas and South Carolina in the USA. This viral disease exists in wild and farmed shrimp and causes high mortality in both. The economic impact of TS in the Americas between 1992 and 1997 exceeded US $2 billion.[79,80,433–435]

- Shell disease of lobster and several species of **crabs** emerged during the 1990s along the East Coast of the USA from Long Island, New York to Massachusetts. This disease causes erosion of chitin (the principal constituent of the animal's shell) and lesions and thinning of the carapace (the shell covering the back of the animal). Mortality is associated with incomplete sloughing of the shell during the molt and subsequent infections of the circulatory system.[436]

The examples cited attest to the diversity of species and types of infectious pathogens impacting wild and cultured shellfish populations. Toxins from algal blooms add to the impacts on these species. Clearly, disease emergence is a significant factor that is challenging the well-being of these important components of ecosystems and food-chains.



[= dolphin morbillivirus = porpoise morbillivirus = canine distemper virus = phocine distemper virus]

1. Atlantic bottlenose dolphin
1987–1988
About 2,500
Atlantic coast

2. Baikal seal
1987–1988
10,000 or more
Lake Baikal, Siberia

3. Harbor seal
1988
18,000 or more
Northwestern Europe
(Denmark, Sweden, Norway, Netherlands, Germany, UK, Ireland)

4. Striped dolphin
1990 first wave
1991–1992 second wave
"thousands"
Mediterranean coast
1. Spain throughout western Mediterranean Sea
2. Eastward to southern Adriatic and Ionian Seas, Sicilian Channel, southern Tyrrhenian Sea, coasts of Greece and Turkey

5. Caspian seal
1997
"thousands"
Caspian Sea

6. Mediterranean monk seal
1997
About 200
(50 percent of last remaining colony of this endangered species)
West Africa's Mauritian coast

7. Caspian seal
2000
About 20,000
Caspian Sea

8. Harbor seal
2002
About 750 initially (total unknown)
Northwestern Europe
(Denmark, Sweden, Netherlands)

Figure 2.11 Examples of recent marine mammal mass mortality events due to infection by morbilliviruses.

Extensive mortality has been associated with some of these pathogens, especially infections caused by closely related viruses of the morbillivirus complex (Fig. 2.11).

The first recognized occurrence of a morbillivirus epizootic in marine mammals was made retrospectively during a June 1987 to May 1988 mass mortality of Atlantic bottlenose dolphins along the eastern seaboard of the USA.[109] An estimated 50 percent of the in-shore population of this species died,[110] causing an unprecedented population loss in recent history.[111] Population recovery could take up to 100 years.[112] Several months after the onset of that event, a mass mortality of Baikal seals occurred in Lake Baikal, Siberia. An estimated 10 percent of the total population of this species died.[113] The virus involved was found to be a strain of canine distemper (CDV), a morbillivirus, and might have been introduced into the seal population by **feral** or domestic dogs.[114]

Northern Europe experienced its first marine mammal morbillivirus epizootic during the spring of 1988. More than 18,000 harbor seals and a few hundred grey seals died from a newly recognized morbillivirus that was designated as phocine distemper virus.[115,116] Mortality reached 25 percent of the seal population in large areas[117] and was estimated to be as high as 60 percent in some areas.[113] This event was the first identification of morbillivirus as a cause of an active epizootic in marine mammals. The findings provided a focus for evaluation of mass mortality events that followed, and for retrospective evaluations, such as the Atlantic bottlenose dolphin mortality of the previous year.[118,119] An unusual southern movement of harp seals, possibly in response to food shortage, was thought to be the source of the virus introduced into harbor seals.[120]

The Mediterranean Sea was the next reported site of marine mammal mortality due to morbillivirus infections. More than 1,100 striped dolphin carcasses were recovered from the thousands of dolphins estimated to have died. That event began in 1990 and a second wave of mortality followed in 1991.[104,121–124] The dolphin morbillivirus (DMV) causing this event, like the porpoise morbillivirus (PMV), is a newly recognized morbillivirus.[108] Relatively small-scale mortality events due to morbillivirus infections followed in 1993–1994 in Atlantic bottlenose dolphin in the USA portion of the Gulf of Mexico[125] and in common dolphin, during 1994, along the Crimean coast of the Black Sea.[126]

The next major epizootic occurred in the Caspian Sea of the former Soviet Union. Thousands of Caspian seals died during the spring of 1997 from a strain of CDV that was different from the strain isolated during the mass mortality event at Lake Baikal a decade earlier.[127] That same year approximately 200 of the 270 endangered Mediterranean monk seals living in a pair of caves on West Africa's Mediterranean coast died, apparently from morbillivirus infection (virus isolated but lesions absent).[128] This colony is the sole remaining population in the wild except for scattered small groups of about 20 animals each.[129] Repeat morbillivirus epizootics struck the seal populations of the Caspian Sea in 2000 and Northwestern Europe in 2002.

About 20,000 Caspian seals died from a strain of CDV that was isolated from a Caspian seal in 1997. The origin of the virus is unknown but anecdotal reports of contact between these seals and terrestrial **carnivores** of the region provide a plausible pathway for virus introduction.[127,130,131] The mass mortality in 2000 was the second major epizootic within a 5-year period and of great concern relative to the long-term survival of Caspian seals, a species identified by the World Conservation Union as being vulnerable to extinction.[131] The 2002 reappearance of PDV in harbor seals off the coasts of Denmark, the Netherlands, and Sweden is also reason for concern given the magnitude of loss experienced in 1988. Initial mortality reports for the 2002 event indicated about 750 carcasses had been found[132] but little information has been published about this event.

Other than morbilliviruses, influenza viruses are the only other viruses that have been associated with mass mortality of marine mammals. That association has been infrequent and has been limited to events along the New England (USA) coast. An estimated 600 harbor seals (at least 20 percent of the local population) died from pneumonia during 1979 along Cape Cod, Massachusetts. Influenza A virus was isolated from those animals and was attributed to be the cause for that mortality event.[101,133] Smaller scale epizootic also occurred during 1982–1983, 1991, and again during 1992.[101] Although not a cause of direct mortality, findings of papillomaviruses in Burmeister's porpoise has raised concern that the genital warts associated with venereal transmission of these viruses may reduce reproductive success and suppress population numbers.[108]

Brucellosis is the most significant emerging bacterial disease of pinnipeds.[106] Potential impacts on reproduction (i.e., abortion) rather than epizootic mortality of juveniles and/or adults is the concern. Nevertheless, until recently, brucellosis had not been reported as a cause of abortion in marine mammals. Serologic evidence for exposure to *Brucella* spp. first appeared during the early 1980s.[134] *Brucella* spp. was first isolated during 1992 from aborted fetuses from captive bottlenose dolphins at a California military facility. Those animals had been captured from Mexican waters.[135] A long list of marine mammals, including several species of whales, seals, dolphins, and porpoises, in addition to a river otter, have now been found to be exposed to *Brucella* spp.[106,134,135]

In 1970, leptospirosis emerged as a cause of epizootic mortality in California sea lions dying along the Oregon and California coast. Repeated epizootics of this bacterial disease have occurred between 1981 and 1994.[136] Several hundred animals were involved during each of the earliest events and lesser numbers since then.[137]

Numerous other emerging infectious diseases have appeared in marine mammals but have not resulted in documented mass mortality events.[106] Included are diseases of bacterial;[102,103] fungal;[103,138] rickettsial;[139] parasitic;[140] and viral origin.[105,108] A substantial number of these diseases, such as brucellosis, tuberculosis, and *Erysipelothrix*, are of zoonotic concern (Box 2–9 and Table 2.5). Some of those same diseases and others such as the marine caliciviruses are of economic concern because of their potential transfer to livestock.

Disease in the California sea otter (Box 2–10) is especially noteworthy because of the recent emergence of infectious disease as a factor inhibiting population recovery for this species.[141] Zoonoses are among the diseases found.

Marine Birds

Globally, a wide variety of diseases have been associated with avian mortality, including birds within the marine environment. Remote areas such as Antarctica and the Galapagos Islands off the coast of Ecuador have been impacted in addition to other areas. Disease emergence is thought to be a factor in the major decline of common eider populations since the late 1980s in the Gulf of Finland.[8,142]

Mass mortality disease events on breeding colonies and other epizootics of disease along migrational routes and on wintering areas are taking a heavy toll on birds within marine environments. Avian cholera (*Pasteurella multocida*), a prominent infectious bacterial disease of **poultry** serves as an example. During the past two decades, major outbreaks of avian cholera have struck wild bird populations in marine environments of Europe, Africa, Antarctica, and North America (Table 2.6). Collectively, these events clearly illustrate the emergence of avian cholera as a mortality factor in marine birds, in addition to its impact on birds in freshwater environments.[143]

Infectious bursal disease (IBD) is a disease of domestic poultry[147] that appears to be emerging in marine birds. Exposure to IBD has been documented by the finding of antibodies to the causative viral agent (IBDV) in sera collected from Emperor and Adelie penguins in Antarctica,[144,145] from spectacled eiders nesting in a remote area of western Alaska,

Table 2.5. Marine mammals known to harbor pathogens that have caused disease in humans.

Disease	Agent	Primary marine mammals affected[a]								
		Whales	Porpoises	Dolphins	Seals	Sea lions	Sea otters	Walrus	Polar bear	Manatee
Poxvirus infection	Virus	●	●	●	●	●	○	○	○	○
Influenza	Virus	●	○	○	●	○	○	○	○	○
Calicivirus infection	Virus	●	○	●	●	●	○	●	○	○
Brucellosis	Bacteria	●	●	●	●	●	●	●	●	●
Erysipelothrix	Bacteria	●	●	●	●	○	○	○	○	○
Leptospirosis	Bacteria	○	○	○	●	●	○	○	○	○
Mycobacterial disease	Bacteria	●	○	●	●	●	○	○	○	○
Mycoplasmosis	Bacteria	○	○	○	●	●	○	○	○	○
Salmonellosis	Bacteria	●	○	●	●	●	○	○	○	○
Vibriosis	Bacteria	●	○	●	●	●	○	○	○	○
Q fever	Rickettsia	○	○	○	●	○	○	○	○	○
Lobomycosis	Fungus	○	○	●	○	○	○	○	○	○
Trichinosis	Parasite	● [b]	○	○	○	○	○	●	●	○

● Animal harbors pathogens; ○ Animal does not harbor pathogens

[a] Not all species infected have been associated with the transmission of these diseases to humans (see Box 2–8).

[b] Beluga whale meat associated with human cases in Greenland, but occurrence in whales is infrequent.[454]

Box 2–9

Marine Mammals and Zoonoses

Marine mammals are some of the world's most charismatic wildlife and are also an important source of food and other needs of native peoples. These factors result in direct interfaces between humans and marine mammals. Responses to stranded marine mammals, associated on-site rescues, and rehabilitation programs are common ways humans can have contact with animals disabled due to various causes, including infectious disease. Also, the rearing and maintenance of cetaceans and pinnipeds in captivity for performance behaviors and other attributes provide potential exposure by their handlers and veterinarians to infectious diseases. Subsistence and cultural uses involving the harvesting, processing, and consumption of meat from seals and other species are additional contact situations.

Nevertheless, despite the variety of human interfaces with marine mammals, the transmission of infectious disease to humans has been minimal. Differences in the strains of some of the pathogens that affect marine mammals and those that affect humans are factors. However, disease transmission does occur and infectious disease emergence and resurgence in marine mammals are accompanied by a variety of causes of human disease acquired from these species.

Viral Diseases

To date, viral diseases of marine mammals have not been a major source for human disease. Sporadic cases of several well-established marine mammal viral diseases have occurred and will continue to do so. Whether or not these agents will become a greater source for human disease and whether or not novel viral diseases will emerge over time due to environmental change are yet to be seen.

- Poxviruses—It is generally accepted that humans may acquire parapoxvirus infections through contact with seals,[437] but little documentation exists. In one instance, isolated, self-resolving lesions appeared on the hands of two of three people handling infected grey seals.[438]
- Calicivirus—A growing body of circumstantial evidence points to the zoonotic potential of caliciviruses that are associated with handling infected animals.[439] Deep skin lesions have appeared in a laboratory worker conducting San Miguel sea lion virus studies and antibody responses to this virus have been detected among coworkers.[437] Also, there is a possible 1974 case involving "blisters on the eyes" of a biologist that handled a northern fur seal with flipper lesions suggestive of San Miguel sea lion virus.[439]

The greatest significance of marine caliciviruses is not their low zoonotic potential or their impacts on marine mammals. Instead, it is their role as a significant pathogen of terrestrial livestock. Calicivirus serotypes circulating in southern California marine populations during the 1930s to 1950s are thought to be the origin of outbreaks of vesicular exanthema of swine that swept across the USA. Eradication of this disease from the USA was accomplished by 1956 after expenditures in direct costs of $39 million.[439,440] The host range for these viruses is now known to encompass aquatic and terrestrial mammals, ocean fish, reptiles, amphibians, and insects,[439] in addition to humans.[440]

- Influenza—Harbor seals are associated with human influenza and have caused localized infection in people handling these animals. In one situation, a handler's eyes became infected following a sneeze by an infected seal; other conjunctival infections have also followed known contamination of the eyes.[441] Recent findings indicate that seals serve as reservoirs for influenza B viruses that have circulated previously in the human population.[442] Also, seals may have a role in genetic reassortment of influenza A viruses; those viruses capable of infecting and replicating in seals may be more adapted to mammalian than to avian hosts.[101]

Photo by Milton Friend

Bacterial Diseases

The great majority of bacteria isolated from marine mammals are not a public health concern. Nevertheless, a few problem pathogens exist and many others are capable of infecting persons with compromised immune systems. Bite wounds are a common means for human infections by marine mammals,[437] and virtually dozens of potential infectious bacteria found in marine mammals have the potential to be transmitted to people by this means. Wound infections following close contact with marine mammals also broadens the potential for transmission of bacterial diseases from marine mammals to people.[103]

- Brucellosis—Beginning in the 1990s, there have been increasing reports of isolations of *Brucella* spp. from marine mammals and increased serological evidence of exposure to *Brucella*. These reports are from the United Kingdom, the USA, Canada, Norway, and Antarctica.[102] A case in a researcher working with *Brucella* strains recovered from marine mammals[443] and two community-acquired human infections with marine mammal-associated *Brucella* spp.[444] emphasize the potential zoonotic aspects of these organisms.[102] Recent isolations from stranded seals at necropsy, documented abortion in dolphins, and other findings strongly suggest the need for caution when handling animals in rehabilitation centers, working on seal rookeries, and the potential for exposure of native peoples who use seals as a food source.[102,103,106,135,437]

- Erysipelothrix—The potential for human infection by *Erysipelothrix rhusiopathiae* from infected marine mammals should not be underestimated. This organism has been isolated from the teeth or gums of elephant seals and northern fur seals, from tissues of stranded pinnipeds and cetaceans, and from many species of captive cetaceans.[102] Isolations also have been made from 12 of 116 bite wounds in handlers of marine mammals.[445]

- Leptospirosis—Veterinarians and others contacting tissues and fluids from infected animals during necropsy have become infected by *Leptospira interrogans*.[437] Transmission to humans can occur by contaminated water, urine, and tissues,[103] thereby, providing multiple potential routes for exposure at wildlife rehabilitation facilities.

- Tuberculosis—*Mycobacteria* spp. are the causative agents of several types of infections, including tuberculosis in humans and animals. Not all *Mycobacteria* cause the type of infection known as tuberculosis nor are all species within this genera of bacteria pathogenic for humans. Reports of tuberculosis in pinnipeds have increased during recent years; isolates from captive pinnipeds (1985–1986), wild pinnipeds (1989–1991), and an infected seal keeper (1988) are all identical. This is a unique strain of *M. bovis* that should be considered part of the *M. tuberculosis* complex.[564] In addition, a seal trainer had a unique strain of *M. bovis* that also was isolated from seals that died of tuberculosis.[446] Cases of cutaneous mycobacteriosis in a manatee and its handler have been attributed to *M. chelonei*.[437] Reports from the 1970s indicate that a dolphin trainer developed *M. marinum* after a dolphin bite[447] and an additional human infection developed after a seal bite.[446]

- Mycoplasmosis—“Whale finger” and “seal finger” are long-standing occupational maladies. The causative agent(s) have been elusive for decades despite the common occurrence of these conditions among whalers and sealers;[448] the Canadian Inuit and others living along coastal Canada, including the Maritime Provinces;[449] and among seal trainers.[450] A 1950 survey of a Norwegian sealing fleet disclosed over 10 percent of the individuals with cases of seal finger.[450,451]

Photo courtesy of the U.S. Fish and Wildlife Service

A 1990 case resulted in the isolation of *Mycoplasma phocacerebrale* from the front teeth of a healthy seal and from the finger of a woman bitten by the seal. These findings suggest that *Mycoplasma* is the cause of seal finger. The organism isolated in the 1990 case was first isolated in 1988 from diseased seals involved in the morbillivirus epizootic in the North and Baltic Seas. Also, a biologist contracted “seal finger” from the mouth of a sedated polar bear he handled.[449] Seals and polar bears are the only known causes of *M. phocacerebrale*.[437]

- Vibriosis—A variety of pathogenic species of vibrios that are known to cause severe or fatal infections in humans are present in the marine environment. Some of these organisms are frequently encountered in cetaceans and less commonly in pinnipeds. Human exposures to these organisms most commonly occur through the ingestion of raw shellfish and by physical contact with marine waters with elevated levels of these bacteria.[437] The greatest human risks for infection by marine mammals is through wounds and abrasions in the skin of people handling tissues from infected animals.

- Salmonellosis—Various species of *Salmonella* have been isolated from cetaceans and pinnipeds.[103] The greatest risks for human disease appear to be associated with consumption of meat from these animals. An overall attack rate of 40 percent occurred during one event in an Alaskan Eskimo village of 265 people. Whale meat was the source of the *S. enteritidis* gastroenteritis outbreak in that village. Whale meat has been implicated in other foodborne epidemics including an event in Japan in which 172 of 178 people who ate the meat became ill from *S. enteritidis*. Other events have occurred in Alaska and in Greenland.[452]

Rickettsial Diseases

Rickettsia are a specialized type of bacteria typically found in the gut of **lice**, fleas, ticks, and mites that vector the transmission of a variety of diseases caused by these microscopic life forms. Typically, rickettsia have not been associated with disease in marine mammals nor have marine mammals been a source for human infections.

- Q Fever—*Coxiella burnetii*, the causative agent of Q fever, was isolated in 1998 from the placenta of an adult female Pacific harbor seal at necropsy (seal died of other causes). This finding is the first record of infection by *C. burnettii* in a marine mammal and raises concern about the potential for zoonotic transmission to wildlife rehabilitation center workers that may be exposed to placental tissues or newborn seal pups.[139]

Fungal Diseases

Direct transmission of fungal diseases from marine mammals is infrequent to rare because the vegetative stages of fungi generally found in diseased marine mammals are usually not infective for humans.[437] However, dermatomycosis (fungal infections of the skin) and some other fungal diseases may be transmitted during close contact situations.[103]

- Lobomycosis—Lobo's disease is a cutaneous-subcutaneous chronic granulomatous disease resulting from infection by the fungus *Loboa loboi* (*Lacazia loboi*). This disease has primarily been reported in people living in Central and South America, especially the Amazon region of Brazil. Infection also occurs in bottlenose dolphins from the Atlantic Ocean and the Gulf of Mexico.[453] A single instance of direct transmission from an infected dolphin to a dolphin handler was documented during the 1980s.[437]

Photo courtesy of the U.S. Fish and Wildlife Service

Parasitic Diseases

In general, parasites of marine mammals are not an important source for human infections. However, native peoples and others that use marine mammals for food may become infected with several species of nematodes (roundworms), such as hookworm and anisakis. Polar bear and walrus meat are potential sources of trichinosis because these species are part of the sylvatic cycle for *Trichinella* in the Arctic.[140,454]

Box 2–10 Infectious Disease and the Southern Sea Otter

Photo by Milton Friend

The southern sea otter is a California coastal species listed as threatened by the U.S. Fish and Wildlife Service in 1977. After experiencing steady but slow population growth since the late 1970s, in 1995 their population declined substantially, causing a reversal in plans for delisting this species from threatened status.[455] Disease emergence is an important source of mortality for this species and appears to be a factor retarding population recovery.

Sea otter mortality was investigated by the California Department of Fish and Game beginning in 1968. By 1989, nearly 1,700 carcasses had been evaluated, and more than half died from undetermined causes. Beginning in 1992, supplemental evaluations consisting of about 50 sea otter carcasses per year for 5 years were necropsied by pathologists at the National Wildlife Health Center (NWHC) and associated laboratory analyses were conducted to determine the causes of death. In contrast to the findings from 1968–1989, infectious disease was found to be the primary cause of death.[141] Nearly 40 percent of the sea otters necropsied at the NWHC died from parasitic, fungal, or bacterial infections.[455]

Acanthocephalan parasites (*Polymorphus* spp.) are the most common cause of death. Historic evaluations indicate that, in the past, the parasites causing this mortality were only found in small numbers within individual animals and that few otters were infected by these parasites. An increasing number of sea otters have now acquired large numbers of *Polymorphus* spp., along with the nonpathogenic species of acanthocephalans (*Corynosoma enhydri*). The findings of protozoal encephalitis and the fungal disease coccidioidomycosis[141] are somewhat unexpected. *Toxoplasma gondii* and *Sarcocystis neurona* are the protozoan parasites associated with the encephalitis.[456,457] Generally, both agents are associated with terrestrial rather than aquatic species.

Toxoplasmosis is typically a zoonosis associated with cats. Infections are believed to result from cat feces containing *T. gondii* oocysts that enter the marine environment through stormwater runoff. Otters eat invertebrates (i.e., mollusks) that may have ingested the oocysts.[456] This supposition is supported by the finding that otters sampled between 1997 and 2001 near areas of maximal freshwater runoff into the marine environment were about three times

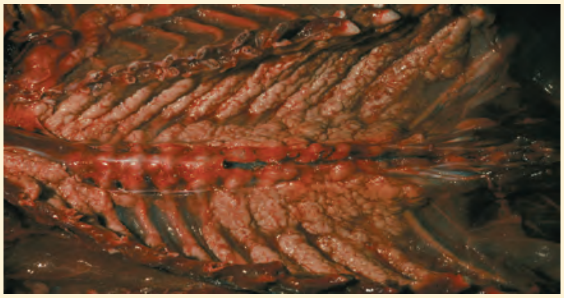
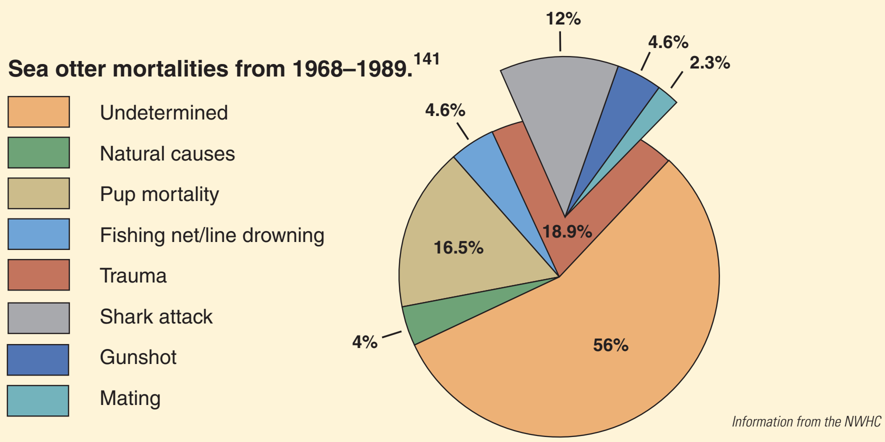


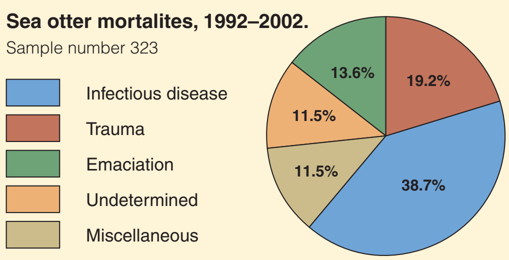
Photo by James Runningen

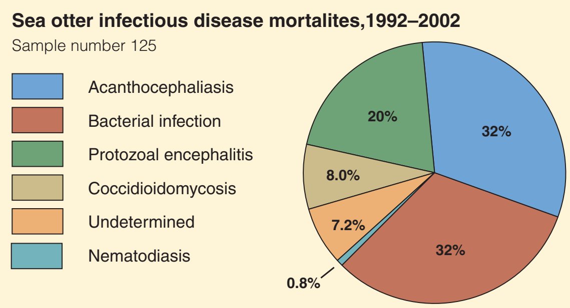
Coccidioidomycosis infection.

Photo by James Runningen

Acanthocephalan infection.







more likely to be seropositive for *T. gondii* than otters sampled in areas of low flow.[458] A similar pathway involving opossum feces containing *S. neurona* sporocysts is thought to be the route for infection of that parasite.[457,459]

Coccidioidomycosis is also a land-based disease of mammals. The causative fungus, *Coccidioides immitis*, is found in soil and is the source of San Joaquin Valley fever of humans. Only one case of this disease had previously been reported in a sea otter (1976) prior to the eight cases diagnosed during the NWHC evaluations.[141] The pathology seen is indicative of inhalation exposure and suggests that wind-borne spores from nearby land areas are the source for these infections.[460]

It is not known how much of the undiagnosed mortality during the period of 1968–1989 was due to infectious disease. Early necropsies were primarily conducted in the field by California Department of Fish and Game marine biologists. Small numbers of those animals were also evaluated under laboratory conditions by physicians and by veterinarians associated with the Monterey Bay Aquarium.[461] It is likely that those individuals would have diagnosed acanthocephalan peritonitis and coccidioidomycosis because of the severity of gross lesions associated with these diseases. Some of the miscellaneous bacterial infections encountered during the NWHC evaluations may not have been detected because of the limited amount of bacteriology done in association with those investigations. Nevertheless, it is reasonable to assume that much of the infectious disease encountered in the southern sea otter is of recent origin. Also, it is noteworthy that multiple infectious diseases are involved rather than a single disease, suggesting that environmental changes are providing new opportunities for sea otters to encounter potential disease agents.

Table 2.6. Examples of avian cholera *(Pasteurella multocida)* epizootics in marine environments.

Continent/ country	Geographic area	Primary species affected	Year of inital event	Comments
North America				
Canada	East coast of Quebec	Common eider	1964	Breeding colonies periodically experience epizootics.[324,468]
USA	East coast of Maine	Common eider	1963	Breeding colonies periodically experience epizootics.[469,470]
	Chesapeake Bay	Long-tailed duck (old squaw), white-winged scoter, other waterfowl	1970	Large-scale winter and spring epizootics killing tens of thousands of birds every few years (a 1994 epizootic killed more than 80,000).
South America				
Chile	Iquique	Marine ducks	1941	Large-scale epizootic in unspecified marine ducks on beaches of Iquique; lesser numbers of pelicans and loons involved.[471]
Europe				
The Netherlands	Vlieland	Common eider, herring gull, black-backed gull	1977	First occurrence in 1945; heavy mortality in winter populations from 1977 until 1980; breeding colony epizootic in 1984.[472]
Denmark	Coast of Hov; Island of Hov Ron, other nearby areas	Common eider, herring gull, other gulls and waterfowl, oystercatcher, cormorant	1996	Spring epizootic followed by mass mortalities among breeding female eiders; mortality in affected breeding colonies close to 90 percent of breeding age females.[473,474]
Africa				
South Africa	Dassen Island	Black-backed gull	1951	*Pasteurella aviseptica* (*P. multocida*) outbreak.[475]
	Coast of western part of South Africa	Cape cormorants	1991	Large-scale mortality event that killed more than 14,500 adults; 16 percent mortality of breeders on Dassen Island and 8 percent overall for the 8 islands involved.[476]
Antarctica	Palmer Station	Brown skua	1979	See citation.[477]
New Zealand	Campbell Island	Rockhopper penguin	1985	Chicks are primary age-class impacted; avian cholera found in four separate colonies on the Island; first report of this disease in this species.[478]

and in nesting common eiders and herring gulls in the Baltic Sea.[146] Investigators were determining the causes of mass mortalities and population declines in those species when they discovered the presence of IBDV. In chickens infected at an early age, IBDV causes severe, prolonged immunosuppression.[147] A similar host response in wild birds would enhance their susceptibility to other infectious diseases in addition to any direct mortality resulting from IBD.

The long-tailed duck is also experiencing population declines. Investigators isolated an adenovirus from dead and live ducks while investigating mortality of this species in 2000 in Alaska.[148] They found evidence of a greater frequency of exposure to the virus in live ducks at the mortality site versus those at a reference area, suggesting the virus was closely associated with the mortality event investigated. The role of the virus in relation to the decline of long-tailed ducks in Alaska since the 1970s is unknown.

The causes for some mass mortality events of marine birds remain unknown even though they are recurring and the subject of considerable investigation. Numerous examples can be found in the wildlife mortality databases of the U.S. Geological Survey's National Wildlife Health Center. For example, during the winter of 2000, several hundred Atlantic brant died along the New Jersey coast. Despite intensive field and laboratory investigations, the cause for this mortality and a similar event that followed could not be determined. Similar results have been associated with repeated **seabird** mortality off the coast of Alaska, Washington and Oregon, for loon mortality along the Florida Gulf coast, and for a number of other large-scale mortality events.[16]

Freshwater Aquatic Environments

Amphibians

Disease emergence and reemergence in amphibian populations (Fig. 2.12) has received recent attention because of the global distribution of mass mortalities;[11,149–153] associations drawn between environmental quality for humans and amphibian health status;[12] media coverage of amphibian deformities;[154] and debate within the scientific community relative to the role of disease versus other factors in amphibian population declines.[152,155] The global distribution of diseases as a cause of amphibian mass mortalities establishes diseases as a contributing factor to population declines and to the disappearance of amphibian species. The magnitude of amphibian population declines is such that this problem has been identified as one of the most important emerging wildlife conservation issues of the latter part of the 20th century.[12]

The fungal disease chytridiomycosis and infections by ranaviruses are commonly associated with mass mortalities of amphibians[12] but are not the only emerging diseases involved (Table 2.7). Chytridiomycosis (Fig. 2.13) is caused by infection of the skin with chytrid fungi.[11] This class of fungi is ubiquitous in nature and has important functional roles in ecosystem dynamics.[149] The fungi causing disease

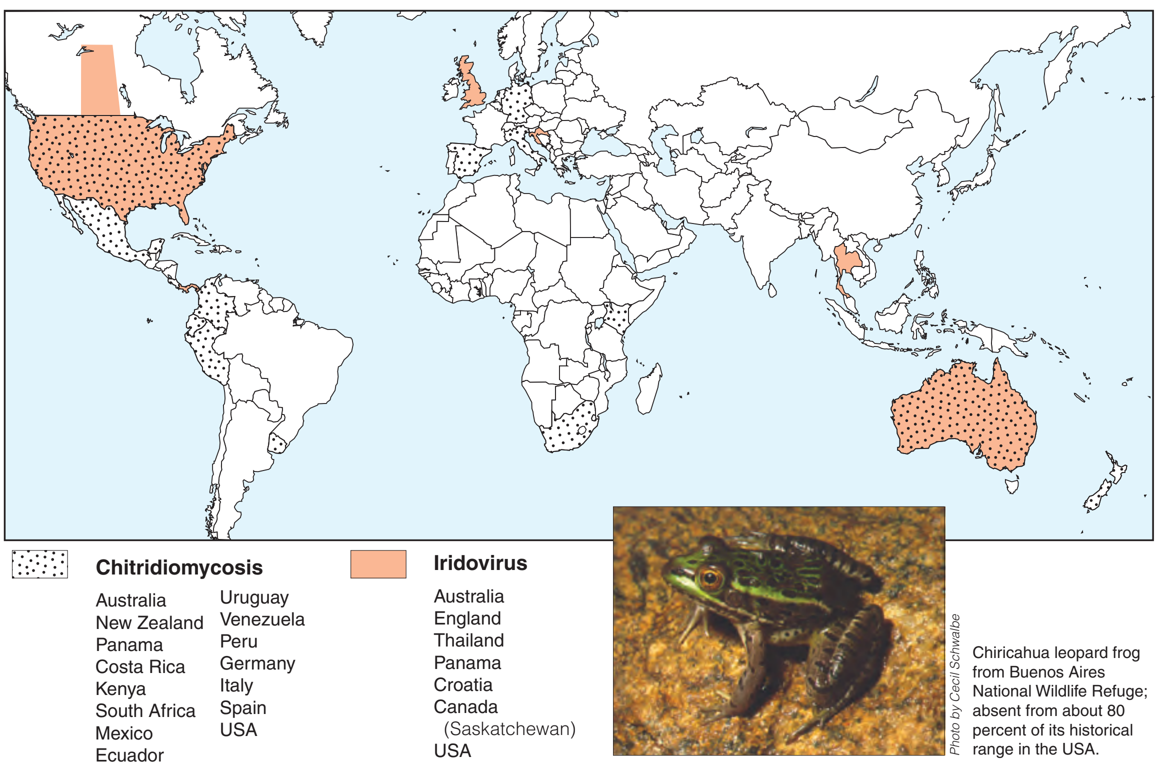


Figure 2.12 Reported global distribution of chytridiomycosis and ranaviral (iridovirus) disease in wild amphibian populations.[12]

Table 2.7. Emerging and enzootic infectious diseases of amphibians (contributed by D.E. Green, U.S. Geological Survey).[a]

Disease/agent	Type	Date first observed	Primary hosts	Geographic area	Comments
Frog virus-3 (FV-3) and tadpole edema virus (TEV)	Ranavirus	c. 1963	Northern leopard frog, bullfrog, wood frog, spotted salamander, others	Upper Midwest and Eastern USA	• FV-3 first isolated amphibian ranavirus and type-species of the genus; isolated from cancerous renal tissue but not associated with morbidity or mortality.[479] • TEV first ranavirus associated with mass mortality of amphibians;[480] numerous large die-offs of more than 10 species from Maine to Minnesota from 1995–2002.[157,565]
Redwood Creek ranavirus	Ranavirus	1991	Northern red-legged frog (tadpole), stickleback fish	California, USA	• Three virus isolates associated with sick and dying tadpoles and fish over 3 years.[481]
Tiger salamander viruses	Ranavirus	c. 1995	Tiger salamanders	Western USA and Saskatchewan, Canada	• Recurring mass mortality of larval and neotenic salamanders in cattle tanks,[482] reservoirs, and lakes;[483] die-offs may kill thousands at a site.[565]
Bohle iridovirus (ranavirus)	Ranavirus	c. 1989	Ornate burrowing frog	Queensland, Australia	• Die-off of young captive frogs.[484]
Unnamed English ranaviruses	Ranavirus	c. 1993	Common European frog	England	• Recurring widespread die-offs of adult frogs in garden ponds.[485]
Pig frog ranavirus	Ranavirus	c. 2000	American pig frog	China	• Recurring mass mortalities of captive pig frogs raised for food.[486]
Other ranaviruses (isolates)[b]	Ranavirus	1996–2002	Numerous species	USA (10 states)	• Numerous, occasionally recurring, mass mortality events in larvae of more than 10 species of true frogs, chorus frogs, mole salamanders, and newts,[157,487] often killing thousands.
Chytridiomycosis (chytrid fungus)	Fungus	c. 1974	Frogs, toads	Global	• First identified in late 1990s in zoo and free-living frogs and toads in USA, Panama, and Australia; recently detected in museum animals involved in die-offs in mid-1970s.[11,151] • Causes rapid population declines even at pristine sites; occurrence corresponds temporally with onset of global amphibian population declines and some amphibian extinctions.[157] • Molecular studies indicate global isolates are very similar, indicating it is a newly emerged pathogen.[488]
Watermold infection (Saprolegniasis)	Fungus	c. 1993	Toad eggs	Oregon, USA	• Cause of massive destruction (1 year's production) of toad eggs;[439] rapidly invades infertile and dead eggs killed by other agents.
Ichthyophonus infection (Mesomycetozoa)	Fungus	c. 1983	Frogs, newts, salamanders	Eastern USA, Canada	• Primarily a fish disease, but causes three types of disease in amphibians: inapparent infections, swollen rumps in frogs and newts, and rarely, deaths in adult frogs.[565,566]

Table 2.7. Emerging and enzootic infectious diseases of amphibians (contributed by D.E. Green, U.S. Geological Survey)[a]—Continued.

Disease/agent	Type	Date first observed	Primary hosts	Geographic area	Comments
Dermosporidium infection (Mesomycetozoa)	Fungus	c. 1980	Toads	Eastern USA and California	• Nonlethal (so far) infection of adult toads causing skin pustules; may be related to *Dermocystidium* of European amphibians.[151,565,567]
Dermocystidium infection (Mesomycetozoa)	Fungus	c. 1910s	Frogs, toads	Europe	• Apparently nonlethal infection causing skin pustules.[568]
Chlamydiosis	Chlamydia	1980s?	African clawed frogs	Global?	• Lethal and occasionally nonlethal disease of captive clawed frogs associated with feeding raw beef liver; one report in free-living giant barred frog in Australia.[490]
Perkinsus-like infection (taxonomic status uncertain)	Protozoa?	1999	Tadpoles of true frogs	Alaska, Virginia, Minnesota, Mississippi, North Carolina, New Hampshire, USA	• Newly identified emerging lethal systemic infection of tadpoles only; often associated with massive die-offs.[565] • Molecular sequencing places organisms with the oyster pathogen *Perkinsus* sp.
Anchorworms	Copepod	Unknown	Bullfrog tadpoles	Global?	• Primarily a parasite of fish; also an infrequent cause of morbidity and mortality in larval and adult amphibians.[158]
Leeches	Leech	Unknown	Frogs, toads, salamanders	Australia, Canada, Germany, USA (probably global)	• Usually innocuous, but may kill tadpoles in USA and Canada; associated with leg malformations in Germany.
Ribeiroia infection	Fluke	1990s	Frogs, toads, salamanders	USA, Canada	• Immature stages (cercaria) kill large numbers of captive tadpoles but deaths in free-living tadpoles have not been diagnosed; major cause of leg malformations in frogs and the only known cause of extra legs.[158,492]
Malformations	Multiple	1995	Frogs, toads, salamanders	USA, Canada	• Unusually high prevalence of deformed frogs were found in most states after initial media reports in 1995.[154,565] • A wide range of deformities found;[154,159] main cause in Americas is the parasite, *Ribeiroia* sp.[491,492] but ultraviolet light causes leg deformities in experiments.[493] • Almost no chemicals have been properly tested experimentally to determine their role in malformations.

[a] National Wildlife Health Center, U.S. Geological Survey.

[b] Isolates differ from tiger salamander virus and FV-3 by restriction fragment length polymorphism analysis.

USGS file photo

Figure 2.13 A tiger salamander with a skin ulcer caused by iridovirus.

in amphibians have been placed in a new genus, *Batrachochytrium*,[156] and have been responsible for mass mortalities of amphibians on several continents.

Chytrid epizootics have occurred at numerous locations within the USA (Fig. 2.14) and because of their insidious nature may easily be overlooked.[157] The causative agent, *B. dendrobatidis*, has been reported in more than 75 species of amphibians captured worldwide in the wild. Forty-seven of those species are from Australia. Other reports are from Europe, Africa, South America, Central America, and North America.[150] It is not known what has triggered epizootics of this disease; however, experimental studies have resulted in 100 percent mortality in conditions where uninfected amphibians remained healthy, thereby suggesting that predisposing immunosuppression is not a requirement for disease in individual animals or for epizootics.[149]

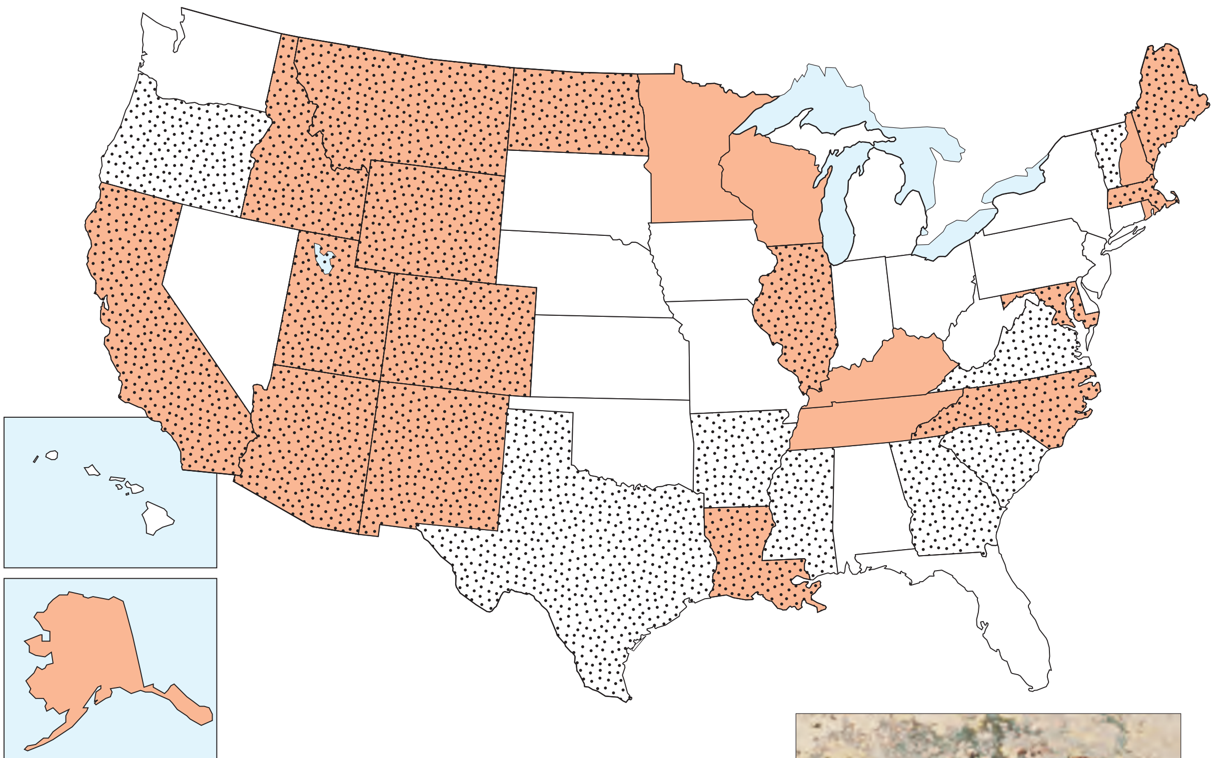


Photo by Stephen Corn

Boreal toad from Rocky Mountain National Park, Colorado; the species has undergone about an 80 percent decline in the southern Rocky Mountains.

Figure 2.14 Reported distribution as of July 2004 of chytridiomycosis and ranaviral (iridovirus) disease in wild populations of amphibians in the United States. (USGS National Wildlife Health Center data; D.E. Green, personal communication.)

Epizootics due to infection by iridoviruses (Fig. 2.15) also have been the cause of mass mortalities of amphibians. These viruses have been isolated from amphibians from 20 states within the USA (Fig. 2.14). Viruses within the genus *Ranavirus* of the family Iridoviridae are the agents involved in these mortalities. These often highly virulent agents cause systemic infections in amphibians. Tadpoles appear to be the most susceptible developmental stage for ranavirus infection and death rates of 100 percent may occur. A variety of viruses, rather than a single agent, are involved (Table 2.7). Some of these viruses appear to be newly emerging as causes for amphibian mortality, while others have been known for some time and are reemerging. Recent **translocations** by humans of amphibians or their egg masses and larvae may be responsible for the dissemination of ranaviral disease.[12]

In addition to the diseases just noted, there is widespread recognition of amphibian malformations (Fig. 2.16). In 1995, a student field trip to a Minnesota (USA) pond disclosed numerous **frogs** with malformations. The publicity associated with those and subsequent findings and the investigations that followed resulted in 38 species of malformed frogs and 19 species of **toads** being reported from 44 states in the USA by 2000 (Fig. 2.17).[154,159] Similar findings have been reported from several Canadian provinces. Multiple factors are involved as causes for these abnormalities.[154,159] Despite this broad geographic occurrence, malformations do not appear to be a major cause for amphibian population declines.[12]

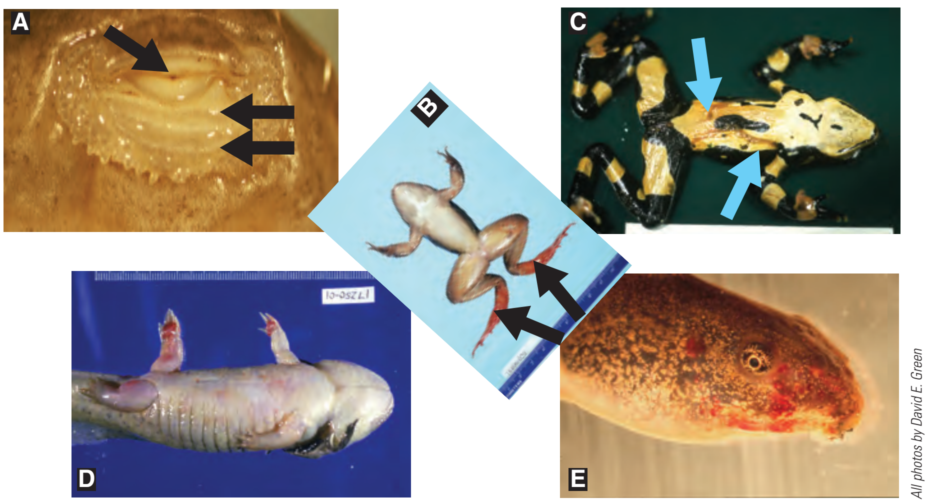


Figure 2.15 (A) Oral disc of tadpole with chytrid fungus infection showing complete loss of black-pigmented keratin from tooth rows and jaw sheaths. (B) Chytrid fungus infection in adult Chiricahua leopard frog showing hyperemia of the feet. (C) Chytrid fungus infection in harlequin frog showing abnormal molting of skin. (D) Larval tiger salamander with Ranavirus infection showing reddening of ventral skin and marked hemorrhages. (E) Wood frog tadpole with Ranavirus infection showing skin hemorrhages.

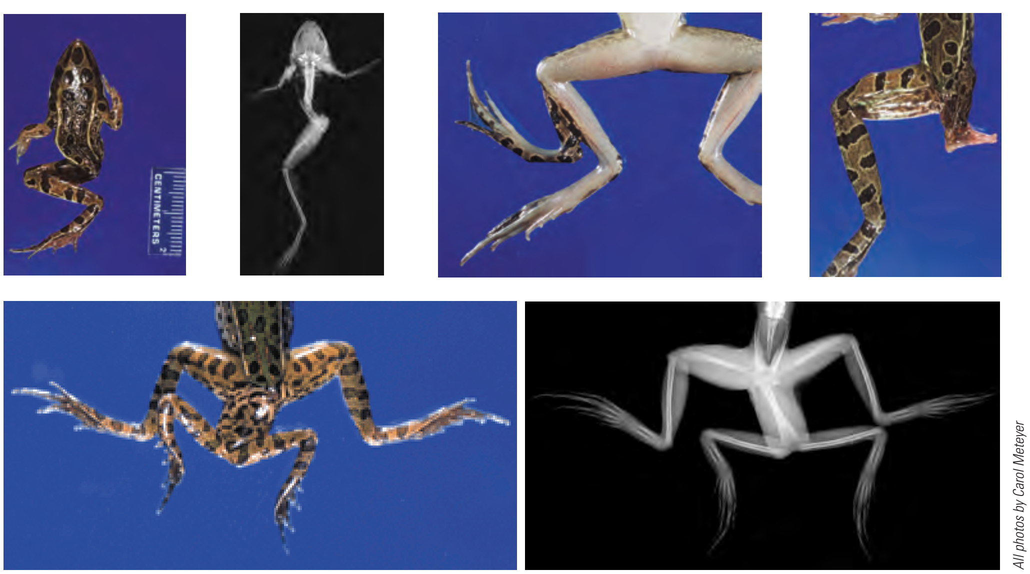


Figure 2.16 Deformities of northern leopard frogs.

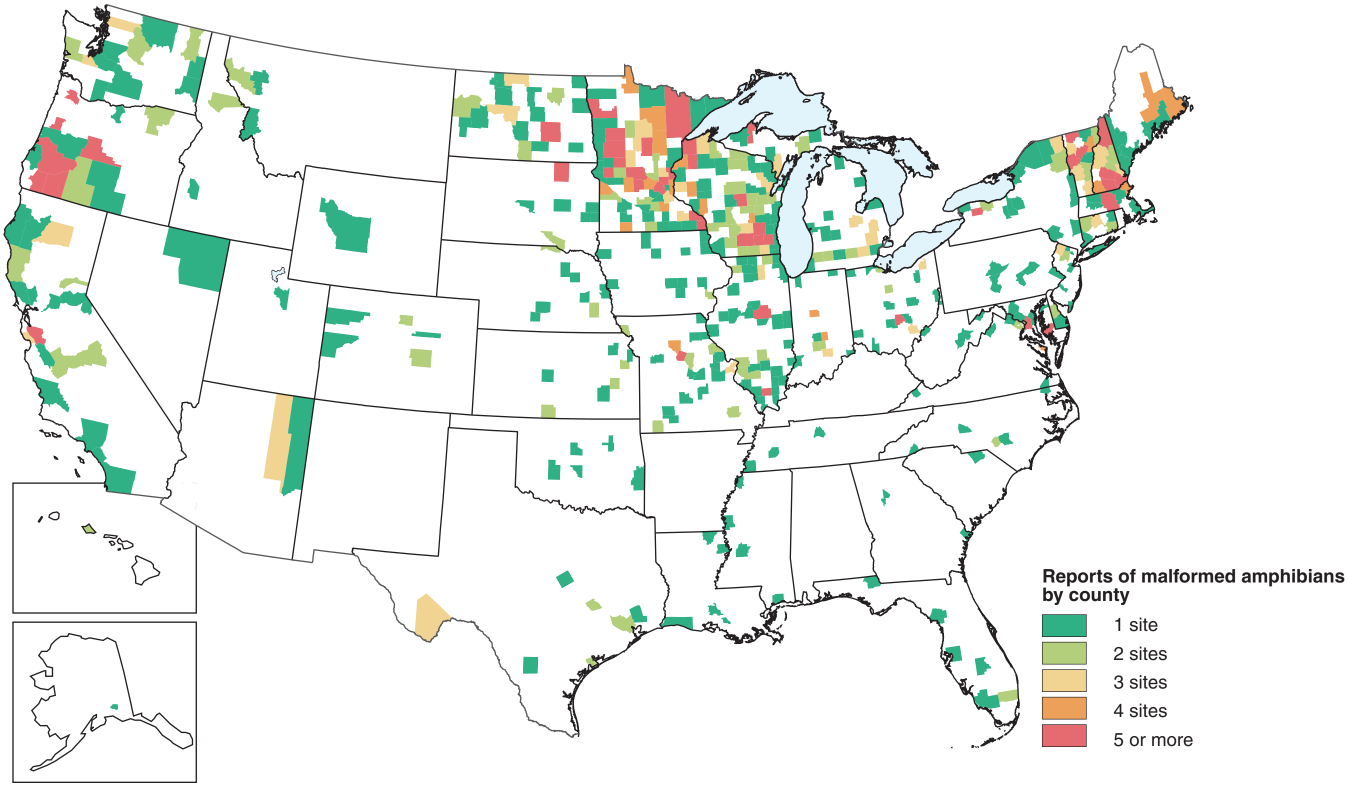


Figure 2.17 United States counties in which amphibian malformations have been reported as of 2003 (data from North American Reporting Center for Amphibian Malformations, National Biological Information Infrastructure).

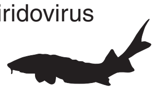
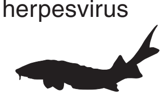
Freshwater Fish

Disease emergence and reemergence are a continual challenge for wild and captive fish populations,[78] and disease often moves freely between both because of human actions associated with the movement of live fish, fish culture, and releases of hatchery-reared fish. For example, the protozoan *Myxobolus cerebralis* causes whirling disease in rainbow trout, but coexists with native European brown trout. Rainbow trout were introduced into Europe near the start of the 20th century[88] and the first cases of whirling disease were seen in 1903.[160] *Myxobolus cerebralis* reached the USA about 1955 in imported frozen trout shipped to Pennsylvania[161] and now affects trout and salmon in at least 21 states.[88] To combat this disease, some fish hatcheries destroy their stock because of the magnitude of losses possible and regulations that prevent the release of fish from infected hatcheries. Whirling disease can decimate wild populations of rainbow trout. In 1994 this disease was introduced into the Madison River in Montana, and the rainbow trout population plummeted from 3,500 fish per mile (1990 evaluation) to 300 per mile by 1994.[162] More recently, whirling disease appeared for the first time in a Wyoming watershed with an important rainbow trout fishery.[163]

Several other notable diseases of **freshwater fish** have also emerged within the USA (Table 2.8). For example, an epizootic disease, spring viremia of **carp**, killed about 10 tons of carp in one lake in Wisconsin.[164] Yellow perch in Wisconsin also have been affected by a new pathogen, the protozoan parasite *Heterosporis* sp.[165]

Aquaculture and hatcheries have been sources for numerous disease introductions and will continue to provide new opportunities for diseases that are brought into those facilities from wild and cultured founder stocks. These diseases accompany fish that are released or escape into the wild from those facilities. Recognition of this problem has resulted in the development of a number of fish health inspection and certification programs for the release of certain types of fishes into some watersheds with the USA, Canada, and other countries. Examples include integrated fish health management in the Great Lakes Basin[166] and the programs of the Office International des Epizooties (OIE). A primary goal for this global organization for animal health is to facilitate international trade in animals and animal products (including aquatic species) while reducing the risk of transfer of serious diseases from one country to another.

Table 2.8. Examples of emerging diseases of freshwater finfish within the USA (contribution of F. Panek, U.S. Geological Survey).[a]

Disease	Type	Period of emergence	Geographic area of concern	Comments
Asian tapeworm (*Bothriocephalus acheilognathni*) 	Parasite (cestode)	1980s	Continental	• Serious exotic parasite that affects many native (USA) cyprinids (minnow family), carp, and some catfish species; probably introduced with grass carp. • Threat to native cyprinids in the Colorado River, including the endangered humpback chub.[494]
Spring viremia of carp 	Virus (rhabdovirus)	Late 1990s	North Carolina, Wisconsin, Mississippi River drainage	• Notifiable foreign animal disease to the Office International des Epizooties (OIE). • Serious threat to aquaculture industry and potentially to native fish populations. • North Carolina aquaculture facility first USA documentation; epizootic in wild carp from the Mississippi River in Wisconsin.[495]
Koi herpesvirus 	Virus (herpesvirus)	1998	Mid-Atlantic States and southern California	• Epizootics involving common carp and koi first appeared in mid-Atlantic area, followed by epizootics the following year (1999) in southern California.[496]
Largemouth bass virus 	Virus (iridovirus)	Mid-1990s	17 southeast and southwest states	• First isolated from largemouth bass from Lake Weir, Florida[501] and linked to largemouth bass mortalities at Santee-Cooper Reservoir, South Carolina.[498] • Transmissible in water and orally.[499]
White sturgeon iridovirus 	Virus (iridovirus)	1988	Oregon, Idaho, California	• Highly virulent, serious threat to cultured white sturgeon. • First isolated from cultured fish in northern California.[500]
White sturgeon herpesvirus 	Virus (herpesvirus)	1989	California, Oregon	• Cause of juvenile mortality among intensively reared white sturgeon populations.[501]
Whirling disease (*Myxobolus cerebralis*) 	Parasite (protozoan)	1990s	Occurs in at least 21 states	• Chronic debilitating disease that is generally considered a disease of cultured trout; several "blue ribbon" trout waters in Colorado and Montana severely impacted during 1990s.[162]

[a] National Fisheries Research Center, U.S. Geological Survey.

Table 2.9. Finfish diseases notifiable to the Office International des Epizooties because of their significance as challenges to aquaculture and wild fish stocks.

Disease	Agent type	Comments
Epizootic hematopoietic necrosis (EHN)	Virus	• Systemic iridovirus (ranavirus) infection caused by three similar viruses; EHN virus (EHNV) is limited to Australia and the other two viruses (European sheatfish virus, European catfish virus) to Europe.[86] • EHNV remains infective for 100–200 days on dry surfaces and in frozen tissue for more than 700 days.[12] • Susceptible host species for the purpose of the International Aquatic Animal Health Code are redfin perch, rainbow trout, Macquarie perch, mosquito fish, silver perch, and mountain galaxias.[502]
Infectious hematopoietic necrosis (IHN)	Virus	• Rhabdovirus with a historic range in western parts of North America; spread to Europe and Far East via importations of infected fish and eggs.[86] • Susceptible host species for the purpose of the International Aquatic Animal Health Code are rainbow/steelhead trout, sockeye, Chinook, chum, yamame, amago, coho, and Atlantic salmon.[502]
Oncorhynchus masou disease	Virus	• Herpesvirus causing oncogenic and skin ulceration disease; present in Japan and probably coastal rivers of Eastern Asia having Pacific salmon.[86] • Susceptible host species for the purpose of the International Aquatic Animal Health Code are kokanee, masou, chum, and coho salmon, and rainbow trout.[502]
Spring viremia of carp	Virus	• Rhabdovirus; in addition to transmission by fish, parasitic invertebrates, including leeches, can transmit this disease from diseased fish to healthy fish.[86] • Until recently, confined to Europe;[502] now in USA.[164] • Susceptible host species for the purpose of the International Aquatic Animal Health Code are common, grass, silver, bighead, and crucian carp, goldfish, tench, and sheatfish.[502]
Viral hemorrhagic septicemia	Virus	• Disease agent recently classified as a Novirhabdovirus, a new group of rhabdoviruses; until mid-1980s thought to be confined to hatcheries in Europe. Now known to occur in wild fish stocks and in marine environments of North America, part of the Pacific Ocean, North Atlantic, and the Baltic Sea; marine fish isolates from species other than salmonids.[86] • Susceptible host species for the purpose of the International Aquatic Animal Health Code are rainbow trout, brown trout, grayling, white fish, pike, turbot, herring and sprat, Pacific salmon, Atlantic cod, Pacific cod, haddock, and rockling.[502]

The Fish Diseases Commission of the OIE has developed a code and manual to guide disease prevention and within that code has developed lists of "notifiable diseases" (Table 2.9) and "other significant diseases." Notifiable aquatic animal diseases are those considered to be of socio-economic or public health importance within countries involved in the international trade of aquatic animals and products. The focus is on diseases with potential to cause serious damage to the aquaculture industries of those countries or their wild populations of fish, mollusks, and crustaceans.[167] Spring viremia of carp recently entered the USA, and is one of the OIE notifiable diseases.

In some instances, transfer of disease agents may occur via birds feeding in hatchery and wild environments. Indigenous and exotic pathogens also will continue to be introduced into fish populations by other means, such as bait fish used by fishermen, contaminated surfaces of boats, ballast water discharges, and unauthorized fish introductions. The significance of disease introduction to farmed and wild stocks of fish only becomes apparent with time[92] despite the explosive expression of disease that may appear in association with initial disease appearances in fish populations. Disease agents released into aquatic environments may not survive for a variety of reasons or they may also adapt to their new environment in unanticipated ways, sometimes as agents of mass mortality or as a source for high levels of chronic **morbidity** and mortality for species they are able to infect. Thus, disease emergence can appear in different forms and at different times following agent entry into fish populations.

Gyrodactylosis is an example of a parasitic disease on the OIE list of Other Significant Diseases that was not recognized as a problem when the causative parasite *Gyrodactylus salaris* was first noted in Swedish hatcheries at the beginning of the 1950s. More than two decades later, following introduction into Norway, this parasite was found to be highly pathogenic for wild and farmed Atlantic salmon **parr** and **smolt** and several other species of salmonids. It has been found in wild populations from rivers in Russia, Sweden, and Norway, and is present in farmed Atlantic salmon and rainbow trout in several Northern European countries.[86]

A host of infectious agents in addition to those already noted have been identified during the past 3 decades as causes of sporadic mortality or reduced body condition of freshwater fish.[82,168,169] In addition, common, well-established diseases of fish culture continue to appear in new geographic areas and to reappear in areas where the disease had been eradicated. For example, the first occurrence of bacterial kidney disease (*Renibacterium salmoninarum*) in Denmark was documented in 1997 in a rainbow trout hatchery.[170] Infectious pancreatic necrosis virus (IPNV) reappeared in Northern Ireland in 2003 for the first time since 1996.[171] IPNV is one of several emerging pathogens causing serious economic damage to aquaculture around the world, including Scotland where the increase in the prevalence of this virus was 10 percent annually at saltwater sites from 1996 to 2001, and 2 to 3 percent at freshwater sites, except for a 6.5 percent increase in Shetland.[172] Tons of hatchery fish are destroyed to combat these diseases, but concerns exist that prior to disease control actions these pathogens already may have spread to wild fish stocks in those areas.

Human alterations of the environment also provide new opportunities for fish pathogens by creating unique habitats with novel host-agent interactions. The primary fish species of the inland saline Salton Sea in California are all exotics, except for the desert pupfish, and include tilapia, typically a freshwater fish, in addition to marine fish.[173,174] The first report of the flagellate ectoparasite *Cryptobia branchialis* in a highly saline waterbody is from the Salton Sea where it causes heavy infection. The gill function of young tilapia fry is affected to the extent that this parasite may be causing significant mortality.[175] Both the parasite and the fish host are introduced species within a human altered and sustained environment.[176]

Little doubt exists about the significance of disease in wild, as well as cultured, populations of freshwater finfish and of the movement of infectious disease between these populations. Also, some serious fish pathogens, such as viral hemorrhagic septicemia, can move between freshwater and **saltwater fish** species. Greater efforts are needed to minimize the potential for such transfers because of the consequences associated with disease emergence. Disease emergence must be considered in conjunction with the development of transgenic fish, which are being proposed to help meet the growing demands for fish.[177–179]

Waterbirds

Birds in freshwater environments, even if they are only seasonal visitors, have been affected by a broad array of emerging diseases caused by viruses, bacteria, and parasites.[8] Notable viral diseases include duck plague (DP) or duck virus enteritis (DVE) and Newcastle disease (ND). DP is caused by a herpesvirus and only affects waterfowl (ducks, **geese**, and **swans**). This European disease of **domestic ducks** first appeared in North America in 1967. An epizootic within the Long Island, New York (USA) commercial duck industry was accompanied by a small number of deaths in wild waterfowl in close proximity to the commercial duck operations.[180,181] Because of the exotic status of DP and its importance as a disease of domestic waterfowl, a major disease eradication effort was undertaken that included depopulating infected commercial duck flocks. Following an initial period when DP was thought to have been eradicated in the USA, the disease reappeared in captive and feral waterfowl and has gradually spread to many states and several Canadian provinces. The majority of this expansion has occurred during the last two decades of the 20th century (Fig. 2.18). The great majority

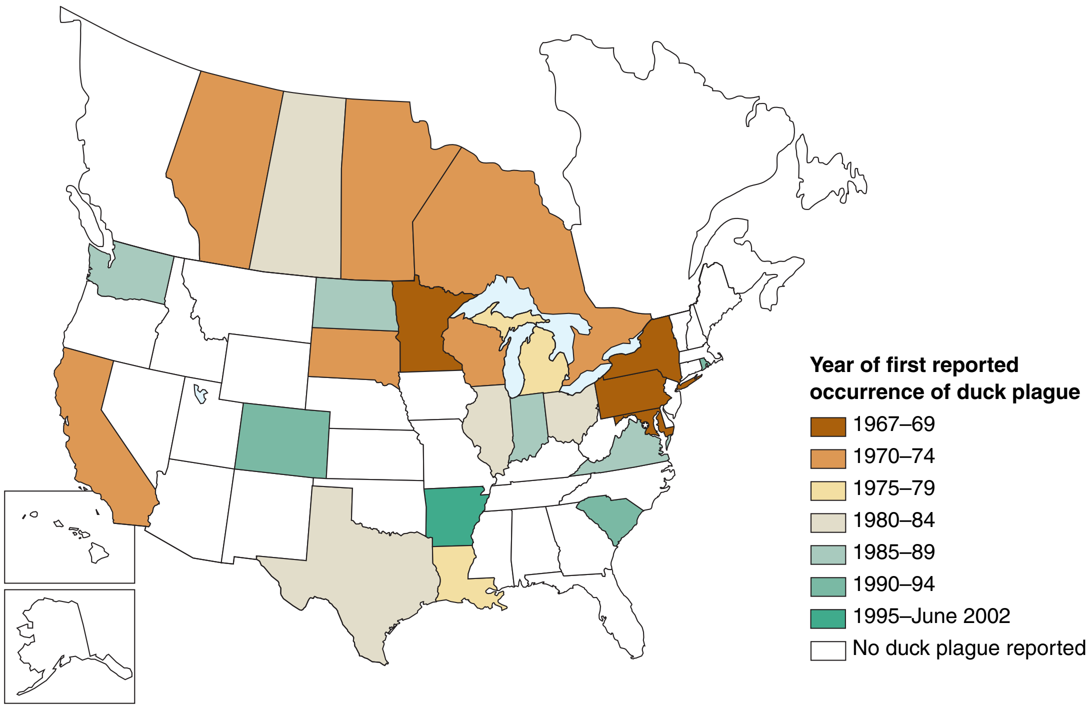


Figure 2.18 Reported North American distribution of duck plague by period of first occurrence.

of DP outbreaks have involved urban/suburban waterfowl, many of which are semicaptive and of mixed breeding involving domestic species. On two occasions, migratory populations have experienced mass mortalities from DP (Fig. 2.19).[182,183]

Double-crested cormorants have been the primary wild bird species victimized by Newcastle disease virus (NDV).[184,334] Highly virulent forms of this virus (velogenic strains) were eradicated from the poultry industries of the USA and Canada during the early 1970s. If velogenic Newcastle disease virus (VNDV) reappears in poultry and other captive species, usually the infected flocks are killed to prevent reestablishment of these strains. A VNDV outbreak causes severe economic impacts for the poultry industry. For example, millions of commercial chickens were destroyed in infected areas of southern California along with some backyard flocks in California and Nevada during 2002 and 2003 as part of the disease eradication effort.

In 1990, ND was determined to be the cause of a mass mortality in cormorants in Canada,[334] and in 1992 a more extensive epizootic swept across the Great Lakes area of North America killing thousands of cormorants, a small number of other waterbirds, and eventually appeared in a North Dakota poultry flock (Fig. 2.20). Additional mortality events followed in cormorant flocks at other locations, including California's Salton Sea (Fig. 2.21), which marked the first mass mortalities west of the Rocky Mountains caused by ND in wild birds.[184] Mass mortalities caused by this disease are rare in wild birds, so the cormorant ND epizootics are especially noteworthy.

Type C avian botulism (*Clostridium botulinum*) (Fig. 2.22) is a bacterial disease that has greatly expanded its historic range within North America during the latter half

Figure 2.19 During the 1975 outbreak of duck plague at Lake Andes National Wildlife Refuge in South Dakota, USA, more than 40,000 mallards died.

of the 20th century and its global distribution during the past three decades (see Figs. 2.1, 2.2). Individual epizootics have killed a million or more birds.[13] Another bacterial disease, avian cholera (*Pasteurella multocida*), has become the most important infectious disease of North American waterfowl (Table 2.10). The North American geographic distribution of this disease in wild birds has expanded greatly since the 1970s[143] and is being reported with increased frequency as a cause of wild bird mortality (Fig. 2.23). Collectively, during most years, avian botulism and avian cholera kill more wild waterbirds than all other diseases combined.

Outbreaks of chlamydiosis (*Chlamydia psittaci*) among wild waterbirds also appear to be increasing.[16] Gulls, waterfowl, white pelican and double-crested cormorant are the primary species associated with recent epizootics (mid-1980s through 2002). This bacterial zoonosis has been a source for infection in biologists handling wild birds[185,186] and is a threat for those that may enter infected bird colonies.

Figure 2.21 Double-crested cormorant chicks that died on the nest from Newcastle disease.

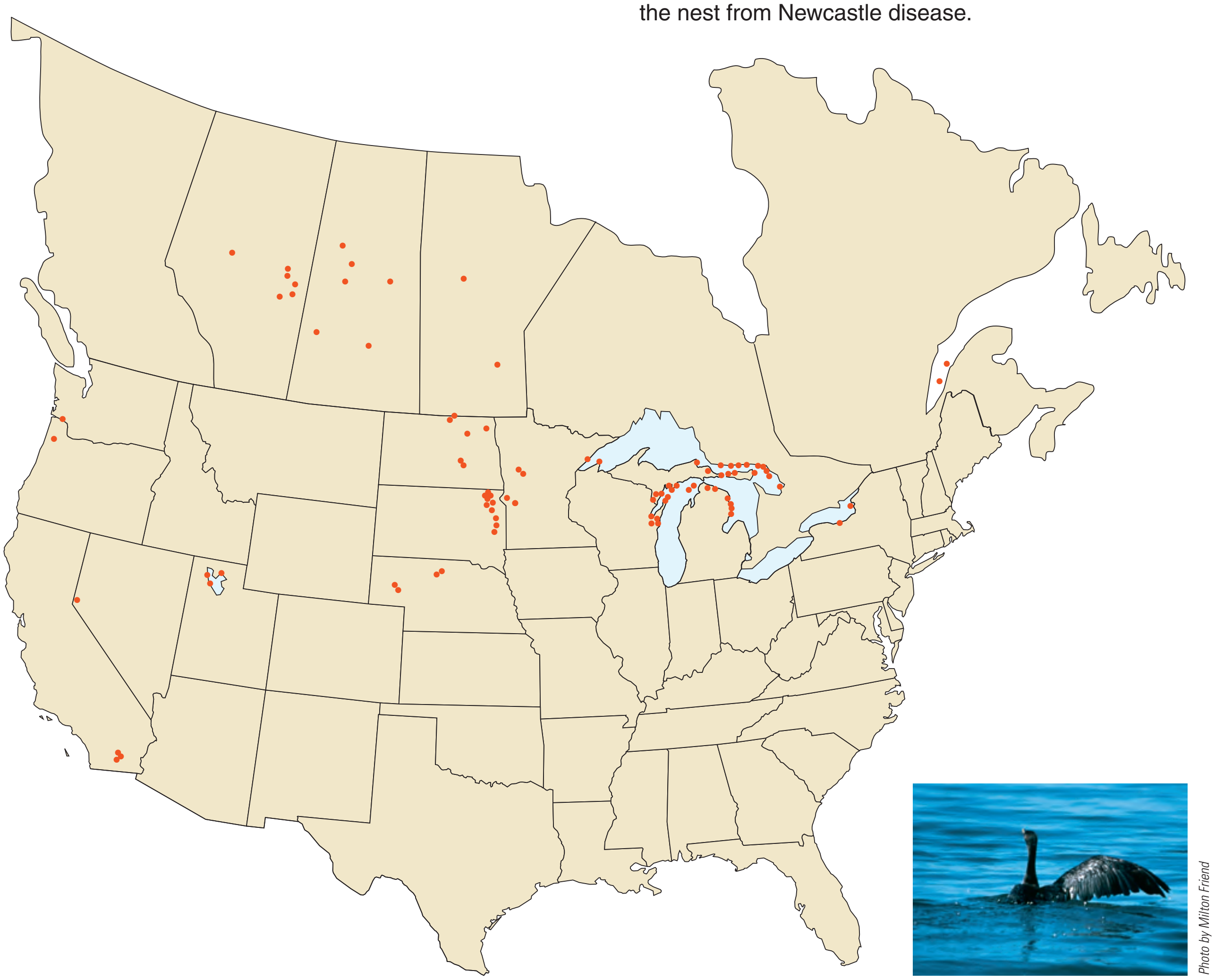


Figure 2.20 Locations in North America where Newcastle disease has caused mortality in double-crested cormorants, 1990–2000.

Table 2.10. Examples of wild bird mass mortalities from avian cholera (*Pasteurella multocida*) in nonmarine environments.

Geographic area	Year	Estimated loss	Primary species affected	Comments
Texas Panhandle, USA	1947	30,000	Ducks	• Wintering area epizootic during winter of 1947–1948;[503] avian cholera first appeared in wild waterfowl in USA in 1944; Texas Panhandle and the San Francisco Bay area, California, were the two sites having simultaneous epizootics that winter.[143]
	1956	60,000+	Ducks	• Wintering area epizootic at Muleshoe National Wildlife Refuge.[504]
San Francisco Bay area, California, USA	1948	40,000	Ducks, geese, swans	• Wintering area epizootic; freshwater ponds and marshes sites for most mortality.[505,506]
Missouri, USA	1963	7,000+	Ducks, geese	• Approximately 7,000 carcasses collected during winter of 1963–1964 at Squaw Creek National Wildlife Refuge; single night mortality of 1,110 snow geese from flock of 20,000 that landed on the refuge.[507]
Florida Everglades, USA	1967	5,000 to 6,000	American coots	• Wintering area epizootic in Everglades National Park; small numbers of other species also died.[508]
Rainwater Basin, Nebraska, USA	1975	25,000	Crow, ducks, geese	• Initial avian cholera epizootic in spring migration stopover area.[509]
	1980	30,667	Ducks, geese	• Actual carcass pickup;[510] total mortality estimated to be 80,000.
	1998	26,225	Ducks, geese	• Actual carcass pickup; total mortality much greater.[16]
Salton Sea, California, USA	1979	9,037	Waterfowl	• Actual carcass pickup; total mortality much greater.[511]
Back Bay, Virginia, USA	1976	25,000	American coots	• Brackish water wintering and migration stopover area.[512]
Saskatchewan, Canada	1988	5,000	Redhead duck	• 4,900 carcasses of 20 species recovered; 75 percent redheads. Epizootic at major molting area; first avian cholera in ducks in Western Canada.[513]
Banks Island, Northwest Territories, Canada	1995	30,000	Snow goose	• Breeding colony epizootic.[514]
	1996	20,000	Snow goose	• Breeding colony epizootic.[514]
Utah, USA	1994	15,000	Ducks	• Fall migration epizootic.[16]
Great Salt Lake, Utah	1998	44,000	Eared grebe	• Fall migration epizootic.[16]
California, USA	1990	12,131	Geese, ducks	• Actual carcass pickup; total mortality much greater. Fall migration epizootic.[16]
	1997	12,500	American coots, waterfowl	• Fall migration epizootic.[16]
	1998	16,062	American coots, waterfowl	• Actual carcass pickup; total mortality much greater. Wintering area epizootic.[16]

American coots are susceptible to a new parasitic disease for the USA. The trematode (fluke) (*Leyogonimus polyoon*) previously had only been known to exist in Europe. In 1996, a mass mortality of American coots was caused by infection by this parasite in a Wisconsin (USA) lake. American coots and common moorhen have died during additional epizootics at that location.[187]

The causes remain elusive for some mass mortalities of wild waterbirds, despite repeated occurrences with recognizable clinical signs and tissue pathology associated with those bird deaths. For example, in 1992 more than 150,000 eared grebes died at the Salton Sea from a malady that has reappeared during most years since then, killing varying numbers of eared grebes each time.[16] This disease condition is readily identifiable by a series of behavioral abnormalities seen in these birds such as coming up on land, gulping of water, and excessive preening.

A condition that causes vacuolation in myelinated central nervous system (CNS) tissue such as brain and spinal cord is affecting bald eagles and several other species of birds, including waterfowl and coots. Microscopically, the lesions of avian vacuolar myelinopathy (AVM) appear as holes in myelinated areas of CNS tissues (Fig. 2.24). About 30 of the bald eagles (65 percent) wintering at an Arkansas (USA) reservoir died from AVM during the winters of 1994–1995 and 1996–1997.[188] Following those initial events, AVM has been documented in several other locations and has caused mortality in additional species[189] (Fig. 2.25). More than 80 bald eagles have been documented to have died from AVM.

Terrestrial Environment

A broad spectrum of diseases has emerged and reemerged as causes of mass mortality of wildlife in terrestrial environments (Table 2.11). The following examples illustrate the scope of diseases relative to the types of species impacted, magnitude of losses, global distribution, and types of infectious agents involved. The rapid geographic spread by several of these diseases has been unprecedented for wildlife populations. Also, their high rates of infection and severity of disease in some species are indicative of novel infectious pathogens entering naive host populations (Table 2.12).

Birds

West Nile fever (WNF) stands out as an emerging disease of wild birds in terrestrial environments and as an emerging viral disease that also affects mammals such as bats, horses, and humans. Following its initial appearance in 1999 in the New York City area (USA), West Nile virus (WNV) appeared

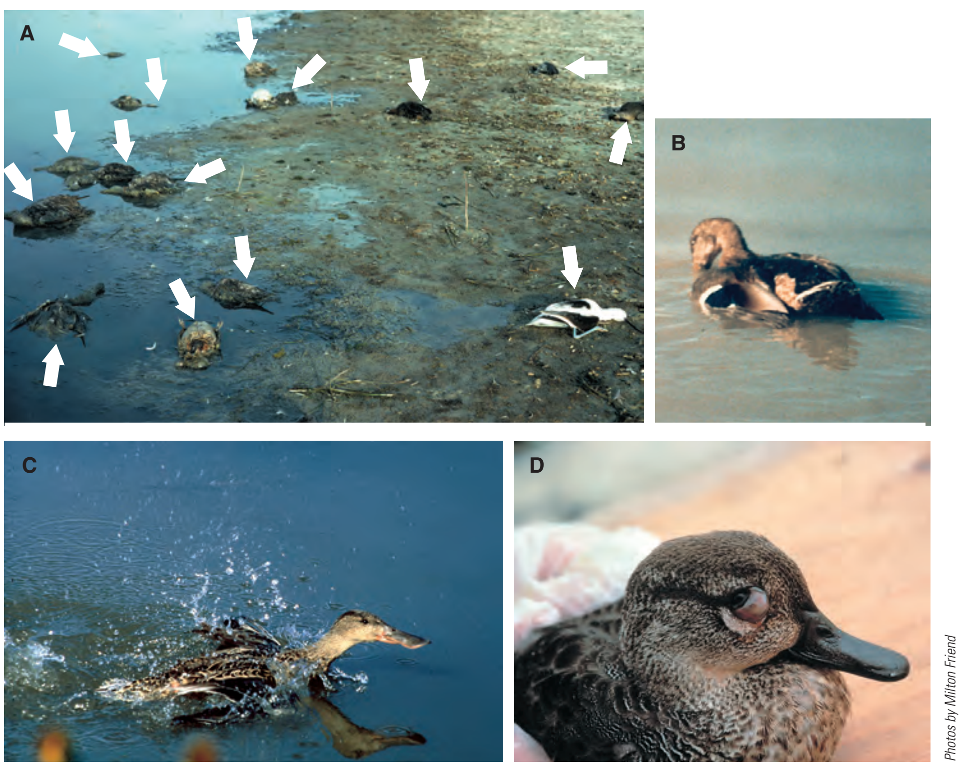


Figure 2.22 (A) Dead birds are often found along the shore in parallel rows that represent receding water levels. (B) Botulism-intoxicated birds often exhibit "limberneck," the inability to maintain posture. (C) Botulism-intoxicated birds that have lost the power of flight and the use of their legs often attempt escape by propelling themselves across the water using their wings. (D) Paralysis of the inner eyelid is a common sign of botulism-intoxicated birds.

Table 2.11. Examples of wildlife mass mortality events in terrestrial environments.

Disease	Type	Primary species	Year	Geographic area	Magnitude of mortality
Canine distemper	Virus	African lion	1994	Serengeti National Park, Tanzania	Approximately one-third of the 3,000 lions in the population died.[200,202,515]
Adenovirus hemorrhagic disease	Virus	Mule deer	1993–1994	California, USA	"Thousands"[516–518]
Plague (*Yersinia pestis*)	Bacteria	Gunnison's prairie dog	1984–1985; 1987	New Mexico, USA	Epizootic wave in this event covered a 100 square kilometer area and killed more than 99.5 percent of the more than 100,000 animals present.[519]
Anthrax (*Bacillus anthracis*)	Bacteria	White-tailed deer	1997; 2001	Texas, USA	Extensive losses in parts of southwest Texas; approximately 80 percent of the deer in some areas died during 1997. Epizootic in 2001 more severe than 1997 event.[520]
Rinderpest	Virus	Buffalo, eland, lesser kudu, giraffe	1993–1997	Kenya, East Africa	Epizootic wave extending over large geographic area; buffalo population in the Tsavo system declined by about 50 percent between October 1994 and July 1995; overall reductions in wild ruminants between 1991 population estimates and 1997 estimates of up to 80 percent. Losses of buffalo (29,095) were 84 percent, eland (4,279) 84 percent, and giraffe (6,936) 77 percent. Other ecosystems also lost large numbers of animals.[521]
Rabbit hemorrhagic disease	Virus	European rabbit	1988	Spain	Subsequent spread throughout Europe. Extensive mortality; has killed 50 percent or more of populations during epizootics.[522]
Sarcoptic mange (*Sarcoptes scabiei*)	Parasite	Many species of mammals, including marsupials (100+)	Variable	Global	Periodic epizootics that decimate populations; entry during 1970s into red fox in Sweden killed over 50 percent of population (about 90 percent in some regions). Main cause of extinction of red fox on the island of Bornholm, Denmark; most common cause of death of chamois and ibex in Europe. Disease also is threat to long-term survival of small remnant wombat populations in Australia.[523–525]
West Nile fever	Virus	Crow	1999	USA	Rapid spread of disease following introduction into New York City area; tens of thousands of birds have died.[526]
Trichomoniasis (*Trichomonas gallinae*)	Parasite	Band-tailed pigeon	1988	California, USA	More than 16,000 birds died.[16]
Intoxication	Drug	Vultures	1999	India	Populations had fallen to less than 5 percent of abundance prior to mortality events.[8,197,527]
Aflatoxicosis	Fungal toxin	Snow goose	1998	Louisiana, USA	More than 10,000.[16,528]
Salmonellosis (*Salmonella typhimurium*)	Bacteria	Pine siskin	1992	Western Canada	More than 10,000.[16]
Mycotoxicosis	Fungal toxin	Sandhill crane	1985	Texas Panhandle	About 5,000.[325]

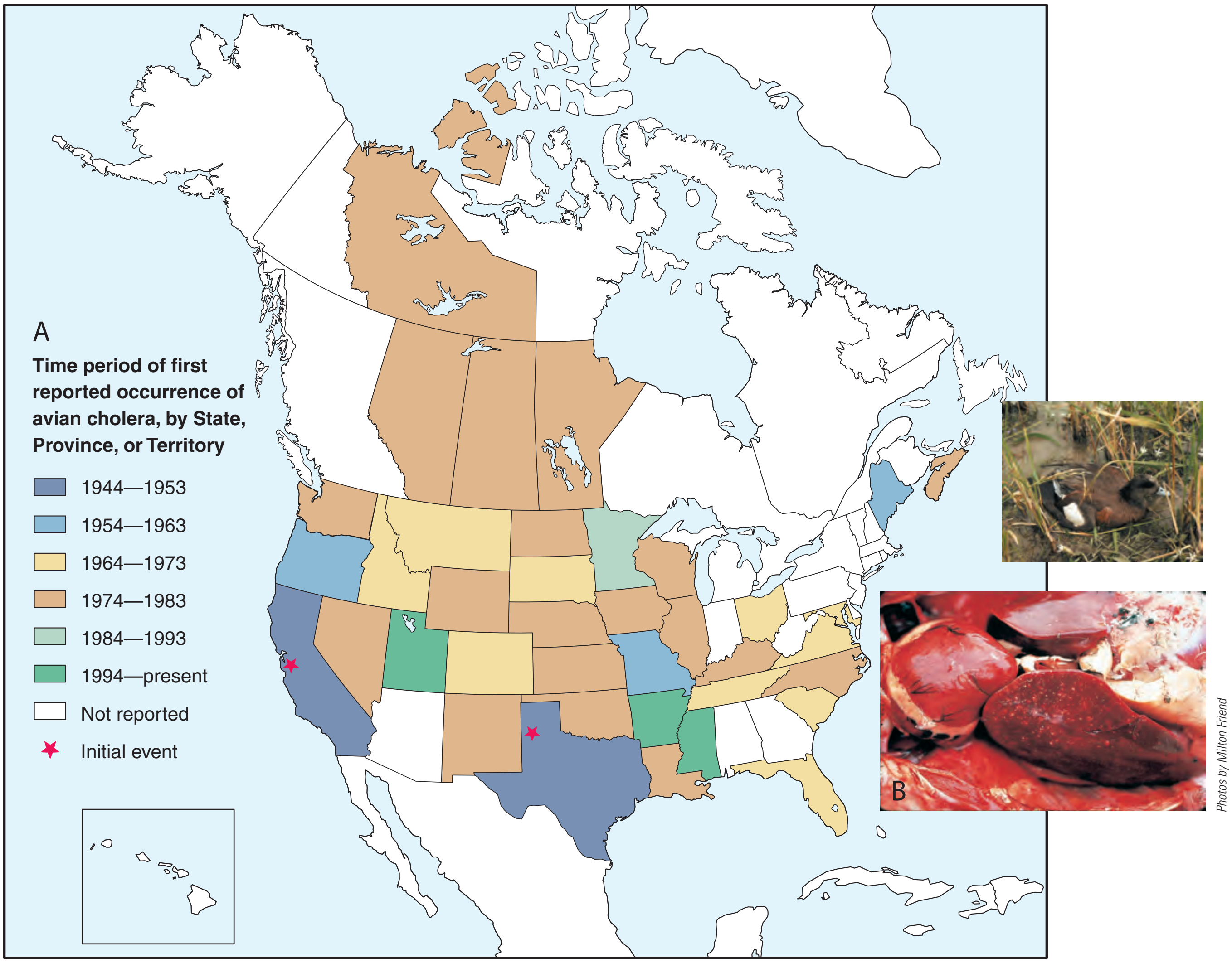


Figure 2.23 (A) Reported occurrences of avian cholera in free-ranging birds in the United States and Canada. (B) Lesions in the liver of avian cholera-infected birds generally appear as small, discrete, yellowish spots. Pinhead-sized hemmorhages in the coronary band and heart muscle are also common.

in 44 of the contiguous states within the USA and also reached Canada within 3 years (Fig. 2.26). WNV has killed many thousands of birds, lesser numbers of other species, caused a few human deaths, and many cases of human illness. The 2002 eruption of WNF in hawks and owls created considerable concern among the wildlife conservation community because mortalities occurred in at least 12 states.[16]

Usutu virus is closely related to WNV and in 2001 emerged as the cause of bird mortality in and around Vienna, Austria. The initial epizootic killed a substantial number of free-ranging Eurasian blackbirds (a thrush species closely related to the American robin and not closely related to North American blackbirds of the Icteridae family) and several great grey owls housed at the Vienna Zoo. An epizootic among barn swallows in Upper Austria, 200 kilometers west of Vienna, followed the initial event. Retrospective analysis of archived bird samples disclosed that Usutu virus was present in Austria in 2000, even though no epizootic from this disease was diagnosed until 2001. This virus had never been observed outside of tropical and subtropical Africa nor had it been associated with severe or fatal disease in animals or humans.[190] Possibly, Usutu virus may become a recurring cause of mass mortality in birds.

House finch conjunctivitis (Fig. 2.27) is an example of an emerging disease caused by the bacterium *Mycoplasma gallisepticum* that spread rapidly following the first reported case in 1994. The initial case was seen at a bird feeder in the Washington, D.C. area. Within 3 years this disease reached

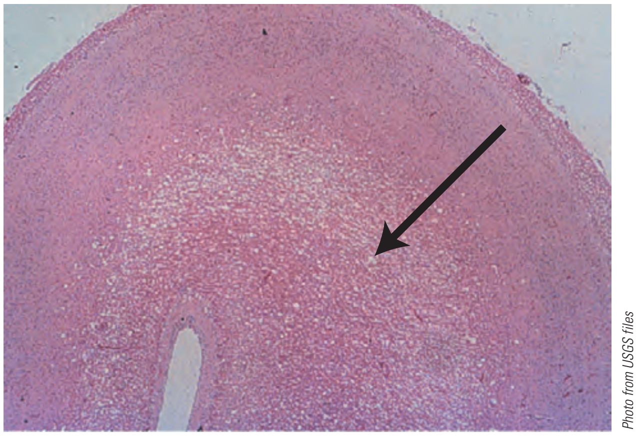


Figure 2.24 The most consistent pathology finding of avian vacuolar myelinopathy (AVM) is the small white dots that represent spaces between the myelin layers surrounding the nerves.

west to the Mississippi River, north to Canada, and occurred throughout the range of the eastern population of the house finch, the primary affected species (Fig. 2.28).[191,192]

Salmonellosis is another bacterial disease affecting birds. This zoonosis has long been a major disease of poultry and an important foodborne disease of humans, but epizootics involving free-ranging wild birds have been rare. However, since the mid-1980s, recurring epizootics of *Salmonella typhimurium* have taken a large toll on **songbirds** in the USA, Canada,[193] and in the United Kingdom.[194] The majority of mortalities occur at bird feeders. Other large-scale epizootics have occurred in **egret** and **heron** colonies.[16] An outbreak of *S. typhimurium* DT160 in New Zealand in the winter of 2000 that first appeared in sparrows in eastern parts of the South Island spread throughout the country killing large numbers of birds and infected other species including livestock and humans.[195] Handling dead wild birds, primarily sparrows, was associated with 13 human cases of salmonellosis; six of these cases were in children less than 5 years of age.[196]

Just as for birds utilizing freshwater and marine environments, notable diseases for which the causes remain unknown have emerged in birds within terrestrial environments (Table 2.12). Since the winter of 1994–1995, more than 50 bald eagles have died from unknown causes in Wisconsin, USA.[16] Despite intensive investigations and common pathological findings among many of these birds, a diagnosis has not been reached. These deaths differ from AVM based on the primary pathology being associated with the liver (Fig. 2.29) rather than central nervous system tissue. Also, cases have not been seen in other species or outside of Wisconsin.

Tortoises

Emerging disease also has victimized the federally listed desert tortoises and gopher tortoises, legislatively protected species throughout their range in the Southwestern United States. Upper respiratory tract disease (URTD) has been associated with population declines in both species of tortoises. The bacterium *Mycoplasma agassizii* has been identified as the primary factor causing this disease.[203,204] Tortoises with URTD were observed in 1988 in California and a survey the following year disclosed 43 percent of 468 live desert tortoises had clinical signs of this disease.[205] The first documented large-scale mortality event from URTD in gopher tortoises occurred in 1989 in Florida. An estimated 25–50 percent of the breeding adults on Sanibel Island died during that event.[206] URTD has become a significant hurdle for conservation efforts to restore tortoise population levels, in addition to a disease causing shell necrosis. The fungus *Fusarium semitectum* has been identified as the cause of necrotizing scute disease.[207]

Tortoises on Ecuador's Galapagos Islands have not escaped recent disease. Giant tortoises at that location died in unprecedented numbers during 1979 (5), 1996 (21), and 1999 (22). Multiple mortalities are unusual for this species and a major departure from a 20-year history in which not more than one tortoise has been found dead in any year other than those noted above.[208] The cause for these mortalities has not been determined.

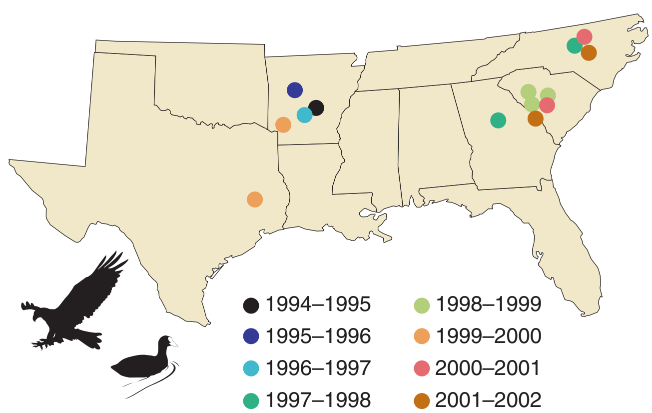


Figure 2.25 Locations of free-ranging bird mortalities from avian vacuolar myelinopathy (AVM) in the USA, 1994–2002.

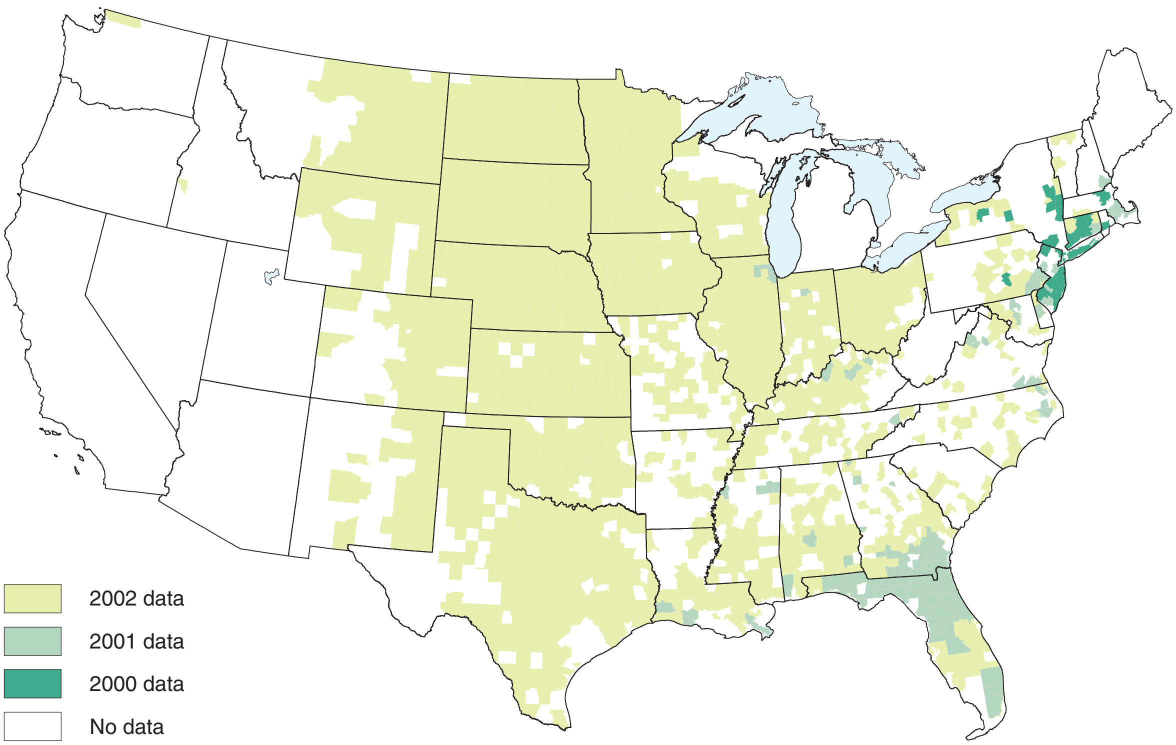


Figure 2.26 (A) The geographic distribution of domestic animal cases of West Nile virus in the United States.

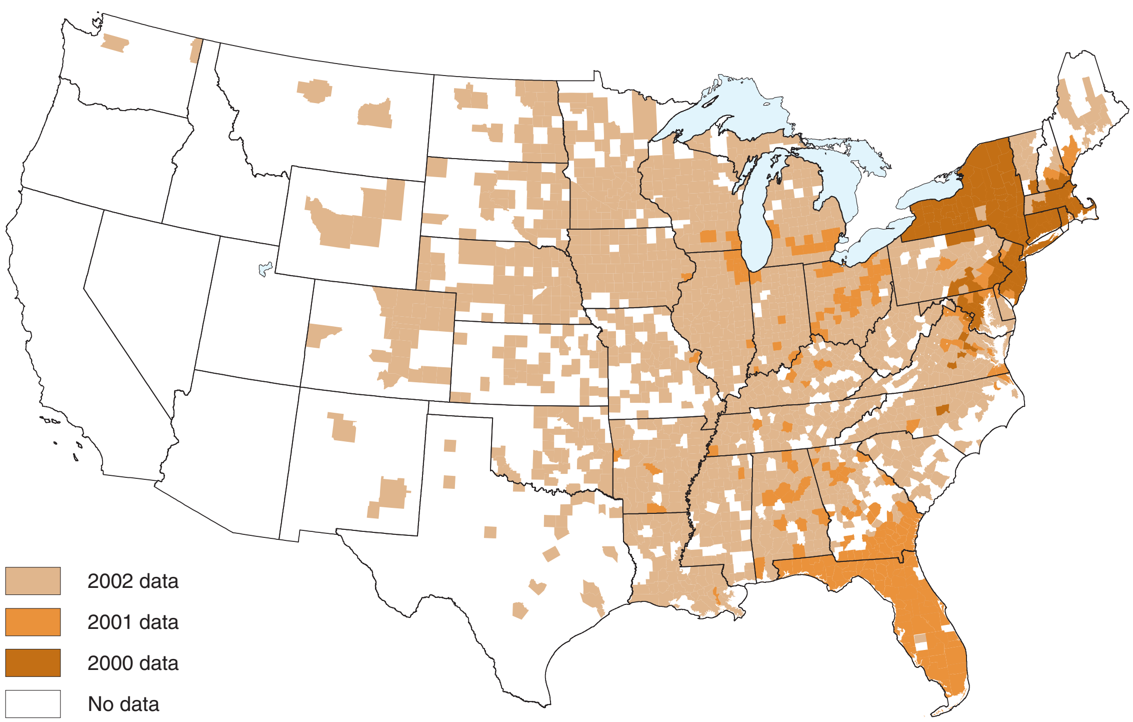


Figure 2.26 (B) The geographic distribution of bird cases of West Nile virus in the United States.

Table 2.12. Examples of emerging and reemerging infectious diseases of free-ranging terrestrial wildlife populations.[a]

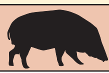
Disease	Agent type	Time of emergence	Geographic area	Primary species affected	Comments
Mammals 					
Hog cholera (Classical swine fever)	Virus	1980s	Europe	Wild boar	• Serious problem with multiple outbreaks involving several countries during period of 1983–2001; most occurrences during 1990s.[529]
Chronic wasting disease	Prion	1980s	USA, Canada	Deer, elk	• Original foci in adjoining areas of Colorado and Wyoming; spread to wild deer in adjacent states of Nebraska and South Dakota.[357,530,531] • Spread to wild deer in Wisconsin, Illinois, New Mexico, and Saskatchewan, Canada, since 2002.
Tuberculosis (Mycobacterium bovis)	Bacteria	1994	USA	White-tailed deer	• Michigan is only known USA focus in free-ranging deer.[532]
Tuberculosis	Bacteria	1990s	Kruger National Park, South Africa	Lion and other species	• Spread from long-time presence of disease in African buffalo. No evidence in 1993 of spread to other species, now widespread.[533]
Infectious keratoconjunctivitis (Mycoplasma conjunctivae)	Bacteria	1980s	Europe	Ibex, chamois, mouflon, thar	• First reported in wildlife in early 1900s from Austria. Mortality during recent epizootics has reached 30 percent; numerous outbreaks during 1990s.[534]
Adenovirus hemorrhagic disease	Virus	1993	USA	Mule deer	• Novel virus responsible for mortalities in 17 counties in California.[517,518]
Canine distemper	Virus	1994	Tanzania, Africa	African lion	• First epizootic of this canine virus in free-ranging large cats.[200,202,515]
Rabies	Virus	1977	Eastern USA	Raccoon	• Index case followed translocation of wild-caught raccoons from enzootic area in the southern USA; new epizootic and enzootic foci now established.[199,535–538]
Canine parvovirus	Virus	1978	Global	Canids	• Appears to have emerged in dogs in Europe; rapid worldwide spread. Infects many species of wild canids including coyote and gray wolf.[539]
Rabbit hemorrhagic disease	Virus	1988	Europe	European rabbit	• Spillover infection from domestic rabbits; rapid spread throughout much of Europe; also present in Australia and New Zealand.[522]
Plague (Yersinia pestis)	Bacteria	1980s	USA	Prairie dogs	• Historic disease that has been expanding its geographic range; has caused mortality in endangered black-footed ferrets.[540,541]

Table 2.12. Examples of emerging and reemerging infectious diseases of free-ranging terrestrial wildlife populations—Continued.[a]

Disease	Agent type	Time of emer-gence	Geographic area	Primary species affected	Comments
Birds					
Woodcock reovirus infection	Virus	1989	Eastern USA	American woodcock	• Novel virus causing large-scale mortality in declining eastern population of woodcock; epizootic areas are New Jersey and Virginia.[542,543]
West Nile fever	Virus	1999	USA	American crow	• Coast-to-coast spread in USA since index cases in New York City area; spread to Canada and Puerto Rico. Hundreds of species affected.[526]
Usutu virus infection	Virus	2001	Austria	Eurasian blackbird; barn swallow	• First mortality caused by this virus in any species.[190]
Salmonellosis (Salmonella typhimurium)	Bacteria	1980s	USA, Canada, England	Passerine birds (songbirds)	• Widespread common disease at bird feeders.[193,194,544]
Mycoplasmosis (Mycoplasma gallisepticum)	Bacteria	1994	USA, Canada	House finch	• Rapid spread of disease throughout entire geographic range of eastern population of house finch.[191,192]
Intoxication	Drug	1999	Pakistan	Vultures	• Disease was thought to be of viral etiology and to have spread to Pakistan and Nepal; now known to be caused by an anti-inflammatory and painkiller, Diclofenac.[197,198,572]
Avian pox	Virus	Late 1970s	USA	Passerine birds, bald eagle	• Increasing frequency at bird feeders and factor contributing to Hawaiian forest bird mortality; numerous cases in bald eagles since species index case in 1979. Epizootics in breeding colonies of marine birds.[545]
Reptiles					
Upper respiratory tract disease (Mycoplasma agassizii)	Bacteria	1988	USA	Desert tortoise, gopher tortoise	• First observed in endangered desert tortoise in California then in gopher tortoises in Florida.[205,206]
Ranavirus infection	Virus	1998	Indonesia	Green python	• First isolation of systemic infection by any ranavirus in any species of snake; detection made in Australia from illegally imported snakes collected from the wild in Indonesia.[546]

[a] Representative examples of emerging and reemerging diseases causing mortality in wildlife; diseases such as Lyme disease that impact species other than wildlife are not included.

Figure 2.27 Field signs of *Mycoplasma gallisepticum* infections in house finches include eye inflammation (conjunctivitis).

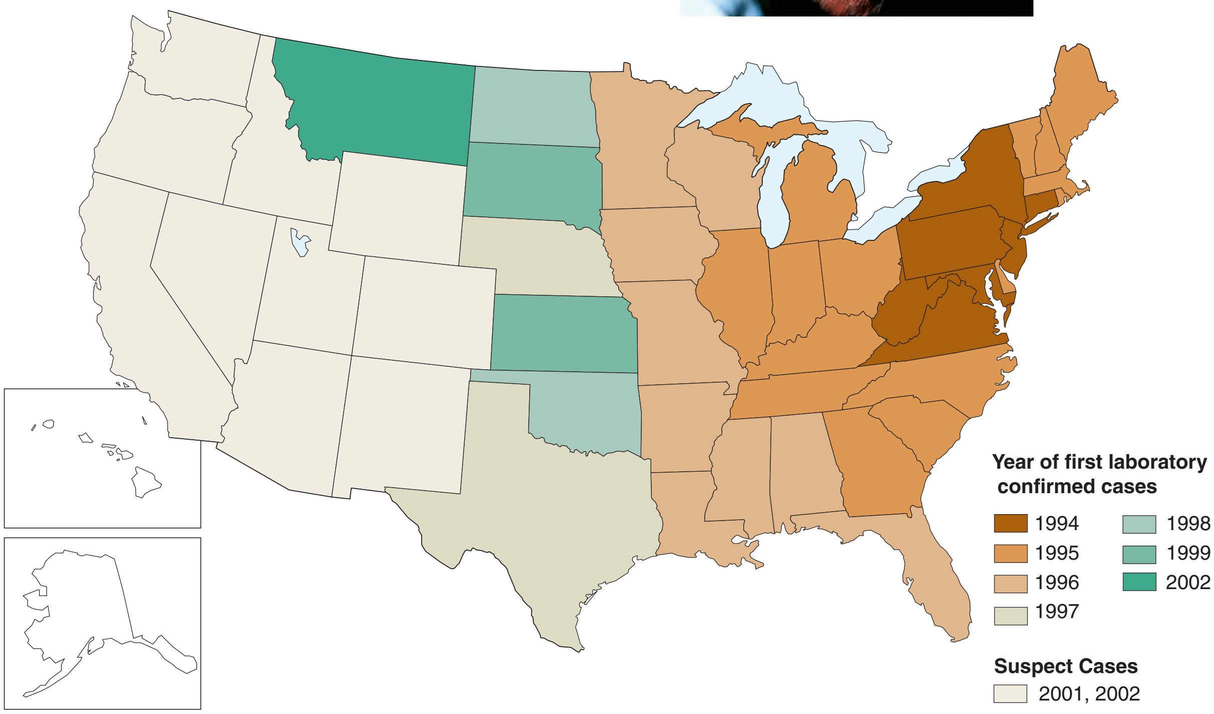
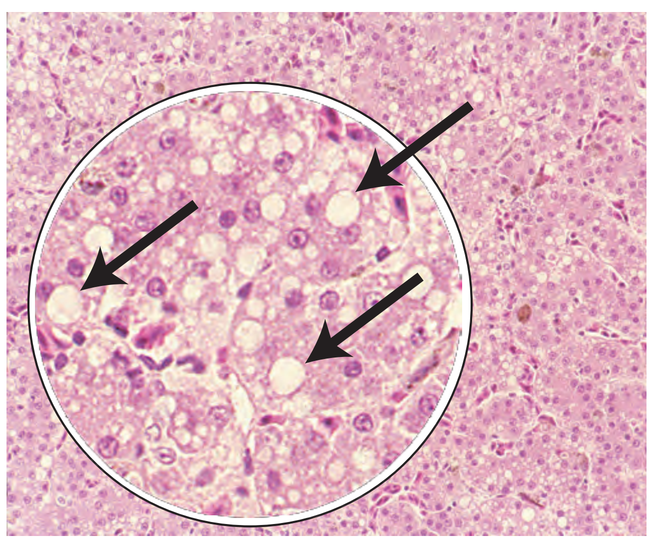


Figure 2.28 Reported geographic spread of house finch inner eyelid inflammation (conjunctivitis) since the initial 1994 *Mycoplasma gallisepticum* observation. (Data adapted from reports in the scientific literature and personal communications between the USGS National Wildlife Health Center and other scientists. See updated data in figure 3.28.)

Figure 2.29 Numerous round, empty spaces in liver cells indicate vacuolar degeneration in an eagle that died from unknown causes in Wisconsin, USA.



Mammals

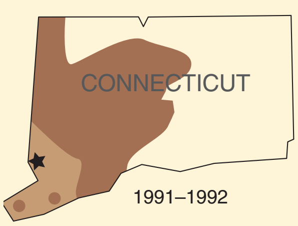
Rabies is an example of a resurging viral zoonosis that has recently become more prominent within the Eastern USA. This age-old disease is the cause of a multistate, long-term epizootic in raccoons with spillover into other species and human exposures. In 1977, some raccoons were moved from an area where raccoon rabies is enzootic within the USA into the border areas of West Virginia and Virginia. Rabies then spread more than 400 miles (approximately 650 kilometers) northeast by 1993, killing large numbers of raccoons and a number of other species along the way.

In 1994, canine distemper, another common viral disease of **canids**, emerged as a cause of mortality in African **lions**. Canine distemper virus had previously only rarely been associated with infection in large cats and only within zoos.[200] However, distemper swept through the lion population and killed many of them at Serengeti National Park, Tanzania (Table 2.12).[201,202] A new variant of the classical canine distemper virus that emerged from local canid populations caused this mortality, and bridged the species barrier between canids and **felids**.[202]

Numerous other emerging and reemerging infectious diseases are affecting terrestrial mammals (Table 2.12). Some diseases, like tularemia and plague, are old diseases capable of causing mass mortalities in small mammals that are now appearing in new locations and under differing environmental conditions. Others, such as chronic wasting disease of deer and elk, are new diseases causing insidious impacts. The spectrum of disease and impacts also includes diseases, such as tuberculosis in deer and hydatid disease, which are of primary importance because of their impacts on other species (including humans), rather than being a cause of wildlife mass mortalities.

Rabies and Raccoons

Historically, in the northern parts of the USA small numbers of raccoons have become infected with rabies through exposure during epizootics in other species such as **foxes** and skunks. The establishment of rabies as an enzootic disease of raccoons in several northeastern states is a dramatic example of how old diseases can exploit new opportunities. The spread of rabies in Connecticut during the epizootic wave of raccoon rabies that began in West Virginia illustrates how quickly disease status can change. The first rabid raccoon in Connecticut was detected in 1991. Prior to that time, Connecticut had been without any cases of rabies in terrestrial vertebrates for more than a decade. In less than 4 years following the 1991 **index case**, 2,500 rabies-positive animals, 80 percent of which were raccoons, were detected in Connecticut.[199]



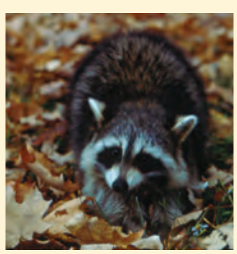
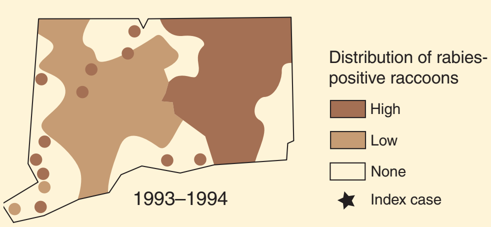


Photo by Milton Friend



Perspective

The magnitude and complexity of emerging infectious diseases will continue to be a major challenge for the foreseeable future. The examples cited provide a cross-section of disease emergence in wildlife, rather than a holistic compendium. Clearly, disease emergence is affecting the broad spectrum of animal resources worldwide in virtually all types of environments. **Reptiles** have not been fully considered in this evaluation, and other species groups have only received moderate coverage, at best, relative to the spectrum of emerging and reemerging diseases. Listings soon become incomplete because of the dynamic nature of disease emergence. Pathogens that cross species barriers are likely to become a more frequent source for disease emergence. These events will result from new opportunities for pathogens that arise from exposure to changing environmental conditions, new species interactions, and increasing densities of potential host species as humans and animals are compressed into diminished amounts of living space. Discoveries associated with technological advances, increased investigational activities, and truly new disease events also assure a continuum of new findings. Captive-reared wildlife are an additional component of emerging diseases. Other emerging diseases are affecting native plants[209–211] and insect populations.

Disease emergence is often associated with conditions of ecosystem stress[212] caused by landscape alterations, social upheaval, and the conditions of war, which are situations that are likely to continue within different regions of the world. The increased levels of environmental stress affecting diverse systems from coral reefs to polar ice caps will be further intensified as humans attempt to provide living space, food, water, recreation opportunities, sustained economic growth and attempt to meet other societal needs.

Contact between humans and wildlife is likely to increase and may lead to more opportunities for disease emergence. Ecotourism associated with African wildlife is but one example. The close association between humans and baboons in the Kruger National Park provides a potential bridge for the transfer of tuberculosis from other Park wildlife through infected baboons to humans.[213] Also, there is growing concern among the wildlife conservation community about ecotourists and others transferring human diseases into wildlife populations. Outbreaks of tuberculosis among mongooses and meerkats in Botswana have been attributed to humans as the source for infection.[214,215] An undiagnosed 1988 epizootic among the endangered mountain gorilla in Rwanda is thought to have been measles of human origin.[216] Also, new intestinal parasites have been found in the feces of mountain gorillas since tourists began visiting their habitat in large numbers.[214,215]

Increased globalization of society and the speed of modern transportation enhance the opportunities for disease agents to enter new geographic areas and naive host populations. Therefore, actions are needed to minimize opportunities for disease emergence in wildlife as precursors for the establishment of new zoonoses and to prevent continued escalation of zoonoses as a public health problem.

Emerging Foodborne Diseases

> **"…to speak of "foodborne disease" is to speak of many pathogens and many diseases" (Tauxe).[217]**

Foodborne transmission has been documented for more than 200 known diseases caused by a spectrum of pathogens ranging from infectious agents to biotoxins.[217,218] Viruses are the leading cause of foodborne disease in the USA, but bacteria are the most prominent causes of foodborne disease resulting in hospitalizations and deaths (Fig. 2.30). Zoonoses are associated with the great majority of those deaths in the USA (Fig. 2.31). It is estimated that one in four Americans have a significant foodborne illness each year with the majority of illness being due to pathogens yet to be identified.[217] The human health toll in the USA from these diseases is estimated in one evaluation to be 40 million cases and 9,000 deaths annually.[219] Another evaluation places this toll at 76 million cases of illness, 323,000 hospitalizations per year, and 5,000 deaths.[218]

Transitions and Transgressions

The general safety of food and drinking water has long been a matter for public concern and regulatory processes. Tainted food and water are often a source for disease, which is reflected in the writings of early history and forms the basis for some of the dietary laws of various religions. The development of sanitary codes, regulatory processes, and a host of other actions focused on sources of contamination, have been created and implemented to maintain health risks at minimal practical levels consistent with technical feasibility.

Within the USA, and in many other areas, bacterial diseases such as streptococcal infections, brucellosis and tuberculosis in milk and other dairy products, and salmonellosis in poultry and eggs have been primary concerns. Trichinosis (trichinellosis) has been an important parasitic disease associated with **swine**. Pasteurization has been notable in combating brucellosis, as has mandated cooking of garbage fed to swine in combating trichinosis. Chlorination and other treatments of drinking water supplies have helped to combat a host of enteric pathogens such as *Salmonellae*. Because of these preventive measures, typhoid fever, tuberculosis, brucellosis, and septic sore throat, a zoonotic streptococcal infection, have been essentially eliminated as foodborne diseases in developed nations. Most instances of trichinosis have also been eliminated.[217]

Although many foodborne zoonoses of the past have diminished as human health problems throughout most developed nations, there has been a resurgence of foodborne zoonoses augmented by a variety of infectious pathogens that previously were not important sources of foodborne disease.[220–223] Every 2 years since 1977, a new foodborne pathogen or a pathogen newly recognized as being foodborne has appeared, many of which are zoonotic in origin.[217] The Pan American Health Organization reports that many foodborne zoonoses have increased by as much as 100 percent within recent years. The number of cases of foodborne illness in some developing countries is estimated to be as high as 10 percent of the population.[224,225] Typically, livestock and poultry have been the dominant domestic animal species involved in foodborne zoonoses. Within the USA, more than a dozen foodborne diseases have emerged during recent years (Table 2.13).

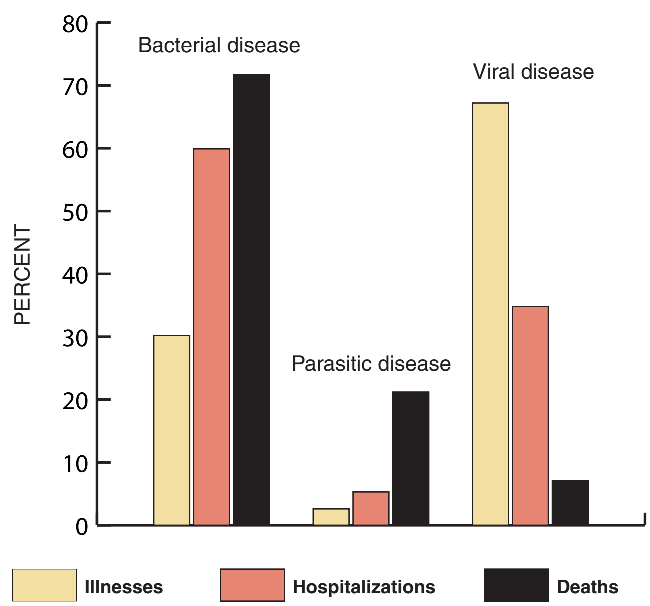


Figure 2.30 Estimated percentage of total illnesses, hospitalizations, and deaths in the United States caused by different classes of foodborne pathogens (adapted from Mead et al.).[218]

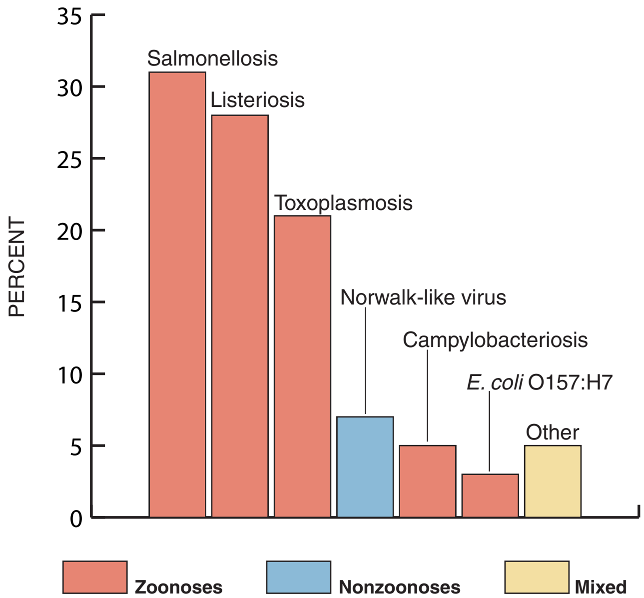


Figure 2.31 The percentage of food-related deaths by disease in the United States (adapted from Mead et al.).[218]

Bovine spongiform encephalopathy (BSE) is an example of not only a new foodborne zoonosis, but recognition of a new type of zoonotic agent. BSE was first diagnosed in the United Kingdom (UK) in 1986, and by August 1998 more than 174,000 cattle were reported as infected. However, it was estimated that one million cattle had probably been infected by that time and that about half of those had entered the food chain. Human infection by the **prion** causing BSE was first reported in 1995 as a new human zoonotic disease designated as new-variant Creutzfeldt-Jakob disease. By mid-1998, more than two dozen human cases of this generally fatal disease were associated with the BSE epizootic in the UK.[219]

The global dissemination of some foodborne pathogens in pandemic form is another example of the changing presentation of foodborne disease. Salmonellosis serves as an example. With the exceptions of Australia and New Zealand, strains of *Salmonella enteritidis* embarked on a global journey in the 1980s that has resulted in this cause of salmonellosis becoming the most common *Salmonella* serotype worldwide. A similar journey, with the same exceptions, began in the 1990s for antibiotic-resistant strains of *S. typhimiurium*.[217]

Associating *S. enteritidis* with eggs rather than poultry meat is a new dimension for this disease[226] and has resulted in debate relative to the roles of poultry and traditional rodent hosts in the ongoing pandemic.[226–228] Also, in 1993 an epidemic caused by *S. enteritidis* resulted in nearly a quarter of a million people in the USA becoming ill from the ingestion of ice cream.[229] Antibiotic-resistant strains of *S. typhimurium* have been linked with antibiotic use in livestock. For instance, a strain responsible for human deaths in Denmark was traced to a Danish pig herd.[230]

The bacterial diseases yersiniosis and a new serotype of *Vibrio parahaemolyticus* also have been recently identified as pandemic foodborne diseases. The strains of *Yersinia enterocolitica* involved appear to be associated with consumption of or contact with raw pork or pork products. Consuming contaminated seafood is the cause of disease from the new serotype of *V. parahaemolyticus*, which emerged in Southeast Asia in the early 1990s, then spread to Japan and the USA.[217]

Escherichia coli O157:H7 became a focus for concern in January 1993, with the detection of what turned out to be a multistate epizootic infecting more than 500 people, including four fatalities in children. At least 93 restaurants in a national chain were implicated, all of which obtained meat from one processing plant.[231] The first two outbreaks by this agent in the USA probably occurred in 1982 in Oregon and Michigan. Both events were associated with consumption of fast-food hamburgers. Microbial evolution is the basis for the emergence of *E. coli* O157:H7. This strain arose from a common origin to diverge genetically, causes three different forms of disease, and has become a worldwide pathogen. The variability of epidemics it causes reflects its adaptive capabilities, and its pattern of development has resulted in *E. coli* O157:H7 being categorized as a "disease of human progress."[232]

Cattle are the most significant reservoir of *E. coli* O157:H7 and other Shiga-toxin producing *E. coli*. However, the current occurrence of more foodborne outbreaks of O157:H7 linked to beef than any other single food source may not prevail over time, considering the range of foods that have been sources for human infection (Table 2.14) and species that this pathogen has been found in other than cattle and humans (e.g., birds, sheep, and deer). *E. coli* O157:H7 was first isolated in swine feces in the USA in 2001, joining Japan, Norway, and Chile, where it has been found previously.[233] Live cattle-to-human transmission, human infections from contaminated drinking water and from recreational water use, and other means of infection have been documented. Disease emergence also has been facilitated by the prolonged environmental persistence of the pathogen (several months) in water and other substrates and its unusual tolerance to environmental stresses.[232]

Campylobacteriosis is currently one of the most noteworthy foodborne diseases worldwide. Infections are acquired by consuming contaminated water, unpasteurized milk, undercooked poultry or red meat, and direct contact with infected human shedders and contaminated surfaces. Children often acquire infection from immature, diarrheic companion animals.[238] Campylobacteriosis became recognized as an emerging foodborne disease during the late 1970s.[239] In 1997, this disease accounted for approximately 14 percent of all diagnosed foodborne infections in the USA. The total

Table 2.13. Principal foodborne infections that have emerged during the past three decades (adapted from Tauxe).[217]

Disease agent	Zoonoses	Primary hosts[a]
Viral diseases		
Astrovirus	○	Humans
Norwalk-like viruses	○	Humans
Rotavirus	○	Humans
Prion diseases		
Prions	●	Cattle
Bacterial diseases		
Campylobacter spp.	●	Poultry, swine, pets, migratory birds
Escherichia coli O157:H7	●	Cattle
Enterotoxigenic *E coli.*	●	Cattle
Listeria monocytogenes	●	Many domestic and wildlife species
Salmonella enteritidis	●	Poultry
Vibrio (non-cholera)	●	Shellfish and finfish
Vibrio cholerae, toxigenic	○	Humans
Vibrio vulnificus	●	Shellfish
Yersinia enterocolitica	●	Swine, pets
Parasitic diseases		
Anisakis spp.	●	Fish
Pseudoterranova spp.	●	Fish
Cyclospora cayetanensis	●	Humans

● Zoonotic infection

○ Not a zoonotic infection

[a] Primary sources for human infections; in most instances a much greater range of species may become infected and be an occasional source for human cases of disease.

estimated number of cases that year exceeded 2.5 million with 13,000 hospital admissions and 124 deaths.[238] In the UK, about 500,000 people became ill with campylobacter enteritis during 1999.[240] *Campylobacter* infections have been reported to be the most common bacterial cause of acute gastroenteritis in the industrialized world and a major cause of intestinal disease in very young children in developing countries.[240,241]

Campylobacter jejuni is responsible for more than 90 percent of diagnosed human cases of this disease[240] and is prevalent in all types of commercial poultry flocks worldwide.[238] An estimated 20 to 40 percent of sporadic *Campylobacter* cases may involve the consumption of chicken.[240] Wildlife also are known to harbor this organism.[242–244]

In the 1990s, cryptosporidiosis emerged as an important gastrointestinal infection transmitted by food and water contaminated by the protozoan parasite *Cryptosporidium parvum* and associated species. Human cases of this disease have been reported in more than 40 countries in 6 continents.[246] The 1993 waterborne outbreak that affected several hundred thousand people in Milwaukee, Wisconsin,[247] is well known. Analyses of that epidemic indicate that the elderly had an increased risk of severe disease, a shorter incubation period than previously reported for adults, and a higher risk of secondary person-to-person transmission.[248] The total cost of outbreak-associated illness was $96.2 million, nearly $32 million of which was medical costs and the remainder was productivity losses.[249] Cryptosporidiosis has also resulted from the consumption of contaminated apple cider, bovine and goat milk, fruits and vegetables, and other foods such as sausage, tripe, and chicken salad. Oocysts (eggs) of the parasite have also been detected in vegetables, meats, and a variety of shellfish that were not associated with human cases of disease.[246]

Seafood consumption also can cause foodborne disease. Marine and freshwater shellfish and finfish are all involved. Most seafood is safe, as are other commercial foods. However, cultural and changing food habits, such as the consumption of raw seafood and undercooking seafood, are providing increased opportunities for diseases to emerge. Parasitic

Migratory Birds As Reservoirs For *Campylobacter*

Several species of domestic and wild animals (including birds) serve as reservoir hosts for *C. jejuni*. Migratory birds, especially waterfowl, may be the most important wildlife reservoir because of their potential to contaminate waterways and other habitat through their feces. The role of migratory birds as a reservoir for *Campylobacter* has been established by the findings of high percentages of some species (overall infection rate of 73 percent in one study) being infected with *C. jejuni*.[242–244] A far greater percentage of ducks have been found infected than Canada geese (5 percent in a Washington study) and the greatest percentage (81 percent) was found in sandhill **cranes**.[243] However, not all evaluations of wild birds have yielded positive results. No isolations of *C. jejuni* were made along the Mississippi River in Wisconsin from waterfowl, or from sediments and water where these birds roost and feed.[245] Nevertheless, the high rate of infection found in some populations of wild birds should be considered when field dressing and preparing these birds for consumption. Appropriate measures should be taken to avoid contaminating hands, surfaces, utensils, and containers used for processing other foods.

Photo by Glen Smart

zoonoses resulting from these food habits are testimony to the risks involved.[223] The consumption of raw fish has led to major increases of anisakiasis and gnathostomiasis in the USA and elsewhere.[250] Both diseases are caused by infections with different species of nematodes (roundworms). More than 90 percent of cases of seafood-borne illnesses within the USA are associated with ciguatoxin and "scombrotoxin."[251] Ciguatoxin is produced by the dinoflagellates *Gambierdiscus toxicus* and is concentrated up the food chain where it accumulates in carnivorous **reef fish** such as barracuda and popular table fish such as grouper, snapper, and sea bass. Ciguatera is the most common fishborne illness worldwide.[252] Scombroid poisoning is a result of inadequate refrigeration of fish. Bacteria (*Proteus* and *Klebsiella*) present on the surface of the fish proliferate and invade the muscle tissue where bacterial degradation processes result in a histamine-like chemical that causes human illness when ingested. Fish species most commonly associated with this food poisoning are tuna, mackerel, jacks, dolphins (mahimahi), and bluefish.[252]

Hepatitis A virus (HAV) and Norwalk-like viruses (NLVs) (*Norovirus*)[254] are the two most important viral diseases transmitted by seafood. HAV is the fourth leading cause of foodborne disease in the USA, causing 4 percent of the outbreaks and 6 percent of the cases when an etiology could be determined. Nevertheless, NLVs may be the most common cause of foodborne disease. They are the most commonly identified cause of infectious intestinal diseases in Western Europe[253] and account for greater than 95 percent of nonbacte-

Table 2.14. Sources of human infections by *Escherichia coli* O157:H7 (developed from Park et al.).[233]

Country	Sources	Comments
USA	Hamburgers and other beef products, drinking water, lettuce, apple cider, venison, apple juice, and recreational swimming	Average incidence of 2.1 cases per 100,000 people in 1997; outbreaks occurred in 1997 and 1998 among people eating alfalfa sprouts.[547]
Canada	Direct contact with cattle, contaminated ground water, exposure to rural environments, undercooked ground beef	Incidence of infection ranged from 3.0 to 5.3 cases per 100,000 people from 1991 to 1996.
Japan	White radish sprouts	About 6,000 people, mostly children, infected in 1996 from luncheon containing radish sprouts; a second outbreak the following year infected 126 people who ate white radish sprouts.[547]
United Kingdom	Hamburger and other beef products	Laboratory confirmed cases increased from 1 in 1982 to 1,039 in 1995; isolated from 18.7 percent of cattle feces tested.
Germany	Goat milk, cheese, swimming in lakes, person-to-person transmission	Hamburgers and other beef products not common sources for infection.
Scotland	Ground beef	1996 outbreak of 496 cases with 20 deaths.

rial outbreaks in Denmark, England, Wales, Finland, France, and Sweden. The percentage is slightly lower (84 percent) in the Netherlands.[254] Human contamination by food handlers is the primary source for these diseases.[221] Multiple outbreaks of gastroenteritis associated with norovirus on cruise ships entering USA ports occurred during 2001 and 2002.[255] Fecal contamination is the source for HAV and NLVs, but shellfish are often a vehicle for human exposure to these viruses[256] (Table 2.15). Shellfish also are a source of bacterial infections. In the USA, *Vibrio* spp., and in particular *V. vulnificus*, account for the second highest number of infectious disease cases associated with shellfish (behind viral agents) and 95 percent of all shellfish-related deaths.[257,258]

In Canada, seafood is the source of about 7 percent of all outbreaks of foodborne disease and 4 percent of all reported cases. About 60 percent of cases are due to microorganisms, 31 percent to seafood toxins, and 9 percent to other chemical agents. Between 1973 and 1987, there were multiple seafood-related disease outbreaks involving infectious agents, several resulted from home food processing (canning and smoking) (Table 2.16).[259]

Foodborne diseases associated with fruits and vegetables are increasing. The mean number of reported outbreaks associated with produce more than doubled from the period 1973 to 1987 to the period 1988 to 1991 (from 4.3 outbreaks per year to 9.75 per year, respectively). The number of human cases of produce-related illness rose from 242 per year to 614 per year when comparing these same time periods.[261] International in scope,[260] this problem is not entirely independent of pathogens in animals, because some of the disease agents involved have animal hosts (Table 2.17). The use of improperly composted manure, contaminated water, and contact with products of animal origin are all factors contributing to the increasing incidence of human illness associated with the consumption of uncooked fruits and vegetables.[262]

Many diseases acquired as foodborne infections also may be directly acquired as waterborne infections and some of the cited nonfoodborne diseases use water as a pathogen-delivery system for infection. The route for disease transmission as foodborne or waterborne may be altered by changing environmental conditions. For example, giardiasis and cryptosporidiosis are more likely to be transmitted through water than food, while the reverse has been true for toxoplasmosis. Nevertheless, giardiasis and cryptosporidiosis are emerging foodborne diseases and toxoplasmosis is an emerging waterborne disease. A recent study of waterborne toxoplasmosis in Brazil disclosed that 84 percent of a subset (lower socioeconomic group) of nearly 1,500 people along a continuum of socioeconomic status in a serological survey had antibody to *T. gondii*, as did 62 percent and 23 percent of the people in middle and upper socioeconomic groups, respectively. Those findings reflect the importance of oocyst transmission by water and the risks for exposure from drinking unfiltered water.[263] It is likely that increases in waterborne zoonotic disease will continue as an outcome of degrading water quality associated with increasing human populations.

The specter of waterborne zoonotic disease extends to bottled drinking water. Recent epidemiological investigations have resulted in the three species of *Campylobacter* that cause disease being identified with different types of exposure; *C. coli* infections were most frequently associated with patients consuming bottled water. The rapidly expanding bottled water industry (5 billion gallons consumed in the USA in 2000; 7.3 billion gallons predicted for 2005) coupled with *C. coli* findings suggest the possible need for enhanced bottled water standards to protect human health from campylobacteriosis.[240]

Wild game meat also may be a source for human disease. Tularemia acquired from rabbits and hares, and toxoplasmo-

Table 2.15. Examples of outbreaks of foodborne viral diseases from the consumption of contaminated shellfish.

Disease agent	Food item	Human cases	Location	Year
Norovirus	Raw clams	813	New York, USA	1982[252]
Norovirus	Raw oysters	204	New York, USA	1982[252]
Hepatitis A virus	Raw clams	300,000	Shanghai, China	1988[256]
Hepatitis A virus	Raw oysters	61	Alabama, Georgia, Florida, Tennessee, Hawaii, USA	1988[256]
Norovirus	Oysters	175+	Eastern Canada	1991[259]
Gastrointestinal virus[a]	Raw/steamed oysters	180	Louisiana, Maryland, Mississippi, Florida, North Carolina, USA	1993[256]

[a]Small round-structured gastrointestinal viruses related to noroviruses.

Table 2.16 Sources of infectious foodborne illness from seafood in Canada, 1973 to 1987 (adapted from Todd).[259]

Disease agent	Number of incidents	Primary sources of infection
Staphylococcus aureus	28	Commercial and home-canned finfish, primarily salmon (12 events); crab (4 events)
Salmonella spp.	17	Tuna, salmon, lobster, and crab
Bacillus cereus	15	Shrimp, lobster chowder, various crab products, clams, scallops
Clostridium botulinum	11	Home-fermented salmon eggs; home-smoked salmon, trout, or char
Clostridium perfringens	5	Fish
Norovirus	1	New Brunswick oysters (~175 people infected)
Anisakiasis (parasite not reported)	1	Sushi from an unidentified species of fish; a case the previous year was reported from eating cod cooked on a campstove

Table 2.17. Foodborne infections from produce in the USA that have emerged during the past 3 decades (adapted from Tauxe,[217] with additions from Millar et al.[246]).

Produce type	Pathogens[a]											
	Viral		Bacterial								Parasitic	
	V1	V2	B1	B2	B3	B4	B5	B6	B7	B8	P1	P2
Lettuce/cabbage/greens	●	●	○	○	○	●	●	○	●	○	○	○
Carrots/celery/scallions	○	●	○	○	●	○	○	○	●	○	●	○
Sprouts	○	○	●	○	○	○	○	●	○	○	○	○
Tomatoes	●	○	○	○	○	○	○	●	○	○	○	○
Melons	○	○	○	○	○	○	○	●	○	○	○	○
Raspberries/strawberries	●	○	○	○	○	○	○	○	○	○	○	●
Fruit/vegetables (unspecified)	○	○	○	○	○	○	○	○	○	○	●	○
Chopped garlic	○	○	○	●	○	○	○	○	○	○	○	○
Apple cider	○	○	○	○	○	●	○	●	○	○	●	○
Orange juice	○	○	○	○	○	○	○	●	○	○	○	○
Coconut milk	○	○	○	○	○	○	○	○	○	●	○	○

● Pathogen found in produce type ○ Pathogen not found in produce type

[a] V1—Hepatitis A; V2—Noroviruses; B1—*Bacillus cereus*; B2—*Clostridium botulinum*; B3—Enterotoxigenic *Escherichia coli*; B4—*E. coli O157:H7*; B5—*Listeria monocytogenes*; B6—*Salmonella* spp.; B7—*Shigella* spp.; B8—Toxigenic *Vibrio cholerae* 01; P1—*Cryptosporidium parvum*; P2—*Cyclospora*

All of these pathogens, except V1, V2, and P2, are zoonotic sis acquired from birds and other species, are examples of diseases more commonly acquired within developed nations when wildlife is a common component of the foodbase. The transition from wildlife sources to domesticated sources of food resulted in more foodborne zoonoses being acquired from domestic animals than from wildlife. However, the wildlife component of foodborne disease is sustained in subsistence cultures and to a lesser degree among sportsmen. In the USA, from 1981 to 1996, nearly 40 percent of all cases of human trichinosis were from eating game meat.[264] Wildlife also are a disease dimension associated with aquaculture, ecotourism, and changes in human lifestyles and food habits.

"Going Native"

The tourism industry is the world's largest employer with nearly 200 million jobs or about 10 percent of the jobs globally.[265] More than 663 million tourists traveled internationally in 1999 and spent more than US$453 billion in the pursuit of their activities. Ecotourism has become a major component of international travel, increasing annually at 10 to 30 percent.[266]

People travel the globe each year to visit exotic places and experience the wildlife and cultures of the area (Fig. 2.32). These sojourns generally provide new experiences, including new types of food and beverages. Wild game, native fruits, and other local items often are the major foods for people in remote areas and in cultures that are closely tied to nature. Tourists often consume these foods as part of their trip experiences. In many situations, those food items are locally harvested and may have minimal to no external oversight relative to health standards. Therefore, it is prudent to obtain basic knowledge of zoonoses that are commonly transmitted through food and water in areas to be visited. Advance knowledge provides a foundation for choices on what one consumes when in those areas and how that food is prepared. These considerations extend to raw fruits and vegetables, as well as to cooked meats, dairy products, and other food items.

Millions of people in the mainstream of industrialized society also "return to nature" through transient personal harvests of shellfish, birds, mammals, and other types of wildlife (Fig. 2.33). These harvests, which generally are devoid of any external food safety evaluations, supplement people's

Photo by Milton Friend

Figure 2.33 Harvested wildlife.

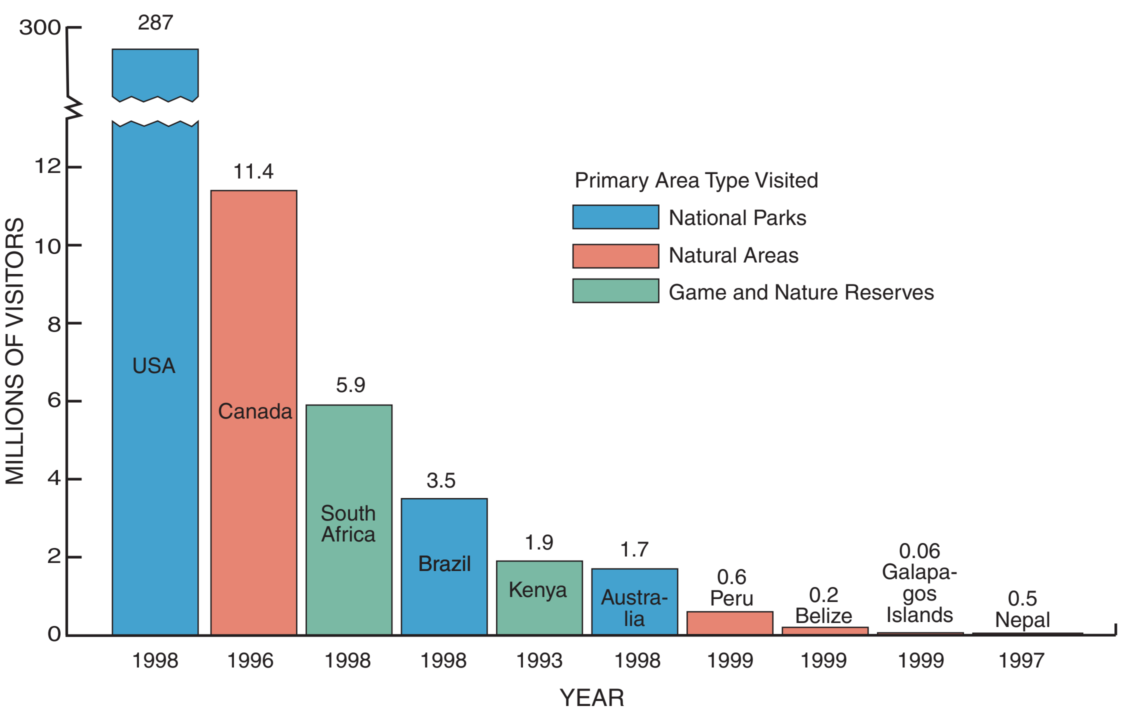


Figure 2.32 Global examples of nature tourism during the 1990s.[266]

foodbase in various ways from basic staples to novel food items. Some tangential protection is provided by regulatory agencies through health advisories issued by government agencies to alert those harvesting wildlife for personal and family consumption about certain types of risks that may be present in specific areas.

However, because there are no programs that routinely and continuously monitor free-ranging wildlife populations for foodborne infectious pathogens, consumers of wildlife are primarily left to their own judgments relative to what to eat and how to prepare it. Experience gained over time in the proper handling and preparation of wild game in ways that minimize risks for foodborne illness is useful, but foodborne illnesses may be obtained from wildlife (and other animals) with no overt clinical signs or gross lesions of disease. Therefore, local knowledge of diseases present in the pursued wildlife also needs to be considered. This is a cumulative learning process that becomes strengthened by becoming familiar with the areas where wildlife are harvested.

The common sense of most people, coupled with the general good health of most wildlife, are major factors why wildlife, from shellfish to mammals, provide wholesome food for millions of people (Fig. 2.34). Nevertheless, problems do occur. Within the USA, home preparation of novel foods often is the cause for the infrequent occurrence of foodborne illness from wildlife. For example, during 1995, **cougar** jerky was the source for 10 cases of trichinosis in Idaho. All of those cases involved jerky made from a single animal taken by a hunter. The meat was not sufficiently heated during the smoking process to kill the parasites present. In North America, wildlife-associated cases of trichinosis most commonly result from the consumption of insufficiently cooked **bear**, wild boar, and walrus meat.[267] Wild boar is an important species associated with trichinosis in Europe, where this disease appears to be an emerging zoonosis.[268] Wildlife also are sources for this disease in South America and Asia.[269]

Perspective

Information provided here and elsewhere clearly illustrates that the nature of foodborne diseases has changed greatly in the USA and globally during the 20th century. A substantial number of the pathogens of greatest concern today have only recently (within the past 25 years) been recognized as causes of foodborne illness.[218] In part, improved technology has helped scientists detect and study the pathogens involved, especially enteric viruses.[221] Nevertheless, the threat from emerging foodborne disease is more a product of our global marketplace and mobile society, than it is a result of advanced technology. Consider for example that the USA is the world's second largest importer, as well as the second largest exporter, of seafood.[251]

The consequences for human health following infection by foodborne diseases often extends beyond initial illness by causing chronic sequelae or long-term disability (Table 2.18).[218,220] The large number of foodborne diseases involving pathogens of animal origin indicates that consideration should be given to disease emergence in wildlife and other animals as factors influencing foodborne and waterborne diseases.

Deer and *Escherichia coli* O157:H7

Annually, about 10 million Americans hunt deer.[234] Venison supplements many larders and is an important staple for some. Preparation of deer meat includes venison summer sausage, jerky, and fondue, in addition to grilling, roasting, and other common ways for cooking beef and other meats. Mule deer (black-tailed deer) and white-tailed deer both have been the source of *E. coli* O157:H7 infections in humans. In 1995, an outbreak involving 11 human cases was traced to the consumption of jerky made from the meat of a mule deer killed the previous week in Oregon.[235] A spontaneous human case was also diagnosed following the consumption of venison from a white-tailed deer killed in Vermont. The meat had been grilled and served rare.[236] Both events were the first documented for the deer species involved. The mule deer event was the first time jerky had been documented as a source for infection.

Deer previously had been linked to human cases of *E. coli* O157:H7 but proof is lacking for those reports. In 1987, the organism was recovered from venison that caused an isolated human case in Washington State. However, cross-contamination from beef butchered at the same facility may have been the source of the organism.[235] In another situation, contamination of an apple orchard by deer feces was hypothesized to be the source for an *E. coli* O157:H7 outbreak caused by unpasteurized apple cider.[237]

Photo courtesy of the U.S. Fish and Wildlife Service

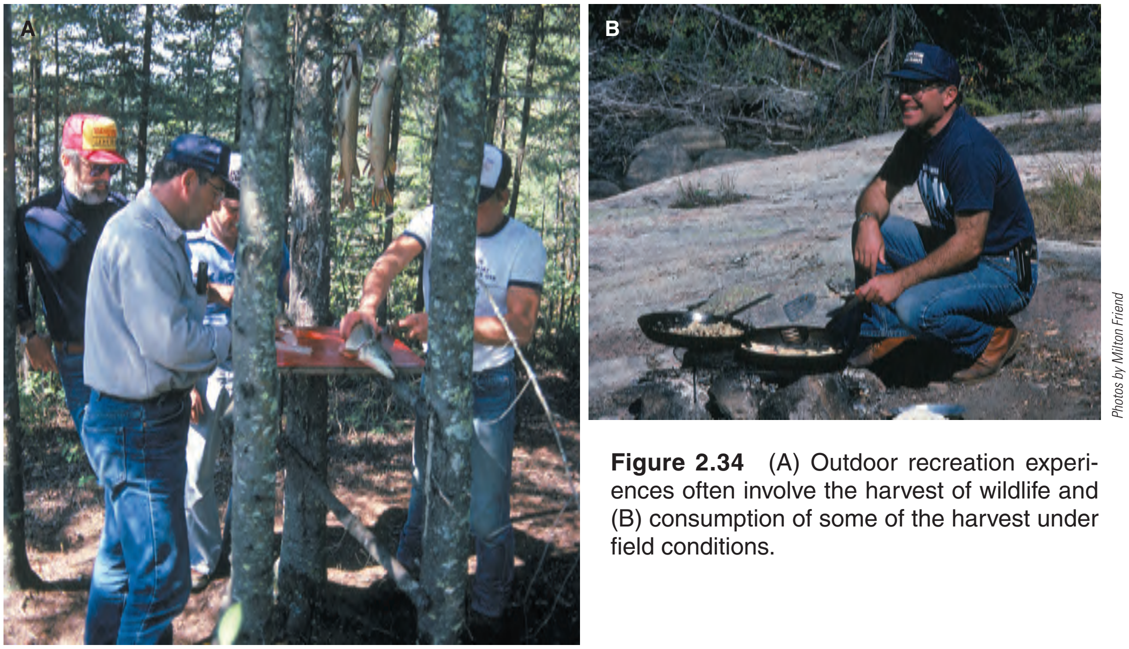


Figure 2.34 (A) Outdoor recreation experiences often involve the harvest of wildlife and (B) consumption of some of the harvest under field conditions.

Table 2.18. Examples of chronic sequelae or disability associated with foodborne disease.

Disease	Sequelae/disability	Comments[a]
Campylobacteriosis	Guillain-Barré syndrome (GBS)	One of the most common causes of flacid paralysis in the USA. An estimated 1,360 cases in 1997 were associated with *Campylobacter* infections; about 30 percent of infections are followed by GBS.
Escherichia coli infections	Hemolytic uremic syndrome (HUS)	*E. coli* O157:H7 is a leading cause of HUS, the most common cause of acute kidney failure in children in USA; about 4 percent of all reported cases develop HUS. In Canada, non-O157 cases of *E. coli* contribute to at least 7 percent and perhaps 20 percent of the HUS cases.
Listeriosis	Miscarriages, meningitis	Cases of meningitis are associated with patients with chronic diseases.
Cryptosporidiosis	Diarrhea	Persons with AIDS generally have a severe protracted course of diarrhea.
Toxoplasmosis	Congenital malformation; retinitis, encephalitis	Involved in mental and physical retardation cases in Korea.[548] In USA, 1:10,000 births results in congenital toxoplasmosis; 300 to 2,100 ocular cases estimated annually. Each year an estimated 4,000 AIDS patients develop *Toxoplasma* encephalitis.
Trichinosis	Chronic illness	In 10 to 20 percent of cases, neurological or cardiac symptoms develop, many are severe and may lead to chronic illness.
Salmonellosis	Arthritis	Infection may cause invasive disease or reactive arthritis.

[a]Information from Altekruse et al., [220] and Mead et al.,[218] unless otherwise noted.

Disease Emergence and Companion Animals

"More than half the households in the English speaking world keep a pet. The most common pets are cats and dogs" (Riordon and Tarlow).[270]

Nearly 60 percent of all households within the USA own either a dog or a cat.[250] Results from a recent survey indicate an estimated 68 million dogs and 73 million cats among the 63 million USA households that own pets.[271] Of the households that owned a pet, the 2000 USA census reports that 36 percent had a dog and 32 percent had a cat.[271] Over 98 million other types of pets, from fish and reptiles to horses, also are part of 20.6 million USA households.[272] The estimated numbers of animals involved are 19 million birds, 19 million small animals of various species, 9 million reptiles, 159 million freshwater fish, and 6 million saltwater fish.[271] An estimated 15 to 20 percent of American households have pet birds and 20 million households have aquariums.[273] Many other countries also have a high percentage of households with pet ownership (Fig. 2.35). Pets can contribute to the physical, social, and emotional health of many, especially enhancing the development of children and the well-being of the elderly.[274] The popularity of companion animals is likely to continue to increase, as is the increase in different species, other than dogs and cats, kept as pets. For example, the number of **iguanas** imported into the USA rose from about 28,000 in 1986 to nearly 800,000 in 1993.[275]

People are generally aware of health hazards associated with pet ownership such as animal bites, allergies, and high-profile diseases like rabies in dogs. However, most individuals are unfamiliar with the diversity of other diseases transmissible to humans that pets may harbor (Table 2.19). There is even less appreciation of emerging diseases as a component of pet ownership.[274,276]

Risk Factors

Health hazards associated with pet ownership can be classified into three classes of disease.[277] Allergic response, asthma, and/or hypersensitivity pneumonitis are immunologic conditions and are not considered here. Bites and/or scratches may induce infections by microbes present in the saliva and on the mouth parts of the pet. For venomous species, toxins may be injected into the body. In the USA, there are an estimated 1 to 2 million dog bites and 400,000 cat bites each year, many of which result in bacterial contamination.[277] Infections occur in about 5 percent of dog bites and 16 to 35 percent of cat bites.[270] A mixture of microorganisms frequently causes these infections. Those most commonly involved include *Staphylococcus* spp., *Streptococcus* spp., *Corynebacterium* spp., *Pasteurella multocida*, *Capnocytophaga canimorsus* (formerly called DF–2), and a variety of anaerobes.[278] The third health-hazard category is transmission of infectious diseases.

The risks of acquiring zoonotic diseases from companion animals differ among groups of people and animal species kept as pets. Factors influencing disease risk include age and source of the animals, type of environment within which the animals are maintained, and physiological status and age of the pet owners. Investigations involving these factors have disclosed that many new dogs and cats are acquired as puppies and kittens. Typically, these young animals have a higher prevalence of parasitism and, if untreated, provide more risk for infection of household members. Young children tend to have a great deal of close contact with those animals and are at increased risk. Pets acquired from animal shelters and pet stores often have greater parasite burdens than pets in personal ownership.[274]

Diseases involving wildlife as companion animals are addressed elsewhere. Here the focus is on dogs and cats, and on providing a conceptual awareness of disease aspects associated with pet ownership. Numerous evaluations of zoonoses transmitted by dogs and cats have been published[270,277–279] including the recent book, "Dogs, Zoonoses and Public Health."[280] Those publications include specific information about infections acquired from dogs and cats.

Dogs and cats confined to the home and those that have controlled outdoor excursions within urban environments have less opportunity to acquire pathogens from wildlife than pets living in rural settings and most hunting dogs that are allowed to roam in adjacent fields and wooded areas. Hunting dogs are generally controlled during their field activities. Dogs and cats that kill and consume small rodents, feed on carrion encountered in the field, or are fed viscera and other waste from animals harvested and processed by humans for food are at risk of acquiring infectious agents. Often the dog or cat does not become infected by the pathogen. Instead, its mouth and claws become contaminated by the pathogen.

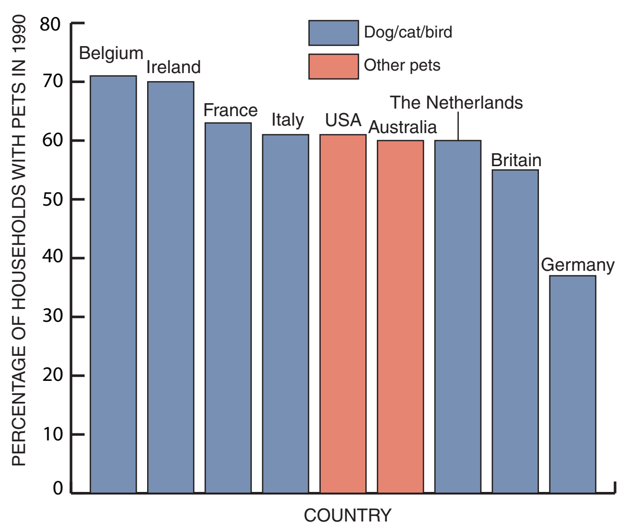


Figure 2.35 The percentage of households with pets, 1990.

Table 2.19. Examples of infectious diseases transmitted to humans by domesticated species of household pets in the USA (adapted from Plaut et al.).[277]

Disease	Pet animals											
	Dog	Cat	Ferret	Rabbit	Hamster	Other rodents	Horse	Parrot	Pigeon	Other birds	Turtle	Fish
VIRAL DISEASES												
Rabies[a]	●	● (orange)	● (orange)	○	○	○	○	○	○	○	○	○
Lymphocytic choriomeningitis	○	○	○	○	● (orange)	● (orange)	○	○	○	○	○	○
BACTERIAL DISEASES												
Campylobacteriosis	●	●	○	○	● (orange)	○	●	○	○	○	○	○
Capnocytophaga canimorsus (DF-2)	●	● (tan)	○	○	○	○	○	○	○	○	○	○
Leptospirosis	●	● (tan)	○	○	○	●	○	○	○	○	○	○
Lyme disease	● (orange)	○	○	○	○	○	○	○	○	○	○	○
Melioidosis	○	○	○	○	○	○	○	○	○	○	○	● (tan)
Mycobacterium marinum	○	○	○	○	○	○	○	○	○	○	○	● (orange)
Pasteurella multocida	● (orange)	●	○	○	○	○	○	○	○	○	○	○
Plague	● (orange)	●	○	○	○	○	○	○	○	○	○	○
Rat-bite fever	○	● (tan)	○	○	○	○	○	○	○	○	○	○
Salmonellosis (not *S. typhi*)	● (tan)	● (tan)	● (orange)	● (orange)	● (orange)	●	○	● (orange)	● (orange)	●	●	○
Tetanus	●	●	○	○	○	○	○	○	○	○	○	○
Tularemia	● (orange)	●	○	○	○	○	○	○	○	○	○	○
Yersiniosis	● (orange)	● (orange)	○	● (orange)	○	● (orange)	○	○	○	○	○	○
Chlamydial and rickettsial diseases												
Cat scratch fever	● (tan)	●	○	○	○	○	○	○	○	○	○	○
Chlamydiosis	○	● (tan)	○	○	○	○	○	●	●	● (orange)	○	○
Rocky Mountain spotted fever	● (orange)	○	○	○	○	○	○	○	○	○	○	○

Disease	Pet animals											
	Dog	Cat	Ferret	Rabbit	Hamster	Other rodents	Horse	Parrot	Pigeon	Other birds	Turtle	Fish
FUNGAL DISEASES												
Cryptococcosis	unreported	unreported	unreported	frequent	unreported	unreported	unreported	unreported	frequent	frequent	rare	unreported
Ringworm	frequent	frequent	frequent	frequent	unreported	frequent	frequent	frequent	unreported	unreported	unreported	unreported
Sporotrichosis	common	frequent	unreported	unreported	unreported	rare	unreported	unreported	unreported	unreported	unreported	unreported
PARASITIC DISEASES												
Cryptosporidiosis	common	common	common	unreported	unreported	common	unreported	unreported	unreported	unreported	unreported	unreported
Cutaneous larva migrans	common	common	unreported	unreported	unreported	unreported	unreported	unreported	unreported	unreported	unreported	unreported
Visceral larva migrans	frequent	common	rare	unreported	unreported	unreported	unreported	unreported	unreported	unreported	unreported	unreported
Echinococcosis	common	unreported	unreported	unreported	unreported	unreported	unreported	unreported	unreported	unreported	unreported	unreported
Scabies and *Cheyletiella*	common	common	unreported	common	unreported	unreported	unreported	unreported	unreported	unreported	unreported	unreported
Toxoplasmosis	rare	frequent	unreported	unreported	unreported	unreported	unreported	unreported	unreported	unreported	unreported	unreported
Giardiasis	common	common	common	unreported	unreported	common	unreported	unreported	unreported	unreported	unreported	unreported

●, frequent; ●, common; ●, rare; O, unreported

[a]Rabies is a rare human disease in USA.

Transmission of disease agents by pets to humans often occurs during play and other close contact. Typically, this results from dogs licking the skin of people and through scratches inflicted to skin surfaces by dogs and cats. Persistence of pathogens in the mouths of pets is much more prolonged than that on the feet. For example, *Pasteurella multocida* has been isolated from the mouths of 50–70 percent of healthy cats. Typically this bacterium causes localized infections in association with bite wounds[279] but more severe outcomes can occur. This same organism has caused meningitis in infants following their faces being licked by dogs.[281] Cat scratch disease, or bartonellosis, is an example of a disease associated with young kittens that is transmitted by scratches, and less frequently by being licked on the face.[270,277]

Dogs and cats may have, or can acquire, ticks and biting insects that are either infected or contaminated with infectious agents. Those arthropods may be transferred within the home environment to members of the household. Infection of humans occurs when the arthropod feeds on the human. Examples include ticks that transmit tularemia, Rocky Mountain spotted fever, and Lyme disease, and **fleas** that transmit plague, bacillary angiomatosis, scabies, and *Cheyletiella* infections. The use of tick and flea collars to prevent attachment of these arthropods to pet animals along with the timely inspection and careful removal of ticks from pets (tularemia has been transferred to humans by crushing infected ticks during removal) can minimize this potential source for human infections.

The probability of dogs being infected with *Giardia* and the chance for acquiring this protozoan parasite is greatest in households with multiple dogs. This is true for a number of parasitic zoonoses where the eggs of these parasites are shed in feces and may persist for some time. Home environments can become heavily contaminated by parasites transmitted by fecal-oral routes if feces are not regularly removed from yards and if cat litter boxes are not cleaned often.[282] Toxoplasmosis, hookworms, and roundworms are examples of these situations. Cats are the major source for transmission of toxoplasmosis and because it takes 1–5 days for the oocysts to become infective, cat litter should be disposed of daily.[270] Dog and cat hookworms are the cause of cutaneous larva migrans and dog and cat roundworms of the genus *Toxocara* are the most common causes of visceral larva migrans. Both types of infection are acquired from soils contaminated by pet feces.

Immunocompetency as a Factor

The potential for humans to become infected by disease agents associated with their companion animals is often related to the physiological condition of the person. Disease emergence and reemergence have been a hallmark of AIDS because of the immunosuppression associated with this disease. For example, the average annual incidence of salmonellosis among AIDS patients is 19.2 times greater than the population without AIDS, that for campylobacteriosis 39 times greater, and between 30 percent and 50 percent of AIDS patients have disseminated tuberculosis caused by the *Mycobacterium avium* complex,[60] organisms that seldom cause disease in humans. Similarly, infectious diseases are often complications for patients whose immune systems have been suppressed by treatments associated with organ transplants, cancer therapy, and by other conditions. When the degree of immunosuppression is great, organisms that typically are unable to cause disease or only minor illness in healthy persons may cause serious disease in immunosuppressed individuals. Similarly, the very young also have increased vulnerability until their immune system becomes fully developed. Vulnerability of the fetus is a factor in protecting pregnant women from disease agents such as *Toxoplasma gondii* that can invade the fetus. This parasite can cross the placenta and cause chorioretinitis and severe brain damage in the fetus.[270] These conditions should be considered in contacts between humans and their companion animals and appropriate steps taken to minimize health risks.

The aging human population is another aspect of reduced immunocompetency that, like AIDS and organ transplants, is an emerging component of modern society. A consequence of aging relative to disease emergence is the potential waning of immunocompetency. In the United States, 2.6 percent of the population was 74 or older in 1950. By 1995, that percentage had more than doubled to 5.6 percent and represented 14.7 million persons versus 3.8 million in 1950.[283] Currently, 20 percent of the USA population is comprised of the very young, the elderly, pregnant women, and **immunocompromised** individuals. This percentage is expected to increase substantially.[60] The increasing percentage of senior citizens in society has been projected for the near term by the Bureau of Census and potentially indicates a greater pool of human hosts with increased susceptibility to pet-transmissible zoonoses. They report that at the beginning of the 20th century less than 5 percent of the United States population was over 65, but by the year 2040, more than 25 percent of the population will be that age or older.[284]

The aging human population is an important consideration relative to the role of companion animals in disease emergence because of current trends to incorporate animals within the environment of nursing homes. These animals provide companionship and other attributes that are important benefits for improving the quality of life for many of the elderly confined to these facilities. The aggregation of elderly within the space limitations of nursing homes provides a potential for epidemics of zoonotic disease transmissible by companion animals. Therefore, it is important that adequate health maintenance be provided for animals maintained within nursing homes and that informed decisions are made on species acquisitions and the sources of animals brought into those facilities.

Pets and Human Wellness

In general, humans benefit from pet ownership. Dogs and cats are a source of great pleasure for humans and significantly contribute to the physical and emotional well being of the elderly, as well as to their safety.[59] For example, a European evaluation disclosed that, in general, pet owners have lower blood pressure and cholesterol levels than non-pet owners and use fewer medications.[285] A study of AIDS patients disclosed less depression among patients who owned pets than for patients who did not.[286] Nevertheless, the potential health risk to humans from enteric parasites harbored by pet dogs and cats is a significant problem throughout the world[276] and the elderly are among those at greatest risk.[287] As noted above, dogs and cats also are sources for diseases caused by a variety of microbes. The challenge is to maximize human benefits from pet ownership by minimizing any associated risks from disease. To do this, there is a need to fully appreciate the nature of the disease risks and how those diseases are transmitted. That information provides the foundation for strategies and actions needed.[60] Public education is an important component of those strategies and actions.[274,276]

Factors Contributing to Disease Emergence

"We have the met the enemy and he is us" (Pogo).

The emergence of infectious disease can be viewed as a two-step process. First, the pathogen is introduced into a new host population; the pathogen then becomes established and is further disseminated within that population.[288] Disease expansion to other populations often follows. Numerous examples have been provided regarding the introduction of pathogens into new wildlife host populations. The steep mortality curves and relatively short duration of the epizootic stage of many wildlife disease events (Fig. 2.36) are typical of "virgin soil epidemics" that occur in naive human populations. World history has documented many such past events having profound impacts on human populations.[1,291–293] The AIDS pandemic and the recent reintroduction of cholera (*Vibrio cholerae* O1) into the Americas are current examples of significant pathogens introduced into human populations.

Pathogens are introduced by numerous means, but these introductions do not necessarily result in disease establishment, further dissemination of disease within the population, or further dissemination of the pathogen to other populations and geographic areas. Numerous novel pathogens and disease conditions have been observed as isolated events, and commonly appear in scientific journals as brief case reports to document the occurrence of the pathogen or disease condition in wildlife and to alert others. In some instances, diseases encountered may be zoonoses.[292–294] For example, a wildlife biologist acquired an isolated case of an exotic fungal disease (streptothricosis) (Fig. 2.37) while checking hunter-killed

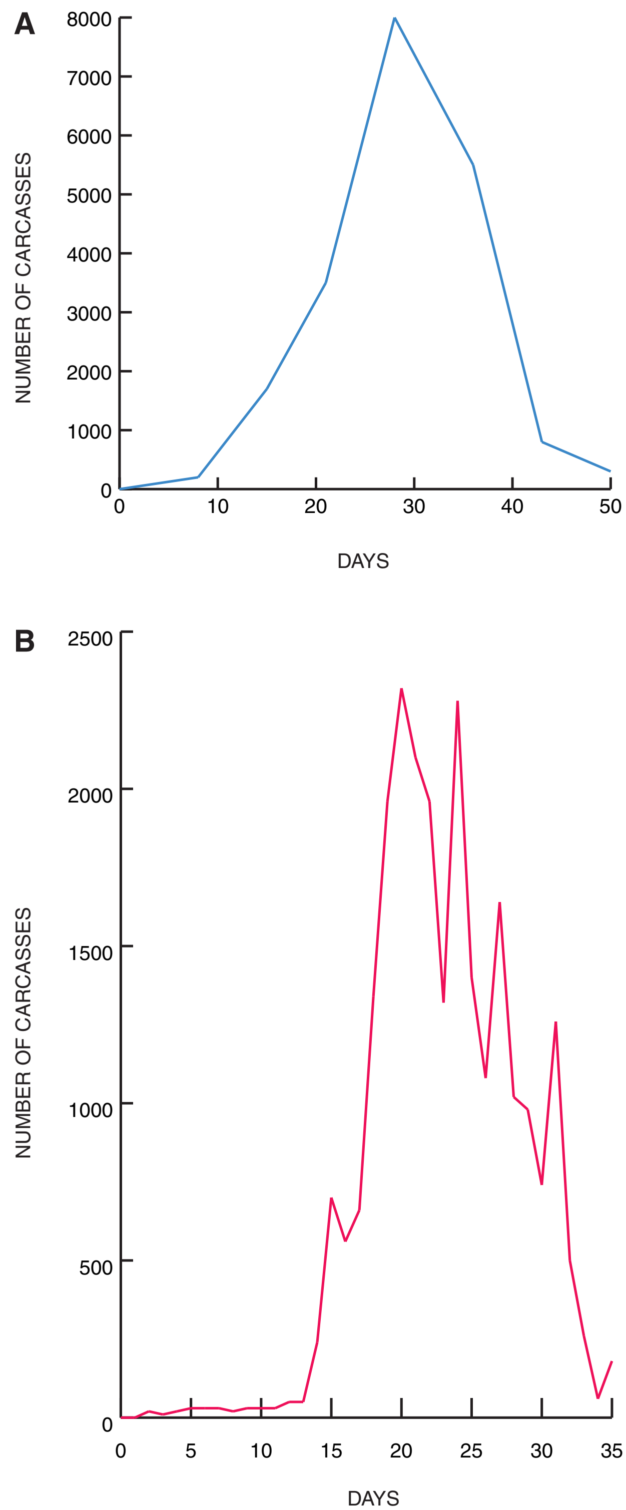


Figure 2.36 Epizootics can cause many wild bird mortalities in a short time period. (A) Mallard mortalities due to duck plague at the Lake Andes National Wildlife Refuge, South Dakota, USA, in 1973. (B) Wild bird mortalities due to avian cholera in the Rainwater Basin, Nebraska, USA, 1975.

deer, a routine activity conducted by hundreds of biologists and technicians every year. Intensive follow-up investigations failed to disclose additional cases.[292]

In many instances, it is the interactions among several factors that facilitate disease establishment within new host populations and the subsequent outcomes of disease **endemicity** and geographic spread. Lists of the primary factors involved have been developed for emerging and reemerging infectious diseases of humans (Table 2.20). Those concepts have also been extended to disease emergence affecting other species.[3–6,28,39,43,46,49,283,295–301]

Different factors are more important for some classes of disease agents (e.g., viruses and protozoan parasites) than others. For example, the absence of a suitable intermediate host for completion of a parasite life cycle can prevent the establishment of a highly pathogenic parasite following its introduction into a susceptible host population. In contrast, if a parasite or microbe that does not require an intermediate host is directly introduced into that same host population, the pathogen could become established and spread to additional populations and geographic areas. Other pathogens may require arthropod vectors for their development, transmission, or maintenance in nature. For example, the introduction of appropriate species of ticks can result in those ticks becoming reservoir hosts that sustain an indigenous pathogen between periods of disease epizootics/epidemics. Also, pathogen numbers may be amplified through biological multiplication within the body of the infected tick. When they take a blood meal, these ticks then transmit the pathogen to susceptible hosts.

Hawaii serves as a classic example of wildlife disease resulting from introduced arthropod vectors. **Mosquitoes** were introduced and became established during the early 1800s into these previously mosquito-free islands. They provided the vectors needed to sustain two important pathogens, avian poxvirus and the protozoan parasite responsible for avian malaria (*Plasmodium relictum*). Both pathogens became established in the Hawaiian Islands after the introduction of mosquito vectors. Pox was present by the late 1800s,[302] but malaria did not reach epizootic status until the early 1900s. Introduced exotic bird species, especially those from Asia, were the probable source for the malaria parasite.[303] Within native forest bird habitat, mosquitoes have become established because introduced pigs create mosquito-breeding habitat in the base of tree ferns that the pigs uproot.[304]

Figure 2.37 Hand lesions caused by streptothricosis.

Mosquitoes are mechanical vectors for avian pox. Conceptually, they are a "flying syringe" that transfers the virus taken in by the mosquito when they previously fed on infected birds. The same species of mosquitoes are biological vectors for avian malaria. In this situation, the mosquito is a required component for the development and multiplication of the malaria parasite and also is a vector for disease transmission. Avian malaria and, to a far lesser extent, avian pox have become limiting factors for populations of native birds on the islands of Hawaii.[302,303,305]

Pathogen Factors

The development of pathogen genotypes better adapted for infection of humans and genotypes or phenotypes associated with a specific pathogenic capacity are factors in disease emergence and reemergence.[306] These attributes of the disease agent are not independently adequate for disease emergence to occur. The predictability of disease emergence in humans based on evaluations of only pathogenic agents is complicated by inadequate knowledge of the ecology of many known diseases and other factors. For example, the routes for transmission of over 200 human pathogens are unknown. Nevertheless, it has been shown that emerging diseases of humans are not caused by a random selection of pathogens. Zoonotic pathogens are overall twice as likely to be associated with emerging diseases than nonzoonotic pathogens. Also, viruses and protozoan parasites are especially likely to emerge as diseases of humans, while helminthes (parasitic worms) are very unlikely to emerge, regardless of their transmission routes or zoonotic status. The reasons for these outcomes have not been adequately determined. Genetic diversity, generation time, and existence of a reservoir for maintenance of the pathogen between periods of disease outbreaks are among the salient factors.[46]

Life as a Pathogen

The biologically relevant endpoints for pathogens are survival, proliferation, and transmission. These endpoints drive pathogen adaptation to their environment. Microbes generally have greater capacity to rapidly adjust to environmental changes than helminth parasites because of their greater genetic capabilities and much shorter generation times. Those capabilities and other attributes also provide microbes with evolutionary advantages over humans and other species that

Table 2.20. Primary factors associated with disease emergence and reemergence in humans.

Category/factors[a]	Comments
AGENT (PATHOGEN)	
Microbial adaptation and change	• Includes selective pressures, mutations, evolution, and associated changes.[3–5,28,549]
Ability to cross species boundaries	• Invasion and establishment in nontraditional hosts of dissimilar species.[48,307,550]
Transmissibility, pathogenesis, and virulence	• Ability to invade hosts, cause disease, and be transmitted to new hosts.[28]
Survival and maintenance	• Environmental persistence during periods of disease quiescence.
ENVIRONMENT	
Ecological change	• Includes climate change and natural processes such as vegetation succession, seismic activity, fires, major flood events, and other weather related events that cause large-scale landscape impacts.[3,28,549]
Animal migration	• Natural cycles of animal movements such as seasonal movements of migratory birds, pursuit of water in arid regions, and movement to calving areas by large mammals.[549]
HUMANS	
Population	• Includes growth, distribution (changes in demography) and density (crowding).[4,5,549]
Behavior	• Includes sexual (e.g., AIDS), social, cultural, and other behaviors as well as attitudinal perspectives and actions.[3–5,549]
Urbanization	• Movement of people from rural to larger communities.[4,549]
Modern travel and commerce	• Movement of goods and people associated with international travel, ecotourism, and the global marketplace.[4,5,301,549–551]
Changes in agriculture and food practices	• Includes cropping patterns, methods of rearing animals for food production, aquaculture development, and food processing and packaging.[3,28,549,550]
Modern medicine	• Includes organ transplants, antibiotics, increasing longevity of human population, and other aspects of health care.[3,4,28,549]
Breakdown in public health infrastructure and measures	• Includes reductions in arbovirus surveillance and other activities and shifting emphasis away from infectious disease.[3–5,549]
Animal relocations	• Includes introductions of exotic species, human movements of agricultural species and wildlife (including fish), and commerce in companion animals (domestic and wild species).[5,549,550]
Environmental change	• Land-use impacts due to human actions such as deforestation, dam construction, large-scale agriculture, urban development, and the development of recreation areas.[3–5,28,550]
Societal events	• Includes war or civil conflict, urban decay, day care for children, and political actions that degrade standards of living.[3,28]
Technology and industry	• Increased speed of transportation (jet aircraft), water reclamation, medical capabilities, air conditioning, and other beneficial products and capabilities that have "side-effects" relative to disease emergence.[4,5,28,301]

[a] Considerable overlap exists among factors within categories and categories are interactive with one another.

Table 2.21. Examples of emerging and reemerging infectious diseases of humans that have crossed species barriers.

Disease	Type	Comments
Influenza	Virus	• Human infections involve viruses composed of a reassortment of genetic material from viruses infecting birds and domestic animals.[552–554]
		• The 1957 and 1968 influenza pandemics contained genes derived from avian influenza viruses; the 1997 locally lethal occurrence of Hong Kong Flu and the 1999 Hong Kong isolates from two severe human cases of disease had all their eight gene segments of avian origin.[48] H5N1 avian influenza has killed poultry in nine Asian nations since its appearance in the late 1990s. Twenty-six people, domestic and large zoo cats, and swine also have died.[570] This virus could potentially evolve into one that can spread amongst humans, causing a pandemic.[571]
		• Influenza B viruses that circulate among the human population have now been isolated from infected marine mammals (seals).[442]
AIDS	Virus	• About 35 million people worldwide have been infected by HIV-1 virus that originated in the chimpanzee; the sooty mangabey is the source of HIV-2 virus.[48]
B-virus (*Cercopithecine herpesvirus* 1)	Virus	• Only 40 human cases have been documented since the 1932 index case, but the case-fatality rate prior to the availability of antiviral therapy was greater than 70 percent.[555]
		• Rhesus macaque and cynomolgus macaque are commonly found with B-virus infection and are commonly used in AIDS and other biomedical research. Other species also found infected.[555]
Marburg hemorrhagic fever	Virus	• Infrequently occurring deadly hemorrhagic fever first seen in 1967 among laboratory workers in Germany and Yugoslavia; all had handled tissues from African green monkeys.[556]
Ebola hemorrhagic fever	Virus	• First occurrence in 1976 in Zaire followed by epidemics elsewhere in 1995 and 1996; case-fatality rate reached 88 percent in initial event (280 deaths).[48,556]
		• As with Marburg hemorrhagic fever, primates are associated with Ebola fever in humans, but the reservoir hosts are unknown.[48]
Hendra virus infection	Virus	• First appeared in Australia in 1994; fatalities in horses and a horse trainer. Reappearances in 1995 and 1996; fruit bats appear to be reservoir hosts.[557]
Nipah virus infection	Virus	• First appeared in Malaysia during 1998 to 1999; up to 40 percent case-fatality rate in people having close contact with sick pigs. Dogs and cats also died; fruit bats appear to be the reservoir hosts.[48,557]
Bovine spongiform encephalopathy (BSE or "mad cow disease")	Prion	• Documented in the United Kingdom in 1985 as a fatal disease of cattle; several species of zoo animals and cats died in 1990s following consumption of food containing material from infected cattle. First human case documented in 1995.[48]

Table 2.21. Examples of emerging and reemerging infectious diseases of humans that have crossed species barriers—Continued.

Disease	Type	Comments
Monkeypox	Virus	• First identified in 1970 in the Democratic Republic of the Congo (DRC); probably existed before but it was confused with smallpox. Only 14 cases in DRC from 1987 to 1992, none from 1993 to 1995; major resurgence of human cases since 1996 (more than 500).[558] The disease appeared in North America for the first time in 2003.
Hantaviruses	Virus	• Initial US event in 1993 among Native Americans in the Southwest. Deer mouse is the natural host and reservoir for the virus, which is shed in their urine and feces. Human infection is often fatal.[559,560]
Ehrlichiosis	Rickettsia	• Human monocytic ehrlichiosis (HME) first identified in USA in 1986, mainly occurs in southwestern and south central USA. Tick transmitted. White-tailed deer are primary definitive hosts for tick vectors.[561] • Human granulocytic ehrlichiosis (HGE) first identified in USA in 1995, mainly occurs in Northeast and northern Midwest. Tick transmitted. White-footed mouse is primary reservoir host. • White-tailed deer may be an important reservoir host for *Ehrlichia ewingii*, one of the several causative agents of ehrlichiosis.[562]
Leptospirosis	Bacteria	• Contaminated recreational waters becoming an increasing source for human infections. Reservioir hosts range from rodents to large mammals to marine species, wild and domestic.[48]
Babesiosis	Parasite	• Distinct species first observed in Eastern and Western USA in 1968; more than 200 cases in eastern USA since 1982 where white-footed mouse is primary reservoir host and white-tailed deer the definitive host for the tick vectors; blood transfusions also can transmit disease.[563] • The western species (WAI-type *Babesia*) reappeared during the early 1990s; isolates from human cases from California are indistinguishable from those from mule deer and suggest large ungulates as the primary reservoir hosts.[563]
Tuberculosis	Bacteria	• Avian and fish strains (*Mycobacterium avium* and *M. marinum*) of the tuberculosis complex are generally of low virulence for humans, however, these strains can cause mortality in people with AIDS.[277]

are increasingly being expressed as emerging diseases.[31] Those capabilities also have converted challenges for pathogen survival posed by antibiotics into opportunities for the emergence of antibiotic-resistant bacteria. Human actions that have resulted in the ubiquity of antimicrobials in the environment have been instrumental in facilitating the resulting evolutionary lessons that continue to occur on microbial adaptation and the power of natural selection in species with the population dynamics and genetic capabilities of microbes.[5,25,31]

The ability of pathogens to cross species boundaries is another important biological aspect of disease emergence. Free-ranging wildlife populations and humans have been victimized by such events.[307] Notable examples of pathogens crossing species boundaries include diseases in humans caused by viruses, rickettsia and other bacteria (Table 2.21), and parasites. The factors that influence the ability of each infectious agent to effectively cross the species barriers are poorly understood. However, human actions can create opportunities for species boundaries to be bridged.[48] In essence, humans set the table at which microbes and parasites feed.

The Human Factor

In 1992, the Institute of Medicine published an insightful evaluation of disease emergence titled, "Emerging Infections: Microbial Threats to Health in the United States."[4] That evaluation addressed the primary factors driving infectious disease emergence. Human actions clearly are an important component in each of the six primary factors identified. To a large extent, these same factors apply to disease emergence in wildlife populations. Understanding and addressing this interconnectivity is important in combating zoonotic diseases and for minimizing the potential for the emergence of these types of diseases.

Human Demographics and Behavior

Population growth, density, and distribution have changed significantly in a manner that facilitates the transmission and maintenance of infectious disease within human populations. Worldwide, less than 1.7 percent of people lived in urban communities in 1800 compared to more than one-third by 1970 and one-half by 2000. This shift in demographics is also accompanied by increased population density in urban communities because of population growth; 225 cities reached population levels of over 1 million in 1985, and 445 cities reached that level by 2000. Twenty-five cities have populations exceeding 11 million people. Often, the infrastructure and economy of these large urban areas is insufficient to provide adequate living space, sanitation, and clean water for many of the inhabitants. Associated conditions of overcrowding, poor sanitation, and degraded environmental conditions facilitate the emergence of various pathogens and disease vectors such as mosquitoes. These factors have facilitated the emergence of dengue fever in the Americas.[4]

A somewhat analogous situation exists for North American waterfowl populations. The millions of ducks, geese, and swans that constitute this biological resource are typically migratory and gregarious species. Population maintenance is accomplished through annual cycles that involve breeding in northern areas followed by seasonal movements along general geographic corridors (referred to as "flyways") to wintering areas and then back to the breeding areas. The greatest numbers of waterfowl are found in the Pacific Flyway, where millions of these birds begin to move southward each fall. Historically, there was an abundance of wetlands available to provide for resting, feeding, and wintering areas along this annual journey. However, between the 1780s and the mid-1980s, 22 of the conterminous 48 states within the USA drained, filled, or otherwise destroyed more than 50 percent of their wetlands. California leads the nation with a loss of 91 percent of its historic wetlands.[308] The significant degradation of an additional 4 percent of the remaining wetlands results in an effective loss of 95 percent of the historic habitat base for **migratory birds** dependent on wetlands. More than one-half of the 7 million waterfowl wintering in the Pacific Flyway depended on California wetlands during 2000.[309]

Wetland loss has resulted in dense aggregations of waterfowl on the remaining habitat for prolonged periods of time (Fig. 2.38). Fecal contamination from these birds is extensive and degrades the water quality of their habitat.[310] These situations facilitate the transmission of infectious agents shed in the feces. Waterfowl also can be exposed to infectious agents present in wastewater that has not been adequately treated. Birds make heavy use of sewage lagoons and other wastewater sites as feeding and loafing areas. In addition, historic migratory patterns have been altered to the extent that Canada geese and some other species have established nonmigratory urban/suburban populations that make continuous use of the same water bodies (Fig. 2.39). These altered environmental conditions have substantially contributed to the unprecedented occurrence of infectious disease as a major mortality factor in migratory birds. Prior to the 1970s, infectious disease was infrequently observed among free-ranging waterfowl populations and seldom accounted for large-scale epizootics, such as those that now commonly kill thousands to tens of thousands of birds per event.[8]

Photo by Milton Friend

Figure 2.38 Waterfowl often gather in dense groups.

Photo by Milton Friend

Figure 2.39 Wild waterfowl are becoming increasingly urbanized.

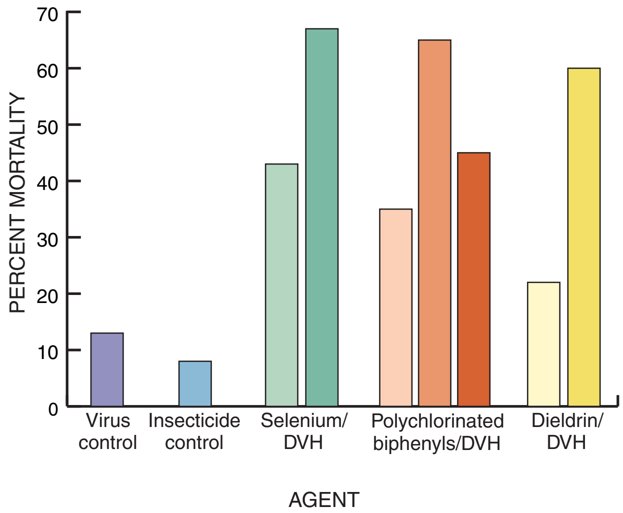


Figure 2.40 Pre-exposure to chemical agents increases susceptibility of mallard ducklings to duck virus hepatitis (DVH). Darker shades reflect higher dosage of agent.

Immunosuppression is another factor that influences the occurrence of infectious disease in humans.[4] For waterfowl, malnutrition associated with altered diets and the potential immunological effects of pesticide exposure threaten their populations. Replacement of wetlands with large-scale agriculture has resulted in a shift to cereal grains as a primary food source for some waterfowl species. These high-energy foods do not meet the full dietary requirements for waterfowl and this inadequacy can increase susceptibility to disease agents. A classic situation is lead poisoning. The toxic effects of ingested lead shot are increased in birds feeding on corn rather than natural foods.[311]

Exposure to pesticides by waterfowl and other wildlife is well documented and often postulated to be an interactive factor with microbes that enhances wildlife susceptibility to mortality. The potential for such occurrences have been demonstrated experimentally by using a duck virus hepatitis-mallard duck model (Fig. 2.40).[312–316] Concurrent disease is another condition that occurs in wildlife as well as humans. Aspergillosis (*Aspergillus fumigatus*) is a common cause of death in Canada geese and swans (Fig. 2.41) that have been incapacitated by lead poisoning.[317]

Technology and Industry

Modern medicine, food processing and handling, and water treatment are primary components contributing to disease emergence in humans as a result of technology and industry. **Nosocomial** (hospital acquired) infections are a major "side effect" of modern medicine that results in an estimated 2 million cases and 20,000 deaths annually in the USA.[4] Antibiotic resistance is a major part of this problem. Technological changes in agriculture, food processing, and food handling to provide greater yields, operational efficiencies, and other benefits have also had emerging disease "side-effects." Feedlots, large-scale poultry operations, and the growth of aquaculture have all provided new environmental opportunities for human pathogens. Hamburger and *Escherichia coli* infections and poultry and *Salmonella enteritidis* are examples of disease emergence associated with the food industry.[4]

Wildlife Rehabilitation—Public values associated with the well-being of wildlife have resulted in a large number of independent, largely private sector, wildlife rescue and rehabilitation programs where oiled, injured, and other afflicted wildlife are brought for treatment. Wildlife with infectious disease are commonly among the animals submitted. The opportunity for wildlife to acquire "nosocomial infections" in these facilities is substantial because of the physical limitations and other inadequacies often present relative to disease **containment**. The return of infected, but clinically inapparent wildlife, to nature may be a source for disease introductions and epizootics.

Antibiotic Resistance—The role of wildlife as contributors to the development of antibiotic-resistant pathogens has not been seriously explored and questions remain. Wildlife are exposed to antibiotic use in wildlife rehabilitation programs and in nature. Antibiotics enter waters that are feeding areas for wildlife and also may be present in poultry and other domestic animal wastes spread on fields where wildlife feed. Some species of birds actively feed on materials present in fresh feces of cattle and some feed among livestock in feedlot operations (Fig. 2.42). Therefore, considerable opportunity exists for some species of wildlife to become exposed to antibiotics. These same wildlife may be involved in the maintenance and transmission of disease agents that affect domestic animals and humans. The effects of antibiotic exposures of wildlife on the pathogenicity of the myriad of microbes and parasites that wildlife share with other species are unknown.

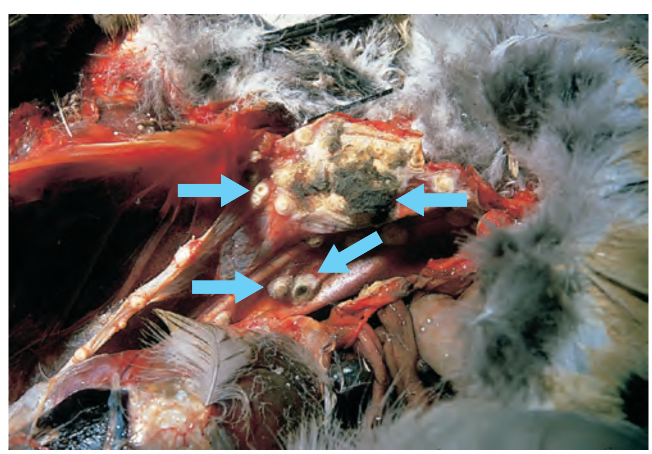


Photo by Milton Friend

Figure 2.41 "Cheesy" plaques and fungal growth in the lungs and air sacs of a bird with aspergillosis.

Photos by Milton Friend

Figure 2.42 (A) Wild birds, such as sandhill cranes, often feed among cattle. (B) Wild birds also congregate near cattle feedlots, may feed among the cattle, or feed in adjacent habitat receiving waste runoff from the feedlot.

Aquaculture and Disease Emergence—Aquaculture has become an increasing source of the human foodbase because of shifting dietary preferences and the inability of natural stocks of finfish and shellfish to supply the needs of the growing human population. In the USA there is large-volume fish consumption, with prices, in some cases, exceeding those for beef, even for species that a half-century ago were considered “trash fish” eaten only by those of low economic status. The growth of aquaculture as a greater component of world food supplies has been stimulated by increased product value, allowing enhanced investments by that industry. These investments lead to technological advances providing an increasing array of shellfish and finfish at marketable volumes that provide adequate economic returns to stimulate further production. Aquaculture contributes up to 15 percent of the seafood utilized in the USA[251] and supplies one-third of the seafood consumed worldwide.[318]

The continued growth of the aquaculture industry is expected, as are emerging diseases as a component of this form of agriculture.[251] For example, in 1987 several hundred persons in the Montreal area of Quebec, Canada, became ill and several died from eating cultured blue mussels. This malady was termed “neurovisceral toxic syndrome” and was found to be a domoic acid toxin associated with the pennate **diatom** *Nitzschia pungens*. That event was the first recognized occurrence of this shellfish-induced toxic syndrome.[319,320]

The most significant diseases of mollusks in cultured and wild stocks have been linked to the introduction and transfer of infectious agents. During recent years, many disease problems in these species appear to be related to changing culture techniques and the diversification of species under culture.[81] Similarly, in less than 30 years, the **penaeid shrimp** culture industries of the world have grown from an experimental beginning into major businesses.[79] Shrimp aquaculture grew by 430 percent between 1985 to 1994 and a high rate of growth continues.[80] This growth has been accompanied by recognition of a host of previously unknown infectious disease agents.[79] Fortunately, for human health, few of these pathogens are zoonoses; however, their emergence commonly impacts wild stocks of the same or similar species. Ecological damage resulting from these diseases can be substantial with staggering economic losses.[79]

Farming of the Chinese or soft-shelled turtle has also developed rapidly in recent years and has been accompanied by an increasing number of diseases. A new iridovirus with the proposed name of soft-shelled turtle iridovirus was found to be the cause of an epizootic of “red neck disease” on a turtle farm in China.[321]

Economic Development and Land Use

Changes in land use commonly are associated with settlement of wild lands or economic development activities. The resulting landscape changes alter the habitat base for **vertebrates** and invertebrates as well as species interactions. For example, the geographic prevalence of tularemia within the USA has shifted greatly during recent decades, in part due to landscape changes that have altered the habitat base for the mammalian hosts and tick vectors for this disease.

Dam building and reforestation provide examples of landscape changes resulting in the emergence of diseases impacting humans. Mosquito-borne Rift Valley fever (RVF) is primarily a disease of sheep and cattle. This disease had only been known to occur in Africa south of the Sahara. In 1977, following the completion of the Aswan Dam, RVF caused an estimated 200,000 human cases of clinical illness and nearly 600 deaths in Egypt. In 1987, following the completion of the Diama Dam, RVF caused more than 1,200 cases of severe illness and nearly 250 deaths in the Senegal River Basin. Sheep and cattle were also affected during both events. In both situations, dam building contributed to the emergence of RVF by providing breeding habitat for the mosquitoes that transmit this disease.[4]

Lyme disease (*Borrelia burgdorferi*) is transmitted by several species of *Ixodes* ticks. In the Midwestern and Eastern USA, the white-footed mouse is the reservoir host for the causative bacterium and white-tailed deer are definitive hosts for the tick vectors. Early development in areas east of the Mississippi River resulted in extensive deforestation and the demise of deer due to the loss of their woodland and forest habitat. Changes in land use that followed the movement of much of agriculture westward, resulted in dramatic reforestation that exceeds the forest cover at the time of settlement. Changes in lifestyles have resulted in the development of suburban communities within these reforested areas. High deer and mouse populations have accompanied the reforestation. The close proximity of human hosts (living in those reforested areas) to the ticks that transmit Lyme disease add to this problem. Lyme disease has become the most common **vector-borne disease** in the USA and it has been reported in all 50 states.[4]

Disease emergence impacting free-ranging wildlife populations has also occurred from economic development and land use. Agriculture practices have directly contributed to disease emergence in wildlife as a result of cropping patterns and the replacement of natural foods with grain as a primary wildlife foodbase. Agricultural crop-related diseases of wild birds include aflatoxicosis,[322] castor bean poisoning,[323] and enterotoxemia due to *Clostridium perfringens*.[324] A wintering area for sandhill cranes in the Texas/Oklahoma panhandles of the USA was developed for peanut farming, which resulted in the emergence of mycotoxicosis as a cause of mortality for these birds. The climate of that area is conducive to freeze-thaw cycles, a condition required for growth of the causative fungi and production of toxin. Waste peanuts left from harvest provide the growth medium for the fungi and cranes then eat the toxic peanuts (Fig. 2.43). Approximately 10,000 sandhill cranes died during the initial epizootics.[325]

The development of livestock and poultry operations has provided various interfaces that have facilitated the transfer and emergence of infectious diseases of commercially raised animals into free-ranging wildlife populations. Avian cholera (*Pasteurella multocida*) in wild birds and brucellosis (*Brucella abortus*) in bison and elk are only two of many diseases that can be cited. Aquaculture has provided a host of diseases from finfish and shellfish culture that have emerged in wild populations of these species, such as whirling diseases (*Myxobolus cerebralis*) in rainbow trout and Taura syndrome virus in shrimp.

Agriculture also affects wetland water quality. Nutrient loading from fertilizer residuals contributes to **eutrophication** that results in algal blooms, some of which have been associated with wildlife toxicity.[62,326–328] Water quality is closely associated with the increased geographic distribution of type C avian botulism (*Clostridium botulinum*) within the USA and globally.[329,330] Wastewater treatment ponds, stormwater runoff into wetlands, and wastewater discharges from the processing of agricultural commodities have all been associated with avian botulism epizootics.

International Travel and Commerce

The emergence of infectious disease as a "by-product" of the movement of people and goods from one region to another is well documented throughout human history. The introduction of smallpox into the New World and syphilis into the Old World are classic diseases associated with human travel. The movement of infected animals and arthropod vectors of disease into new regions has occurred through commerce, often as hitchhikers present in the transport vessels.[4] For example, introduction of the Asian tiger mosquito into the USA occurred in used tires, rats infected with disease have entered various ports from ships that began their voyages in other parts of the world, and the discharge of ballast water is thought to be the source of the cholera (*Vibrio cholerae*) outbreak in the Americas that began in 1991. Also, the speed of modern transportation facilitates the movement of diseases between continents by travelers who are incubating serious infections, such as **SARS**. Contacts with people along the way at the time when infected individuals are shedding disease agents further enhance the potential for disease distribution.[301]

Wildlife also are moved regionally and internationally by human actions. The raccoon rabies epizootic of the eastern USA is the result of a translocation of raccoons for sporting purposes.[537] Inclusion body disease of cranes was likely brought into the USA in zoological collections or in cranes needed for captive breeding programs. Diseases of finfish and shellfish have been moved between continents in founder stocks for aquaculture and by trade in aquarium fish. Bovine tuberculosis and malignant catarrhal fever have jeopardized captive-breeding populations of endangered spe-

Photo by Ronald Windingstad

Figure 2.43 Sandhill crane that died from eating peanuts contaminated with mycotoxins.

cies of wild **ruminants** following the international movement of infected animals into those breeding populations. Other disease introductions and the emergence of novel diseases for captive and free-ranging wildlife populations also have occurred by this means.

Microbial Adaptation and Change

The adaptation of microbes to their environment is highly complex, involving such components as natural variation or mutation by microbes (e.g., influenza A virus), and selective pressure and the development of resistance in known infectious agents (e.g., multidrug-resistant tuberculosis); and microbes acting as cofactors in chronic disease (e.g., *Chlamydia pneumoniae* and atherosclerosis).[4] It is reasonable to assume that similar adaptations are occurring within wildlife populations. Examples have been cited within this chapter of classic pathogens (e.g., canine distemper virus emerging as a cause of disease in new hosts, such as lions and marine mammals). Historic diseases such as rabies are now known to have strain variants that are adapted to specific groups of animals. Continual opportunities for adaptation are provided to microbes by the plethora of introductions of exotic species of vertebrates and invertebrates associated with human induced landscape changes and other actions. New species interactions including the potential for transfer of microbes and parasites between naive hosts and the involvement of new arthropod vectors are potential outcomes from these introductions. Human engineered, newly created major ecosystems appear within short time frames around the globe as a result of dams, deforestation, and urban development. In addition, alteration of the gene pool for some vertebrate species as a result of large-scale releases of captive-reared animals is another potential opportunity for microbes to exploit.

Breakdown of Public Health Measures

The reappearance of diseases such as cholera (*Vibrio cholerae*) due to inadequate sanitation, measles due to complacency towards immunization, and a host of other diseases associated with the conditions of war and postwar periods are components of the public health infrastructure factor.[4] A recent vivid example is the devastating diphtheria epidemic that occurred in Russia following the breakdown of the Soviet Union and its transition to other forms of government. When the epidemic began in 1990, reported diphtheria (*Corynebacterium diphtheriae*) cases increased from 603 in 1989 to 47,802 in 1994 causing 746 deaths that year.[333] More than 80,000 people were infected and more than 2,000 died by early 1995.[332] In addition, several major outbreaks of tularemia have occurred in postwar Bosnia and other nearby areas associated with that conflict. Contamination of water supplies by diseased animals is thought to be the source for those events.[331] The 1993 cryptosporidiosis outbreak in Milwaukee, Wisconsin, USA due to failure of water treatment, resulted in 403,000 human cases of this emerging disease.[247,336]

Unlike human and domestic animal health, there is no comparable infrastructure for wildlife health. Short-term crisis response is the general action the wildlife conservation community takes. As a result, infectious diseases may be able to establish a foundation for their perpetuation before they become recognized as emerging infections. During recent decades, several multidimensional programs devoted to addressing disease in free-ranging wildlife populations have been developed within government agencies and the university community (Table 2.22). These programs complement other programs within wildlife conservation agencies that respond at various levels to wildlife health issues. While these programs have continually demonstrated their value, they remain few in number, small in size, and isolated from the much larger programs developed to address infectious diseases in humans and domestic animals. To help combat wildlife disease, there is a need to enhance infrastructure and wildlife programs to provide essential information on wildlife diseases. The need for enhanced coordination and integration of efforts is evident from the high percentage of zoonoses that are of wildlife origin and the increasing interface between humans and other species that will continue to occur as a result of human population growth and associated landscape changes.

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Table 2.22. Major North American wildlife disease programs (free-ranging wildlife).[a]

Program	Type	Comments
Canadian Cooperative Wildlife Health Center	Cooperative	• Four regional programs operate out of the Schools of Veterinary Medicine, University of Prince Edward Island; University of Guelph; Université de Montréal; and University of Saskatchewan. • Program support and interfaces with Environment Canada (federal), Provincial and Territorial wildlife departments, other government agencies, and private sector organizations. • Conduct laboratory and field investigations to determine causes of wildlife mortality; research to resolve the ecology of various diseases; public outreach and education; and train students.
National Wildlife Health Center USGS science for a changing world	Federal	• Federally funded science program of the U.S. Geological Survey; headquarters in Madison, Wisconsin, with a field station in Honolulu, Hawaii. • Government owned and operated site with biosecurity level-3 facilities for both laboratory and live animal investigations. • Conduct laboratory and field investigations to determine causes of wildlife mortality; research to resolve the ecology of various diseases; public outreach and education; and train students.
Northeastern Research Center for Wildlife Diseases University of Connecticut	Cooperative	• Established within the Department of Pathobiology, University of Connecticut, Storrs, Connecticut. • Program support provided by numerous sources, including member state wildlife agencies. • Conduct laboratory and field investigations to determine causes of wildlife mortality; research to resolve the ecology of various diseases; public outreach and education; and train students.
Southeastern Cooperative Wildlife Disease Study Southeastern Cooperative Wildlife Disease Study	Cooperative	• Established within the School of Veterinary Medicine, University of Georgia, Athens, Georgia. • Program support provided by numerous sources, including southern and eastern member state wildlife agencies. • Conduct laboratory and field investigations to determine causes of wildlife mortality; research to resolve the ecology of various diseases; public outreach and education; and train students.

[a]Does not include programs devoted solely to fish disease or small scale wildlife disease programs such as those carried out by a number of state wildlife agencies.

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Chapter 3

The Wildlife Factor

"There are some who can live without wild things and some who cannot." (Leopold)[1]

Photo by Milton Friend

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Chapter 3

The Wildlife Factor

Conservationist Aldo Leopold's essays in *A Sand County Almanac* "are the delights and dilemmas of one who cannot" live without wild things. Those essays were intended to focus public attention on the degradation of wild places and wild things resulting from society's pursuit for a "better life." His writing reflects inherent values of those who have a close association with the land because of cultural, spiritual, and personal beliefs and experiences. Wild things include the land as well as species living in areas not substantially degraded by the human footprint.

Human population growth and urbanization results in greater numbers of people that live further removed from "wild things" because of changing values, economic factors and less contact with natural landscapes. Some people have little reason to cherish wild land and free-ranging wildlife as being an essential part of life (Fig. 3.1). Also, human encroachment into wild places is becoming more frequent and intense, and the resulting landscape changes have negatively affected many free-ranging wildlife populations. Nevertheless, compassion for wildlife and associated economic interests often has resulted in actions intended to compensate for some of the negative consequences on "wild things," but some of these actions have further compromised, rather than enhanced, the well-being of those wildlife populations. In some instances, diseases have been introduced and enhanced, and this is an increasing outcome requiring vigilance and attention. This chapter focuses on a broad spectrum of human actions, defined here as The Wildlife Factor, that are unwittingly resulting in disease emergence and spread among wildlife populations.

Disease is an increasing threat for the continued viability of some wildlife populations,[2–7] and has negative economic effects on some recreational activities (e.g., hunting, ecotourism) and the support community for those activities.[8] Often, the potential exists for disease to spread from wildlife to humans and domestic animals. Greater proactive measures to minimize disease occurrence in free-ranging wildlife populations would benefit wildlife, domestic animals, and humans alike. The effectiveness of such measures will be enhanced by understanding how human actions and behaviors can result in disease entry into free-ranging wildlife populations and disease spread.

A. Photo by Milton Friend

B. Photo courtesy of the U.S. Fish and Wildlife Service

Figure 3.1 A) Urban parks, similar environments, and their wildlife are increasingly serving the needs of humans to interact with "nature." (B) Conversely, many natural landscapes and wildlife are becoming historical vignettes of the "natural world" that are increasingly difficult to sustain because of human encroachment and development.

Table 3.1 Examples of human-wildlife interface activities associated with disease emergence and reemergence.

Activity type	Primary[a] purposes for activity	Primary[b] sectors of society involved	Comments
		Wildlife management	
Captive-propagation releases	A, B, C	1, 2, 4	Wildlife releases in habitat held in public trust; commonly involves nonindigenous species
Translocations (agency)	A, B, C	1, 2	Wildlife releases in habitat held in public trust; occasionally involves nonindigenous species.
Translocations (private sector)	A, B, C	2, 4	Wildlife releases in habitat held in private ownership and control; commonly involve nonindigenous species.
		Commercial enterprise	
Game ranching	D	4	Focus is on marketable products such as meat or hides; often involve nonindigenous species.
Fee-hunting and fishing	A, B	4	Primarily fee-based harvest of wildlife in private ownership; may involve nonindigenous species.
Ecotourism	C	1, 4	Focus is on viewing free-ranging wildlife in nature.
"Bush meat"	D	4	Marketing of meat from free-ranging wildlife.
Wildlife pets	E	4	Primarily a wildlife trade activity involving exotic wild species and commercially raised species.
Zoological collections	F	1, 2, 4	Collections for viewing by the public and private holdings; commonly contain nonindigenous species.
		Public activity	
Wildlife rehabilitation	G	1, 3, 4	Care, treatment, and release of free-ranging wildlife.
Wildlife feeding	A, H, I	1, 4	Feeding of free-ranging wildlife.

[a] Primary purpose
A = Hunting
B = Fishing
C = Species introductions/reintroductions
D = Products (e.g. meat)
E = Pet
F = Education
G = Medical assistance
H = Viewing
I = Supplemental rations

[b] Primary sector
1 = Government
2 = Zoos
3 = University
4 = Private

Human-Wildlife Interfaces

Human-wildlife interface activities associated with disease emergence and reemergence in free-ranging wildlife populations occur in many forms and include activities directly associated with consumptive wildlife uses, such as hunting, and those associated with nonconsumptive uses, such as ecotourism (Table 3.1). Both types of uses may be involved in some activities, such as wildlife feeding, and either or both may be pursued by various cohorts of society. Personal values and orientations often differ among individuals involved with wildlife in different ways. However, these differences are irrelevant here because the sole focus is on disease associations (Table 3.1). The activities highlighted in this chapter have all been shown to have a disease component, and modifications in how those activities are carried out could promote better wildlife stewardship while still satisfying basic human needs and a broad spectrum of cultural and personal values.

Linkages and Differences

Human activities have become more global, resulting in increased and new interfaces among wildlife, humans, and domestic animals. This results in new opportunities for pathogens to move between species and thus their retransmission to the same or other species. This is evident by the recent appearances of novel pathogens that have crossed species barriers to cause disease in wildlife, domestic animals, and humans (see Chapter 2). These interactions support the concept of "the one medicine"[9] that stresses the important relationship between animal and human health proposed in the late 19th century and championed again in the late 20th century.[10] However, "the one medicine" concept has not yet become a unified and preemptive approach for addressing disease (Fig. 3.2). Instead, human, domestic animal, and wildlife disease programs tend to function as independent rather than integrated efforts.

Considerable disparity exists in the levels of program development to address disease in wildlife hosts compared with programs for domestic animals and humans (Box 3–1). Less than half of the U.S. state wildlife agencies have wildlife disease programs (Fig. 3.3), and they are generally small despite long-recognized large-scale wildlife mortality from disease (Fig. 3.4) and the movement of disease between wildlife and other species. Also, except for response to some crisis events, the general public is less aware of wildlife disease than it is about disease in domestic animals and humans. This retards developing integrated programs and collaboration among these different but related interests.

The economic and social costs from wildlife disease are staggering (Table 3.2) and justify scientific inquiry and other programs focused on disease prevention and control, and the development and continual evolution of the human and domestic animal health industries. In North America and in many other countries, additional attention to wildlife health and disease is necessary in order to measure up to human and domestic animal disease prevention and control programs and address the general phenomena of infectious disease emergence and reemergence (Box 3–1). To a great extent,

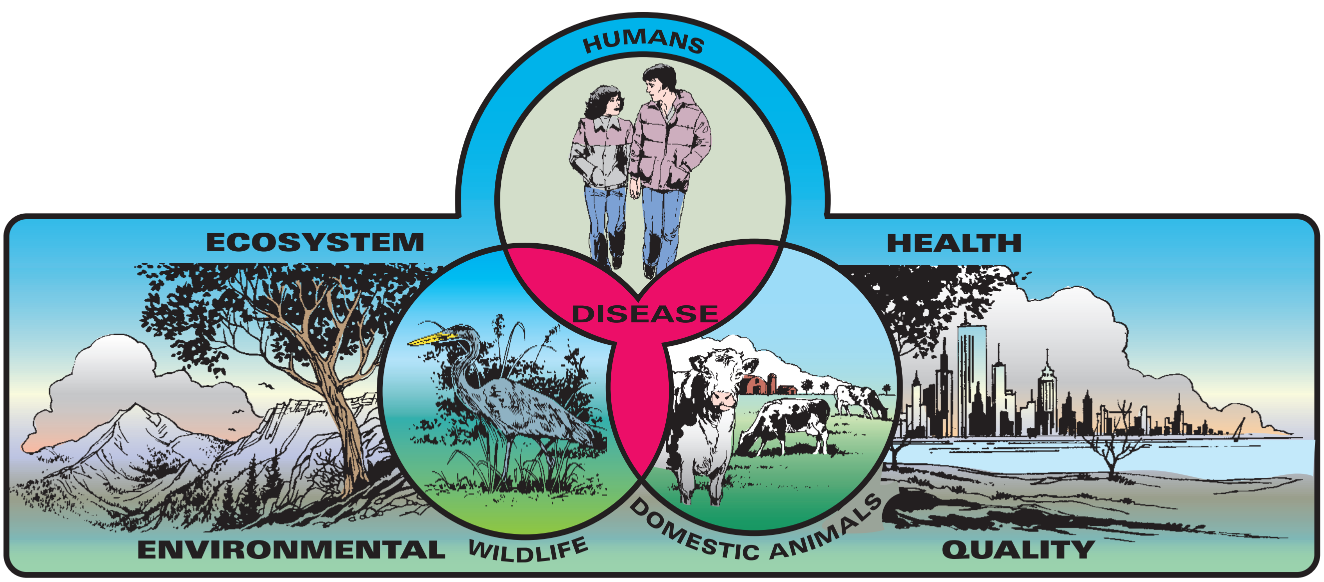


Figure 3.2 Ecosystem health is a reflection of environmental quality, an important factor in the well-being of humans, domestic animals, and wildlife alike. The interfaces that commonly occur between all of these components support the need for a holistic approach of "one medicine" for the benefit of all.

Box 3–1

Human, Domestic Animal, and Wildlife Disease Programs

"Until recently there has been greater attention bestowed upon the arrest of disease in animals than man as far as Governments were concerned." (Grant)[124]

Similarities and Disparities

The four basic pillars and their support platform for combating disease (Fig. A) are the same for humans and other species. Investments made in the basic platform provide the nutrients for growth that bond these components, creating the support base for combating disease (Fig. B). These investments must provide for program maintenance and growth. Without maintenance, the foundation crumbles and can no longer adequately support the pillars (Fig. C). When this happens, diseases gain footholds that otherwise may have been prevented. A paradox in human medicine is that the successes made in combating **vector-borne** and other infectious diseases led to the shifting of resources away from maintaining surveillance and monitoring programs. The weakening of the strong foundation built within developed nations to combat these diseases provides opportunities for disease emergence and resurgence. As a result, vector-borne and other infectious diseases have once again established their significance in the USA as factors impacting human health and economic well-being.

Without investments in program growth embodied by enhanced knowledge and the ability to apply that knowledge in ways that can effectively combat disease, the foundation becomes weakened by stagnation and cannot cope with the array of increasing challenges posed by disease. These challenges will continue to occur because of the adaptive capabilities of microbes.[125–135] Another constant is that disease emergencies that cannot be foreseen will appear (e.g., AIDS, SARS) and demand immediate attention. However, because fiscal resources are finite and competition for those resources seems infinite, a constant struggle exists relative to their allocation. Nevertheless, the consequences from disease require that sufficient infrastructure be in place to provide basic platforms for launching responses and developing controls.

Pillar 1—Early Detection

Disease surveillance and monitoring is the backbone of early detection of disease and takes many forms. Physical examinations and associated laboratory assays of body fluids and tissues are common examples for humans and domestic animals. The use of caged chickens and other animals that are placed in nature and periodically tested for antibody to specific disease, sampling arthropods (e.g., mosquitoes and ticks) for the presence of specific pathogens, and sampling surface waters for harmful pathogens are other human health examples. These activities are components of structured program efforts to combat human and domestic animal disease. In contrast, most wildlife-disease surveillance and monitoring in the USA are **ad hoc** and opportunistic rather than being associated with structured program efforts. Monitoring activities associated with disease crises such as West Nile fever and chronic wasting disease are temporary exceptions initiated after events occur and are focused on tracking disease spread rather than providing surveillance for detecting disease emergence. Typically, wildlife disease surveillance and monitoring is dependent upon chance field observations of unusual numbers of sick and dead wildlife being observed and reported.

Pillar 2—Disease Diagnosis

Rapid and accurate diagnosis of the pathogens responsible for illness and death are basic to controlling human and animal disease. These findings guide strategies to combat the disease. A primary difference between initial evaluations in diseased wildlife versus those for humans and domestic animals is that the former are usually dead whereas the latter usually involve live individuals. Regardless, the same types of specialists are needed for human and animal (including wildlife) disease evaluations. Few wildlife disease programs have adequate facilities and are insufficiently staffed or integrated with other programs to provide analyses and the spectrum of expertise required (Fig. D) to meet the demands of rapid, accurate diagnoses for guiding disease response efforts. This is especially true and important when unfamiliar diseases are encountered.

Very few diseases of wildlife result in clinical signs or pathology seen at necropsy (gross examination of internal organs and tissues following death) that are specific for one disease, thus, a spectrum of diagnostic technology needs to be readily available. Also, the same disease may result in different pathology in different species. Misdiagnosis can result in disease control responses that inadvertently spread disease because different approaches are often needed for different infectious diseases.

Pillar 3—Timely Response

In general, response to disease in humans and domestic animals is guided by well-defined areas of responsibility, established regulations and protocols, existing organizational structures, pre-established communication processes, and other components that provide a reasonably cohesive infrastructure for carrying out this important activity. The situation for wildlife is quite often different. Responses are generally ad hoc and are guided by biologists within the agency managing the site with the disease event, often in consultation with wildlife agency disease specialists (Fig. 3.3). Collaboration with human

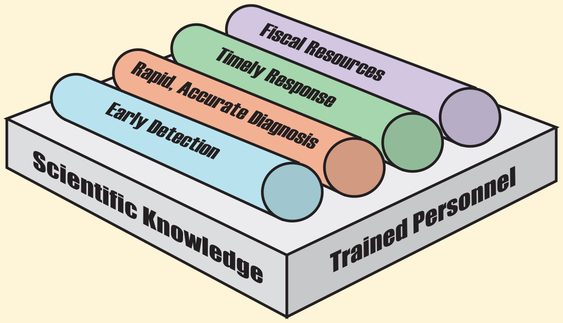


Figure A. Basic pillars and support platform for combating disease.

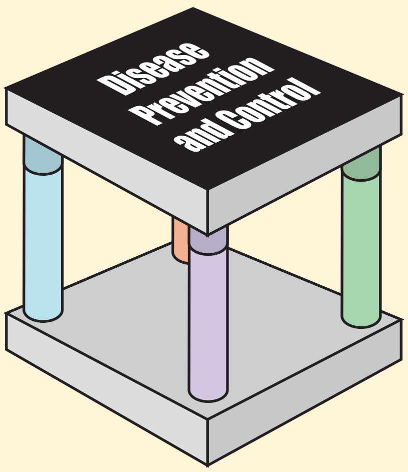


Figure B. Disease prevention and control requires a sound foundation of basic components.

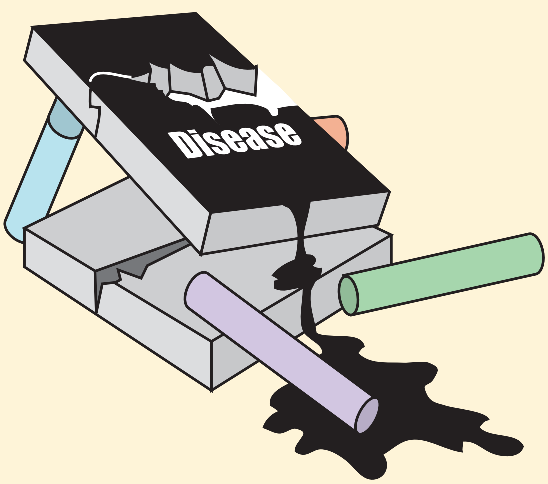


Illustration by John M. Evans

Figure C. Maintenance is essential to prevent foundation deterioration and collapse that allows disease to gain a foothold.

and domestic animal programs is primarily associated with crisis situations that also involve humans and/or domestic animals. This collaboration tends to be transient and irregular rather than planned. A notable exception is the Regional Disease Emergency Operations Program developed by the Animal Plant and Health Inspection Service (APHIS) of the U.S. Department of Agriculture (USDA). That program has a mission of preventing foreign animal diseases from being established within the USA and has broad powers vested in the Secretary of Agriculture. The USDA can take regulatory action once the Secretary declares a disease emergency for a disease that threatens the livestock and poultry industries of the nation. This program's responsibility is to protect those industries, not the wildlife of the nation.

Pillar 4—Fiscal Resources

Human and domestic animal health are agency mandates at most major levels of government (i.e., municipal, state, federal, provincial) and have direct budget allocations for disease program development and operations, and often are able to obtain supplemental funding when disease emergencies arise. In contrast, wildlife disease is not a mandated activity of natural resources agencies and decisions to allocate funds and develop capabilities for this type of activity are internal administrative decisions. State natural resources agencies that have invested in this activity (Fig. 3.3) have devoted limited resources to address disease in wildlife under their stewardship and jurisdiction. These investments generally consist of less than two professional level staff and limited internal laboratory facilities for scientific evaluations.

The U.S. Geological Survey's (USGS) National Wildlife Health Center (NWHC) is unique in the breadth of in-house technical disciplines and physical facilities devoted to wildlife disease investigations. The NWHC is the only government program (federal or state) with this level of major investment in wildlife disease. The Southeastern Cooperative Wildlife Disease Study (SCWDS) and the Canadian Cooperative Wildlife Health Centre (CCWHC) are university-based programs at schools of veterinary medicine that also have broad capabilities through a combination of in-house staff and program associations within their universities.

The NWHC was created within the U.S. Fish and Wildlife Service of the U.S. Department of the Interior (DOI) in 1975, with a total budget of less than \$0.5 million to cover all costs. Further investments over time, based on program accomplishments and merit, resulted in the development of the most complete facility and greatest staffing level devoted solely to wildlife disease worldwide (Fig. E). This national and international program has functioned throughout the 1990s and into the 21st century with fiscal resources for internal NWHC activities that ranged from about \$2.7 million to \$5.8 million annually. Further, most other wildlife disease programs have only a small fraction of the resources that exist at the NWHC. The collective resources allocated for wildlife disease investigations within North America by natural resources agencies are only a small percentage of the total resources allocated

Table A. Differences in the knowledge base for factors associated with disease prevention and control

Factors	Humans	Domestic Animals	Wildlife
Species biology and ecology	Well known	Well known	Highly variable
Disease ecology[a]	Well known	Well known	Poorly to moderately known
Probability for effective disease control	Moderate to high	Moderate to high	Poor to limited success[b]
Professional longevity	Long standing	Long standing	Recent orign

[a] For established diseases

[b] Based on current levels of investment in wildlife disease

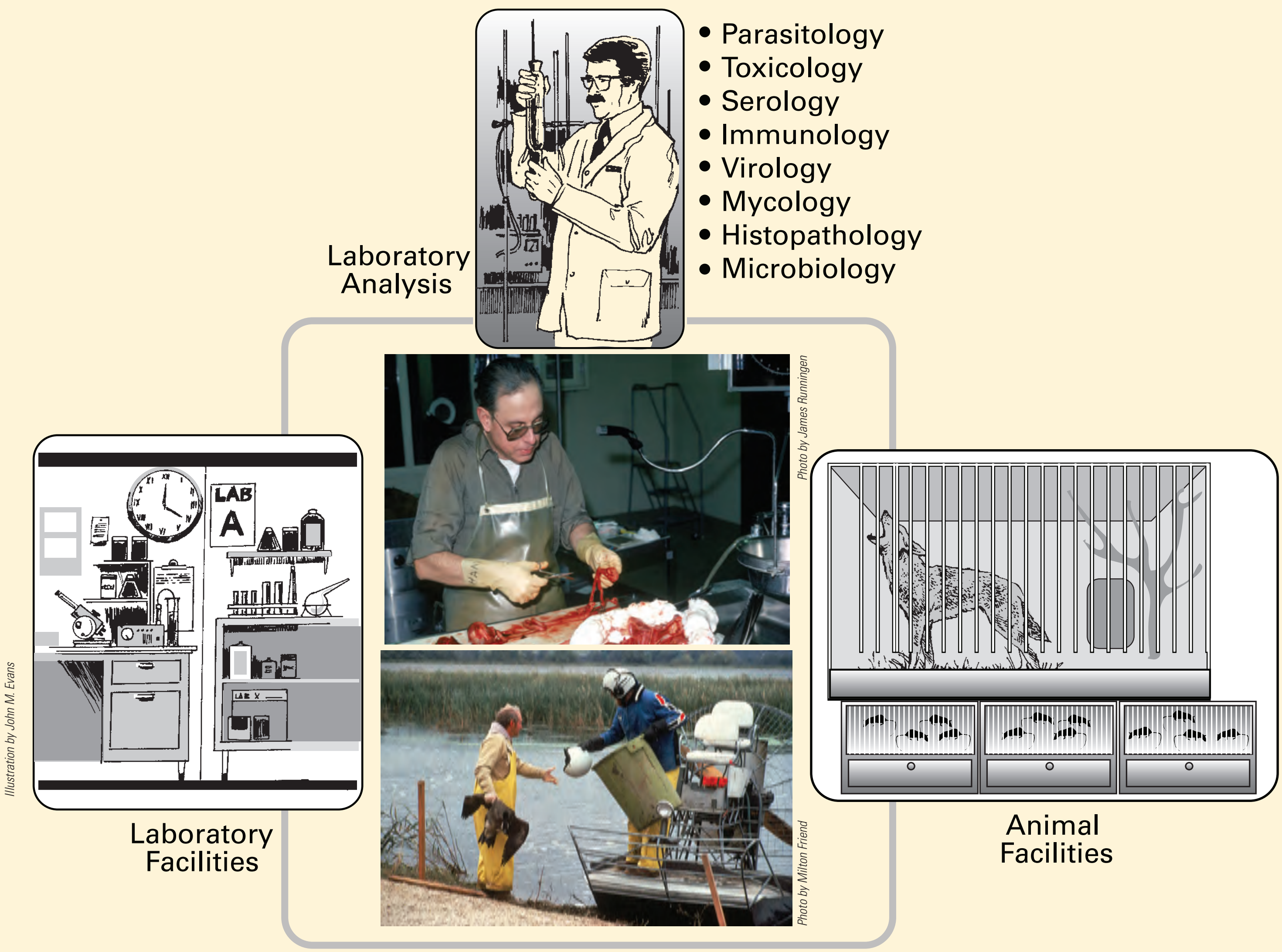


Figure D. A broad spectrum of expertise, technical assays, and facilities are needed to provide timely, accurate diagnosis of disease occurrence and support disease prevention and control in wildlife populations.

for the Centers for Disease Control and Prevention (CDC) of the U.S. Department of Health and Human Services to combat human disease and those allocated to the USDA to combat domestic animal disease.

Knowledge Base—A Critical Platform Component

The types of knowledge required to address disease in humans, domestic animals, and wildlife are similar, but differences in the knowledge base for each are major (Table A). Nevertheless, information gained from disease in one group may be of value for combating disease in another group. For example, a 1885 publication titled “The Epidemic Zymotic Diseases Of Animals And How They Are Communicated To Man,” stated:

> “For many years, while directing some little attention to Natural History, I have noted points in pathological anatomy closely allied with the diseased manifestations in the “genus homo,” and being a wide field for the practical exercise of pathological research. … Endemic and epidemic diseases are not alone confined to the human species, but extend alike to animals, and the manifestations are doubtless of peculiar interest.” [124]

As knowledge about human and domestic animal diseases increases, this gives rise to more specialists whose focused areas for investigation contribute to a collective understanding that serves the overall objectives of disease prevention and control. Addressing the wildlife interface component of diseases that also affect humans and domestic animals is complicated by the factors in Table A. These same complications extend to combating diseases that primarily impact wildlife populations.

Strengthening the Foundation—The Road to Accomplishment

The events of September 11, 2001, and subsequent terrorist activity have emphasized the need for greater vigilance regarding infectious disease. Many diseases of humans are readily transmitted by animals and wildlife are an especially important factor in the transmission of zoonoses. National security could be enhanced by a better understanding of the potential hazards from intentional disease introductions along with enhanced surveillance and monitoring of disease in free-ranging wildlife.

Movement of the NWHC and other biological science programs of the DOI into the USGS during a 1993 reorganization within the DOI has provided a unique opportunity for bridging many information gaps that exist for diseases of wildlife. As a result of this reorganization, the USGS not only has major capabilities for the direct investigation of wildlife diseases, but it also has internationally recognized programs in other aspects of biological sciences, in the physical sciences, and in remote sensing and mapping. These core program areas and a fundamental mission component of being the “science arm” for the DOI are basic components for the development of a sound wildlife health program infrastructure. That infrastructure not only serves the DOI, but because of DOI statutory responsibilities, it also effectively networks with federal and state human and domestic animal health programs. Reducing the disparity of resources spent on the study of wildlife health and disease, as compared to that for human and domestic animal health and disease, could provide substantial benefits for all three health sectors and for society at large.

Photos by Milton Friend

Figure E. The Biological Security Level–Three laboratory and animal facilities of the National Wildlife Health Center allow investigators to work with highly infectious disease agents such as plague, West Nile virus, and other zoonoses. These types of containment facilities also are essential for the investigation of highly pathogenic, newly discovered disease agents for which little information exists.

this weakness results from the contrast between perspectives toward disease in free-ranging wildlife compared to perspectives toward disease in humans and domestic animals.

Disease In Humans and Domestic Animals

Pursuit of human disease prevention and control involves benefits such as prolonged life, alleviation of pain and suffering associated with various diseases, economic benefits associated with workplace productivity, enhanced returns from agriculture, and social values oriented at benefiting human and other species. Disease can affect people and their families personally, so human disease involves "ownership." Diseases such as SARS (severe acute respiratory syndrome) and AIDS also disrupt mainstream human activities. Personal ownership is also a factor for disease prevention in domestic and **companion animals** and provides a direct linkage between humans and the well-being of those animals. Economic returns from domestic animals and emotional ties to companion animals are the primary factors involved. Many people who have cared for pets can attest to the personal anguish and pain that often results from the loss of those animals.

Disease in Wildlife

In contrast to domestic and ranched animals, free-ranging wildlife in the USA generally are in public ownership even when these wildlife are on private lands. State and federal agencies are responsible for holding wildlife in the public trust. However, public ownership of wildlife does not provide public access to private lands or unrestricted access to those lands by government agencies. Also, the harvest of public-trust wildlife on private lands is subject to the same conditions, bag limits, and seasonal take of these animals that apply to public lands. Therefore, private landowners are

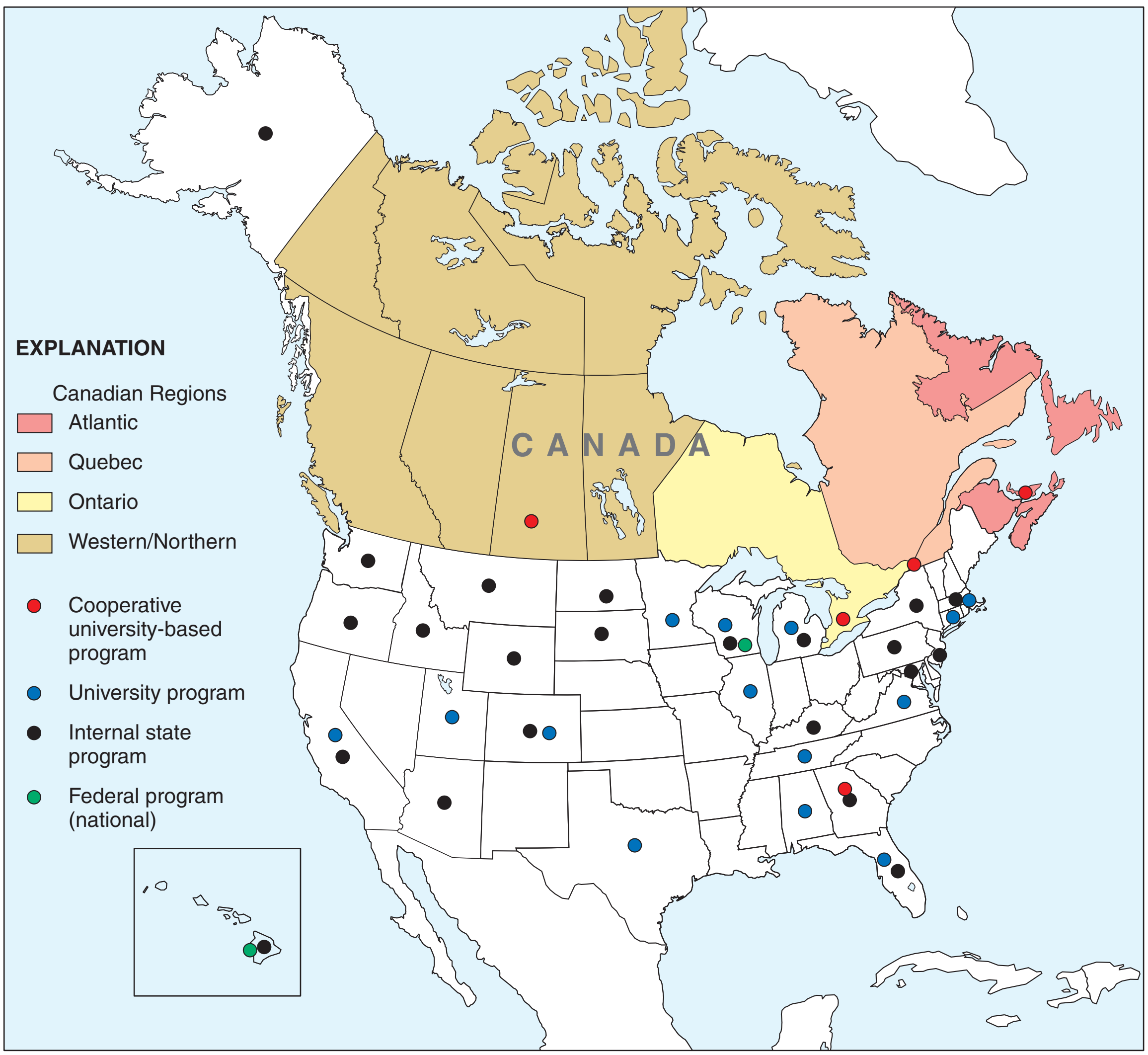
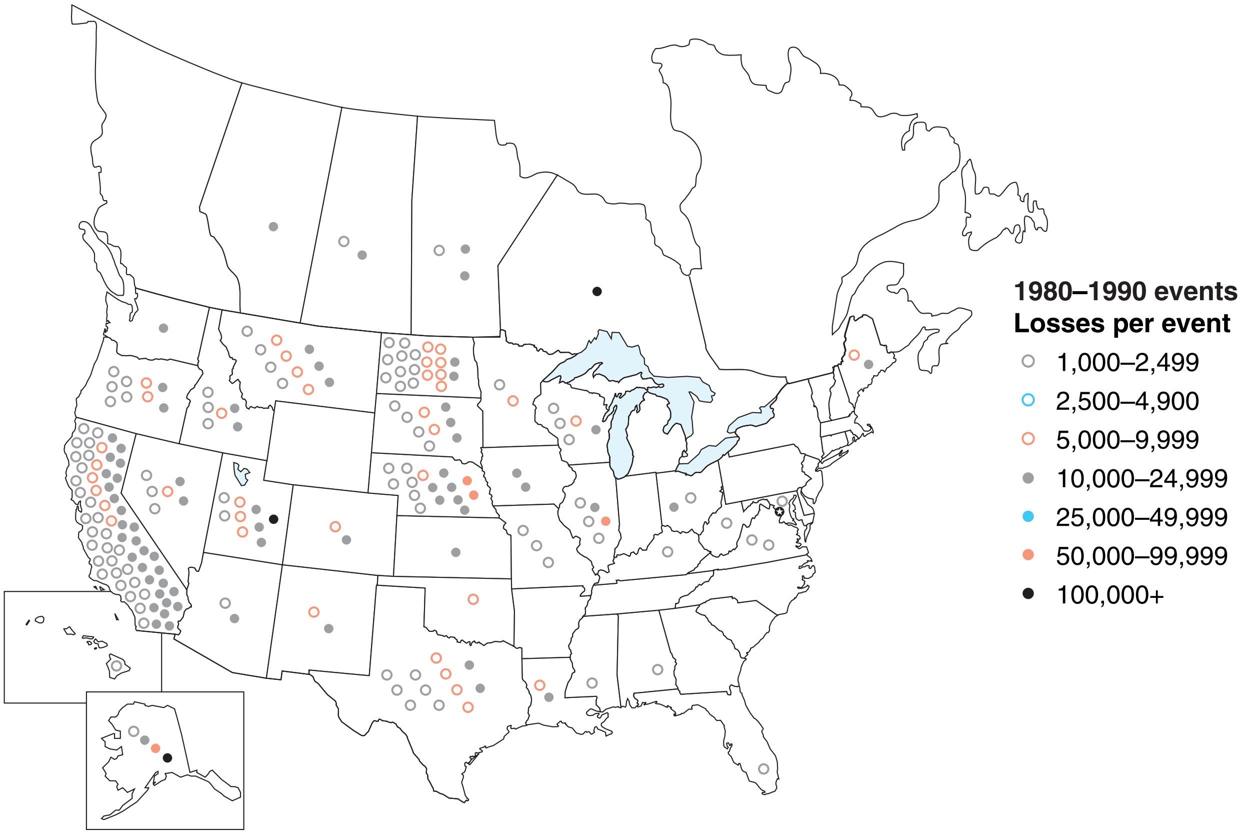


Figure 3.3 Locations and sponsorship of North American programs devoted to disease investigations involving free-ranging fauna (state, federal, University cooperative programs).



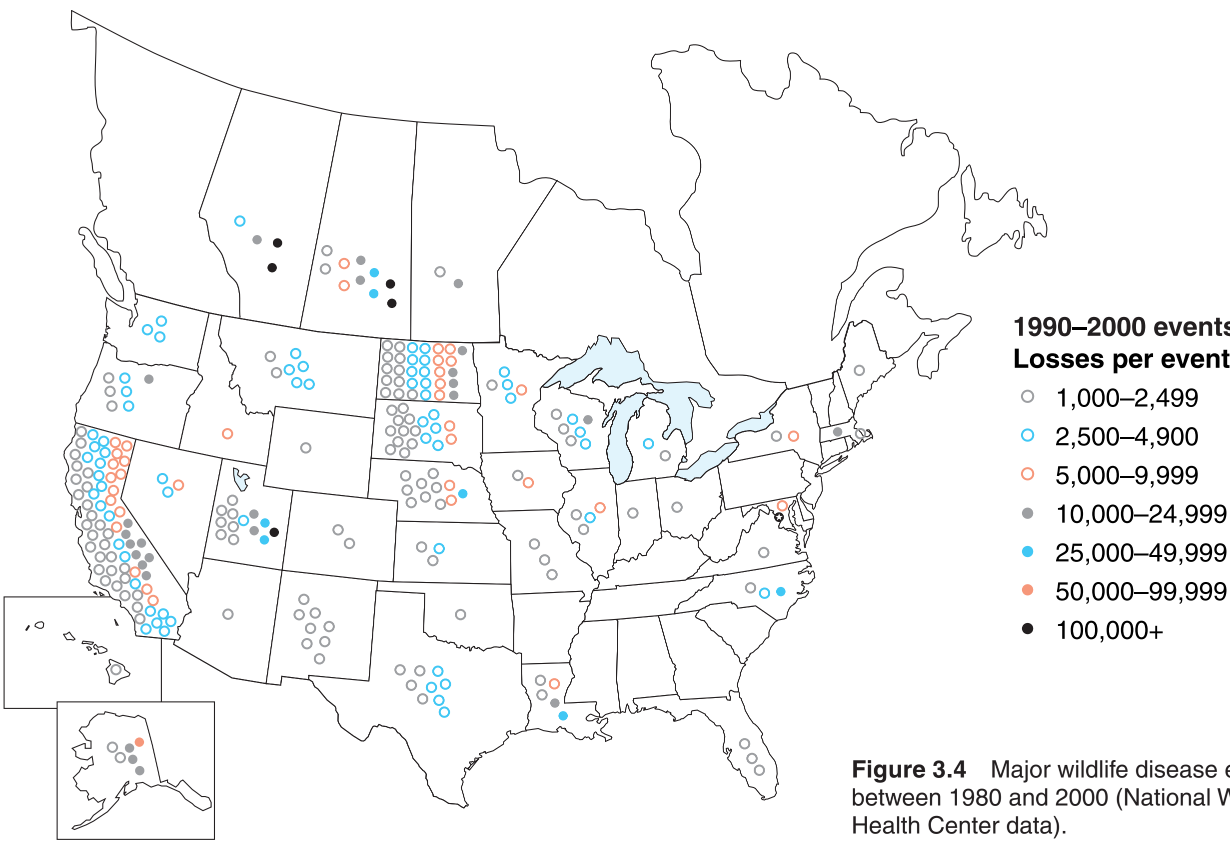
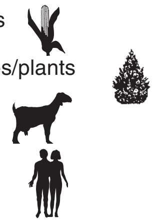
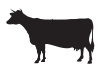
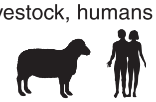
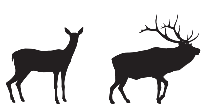


Figure 3.4 Major wildlife disease events between 1980 and 2000 (National Wildlife Health Center data).

Table 3.2 Examples of costs incurred by society from infectious disease

Disease/cause	Primary species affected	Estimated costs ($US)		Comments
Exotic pathogens	Plant crops Forest trees/plants Livestock Humans 	21.5 2.1 9 6.5	million million million million	Annual costs to USA.[168]
Water-borne pathogens	Humans 	21.9	billion	Estimated annual costs in USA based on 1991 dollars.[169, 170]
Cryptosporidiosis	Humans 	96.2	million	Total costs of outbreak-associated illness from the 1993 epidemic in Milwaukee, Wisconsin, USA.[169]
SARS	Humans 	50-100	billion	Estimated economic impacts associated with disease in humans between the April 2003 appearance of SARS and July 2003.[171]
Foot and mouth disease	Livestock 	1.8	billion	Direct cost of compensation to farmers as a result of the 2001 epizootic in the UK; total economic costs from FMD greatly exceeded those for direct compensation.[172] An estimated cost of at least $3.6 billion was projected by one evaluation.[173]
Bovine spongiform encephalopathy (BSE) or "Mad Cow Disease"	Livestock, humans 	~7	billion	Estimated cost of BSE in the UK since the 1986 appearance of this disease in livestock and subsequent human cases caused by a pathogenic variant of the disease agent.[174]
West Nile fever (WNF)	Humans, wild birds, horses 	Millions		The 4,007 human cases during 2003 in the USA resulted in an estimated $69 million for inpatient medical costs; epidemic costs for Louisiana in 2003 exceeded $24 million (including mosquito control).[175] Vaccination costs for horses and other equids (donkeys, mules and ponies) during 2002 in Nebraska and Colorado exceeded $2.75 million.[176]
Chronic wasting disease	White-tailed deer, elk 	Millions		The 2001 appearance of CWD in Wisconsin, USA has resulted in intensive efforts to eradicate this disease within the State. Projected economic impacts in Wisconsin during 2002 were a loss of $69 million to $105 million in recreational benefits for deer hunters and $5 million to $10 million in losses to the State economy from out-of-state hunters deterred from hunting because of CWD.[177] Economic impacts include lost revenue from hunting license sales, costs of disease testing and control activities, and local impacts on motels and other businesses that provide support activities from meat processing to equipment sales. Nationwide, Federal indemnity payments for captive herd depopulations to combat CWD were nearly $20.3 million by 2003.[178]
Newcastle disease	Poultry 	228	million	Cost for eradication effort associated with 1971 epizootic in California (in 2002 $) during which almost 12 million birds in 1,341 infected flocks were destroyed. Modeling for this disease in Tennessee projects that a 4-month outbreak would cost the State $158.9 million in economic loss along with a loss of over 6,000 jobs.[179]
Avian influenza	Poultry 	65	million	Cost for eradication efforts associated with 1983 and 1984 epizootics in the northeastern USA (in 1983–84 $) during which more than 17 million birds were destroyed. Retail egg prices increased by more than 30% due to the loss of poultry from this epizootic.[180]

restricted in the manner in which wildlife on their lands held in the public trust can be used by them and by others.

The differences in ownership between free-ranging wildlife populations and other animals in the USA and in many other countries results in different dynamics regarding incentives for disease prevention and control in wildlife than that for other species. Because wildlife stewardship in the USA is the responsibility of government agencies and because "market hunting" of free-ranging wildlife is illegal, the economic incentives that exist for minimizing disease in livestock and poultry operations are absent for wildlife. Also, because free-ranging wildlife and many of the pathogens that cause disease are considered to be part of nature, disease is viewed by many wildlife managers as a natural event that need not, and even should not, be addressed. Those individuals generally believe that impacts from disease are transient and are not consequential for species survival.[11]

Wildlife Management Activities

Hunting and fishing are major recreational activities within North America and in many other areas of the world. The magnitude of these activities and their consumptive characteristics create demands in many countries for supplemental stocking. Natural resource agencies release captive-**propagated** wildlife on public lands and in public waters to address this need (Fig. 3.5). Commercial sources of animals are used for stocking of private lands that are primarily associated with fee-based recreational opportunities (Fig. 3.6). Another common wildlife- management activity involves capturing free-ranging wildlife, then releasing them at other locations (Fig. 3.7); this establishes or reestablishes new populations of animals (nongame or game species) or supplements existing populations (Table 3.3). Also, captive-propagated stock may be used for founder or supplemental stock in addition to translocating animals captured in nature (Fig. 3.8). All of these activities have inherent disease risks associated with them.[12]

Despite the perspectives of some, there is nothing about most wildlife species that makes them especially resistant to infections, intoxications, or a host of other disease conditions. Some **scavenger** species, such as **vultures**, are often able to feed on diseased carcasses and not become infected, but in general, wildlife are susceptible to a wide range of disease agents.

Captive Propagation

The potential for infectious disease occurring within captive wildlife propagation programs is in part a function of the health status of breeding stock, environmental conditions and animal numbers within the facility, and other factors.[13,14] The close contact among animals in propagation facilities aids transmission of infectious disease agents that may be harbored by a small number of the breeding stock (Fig. 3.9). In addition, environmentally persistent organisms

Photo by Milton Friend

Figure 3.5 Releases of captive-reared ring-necked pheasants on public lands to augment hunting opportunity is a common practice of numerous USA state wildlife agencies.

shed by infected animals may be sustained at threshold levels within propagation facilities and infect subsequent groups of animals.

Captive wildlife propagation programs and aquaculture have much in common. Both involve wildlife species, have brood stock that originated in nature, are rarely self-contained closed systems, and are responsive to market demands. The recent explosive growth of aquaculture around the world has resulted from food demands for **finfish** and **shellfish** that no longer can be sustained by wild stocks. Advances in industry technology have greatly expanded aquaculture relative to species types and amount of market product compared to past commercial production. However, disease has become an important factor impacting aquaculture productivity, economic returns, and in some instances, human health (see Chapter 2).

Wildlife in captive-propagation programs (including aquaculture) can bring pathogens from nature into propagation facilities. Some of these pathogens may emerge as causes of significant diseases within the propagation program and/or for species they share environments with once propagated stock are released. Other pathogens may enter the propagation programs from external sources (e.g., feed, transient wild or feral animals). In addition to releases of infected propagated stock, pathogens may also be transported from the propagation area by water discharges from the site, the movements of transient animals that have fed on infective material, and other means (Fig. 3.10).

Combating disease in captive wildlife propagation is as crucial as it is for domestic animal production and requires a similar level of attention. In both situations, disease jeopardizes the investments, but the larger concerns are associated with the spread of disease beyond the propagation facility; within agriculture, this has resulted in the development of industry, national, and international programs and infra-

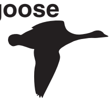
Photo by Milton Friend

Figure 3.6 Hungarian partridge being released on private shooting preserve, which provides supplemental hunting opportunities in many parts of the USA. Hunting is controlled by the preserve owner and fees charged are associated with the number of birds taken.

Photo by Julie Langenberg, International Crane Foundation

Figure 3.7 Translocation of a desert bighorn sheep (USA). The conservation of this species has been greatly aided by this type of activity.

Table 3.3 Noteworthy examples of successful wildlife translocations.

Species	Primary translocation purposes	Comments
Wild turkey 	Reestablishment within historic range and recreational hunting.	An estimated 7-10 million wild turkeys existed in what is now the USA prior to colonization by Europeans, but by the early 1900s this species had become rare in most of its former range.[181] The last recorded observations of native turkeys in many eastern states and those as far west as South Dakota and Nebraska varied from 1813 (Connecticut) to 1906 (Indiana) prior to recent reintroductions and range extensions.[182] Today, wild turkeys have been restored to much of their former range and have extended beyond historic range due primarily to the success of the trapping and transfer of wild birds.[181]
Ring-necked pheasant 	Recreational hunting.	No introduced foreign game species has succeeded in establishing itself in so large an area of the USA as the ring-necked pheasant.[183] "Like us, he's an alien in a man-made habitat".[184] The first success began in Oregon in 1881 and today only about a dozen of the states within the USA do not have resident populations of this species.[185]
Canada goose 	Reestablishment within historic range and enhancement of local populations for recreational hunting.	The giant Canada goose, a distinct subspecies of Canada geese, was common in the North American plains region at the time of settlement, but by 1900 had disappeared from much of its breeding range and was even thought to have gone extinct by some authorities. Following the 1962 discovery of a remnant population in Minnesota, USA, restoration through captive-propagation and translocations of wild captures has resulted in an abundance of these birds.[186] Nonmigratory urban and suburban Canada goose flocks in North America and on other continents have achieved nuisance status. As a result, these birds are often viewed as "the great American pest species."
Whooping crane 	Reestablishment within historic range and population enhancement to reduce the potential for species extinction.	The whooping crane has existed as a North American species since pre-historic time but was never very abundant in modern times. Less than 1,500 of these birds were present in the mid-1800s. The reported wintering population between 1938–1978 was less than 40 prior to 1964 (1942), with a low of 19 (1945). The population reached 50 in 1968 and was 84 in 1978. The total world population (captive and wild) was 110 during the winter of 1978–1979.[187] Initial attempts to supplement the wild population involved the development of a second migratory flock through translocated whooping crane eggs parented by wild sandhill cranes. Initial success ended in failure from disease and other factors (National Wildlife Health Center files). Since then, a nonmigratory flock has been established using translocated captive propagated birds[188, 189] and more recently, a migratory flock also has been established with captive-propagated whoopers that move between Wisconsin and Florida.[189, 190] The total world population of whooping cranes reached 452 in 2003, 318 of which are in the wild.[191]
Beaver 	Reestablishment within historic range.	Beaver populations in North America fell from an estimated 60 million animals before the arrival of Caucasians to about 100,000 by 1900. Restoration efforts reestablished this species by the mid-1970s on almost all major watersheds where they existed prior to colonization of the USA. Population numbers during the mid-1970s had rebounded to approximately 15 million beaver.[192] The European beaver also has been restored to much of its historic range during recent years.[193]
White-tailed deer 	Reestablishment within historic range and enhancement of wild populations for recreational hunting.	An estimated 23–34 million white-tailed deer were present in North America in 1500 and dropped to a low of about 350,000 by 1900.[194] More than 14 million whitetails are now present with many areas having too many deer.[195] The result is that, "in the annals of wildlife management in North America there are few success stories as great as that of the white-tailed deer....the whitetail's modern history has been remarkable".[194]
Elk 	Reestablishment within historic range, enhancement of wild populations for recreational hunting, and restoration for cultural purposes of native peoples.	Elk were the most widely distributed member of the deer family in what is now the USA at the time Caucasians first arrived in North America.[196] By 1920, half of the six original subspecies had been eliminated and the estimated population of 10 million elk prior to settlement was reduced to less than 50,000 early in the 20th century. In some Rocky Mountain states of the USA, the numbers of elk in current herds now are as great as ever recorded.[197]
Desert bighorn sheep 	Reestablishment within historic range and enhancement of wild populations for recreational hunting.	Data are sparse relative to past population numbers but desert bighorn populations have never been large. This species occupied most of the suitable mountain ranges before the arrival of European settlers. An estimated 9,212 animals were present in the USA in 1974.[198] An estimated 15,360–20,290 were thought to be present in the USA and Mexico in 1978, of which 9,800–11,490 were in the USA.[199] In 1985, the USA total has risen to 15,645. Trapping and transplanting to restore wild sheep to historic ranges has been one of the most successful aspects of sheep management. From 1979–1985, more than 1,350 desert bighorn sheep were relocated following their capture.[198]

structures designed to minimize disease risks and respond to disease outbreaks. Deemed necessary to protect economic returns associated with agriculture, these programs also protect human health from **zoonotic** diseases. Programs of similar rigor do not exist for wildlife propagation and release programs.

Sportfishing

The magnitude and economics of sportfishing is such that hatchery-supplemented and hatchery-based sportfishing programs will persist for the foreseeable future in the USA (Table 3.4). Humans are not susceptible to most pathogens of hatchery fish. However, disease spread to wild stocks of fish or to aquaculture facilities can result in major economic losses.

For decades, some state and federal hatchery programs that supplement wild fish stocks for sportfishing have incorporated disease evaluations into their program activities. Since 1968, the U.S. Fish and Wildlife Service (USFWS) has had a Fish Health Policy directed at preventing the introduction and spread of fish pathogens, and in 1988 they expanded fish disease control efforts. This new Fish Health Policy superseded and replaced the agency "Fish Health Protection Policy and Salmonid Fish Health Protection Program" initiated in 1984,[15] but the newer policy remains limited to the USFWS and focuses on salmonids.

Fish health programs generally include laboratory-based disease testing (Fig. 3.11) leading to the certification of hatcheries as being specific-pathogen free (SPF) and include watershed requirements that only SPF fish can be released.[16] When warranted, infected hatchery stock is destroyed, and the hatchery is rigorously cleaned and disinfected (Fig. 3.12). Nevertheless, there still exists a potential—no matter how careful hatchery management practices—for release of diseased fish into the wild (public waters) (Fig. 3.13). There also currently is no consistent oversight of the health status of **sportfish** and their movement in the USA, such as that which exists for domestic animal production. Despite these difficulties, fish hatchery programs pay far greater attention to disease prevention compared to most other wildlife propagation and release programs.

Recreational Hunting

Like sportfishing, hunting is a major recreational activity in many countries (Table 3.5). **Upland game birds** and waterfowl are most commonly propagated for release to supplement wild populations (Table 3.6). In addition, considerable opportunities for recreational hunting are provided from successful wildlife translocation programs that are used to enhance existing populations, restore species to historic ranges, and establish new species in vacant habitat niches. Recreational hunting programs would be wise to focus attention on disease risks associated with stocking programs. Within North America, consideration of diseases introduced into wildlife populations, other than fish (including health evaluations of animals involved) is largely self-imposed and rarely involves technically based regulatory oversight, such as laboratory assays, by wildlife agencies.

Wildlife Translocations

Animal translocation has simply been defined as the movement of living organisms from one area for release in another,[17] and is done for many reasons (Table 3.3). Following their release, the animals typically are not constrained

Table 3.4 Sportfishing is big business in the USA.[200]

Facts	Comments
44.3 million anglers	• More Americans fish than play golf and tennis combined. • A 2001 Harris poll identified recreational fishing as American's top outdoor leisure time activity. • Surveys indicate that 95% of Americans support legal recreational fishing.
$41.5 billion in retail sales associated with sportfishing	• On average, an angler personally spends over $1,200 related to fishing every year. • The overall impact of angler expenditures would make sportfishing 32nd on the Fortune 500 list of America's largest companies.
$116 billion in overall economic output	• Sportfishing provides 9 times the economic benefits of commercial fishing.
1,068,046 jobs	• Nine times more jobs are supported by anglers than there are jobs within AT&T.

Figure 3.8 Biologist in crane costume attending captive-reared whooping cranes translocated to Florida (USA) to reestablish this species in historic range where they have been absent for decades.

Figure 3.9 A mallard duck captive-propagation facility. These types of facilities provide birds for releases into the wild, for use on shooting preserves, and for other purposes that may or may not result in interfaces with wild waterfowl or other species.

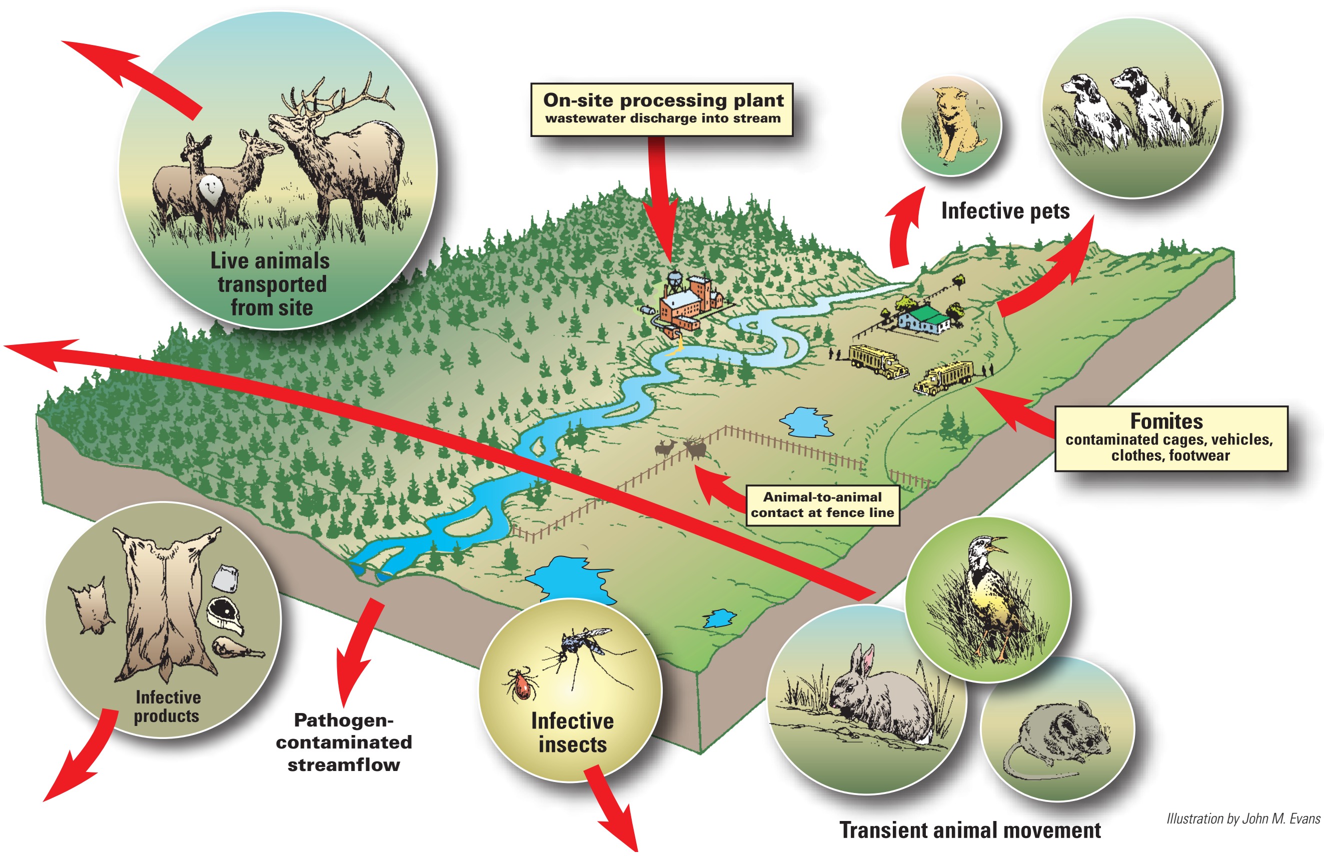


Figure 3.10 Numerous pathways exist for the potential movement of pathogens between wildlife propagation facilities, surrounding environments, and other locations. Sound management of these facilities requires an emphasis on disease prevention.

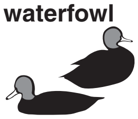
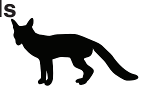
Table 3.5 Examples of socioeconomic effects of recreational hunting.[38]

Region continent	Activity level	Economic effects ($US)
USA[92, 201] 	• 7% of population 16 years and older hunt	• $20.6 billion in expenditures by hunters • $61 billion in overall economic output • 704,000 jobs
Canada[202] 	• 5.1% of population hunt	• $824 million in total estimated expenditures by hunters • $692 average annual expenditure per hunter
Latin America[203] 	• Recreational hunting limited to middle class urban populations	• $2 million from waterfowl hunting in some areas of Venezuela
Europe[204,205] 	• About 10 million hunters—high of 5.9% of population in Denmark hunt to a low of 0.25% in Poland	• Hunting is the most important use of wildlife in Europe • Euro $9.88 billion (not $US) financial flux generated by hunting in the European Union • 100,000 jobs
Africa[38] 	• 20 out of 50 countries have developed a tourism industry that includes hunting	• Safari hunting provides bulk of revenue earned in communal areas of Zimbabwe and $12 million to $30 million in Zambia, South Africa, Namibia and Botswana • $1.45 million and $1.32 million returns from hunting in Tunisia in 1997 and 1998, respectively

Photo courtesy of the U.S. Geological Survey Columbia Environmental Research Center

Figure 3.11 Health evaluations of hatchery brood stock and fish to be released are often done as a disease prevention measure.

Table 3.6 Examples of wildlife species propagated in captivity and released for hunting within the USA.

Species	Relative frequency of releases	Comments
Ring-necked pheasant 	Frequent	Perhaps the most popular gamebird nationwide; annual releases by numerous state wildlife agencies and large numbers of releases on private sector shooting preserves.
Bobwhite quail 	Common	Large numbers of bobwhites are released within the Southeastern USA and lesser numbers in other regions of the country. This species is more commonly released on shooting preserves than on public lands.
Chukar partridge 	Occasional	Releases on public lands are most common in the Western USA. Chukars are provided as a novelty species on some Eastern and Midwestern shooting preserves.
Hungarian partridge 	Occasional	This species is infrequently released for hunting by state wildlife agencies but is available on many shooting preserves.
Turkey 	Infrequent	Limited supplemental stocking of captive-propagated turkey is done by state wildlife agencies; this species is generally a high cost luxury species on shooting preserves.
Mallard duck 	Frequent	Nearly all North American captive-propagation and releases of this species now occur within the private sector. Large numbers of mallards are released in some areas of the eastern USA.
Canada goose 	Occasional	Captive-propagation and releases of Canada geese by state wildlife agencies were popular in the past but are no longer common.
Other waterfowl 	Infrequent	A variety of waterfowl such as redhead ducks and other species have been propagated in the past by state wildlife agencies and released to supplement wild populations. These programs have largely been abandoned.
Mammals 	Infrequent	In the past, rabbits, foxes, raccoons, and even deer were captive-propagated for release. This type of hunting activity now is primarily with the private sector.

in their movements by fencing or other human-constructed barriers. However, barriers must be considered within a context of scale. For example, releases may occur on land areas of sufficient size to satisfy the animal's "natural" movement patterns, but the area boundary, such as in national parks, game ranges in some countries, and large ranches devoted to wildlife, may be maintained by electric fencing or other barriers to contain and protect the animals from external dangers, such as poachers.

Despite more restrictive definitions for wildlife translocations, the "real world" of human-assisted wildlife movements includes the use of both captive-propagated and wild caught animals. Animals are released into relatively confined areas as well as natural areas, and non-indigenous species are involved in some instances. Recent evaluations of these programs reflect greater success for natural areas when wild-caught animals are involved[18–20] but options are often not available.

Wildlife translocation programs have great public and political appeal,[21] are a commonly used, popular activity for the conservation of biodiversity,[18] and for wildlife management. In the past, wildlife translocations were primarily associated with direct and exclusive benefits for humans[21] and often involved bringing exotic species to areas for sporting or other purposes. Because of the negative impacts resulting from introducing some exotic species, mostly native wildlife species are now translocated. Fifty-six percent of the 1985 translocations reported by U.S. state wildlife agencies involved native game species (Table 3.7), which are most often translocated in addition to charismatic threatened and endangered species (Fig. 3.14). A survey from a 13-year period (1973–1986) reported that at least 93 different species were translocated.[19] Results from a 1985 survey of 50 state wildlife agencies (USA) regarding mammal translocation indicated that 29 of the 45 states that responded had translocated mammals within their state that year, and 19 states reported that private groups had translocated mammals within their state.[22] Birds are more commonly translocated than mammals and other species (Fig. 3.15) but this determination is confounded by what is tallied as a translocation.

Recent evaluations have disclosed a general increasing trend for wildlife translocations.[18–20,23] It has been estimated that world totals probably exceed 1,000 translocations annually, excluding "put and take" stocking for sporting purposes, relocations of problem animals, and **wildlife rehabilitation** releases.[24]

Different levels of disease risks are associated with captive-propagated and wild caught animals. Disease monitoring and surveillance of free-ranging wildlife populations are limited, and often background knowledge about disease activity in the species and in the area from which those wildlife are being moved is lacking. Disease risks are better known

Photo by Milton Friend

Photo by Milton Friend

Photo courtesy of Wisconsin Department of Natural Resources

Figure 3.12 Depopulation of infected fish stocks and rigorous disinfection of rearing facilities are common responses to infectious diseases that appear in fish hatcheries.

Photo courtesy of Wisconsin Department of Natural Resources

Figure 3.13 The stocking of public waters with hatchery-propagated and reared fish is an important component of sportfishing. Protection of wild stocks and the recreational opportunities from fish releases requires that only fish free from serious pathogens be released.

Table 3.7 Primary species of mammals translocated in the USA during 1985 by state wildlife agencies for restoring and supplementing populations.[22]

Species type	Number of: Animals released	Number of: Releases	Number of: Release sites
White-tailed deer	1,243	185	31
Pronghorn	578	9	9
Bighorn sheep	426	25	26
Elk	167	4	6
Moose	33	15	4
Mountain goat	24	4	4
Black bear	9	9	3
Collared peccary	34	1	1
Cottontail rabbit	15	1	1
Snowshoe hare	405	1	25
Beaver	28	2	4
River otter	91	21	9
Fox squirrel	12	1	1
Eastern chipmunk	50	1	2
Pine marten	42	?	1
Prairie dog	135	4	3

for captive-propagated wildlife when proper evaluations are made during the operations of the propagation facility (Fig. 3.16); however, such evaluations or the reporting of findings are not required. Also, while in captivity, wildlife may acquire or develop infectious diseases that may be suppressed through veterinary treatment; unfortunately, these wildlife may become **disease** carriers and serve as sources for infection following their release. Further, disease only suppressed, rather than cured by treatment during captivity, may reappear once the animals are no longer being treated.

Knowledge of disease introduced by translocated wildlife has led to a call for more action to minimize disease risks.[12, 17, 25–31] Fish, reptile, bird, and mammal translocations have all been associated with disease introductions at sites where wildlife have been released; humans, domestic animals, and wildlife have all been affected (Table 3.8). In some instances, disease was a factor for failed translocations or as a reason for not completing a translocation.[18, 20, 25, 32–34]

Commercial Activities

The estimated total economic value of harvested wild species probably exceeds $500 billion (U.S.) annually and is at least 20 times greater than the best estimates for global revenues from nature tourism.[35, 36] Another evaluation places the estimated annual value of legal global international trade in wildlife and other biological resources during the 1990s at nearly $159 billion. Billions of dollars in illegal sales also occur annually.[37] These economic returns primarily involve the taking of biological resources from the wild and illustrate that, in addition to their high aesthetic and recreational values, wildlife also have high commodity values. Because of these values, commercial ventures involving wildlife are created. Some of these ventures involve the captive-rearing and harvest of wildlife for meat, hides, and other products (e.g., game ranching), while others are of a nonconsumptive nature (e.g., ecotourism). Worldwide, meat is the most common wildlife product.[38] Disease emergence and spread are associated with consumptive and nonconsumptive commercial activities and are problems requiring increased attention. The commercial activities highlighted below are those for which the emergence and spread of infectious disease are best documented or are of the greatest concern.

Game Ranching

A variety of wildlife species are commercially reared for their meat, hides, and other products, and some are sold as work animals and as pets (Table 3.9). This growing industry is referred to as game ranching, game farming, alternative agriculture, and by other designations. Some individuals include ecotourism and hunting within game ranching and use the term game farming for commodity production activities.[38] Game ranching in the context of this chapter is analogous to domestic animal husbandry and has similar challenges associated with disease. Some examples include the rearing of wildlife species, other than finfish and shellfish (aquaculture), for harvest of the animals, for their products such as

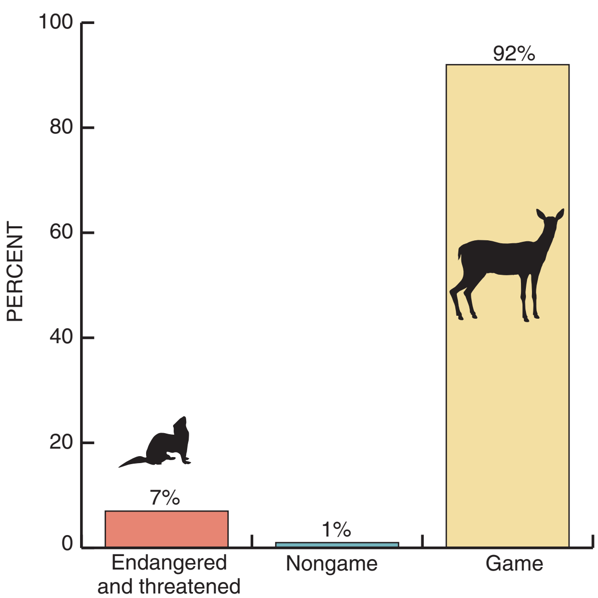


Figure 3.14 Wildlife translocations within the USA, Canada, New Zealand, and Australia, 1973–1989.[19]

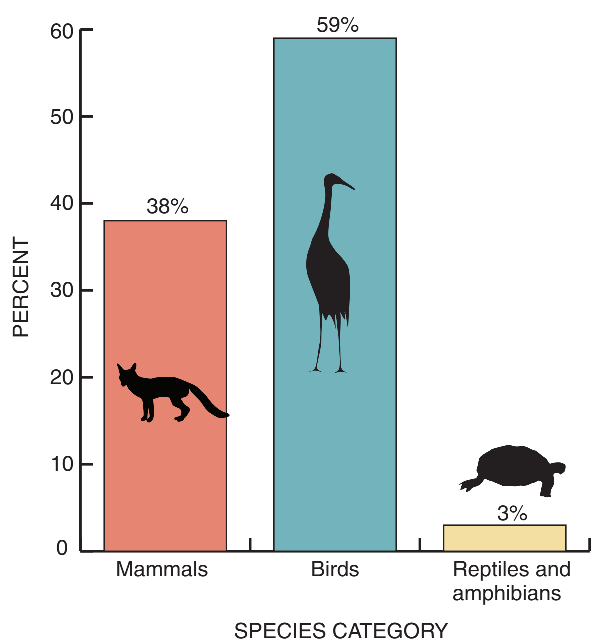


Figure 3.15 Percentage of translocations by wildlife type, 1971–1986.[19, 23]

wool, or for live animal sale (excluding recreational harvest of these species); the latter is considered under hunting and shooting preserve activities.

Disease in captive-reared wildlife has emerged since humans first undertook the husbandry of wildlife, often with devastating consequences.

"The primate herdsman or agriculturist would soon discover that….diseases unknown to him when the creatures were in a wild state, would appear; and from their unusual character, the suddenness of their attack, and the great mortality attending them, would strike him with fear and amazement."[39]

The types of diseases associated with wildlife husbandry have differed over time, vary with the species being brought into captivity, and are influenced by the conditions under which wildlife are reared.

Fur farming was a major game ranching activity in North America that has diminished greatly because of changing social values that have reduced demand for furs. Disease was the greatest obstacle for successful fox-farming since the beginning of that industry in 1887, and in 1927 resulted in the U.S. Congress increasing funding for the Bureau of Biological Survey to enhance its investigations into the contagious diseases of fur animals.[40] Mink and chinchilla are species that are commonly ranched for their fur, and rabbits for fur and meat. The wide variety of diseases affecting these species[41] resulted in numerous agriculture extension publications and other documents to assist ranchers in minimizing disease within their operations.[42–50] The brush-tailed possum, introduced into New Zealand as a fur animal, has not only resulted in these possums becoming a major pest species, but they have also become a wildlife reservoir for the zoonotic disease, bovine tuberculosis (*Mycobacterium bovis*).[51–54]

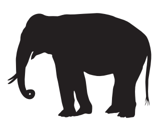
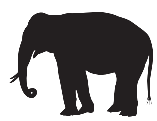
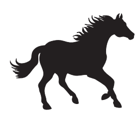
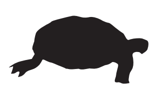
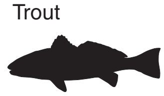
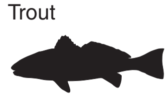
The focus of this chapter is wild stocks of animals not yet genetically altered for the selection of traits that serve the ranching industry. Wildlife ranching is a growing industry of considerable local and regional economic importance for many developing countries.[38] The changing values resulting in major declines in fur farming have been replaced by those stimulating increased ranching of wildlife for other products such as exotic leathers and game meat associated with changing food habits in developed countries (Fig. 3.17).

Unlike ranching for domestic species, game ranching brings a variety of wild species of unknown health status into captivity and often provides environmental conditions conducive to transmission of infectious diseases. Disease movement between domestic animals and wildlife and vice versa is a concern where these species are in close proximity. In some parts of Africa, game ranching is integrated with cattle ranching in the same area. For example, there are 4,000 integrated mixed game and cattle ranches in South Africa.[38] In many other areas, including North America, health inspections and

Photos by Milton Friend

Figure 3.16 Periodic health evaluations supported by laboratory evaluations are an important aspect of disease prevention and control.

Table 3.8 Examples of disease impacts associated with wildlife translocations.

Disease	Agent	Initiating species	Affected species	Comments
Squirrel parapox	Parapoxvirus	Gray squirrel 	Red squirrel 	Virus introduced into the UK with gray squirrels from North America;[206–208] gray squirrels are not affected by disease [209] but are a reservoir host.[210] Virus is an important factor in the red squirrel decline in the UK.[209, 211]
Rabies	Rhabdovirus	Raccoon 	Numerous	Translocation of raccoons from an area where rabies is enzootic in this species to a more northern area of the USA resulted in a multistate epizootic affecting thousands of animals and the establishment of new enzootic foci for raccoon rabies. Several thousand humans have received post-exposure rabies prophylaxis due to contact with infected animals.[212]
Tularemia	*Francisella tularensis*	Rabbits 	Rabbits 	This disease has been moved from early enzootic areas of the USA to other areas within the USA and some areas of Europe by translocated hares and rabbits. Human cases of disease have resulted, in addition to wildlife epizootics.[213–216]
Herpesvirus Infection	Herpesvirus	Elephant 	Elephant 	Zoo populations of Asian and African elephants have recently experienced mortality from a previously unknown, highly fatal endotheliotropic herpesvirus disease. This disease imperils the successful propagation of elephants for the future, because its impact is on young animals and is considered to be a threat to elephant conservation.[217]
African horse sickness	Orbivirus	Zebra 	Horse 	Zebras captured in a national park in Africa and then shipped to Spain via Portugal introduced this disease to horses in Spain. Zebras are the natural host for this virus and do not suffer clinical disease. An estimated $20 million in lost income to horse breeders in Spain resulted.[32, 218]
Upper respiratory tract disease (URTD)	*Mycoplasma* sp.	Desert and gopher tortoises 	Desert and gopher tortoises 	The introduction of URTD into endangered desert tortoise populations of the western USA is jeopardizing the survival of this endangered species. Releases of tortoises held in captivity and those from rehabilitation programs are thought to be the source for this disease. Gopher tortoises in Florida (USA) also are being impacted from mycoplasmosis. The release of tortoises used in tortoise races is thought to be the origin of disease.[14]
Psittacine beak and feather disease (PBFD)	Circovirus	Captive psittacines 	Captive psittacines 	PBFD has been spread to many parts of the world by human movement of captive birds and is negatively impacting live-bird holdings.[219–222]
Whirling disease	*Myxosoma cerebralis*	Trout 	Trout 	Whirling disease is a devastating protozoa disease that has become enzootic in the USA since its introduction from Germany (see Chapter 2). Transfers of rainbow trout from the USA have introduced this disease into trout in the UK.[29]

other regulatory processes for disease prevention associated with wildlife movement, sales, and meat is generally far less than that for domestic livestock and poultry. Greater controls exist for international trade,[55] but much of the meat associated with game ranching is used locally or regionally.

The American bison has been ranched for meat in the USA since at least 1900. However, the National Bison Association was formed in 1967 and is considered the beginning of the bison industry. Nearly 90 percent of the more than 250,000 American bison that exist today are owned and managed by the private sector.[56] Factors such as the high percentage of bison in private ownership, moderate growth of the bison industry, and concern regarding the potential transmission of brucellosis and bovine tuberculosis to domestic livestock are reasons that interstate and international bison movements in 1986 came under U.S. Department of Agriculture controls similar to those for livestock.

Increasing numbers of deer and elk are raised in captivity now because of the growing demand for venison. Between 500 and 1,000 tons of venison are imported by USA restaurants annually. West Germany imports more than 20,000 tons of venison annually despite having about 2,000 deer farms.[57] Just as for cattle, hides are an important byproduct for the bison and wild **cervid** industries. Antler velvet, shed antlers, and musk are other products harvested from cervids for specialty markets, primarily in Asia. The potential for transmission of disease from captive cervids to free-ranging elk and deer has become a major concern among the wild-

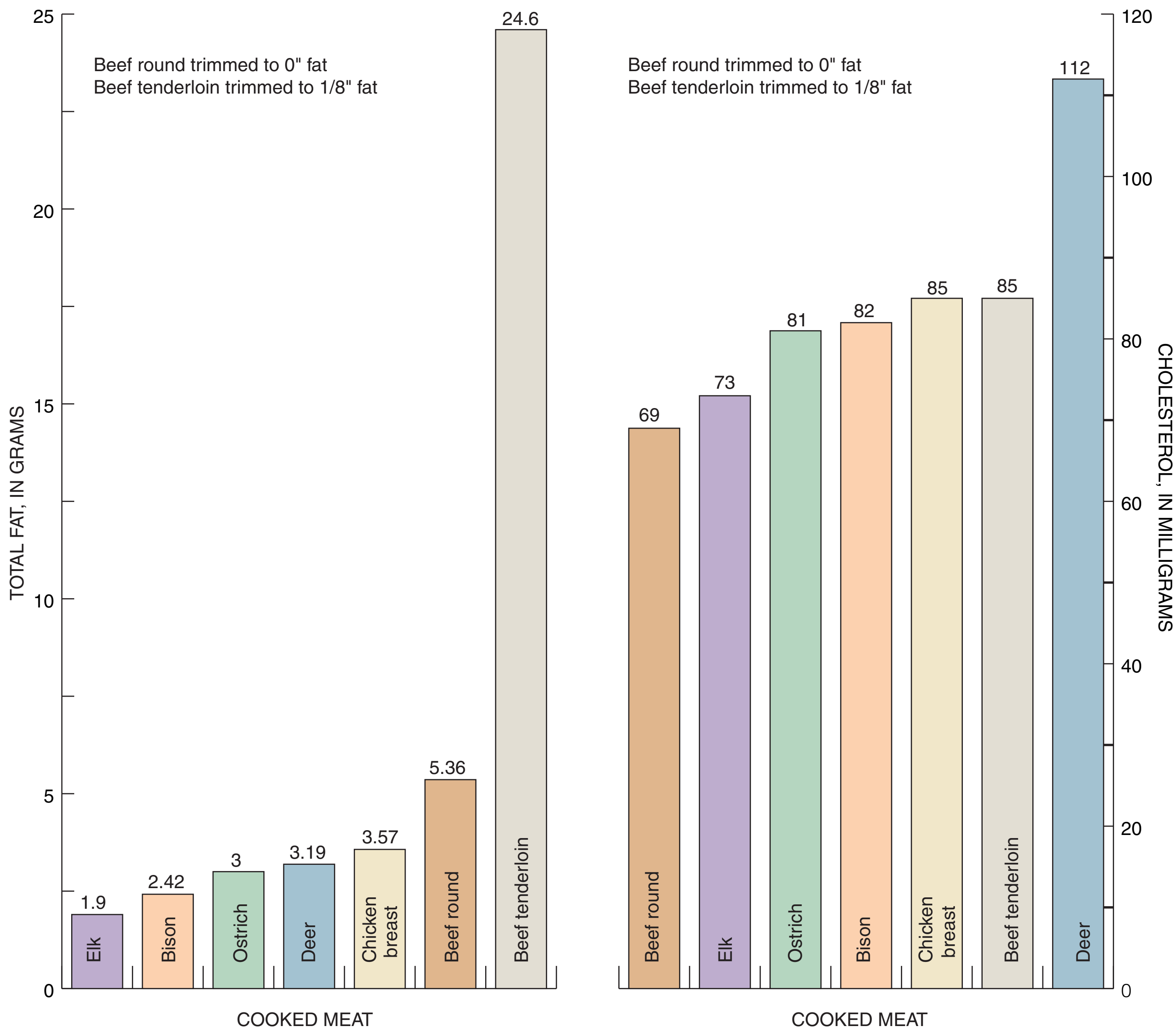
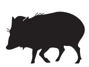
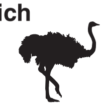


Figure 3.17 Total fat and cholesterol per 100 grams of edible portion of cooked meats.[60]

Table 3.9 Examples of wildlife species bred for commerce (excluding fur trade, aquaculture, biomedical, and other research).

Group/species	Commercial products								Comments
	Food[a]	Fiber[b]	Medicinals[c]	Scents[d]	Bone[e]	Burden[f]	Hunting[g]	Pets[h]	
Cervids **Rusa, red, fallow, axis, white-tailed, sambar, white-lipped deer; wapiti (elk)** 	●	●	●	●	●	○	● (orange)	○	Worldwide activity with farming/ranching of species done in some countries within Africa, Americas, Asia, Europe and the Pacific.[38] An estimated 5 million cervids are maintained by this industry.
Reindeer 	●	●	○	○	●	●	○	○	Husbandry primarily in Russia, Scandinavia, and Alaska, USA.[38] An estimated 3.5 million animals are involved.
Bison 	●	●	○	○	● (orange)	○	○	○	Nearly 90% of the approximately 250,000 bison alive today are owned and managed by the private sector.[56]
Llama 	○	●	○	○	○	●	○	●	In the USA, 12,000 llamas are owned by 3,500 people.[57]
Collared peccary 	●	●	○	○	○	○	○	○	Farmed in South America for restaurant and other trade.[38]
Capybara 	●	●	○	○	○	○	○	○	High interest in production of this species in Latin America.[38]
Grasscutter (Cane rat) 	●	○	○	○	○	○	○	○	Species providing the best economic return from small-scale farming activities in Africa.[223]
Ostrich 	●	●	○	○	○	○	○	○	Commercially ranched in Africa since 1850s;[13] first raised in USA in 1981. A breeding pair of adults has commercial value of $12,000 to $30,000 and chicks old enough for sex differentiation, $1,000 a piece.[57]
Gallinaceous birds **Pheasant, quail, partridge** 	●	●	○	○	○	○	●	● (orange)	Millions raised for restaurant trade, for public consumption, and for releases for hunting in many regions of the world.

Group/species	Commercial products								Comments
	Food[a]	Fiber[b]	Medicinals[c]	Scents[d]	Bone[e]	Burden[f]	Hunting[g]	Pets[h]	
Waterfowl Ducks, geese, swans	●	●	○	○	○	○	●	◉	Less are bred compared to gallinaceous birds, but still large numbers are propagated for similar purposes in various regions of the world.
Spectacled caiman	●	●	○	○	○	○	○	●	Between 1991 and 1993, Venezuela exported about 24,500 caiman hides and 30,000 live caimans for the pet trade.
Crocodiles/ alligator	●	●	○	○	○	○	○	◉	
Iguana	●	●	○	○	○	○	○	●	
Turtles	●	●	○	○	◉	○	○	●	In Brazil, 340,000 turtles were produced in captivity.
Frogs	●	●	○	○	○	○	○	○	Commercial frog breeding involving countries on several continents is increasing but remains a small percentage of the frogs harvested.[38]
Snails	●	○	○	○	●	○	○	○	Some farms in Belgium produce 15,000 snails each week. About 452 tonnes of snails traded in 15 months in the Côte d'Ivoire.[38]

[a] Meat, milk, etc.

[b] Feather, wool, hides.

[c] Antler velvet, bile, etc.

[d] Urine and other substances used as attractants, repellants, perfume, etc.

[e] Antler, horns, shells (snails) and other bone and bone-like materials.

[f] Pack and work animals.

[g] Propagated and released for short-term harvest by hunting.

[h] Companion animals and private collections of live animals.

● Primary ◉ Secondary ○ None

life conservation community, and the potential for disease transmission to livestock has raised similar concerns within the agriculture community.

The prion disease, chronic wasting disease, and a wide variety of viral, bacterial, and parasitic diseases have affected ranched deer and bison, as well as free-ranging animals.[58, 59] Several of these diseases are zoonoses (Table 3.10). Malignant catarrhal fever is the most important viral disease affecting ranched deer and bison.[58] Bovine tuberculosis (*M. bovis*) and Johne's disease *M. avium* subsp. *paratuberculosis* are especially significant bacterial diseases because of the potential for infected ranched deer and bison to become wildlife reservoirs of infection. Yersiniosis (*Yersinia pseudotuberculosis* and *Y. enterocolitica*) is one of the most serious and common diseases causing losses of farmed deer.[59]

A recent evaluation of the potential for disease transmission between captive and free-ranging cervids documented nine diseases of concern,[60] although the list of potential pathogens is far greater.[58, 59] That same evaluation documented a steady increase in the numbers of captive cervids within the USA from 26,062 in 1992 to 83,270 in 1997, and placed the value of those animals at more than $56 million in 1997.[60] A 1999 USDA evaluation tallied nearly 160,000 captive cervids being maintained on 5,342 premises.[61] Fallow deer, red deer, and white-tailed deer comprise the majority of captive cervids within North America.[60] Michigan illustrates recent growth of the cervid industry within the USA. Between 1994 and 1999, the number of captive deer and elk in that state has grown 50 percent and 100 percent respectively. By 1999, Michigan had 21,000 deer and 2,600 elk with a market value of about $30 million within 630 permitted enclosures (Fig. 3.18). Bovine tuberculosis was first diagnosed in captive deer in 1997.[259]

Several other species have also become a focus for the game ranching industry (Table 3.9). Ranching of cold-blooded wildlife species is more popular in Latin America and Asia than in North America and Europe (Tables 3.11 and 3.12). Crocodile ranching is well developed in some African countries since the beginning of the 20th century and is a developing industry in Asia.[38, 62] In 1990, the American alligator (wild and captive) accounted for $19 million in revenue for the state of Louisiana, and in 1992, alligator meat sales alone exceeded $5.5 million.[63]

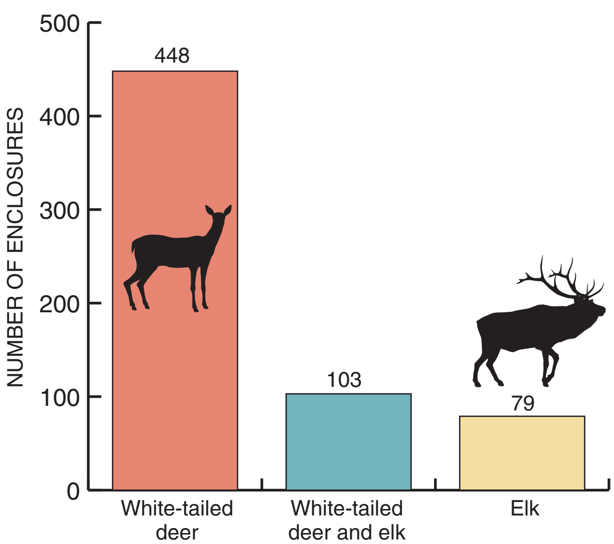


Figure 3.18 Licensed enclosures with captive cervids in Michigan, 1999.[67]

Recreational Fee Hunting and Fishing

Not all hunting and fishing in North America is carried out in the **public domain**. The recreational pursuit of captive-propagated and translocated wildlife in private ownership frequently occurs on private lands commercially managed for that purpose. These fee-based operations may include membership-only facilities, as well as those open to the general public on a reservation basis. The size of these operations, the species offered for harvest, and the costs for participation vary greatly. Many fishing operations are only a few acres and are limited to a single species, such as rainbow trout. Shooting preserves for upland game birds vary in size from less than a couple of hundred acres to much larger areas. Ring-necked **pheasants**, quail, and partridge are the primary species offered and many of these facilities also process the birds taken so that the client departs with "poultry" near ready for the oven. Large-scale ranches also exist, covering many miles where trophy hunting for exotic species of large mammals and other species may be pursued.

Game ranches in Africa and other areas commonly control large land areas because of species' needs and because hunting is an important component of those operations. For example, the 13,000 ranches that deal with wildlife in South Africa occupy 13.6 percent of the land mass of that country or 2.5 times more area than the National Parks. Globally, income derived from wildlife ranches (separate from wildlife farming) is 80 percent from hunting, 10 percent from ecotourism, and 10 percent from sales of live animals.[38]

Within the USA, fee-based hunting and fishing provide alternatives for people who do not wish to compete with those hunting and fishing on public lands. Increased crowding of hunters and reduced hunting/fishing success rates are common for many public lands because of habitat losses from land development. Because commercial operations primarily involve privately owned wildlife propagated for harvest, the period of the year when these animals can be harvested generally exceeds time periods for the taking of similar free-ranging wildlife species. Also, the numbers of animals that can be taken by the client is essentially a function of how much he or she is willing to pay, as each animal has a market price. Many of these commercial operations are close enough for people from large metropolitan and suburban areas to have a "day in the field" without a long trip. Some of the larger operations offer fly-in services to local or private air strips.

Table 3.10 Examples of infectious diseases affecting ranched/farmed bison and deer.[58, 59]

Disease	Primary species affected	Zoonoses	Comments
		Virus	
Malignant catarrhal fever (MCF)	Bison, deer	No	MCF is the most important viral disease of farmed or ranched bison and deer, has affected numerous species, caused problems in zoos and endangered species breeding programs, and involves several viral strains that infect various species.
Infectious bovine rhinotracheitis (IBR)	Bison	No	Vaccination is carried out in USA and Canada, but is of questionable value in the control of IBR.
European cervid herpes- viruse, type 1	Red deer	No	Disease is most commonly associated with stress, such as weaning.
Parapox	Red deer	No	Ranched/farmed cervid cases have been only reported from New Zealand; disease is primarily associated with stressed animals.
Bovine viral diarrhea	Bison	No	Bison often vaccinated but the efficiency of these vaccines remains questionable.
Scours	Bison, deer	No	Coronavirus and rotavirus infections are involved.
		Prion	
Chronic wasting disease (CWD)	Mule deer, elk, white-tailed deer	No	High profile disease because of recent expansion in wild and associations drawn with bovine spongiform encephalopathy (mad cow disease) in cattle.
		Bacteria	
Johne's disease *Mycobacterium avium* subsp. *paratuberculosis*	Bison, deer	Possibly	One of the most widespread infectious diseases of ruminants. Associated with Crohn's disease in humans.[224]
Leptospirosis *Leptospira* spp	Deer	Yes	Farmed deer have been affected in New Zealand, China, Scotland, and the former USSR.
Necrobacillosis *Fusobacterium necrophorum*	Bison, deer	No	Common disease.
Pasteurellosis *Pasteurella multocida*	Bison, deer	Yes	Sporadic outbreaks in captive bison and deer. Infection complicating chronic respiratory tract disease is one of the most common non-bite forms of human infection and occurs predominantly among the farming population.[225]
Tuberculosis *Mycobacterium bovis*	Bison, deer	Yes	Diagnosed in farmed deer in almost every country with deer farming; infection in bison has been associated with livestock origin for disease.
Yersiniosis *Yersinia pseudo-tuberculosis*	Deer	Possibly	One of the most common and serious infectious diseases of farmed deer in New Zealand. Infection transmitted from animal to humans other than via contaminated food has not been definitively established.[226]

The number of commercial fee-based hunting and fishing facilities within the USA has not been fully evaluated and is difficult to determine because of differences among states in licensing requirements, nomenclature that is not always adequately descriptive for separating facilities where recreational harvests take place from those where it does not, and because of other problems. A 2001 survey of 48 contiguous states and Alaska within the USA reported more than 4,600 shooting preserves that year;[64] however, that does not include fishing operations unless they occur on a preserve that also harvests birds and mammals. There probably are a substantial number of additional hunting preserves in private ownership and other commercial enterprises providing fee-based recreational harvests of captive-propagated and translocated wildlife. Texas (USA) leads all other states in the extent and variety of fee-based hunting opportunities available (Fig. 3.19). Ranches for this type of hunting of exotic species and ranches with high fences to contain trophy and other white-tailed deer hunting show similar increasing trends.[65]

In general, disease transmission between wildlife within commercial operations and free-ranging populations is a focus of increasing concern.[66–70] Information about disease emergence associated with these facilities is limited by the lack of reporting requirements, and a general lack of disease monitoring and surveillance. During recent years, enclosures developed for running **hounds** have become a focus for attention because of disease issues. At least 450 enclosures for fox-chasing, some larger than 1,000 acres, have been developed in the Southeastern USA. These enclosures are stocked with wild-caught foxes and coyotes translocated from other areas. Rabies has been translocated along with these animals in some instances, and there is concern that hydatid disease will become established in new areas through these enclosures (Southeastern Cooperative Wildlife Disease Study brochure, *Out-of-State Foxes and Coyotes Are Serious Disease Risks*). Hydatid disease is caused by a zoonotic tapeworm and can result in fatal human infections. Duck plague has appeared in waterfowl bred for release on shooting preserves[71] and is a growing concern associated with mallard duck releases on these types of areas (Box 3–2).

Ecotourism

Many people view ecotourism as being a rather benign form of outdoor recreation that does not negatively affect natural resources. However, ecotourism is big business (see Chapter 2), including the large component of this industry that is based on wildlife viewing (Table 3.13). Like other businesses, the collective activities that are considered ecotourism require appropriate infrastructure, supplies, and human activities to provide the services and functions needed for delivery of the products sought by ecotourists. Much of this activity involves people and goods entering areas distant from where they originated. The resulting human/animal contacts, direct and indirect, have inherently similar mixing of disease factors as those associated with disease emergence in humans due to global travel and commerce.[72]

Diseases may be introduced into area wildlife populations by infected humans, their companion animals, and food supplies, and by other means. Also, humans and other species entering those areas may contract diseases enzootic for wildlife at those locations. Ecotourism in Africa and Antarctica has introduced disease, which also is a concern in the Galapagos Islands (see Chapter 2). The close relationship between humans, **monkeys**, and **apes** results in a high degree of susceptibility for human pathogens infecting

Table 3.11 Examples of commercially produced non-poisonous lizards and snakes (developed from Whitaker, 1997).[244]

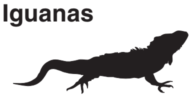
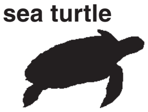
Species	Countries	Primary uses	Comments
Iguanas 	South and Central America	Meat, skins, pet trade	Iguana lizards and boas are integrated with crocodile farming in Colombia; in Panama and Costa Rica farming of green iguanas is being promoted.
Monitor lizards 	Thailand, Philippines, Pakistan, India	Skins, meat, fat	Experimental farming only, commercial production has not yet become a reality.
Tegus 	South and Central America	Skins, pet trade	Experimental farming only; reproduction in captivity achieved during 1987.
Pythons 	Asia	Skins, meat, medicinals, pet trade	Large numbers produced in Thailand and in China.
Boas 	South America, Asia	Skins, meat, medicinals, pet trade	Experimental farming in most instances

Table 3.12 Examples of commercially produced turtle species (developed from Sachsse, 1997[245]; Wood, 1991[246]).

Species	Countries	Farming began	Primary uses	Comments
Softshell turtle 	Japan, China, Taiwan	1875	Meat	Long history of farming in Southern Asia
Red ear slider 	USA	1980s	Pet industry	Major source for salmonellosis in humans prior to corrective actions being implemented.
Diamondback terrapin 	USA	Early 1980s	Meat	Historic use to feed slaves; then farmed as gourmet food; no large-scale farm operations for this species exist today.
Green sea turtle 	Cayman Islands, Surinam, French Reunion, Australia	Late 1960s	Meat, leather, curios	Referred to as "the world's most valuable reptile."[247]

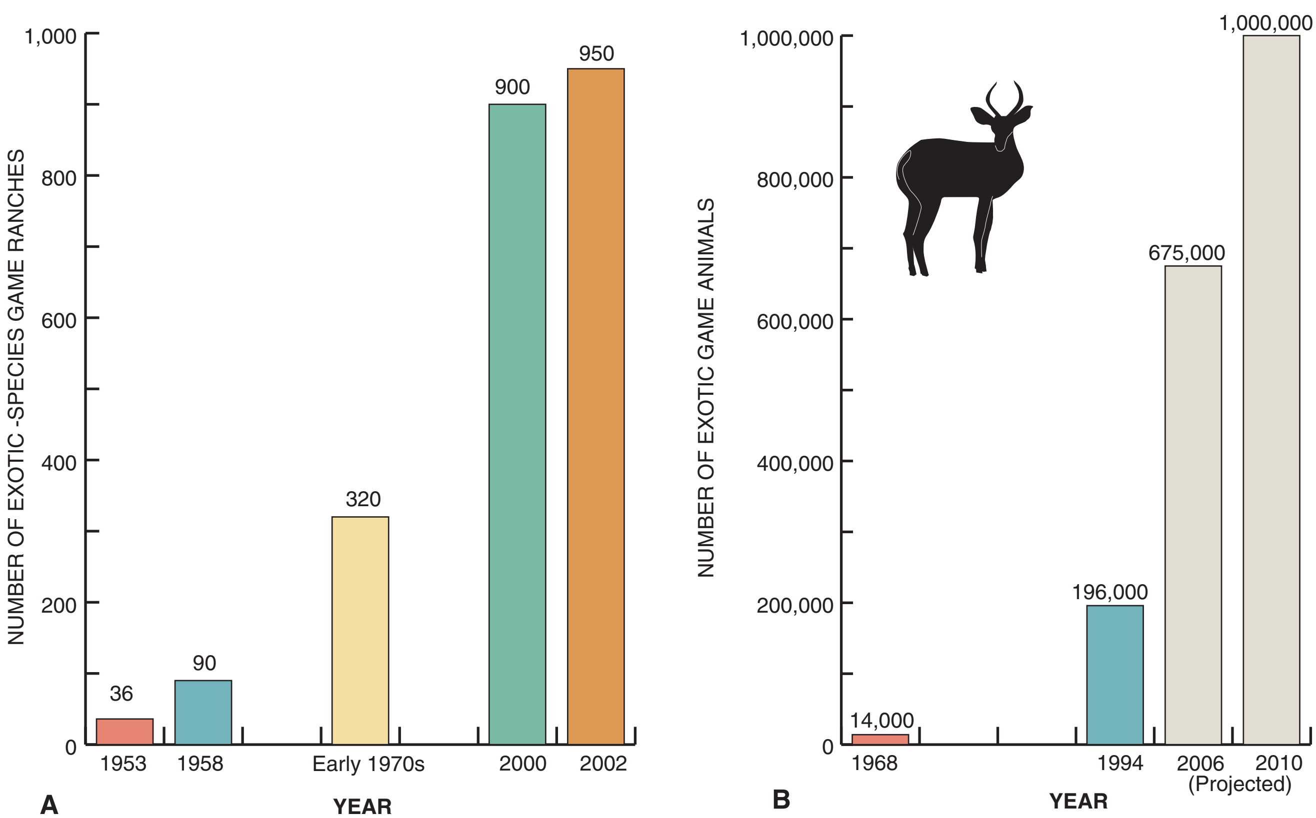


Figure 3.19 (A) Trends in numbers of exotic-species game ranches and (B) numbers of exotic game animals in Texas.[65]

Box 3–2 Establishing Wildlife Health Standards: Trials and Tribulations

Throughout history, the specter of disease has been a powerful force leading to the development of various standards and processes to protect human and domestic animal health. However, wildlife in the USA and many other counties have not been subject to the same types of health oversight. Attempts to initiate health certification for captive-propagated waterfowl that are released into nature serve as examples of the lack of progress.

Waterfowl Propagation and Releases

In 1927, more than 45,000 waterfowl, primarily mallard ducks and Canada geese were raised on game farms throughout the USA under federal permits.[40] A 1993 survey of 49 states in the USA (Hawaii not included) indicated that 230 licensed shooting preserves released more than 185,000 captive-propagated mallards that year.[136] State wildlife agencies also release mallards to augment the natural population. For example, the Maryland Department of Natural Resources released nearly 410,000 mallards between 1967 and 1991. In addition, an estimated 100,000 to 150,000 mallards per year are released on private lands by private parties.[23] Between 1981 and 1994, about 1.2 million captive-propagated mallards were released in a single county in Maryland.[136,137] These mallards are released into the wild where they share environments with wild waterfowl and other species and can also share pathogens (Fig. A).

In May 2001, the U.S. Fish and Wildlife Service repeated the 1993 survey. Results from 39 states (10 states indicated they did not have records of numbers of mallards released) indicated nearly 272,000 mallards were released that year on licensed shooting preserves. Estimates of the number of captive-propagated mallards released on these private holdings exceed 300,000 annually. Additional mallard releases take place on state lands and other holdings.[64]

Photo by Milton Friend

Figure A. Captive-reared and released mallards on a private hunting club pond immediately adjacent to a major public area used by migratory waterfowl. The intermixing of both types of birds as a result of bird movements between these types of areas is common.

Rejection of Waterfowl Health Regulation

Health certifications that protect wild waterfowl from diseases potentially introduced by captive-propagated mallards are rarely a prerequisite for their release into nature. The catastrophic appearance of duck plague in wild waterfowl on a National Wildlife Refuge[138] stimulated a 1975 resolution by the International Association of Game, Fish and Conservation Commissioners calling for testing and health certification for waterfowl propagation flocks (Fig. B). Other factors involved in the appearance of duck plague were that the history of this exotic viral disease is closely associated with captive-propagated and feral waterfowl[139] and that releases of captive-propagated mallards were common practice. In addition, in 1980, duck plague appeared in three different captive flocks following additions of captive-propagated mallards received from a single source.[71] As in the 1970s, attempts during the early 1980s to implement health certification requirements for waterfowl releases into nature also failed, despite broad support within wildlife conservation agencies.

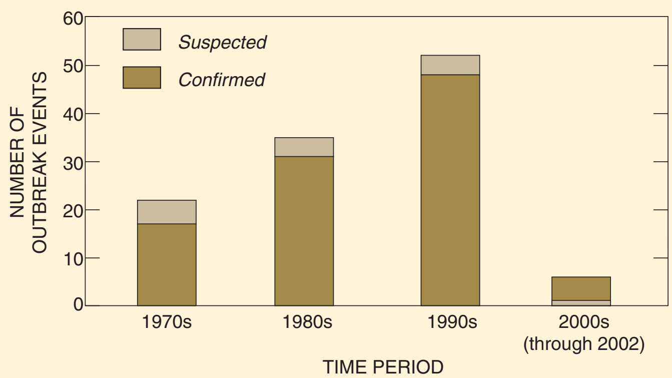
Current Situation

In 1985, regulations involving the harvest of captive-propagated and released waterfowl were reinterpreted, and state-imposed limits on the number of these birds a hunter could take per day were removed. This removal of bag limits resulted in major increases in mallard releases in some areas. Nevertheless, once again attempts to initiate health certification requirements failed despite the increasing number of duck plague outbreaks occurring in the USA (Fig. C) and concern that mallard releases may be a contributing factor.[139,140] Disease concerns extend beyond duck plague to other potential pathogens that may be released along with these birds.

Figure B. Some of the estimated 40,000 mallard ducks dying from duck plague at the Lake Andes National Wildlife Refuge during the winter of 1973.

Other actions to regulate mallard releases were initiated in 1993 and again in 2001. Notices of intent for regulations associated with "Release of Captive-Reared Mallards" were issued for comment in the Federal Register; however, no actions to address disease concerns associated with these birds have resulted from those initiatives.[141] More recently, a 2003 U.S. Fish and Wildlife Service report regarding captive-reared mallard regulations concludes "…there is evidence of the potential for increased risks of disease transmission…" among other concerns.[64]

Wildlife conservation agencies are still pursuing the regulation of releases of free-flying, captive-reared mallards. The main concerns appear to involve "gene pollution" and law enforcement issues. Interbreeding with wild birds results in concerns that wild traits of free-ranging populations may be replaced by less desirable traits present in captive-propagated birds. Also, the harvest of any wild waterfowl associated with the harvest of released captive-propagated mallards is a law enforcement issue. Some consider this a form of the prohibited practice of shooting over live decoys.[64] In general, despite the concerns noted, the release of captive-propagated waterfowl continues without requirements for adhering to health standards and is considered by many to be a continuing threat for the conservation of wild waterfowl.



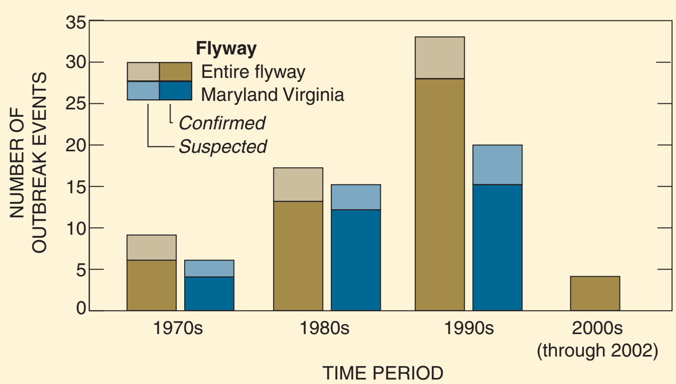


Figure C. Number of duck plague outbreaks occurring in the USA.

nonhuman primates as well as humans becoming infected by pathogens of nonhuman primates. Ecotourism's popularity to view gorillas and other primates in their natural habitat is accompanied by the increased appearance of human pathogens in these species (Box 3–3), which has become a major issue for primate conservation.[73–76]

Companion animals are another potential source for disease introduction into wildlife populations. Regulations that prevent pets from running free within National Parks do not prevent disease introductions into those environments through the infection of insects that may feed on infected pets and then feed on susceptible wildlife hosts. Heartworm (*Dirofilaria immitis*) is an example of a dog disease that has been transmitted to wild **canids**, such as **wolves** (Fig. 3.20). Fecal material from companion animals and inadequate facilities for the containment or treatment of human feces also are potential sources for ecotourists to introduce pathogens into environments being visited. Canine parvovirus in wild canids is an example of this type of disease transfer. Another potential disease source is from food brought into an area for visitors. Food wastes may be associated with the appearance of several poultry diseases in remote populations of marine birds in Antarctica, on isolated oceanic islands, and in the Galapagos Islands.[257,258]

Ecotourism is expected to continue to grow in popularity, and this will result in increased human presence in natural areas and further excursions of humans into virgin and infrequently visited wild areas. Disease emergence that already has occurred indicates that disease prevention needs to be considered as a factor in the further development of this industry. Such an approach is in the best interests of ecotourism because it protects the wildlife resources that are the primary value supporting much of the ecotourism industry.

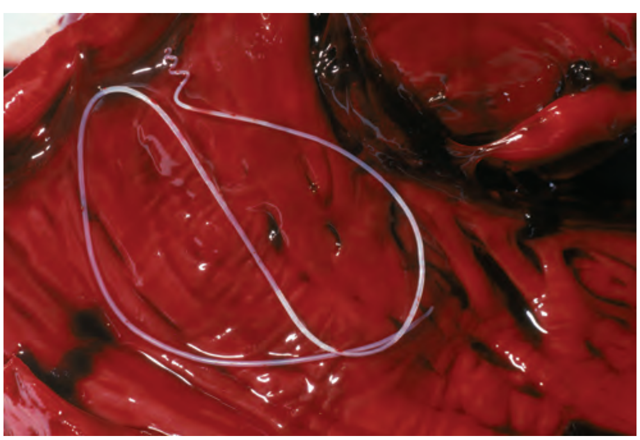


Photo courtesy of the U.S. Geological Survey, National Wildlife Health Center

Figure 3.20 Heartworm in an endangered red wolf. This parasite of dogs is transmitted by mosquitoes and has been responsible for wolf mortality in the USA.

Game Meat

Game meat is referred to by various terms depending on locality and type of meat involved. Among the terms used are wild meat, game, venison, bush-meat, *nyama*, *caza*, *gibier*, and *vianole de brousse*.[38] Ties to this source of protein are strong in some cultures and involve two primary uses of this meat: subsistence, and as a market product. Subsistence hunting of wildlife has been an important aspect of human history and remains so for many people. Tropical-forest people have obtained food by this manner for at least 40,000 years in Africa and Southeast Asia, and for at least 10,000 years in Latin America.[77] Some native peoples in North America, especially those in far northern regions, continue to obtain much of their food through subsistence hunting, trapping, and fishing along with gathering plants, fruits, nuts, and other edible foods. The pursuit of game for any purpose provides possibilities for the transfer of infectious disease. For example, the origin of human HIV infections that have resulted in the AIDS **pandemic** is likely associated with the harvesting of nonhuman primates for food (see Chapter 2).

With the exception of some fur bearers (such as muskrat and nutria), finfish, and shellfish, commercial harvest of wildlife no longer occurs in the USA. Game meat purchased by restaurants is either imported from other countries or has been harvested within captive-propagation facilities in the USA. In general, game meat is not available in public markets. In contrast, trade in game meat is a major economic activity for some countries (Tables 3.14 and 3.15). Game is preferred by many people over domestic animals and is an important source of protein in many areas of the world (Table 3.16). Europe imports about 53,000 tons of game meat per year, including birds, deer, wild boar, and hare,[78] in addition to frogs, **snails**, and other types of game. Considerable game meat is also harvested locally from the wild or ranched. For example, in 1991 the volume of game meat in France was estimated to be 37,000 tons, of which 28,000 tons resulted from hunting, 2,900 tons from farming (game ranching) and 10,300 tons were imports.[38]

Many species of mammals, birds, fish, amphibians, reptiles, and invertebrates appear as food items in different parts of the world. Game meat often does not receive food safety evaluations provided for domestic meats, and commonly involves populations of animals for which disease knowledge is inadequate to assess the presence of health risks for the consumer (See Chapter 2). Caution and personal evaluations are necessary when considering the consumption of unfamiliar game meat, such as may occur during travel and social events.

The recent emergence of SARS attests to the potential for novel disease agents to move from game meat to humans. SARS also demonstrates the need for constant vigilance and aggressive investigations of unusual disease conditions that arise. Findings of emerging and other significant diseases detected need to be reported in a timely manner to account-

Table 3.13 Examples of wildlife-related ecotourism activity and economic returns.[38]

Area	Activity level	Economic returns ($US)
USA	• In 1996, about 31% of resident population 16 years or older participated in some form of nonconsumptive wildlife use	$29 billion in 1996
Canada	• In 1996 wildlife viewing attracted 526,000 visitors from the USA to Canada	$1.3 billion for activities by Canadians and visitors in 1996
South America	• Galapagos Islands National Park in Ecuador is one of the most popular areas for viewing wildlife in Latin America and attracted 62,800 visitors in 1997	$35 million in 1992
	• Top source of foreign exchange for Costa Rica; over 610,000 visitors in 1992	$42.1 million in 1992
Europe	• Wildlife generally not the main reason for visitors at national parks	Not reported
	• Abruzzes National Park in Italy is an exception; 2 million annual visitors to view nature and wildlife; Bialowieza National Park in Poland is another exception	
Africa	• Tourism is the leading foreign exchange earner in Kenya and much of this activity is wildlife based; 863,400 visitors in 1994	$484 million in 1994; about 35% of the total foreign exchange earnings
	• Wildlife tourism is a major activity in Tanzania	$574 million generated annually
	• 90% of 1.05 million registered tourists in South Africa during 1995 visited the national parks	$13 million in economic flux during 1995
	• "Gorillas in the Mist" movie stimulated tourism in Volcanoes National Park in Rwanda	$10 million in 1986 from Volcanoes National Park; one-third of foreign currency earnings
Asia	• Yala and Uda Walawe National Parks in Sri Lanka receive about 250,000 visitors per year	$0.6 million from the two parks
	• During 1998–1999 season nearly 106,000 tourists visited Chitwan Royal National Park in Nepal	$0.75 million (1998–1999 season)

able officials who can initiate appropriate actions to contain and combat the disease. Epidemiological investigations and modeling indicate that although SARS is sufficiently transmissible to cause a very large epidemic if unchecked, it is controllable when dealt with properly.[79] Timely control efforts are essential for diseases with this level of transmissibility. If uncontrolled, SARS likely would infect the majority of people exposed to the virus wherever it was introduced.[79] The epidemics that did occur were driven by large clusters of infection linked to single individuals and/or spatial locations.[80]

Wildlife As Pets

The wildlife pet trade is a major global business (see Chapter 2) that is part of the larger trade industry in biological resources estimated to be worth billions of dollars.[37] A wide range of species, most of which are taken from the wild, are sold in international commerce. The conditions for animal movement and trade within this industry increase opportunities for disease agents to move between species whose ranges do not normally overlap in nature. Thus, pathogens and disease vectors are presented with unique opportunities

Box 3–3 Loving Primates to Death

"The prevention of exposure to infectious disease is an important, fundamental aspect of primate conservation…" (Wallis and Lee)[75]

Nonhuman primates are popular within zoological collections, and during recent years world populations of gorillas and some other primates in the wild have become an increasing attraction for ecotourism. Nonhuman primates are also an important focus for social science and biomedical investigations. These direct and indirect contacts have repeatedly demonstrated the movement of significant infectious diseases from these species to humans and vice versa. Prior to reducing tuberculosis (*Mycobacterium tuberculosis*) to very low levels in human populations of developed nations, it became necessary to separate nonhuman primates in zoos by full glass partitions to prevent the primates from contracting tuberculosis from humans. Human visitation into the natural environments of primates by ecotourists, scientists, and indigenous peoples is proving to be even more hazardous for these species because of a variety of infectious diseases introduced by the visitors.

The list of diseases shared between humans and other primates continues to grow (see Table below), and, in some instances, diseases such as Ebola hemorrhagic fever have become a major challenge for the survival of species.[73,142,143] Diseases introduced into wild primate populations are believed to be of such biological significance that a solution to this problem "…requires effecting change in the behavior and policies of many individuals, including field researchers, veterinarians, human health care providers, park personnel, government officials, local villages, and tourists".[75] Failure to adequately address disease transmission from humans to nonhuman primates will likely result in the extinction of some populations. Current small population numbers and age structures that are not resilient enough to overcome major losses from disease will be factors in these extinctions.

Photos courtesy of Teresa Wawrzyniczyk, Twycross Zoo, United Kingdom

Examples of human pathogens that have entered wild populations of nonhuman primates.[74–76,144]

Disease	Agent type	Species affected	Year	Comments
Tuberculosis (TB)	Bacteria	Multiple	Historic to present	• Primary concern is *Mycobacterium tuberculosis,* but 10–30% of simian TB may be due to *M. bovis* • Humans may become infected with *M. bovis* from cattle/milk and then retransmit TB to other species • Major problem in India
"Polio"	Poliovirus and/or polio-like virus	Chimpan-zee 	1964, 1966	• Six deaths and at least 6 other chimps paralyzed for life during outbreak in Gombe National Park, Tanzania (1966) • At least 7 of about 48 animals under study at Beni, Zaire (now Democratic Republic of the Congo) with limb paresis (1964)
Measles	Virus	Gorilla 	1988	• Outbreak that killed 6 animals at Volcans National Park, Rwanda and caused disease in 27 others believed to be measles • Primates living in the wild without human contact are thought to be free of measles virus but are highly susceptible to transmission from humans
Respiratory disease	Bacteria, virus	Chimpan-zee 	1968, 1975, 1978, 1987, 1996	• Warnings published since 1920s of high susceptibility of apes for human respiratory infections • Gombe National Park outbreaks (1968–1996) have killed 1 to 11 animals per event and left others clinically ill • *Streptococcus pneumoniae*, the cause of pneumonoccal pneumonia; the common cold and influenza are all sources for disease in nonhuman primates
Yaws	Bacteria	Olive baboon 	1989	• Mortalities in addition to clinical cases at Gombe National Park
Scabies	Ectoparasite (mite)	Gorilla, chimpan-zee  	1996, 1997	• First record of sarcoptic mange in free-ranging gorillas occurred in Uganda (1996); an 8-month-old infant died and the 4 members in that group were all infected • An outbreak in Gombe National Park (1997) killed 3 chimpanzees of 19 infected
Parasitism	Endopara-sites	Multiple	1980s, 1990s	• Chimpanzee community at Gombe National Park having most contact with humans during 1989 to 1996 had a wider variety and higher prevalence of parasites than the community living the greatest distance from humans • Studies in chimpanzees south of Gombe during 1993 and 1994, gorillas in Rwanda during 1996–1997 and of howling monkeys in Costa Rica during the 1980s also suggested human sources of parasitism

to enter new hosts. Also, the speed of modern transportation can convey infected animals for delivery to distant locations before clinical disease appears. This is illustrated by the recent outbreak of monkeypox (Box 3–4).

The appearance of monkeypox in wild pets is not a rare, isolated disease event within the wildlife pet trade. These types of events have been occurring since humans began converting wildlife to pets. During the early 1960s when the striped **skunk** became a popular pet in some areas of the USA, rabies in de-scented baby skunks resulted in the need to trace shipments of litter mates that died to other states. One multistate skunk episode involved diagnosis of rabies in one of about 70 young skunks; at least 72 bite exposures occurred among more than 340 persons at risk due to contact with those skunks.[83–85] Rabies has been documented in pet wildlife within North America on a number of occasions, including an event in which 80 persons were exposed to a rabid pet coatimundi in a tourist hotel.[86] Several months prior to the appearance of

Table 3.14 Examples of economic value of game meat.[63, 227]

Area	Value in millions (US$)	Comments
Northwest Territories, Canada	25	• Mid-1980s evaluation[63]
Sweden	61	• 1987 evaluation; primarily moose meat[63]
Former USSR	40	• Average from 1970s until early 1980s; includes hides and other products in addition to meat[63]
Central African Republic	22	• Annual trade value of ranched game meat[227]
Côte d'Ivoire	200	• 100,000 tons harvested in 1996[37]
Côte d'Ivoire	105	• Annual trade value; 1996 evaluation[227]
Gabon	26	• Urban area; 1993 evaluation[227]
Gabon	22	• Rural area; 1993 evaluation[227]
Ghana	205	• Annual trade value; 1996/1997 evaluation[227]
Ghana	275	• 305,000 tons sold annually[38]
Liberia	42	• Annual trade value; 1989 evaluation[227]
Amazon Basin, South America	175	• Average annual harvest[228]

"Animal Stew" Brews Novel Pathogens

The struggle for survival is as old as life itself and will continue as long as there are life forms of any type. Microbes are part of this endless struggle, and like other species, they compete with their own kind and with other life forms for their own survival. Many microbes excel at adapting to changing environments, an important attribute for survival. The ability to enter new environments (infect new hosts), adapt to those environments (utilize the host environment to complete essential life processes), and colonize for population sustainability (spread of infection to increasing numbers of hosts) is a high capacity evolutionary capability of many microbes.

The intermixing of multiple species and high population density of higher life forms provides a virtual "buffet" for microbes to sample and select from. Adaptive changes by the microbe that accompany these forays often result in forms that are pathogens for some hosts. It appears that SARS is an outcome of a microbe becoming a pathogen as it moved from one host species to another. Preliminary investigations have indicated that the SARS infection of humans originated from **civet cats**, probably the masked palm civet. Recent findings indicate bats are the origin of the virus. Civet cats are eaten as a delicacy in China, and it is postulated that the virus moved from civets to humans in the food markets of China where it adapted to its human host.[81] Masked palm civet cats are native to China and are one of several species of civets found in Africa and Asia.[82]

The origin of SARS is associated with marketplace conditions where large numbers of live animals of many types are kept in cages in close proximity to one another until they are selected as food items. The individuals maintaining these animals in the marketplace often are involved in the processing of selected animals.

Table 3.15 Primary countries providing game meat derived from farming, ranching, or intensive commercialized hunting operation (adapted form Roth and Merz, 1997[248]).

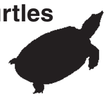
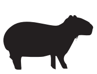
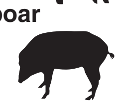
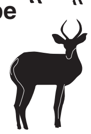
Type of meat	Producer countries	Comments
Crocodile, alligator 	Southeast Asia, Zimbabwe, Colombia, Australia, USA	Crocodile meat is a highly prized export commodity in South America and Africa, and is a primary purpose for farming these species in Asia).[248] Alligator meat had a 1999 market value of US$5.40/lb.; total sales in Florida (1999) were about $710,590,[249] and 1992 sales exceeded $5.5 million for producers in Louisiana, USA.[63]
Snakes 	China	Numerous species are farmed for meat and organs because of dietary and medicinal uses.
Turtles 	China, Southeast Asia, India	Market prices in excess of US$9.00/kg in Japan by the late 1980s have contributed to the expansion of softshell turtle farming.[246] Pond culture for these turtles on one Singapore farm involves a stock of 300,000 to 400,000.[245]
Ostrich 	South Africa, Zimbabwe, Israel, USA, Australia	South Africa produces the most.
Quail, pheasant 	Japan, France, Italy, United Kingdom	Commercial rearing of upland gamebirds for meat and eggs is increasing throughout the world. The total quail egg production in Japan is similar to hen egg production; India and Pakistan are other large quail producers, as are France, Spain and Italy. France consumes 260 million quail a year.
Kangaroo 	Australia	Primarily harvested by commercial hunting. Meat is mostly used for pet food.
Hares, rabbits 	Argentina, Australia	Argentina is largest exporter of hares; the annual export of 10,000–14,000 tons of meat provides millions of dollars to the economy and employment for thousands of people. Harvest is primarily of wild stocks.
Nutria 	USA, Argentina	Harvest is from wild stocks. During 1992–93 about 200 tons of meat were produced in Louisiana, USA.
Capybara 	Venezuela	Approximately 57,000 of these large rodents (up to 60 kg each) were harvested annually for in-country markets during 1977–1984.
Wild boar 	Australia, Eastern Europe, France, Canada	Includes feral swine. Most harvest is by hunting. International demand for boar meat increased greatly during the 1980s and exceeds 10,000 tons per year. Poland is the world's biggest exporter, followed by Australia and Germany.
Deer venison 	New Zealand, Eastern Europe, Canada	A 1992 evaluation estimated that approximately 17,000 deer farming and ranching operations existed worldwide, with collective holdings of nearly 2.5 million animals, and production of more than 19,000 tons of venison.
Reindeer venison 	Former USSR, Canada, Fennoscandia	Reindeer husbandry in Russia is the economic basis for millions of people living in northern and central regions. It is the second most important aspect of the economy in central Siberia.[250]
Antelope 	South Africa, Namibia, Zimbabwe, former USSR	Ranching and farming of these species has steadily expanded since the 1960s. A 1981 evaluation of potential production from antelope species in South Africa alone was nearly 9,000 tons of meat[251] with an estimated market value of approximately US$20 million (1980 dollars). Saiga antelope in the former USSR provided nearly 6,000 tons of meat annually from commercial hunting during the early 1970s but much less now due to declining populations.[252]
Bison 	Canada, USA	A 1989 evaluation indicated that about 10,000 bison are harvested annually in the USA and an additional 1,000 in Canada.[253] At that time, the demand for bison meat exceeded the supply.

Table 3.16 Examples of the importance of game meat in the human diet.

Area	Game meat consumption
Sarawak, Malaysia	• 67% of the meals of Kelabits contain wild meat; main source of protein; about 23,500 tons annually[77],[228]
Côte d'Ivoire	• 83,000 tons annually[229]
Central African Republic	• 51,000 tons annually[38]
Gabon	• 17,000 tons annually[230]
Central Africa (collective)	• 1 million to 3.4 million tons harvested annually[231,232]
Kenya	• 80% of rural households depend on game meat for the majority of meat protein[233,234]
Liberia	• 75% of meat is from wild animals; 105,000 tons eaten annually[231,228]
Ghana	• 70% of the population eats game meat; main source of animal protein for rural communities[235]
China	• About 800,000 muntjac deer harvested annually[236]
Brazilian Amazon	• 67,000 to 164,000 tons of game meat harvested annually[237]
Peru	• Collared peccary provides 34% of the meat eaten locally in Iquitos[38]
Venezuela	• About 400 tons of capybara meat harvested annually[238]
Sweden	• 80% of meat produced in Sweden is moose meat[38]

monkeypox in prairie dogs, an outbreak of tularemia occurred in prairie dogs within the pet trade.[87, 88] Like monkeypox and rabies, tularemia is a zoonosis. Many of the prairie dogs in the population experiencing the tularemia outbreak were slated for animal markets in Asia.

Disease issues within the pet wildlife trade are difficult to address biologically and politically because of the broad spectrum of species involved, large size of the industry and the many unstructured components of this internationally complex business. Birds, reptiles, and **ornamental fish** dominate international trade in live wildlife, but large numbers of mammals, amphibians, and invertebrates are also involved. Within the USA, increased import restrictions have significantly reduced the number of wild birds imported, but there has been an increase in imported reptiles.[37] A novel strain of *Salmonella* sp has accompanied the importation of iguanas into the USA.[89] During recent years, iguanas, especially the green iguana, have become a higher percentage of the total number of imported reptiles (Fig. 3.21).

The USA is both a major importer and exporter of live reptiles for the pet industry. During the early 1990s, the USA conducted about 80 percent of total world trade in about 70 reptile species subject to the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). Throughout the 1990s, about 2 million live reptiles were imported annually (Fig. 3.22). In 1998, these reptiles originated from about 80 countries; 10 countries (Fig. 3.23) accounted for 82 percent of the total reptiles imported.[90]

An estimated 1.5 to 2.5 million USA households owned one or more reptiles in 1996; snakes and turtles were the predominant species.[90] The number of reptile owners increased to 2.7 million households in 1998. The royal python is a popular snake of the pet trade because it is not aggressive. Some African countries such as Ghana, Togo, and Benin, now use this species as a major wildlife export because of bans on species of **parrots** traded previously. Togo exports 50,000 pythons a year. In Ghana, the royal python has become the top wild species export relative to foreign currency earnings for that country, accounting for 47 percent of those earnings between 1991 and 1995 when 102,578 of these snakes were exported.[38] Salmonellosis is the most common disease in humans that is associated with pet reptiles, but other infectious diseases have been acquired from these species in addition to exposure to venoms, other toxins and painful bite wounds.[90]

Other Activities

There also are activities other than those categorized in this chapter as Wildlife Management and Commercial Activities that involve human-wildlife interfaces associated with disease emergence. Two examples are wildlife rehabilitation and wildlife feeding.

Wildlife Rehabilitation

Within the USA and in most other countries, wildlife rehabilitation is primarily a private sector activity rather than one carried out by government wildlife agencies. A notable exception in the USA is the Oil Spill Prevention and Response Program of the California Department of Fish and Game. The program resulted from numerous oil spills along the California coast and is funded by a special tax levied on each barrel of oil extracted from California. Also, several university-based wildlife rehabilitation programs are associated with schools of veterinary medicine and several major private sector wildlife rehabilitation programs exist (Table 3.17). These public/private sector programs are highly dependent upon public donations and grants for support and are staffed by veterinarians and other professionals trained in wildlife health. However, the majority of wildlife rehabilitators are private citizens who donate their time and money to the care of orphaned, injured, and otherwise debilitated wildlife, often within the rehabilitators' homes.

Disease is a common visitor to wildlife rehabilitation facilities. Animals taken in may be clinically infected, and latent disease may advance to clinical disease due to the stresses associated with the conditions that caused their admission or from the stresses of confinement. Confined wildlife may also be introduced to disease within these facilities, as often few to no disease-prevention barriers exist. The opportunity for pathogens to move among animals is also high because of the wide variety of species generally present, the close proximity to other animals, and inadequate barriers to prevent the spread of infectious diseases by aerosol, mechanically on personnel caring for the animals, and by other means.

Few wildlife rehabilitators within the general public have access to or can afford the costs of disease assessments for clinically ill animals within their care. Similarly, animals that die seldom are evaluated by disease specialists to determine cause of death, unless there is high mortality within a facility and government agencies respond. An exception is species covered by state and federal listings of threatened and endangered species. Permission granted to possess such species may require evaluation of animals that die. Therefore, sound knowledge of the types of diseases present within these facilities is often lacking. In addition, the general absence of requirements for health certification for animals released by wildlife rehabilitators can inadvertently allow the release of diseased animals into the wild. These releases could jeopardize the free-ranging wildlife populations that wildlife rehabilitators are trying to help. The deep personal commitments and associated emotional attachments that often develop between wildlife rehabilitators and the animals in their care make it difficult to deal with disease situations that arise; euthanasia and other actions are often avoided because of personal investments and beliefs.

Large numbers of wildlife, primarily birds, are cared for by wildlife rehabilitators annually. The public often turns to wildlife rehabilitators first when they observe or find debilitated wildlife. Animals taken in are generally of unknown health status, beyond readily observable conditions such as oiling and traumatic injuries. The nature of these activities results in moderate probabilities that diseased individuals will be among the animals submitted for rehabilitation. However, the ability for early detection of diseases present is often quite limited. Nevertheless, some of these facilities have developed and are utilizing wildlife health surveillance systems as time-sensitive indices to changing trends. Spatial and temporal origins of animals rescued and admitted to these facilities demonstrate the frequency of specific

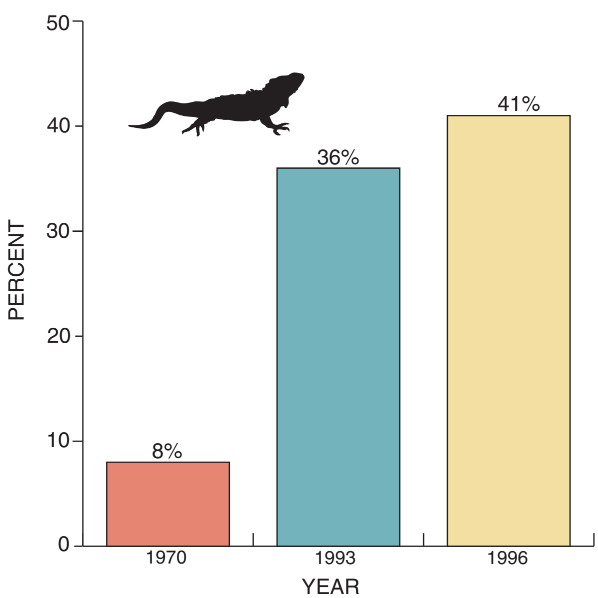


Figure 3.21 Iguanas imported into the USA as a percentage of total imported reptiles.[243]

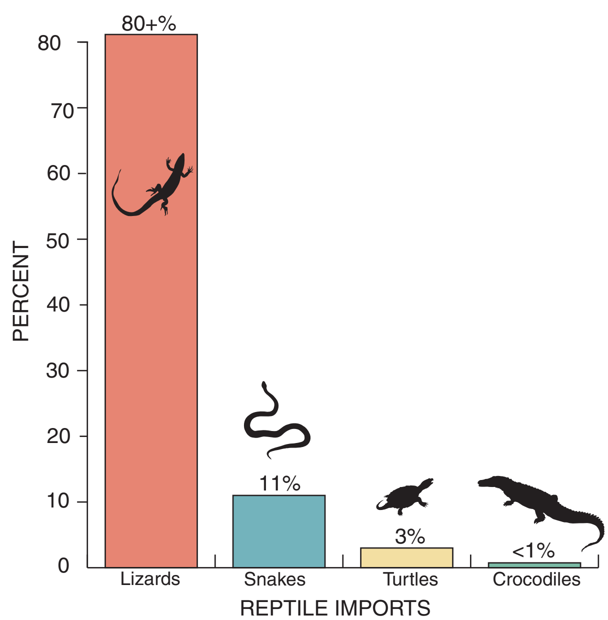


Figure 3.22 Percentages of live reptiles imported into the USA during the mid- to late 1990s.[90]

Box 3–4 Monkeypox– A Lesson Not Yet Learned

Monkeypox (Fig. A) is an emerging infectious disease caused by an orthopoxvirus, which can result in infections that resemble smallpox in humans.[145] Although most infections are clinically mild to moderate, severe infections can result in death, especially in young children.[146] Among 338 human cases in the Democratic Republic of Congo (DRC; formerly Zaire) from 1981 to 1986, there was a case fatality rate of 9.8 percent; 86 percent of those cases were young children. Disease spread to unvaccinated family members at a rate of 9.3 percent.[145,147] Primary transmission to humans occurs by direct contact with infected animals. Secondary human-to-human spread occurs by aerosol or direct contact.[148] Monkeypox is endemic in the rain forests of Central and West Africa, where it causes small numbers of human cases annually. However, during recent years, there has been an increasing number of cases.[148–150]

Early Disease Emergence

Monkeypox virus probably has been maintained in wildlife of Central and West Africa for hundreds of years prior to its initial discovery[146] in 1958, when it caused an outbreak in laboratory monkeys in Denmark. During the next 10 years, 9 additional outbreaks occurred in captive primates in Europe and North America. No human cases were associated with any of those outbreaks.[146] The first human case was identified in 1970 in a 9 month-old child from the DRC who had not been vaccinated against smallpox. Investigations of that case disclosed that viruses isolated from clinically similar cases of disease in Liberia and Sierra Leone also were monkeypox.[151] Only 54 human cases of monkeypox were recorded between 1970 and 1980, nearly all of these in the DCR.[146]

Disease Advancement

From the start of 1980 until the end of 1983, an additional 101 cases of human monkeypox were detected. Although 92 percent of the 155 cases documented were from the DRC, the other cases appeared in five other countries of the region (Fig. B).[146] About 65 cases per year appeared over this broad geographic area until 1996. At that time, an outbreak in the DRC exceeded the average annual number of cases and was the largest recorded monkeypox event with 88 human cases identified during a 12-month period.[148,150]

Photo courtesy of the Centers for Disease Control and Prevention

Figure A. Typical lesions of monkey pox infection.

These and other cases of monkeypox resulted in concern that disease emergence was occurring.[149] Investigation of seven outbreaks of suspected human monkeypox in the DRC during 2001 disclosed that two of the outbreaks (16 cases, 4 deaths) were caused by this disease and that two other outbreaks (7 cases, 1 death) involved monkeypox and *varicella-zoster* virus (chicken pox). Monkeypox was not present in the other three events (8 cases, no deaths).[145]

Reservoirs and Vectors

Early investigations into the source of human infections by monkeypox focused on nonhuman primates in the DRC. Antibodies to the causative virus were detected in several species of monkeys and apes.[151] Larger-scale evaluations that followed in 1971 and 1979 included monkeys, rodents, and other types of mammals. Although no virus was isolated from about 1,500 animals tested, monkeypox antibody was detected in at least four species of forest-dwelling monkeys. However, investigators concluded that while human use of these species for food likely provided an important pathway for human infection, they were unlikely **reservoir hosts** because monkey troops in the forest were isolated.[146]

Epidemiological evaluations of presumed animal sources of human infections provided a longer list of suspect species (Table A). Subsequent evaluations associated with the 1996 outbreak in the DRC disclosed that all patients had eaten the meat of wild animals, identified the species most commonly eaten, and identified squirrels, the Gambian rat, and the **elephant shrew** as species with antibody to monkeypox.[150] Those findings (Table B) led to the conclusion that “Gambian rats may play a role in monkeypox virus circulation.”[150] The Gambian rat inhabits most of the African continent and is a forest and thicket dweller. Also referred to as the African giant pouched rat, they weigh about 1 kg, become tame in captivity, and are reported to “make delightful pets.”[82] The Gambian

Table A. Animals found to be infected by monkeypox virus.[108, 146, 150]

Captive species[a]	Free-ranging species[b]	Experimental infections
Gorilla	Domestic pig	Laboratory rat
Orangutan	Elephant shrew	Laboratory mouse
Chimpanzee	Thomas's tree squirrel	Domestic rabbit
Cynomologus monkey	Kuhl's tree squirrel	
Rhesus monkey	Sun squirrel	
African green monkey	Gambian rat	
Squirrel monkey	Spot-nosed monkey	
Marmoset	Lesser white-nosed guenon	
Indian langur	Allan's monkey	
Malayan langur	Colobus monkey	
Cercopithecus		
Gibbon		
Pigtailed macaque		
Giant anteater		
Prairie dog		

[a] Spontaneous infections in animals' holdings.

[b] Animals sampled in the wild found to have antibody against monkeypox virus.

Photo courtesy of U.S. Fish and Wildlife Service

rat is likely secondary to squirrels (*Funisciuvus* spp. and *Heliosciuvus* spp.) as being the primary reservoir for the virus in nature.[148]

The USA Experience

Monkeypox first appeared as a disease of humans in the USA during mid-May 2003 and became widely distributed geographically through the exotic pet trade, the source for virus entry into and distribution in the USA.[107,108,152–154] Investigations (Fig. C) indicate virus entry via an April 9, 2003, shipment of about 800 small mammals coming from Gambia and going to Texas. The Texas shipment included squirrels (*Funisciuvus* and *Heliosciuvus* spp.), considered to be the primary natural reservoir for monkeypox.[148] Gambian rats and other rodents may also serve as virus reservoir species.[150] The virus was then transferred via exotic pets to an Illinois animal distributor, then to a Wisconsin animal distributor, and then to area pet stores. The virus continued to spread through local pet stores, swap meets, and wild animal trade centers before intervention began.[108] The Centers for Disease Control and Prevention tested rodents in the shipment and found a Gambian rat and two rope squirrels infected with monkeypox virus.[154]

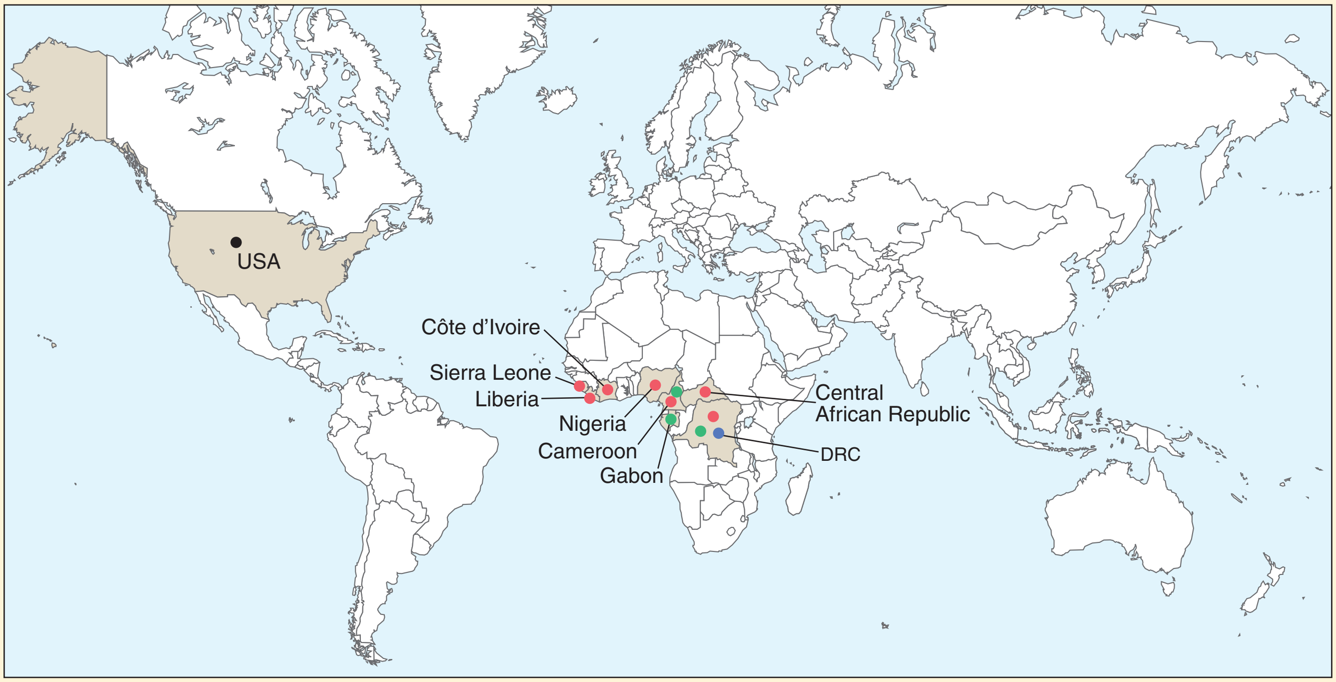
The human index case in the USA was a 3-year-old child who was hospitalized. Her parents developed milder forms of the disease.[155] Subsequent cases were reported from Wisconsin, Illinois, Indiana, Ohio, Kansas, and Missouri.[154] More than 80 human cases, 32 of which had been confirmed by laboratory testing were reported by July 2, 2003.[154] Prairie dogs are thought to have initially become infected by an infected Gambian rat during animal shipments among distributors, and then these prairie dogs served as sources for infection of other prairie dogs that infected humans in close contact with these animals.[108,156] Fortunately, no deaths have been associated with monkeypox in the USA, despite a significant case fatality rate in Africa.[145,150] Monkeypox cannot sustainably infect human populations without wildlife reservoirs reintroducing the virus.[145,146,150] Currently, the 2003 monkeypox introduction into the USA has not resulted in an established wildlife reservoir for this virus, although it may still be too soon to tell.

Epilogue

Monkeypox's appearance in the USA has once again illustrated a high level of vulnerability to exotic pathogens because of inadequate disease safeguards associated with humans transporting wildlife. Demand for exotic pets provides a profitable marketplace for those who wish to supply those animals. The potential for disease acquisition along with the wildlife being purchased is higher than necessary because of inadequate health evaluations of animals that are traded, lax regulations for pet trade animal-holding conditions, and no requirements for professional evaluations of animals that die or for reporting findings about those deaths. Perhaps the recent occurrence of monkeypox in the U.S. will serve as a catalyst for collaboration to minimize the potential for future disease events - or perhaps the current lesson will continually need to be relearned (see also Boxes 3.2 and 3.5).

Table B. Suspected wildlife reservoirs for monkeypox virus.

Species	Comments
Squirrels Kuhl's tree squirrel Thomas's tree squirrel Sun squirrel	Considered possible reservoirs in Zaire on the basis of serologic finding and isolation of the virus from one Thomas's tree squirrel;[147] also implicated in later studies.[150]
Gambian rat	High percentage of human cases during 1996–1997 epidemic involved eating and other exposures to Gambian rats; also 16% of rats tested had antibody to monkeypox virus.[150]
Porcupine	Similar finding to Gambian rat but no live animals sampled.[150]



EXPLANATION

Human cases of monkeypox

- **1970–1986** Cameroon, Central African Republic, Côte d´Ivoire (Ivory Coast), Zaire/Democratic Republic of Congo (DRC), Liberia, Nigeria, Sierra Leone
- **1987–1995** Cameroon, DRC, Gabon
- **1996–1999** DRC
- **2000–2004** USA

Figure B. Geographic distribution of reported human cases of monkeypox from 1970 (first case identified) through 2002.[146]

Figure C. Entry of monkeypox into the USA and spread of disease during 2003.

species being submitted, and unusual clusters of submissions, such as occurred with West Nile fever emergence in **raptors**. The timely identification of such events would be useful for identifying field situations that may warrant investigations by wildlife disease specialists.

Wildlife Feeding

Many people enjoy feeding wildlife. In many instances, the motivation is to lure wildlife to places where they can be viewed and their beauty enjoyed. Sometimes people are motivated to help wildlife during times of limited food supply due to severe weather conditions or to sustain more animals in an area than the habitat can support for prolonged periods. During earlier decades, many biologists considered feeding wildlife in winter a necessity.[91] In the USA, these efforts were motivated by the desire to restore diminished wildlife stocks and supported perspectives that continued to persist. The feeding of elk wintering at Jackson Hole, Wyoming, is an example (Fig. 3.24). Feeding **squirrels**, **pigeons**, and waterfowl in city parks and similar areas is a popular activity as is feeding birds from backyard feeders (Fig. 3.25). Within the USA, an estimated $3.5 billion is spent annually on birdseed, bird feeders, bird houses, birdbaths, and nest boxes.[92] The common practice of resort and cabin owners providing food for deer has now extended to suburban/exurban environments where it also is a popular activity (Fig. 3.26).

Several noteworthy infectious diseases have emerged in association with wildlife feeding (Table 3.18). Factors involved are crowding at feed stations, contamination of food and feeding areas by infected animals, and alteration of normal animal movement patterns, that is, animals remain in an area that they normally would have vacated during periods of high physiological stress. In the USA, brucellosis only exists as a self-sustaining disease in the wild elk populations on feed grounds.[93–96] Also, deer feeding is thought to be a major factor in the spread of chronic wasting disease in Wisconsin and has been temporarily banned in that state.[8] Deer feeding also has been associated with bovine tuberculosis in Michigan deer and elk.[260,261] Birds routinely move from one feeder to another and in doing so can transport pathogens throughout the "feeding station circuit." This "circuit" was likely an important factor in the rapid spread of house finch conjunctivitis across North America (Fig. 3.27) and for the devastation among songbird populations caused by salmonellosis.[97–99]

Informational brochures to alert people of disease problems at bird feeders (e.g., National Wildlife Health Center brochure on *Coping with Diseases at Bird Feeders*, 1995) have improved sanitation at these stations as one aspect of disease prevention. Tubular rather than platform feeders (Fig. 3.28) also may reduce disease risks by minimizing the surface area where pathogens may be deposited. Generally, bird feeders with smooth plastic or metal surfaces can more easily be decontaminated than those constructed from wood. However, spilled and soiled feed can collect on the ground beneath feeders (Fig. 3.29) and can cause problems. People are likely to continue feeding wildlife. Therefore, it is important to better understand the ecology of associated

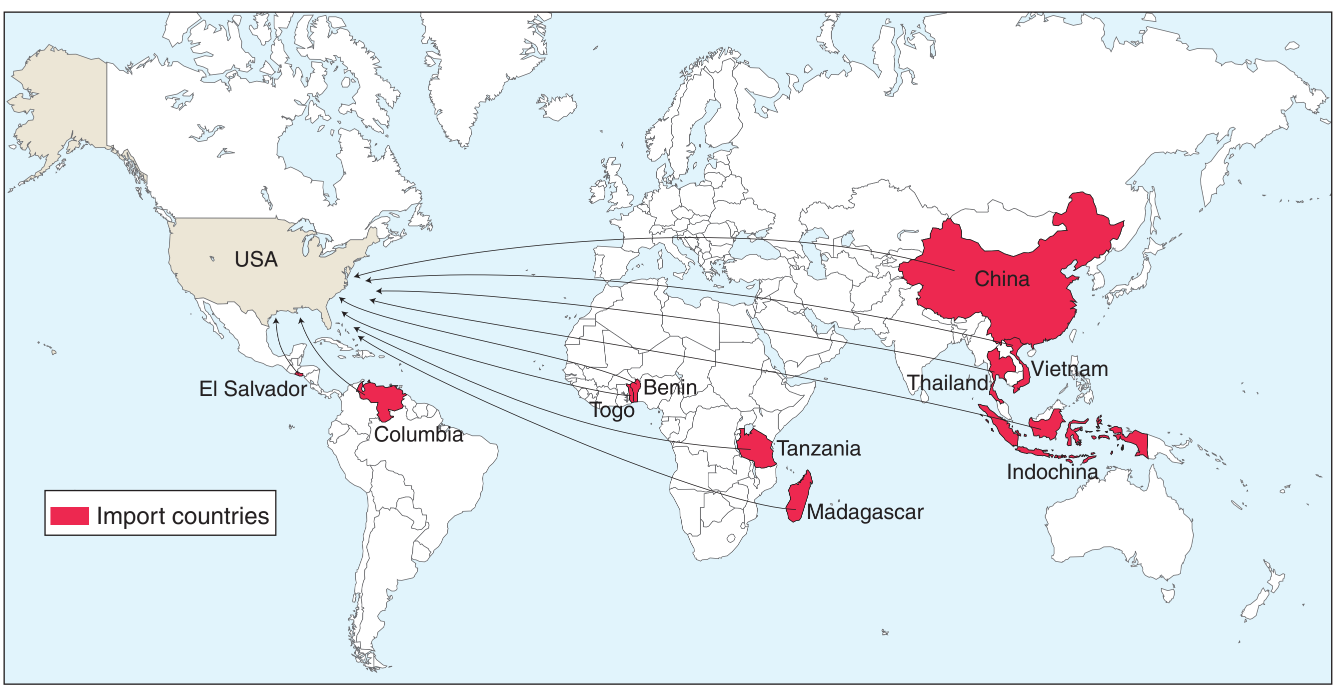


Figure 3.23 Countries of origin for reptiles imported into the USA during 1998.

Table 3.17 Examples of major USA wildlife rehabilitation programs.

Program	Affiliation	Location	Primary activity	Web site
Alaska SeaLife Center	Non-profit	Seward, Alaska	Marine ecosystem research, rehabilitation, and education.	http://www.alaskasealife.org/
Audubon Center for Birds of Prey	Non-profit	Maitland, Fla.	Specializes in rescue, medical care, rehabilitation, and release of sick injured, and orphaned raptors.	http://www.audubonofflorida.org/conservation/cbop.htm
California Raptor Center	University	Davis, Calif.	Dedicated to the care and rehabilitation of ill, injured and orphaned raptors.	http://www.vetmed.ucdavis.edu/ars/raptor.htm
International Bird Rescue Research Center	Nonprofit	Cordelia, Calif.	Rehabilitation program concentrates on aquatic species, as these are the animals most commonly affected in oil spills.	http://www.ibrrc.org/index.html
Lindsay Wildlife Museum	Nonprofit	Walnut Creek, Calif.	Treats more than 6,000 injured and orphaned wild animals each year.	http://www.wildlife-museum.org/
The Marine Mammal Center	Nonprofit	Sausalito, Calif.	Care of marine mammals.	http://www.marinemammalcenter.org/index.asp
Marine Wildlife Veterinary Care & Research Center	California Department of Fish and Game	Sacramento, Calif.	Specializes in care for marine wildlife affected by oil spills. Also serves as center for sea otter and marine wildlife health research	http://www.dfg.ca.gov/ospr/index.html
PAWS Wildlife Center	Nonprofit	Lynnwood, Wash.	Bears, coyotes, opossums, seals,starlings, bobcats, squirrels, and many other species of wild animals cared for that populate the Pacific Northwest.	http://www.paws.org/work/wildlife/
The Raptor Center	University of Minnesota	St. Paul, Minn.	Medical care, rehabilitation, and conservation of birds of prey	http://www.raptor.cvm.umn.edu/
Suncoast Seabird Sanctuary	Nonprofit	Indian Shores, Fla.	Rescue, repair, rehabilitation, and release of indigenous wild birds	http://www.seabirdsanctuary.org/
Tristate Bird Rescue and Research Inc.	Nonprofit	Newark, Del.	Professional care for a wide range of wild birds from hummingbirds to bald eagles	http://www.tristatebird.org/
Tufts Wildlife Clinic	University	North Grafton, Mass.	Emphasizes veterinary education in wildlife and zoological medicine.	http://www.tufts.edu/vet/wildlife/
The Wildlife Center of Virginia	Nonprofit	Waynesboro, Va.	Rehabilitation of 2,500 wild animals from across Virginia and surrounding states each year.	http://www.wildlifecenter.org/vet.htm/
Willowbrook Wildlife Center	Nonprofit	Glen Ellyn, Ill.	Treatment and rehabilitation of native wildlife.	http://www.dpageforest.com/EDUCATION/willowbrook.html

disease events, so that the intended benefits for wildlife are realized, without the negative consequences.

A Need For Change

The world has become a much smaller place during the past 100 years, in regard to loss of open space and decreased transit time to move people and goods from one distant location to another. The growing human population and advances in technology are major contributors of landscape and other changes altering historic species distribution patterns and creating environmental conditions and species interactions that allow and promote the spread of infectious diseases. Diseases will continue to emerge and reemerge resulting in negative effects on wildlife and many segments of society unless attentiveness to wildlife disease is enhanced around the world.

The concept of "the one medicine" alluded to earlier[10] offers a way to philosophically and functionally change. An integrated approach is needed because of the strong ties for many infectious diseases that exist among humans, domestic animals, and wildlife. These diseases need to be addressed in an integrated manner across this spectrum of hosts and contributors. We need to move away from crises reactions to address disease prevention rather than symptomatic response. The application of "one medicine" to wildlife disease will lead to major changes in how agencies and people conduct their activities within the "commons" of Planet Earth, especially as those activities involve wildlife.

Within the USA and in many other countries, wildlife are treated as a "commons" relative to disease prevention in the context of the classic paper by Hardin[100] in which he noted that "Freedom in a commons brings ruin to all." In a later commentary on the current meaning of that paper, Hardin[101] noted that "Individualism is cherished because it produces freedom, but the gift is conditional: The more the population exceeds the carrying capacity of the environment, the more freedoms must be given up." Disease emergence aided by human actions has reached a point requiring the loss of some "freedoms" if disease is to be managed for the benefit of wildlife, as well as for humans and domestic animals.

Regulatory Needs

Among the 50 State Agricultural Agencies, 50 State Departments of Natural Resources, the U.S. Department of Agriculture, the U.S. Department of the Interior, and the U.S. Department of Health and Human Services, current regulations concerning the ownership, sale, and transportation of nondomestic animals fragment the responsibility for disease prevention and control. During the 1970s and 1980s, attempts by the conservation community to implement a "Model State Regulation for Control of Zoological Animals" failed, as have other efforts to establish uniform health standards for transporting and release of wildlife. External pressures on government agencies with authority and stewardship responsibility for wildlife, by special interests, cost factors, and perspectives that minimize the role of disease in wildlife, continue to inhibit needed oversight (Box 3–2).

Photos by Milton Friend

Figure 3.24 (A) Elk on winter feed grounds, Jackson Hole, Wyoming (USA); (B) Feed truck being loaded with alfalfa pellets; and (C) Alfalfa pellets used for feeding elk.

Table 3.18 Examples of infectious diseases associated with wildlife feeding activities.

Disease*	Type of agent	Primary species affected	Comments
Salmonellosis	Bacteria	Songbirds	Common disease at residential bird feeders; large-scale mortalities have occurred.[97]
Mycoplasmosis	Mycoplasma (bacteria)	House finch	Epizootic that began in 1994 swept throughout entire eastern range for the house finch following the index case at an east coast bird feeder;[239] disease has now reached the west coast. Most transmission probably occurs at bird feeders.
Trichomoniasis	Protozoan parasite	Doves, pigeons	Bird feeders have been involved in some epizootics.[240]
Avian pox	Virus	Songbirds	Bird feeding stations have been the site for numerous epizootics in the USA.[241]
Aspergillosis	Fungus	Variety	Songbirds, blackbirds, and other species that utilize bird feeders have been affected; waterfowl, crows and upland game birds fed waste grain have also been affected.[242]
Brucellosis	Bacteria	Elk	A common disease of elk provided supplemental feed on winter areas in Wyoming, USA. Brucellosis is rare in elk that are not maintained by winter feeding.
Chronic wasting disease	Prion	Elk, deer	Feeding of deer and elk concentrates these animals and is believed to be a factor in the transmission of CWD.
Bovine tuberculosis	Bacteria	Elk, deer	Feeding stations are strongly associated with this disease in free-ranging deer and elk in Michigan.[260,261]

* None of these diseases are limited to wildlife feeding situations.

Photo by Milton Friend

Figure 3.25 Wildlife feeding is a popular activity in urban areas.

Photo courtesy of David Kenyon, Michigan Department of Natural Resources

Figure 3.26 Corn, apples, and other feed is used to attract deer for viewing at some resort areas and vacation cabins in the USA.

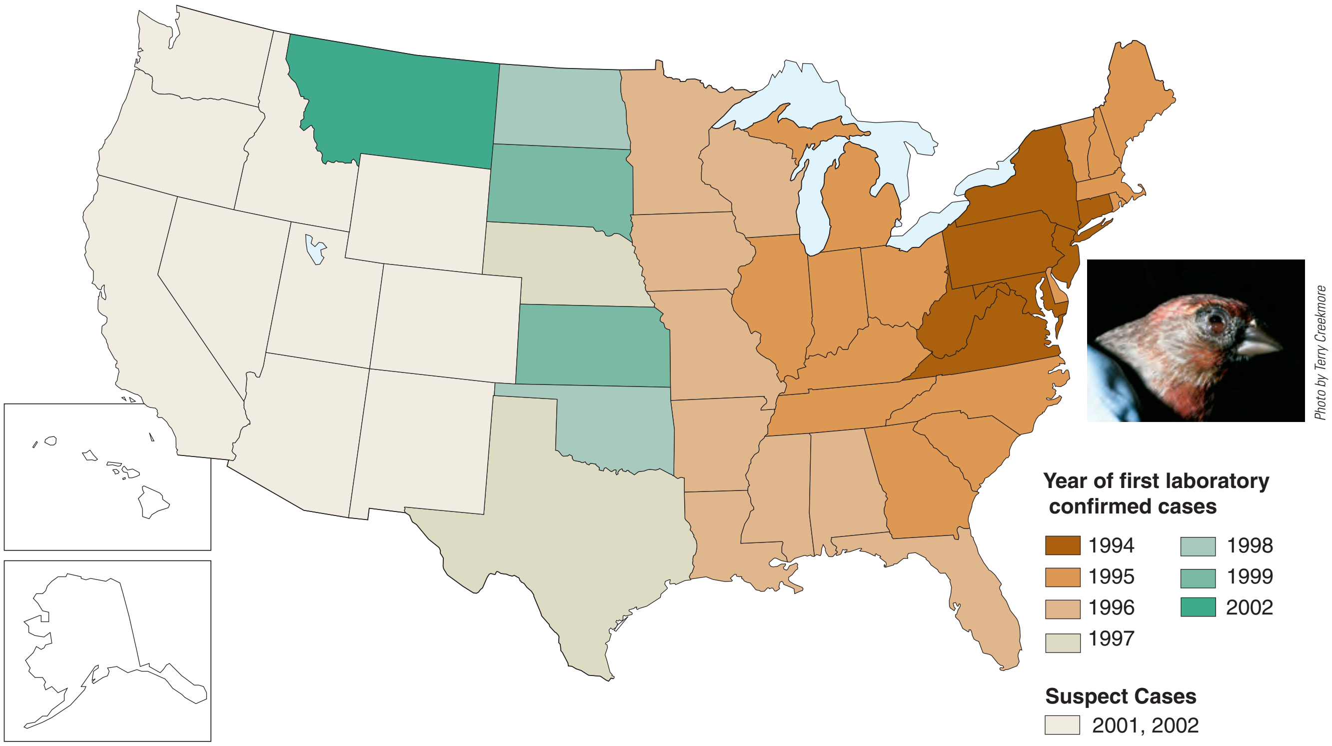


Figure 3.27 The spread of housefinch conjunctivitis within the USA.[71,239,254,255,256]

Figure 3.28 Disease is often a visitor to bird feeders; periodic cleaning of feeder surfaces with a 10-percent solution of household bleach and the use of non-platform type feeders are steps that can help reduce disease occurrence.

In general, regulations implemented for disease control in wildlife result from disease and species specific crisis situations where there are perceptions and concerns about domestic animal and human risks. Current examples are chronic wasting disease of wild cervids[8, 102–104] and the entry of monkeypox into the USA. Monkeypox resulted from human contact with infected wildlife imported by the pet-trade industry. The U.S. Department of Health and Human Services responded by ordering a ban on importing all rodents from Africa and on the interstate sale of Gambian rats, tree squirrels, and four other types of large African rodents.[105] Additional regulations that prohibited transporting and releasing pet prairie dogs were implemented by some state agencies.[106–108]

In implementing regulatory requirements, external pressures come into play. For example, the 1978 appearance of an exotic viral disease of cranes in an endangered species captive-propagation facility within the USA[109] resulted in the U.S. Fish and Wildlife Service requiring that before imported cranes could enter the USA, they had to be tested and found negative for the presence of this virus. Shortly after this requirement was imposed, birds imported from China tested positive. External pressures caused the certification requirement to be suspended (National Wildlife Health Center files). Reinstatement of these testing requirements was achieved at a later time.[110]

State wildlife agencies have successfully implemented some provisions for health assessments of wildlife released on state lands and waters. Momentum for such actions has increased during recent years because of increasing wildlife disease awareness. However, these commendable efforts remain fragmented and are limited in scope. Based on the lessons learned from domestic animal production and the increased disease documentation within captive-propagated wildlife, the potential for disease introduction via the release of captive-propagated wildlife should be addressed before animals are released. A single disease event resulting from the release of infected stock can result in losses that jeopardize the viability of the endangered populations (Box 3–5).

Photo by Milton Friend

Figure 3.29 Surfaces below bird feeders where bird feces and contaminated feed are deposited should periodically be cleaned and disinfected with household bleach.

As for captive propagation and release programs, actions taken to minimize disease risks associated with wildlife translocations also are largely self-imposed by the agency or organization carrying out the translocation. The result is a general lack of operational standards and regulatory oversight to ensure that adequate evaluations are in place and followed. The zeal of those pursuing translocations is generally high and has occasionally resulted in disease considerations being viewed as obstructions by government agencies that need to be pushed aside (e.g., crane example cited above). Fortunately, many of these programs now involve individuals with sensitivity to and awareness of the impacts of disease, and thus, self-imposed requirements often are implemented by those programs to minimize disease risks. For example, translocated animals are reported to have undergone visual health assessments by a veterinarian or biologist who has examined these animals for the presence of external parasites, disease, or injury prior to release 76 percent of the time in one evaluation involving several hundred translocations.[24] External examinations, while useful, are inadequate if not supported by more rigorous procedures including sampling and laboratory analyses (Fig. 3.11). Guidelines and protocols are available and are in development that, if implemented, will greatly reduce the potential for translocated wildlife to introduce diseases.[17, 111–114]

A period of quarantine is a standard need for most animal translocation situations. This provides a period for observation that may disclose the presence of disease that was not apparent at the time of capture. It also allows further testing and completion of laboratory assays and analyses of results that may be needed for health assessments. Quarantine may not be done or may be compromised relative to the conditions for isolation of the animals being held or for the length of time for confinement. The cost of holding animals, human desire to quickly release the animals into the wild, seasonal timing of release, and other factors can influence the type and extent of quarantine, associated health-screening procedures, and whether or not more complete examinations are conducted.

Among the arguments often given by those opposed to quarantine, health inspections, and certifications are: reliable methods are not available to certify animals as being "disease free"; tests developed for disease in domestic animals may result in false positive findings when applied to wildlife; such testing might prevent the release of animals that do not actually pose a threat; stresses imposed on the animal by quarantine are detrimental to their health and to their survival once released; diseases present in the geographic areas where the animals were captured and where they are to be released are similar, thus no new disease risks are involved; project funds are insufficient to cover the costs for these procedures; and the importance of the translocation outweighs any disease risks

Box 3–5 A National Wildlife Health Strategy: A Long Overdue Need

Several facts relative to disease in free-ranging wildlife populations are:

- The toll from disease during recent decades amounts to millions of wildlife.
- Numerous infectious diseases that were previously of minor importance or unknown have emerged as diseases of major concern.
- Wildlife are associated with a wide variety of new, emerging, and reemerging diseases of humans.
- The movement of infectious diseases from wildlife to domestic animals is a significant concern for many livestock and poultry operations.
- Wildlife disease and wildlife diseases transferred to other species are a continual drain on society that cost billions of dollars.

Wildlife disease is a substantial challenge to the well-being of free-ranging wildlife populations, other species, and local and global economies. Because of these costs, preemptive approaches need to replace ambivalence toward disease prevention and lessening disease impacts on free-ranging wildlife.

The open pathways that commonly exist between captive-propagated or maintained wildlife and free-ranging populations, and those between wildlife and other species suggest the need for increased management of disease in both free-ranging and captive wildlife (see Boxes 3.2 and 3.4). Implementing a "National Wildlife Health Strategy" could be of significant value for guiding the conditions for wildlife translocations, releases of wildlife following rehabilitation, and releases of captive-reared wildlife into nature. Standards for health certification and disease reporting are critical components of a meaningful and strategic program for wildlife health.

Captive-Propagated Wildlife

The zoological component of the wildlife conservation community is closely associated with endangered species captive-propagation and release programs. Concerns about disease threats resulted in a 1992 International Conference on Implication of Infectious Disease for Captive Propagation and Reintroduction of Threatened Species. The conference organizers clearly stated the issue by noting:

> "The impetus for this conference was a rising concern among the conservation community that current programs of reintroduction or translocation of captive wildlife may pose a serious risk of introducing infectious diseases into naïve wildlife populations. …Some have suggested that this risk is sufficiently serious to preclude the use of captive animals for release into new or historic habitats."[157]

A broad range of species were considered in the conference deliberations, and the conference presentations clearly illustrated that disease is an issue requiring increased attention. For example, one presenter noted that disease epizootics are well documented in captive reptiles, as they similarly are in birds and mammals, and the potential for introducing new pathogens into wild populations through the release of captive-bred, captive-reared, and captive-held reptiles is a concern.[14] It was also reported that disease concerns were a major factor in the decision not to release captive-bred golden lion tamarins into areas of Brazil where wild populations still exist.[25] Working groups of participants developed action plans for addressing various needs associated with disease prevention and control. In essence, those action plans by the conference organizers and participants provide a "blueprint" for the conservation community-at-large to build upon by applying the knowledge presented in the papers and embracing the guidelines within the reports.[157]

A later publication[158] focused on the efforts of husbandry practices on diseases of wild animals maintained in captivity. This contribution by 31 scientists and practitioners further highlights the problems, challenges, and adjustments needed to reduce the potential for disease emergence and transfer between captive and wild populations. As noted in the preface to that review:

> "Interactions between wild animals and domestic animals and humans occur on a routine basis through sales, actions, public visits.… The papers presented here may assist all those who are or should be endeavoring to enhance the well-being of wild animals."[159]

Free-Ranging Wildlife

The effects of disease on wildlife populations are a common subject of debate. Conservationist Aldo Leopold, considered by many to be the founder of modern wildlife management in North America, noted that the "role of disease in wildlife in conservation has been radically underestimated".[160] Others have expressed similar viewpoints,[161–165] and those viewpoints are supported by the belief of many that disease can greatly suppress population size and population resiliency and result in wildlife extinction.[2,6] Disease emergence has become a formidable challenge for the sustainability of wildlife populations and the conservation of species of many types during recent decades (see Chapter 2). Losses during individual events commonly exceed 5,000 animals and have ranged from as large as 100,000 to more than 1,000,000 animals in some cases.[3, 121]

Disease Prevention

Human and domestic animal health providers stress disease prevention as a primary focus for combating infectious and other diseases. Scientists combating those diseases have long focused attention on the inadequacy of similar disease prevention for wildlife.[166] Developed nations invest heavily in disease prevention for humans and domestic animals because the social and economic costs of not doing so are unacceptable. The costs associated with wildlife losses from disease have reached a level requiring a broader focus on disease prevention to include wildlife. This need extends beyond disease impacts on wildlife to include prevention of disease spread to other species.

Habitat losses and other ecosystem factors have reduced the resiliency of wildlife populations to recover from the increasing losses due to disease. Consequently, substantial erosion of our wildlife heritage is occurring from failure to aggressively approach disease prevention in free-ranging wildlife. A National Wildlife Health Strategy is a commitment to sustain our nation's wealth:

> "The nation's biological resources are the basis of much of our current prosperity and an essential part of the wealth that we will pass on to future generations."[167]

> "We do not inherit the Earth from our Ancestors,…We borrow it from our Children" (Native American proverb).

Photo courtesy of U.S. Fish and Wildlife Service that may be present. These concerns need to be addressed and overcome, if possible, because they may jeopardize the well-being of the free-ranging wildlife populations and other susceptible hosts within the release area when pathogens or disease vectors are a by-product of the wildlife releases onto the landscape.

Infrastructure Needs

The stewardship of free-ranging wildlife populations within North America lies with federal, provincial, tribal, and state wildlife agencies. Therefore, it is important for those agencies to identify and address regulatory needs. Infrastructure development and expanded capabilities for scientific and disease response activities are part of the equation. Scientific and management capabilities should be at sufficient levels to proactively address disease emergence and provide timely, aggressive prevention of and response to diseases that cross organizational jurisdictions of responsibility. Basic, cooperative investments most likely include:

- Methodical surveillance, monitoring, and data analyses to detect changing patterns for major wildlife diseases and provide early detection of disease emergence;
- Structured, interagency, and interdisciplinary disease response capabilities for the containment of epizootics caused by infectious agents;
- Regulatory programs for wildlife health that focus on disease prevention and that authorize aggressive disease controls when needed for response to emerging infectious diseases;
- An appropriate level of scientific inquiry and facilities to address the magnitude and variety of wildlife diseases affecting wildlife; and
- Establishment of a Web-based national wildlife disease reporting notification system that includes:

Accurate and credible reporting of high-risk diseases for free-ranging wildlife populations;

Linkage for zoonotic diseases with national human health disease surveillance reporting systems;

Linkage with national domestic animal disease surveillance and reporting systems for diseases of mutual concern for wildlife and agriculture agencies; and,

Eventual linkage and interfacing with international systems for disease tracking and trends analyses.

The Bottom Line

Investments for wildlife disease are usually the result of a crisis situation and are small-scale and short-term, relative to support for domestic animal and human health. The billions of dollars in economic values associated with wildlife resources need to be built into health equations.[38] As noted by

Figure 3.30 As in human and domestic animal health, a full range of specialists is needed to effectively combat wildlife disease. Some examples of necessary disciplines include: A) Pathology, B) Virology, C) Bacteriology.

Deem et al.,[2] "…it is no longer possible or ethical to justify a "hands-off" approach when confronted with wildlife disease issues in a conservation context"; "…viable conservation initiatives can no longer be designed without addressing the health issues of wildlife." Further, because the majority of zoonoses and many domestic animal diseases have a wildlife connection,[115–123] human health and agricultural interests will benefit substantially from increased disease prevention and control in free-ranging wildlife populations. Many human activities and behaviors collectively constitute The Wildlife Factor and contribute to disease emergence and spread. Wildlife health issues need to be fully incorporated within wildlife conservation to avoid the demise of wildlife populations from disease and the attendant spread of infections to other species.

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Chapter 4

Zoonoses and Travel

"The movement of populations shapes the patterns and distribution of infectious diseases globally." (Wilson)[1]

Photo by Milton Friend

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Bolded words within the text indicate terms that are defined in the Glossary.

Chapter 4

Zoonoses and Travel

The escalating speed of transportation expands the global mobility of society, allows many products and services to be rapidly obtained anywhere in the world, and promotes the explosive growth of tourism (Fig. 4.1). Ecotourism is especially popular. Within a single day's time, people can travel to rural and remote areas where there are unique and often concentrated collections of wildlife. When traveling to these areas, people can be exposed to pathogens not common in their home location.[1–3] Timely and accurate diagnoses of the pathogens involved are often essential to prevent life-threatening stages of disease from developing. Also, travelers who contract infections can serve to initiate epidemics (e.g., SARS) (Fig. 4.2). This chapter focuses on travel as a factor in exposure to zoonoses and other factors potentially confounding diagnoses.

Infections that travelers can obtain while far from home can complicate timely diagnoses. Travelers may also unknowingly bring home exotic pathogens through foods and other products. When local medical practitioners are taking a medical history, they may forget to ask, or the patient may forget to offer information about previous travel or exposures through other unusual means (Box 4–1). Some medical practitioners may have little familiarity with the pathogen involved or little reason to consider that pathogen without the patient offering adequate historical perspective. The medical practitioner may miss the diagnosis because of the similarity in clinical signs and symptoms that are associated with multiple diseases, especially during early stages of illness. Thus, the primary objectives for this chapter are: (1) to raise general awareness of human activities for which exposure to zoonoses may be underappreciated, and (2) to provide guidance for individuals seeking medical assistance that may help with timely and accurate diagnoses.

Exposure to Zoonoses

Because of the different types of exposure that people have with animals, there are many pathways for exposure to zoonoses while traveling. With well-known or understood direct pathways for disease transmission, such as animal bites and rabies, physicians and other health-care providers are likely to recognize specific disease concerns. Other exposure pathways are often less obvious, and neither physician nor patient may recognize or appreciate risk factors or potential exposures associated with human/wildlife/environmental connections (Fig. 4.3). Failure of the traveler to identify and disclose those situations can greatly complicate disease diagnoses when the pathogens involved may not exist in the geographic area where medical assistance is sought. In addition, an increasing number of pathologic agents of animal origin have not historically been human health concerns, yet may be emerging or resurging causes of disease in immunocompromised people. This trend is likely to continue in the world's developed nations where there is a large aging human population and many people are treated for cancers and/or receive organ transplants. In developed and developing nations, infants also may be at risk, due to being immunocompromised or unvaccinated. The AIDS pandemic and tuberculosis are just two diseases involving immunocompromise that have emerged and resurged in recent history.

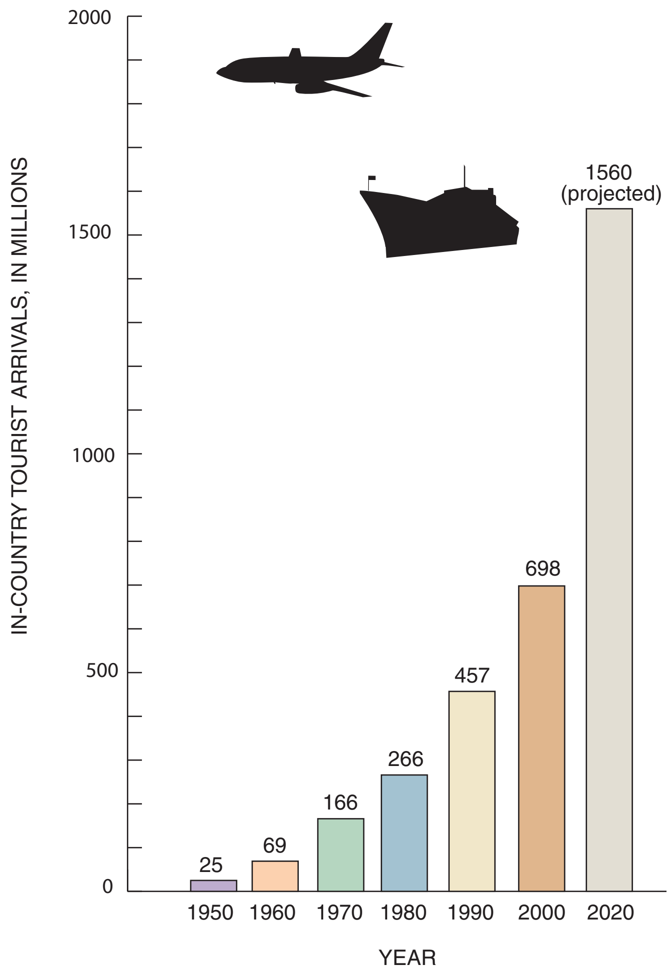
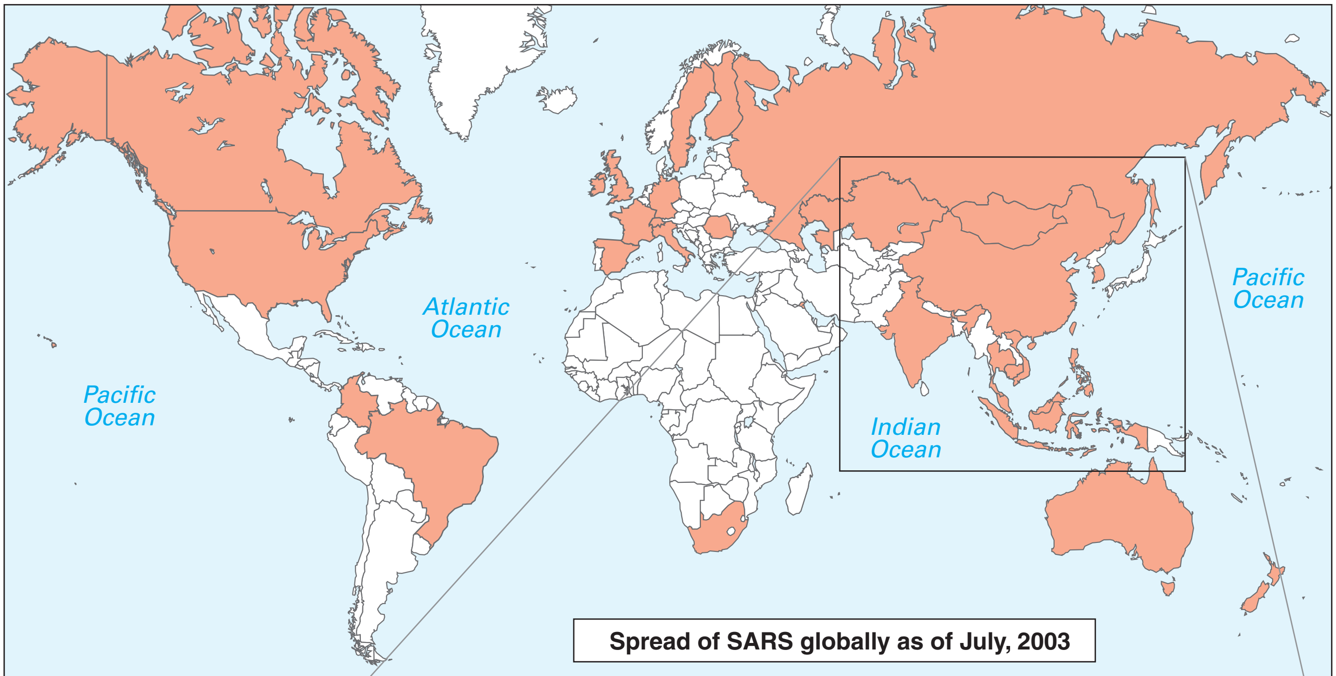


Figure 4.1 Tourism is the fastest growing industry worldwide, and the number of in-country arrivals is projected to double by the year 2020.



EXPLANATION

Countries with SARS cases

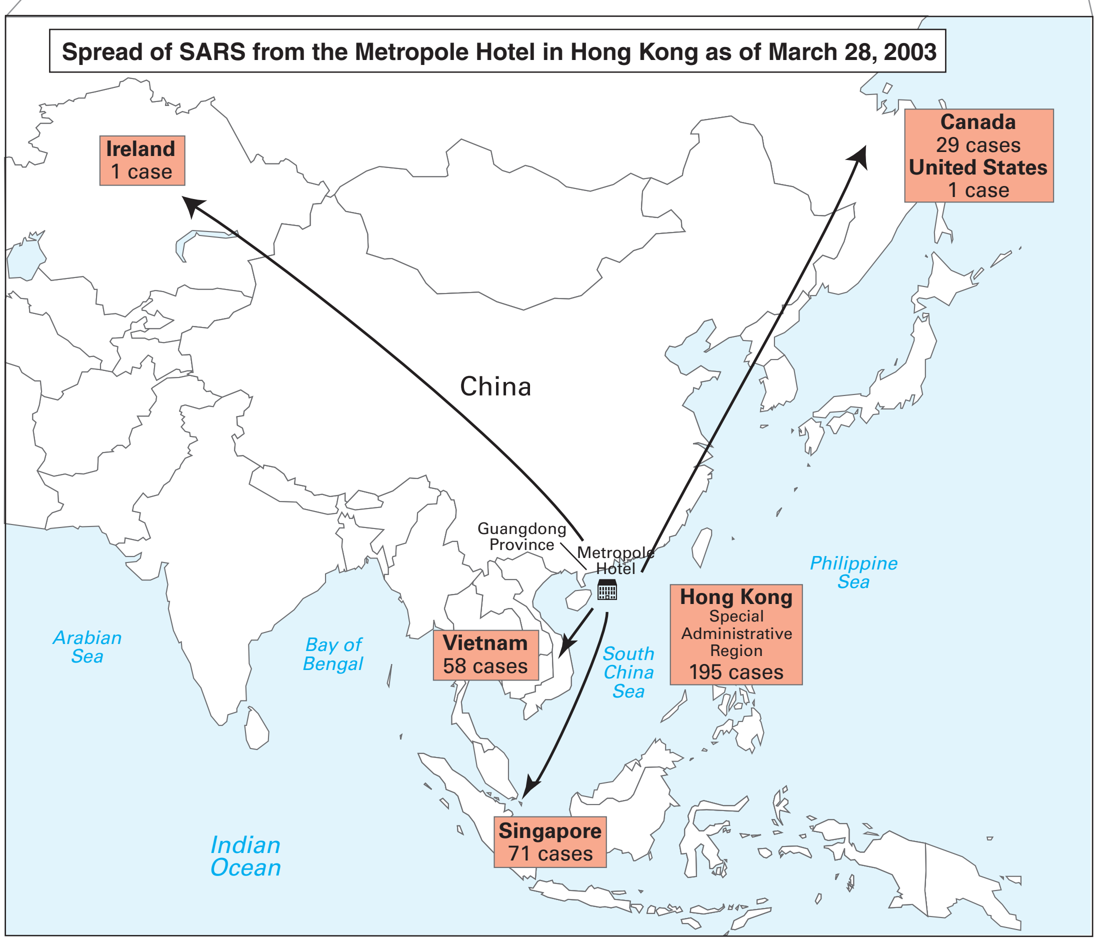
- Canada
- USA
- Columbia
- Brazil

- Finland
- Sweden
- Ireland
- UK
- Spain
- Germany
- France
- Switzerland
- Italy
- Romania

- Russia
- Mongolia
- China
- India
- Kuwait
- South Africa
- Thailand
- Vietnam
- Singapore

- Malaysia
- Indonesia
- South Korea
- Taiwan
- Hong Kong S.A.R.
- Macau S.A.R.
- Philippines
- Australia
- New Zealand

Figure 4.2 Reported global distribution of SARS by July 2003 following the November 2002 eruption of this disease in rural China.[32]



Direct Pathways

From a perspective of disease transmission, exposure to domestic animals and wildlife is potentially of greater significance in remote areas of developing countries than in urban areas of industrialized countries. However, the worldwide occurrence of infectious disease emergence and resurgence during recent decades results in a need for increased vigilance, risk assessment, and prediction of zoonotic diseases. Currently, even direct pathways for disease transmission are greatly underreported. For example, despite concerns such as rabies, it is thought that less than 50 percent of the more than 1 million animal bites in the USA annually are reported.[4] Abrasions from scratches caused by animals probably have an even greater rate of underreporting.

Familiarity with the animal (pet or wild animal), its immunizations, and the severity of the wound from the animal are factors that influence the traveler's decision to seek medical assistance, and thus report the incident. In general, people are more likely to seek treatment for a bite or scratch from a wild animal than from a pet. Furthermore, an increasing body of evidence indicates that rabies is transmitted to humans by insectivorous and vampire bats, but people may be unaware that they have been bitten, especially during sleep.[5]

Although less than 1 percent of animal bite wounds in the USA involve wildlife (captive and free-living), infections caused by a variety of pathogens have resulted[4] (Table 4.1). Some of these, such as **cat** scratch fever, are specifically associated with domestic animals. Although biological transmission of *Bartonella henselae* and several other *Bartonella* spp. typically involve bites by the cat flea, mechanical transmission to humans is associated with cat bites and scratches. In those instances, the cat's teeth and claws have been contaminated by flea feces.[6] In contrast, infections acquired from *Pasteurella multocida* may be acquired from a broad spectrum of animal species and by other means in addition to animal bites.[4]

Most zoonoses are acquired by pathways other than animal bites; bites from ticks, mosquitoes, and fleas are examples. Direct contact with infectious tissues, body fluids, and secretions or excretions is primarily an occupational hazard of animal disease investigators, wildlife rehabilitators, or processors of animals (butchers, etc.). Hunters, trappers, fishermen, biologists, and others that may only have contact with animals that appear healthy, are at lower risk. These individuals may forget or dismiss associations between their handling of wildlife and personal illness, even though sufficient human illness has been documented from animal contact.

The handling of wildlife or "pocket" pets, such as gerbils, hamsters, and guinea pigs, is an additional potential source of contact transmission and/or exposure to pathogens while traveling or at home. Table 4.2 provides a few examples from many documented cases of disease resulting from direct contacts with live animals and animal tissues. Indirect transmission can involve such common situations as contact with contaminated water for aquaria (e.g., Mycobacteria), aerosol transmission of psittacosis (ornithosis) by feather dander, and salmonellosis from human contact with surfaces contaminated by pet reptile and bird feces (see Chapter 2).

Exposure to pathogens through the consumption of game meat and foods is briefly addressed here; see Chapters 2, 3, and 5 for more in-depth discussion of this topic. Moore and others state, "The ease of international travel in the 21st Century has resulted in persons from Europe and other western countries traveling to distant areas of the world and returning with an increasing array of **parasitic infections** rarely seen in more temperate zones." They report on **gnathostomiasis** as an emerging imported disease in the UK, "the rarity of the condition in areas in which the condition is not endemic might lead to diagnoses being overlooked." They also note that the increasing geographic distribution of infections by *Gnathostoma spinigerum* and other parasites, along with the adventurous eating habits of travelers, are likely to result in an increased incidence of this disease.[2]

Indirect Pathways

Humans are exposed to zoonotic pathogens by a variety of indirect pathways, including contact with contaminated environments (Fig. 4.3). These pathways for infection are often associated with wilderness travel or "adventure travel." Included within this category are types of "eco-challenge" and "extreme" multisport athletic and "reality television" events held throughout the world. A recent leptospirosis outbreak among international competitors in Malaysian Borneo had an attack rate of nearly 50 percent, with a hospitalization rate of 36 percent, despite the young age and fitness of these endurance athletes.[3] Other outbreaks of this bacterial disease have occurred in association with white-water rafting in Costa Rica,[7] swimming on Oahu, Hawaii,[8] and among triathletes who swam in lakes in Wisconsin and Illinois, USA.[9] Exposure to the leptospira organisms in all of these events was most likely due to contact with, or inadvertent ingestion of, contaminated waters.

Some consider leptospirosis as the zoonosis with the widest geographical distribution. A wide variety of domestic and wild animals, such as dogs, sea lions, and rats, are reservoirs for infection and can shed these spirochete organisms in their urine (Fig. 4.4); however, leptospira are very sensitive to dry conditions. They require moist soil, standing water, or surface waters to maintain their virulence and persistence outside their animal hosts.[10] Contact with these contaminated substrates has resulted in many human cases of leptospirosis in divers, swimmers, canal workers, and adventure tourists traversing swamps and jungles, in addition to eco-challenge athletes and more traditional means of exposure.[11]

Box 4–1 Working Together to Combat Zoonoses

Travel to exotic places may result in exposure to uncommon pathogens not widely recognized within the medical community. The following information is for health-care providers and patients alike, in order to accurately and rapidly determine diagnosis and treatment.

For health-care professionals: Questions to ask	For travelers/wildlife or animal-care professionals/wildlife hobbyists: Information to provide
When taking a patient's history, include at least the first two questions below in order to address occupational and/or travel-related illness. • Do you have any medical problems which may cause you to be immunocompromised (cancer, chemotherapy, liver disease, transplants, HIV, AIDS, or any medications for rheumatoid arthritis or asthma)? • In the last year, have you traveled to any exotic or unusual locations outside of your home region? If so, what kind of activities did you do there (e.g., kayaking, swimming, fishing, hunting, hiking, visits to farms, zoos, or wilderness areas)? • Have you in the last year suffered from any fever of unknown origin? • Do you work with or come in contact with any terrestrial or aquatic wildlife, invertebrates, or other animals? • Do you spend considerable time outdoors in your regular daily activities? • Do you wear protective clothing when working with animals and/or when working outdoors? • Have you been bitten by any insect or animal, possibly when you were unaware (e.g., have you awakened to find a welt or bite anywhere on your body)? • Have you noticed any type of allergic reaction to anything you have come into contact with in recent history (e.g., plants, pelts, food products, gifts made from animal parts)? • Can you remember if you had any open cuts or wounds while on your travels or while working with animals during the last year? • Do you remember coming in contact with any aerosol from any wildlife, animals (e.g., being sneezed on, collecting samples from a blowhole, inhaling the expiring breath of hunted wildlife)?	Before relaying your symptoms, tell your physician your profession/hobby and that you travel worldwide. Each time you are ill and visit your physician's office, remind them. Inform your physician about: • Any medical problems that may make you immunosuppressed (e.g., cancer, chemotherapy, liver diseases, transplants, HIV, AIDS). • Any foreign travel you have taken in the last year. • Whether you have visited any unusual locations where you may have been near wildlife, alive or dead, or had close contact with any aquatic or terrestrial animals (e.g., farms, zoos, wildlife or conservations areas, or watersports). • The circumstances by which you may have come in contact with any animals, fish, invertebrates, or plants (e.g., did you go hunting, or clamming, etc., did you investigate any invertebrates/plant interactions, did you explore any tidepools). • Any other wild or domestic animal products/samples you may have come in contact with (e.g., cleaning a carcass, collecting blood samples, tracking wildlife, viewing, examining scat). • Any indirect terrestrial and/or aquatic wildlife contact you may have had during your travels (e.g., aerosol inhalation, insect infestations, tents with inadequate mosquito netting, eating of bushmeat, handling of pelts/hides). • Whether you remember having any open wounds, welts, or cuts during your travels or occupational activities.

Table 4.1 Examples of human infections resulting from bites and scratches from wildlife (adapted from Krauss et al.[11] and Weber and Hansen[4]).

Pathogen type	Wildlife species										
	Alligator	Lizards	Snakes	Fish	Birds	Rats/ Mice	Hamsters	Squirrels	Opossum	Seals	Other
BACTERIA (GENUS)[A]											
Acinetobacter	●	○	○	○	○	○	●	○	○	○	
Aeromonas	●	○	○	●	○	○	○	○	●	○	
Bacteroides	●	○	●	○	●	○	○	○	○	○	
Citrobacter	●	○	●	●	○	○	○	○	●	○	
Clostridium	●	○	●	●	●	○	○	○	○	○	
Corynebacterium	●	○	●	○	○	●	○	○	○	●	
Enterobacter	●	○	●	○	○	○	○	○	○	○	
Erysipelothrix	○	○	○	●	○	○	○	○	○	●	
Escherichia	○	○	○	○	○	○	○	○	○	●	Lion, tiger
Francisella	○	○	○	○	○	○	○	●	○	○	Coyote
Fusobacterium	●	○	○	○	○	●	○	○	○	○	
Leptospira	○	○	○	○	○	●	●	○	○	○	
Micrococcus	○	○	●	●	○	○	○	○	○	○	
Pasteurella	●	○	●	○	●	●	○	●	●	○	Carnivores
Proteus	●	○	●	○	○	○	○	○	○	○	
Pseudomonas	●	○	●	●	○	○	○	○	○	○	
Serratia	●	●	○	○	○	○	○	○	○	○	
Spirillum	○	○	○	○	○	●	○	○	○	○	
Staphyloccoccus	○	●	●	●	○	○	○	●	●	○	
Streptococcus	○	○	●	○	●	●	○	●	●	○	
Vibrio	○	○	○	●	○	○	○	●	○	○	
FUNGI (GENUS)											
Aspergillus	●	○	○	○	●	○	○	○	○	○	
VIRAL DISEASE[B]											
Rabies	○	○	○	○	○	○	○	○	○	○	Bats, canids, skunks, others
Lymphocytic choriomeningitis (LCM)	○	○	○	○	○	●	●	○	○	○	
Herpes Type B	○	○	○	○	○	○	○	○	○	○	Monkeys
Monkeypox	○	○	○	○	○	○	○	○	○	○	Monkeys, prairie dogs

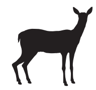
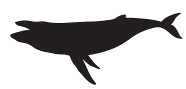
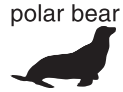
[a] For species and a more complete tally see Krauss et al.[11]

[b] Examples only, other viruses have been transmitted by animal bites.

● Human infections documented

○ Human infections not reported

Table 4.2 Examples of human infections acquired from handling wildlife (non-bite or scratch exposures)[a].

Disease	Agent type	Wildlife involved	Comments
Streptothricosis *Dermatophilus congolensis*	Fungus	White-tailed deer 	Biologist examining hunter-killed deer developed infection on his hands. First documentation of transmission from wildlife.[19]
Ornithosis *Chlamydia psittaci*	Bacteria	Waterbirds 	Wildlife disease investigators conducting field investigations involving other diseases contracted life-threatening illness. Snow geese and/or sandhill cranes were thought to be the probable sources for infection.[20]
Erysipelothrix *Erysipelothrix rhusiopathiae*	Bacteria	Marine animals 	Handlers of marine mammals have become infected during standing and other rescue and rehabilitation activities.[21] Following the field necropsy of a marine bird found dead along an east coast beach (USA), an author (M. Friend) became infected.
Salmonellosis *Salmonella* spp.	Bacteria	Iguanas, turtles 	Pet turtles have been a major source of salmonellosis in North America and elsewhere. The increased popularity of the green iguana and other lizards as pets has contributed numerous human cases of salmonellosis in North America, including the appearance of novel strains of this bacteria.[22–24]
Melioidosis *Burkholderia (Pseudomonas) pseudomallei*	Bacteria	Marine mammals 	A veterinarian working at an aquarium in China contracted melioidosis while unknowingly inhaling a whale's expiration during blowhole sampling. The causative agent has also been documented to be present in air during Hong Kong monsoons.[25]
Monkeypox Orthopoxvirus	Virus	Prairie dogs 	Handling of prairie dogs purchased in the pet trade that became infected from imported rodents initially housed with them resulted in the first presence of this disease in North America. Numerous human cases have occurred in several states within the USA.[26]
AIDS Human immunodeficiency viruses (HIV-1, HIV-2)	Virus	Primates 	The harvest of primates and processing of meat from those animals is believed to be the origin of the viruses that crossed over and adapted to humans who then served to spread these human immunodeficiency viruses (HIV-1 and HIV-2) globally.[27–30]
"Seal finger" *Mycoplasma* spp.	Bacteria	Whales, seals, polar bear 	Long-standing occupational disease of those involved with the commercial harvesting of seals and whales; also prevalent among Canadian Inuit and among seal trainers (see Box 2–9).

[a] These few examples are from a long list of diseases and circumstances that could be cited. Animal handlers must use protection when handling wildlife and have a general understanding of the disease risks involved.

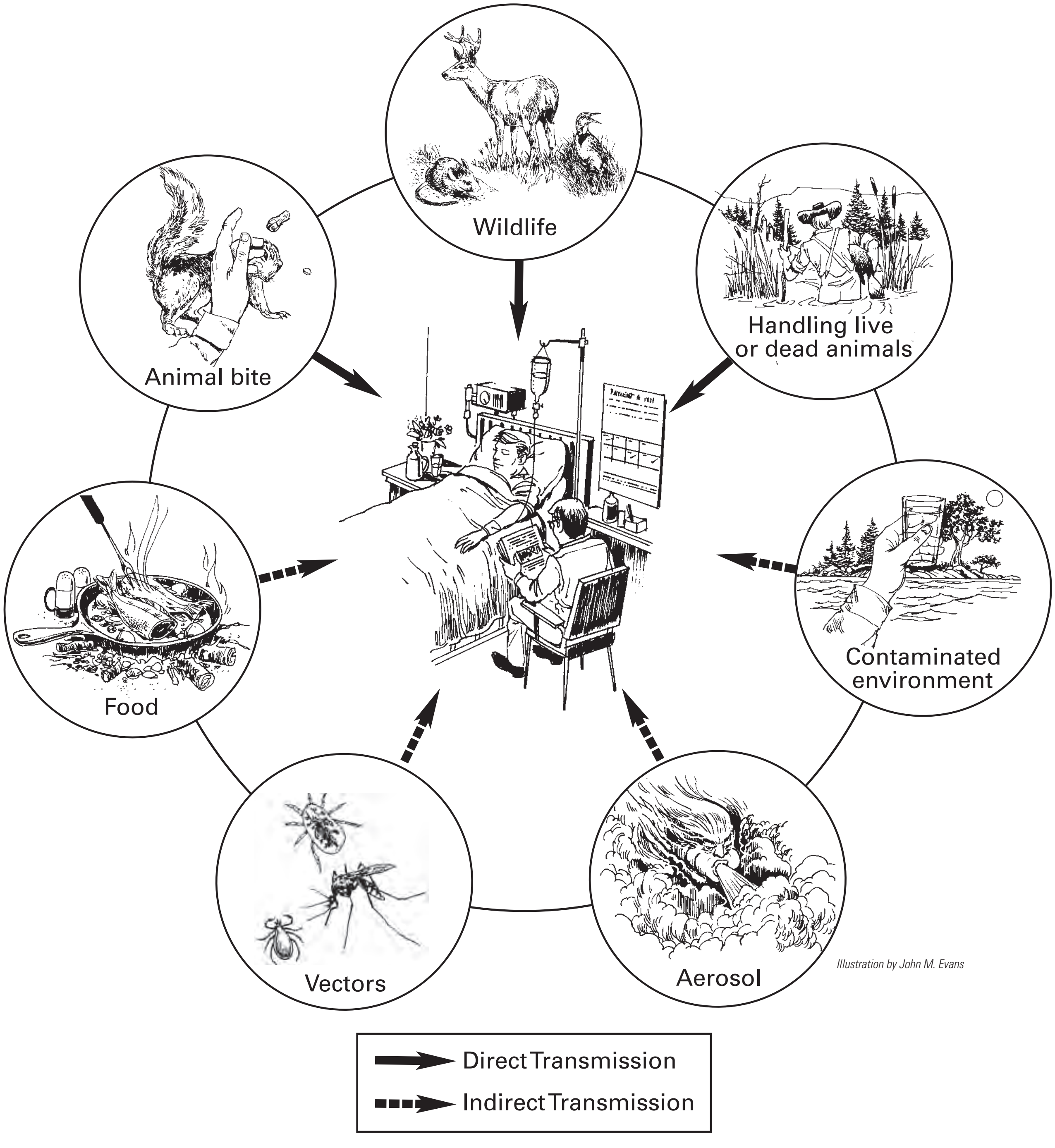
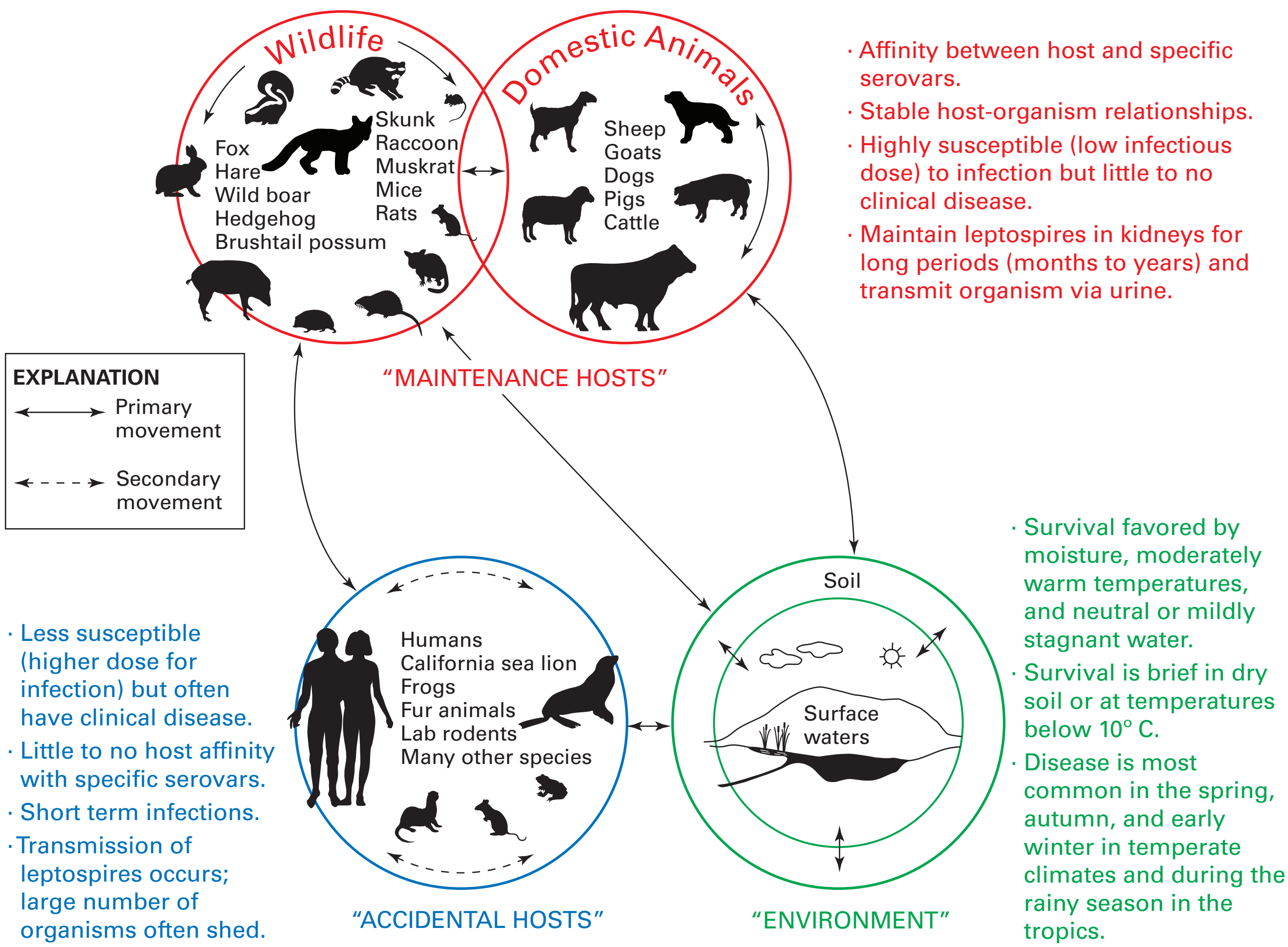


Figure 4.3 Common routes for potential transmission of infectious diseases between animals and humans and vice versa.

LEPTOSPIROSIS

- Acute, systemic, bacterial infection caused by approximately 200 serovars (variants) of *Leptospira interogans*.
- Worldwide distribution; zoonoses with the widest geographical distribution.
- Humans, domestic animals, California sea lion among species commonly affected.



- Dynamic epidemiology with constant shifts in host-agent relations altering relative importance of available hosts.
- Shifts of the most important host for human cases between domestic animals (e.g., cattle, dogs) and various rodents is common.
- Humans are always accidental hosts, thus are not important for maintenance of infection.
- Human infection primarily occurs through wet or abraded skin, ingestion, and through the mucous membranes of the mouth, conjunctive, or genital tract.
- Among those at greatest risk are agriculture workers, veterinarians, dog breeders, abattoir workers, butchers, people handling raw meat, cooks, dog owners, hunters, animal trappers, sewage workers, rural dwellers, wildlife biologists, farmers, wildlife rehabilitators, zookeepers, ecotourists, and eco-challenge athletes.

Figure. 4.4 Leptospirosis: a worldwide disease of many species and bacterial variants.

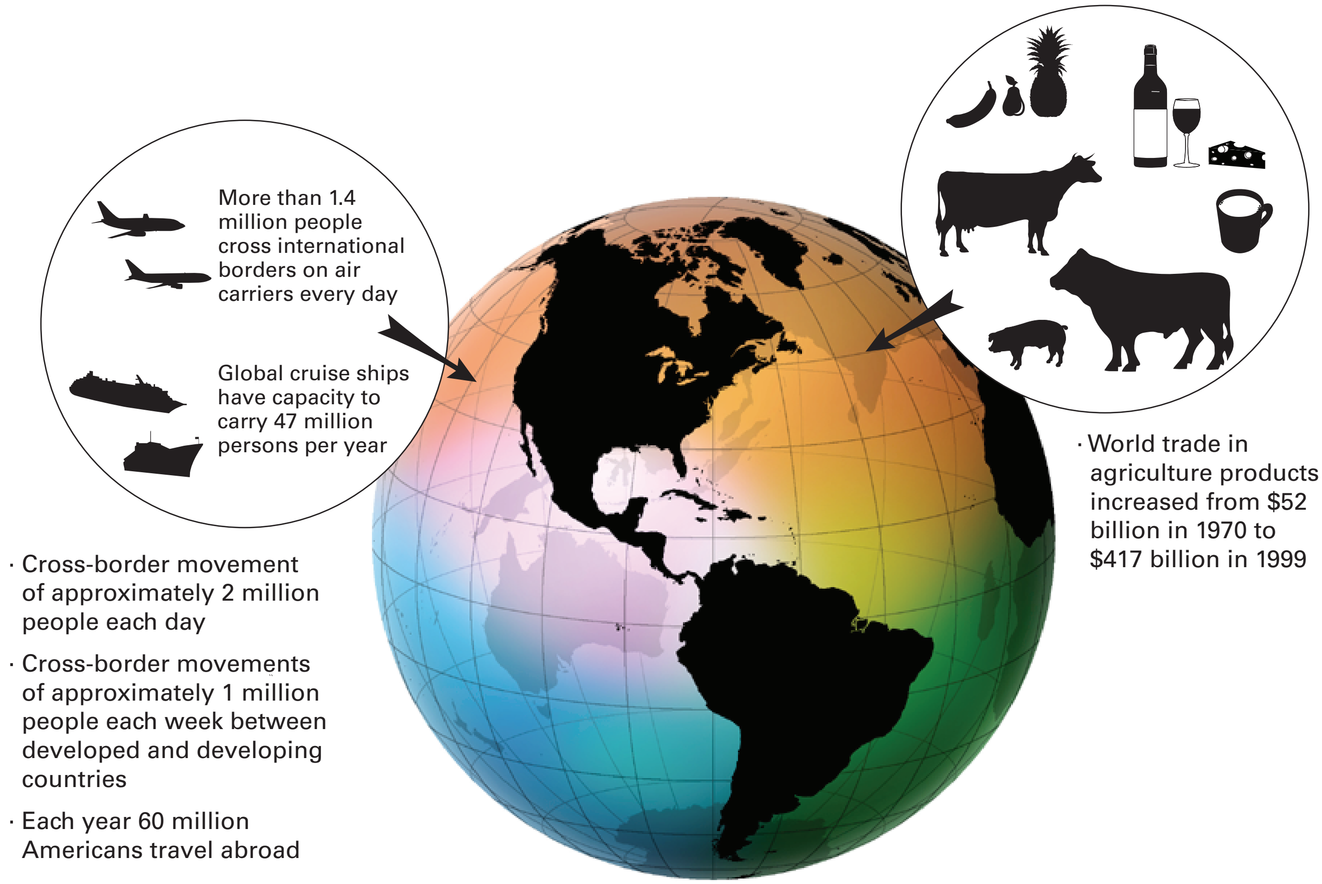


Figure 4.5 Tourism and commerce: cornerstones for "A World of Movement."

Leptospirosis is but one example of the changing pattern for some established zoonotic diseases due to changes in human activities and mobility. Other zoonoses also are becoming reestablished and novel zoonoses are appearing. Clearly, the task of protecting humans from these diseases is becoming more complex than it was historically. The human patient and the medical community each have important roles to play and contributions to make in this arena. Only by addressing and diagnosing zoonotic diseases in patients who are exposed while in unique situations or surroundings will we be able to prevent, control, or suppress the expansion and establishment of such diseases.

Travel, Zoonotic, and Other Infectious Diseases

About 60 million Americans travel abroad each year.[3] Around the world, more than 1.4 million persons cross international borders on air carriers everyday.[1] In 2000, the total numbers of international arrivals worldwide reached nearly 700 million, and the World Tourism Organization estimates that number to increase to more than 1.5 billion by 2020 (Fig. 4.1).[12] In addition to airline travel, cruise ships can carry 47 million passengers per year[1] (Fig. 4.5). This global mobility of humans leads to the potential contracting and spreading of infectious diseases, the rapid change in disease distribution patterns,[13] and requires us to consider infectious diseases of humans from a global perspective.[14]

The situation of the human traveler and emerging or resurging zoonotic disease is somewhat analogous to the "canary in the coal mine." The canary is a sensitive indicator and an in situ monitor for air quality required to sustain human life. The health status of human travelers has become an index for emerging infections. However, unlike the caged canary in the mine, the traveler serves as sentinel, courier, and transmitter for emerging diseases.[1] This salient human effect extends beyond the health of any individual and far beyond the geographic location where clinical disease may be observed in that individual. "The traveler can be seen as an interactive biological unit who picks up, processes, carries and drops off microbial genetic material. A traveler can introduce potential pathogens in the absence of signs or symptoms."[1] These concepts apply to all infectious agents (e.g., diseases caused by parasites, microbial agents, and possibly, even prions), not just those that are also zoonoses. Thus, global commerce, human travel, emigration, and

Table 4.3 Some information sources addressing travel medicine.

Source	Type	Program	Comments
National Center for Infectious Diseases (CDC)	Web site	Travelers' Health	Provides health information on specific destinations, notices of disease outbreaks, and a variety of other relevant information. Links expand coverage and information for specific topics. Visit http://www.cdc.gov/travel/
National Center for Infectious Diseases	Web site	Travelers' Health	Information on travel-related diseases with links to specific topics. Visit http://www.cdc.gov/travel/diseases.htm
World Health Organization	Web site	International Travel and Health	A compendium of information that can be accessed by country and disease. The focus is on health risks likely to be encountered at specific destinations relative to different types of travel from business to backpacking and adventure tours. Visit http://www.who.int/ith/
Travel Health Care	Web site	Travel Health Information	General information about staying healthy when traveling, diseases of that region, and general travel advice. Visit http://www.travelhealth.com.au/Travel_Health/Travel_Information.html
Wilderness Medical Society	Web site	Wilderness medical issues	Educational programs and publications addressing medical problems encountered in wilderness situations. Membership organization focused on health professionals. Visit http://www.wms.org/
International Society of Travel Medicine	Disease surveillance	Geo Sentinel	Global surveillance network of 26 travel and tropical medicine clinics in the USA, UK, Australia, Canada, Germany, Israel, Italy, Nepal, New Zealand, and Switzerland. Geo Sentinel network members are International Society of Travel Medicine provider clinics that serve as a rapid notification system for significant diagnoses of unusual disease events. Visit http://www.istm.org/
Other	Web site	Traveler's health care	A variety of subscriber programs can be found on the Internet for obtaining pre-travel information, arranging for immunizations, obtaining medical services in various countries, and ordering publications.
"Atlas of Travel Medicine and Health[31]	Book	BC Decker, Hamilton, Ontario, Canada	Basic information for pre-travel planning. Addresses general risks and precautions; descriptions and maps of specific diseases; county specific information for important disease and popular destinations.
"Traveller's Health: How to Stay Healthy Abroad," 4th edition[18]	Book	Oxford University Press, United Kingdon	Comprehensive book (75 chapters) written by subject matter experts. Intended for all audiences from general public to health professionals.
Centers for Disease Control and Prevention	Book	The Yellow Book "Health Information for International Travel." 2003–2004	Published every 2 years by CDC as a reference for those who advise international travelers on health risks; available for purchase: http://bookstore.phf.org/cat24.htm. On-line edition is periodically updated: http://www.cdc.gov/travel/yb/index.htm
Other	Books, journals	Traveler's health, emerging diseases, updates of disease status	A variety of books and scientific journals developed to provide information for professionals in the health field are available for purchase and subscription. Other publications are intended for general audiences. When considering purchase or subscription, take into account the dynamic nature of disease occurrence and scientific knowledge. Information should be as current as possible and developed by authoritative sources.
Personal health care provider	Contact visit	Health care	Many physicians have access to online programs where they can obtain specific information for you relative to your travel.

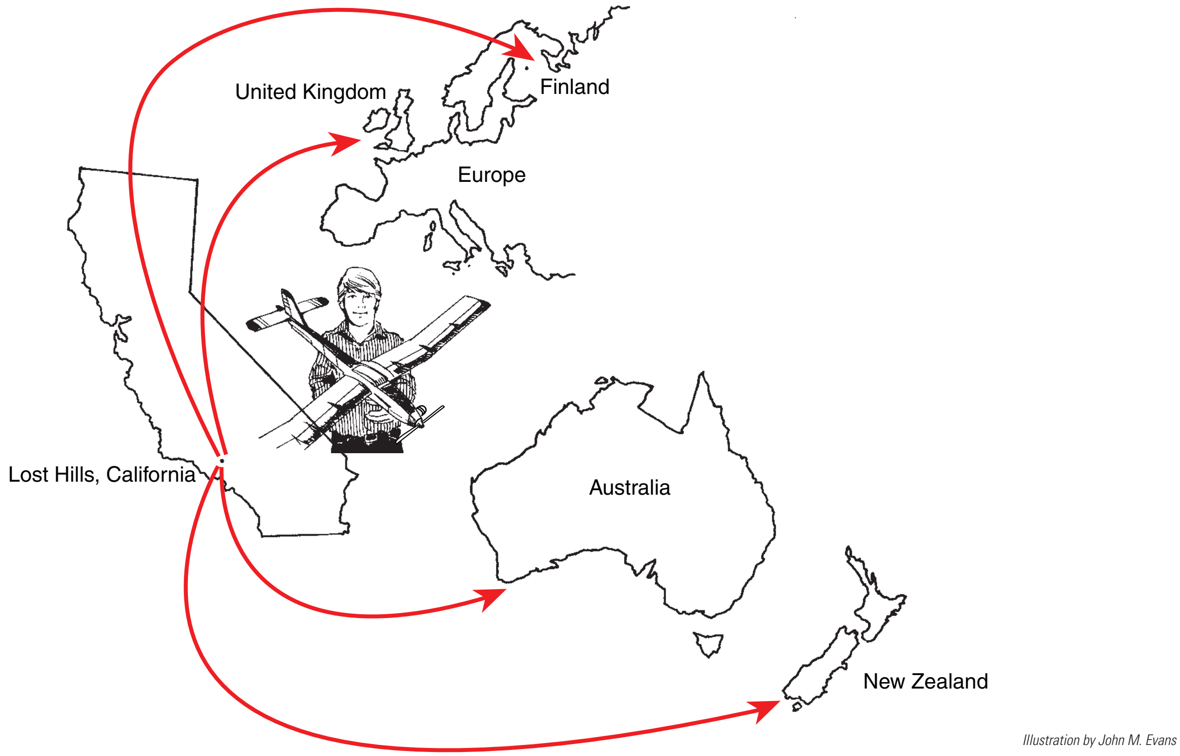


Figure 4.6 International cases of coccidioidomycosis acquired during a World Championship Model Airplane Flying competition.[36]

immigration are major factors in the global dispersal of infectious diseases.[15]

Increases in travel-associated fungal infections have resulted in histoplasmosis and coccidioidomycosis recently being included as travel-related illnesses in the CDC's Yellow Book "Health Information for International Travel, 2003–2004" (http://www.cdc.gov/travel/yb/index.htm). Fungal infections are a cause of disease for visitors to the USA, as well as for travelers from the USA (Fig. 4.6). Mycotic infections of travelers who reside in places far from endemic areas for mycoses are presenting increasing diagnostic challenges for health-care providers, especially for diseases such as paracoccidioidomycosis (*Paracoccidioides brasiliensis*), for which symptomatic disease may not develop for years after a person resided in an endemic area.[16]

Travel and wilderness medicine are now specialties in their own right, with pre-travel counseling that minimizes risks and improves protection from disease, post-travel recognition of diseases that travelers may encounter,[13] and accurate and timely diagnoses and notifications of disease events.[17,18] Various publications, Web sites, and other information sources provide detailed information on disease risks, prevention, control, and treatment useful for travelers and health-care providers alike (Table 4.3). Each year, efforts in these medical specialty areas expand, the public demands updated information, and medical professionals must provide adequate explanations to patients on how to avoid risks relative to infectious disease. Only through such efforts will we be able to minimize the impacts of zoonotic diseases on individuals and the potential spread of zoonoses to new locales. Such efforts will, in the long term, improve human health, decrease impacts on domestic and wild animal populations, and reduce economic hardships to local and regional economies where outbreaks could occur. Disease prevention, control, and early intervention are important factors for sustaining the health and well-being of all living creatures (Box 4–1).

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Chapter 5

Is This Safe to Eat?

"A crust eaten in peace is better than a banquet attended by anxiety." (Aesop, 6th century B.C.)

"There is no love sincerer than the love of food." (George Bernard Shaw)

Photo by Milton Friend

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Chapter 5

Is This Safe to Eat?

The harvest and consumption of wildlife is as old as humankind and often has sustained human exploration into unsettled areas. Wildlife still remain a primary foodbase for many native peoples throughout the world. From shellfish to bear, humans today continue to hunt, fish, and otherwise harvest wildlife for recreation, social and cultural needs, dietary supplementation, subsistence, and other purposes that result in the consumption of game meat (Fig. 5.1).

Over time, experience has taught people what food is safe to eat and how it should be prepared. This is especially true for those who subsist upon wildlife. Fortunately, the meat from wildlife generally is safe to eat when properly harvested and prepared; however, many people infrequently consume wildlife and are less experienced than subsistence users of wildlife in making judgments about what is safe to eat, how to handle the meat between the times of harvest and preparation, and how the meat should be prepared (Table 5.1). Disease emergence and resurgence has added a dimension that also must be considered for wildlife (e.g., chronic wasting disease in deer and elk) and domestic foods alike (see Chapters 2 and 3).

This chapter provides guidance for sporadic consumers of wildlife because, unlike farmed food animals (domestic and captive-reared wildlife species) or commercially harvested finfish and shellfish, the meat from free-living wildlife in the USA and many other countries is not regulated and inspected by government authorities. The safe consumption of game harvested by the public in these situations depends entirely on the actions and discretion of those harvesting and preparing these food items. These individuals commonly encounter conditions in wildlife carcasses that cause them to ask the question "Is This Safe to Eat?" (Fig. 5.2) and in some situations to unnecessarily discard edible meat.

Recreational harvest of wildlife and **ecotourism** (see Chapters 2 and 3) are two situations where knowledge about the wholesomeness of wildlife food items is beneficial. Relevant insights can be gained from the Internet, publications such as this one, and agency health advisories associated with wild game. Recommendations and guidelines developed by health specialists should be heeded. Most importantly, when in doubt about the safety of the meat, "play it safe" and dispose of the meat in a responsible manner, rather than consume it.

Do not feed "tainted" meat to **companion** or farm animals because that could jeopardize their health and result in those animals becoming diseased and infecting others. Unfortunately, no matter how much we know about the meat being considered for consumption, there always will be some degree of risk. Some hazards can be invisible and thus, at times, impossible to avoid (e.g., eggs and salmonellosis, hamburger and *Escherichia coli*).

General Guidelines

"What you don't know can hurt you" (Anonymous)

"Knowledge is the antidote to fear…" (Ralph Waldo Emerson)

The following general guidelines regarding the harvest and preparation of wild game meat apply to all species and geographic areas despite this chapter's focus on North American vertebrates. Invertebrates, like shellfish, are important food items in many parts of the world and also are subject to a wide array of diseases (see Chapter 2). These species are **filter feeders** and, in underdeveloped countries, they are found in water often contaminated by human waste. Also, worldwide, harmful algal blooms that produce toxins hazardous to humans can contaminate their habitat. Therefore, shellfish harvesters need to be well-informed about environmental conditions where they are harvesting shellfish. Hepatitis and various forms of shellfish poisoning can result from ill-informed choices involving the harvest and consumption of clams, oysters, and other species.

Learn About the Local Area

Individuals harvesting wildlife should be well informed about wildlife disease activity and concerns in the local area where harvest is being pursued. This holds true for the patch of woods in the "back forty," as well as for a safari in Africa. For example, appropriate inquiry could inform a novice hunter in Arkansas that the bacterial disease tularemia is present in that state. The hunter could then take appropriate precautions when handling wild rabbits or rodent species and also avoid exposure to ticks and other potential vectors of tularemia. Fishermen who check local water conditions often can obtain information about contaminant levels and health advisories about the safe amount of fish to be eaten from that area.

Know Whom to Contact

Wildlife consumers can contact local public health authorities and the local fish and game agencies to pursue questions or concerns about the health status of wildlife.

Learn Proper Handling and Preparation

Quality care of carcasses in the field and proper technique for removing internal organs and other viscera are important for maintaining the quality of the meat to be consumed. Learn these techniques from an experienced person when possible. Wildlife extension and hunter education specialists within universities and state wildlife agencies often are good sources for information on how to handle wild game in the field and prepare it for the table.[1] Various extension bulletins, pamphlets, and other publications addressing these matters are available. For example, *A Bibliography of Cooperative Extension Service Literature on Wildlife, Fish, and Forest Resources* is a comprehensive list of relevant publications from all over the USA.[2] Another good source for finding wildlife related resources is http://www.uwex.edu/ces/wlb. Guidance also can be obtained from sportsman-related manuals and video tapes.

Consider how much time will lapse between actual harvest of the animal, cleaning, and proper storage prior to transport to the site where it will be prepared for food. Field and weather conditions are important aspects of this evaluation, as decomposition increases with temperature. Also, blowing dust, **flies**, and other field conditions may require protective bags and other containers to protect the carcass. Ambient temperatures may also require refrigeration or other means for cooling carcasses to prevent spoilage.

Figure 5.1 Game meat serves the food, cultural, and social needs for a wide variety of peoples.

Internal organs and intestines from large mammals, such as deer, should be completely removed immediately after harvesting the animal. In warm climates, it is advisable to "field dress" large game birds and medium-sized animals as well. Care should be taken not to rupture the stomach, intestines, or other internal organs. Thoroughly clean the inside of the carcass if wounds associated with the animal's harvest or removal of viscera have resulted in their rupture and soiling of the body cavity. Cut away and discard hemorrhaged tissue from wounds as these tissues may contain lead and other bullet and shot fragments.

Wear disposable gloves to prevent skin contact with viscera and blood from animal carcasses when field dressing and preparing carcasses for consumption (Fig. 5.3). Abrasions on the preparer's skin allow bacteria and other pathogens present in the carcass to cause infection, if skin protection is inadequate. Preventing skin contact with the carcass by outer clothing also can serve as a barrier from ticks and other ectoparasites.

When cleaning wild game, dispose of unwanted parts responsibly to avoid endangering local domestic and wild animals. For example, discarding the viscera from cottontail rabbits in a manner that allows dogs or other **carnivores** to feed on that material facilitates the life cycle of a common tapeworm (Fig. 5.4). Similarly, fish-cleaning stations are commonly provided at some boat launching areas for the disposal of unwanted fish parts.

Various techniques are used to preserve and prepare game meat for consumption. Basic understanding of the proper application of techniques is important for avoiding health problems (Table 5.2). For example, smoking meat is a popular way to prepare fish and game, although, if done

Table 5.1. Characteristics of game-meat consumers in the USA and sources for that meat.

Consumer type	Typical role of game meat in diet	Primary source of meat	Primary harvest of meat	Primary origin of meat	Comments
Subsistence	Primary source of animal protein	Wild	Personal	Local to regional	Individuals (primarily native peoples and those living in remote areas) are usually knowledgeable about harvesting, processing, and food preparation; practical knowledge of species being harvested and the appearance of normal body conditions.
Supplemental	Frequent and important source of animal protein	Wild	Personal	Local to regional	Same as subsistence and includes larger percentage of general public in locations such as Alaska where there is an abundance of wildlife and relatively few people.
Recreational	Occasional source of animal protein	Wild	Personal	Local to interna-tional	Many individuals infrequently harvest wild-life and may have little knowledge of their diseases. Levels of knowledge vary and range from high to low.
Novelty	Infrequent novelty food	Wild	Other	Local to interna-tional	Meat typically provided by friend who har-vests wildlife; consumer with very limited information relative to harvest conditions and care of meat.
Cultural	Important component to satisfy food needs	Wild/ com-mercial	Other	Local to interna-tional	Meat, organs, powders, and other consum-ables from wildlife for medicinal, spiritual, sexual, and other purposes. Primary native peoples; minority of general public.
Gourmet	Low frequency specialty cultural mores	Commercial	Other	Local to interna-tional	Generally government inspected foods from farmed, ranched, and sometimes wild stocks of animals.
General public	Commercial products	Commercial	Other	Local to interna-tional	Government inspected foods; finfish and shellfish primary species involved. Product may be from captive or wild stocks depending on species.

improperly, can result in serious consequences. Improper smoking of fish, commercial and individual, from the Great Lakes (North America) has resulted in human fatalities caused by type E botulinum toxin.[3–6] The temperature during the smoking was not high enough for a long enough period of time to inactivate *Clostridium botulinum* toxin. Regulations for commercial smoking of fish within the USA have been adjusted to provide safer products from this process. Home smoking is controlled by the individual.

Photos by Milton Friend

Figure 5.2 Questions about the safety of game meat may arise after animals have been harvested and possible abnormalities are seen, or because disease events in the region cause higher awareness.

Photo by James Runningen

Figure 5.3 The use of disposable or reusable impermeable gloves affords a great deal of protection at little expense and inconvenience when processing wildlife carcasses in the field and when handling the meat and tissues from these animals prior to their being prepared as food.

Other general precautions with hunted game include considerations involving bullet fragments and shotshell pellets present in tissues of harvested animals. Lead shot used for bird hunting has been the cause for cases of appendicitis in people who have ingested this shot along with the meat.[7] This shot has a tendency to lodge in the appendix and cause a rupture; it is not a cause for lead poisoning in people. However, shot and bullet fragments can be embedded in meat and can cause chipped and broken teeth if bitten into. Finally, it is unwise to consume animals found dead if the cause of death is unknown. An experienced person may be able to evaluate a "freshly dead" carcass and determine the cause of death, thereby salvaging the meat for consumption when appropriate. However, seldom is such action warranted.

General Risk Assessment

Below are three recommendations for hunters to evaluate the health of their quarry:

1) Before the animal actually is killed, its behavior and general appearance should be noted. Sick and, of course, dead animals should not be harvested for food consumption. However, a decision should be made at the time as to whether problematic animals should be left alone or collected for evaluation purposes. Circumstances will dictate what should be done, and it is important not to violate any regulations regarding taking and possessing wildlife. Whenever apparent disease conditions are encountered, local wildlife authorities (e.g., wildlife agencies) should be notified.

2) At the time of harvest, thoroughly inspect the outside of the carcass.

   External Exam:

   - Do the haircoat, feathers, or other body coverings look healthy? (Fig. 5.5A, B)
   - Is the animal in good body condition or is it very thin or emaciated? (Fig. 5.5C, D)
   - Are abnormal conditions present, such as growths, deformities, or injuries? (Fig. 5.5E–K)
   - Are there other signs of illness, such as evidence of diarrhea (abnormal looking or soft stool adhered to the vent area)? (Fig. 5.5L, M)

   When conducting external examinations, it is important to recognize that infectious disease is not the only cause for unfit appearance of an animal. Old age, malnutrition, mechanical injury,

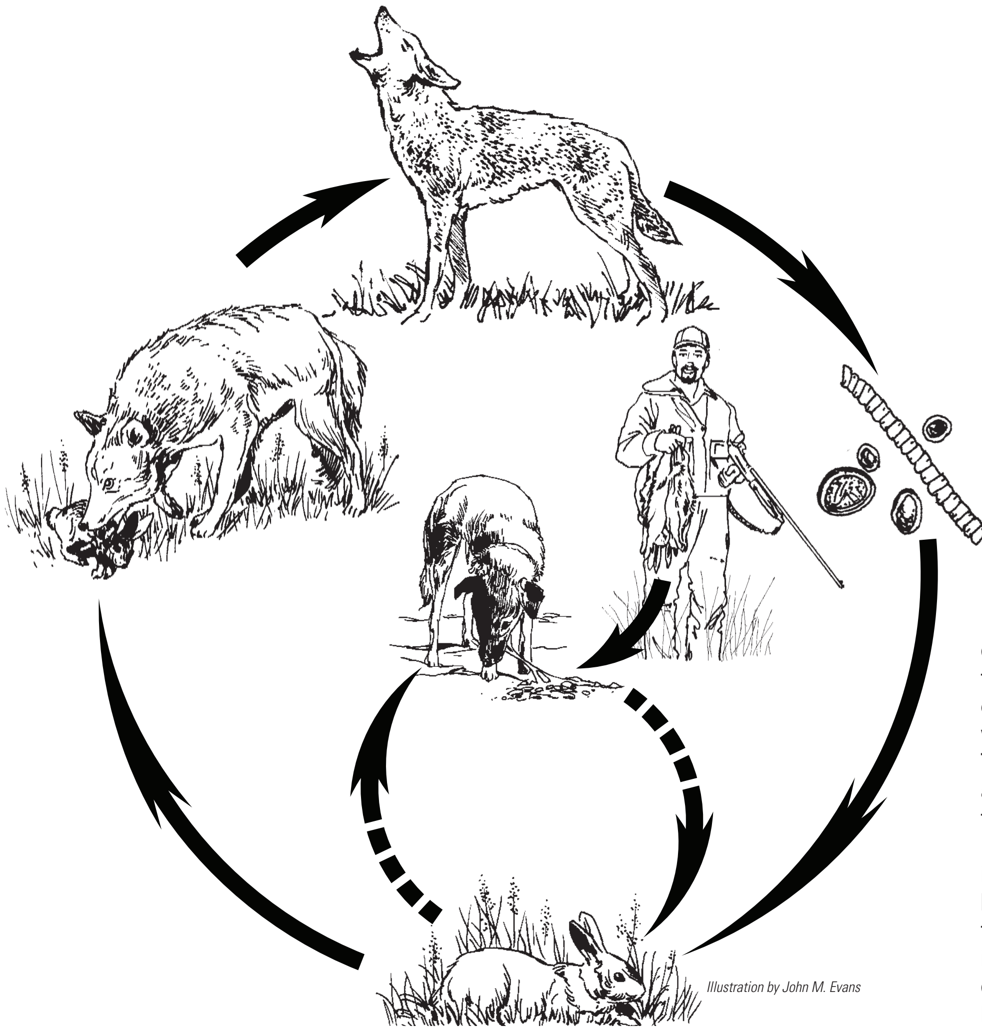


Figure 5.4 Infective eggs of the dog tapeworm are shed in the feces of carnivores, such as coyotes, and are ingested by rabbits while feeding along the ground. The eggs hatch within the rabbit and the resulting larvae migrate to various tissues within the rabbit's body. Carnivores become infected when they consume rabbits containing these larvae (cysticerci). Dogs commonly become infected by feeding on improperly discarded remains from rabbits harvested by hunters.

and physical defects that inhibit food gathering and eating are among other factors that can lead to this type of appearance. For example, fish with **lamprey** scars may be thin because of the lamprey's effects on the fish (Fig. 5.6).

Tumors on some fish (Fig. 5.7) have been associated with environmental contaminants;[8,9] if tumors are found, check whether fish consumption advisories have been issued for the respective area. Consider observations made during the external examination, along with those from the internal examination, in deciding about the suitability of the meat for consumption. Carcasses that appear to be grossly diseased should not be opened for internal examination.

3) After harvest, and following the external exam, the inside of the carcass should be inspected when the animal is field dressed or otherwise processed.

Internal Exam:

- How does the carcass smell?
- Do any of the tissues or organs appear irregular or abnormal in shape or color? (Fig. 5.8A–F)
- Do any of the tissues or organs appear to contain abscesses? (Fig. 5.8G)
- Are there any tissues or organs that contain what appear to be parasites? (Fig. 5.8H–J)

Use all of your senses when examining a carcass. Bad odors generally arise from rotting tissues, perhaps from an old injury that has abscessed. However, the spillage of intestinal tract content into the body cavity during removal or from rupture during harvest may also be the source for such odor. The food source of the animal may also result in strong odors that are not an indication of disease. Cedar, sagebrush, and bivalves (mussels) are examples of foods consumed by

Photo A, U.S. Fish and Wildlife Service; B, Nick Drahos, NYDEC; C, Milton Friend

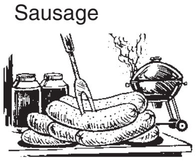
Photo D, James Runningen; E, Milton Friend; F and G, James Runningen

Photos H, I, and J, Milton Friend

Photo K, USGS National Wildlife Health Center; L and M, Milton Friend

Figure 5.5 Aberrations in hair/feather coat, emaciated body condition, deformities, "sores", and soiling of the vent area are common external indications that an animal may be afflicted by disease. (A) The extensive loss of feathers on the head of this loon is believed to have been caused by ringworm resulting from infection by *Trichophyton* sp. fungi. (B) The white, wooly-like hair within the hair coat of this white-tailed deer also is aberrant, but has genetic rather than a pathologic basis. (C) Emaciation such as that seen in the breast of the lower pheasant and (D) by the rib cage of this gray wolf may result from food deprivation (malnutrition), chronic infectious diseases, and other causes. (E) The shorter than normal lower jaw of this white-tailed deer is genetic, while the deformed upper portion of the bill on this white pelican (F) was likely caused by injury rather than infectious disease. In contrast, (G) the nodule on the face of this canvasback duck was caused by avian tuberculosis. (H) The greatly swollen mammary glands of this white-tailed deer (mastitis) and (I) the swollen lower portions of the feet of another white-tailed deer are caused by different types of pathogenic bacteria capable of causing disease in humans. Handling these types of animals without protective gloves is hazardous as contact with drainage from infected areas can cause human infection through abrasions in the skin. (J) The lesion on the tongue of this white-tailed deer was caused by bluetongue virus, one of the causes of hemorrhagic disease in deer, livestock, and some other mammals. (K) The lesion under the tongue of this mallard duck was caused by duck plague virus. (L) The blood-soiled vent area of this mallard duck also is due to duck plague, a viral disease of waterfowl and (M) the green soiled vent area of this Canada goose is due to lead poisoning.

Table 5.2 Common techniques for home preparation of game meat within the USA[a,b]

Method	Description	Species commonly prepared	Comments
Smoking 	Meat is brined for several days to weeks and then placed in a closed but vented chamber where it is heated for hours to several days. Flavoring results from the type of wood/sawdust used for specifically creating smoke during the heating process.	Many types of meat including venison, birds, fish, and occasionally shellfish.	Homemade and commercial smokers, including small volume electric units are used. Insufficient heating relative to temperature reached and time that highest temperature is maintained fails to kill spore-forming bacteria that may be present.[38,39] Human cases of botulism (*Clostridium botulinim*) have resulted from home-smoked fish and other game meat.[3,5]
Jerky 	Typically, uniform thin strips of lean meat that have been air dried, often following a prolonged period of brining (several weeks). Smoking is commonly used as a part of the drying process.	Deer, caribou and other large mammals.	Popular for venison and sometimes used for novelty preparation of species not typically prepared for food. Insufficient heating during the drying process may result in the survival of larval forms of parasites encysted within game meat along with contamination by bacterial organisms during processing of the carcass. Examples include human cases of trichinellosis from the consumption of cougar jerky[40] and *Esherichia coli* 0157:H7 from venison jerky.[41]
Sausage 	Highly seasoned minced game meat, such as venison, combined with domestic beef and /or pork to increase fat content. This mixture is usually stuffed in casings of animal intestine and then cold smoked (low temperature) for several days and then finished by hot smoking (cooking temperature) for 24 hours.	Same as jerky.	Popular use for less prized cuts of game meat from deer and elk. Commonly served as snacks at the homes of hunters, distributed to friends, and used as sandwich meat. Because of the relative low meat temperatures (about 150°F) reached during preparation, it is important that both the game and domestic meat be from wholesome animals. Secondary bacterial contamination that may occur when processing the carcass is especially important and requires that basic sanitation be incorporated throughout all aspects of processing the animal and during sausage preparation.
Canning 	Previously treated (cooked, cured) or raw meat is heated in a sealed container to exclude air.	Same as smoking.	"Canning is the oldest and most important means of preparing ambient, stable long shelf-life foods."[42] *Clostridium botulinium* is the pathogen of greatest concern for the commercial canning industry[43] and also for home-canning. The anaerobic environment resulting from canning facilitates the germination of *Cl. botulinium* spores that may be present. The combination of temperature and time required to destroy botulinum toxin produced by these bacteria is 212°F for 10 minutes.[39] The thermal death time for spores of *Cl. botulinium* at 250°F is 2.45 minutes. These temperatures must be maintained at the center of the interior of the container.[38]
Direct cooking 	Essentially all methods used for cooking domestic meats (fish, poultry, beef, etc.) are used to cook game meat.	Mammals, birds, fish, shellfish and incidental species, such as frogs and turtles.	Game meat is often eaten rare to maintain the delicate flavors of different meats or prevent drying due to the low fat content of many species. Proper handling, including temperature control (refrigeration/freezing) to prevent spoilage and secondary bacterial contamination is important for sustaining the wholesomeness of the meat.[44]
Other 	A variety of other techniques such as salting, fermentation and other processes are used to prepare game for consumption.	Various	Use of these techniques is generally less common than the above techniques except for regional and ethnic/cultural preferences. Similar cautions identified for the above techniques apply. Detailed information about various methods for food handling and preparation that apply to game meat is available from many sources and should be consulted when considering unfamiliar methods.[38,39,44,45]

[a]Game meat is generally wholesome. All of the methods identified in this table are generally safe when properly applied. Unlike domestic meats, the health status of the animal is not known nor is there a regulatory inspection process to evaluate game meat. Therefore, the burden for inspection and quality control from harvest through processing and food preparation lies with those involved in the utilization of game meat.

[b]Extreme examples of the edibility of meat from wild mammals are reports of meat eaten from a young mammoth frozen in the Siberian tundra for about 15,000 to 20,000 years and bone marrow from a horse that had been frozen in Alaska for 50,000 years and was served at a dinner in New York.[39]

wildlife that may make them smell odd, but do not represent potential human health hazards. The appearance of internal organs and tissues is often compromised by damage during the harvest of the animal and may be difficult to evaluate. However, the appearance of abscesses, fungal growth, and tumors within the body cavity should generally result in the rejection of the carcass for consumption.

"Conditions/Things" One Might Encounter

"Nature does nothing without a purpose" (Anonymous)

"Neurosis seems to be a human privilege" (Freud)

Most wildlife are wholesome and do not pose any significant risks for disease when cleanly harvested, properly handled, and prepared appropriately as food. Nevertheless, there are a number of conditions of wildlife that may be encountered. Some are harmless, but cause uninformed observers to discard edible meat. Others are potentially hazardous. Some of the conditions commonly seen within the USA are highlighted in the remainder of this chapter.

Photo courtesy of the U.S. Environmental Protection Agency, Center for Great Lakes and Aquatic Sciences

Figure 5.6 Those not familiar with lamprey-induced wounds may mistake the lesions in the flesh of fish to have been caused by disease agents instead of the attachment and detachment of lampreys.

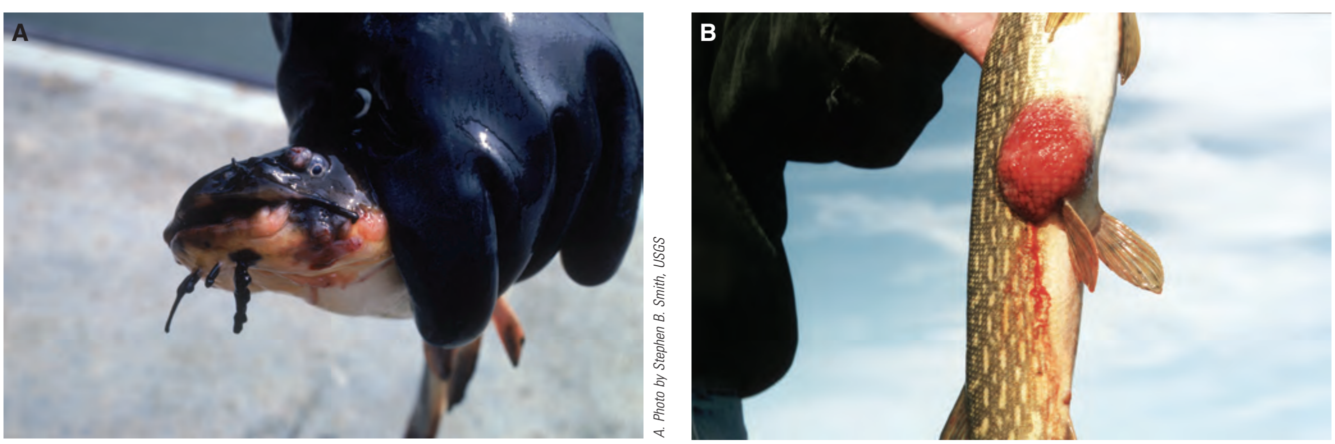
Parasites

Parasites generally are more apparent than other pathogens to those processing wildlife for their meat and other purposes. Parasites, or evidence of their presence, may be seen externally on the animal and internally within the intestines, on major organs such as the liver, and as a result of cyst formation within muscle tissue (Table 5.3). If present, people may want to know what they are and whether it is safe to eat the meat from this animal.

External Parasites

Most people are not surprised or concerned when they encounter ectoparasites, such as ticks and lice (Fig. 5.9) on wildlife carcasses. However, that is not the situation when larval forms of bot and warble flies are encountered for the first time. Depending on the fly species and wildlife host, these larvae may be encountered in nasal cavities, sinuses or **retropharyngeal pouches**, subdermal, and even in muscle tissue.[10] Despite the outward appearance (Fig. 5.10), the meat from infested carcasses is safe to eat.

Sarcoptic mange (*Sarcoptes scabiei*) is another external parasitism that causes considerable concern (Fig. 5.11).[11] Infestation does not, by itself, render the animal unfit for consumption, but severe infestations can result in unhealthy animals and secondary infections by opportunistic bacteria can render such carcasses unfit for consumption. Protective gloves should always be used when handling animals with mange, because some of the subspecies of mites that cause this disease are capable of transient human infestations.[11]



A. Photo by Stephen B. Smith, USGS

B. Photo by Milton Friend

Figure 5.7 (A) Tumors within the mouth area of some fish, such as the brown bullhead, have been associated with environmental contaminants; (B) the tumor on this northern pike is of unknown cause. Fish that have external tumors should not be consumed.

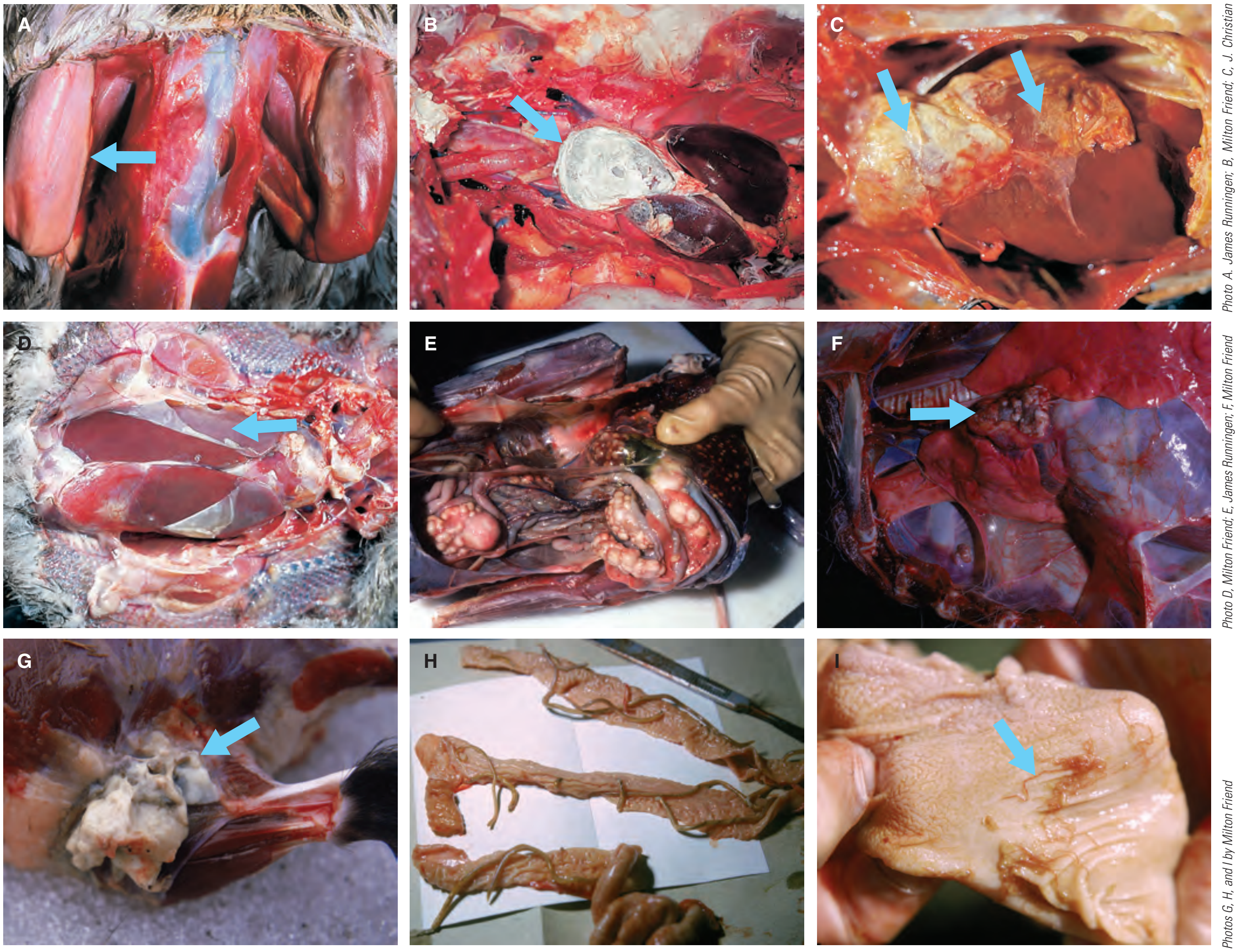


Figure 5.8 Abnormal coloration, size, and shape of organs, the presence of growths within the body, and other indicators of disease are often readily seen when carcasses are opened. Examples include: (A) pale coloration of tissues, such as that caused by stress associated with improperly handling live animals (capture myopathy); (B) the accumulation of white, gritty deposits in the surface of organs, such as the heart of this bird due to dietary protein imbalances (visceral gout); (C) encasement of the heart and part of the liver by a fibrous covering in this bird, and (D) the translucent covering of the liver in another bird are the result of infection by the bacterium *Escherichia coli*. (E)The numerous, raised, firm nodules seen in this whooping crane are the result of avian tuberculosis. (F) The nodular area in the lung of this deer is a malignant tumor. (G) Abscesses, such as those in the leg of this muskrat, are sufficient reason to reject the use of meat from the carcass. (H) Parasites, such as these roundworms in the intestine of a raccoon, (I) stomach worms in a white-tailed deer, and (J) tapeworms in the intestine of this goose are commonly seen in wildlife carcasses. These parasites do not represent a state of disease and are not reasons to discard the carcass.

Table 5.3 Examples of parasite infections that may be observed in North American wildlife harvested for human consumption[a]

Disease/ parasite	Parasite type	Primary wildlife for occurrence	Observations	Human risks	Recommended action
Tracheal worm *Syngamus trachea*	Nematode (roundworm)	Upland game birds[b]	Large red worms in the trachea (Fig. 5.15)	None	Meat is edible
Gizzard worms *Amidostomum* spp.	Nematode	Upland game birds	Groups of small worms within the gizzard	None	Discard severely parasitized gizzards; thoroughly cook parts, if only lightly parasitized
Histomoniasis *Histomonas meleagris*	Protozoan	Upland game birds	Lesions only, parasite is microscopic; liver with discrete circular pale areas, ceca with necrotic debris (Fig. 5.17)	None	Discard liver; consumption of muscle tissue acceptable
Sarcosporidiosis *Sarcocystis* spp.	Protozoan	Waterfowl	Immature form of parasite that look like grains of rice in muscle tissue (Fig. 5.13)	None	Discard heavily infected tissue due to poor texture
Trichomoniasis *Trichomonas gallinae*	Protozoan	Doves, pigeons	Lesions only; parasite is microscopic; yellow cheese-like masses in mouth, throat, and crop (Fig. 5.16)	None	Meat is edible
Thorny-headed worms	Acanthocephalan	Waterbird, wild pigs, raccoons, turtles, fish	Nodules on the surface of the intestine and worms protruding through the intestine (Fig. 5.14)	None	Meat is edible
Dog tapeworm *Taenia pisiformes*	Cestode (tapeworm)	Rabbits	Bladder-like larval cysts free in the body cavity (Fig. 5.18)	None	Meat is edible; do not feed viscera to dogs or other canids
Myiasis	Warble and bot fly larvae	Rabbits, squirrels, caribou	Larvae imbedded in skin, muscle, or present in nasal passages (Fig. 5.10)	None[c]	Meat is edible after removal of areas of larval infestation
Larva migrans *Baylisascaris procyonis*	Nematode	Raccoon	Adult worms found within intestine (Fig. 5.8H)	Yes	Well-cooked meat can safely be eaten. However, need to avoid exposure to fecal material and intestinal tract contents because larvated eggs are infectious for humans if accidentally ingested
Mange *Sarcoptes scabiei; Notoedres douglasi*	Mites	Squirrels[d]	Major hair loss, crusted, thickened skin (Fig. 5.11)	Yes	Meat is edible but heavy infestations can result in secondary bacterial infections that preclude eating the meat. Avoid skin contact with carcasses as transient infections by *S. scabiei* possible
Demodectic mange *Demodex odocoilei*	Mite	Deer	Hair loss, thickened skin, pustules on skin	None	Same as other manges, but no risk for human infestation
Liver fluke *Fascioloides magna*	Trematode (Fluke)	Deer	See text (Fig. 5.19)	None	See text
Cysticercosis	Cestode	Moose	See text (Fig. 5.20)	None	See text
Ich *Ichthyophthirius multifiliis*	Ciliate	Fish	Readily seen, small white spots on skin, fins, gills	None	Heavily infected fish may have secondary infections and should be discarded; other fish are edible

Table 5.3 Examples of parasite infections that may be observed in North American wildlife harvested for human consumption[a]—Continued.

Disease/ parasite	Parasite type	Primary wildlife for occurrence	Observations	Human risks	Recommended action
Black spot/grub *Uvulifer ambloplitis*	Digenetic trematode (fluke)	Fish	Readily seen, small (pinhead size) black spots on skin, fins, and embedded in flesh	None	Fish are edible
White grub *Posthodiplostomum minimum* and others	Digenetic trematode	Fish	Small (1 mm or less) white spots in internal organs	None	Heavily infected fish may have secondary bacterial or fungal infections and should be discarded
Yellow grub *Clinostomum complanatum*	Digenetic trematode	Fish	Large (3 to 8 mm) nodules appearing under the skin and in the flesh	None	Parasites are highly visible after skinning the fish because of their yellow color and size; flesh should be thoroughly cooked or remove parasites prior to eating fish
Heterosporis *Heterosporis* spp.	Microsporidian	Fish	See text (Fig. 5.12)	None	See text

[a] Information provided is for wildlife species commonly eaten by humans. Some of these parasites also infect a wide range of other species. There are many parasites observed (some of which are pathogenic for humans) in other wildlife species that generally are not eaten by humans with access to commercial sources of food.

[b] Upland gamebirds = species such as wild turkey, grouse, pheasant, quail, and partridge.

[c] Humans can become infested by some species of fly larvae following the deposition of eggs on the human body by adult flies.

[d] Sarcoptic mange is most commonly seen in canids such as coyotes and foxes, species not commonly used by humans for food.

Ich or white spot is probably the most important freshwater fish parasite in the world; it is seen in the skin of many species of fishes in the temperate zone, but has no human health significance.[12] Heterosporis (*Heterosporis* spp.) is a newly identified parasite of fishes in the upper Midwest (USA) and in Canada that infects muscle tissue. Infected areas appear white and opaque (Fig. 5.12) and, in heavily infected fish, 90 percent or more of the body may consist of the parasite spores rather than muscle tissue. There is no evidence that humans can be infected by this parasite.[13] Other common fish parasites causing spot-like lesions are the grubs (digenetic trematodes or flukes) that infect warm-water fishes. The black grub (*Uvulifer ambloplitis*) causes black spot disease. The white grub (*Posthodiplostomum minimum*), which is found in internal organs, and the yellow grub (*Clinostomum complanatum*), which is found under the skin and embedded in flesh, are other spot-like diseases.[14] These parasites are not considered to be of human health importance (Table 5.3).

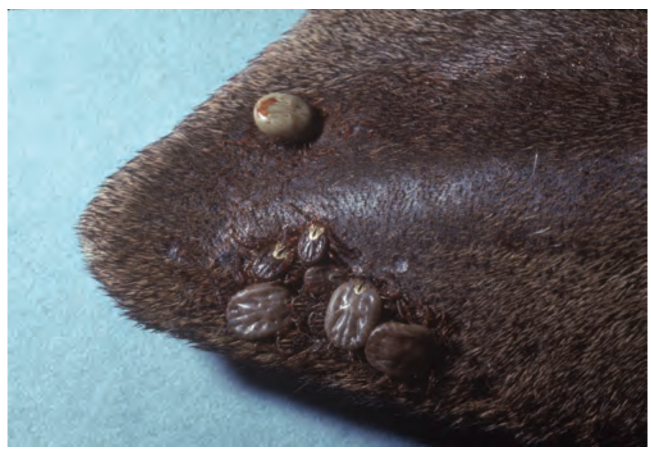


Photo by Milton Friend

Figure 5.9 Ticks are commonly found on both mammals and birds, and may vector a variety of diseases to humans. Therefore, precautions should be taken to avoid their transfer when handling wildlife carcasses. Self-inspection should follow the processing of carcasses when ticks are observed and prompt removal of any ticks found should be done in an appropriate manner (e.g., avoid crushing the tick and leaving their mouth parts imbedded in person's skin).

Internal Parasites

The most commonly seen and questioned internal parasites of wild game in North America are *Sarcocystis* spp. and acanthocephalans in birds, the **dog** tapeworm in cottontail rabbits, liver flukes in white-tailed deer, and **cysticercosis** in moose. Lesions caused by other parasites are commonly seen, but those parasites may be too small to be seen without magnification or are not readily visible because of their locations within the host (Table 5.3).

Photos by Milton Friend

Figure 5.10 (A) Fly larvae embedded in the tissues of a nestling cottontail rabbit, and (B) more mature larval stages ("bots") embedded in an adult cottontail.

Sarcosporidiosis, or "rice breast" disease, is a common parasitic disease of some species of waterfowl and other wildlife; it is present under the skin rather than internally within the body.[15] The cysts formed in muscle tissue appear as rice-grain sized bodies, thus, the common name for this disease (Fig. 5.13). This highly visible protozoan infection does not constitute a public health threat, and properly cooked meat containing this parasite is safe to eat. Parasites of the Phylum Acanthocephala also are commonly seen in some species of birds (Fig. 5.14)[16] and mammals.[17] Their presence does not constitute a public health threat. Other common parasitic infections that may be seen in game birds include tracheal worms in pheasant (Fig. 5.15), trichomoniasis in **doves** (Fig. 5.16), and blackhead in turkey (Fig. 5.17).

Larvae of the dog tapeworm, *Taenia pisiformis*, are commonly encountered by rabbit hunters (Fig. 5.18), because rabbits are a primary intermediate host for this parasite. Humans are not infected. Hunters that feed the viscera from rabbits to their dogs may infect those dogs because, along with coyotes, foxes, and several other carnivores, dogs are definitive hosts for the parasite.[18]

Discovering the large American liver fluke, *Fascioloides magna*, within fibrous capsules in deer liver is often a startling finding for those unfamiliar with this parasite (Fig. 5.19).

Photos A and B, Milton Friend. Photo C, USGS National Wildlife Health Center file photo

Figure 5.11 Mange is a common disease of wildlife that affects numerous mammal species including the (A) gray squirrel, (B) red fox, and (C) wolf.

Photo courtesy of Karl Hayden, Fisheries and Applied Aquacultures, Auburn University, Alabama, USA

Figure 5.12 "Black grub" infection of *Heterosporis* spp. in muscle of largemouth bass.

Photo by James Runningen

Figure 5.13 Cysts of *Sarcocystis* sp. in the breast muscle of a mallard duck.

These flukes occur in pairs or groups within those capsules and can be up to 8 cm long. There are no records of humans being infected by this parasite[19] and no reason for the meat of the animal to be discarded, even if the unpalatable appearance of an infected liver may cause rejection of that part of the animal as food.[20]

Cysticercosis due to infection by *Taenia ovis krabbei* is common in moose populations that are closely associated with wolves, the definitive host for this tapeworm. Parasite prevalence of 60 to 70 percent has been reported for some moose populations in Canada.[18,21,22] The larvae of this parasite encyst in skeletal muscles and in the connective tissue fascia in and between those tissues (Fig. 5.20). Heavy infections can result in significant tissue damage or loss of good body condition. Although human infections do not occur, reindeer meat infected with cysticerci is unacceptable for human consumption.[18] Despite the appearance of infected meat, heavily parasitized meat can be consumed without adverse effects on humans.[23]

Not all parasites of wildlife can be seen or easily detected and some of those that are "hidden" are pathogenic for humans. Hunters should be familiar with any disease activity in the areas where they hunt and know how to properly cook game meat to prevent exposure to parasitic diseases, such as trichinellosis and toxoplasmosis. Trichinellosis in humans is caused by ingestion of the nematode *Trichinella*

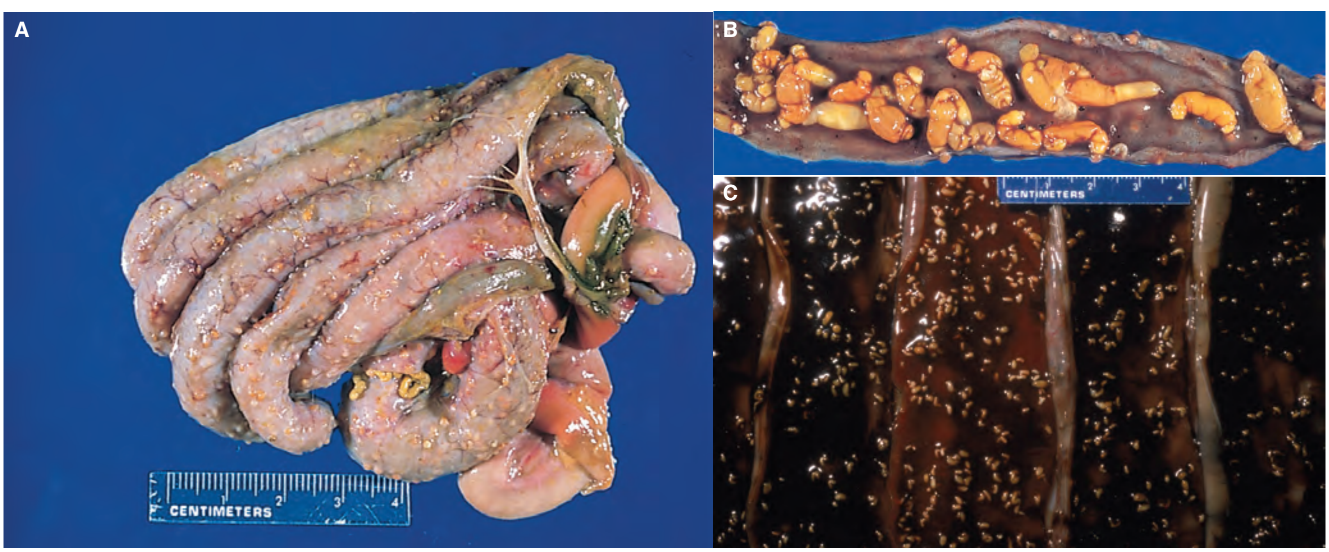


Photo by J. Christian Franson

Photo by James Runningen

Photo by Rebecca A. Cole

Figure 5.14 (A) Large numbers of acanthocephalan parasites may be seen protruding from the intestine of some birds; (B) these parasites attach to the inner surface of the intestine. Severe infections by some species, such as in this sea otter (C), may be pathogenic for the animal.

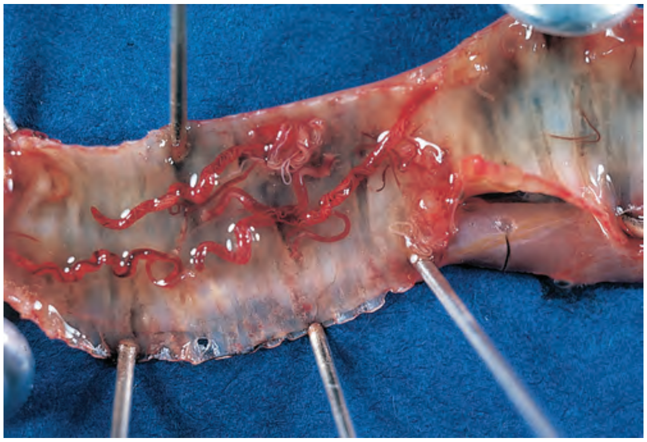


Figure 5.15 Tracheal, or gapeworm infection of a ring-necked pheasant. This parasite does not infect humans.

Figure 5.16 Trichomoniasis is the cause of the yellow, cheesy-like growths in the esophagus of this mourning dove.

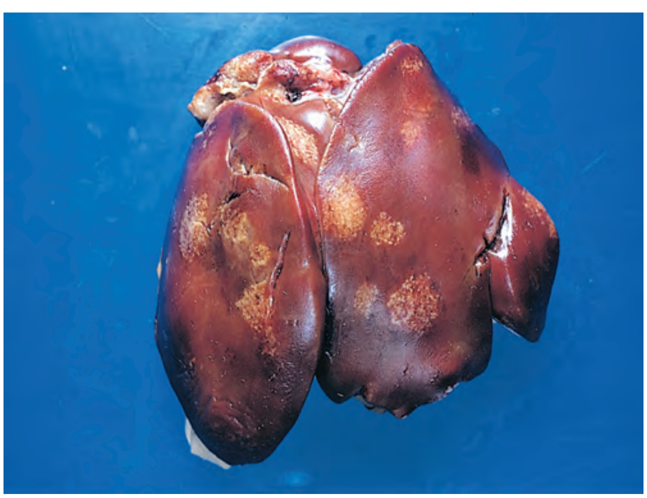


Figure 5.17 The pale areas within the liver of this partridge are due to histomoniasis, or blackhead.

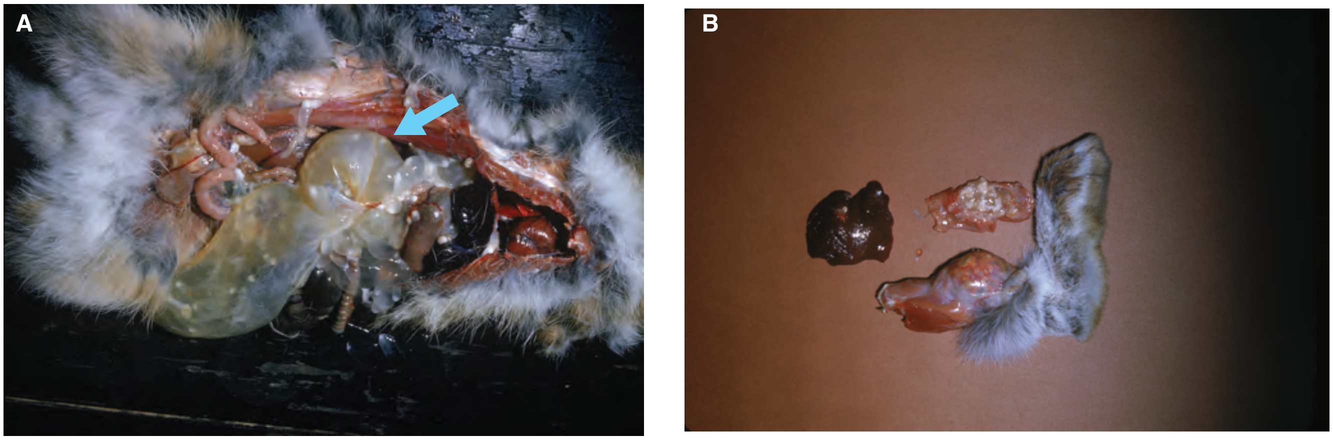
spp. (primarily *T. spiralis*) that are encysted in striated muscle tissue of infected animals, such as wild swine and carnivores (e.g., bears). Natural infections occur in many different species of wildlife, including predatory birds.[24] Since infection is not readily detectable, except by laboratory methods, it is important to thoroughly cook the meat from wild game commonly associated with this disease.[25] Recent cases of trichinellosis involving jerky made from cougar meat serves as an example of the consequences of inadequate food preparation (see Chapter 2).

Toxoplasmosis (*Toxoplasma gondii*) is a common and sometimes serious infection of humans. Infections most commonly occur by ingestion of cysts in infected meat and by oocysts (infective eggs) in food and water that have been contaminated by **cat** feces. Many species of wildlife and domestic animals are naturally infected with *T. gondii*. To prevent exposure, wild game meat should not be consumed raw. Meat from any animal should be cooked to 150° F prior to consumption, meat should not be tasted while cooking, nor should homemade game sausages be tasted during seasoning. Cooking destroys encysted organisms, and thorough hand washing removes surface contamination and should follow any handling of raw game meat.

A variety of nematodes (roundworms) and cestodes (tapeworms) may be encountered when cleaning fish. Most of these are harmless if accidentally ingested,[12] but several, such as the cod worm, *Phocanema decipiens*, have caused human cases of disease (see Chapter 2). *Eustrongylides* spp., a nematode that causes massive bird mortalities (Fig. 5.21),[26] also has been the cause of several human cases of serious disease.[12] *Diphyllobothrium latum* and other species within this genera commonly infect humans when fish are eaten raw.[49] Thoroughly cooking fish eliminates any hazards from parasites that may be present.

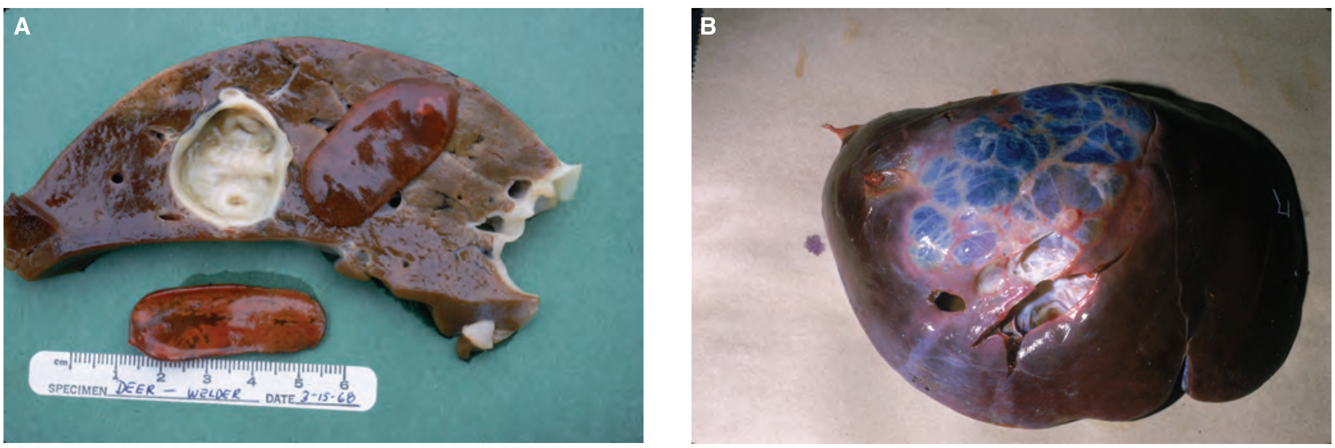
Bacteria

Although most wildlife harvested do not have bacterial diseases of significance for humans, exceptions do occur (Table 5.4). Like other species, wildlife are subject to a wide variety of bacterial infections. Some are primary infections, such as avian cholera (*Pasteurella multocida*) and tularemia (*Francisella tularensis*), while others involve secondary invasion of wounds and other debilitating processes. Types of diseases encountered will vary with the species harvested and geographic area. However, humans are unlikely to harvest wildlife affected with diseases that kill rapidly, such as anthrax and avian cholera. Therefore, unless animals found dead are being processed for food, there should be little concern about those types of diseases when consuming personally harvested game meat. Also, the majority of bacterial diseases present, result in significant (but not diagnostic) lesions in infected animals, thereby providing visible evidence of disease, even to the "untrained eye" (Fig. 5.22). Because unapparent infections can occur and intestinal contents may



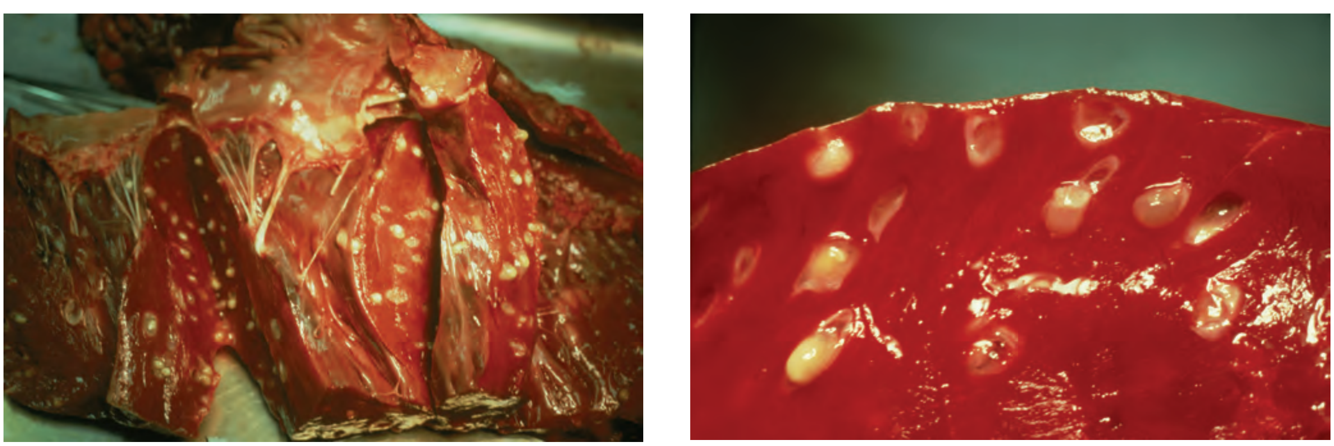
Photos by Milton Friend

Figure 5.18 The bladder-like structure (arrow) in the body cavity of this cottontail rabbit contains large numbers of cysticerci (larvae) of the dog tapeworm. These larvae have also been found encysted in other parts of the body, (B) such as within the fascia of the leg of this snowshoe rabbit and in its liver.



Photos by Milton Friend

Figure 5.19 (A) The large American liver fluke is a common parasite of white-tailed deer in some regions of the USA. (B) Tissue damage to this organ can be extensive.



Photos by Ed Addison

Figure 5.20 Larval forms of the tapeworm *Taenia ovis krabbei* are commonly found encysted in the muscle tissue of moose.

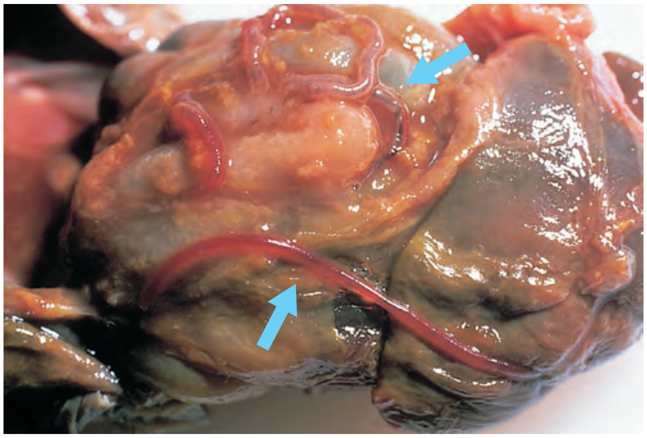
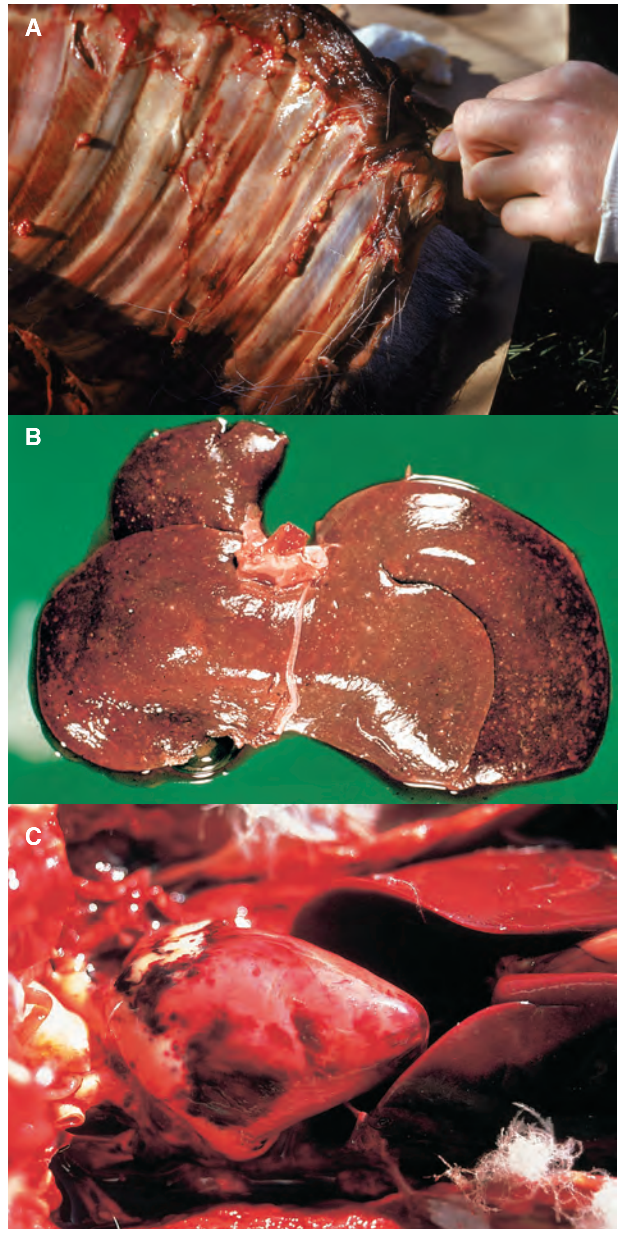


Photo by J. Christian Franson

Figure 5.21 The roundworm *Eustrongylides* sp. and the raised tunnels (arrows) it causes within the intestine are seen in this snowy egret.



A. Photo by Milton Friend

B. Photo by James Runningen

C. Photo by Milton Friend

Figure 5.22 Examples of visible evidence of infectious disease associated with some bacterial diseases of wildlife are: (A) nodules along the rib cage of this white-tailed deer with bovine tuberculosis; (B) numerous, small, yellow and white spots on the liver of this beaver that died from tularemia; and (C) hemorrhages on the heart of a goose that died from avian cholera.

contain *Salmonella* and other enteric pathogens, when processing game meat, it is important to avoid contamination of meat by fecal material. In general, the presence of lesions on internal organs suspected to be caused by infectious bacterial diseases is reason to discard the carcass.

Brain abscesses are occasionally found by deer hunters, but these lesions do not pose a health threat for humans and should not result in disposal of the carcass. These abscesses are thought to result from invasion by skin-inhabiting bacteria. They are much more prevalent in males than females, often are associated with the antler pedicel, and generally occur following velvet shedding to shortly after the antlers are shed.[20] Brain tissue from infected animals should be discarded. Even if not infected, brain should no longer be utilized in any foods because of the emergence of chronic wasting disease (see *Prions*, this chapter).

Viruses

Wildlife are affected by a broad spectrum of viral diseases. However, in North America few of these diseases are likely to be encountered by people harvesting wildlife for food. Many of these diseases primarily occur in species not typically eaten by most people (e.g., small rodents) or the disease has caused severe illness or death that makes the harvest of infected animals unlikely.

Viral diseases that cause external tumors typically occur infrequently, seldom are lethal, and are readily observed. Cutaneous fibromas of deer are hairless tumors that hang from the skin and generally are of no significance for the animal unless their location interferes with sight or feeding (Fig. 5.23). These papillomas pose no health hazards for humans and the meat from these animals is suitable for consumption. Aggregations of tumors, or especially large tumors, often become abraded, which then can allow infection by bacteria and fungi. These animals should not be eaten.

Table 5.4 Examples of potential bacterial infections in North American wildlife commonly harvested for human consumption[a]

Disease	Pathogen	Primary wildlife for occurrence	Observations	Human risks	Recommended action
Brucellosis	*Brucella* spp.	Bison, elk, caribou, feral swine	Enlarged reproductive organs, enlarged leg joints, retained placental materials	Yes	Wear protective gloves when processing carcass, minimize contact with reproductive organs, do not open enlarged joints or areas of fluids that may be encountered within the carcass, and cook meat thoroughly.[46]
Brain abscessation	*Actinomyces* spp., *Staphylococcus* spp., *Streptococcus* spp.	Deer	Abscess within the brain, pus at antler base	Yes	Meat of animal is safe, prevent contact with abscesses and contamination of carcass. Wear protective gloves when removing antlers for trophy use; discard gloves along with head and replace with new gloves if further handling/processing of animal is to occur.
Dermatophilosis	*Dermatophilus congolesis*	Numerous; deer to rabbits	Major thickening of areas of the skin with pustular, scabby lesions and associated hair loss	Yes	Prevent contact with infected areas of skin; self-limiting focal infections can occur in humans and more severe infections may occur in immunocompromised people.[47] Meat from animal is safe to eat.
Tuberculosis	*Mycobacterium bovis*	Deer, elk, bison	Nodules containing cheesy-like material or granular-like substances within lymph nodes, organs, and along the internal surface of the rib area (Fig. 5.22A)	Yes	Properly discard infected animals and notify authorities of findings. Meat from animal should not be consumed.
Avian tuberculosis	*M. avium*	Birds	Masses of nodules within major organs and/or along intestines (Figs. 5.5G and 5.8E)	Yes	Same as for mammalian tuberculosis.
Tularemia	*Francisella tularensis*	Rabbits, beaver, muskrat	Pale spots scattered within the liver and spleen (Fig. 5.22B)	Yes	Thoroughly cook meat to be eaten, wear protective gloves when handling carcasses, and prevent transfer of ticks and other biting arthropods.
Furunculosis	*Aeromonas salmonicida*	Trout[b], salmon	Ulcers on skin[c] and in muscle tissue; organ haemorrhages	No	Discard carcass, consumption not recommended.

[a] Information provided is for wildlife species commonly eaten by humans. Some of these bacteria also infect a wide range of other species. There are many bacteria observed (some of which are pathogenic for humans) in other wildlife species that generally are not eaten by humans with access to commercial sources of food.

[b] Now recognized that many species of fish are infected by *A. salmonicida*.[48]

[c] Classical disease produces boil-like lesions on skin and in muscle tissue; pathology varies widely with age of fish, type of disease caused, and whether typical or atypical *A. salmonicida* infections are involved.[48]

Photo by Milton Friend

Figure 5.23 A white-tailed deer with multiple cutaneous fibromas.

Photo by Milton Friend

Figure 5.24 Fibromas on gray squirrels collected from a city park.

Fibromas of viral origin also occur in the gray squirrel (Fig. 5.24). There is no known human health hazards associated with these tumors or any of the other papillomas found on wildlife throughout the world, with the possible exception of those from nonhuman primates.[27] Within the USA, Shope's fibroma (Fig. 5.25), a poxvirus infection of cottontail rabbits, is perhaps the most common tumor-like disease seen in wildlife. As for the papillomavirus, this fibroma generally is of little consequence for infected animals and has no human health implications.[28] Poxvirus infections also occur in birds (Fig. 5.26), sometimes resulting in death because of impaired vision and inability to feed. Here again, there are no known human health risks associated with these viruses.[29]

Hemorrhagic disease is another malady hunters may encounter in wild ruminants such as deer and **antelope** (Fig. 27). Epizootic hemorrhagic disease (EHD) viruses and bluetongue (BT) viruses are the causative agents. Epizootics of EHD and BT periodically kill large numbers of wildlife, but the viruses involved are not infectious for humans.[20]

Prions

Prion diseases continue to be a relatively little understood yet heavily studied group of emerging infectious diseases. They include scrapie, a long existing sheep disease; bovine spongiform encephalopathy (BSE) of cattle; Creutzfeld-Jacob disease (CJD) and kuru of humans; a variant CJD (vCJD) associated with BSE that causes disease in humans; mink spongiform encephalopathy; and most recently chronic wasting disease (CWD) of deer and elk.[30,31]

CWD is of great concern to hunters and game ranchers as it is ultimately fatal and affects several deer species (Fig. 5.28). Unlike the vCJD associated with BSE, no link has been found between CWD and disease in humans. However, because there are many unanswered questions about CWD,

Photo by Thomas Yuill

Figure 5.25 Shope's fibroma on the foot of a rabbit.

Photo by James Runningen.

Figure 5.26 A bald eagle with an extreme avian pox infection leading to its death because of an inability to feed.

health officials advise against consuming meat from animals known to be infected with CWD. In addition, hunters should wear disposable gloves when field dressing deer or elk taken in areas where this disease is found and when deboning meat. The purpose for deboning is to remove associated neural tissue, the consumption of which is considered to be the primary pathway for exposure to prions. A separate knife, not the one used to butcher the deer, should be used to sever the spinal cord when the head is removed. This precaution avoids contamination of the primary butcher knife by nerve tissue that may contain the disease agent if the animal was infected. Also, avoid handling and consuming brain, spinal cord, lymph nodes, eyes, tonsils, and spleen when processing deer and elk from areas where CWD is known to be present.[30–32] Complete instructions on handling, testing, and disposing of deer and elk carcasses can be obtained from the Department of Natural Resources in the state where the deer or elk are to be harvested. Observations of deer or elk with the appearance of CWD should be reported to that agency.

Fungi

Wildlife may either become infected by fungal organisms, such as *Aspergillus* spp. (Fig. 29), or they may be affected by toxins produced by fungi (e.g., mycotoxins). Aspergillosis is the most common fungal disease likely to be seen in birds and is likely to be highly visible. Typically, infected birds have yellow plaque-like lesions that have a cheesy appearance and consistency and are found in the lungs and airsacs. Lesions similar to bread mold also may be present.[33] Severely infected birds often are very thin and are likely to be discarded on this

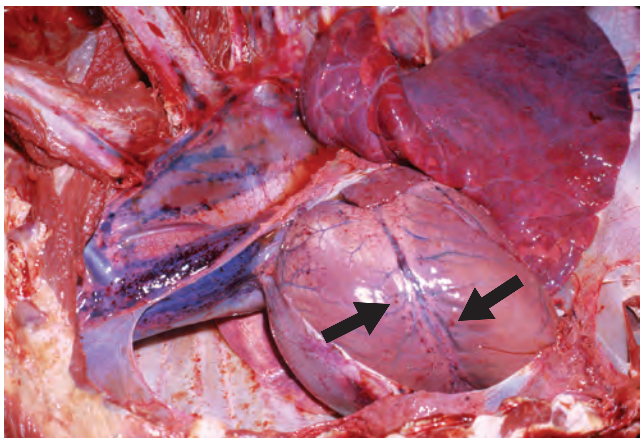
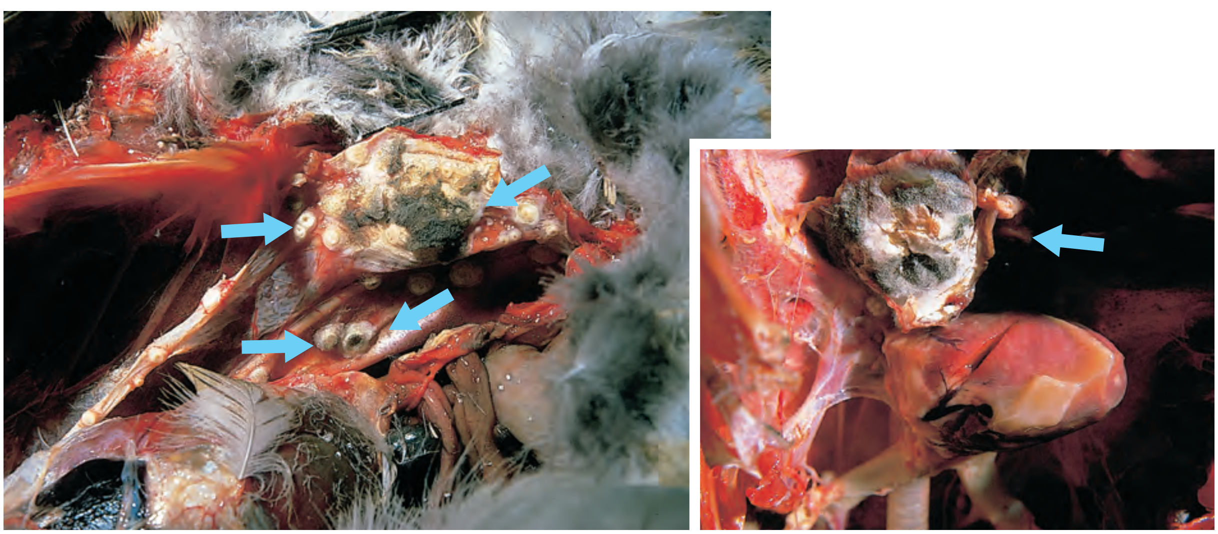


Photo by Milton Friend

Figure 5.27 Hemorrhages in the tissues and organs, such as in this white-tailed deer, are common findings in deer and antelope dying from epizootic hemorrhagic disease and bluetongue.

Photo courtesy of Christina Sigurdson, Colorado State Univeristy

Figure 5.28 Clinical signs and the unthrifty appearance of animals, rather than internal pathology, are indications of the potential that a deer or other cervid is infected with chronic wasting disease. Testing of appropriate tissue is required for a diagnosis.



Photos by Milton Friend

Figure 5.29 The presence of "cheesy" plagues and the "bread mold" present on the surface of tissues within this Canada goose is indicative of the fungal disease aspergillosis.

basis. The potential for human infection resulting from exposure to fungi present in the carcass is very low and properly cooked meat would be safe to eat. Nevertheless, consumption of these carcasses is not recommended.

Individuals harvesting mammalian wildlife may encounter superficial (skin) fungi that may or may not be involved with skin lesions that appear as discrete round areas of scaling, crusting, and hair loss. Typically, these lesions appear on the head and back, may result in depigmentation and a thickening of the skin in areas of infection. These infections are commonly referred to as ringworm or tinea and, medically, as dermatophytosis. Several genera of fungi are involved. *Microsporum* spp. and *Trichophyton* spp. are the most likely to be transmissible from animal to humans.[34] Meat from infected carcasses poses no known human health risks. Human exposure is prevented by wearing protective gloves when handling carcasses and hides.

Toxins

Wildlife may be exposed to a wide variety of toxins in addition to infectious agents. These toxins may be of natural (e.g., microbial) or synthetic (e.g., pesticides) origin. Rarely will the carcass reveal any obvious signs that the animal had been exposed to these toxins. Therefore, coverage of these types of agents is beyond the scope for this chapter. Birds clinically ill from diseases, such as avian botulism and aflatoxicosis (Fig. 5.30), may be seen in the field because the time between intoxication and death often extends for several days.[35] Those concerned about natural and synthetic toxins should avoid consuming wildlife that appear to be excessively thin and, prior to harvesting wildlife, check with the state Department of Natural Resources to determine if any health advisories have been issued.

Should I Eat This?

"The discovery of a new dish does more for human happiness than the discovery of a new star." (Brillat-Savarin)[36]

The type of food eaten is a personal choice. The popularity and high nutritional value of finfish and shellfish are reflected in the rapid growth of aquaculture during recent years, because wild stocks can no longer meet the demands for those food items. Greater demands for venison, bison, and other wildlife meats have resulted in substantial increases in the captive-rearing of various wildlife as alternatives for domestic species whose meat has higher fat and cholesterol content (see Chapter 3, Fig. 3.18). From a human nutritional perspective, wildlife often are a better choice than livestock and poultry.

Within the USA, most game meat consumed is from free-ranging rather than ranched wildlife. Emergence and reemergence of infectious diseases in wildlife and other species (see Chapters 2 and 3) continues to result in new diseases of concern. Some of these, like bovine tuberculosis (*Mycobacterium bovis*) are old diseases that have gained new prominence.[37] Therefore, hunters and game consumers within the USA need to be informed about diseases affecting wildlife in areas where harvests are being considered because major differences in risks are associated with inspection processes for commercial meats versus individuals handling and processing their own game meat.

Because free-living wildlife do not receive preemptive human intervention to combat disease (e.g., antibiotics in feed, vaccines, etc.), there is a high probability that vertebrates infected by significant pathogens will die before they are harvested. Therefore, at least within North America, there is little reason to consider properly handled and prepared game meat to be of greater risk as a source for disease than domestic meat. Nevertheless, local exceptions involving chronic diseases, such as bovine tuberculosis, may exist. Therefore, general knowledge of the health status of wildlife in the area of harvest is important. This knowledge constitutes informal health advisories and is helpful in making informed choices about what one chooses to eat and how to prepare it. Similar judgments are made in response to formal health advisories issued for domestic foods and advisories issued for environmental contaminants that may be present in fish and other foods harvested from aquatic environments.

Common sense should always be a factor in what one eats and does not eat, regardless of the source of the food item. Game meat is a staple food item for many people throughout the world, a gourmet food for some people, and for most people, food that is greatly enjoyed. Bon appétit.

Pauline Nol and Milton Friend

Photo by Ronald Windingstad

Figure 5.30 In general, wildlife with abnormal behavior and appearance, such as this sandhill crane affected by a fungal toxin, should not be harvested for human consumption.

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Chapter 6

Biowarfare, Bioterrorism, and Animal Diseases as Bioweapons

"BW [biological warfare] is a special weapon, with implications for civility of life that set it apart from many other kinds of violence."

"...the intentional release of an infectious particle, be it a virus or bacterium, from the confines of a laboratory or medical practice must be formally condemned as an irresponsible threat against the whole human community." (Lederberg)[1]

Photo by Milton Friend

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Chapter 6

Biowarfare, Bioterrorism, and Animal Diseases as Bioweapons

"The study of germs offers so many connections with the diseases of animals and plants, that it certainly constitutes a first step in the …serious investigation of putrid and contagious diseases." (Pasteur)[2]

Linkages between disease in humans and the maladies of animals continue to be a focus for those concerned with disease effects on human health. References to animal diseases, particularly zoonoses such as rabies and glanders, are found in the writings of Greek (Hippocrates, Democritus, Aristotle, Galen, Dioscorides), Byzantine (Oribasius, Actius of Amida), and Roman (Pliny the Elder, Celsus) physicians and naturalists.[3] Also, early advances in disease knowledge were closely associated with the study of **contagions** in animals to the extent that "The most complete ancient accounts of the concepts of **contagion** and contamination are found in treatises on veterinary medicine."[4,5]

Opportunities for disease transfer between animals and humans have increased during modern times, partly because of advances in animal husbandry and intensive agriculture that result in increased contacts among humans, domestic animals, and wildlife. Infectious pathogens exploit these contacts, and must be considered in this era of increased world tensions and international terrorism (Fig. 6.1).

Disease emergence and resurgence are generally associated with natural processes and unanticipated outcomes related to human behavior and actions. That perspective has been broadened by recent acts of bioterrorism. A new category of deliberately emerging diseases contains emerging microbes that are developed by humans, usually for nefarious use.[211] Included are naturally occurring microbial agents and those altered by bioengineering. This chapter highlights the wildlife component of the pathogen-host-environment triad to focus attention on the potential for bioterrorists to use wildlife as a means for infectious disease attacks against society. The value of this focus is that the underlying causes of disease emergence and the optimal prevention or control response frequently differ for disease emergence, resurgence, and deliberately emerging diseases.[211] Differences also exist relative to the potential importance of wildlife as a component of biowarfare and as a component of bioterrorism activities.

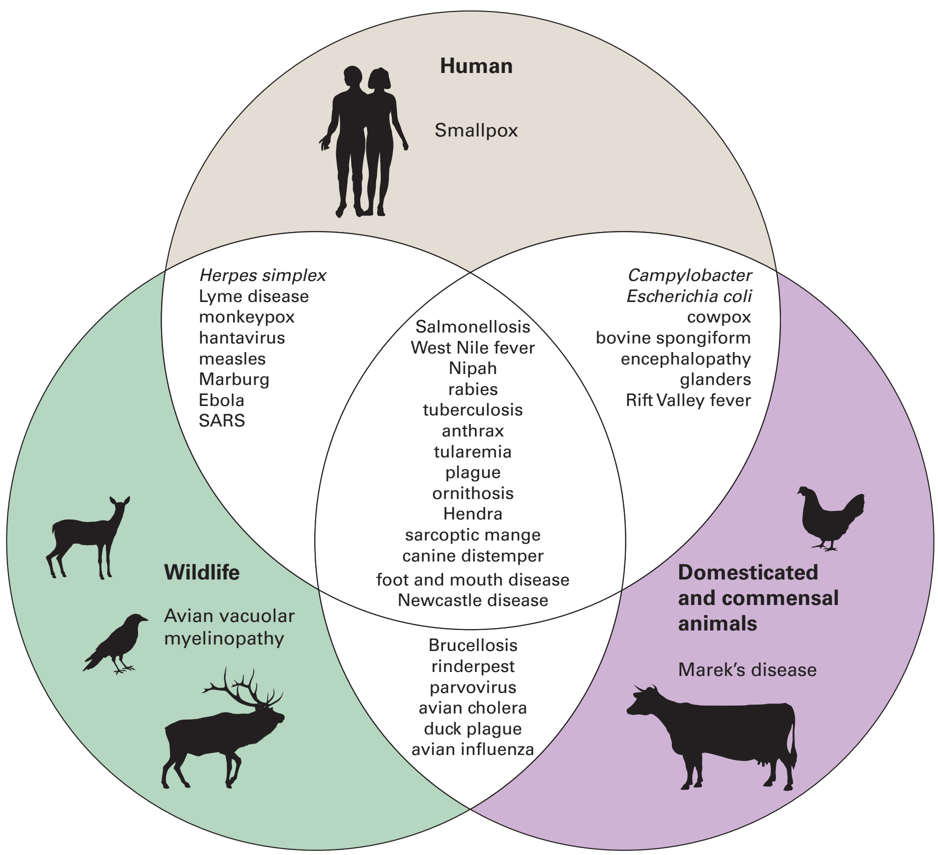


Figure 6.1 Examples of linkages between important infectious diseases of wildlife, domestic animals, and humans. (Modified from Dudley and Woodford[41]).

Between 1936 and 1980, more than 100 definitions for terrorism were coined.[110] Within the USA, two official definitions of terrorism have been used since the early 1980s; the Department of State uses one for accounting purposes (statistical and analytical endpoints), and the U.S. Congress uses the other for criminal proceedings ("act of terrorism").[57] The context of bioterrorism within this chapter follows a recent definition in the scientific literature and is separated from biowarfare on the basis of the latter involving a declaration of war or the perception of war being waged between nations as evidenced by an appropriate level of hostile actions between nations. Keeping that distinction in mind, "Bioterrorism is the intentional use of microorganisms or toxins derived from living organisms to cause death or disease in humans, animals, or plants on which we depend."[77]

Past Biowarfare and Bioterrorism

> **"A man may imagine things that are false, but he can only understand things that are true." (Isaac Newton)[2]**

The ravages of naturally occurring disease documented throughout history[2,6–11] substantiate infectious disease use as potential weapons among enemies. In fact, biological warfare was used in varying degrees well before the germ theory for disease was first proposed in 1530,[12] demonstrating that infectious disease used as weapons against humans and animals is not a new concept.[13–16]

Plague and Smallpox as Bioweapons

The 1346 Siege of Caffa (also spelled Kaffa, which is now Feodosija, Ukraine) involved the most gruesome and crudest example of biological warfare when the Mongol army catapulted plague-infected cadavers into the besieged city. "Mountains of dead were thrown into the city," infecting the inhabitants and resulting in many deaths from the Black Death (plague). However, plague also devastated the Mongols attacking the city and the infected cadavers did not alter the outcome of the siege. Furthermore, fleeing survivors were not a major factor in plague spreading from Caffa to the Mediterranean Basin because of other factors contributing to the plague epidemic.[16,17]

Plague is a zoonotic disease caused by the bacterium *Yersinia pestis,* typically harbored by wild rodents (Fig. 6.2). The plague epidemic that swept through Europe, the Near East, and North Africa in the mid-14th century was probably the greatest public health disaster in recorded history. An estimated one-quarter to one-third of Europe's population died from plague during the 14th century **pandemic,** and North Africa, the Near East, and perhaps the Far East had similar high levels of mortality.[16,18] However, the first recorded plague pandemic began in 541 in Egypt when the world population was considerably smaller and decimated an even greater percentage of the population. This pandemic swept across Europe and parts of Asia; between 50 and 60 percent of the human population died in many areas.[19,20]

Given the explosive nature and history of disease spread over wide areas, plague could be a dangerously effective biological weapon[18,20, 21] and nations pursuing bioweapons development have often focused on this agent. During World War II (WWII), Japan successfully initiated plague epidemics in China by releasing as many as 15 million laboratory-infected fleas per attack from aircraft over Chinese cities.[22,23] Nevertheless, the complexity of biological factors involved in plague transmission results in fleas being unreliable as a delivery system for **biowarfare**.

Early in the history of the Black Death, the original bubonic-flea-borne variety of plague evolved to the far more contagious pneumonic variety as a cause of human epidemics.[1] Direct human exposure by **aerosolized** plague bacilli is the most effective way to cause human illness and death;[19,24,25] the biological weapons programs of the USA and the former Soviet Union have pursued aerosol transmission capabilities for plague.[19,26,27] The Soviets had intercontinental ballistic missile warheads containing plague bacilli available for launch before 1985.[28] Yet, virtually insurmountable problems arose in the production and aerosol dispersal of substantial quantities of plague organisms by modern weapon systems.[29] Despite these difficulties, plague is viewed as a high-risk disease for bioweapons.[32]

Smallpox also has intentionally been used against humans. Unlike plague, smallpox is strictly a disease of humans; it is not zoonotic (Fig. 6.3).[30] In 1763, during the Pontiac Rebellion (Indian Wars) in North America, contaminated blankets and a handkerchief from a smallpox hospital were given as gifts by British forces to Native Americans. This Trojan horse approach introduced the smallpox virus into the tribes and caused major casualties.[17,22,31] Capabilities for aerosol exposure of humans to smallpox exist, while access to the virus remains tightly controlled following global eradication of this disease during the 1970s. World Health Assembly resolution WHA 52.10 called for the destruction of all remaining stocks of the smallpox virus by the end of 2002, but further evaluation by the World Health Organization concluded that live virus was needed for specific scientific purposes. That position was supported by the World Health Assembly.[208] Virus stocks are maintained for that purpose in the USA and Russia under international oversight.

Other Applications of Bioweapons Targeting Humans

Numerous reports of using disease as a **bioweapon** during times of war exist, but few can be confirmed from available records. For various reasons, information about the use of these weapons and their consequences often are unavailable. From 1932 through WWII, Japan clearly had the most aggressive biological warfare program ever applied at the field level.[14,23] This program resulted in the estimated deaths of at least 10,000 people in laboratory experiments (prisoners of war) and as many as several hundred thousand others in military field operations. Zoonotic diseases employed at the field level included typhus, paratyphus, cholera, salmonellosis, plague, anthrax, typhoid fever, glanders, and dysentery (probably *Shigella* sp.).[23,33] A comprehensive historical account of these covert operations, which have been referred to by author James Bradley as "One of mankind's biggest yet least known crimes," is provided in the book *Factories of Death*.[23]

Prior to WWII, biological warfare did not have deadly consequences because of inadequacy of development programs.[14] Nevertheless, the extent of biological warfare in medieval and Renaissance times, during early North American settlement, and during WWI was probably greater than recognized[17,34] (Table 6.1). Biological weapons also have been used against animal and food resources (see Animal Disease and Bioterrorism section).

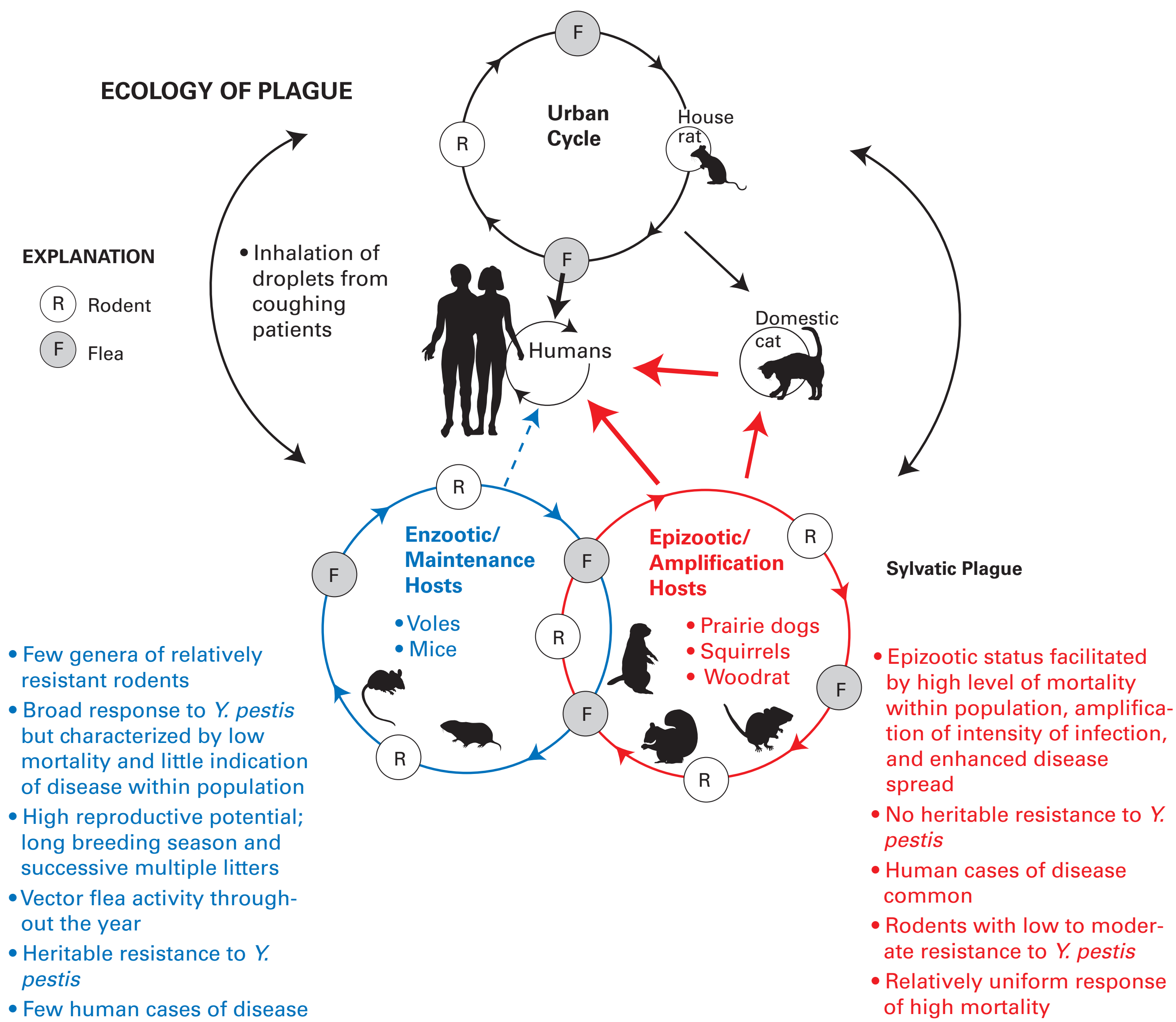


Figure 6.2 General ecology of plague (*Yersinia pestis*). (Developed from Butler,[202] Gasper and Watson[203]).

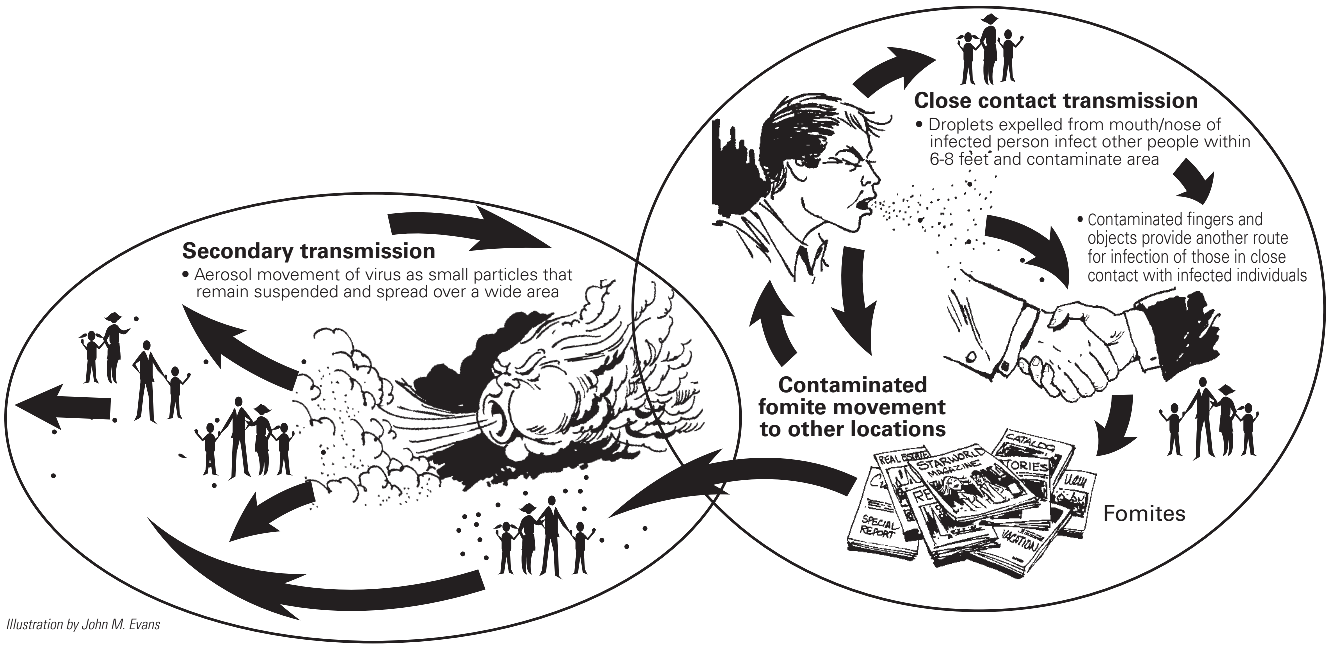


Figure 6.3 Smallpox, a person-to-person and person-to-fomite-to-person disease (developed from Fenner et al.[30]).

Present Biowarfare and Bioterrorism

> **"In my opinion biological agents, along with death rays, sonic beams, neutron bombs and so on, belong more to the realms of science fiction than to practical warfare. But my opinion is not widely shared and the fount [supply] of human imbecility seems inexhaustible,…"[35]**

The increased threat to society from bioterrorism that ushered in the 21st century within the USA was a growing concern during the 1990s.[36–40] That concern was based on increases in terrorist incidents taking place globally, disclosures of major covert bioweapon development in the former Soviet Union and Iraq, and evaluations that indicated a shift in terrorist motivations. Primary motivations from 1975 to 1989 were protests against government policies. Since 1990, the primary motivations include retaliation or revenge and the pursuit of nationalist or separatist objectives.[28,40]

Concerns about increased risks from terrorism were expressed in prophetic statements such as, "Many experts agree that it's just a matter of time until the United States or another country suffers a significant bioterrorist attack."[36,41] Primary concerns raised at that time focused on the inadequacy of USA preparedness and infrastructure to respond to an attack in which infectious disease agents were the weapons.[1,42] Indeed, from October 30 through December 23, 1998, the Centers for Disease Control and Prevention (CDC) received reports of a series of threats involving anthrax-laced letters being sent though the mail. All were investigated and found to be hoaxes. Nevertheless, the CDC issued interim guidance for response to such threats becoming reality.[43] Those hoaxes followed the highly publicized arrest of a microbiologist linked to a white-supremacist group who had threatened to use military-grade anthrax in attacks against the government.[40]

In 2001, the Johns Hopkins Center for Civil Biodefense Strategies further raised attention to the dangers of microbial terrorism by staging a mock smallpox attack within the USA called "Dark Winter," which illustrated a major need for better preparation[44] as did TOPOFF, a mock plague outbreak held in 2000.[27] Concerns in the USA about terrorism and the level of preparedness became reality with the infamous events of September 11, 2001, and the subsequent anthrax attacks through the U.S. mail system.[45,46]

The anthrax letter attacks of 2001 generated great terror among the public,[27,47–49] reemphasized that the USA population is not immune from terrorist attacks with biologic agents,[50] and, despite the previous anthrax threats and letter hoaxes,[40,43] emphasized that the greatest threats from bioterrorism will likely involve something never before seen as an application.[51] Although the potential for biowarfare remains a concern and **disarmament** efforts by the international community continue,[52–54] the threat of bioterrorism is now of greater concern in the USA and in many other nations[55,56] (Box 6–1).

Biowarfare versus Bioterrorism

Biological weapons are considered to be weapons of mass destruction or, more appropriately, weapons of mass casualty. "Because they are invisible, silent, odorless, and tasteless, biological agents may be used as an ultimate weapon—easy to disperse and inexpensive to produce."[67] The international

Table 6.1 Examples of infectious agents applied as weapons during wartime prior to 1970 (developed from Christopher et al.[22] with additions).[a]

Agent	Agent/disease characteristics				Bioweapons use						
	Type	Disease	Zoonoses	Animal reservoirs[b]	Targeted species		Geographic area events				Era[c]
					Humans	Animals	Europe	Asia	USA	South America	
Yersinia pestis	Bacteria	Plague	●	Small rodents	●	○	●	●	○	○	14th century; WWII
Bacillus anthracis	Bacteria	Anthrax	●	Livestock, herbivorous wildlife	○	●	●	○	●	●	WWI
Burkholderia mallei	Bacteria	Glanders	●	Horses, mules, donkeys, camels	○	●	●	○	●	●	WWI
Vibrio cholerae[d]	Bacteria	Cholera	●	Zooplankton	●	○	○	●	○	○	WWII
Salmonella spp.	Bacteria	Salmonellosis	●	Many, depends on *Salmonella* spp.	●	○	○	●	○	○	WWII
Francisella tularensis	Bacteria	Tularemia	●	Rabbits, voles	●	○	●	○	○	○	WWII[e]
Shigella spp.	Bacteria	Shigellosis	○	None	●	○	○	●	○	○	WWII
Variola major	Virus	Smallpox	○	None	●	○	○	○	●	○	1754–1767

[a] Numerous other disease agents were evaluated and some pursued for bioweapons by the USA, Iraq, USSR, and others. Reported wartime use of infectious agents has essentially been limited to the pathogens listed with the exceptions of experiments conducted and diseased animal carcasses and sewage intentionally used to contaminate human drinking water supplies.

[b] Primary species for disease maintenance between periods of natural outbreaks; also species associated with outbreaks.

[c] WWI= World War I; WWII=World War II; 1754–1767=French and Indian War; 14th century= Siege of Caffa (Kaffa).

[d] Cholera is typically a waterborne and foodborne disease involving their contamination by the bacteria; the disease does not rely on animal hosts other than zooplankton, but a wildlife component, such as contaminated shellfish, can be involved in disease transmission.

[e] Debate remains whether massive outbreaks of tularemia on the Eastern Front was a biowarfare application against German troops or occurred naturally.

●= positive; ○= negative

Box 6–1 See No Evil, Hear No Evil, Speak No Evil

"Russia has…never developed, produced, accumulated, or stored biological weapons."—Address by Grigory Berdennikov, head of Russian delegation to a November 1996 conference of signatories to the 1972 Biological Weapons Convention[26]

Catastrophic events often result in basic questions being asked. Why did this happen? Could this have been prevented? Should we have been better prepared? These and other questions clearly apply to bioterrorism. Inadequate levels of preparedness are in part reflections of problem denial and other priorities within national policy circles, and the belief that open dialogue in this subject area should be avoided so that potential perpetrators would not be enticed to pursue such actions.[32] In essence, past approaches to the issues of bioterrorism have generally followed the first two components of the adage "See No Evil, Hear No Evil, Speak No Evil;" while at the same time, some nations were undertaking the development of biological weapons for defensive purposes.

Microbes as Weapons

Biological weapons, or bioweapons, are those containing replicating microorganisms (viruses, fungi, and bacteria, including chlamydia and rickettsia), prions, protozoa, or poisonous chemical toxins produced by living organisms (e.g., botulinum toxin, cobra venom, and the plant toxin, ricin).[139] Depending on the pathogen being used, these weapons may be employed against humans, animals, or crops.[110,140] In some instances, multiple species groups

Table A. Examples of current publications dealing with biowarfare and/or bioterrorism.[a]

Title	Content
Biological and Toxin Weapons: Research, Development and Use from the Middle Ages to 1945 [14]	Publication title indicates content.
Bioterrorism and Public Health: An Internet Resource Guide[204]	An Internet resource guide to a wide range of Web-based resources; basic information also included as text.
PDR Guide to Biological and Chemical Warfare Response[205]	Signs, symptoms, and recommended treatments for over 50 biological and chemical agents.
Bioterrorism: Guidelines for Medical and Public Health Management[49]	Compilations of consensus statements from the Working Group on Civilian Biodefense, anthrax case reports, and intervention analysis.
When Every Moment Counts: What You Need to Know About Bioterrorism from the Senate's Only Doctor[27]	Questions and answers about anthrax, smallpox, plague, botulism, tularemia, Ebola, other viral hemorrhagic fevers, and other relevant subject areas.
Terrorism and Public Health: a Balanced Approach to Strengthening Systems and Protecting People[177]	Organized under main subject areas of The Public Health Response to September 11 and Its Aftermath, Terrorist Weapons, Challenges and Opportunities.
Factories of Death: Japanese Biological Warfare, 1932–1945, and the American Cover-up[23]	Comprehensive account of the Japanese biological warfare program (experimental and field applications) from 1932–1945.
Biohazard: the Chilling True Story of the Largest Covert Biological Weapons Program in the World, Told from the Inside by the Man Who Ran it[26]	Personal account of the biological weapons program of the former USSR by the leader of that program.
Secret Agents: The Menace of Emerging Infections[206]	Primary focus is on the emergence of infectious disease but contains a major chapter on the evolution of bioterrorism.

[a] These examples are not considered of greater value than other publications in this subject area.

(e.g., animals and humans) may be affected. The use of such weapons by a nation against other nations and by insurgents within nations is generally referred to as biowarfare, while the use of these weapons for terrorist activities is generally referred to as bioterrorism. The distinction between these terms is not always clear and can be a subject for legal debate, when charges are pressed against those involved with using bioweapons.

Myths vs. Reality

During the 1980s and late 1990s,[32,141] many held the false impression that bioterrorism events were unlikely. The attacks on the USA during September and October 2001 elevated society's awareness of vulnerability to terrorist attack and the use of biological weapons.

The Fear Factor

The concept of "weapons of mass destruction" has evolved technologically over time and is now seen as a great threat to society. The agents posing the greatest hazard are microbes of antiquity, rather than nuclear or chemical weapons,[32,141] with these types of weapons gaining prominence in people's conversations, anxieties, and fears.

Bioterrorists exploit the fear factor through use of bioweapons,[12,47,142] which the USA and other countries are least prepared to address.[29,143] Prior to September 11, 2001, the most common vision of a biological attack was that of a pathogen-laden aerosol being dispersed over the landscape delivered by missile, "dirty bomb," or other

Table B. Primary factors associated with bioweapons use (developed from Osterholm[15] with adjustments).

Action	Critical factors[a]		
	Potential perpetrators	**Availability of biologic agents**	**Technical means for pathogen dissemination**
General	Wide variety of individuals and groups; actions taken may be for criminal purposes as well as terrorist or political motivations. For example, animals could be targeted to rid an area of unwanted species or to impose economic losses on a business competitor.	Ideal agents are inexpensive; easy to produce; can be aerosolized; are resistant to sunlight, heat, and drying; cause lethal or disabling disease; can be transmitted person-to-person; and cannot be effectively treated.[b]	Pathogen entry into the body can occur by several means including inhalation (aerosol), ingestion (oral), injection (bites and through abrasions following direct contact), and absorption (dermal).[c]
Biowarfare	Government action against other governments; insurgents within nations against their own governments.	Stockpiles exist in a number of nations despite disarmament efforts. Iraq's biological weapons program had produced considerable quantities of botulinum toxin, anthrax, and at least two other pathogens.[71] The weapons program of the former USSR produced tons of anthrax, smallpox, and other organisms.[26,28,45] The USA program was also productive.[22]	By the late 1960s the USA program had weaponized three lethal and four incapacitating agents of viral and bacterial (including rickettsial) origin. Stockpiles of these agents were destroyed between 1971–1973.[22] The technology to deliver biological agents as weapons of war developed by the USA, the Soviets, and others has not been lost and has been improved on since the 1970s.
Bioterrorism	Individuals, cults, nonaligned groups.	Many naturally occurring pathogens that could be used as well as the potential for obtaining pathogens being worked with in various laboratories. Relatively inexpensive to obtain agents capable of causing moderate disease outbreaks.[45]	Biological weapons suitable for terrorist attacks are easy to produce, conceal, and transport. Elaborate "weaponization" is not needed for attacks to cause considerable damage.[45]

[a] All three factors must be fully satisfied for a viable attack to occur.

[b] Context is for human disease; other desirable attributes include the ability to affect other species in addition to humans (zoonoses) and to be maintained in nature as a self-sustaining disease.

[c] Not all pathogens can enter by all means; inhalation and ingestion are common routes for many pathogens; bites by infected arthropods is the primary route for many others; a small number can be absorbed through the skin (dermal exposure).

means.[15,144] This vision arises from development of bioweapons programs around the world that project casualties from aerosol deployment of these weapons.[19,24,29,58,145]

The bioterrorist attacks prior to the 21st century were generally amateurish in design, received limited publicity, and did not greatly elevate public concerns.[146] However, the terrorist actions against the USA on September 11, 2001, and the anthrax letter attacks of October 2001 rapidly reshaped public psyche towards bioterrorism. Government agencies began to recognize that terrorist activities had the potential for turning pathogens into contemporary weapons beyond aerosolization. CDC Epidemic Intelligence Service investigators noted that,

> "Viewing the bioterrorist's preferred weapon as a high-threat, aerosolizable infectious agent that may cause immediate, widespread outbreaks may mislead preparedness efforts."[77]

The CDC's message is meant not to disregard pathogens as weapons, but to warn the Nation and the world to better prepare for biological weapon application beyond aerosolization.

Combating Ignorance

Recently, a profusion of books (Table A) and other sources for information about bioterrorism and pathogens as bioweapons have been published. These sources contain a great deal of factual information that can help people gain knowledge about bioterrorism and bioweapons, and increase their understanding of relative risks posed by various pathogens, their potential application as bioweapons, and appropriate responses in the event of exposure. Because "terrorism feeds on fear, and fear feeds on ignorance,"[104] such knowledge helps combat terrorism.

Reality Check

Biowarfare and bioterrorism share the same three critical elements necessary for an event to occur: (1) potential perpetrators; (2) availability of biologic agents; and (3) technical means for dissemination.[15] Yet, the potential for bioterrorism grew, while that for biowarfare diminished (Table B). The concept of microbes as "weapons of mass destruction," is more a biowarfare than a bioterrorism issue, because terrorists are limited by high costs and limited availability of sophisticated bioweapons systems. Terrorists are less likely to access pathogens with enhanced virulence or resistance to treatment because of greater laboratory security in existence today. They are also less likely to locate amounts of disease agents able to be delivered by wartime weapon deployment. In addition, terrorists may attack less strategic sites, because access to more desirable sites that could be struck by military weapon systems may be difficult.

The terrorist events against the USA during 2001 have served as a general "wake-up call" for society. In addition to human deaths, collateral impacts involving fiscal costs and alterations in activities and services caused mass disruption of society. Today there are not only more choices of terrorist weapons,[29,78,143] but also increasing numbers of people willing to carry out terrorists activities, even at the cost of their own lives.[57,73] Therefore, combating enhanced threats requires greater vigilance so that we can "see and hear the evil" and respond to it before others can "do evil" to us.

community experiencing the ravages from chemical weapons during WWI, banned their proliferation and use. Biological warfare was partially incorporated within the diplomatic efforts leading to the 1925 Geneva Convention (Geneva Protocol for the Prohibition of the Use in War of Asphyxiating, Poisonous or Other Gases, and of Bacteriological Methods of Warfare).[22,68] In 1972, the Convention on the Prohibition of the Development, Production, and Stockpiling of Bacteriological (Biological) and Toxin Weapons and on Their Distribution (BWC) was signed by more than 100 nations, was ratified, and went into effect in 1975.[69] Those and subsequent actions by the international community have diminished, but not eliminated, the threat of these types of weapons.

A difficulty with the BWC is that it is largely an agreement based on trust; there are inadequate oversight activities to monitor compliance.[53,70] Major transgressions among signatory parties to the BWC included strategic weapons development by the former Soviet Union, Iraq, and others.[22,31,71] These transgressions are ominous deviations from beliefs of Vannevar Bush (cited by Lederberg[70]): "Without a shadow of a doubt there is something in man's make-up that causes him to hesitate when at the point of bringing war to his enemy by poisoning him or his cattle and crops or spreading disease. Even Hitler drew back from this. Whether it is because of some old taboo ingrained into the fiber of the race…. The human race shrinks and draws back when the subject is broached. It always has, and it probably always will."[72] Some limited use of biological and chemical weapons has occurred since these statements by Vannevar Bush. Nevertheless, in recent times, countries that possess such weapons are reluctant to use them, many countries are abandoning these weapon programs, and most who possess stockpiled biological weapons are destroying them. However, global increases in terrorism have resulted in an increased potential for infectious diseases to become common weapons (Table 6.2).[73] A virtual cornucopia of pathogens exist that could potentially be used for terrorist activities. Many of these biological agents are readily available, and bioterrorists need not have sophisticated knowledge or expensive technology as the following examples demonstrate.

In Oregon (USA) in 1984, the Rajneeshee cult intentionally contaminated salad bars at ten restaurants with *Salmonella typhimurium* as a trial run for another planned action intended to disrupt local voter turnout for an election. More than 750 cases of enteritis and 45 hospitalizations resulted from the salad bar incidents.[22,74] The cult's attempted *Salmonella* contamination of a city water supply was a failure.[75]

In 1996, a Texas (USA) hospital laboratory worker intentionally contaminated pastries with a strain of *Shigella dysenteriae* stolen from the laboratory. He then left those pastries in a break room where they were eaten by coworkers who became ill.[76] The following year, an incident of possibly intentional contamination by the use of *Shigella sonnei* occurred among workers in a hospital laboratory in New Hampshire, USA.[77]

Other attacks likely have taken place that were unsuccessful or have not been identified as acts of bioterrorism. It was more than a year after the Oregon salad bar events that intentional contamination was determined to be the cause.[78] Failed attempts to employ biological agents in acts of terrorism by the Aum Shinrikyo cult also did not become known until later. This cult was responsible for the 1995 chemical

Bioweapons and Human Impacts

Biowarfare programs seek to "inflict sufficiently severe disease to paralyze a city and perhaps a nation."[32] However, only a few of the thousands of biological agents capable of causing disease in humans are suitable pathogens for this purpose.[29,32] To be effective, bioterrorism does not need to achieve the level of impact sought by biowarfare programs. Bioterrorism impacts humans through fear as well as through disease and death, thereby exploiting pathogens as weapons for mass disruption. Bioweapons are unsurpassed by any other weapon relative to effectiveness and usability because they satisfy all of the following attributes required for effective weapons.[15]

Attribute	Practicality
Within the economic and practical means of the perpetrator(s)	"Biological weapons are relatively inexpensive, easy to produce, conceal and transport, and can cause considerable damage."[45] "Only modest microbiologic skills are needed to produce and effectively use biologic weapons. The greatest, but not insurmountable, hurdle in such an endeavor may be gaining access to a virulent strain of the desired agent."[58]
Capable of reaching the intended target	Great arrays of delivery systems are available from hand-carried and applied introductions to deployment through munitions for the release of infectious agents and biological toxins.
Cause limited collateral damage, in particular to those staging the attack	Self-protection can be gained through immunizations for some diseases and other appropriate steps taken during the preparation, transport, and discharge of the pathogen. Many terrorists often are willing to die for their cause so personal exposure may not be a major issue. Because occupation of territory may not be a near-term goal, residual disease and secondary impacts also may not be of concern.
Must result in the desired outcome, usually death	Selection of appropriate pathogens results in high probability for the outcome to infect at least some of the population.

The above characteristics reflect the criteria developed in 1999 by a group of infectious disease, public health, intelligence experts, and law enforcement officials who met to evaluate the potential impacts from pathogens if used in terrorist attacks (see Tables 6.3–6.5).

The criteria used for their evaluations were: "1) public health impact based on illness and death; 2) delivery potential to large populations based on stability of the agent, ability to mass produce and distribute a virulent agent, and potential for person-to-person transmission of the agent; 3) public perception as related to public fear and potential civil disruption; and 4) special public health preparedness needs based on stockpile requirements, enhanced surveillance, or diagnostic needs…." That evaluation was oriented for large-scale attacks because public health agencies must be able to cope with worse-case scenarios, even though small-scale bioterrorism events may be more likely.[59]

Table 6.2 Examples of disease transfer between wild and domestic species (adapted from Bengis et al.[64] with additions).

Disease	Causative agent	Agent type	Original maintenance host	New hosts	Epizootic potential	Comments
Rinderpest	Morbillivirus	Virus	Cattle	Wild artiodactyls (hoofed-mammals, e.g., antelope)	Major	Infected cattle from India initiated major pandemic of 1889–1905 in sub-Saharan Africa. Now a major disease of livestock and wildlife in that region.
Bovine tuberculosis	*Mycobacterium bovis*	Bacteria	Cattle	Bison, buffalo, deer, many other species.	Moderate	Probably introduced into Africa with imported dairy and beef cattle during the colonial era. Wildlife reservoirs in other countries also likely to have acquired infections from livestock (deer in USA, badger in UK, brush-tailed possums in New Zealand).
Canine distemper	Morbillivirus	Virus	Domestic dog	Wild dog, lion, jackals, hyenas, seals	Moderate	Introduced into Africa with domestic dogs; dogs are thought to be source of recent epizootics in seals in the Caspian Sea and in Lake Bikal, Russia.
African swine fever	Asfarvirus	Virus	Wild porcines	Domestic swine	Major	Introduced into Portugal in the early 1960s and spread throughout much of Europe before being eradicated in domestic pigs from most of this area.
African horse sickness	Orbivirus	Virus	Zebras	Horses, donkeys	Moderate	Spread from sub-Saharan Africa to Middle East and Iberian Peninsula; appears to be related to importation of zebra from Namibia.
Avian cholera	*Pasteurella multocida*	Bacteria	Poultry	Wild waterfowl	Major	Most likely brought into North America with poultry brought from Europe during colonial days; first appearances in wild waterfowl in USA in 1944 appeared to be spill-over events from epizootics in chickens; has become the most important infectious disease of wild birds.[173]
Duck plague	Herpesvirus	Virus	Domestic ducks	Wild waterfowl	Moderate	First North American appearance in 1967 as epizootic in Long Island, New York (USA) white Pekin duck industry. Now established in USA in wild and feral species of waterfowl in some geographic areas.[174]
Newcastle disease	Paramyxovirus	Virus	Poultry	Wild birds	Major	First arose sometime prior to 1926 in Indonesia (first event) and in 1926 in the UK as a new disease of poultry.[175] Eradicated from the USA and Canada (lethal strains) by early 1970s; became established in cormorants in these areas since 1990.[176]

attack (Sarin) of the Tokyo subway system, and used anthrax bacteria (*Bacillus anthracis*) and botulism toxin during three unsuccessful attacks in Japan.[79–81] Although unsuccessful, their 1993 spraying of *B. anthracis* from the roof of an eight-story building in Tokyo was the first documented instance of bioterrorism with an aerosol containing this pathogen.[81]

A major difference between bioterrorism and biowarfare is that bioterrorism can have a major impact with only small numbers of cases of disease. For example, the previously mentioned October 2001, anthrax-laced mail within the USA caused disease in 22 people[82] and 5 deaths.[83] However, the billions of anthrax spores contained in those letters had the potential to create a major epidemic, including many more deaths. The resulting public fear disrupted people's lives; resulting investigations and responses were costly, and there were extensive disruptions in public services.

Collateral Impacts

The costs from acts of terrorism extend far beyond the direct damage inflicted by the weapons employed. Within the USA, efforts to bolster national defense and response capabilities against further acts of terrorism have included flurries of activity focused on infrastructure enhancement, training, investigations, and associated matters within the public health, biomedical, law enforcement, and intelligence communities. In late 2001, the U.S. Congress created the Department of Homeland Security, and a series of administrative and regulatory actions were set in motion. These and other actions have created new biodefense opportunities and affected traditional scientific, social and other mainstream aspects of life.

Biodefense Spending Boom

Billions of dollars are being allocated to biomedical research to help build a protective shield against infectious diseases and their potential uses by terrorists as bioweapons.[84–87] The construction of biosafety level (BSL)-4 facilities—laboratories where the most hazardous pathogens can be contained and handled—is a major component of increases in biodefense funding. Worldwide, only about five BSL-4 facilities existed between 1970 and 1995. During the 1990s, global threats from emerging infectious diseases made the need for additional BSL-4 and BSL-3 facilities evident (BSL-3 facilities are also high security, but handle slightly less hazardous pathogens than BSL-4).

A veritable building boom for high security infectious disease facilities began during the 1990s and was further stimulated by the events in the fall of 2001.[88] By 2000, the USA had five BSL-4 laboratories and others planned.[89] During 2003, Boston University in Massachusetts (USA), and the University of Texas Medical Branch in Galveston, Texas (USA), were awarded $120 million each in construction grants to initiate construction of BSL-4 facilities. Nine other institutions were awarded grants of $7 million to $21 million to build BSL-2 and BSL-3 laboratories as part of a new system of regional biodefense research centers.[85,86,90]

A record budget increase during 2003 for the National Institutes of Health (NIH) resulted from bioterrorism-directed funding.[91] Other major USA initiatives include the President's requests for "Project BioShield" to develop new treatments and vaccines for potential bioterror agents ($6 billion) and the "BioWatch Initiative" to upgrade and establish 3,000–4,000 pollution-monitoring stations with high-tech sensors (billions of dollars to establish plus annual costs).[92] Vaccine production is another major investment. In 2003, contracts worth more than $770 million were awarded by the U.S. government for the production of smallpox vaccine.[93] Much of the biodefense funding allocated to the biomedical area will enhance the public health infrastructure and the capabilities needed for the battle against emerging infectious diseases.

Pathogens of Concern

> **"[We are] determined for the sake of all mankind, to exclude completely the possibility of bacteriological agents and toxins being used as weapons; [We are] convinced that such use would be repugnant to the conscience of mankind and that no effort should be spared to minimize this risk..."**
> **—Preamble to the Biological and Toxin Weapons Convention, 1972.[26]**

Public health and agriculture agencies are guided by listings of pathogens of concern related to their areas of responsibility (Appendix C); these lists include hazardous agents that could be used potentially in bioterrorism. Public health listings are separated into priority levels of A, B, and C, and the pathogens within each level are arranged in priority order (Tables 6.3–6.5). Many of the diseases of concern for human health can also affect domestic animals and wildlife.[60–66] Conversely, several of the 22 diseases of concern for agriculture (Table 6.6) can affect human health. However, there is little duplication between these lists. Anthrax (Table 6.3), ornithosis, and Venezuelan **equine** encephalomyelitis (Table 6.4) are the only diseases shared.

Indirect Impacts from Bioterrorism

Bioterrorism aimed at society, a government, and/or its citizens is meant to cause destabilization, fear, and anxiety.[94,95] It threatens conduct of scientific investigations involving pathogens of concern,[84, 90, 97–99] and hinders free flow and exchange of scientific findings and information.[100–105] It changes emergency medical preparedness and response,[42, 94, 96] and muffles transparent communication.

Changes in the guidelines for scientific investigations involving pathogens of concern include new criminal charges and fines that could affect scientists and scientific institutions.[207] A graduate student at a university in the Eastern USA was the first researcher charged under new antiterrorism laws with mishandling a potential bioterror agent (possession of anthrax-tainted cow tissue collected in the 1960s and maintained in a locked laboratory freezer).[106] A higher profile incident involved a prominent USA plague researcher jailed on charges of lying to federal agents about the fate of plague samples, mishandling laboratory samples, and illegally importing plague samples into the USA.[107,108] Actions of this type are also occurring outside the USA. A top research institute in the UK was ordered to pay nearly $65,000 in fines for not having adequate security to protect laboratory workers and the public from potential exposure to a hybrid virus they were developing.[109]

The costs from bioterrorism go beyond the direct impacts of terrorist attacks. Indirect costs, such as those highlighted here, are part of the costs imposed by the potential for attack that causes society to take defensive actions to minimize the potential for success by terrorists.

The differences between the lists for human health and agriculture are because domestic animal pathogens are primarily considered from the perspective of economic trade impacts and/or ease of transmissibility. Human pathogens are considered more from the perspective of potential mortality rates and/or public fear of the disease. Although anthrax appeared on the 1952 list of potential animal **bioweapons** it "was assumably dropped from the anti-animal biological weapons agent lists because an effective vaccine had been developed."[110] Smallpox has been eradicated and, theoretically, the virus only exists within the rigid control of repositories in Russia and the USA. Nevertheless, governments have developed smallpox response strategies.

In part, pathogens of concern appearing on various lists reflect the orientation of those developing the lists and the geographic area of coverage. For example, the Office International des Epizooties (OIE) headquartered in Paris previously maintained lists for two levels of animal diseases of concern for international trade involving live animals and animal products (Table 6.7 and 6.8). Several of the list A diseases (Table 6.7) are absent from the USA list of animal diseases (Table 6.6). Also, differences exist between these lists and the agriculture disease list of the Ad Hoc Groups of State Parties to the BWC (Table 6.9). In 2005, the OIE A and B lists were replaced by a single list of diseases notifiable to the OIE, thereby giving all listed diseases the same degree of importance in international trade (http://www.oie.int/eng/Edito/en_edito_apr04.htm). The new list is restricted to livestock and poultry diseases, adds anthrax and some other diseases, but eliminates diseases of **bees** and aquaculture that previously appeared on the B list (http://www.oie.int.eng/maladies/en_classification.htm).

Differences notwithstanding, the combined list of pathogens of concern is long (Appendix D). This list is subject to change because of the continued emergence of new infectious diseases; the emergence of treatment-resistant strains of established pathogens; and social, technical, and ecological changes that allow new opportunities for diseases to be introduced as weapons. The connectivity for many of these diseases across species groups (Fig. 6.1) is an important dimension to consider, regardless of whether an individual's interest is human, domestic animal, or wildlife health.

Animal Disease and Bioterrorism

> **"Detection of disease in lower animals may be essential to detecting a bioterrorism event because most of the bioterrorism threat agents are zoonotic disease agents."[77]**

History has recorded the use of animals as vehicles for the transmission of disease and as intended victims for disease introduction. Enemies propelled dead animals into besieged cities[17] and used diseased animal carcasses (natural causes of disease) to contaminate wells, reservoirs, and other water sources of armies and civilian populations.[22] During WWI, British troops successfully used this latter concept to deny the German army use of critical water resources in a remote area of East Africa, while retaining use by their own troops. They shot antelope and scattered the carcasses around the edges of the waterhole to give the impression that the water was unfit for human use.[41]

German saboteurs during WWI used bacteria that cause anthrax and glanders to infect military horses and **mule**s of the Allied forces. Livestock food sources for the military were

Table 6.3 Category A (highest priority) critical biological agents for public health response activities (list is from Levy and Sidel[177]).[a]

Agent	Type	Disease	Zoonoses	Previous[b] use	Weaponized[c]	Comments
Variola major	Virus	Smallpox	○	●	●	Not used in modern times but remains a major threat because of high susceptibility of human population and ease of disease transmission.
Bacillus anthracis	Bacteria	Anthrax	●	●.	●	Enzootic disease in several areas of the world; naturally occurring outbreaks in white-tailed deer sporadically occur in the USA.
Yersinia pestis	Bacteria	Plague	●	●	●	Enzootic disease within the USA.[3]
Clostridium botulinum toxin	Bacterial toxin	Botulism	○	●	●	Attempted uses have not been very successful but one of the most potent toxins known.
Francisella tularensis	Bacteria	Tularemia	●	●	●	Enzootic disease in many areas of the world including the USA; rabbit strain (Type A) more virulent than aquatic rodent strain (Type B).
Ebola virus (Filovirus)	Virus	Ebola hemorrhagic fever	●	○	○	High mortality rates (up to 90 percent); endemic in parts of Africa but little known about the ecology of Ebola. Former USSR bioweapons programs pursued weaponization of Ebola and Aum Shinrikyo cult pursued acquisition of this virus.[27]
Marburg virus (Filovirus)	Virus	Marburg hemorrhagic fever	●	○	○	Rare disease associated with handling non-human primates; high mortality rates.
Lassa virus (Arenavirus)	Virus	Lassa fever	●	○	○	Endemic within parts of West Africa; mice maintain this arenavirus in nature; human to human transmission more common than with other hemorrhagic fevers.[62]
Junin virus (Arenavirus)	Virus	Argentine hemorrhagic fever (AHF) and related viruses	●	○	○	Endemic within South America; maintained within mice and other small rodents; AHF human fatality rate is between 10–20 percent. Other arenaviruses also associated with small rodent reservoirs have recently appeared in the USA.[62]
Machupo virus (Arenavirus)	Virus	Bolivian hemorrhagic fever (BHF)	●	○	○	Endemic in Bolivian province of Beni; mice are the reservoir host; mouse excretions most important source for human infections; human fatality rate is about 18 percent.[62]

[a] Category A agents "include organisms that pose a risk to national security because they can be easily disseminated or transmitted person-to-person; cause high mortality, with potential for major public health impact; might cause public panic and social disruption; and require special action for public health preparedness."[178]

[b] Confirmed applications of agent during wartime, by terrorists, and/or as criminal activity.[23,33,37,179]

[c] Agent produced for weapons use by nations with biowarfare programs.[14,22,23,33,52]

●= positive; ○= negative

Table 6.4 Category B (second highest priority) critical biological agents for public health response activities (list is from Levy and Sidel[177]).[a]

Agent	Type	Disease	Zoonoses	Previous[b] use	Weaponized[c]	Comments[d]
Brucella spp.	Bacteria	Brucellosis	●	○	●	Widely occurring, debilitating disease prevalent in parts of Europe, Africa, Asia, Latin America (including Mexico) and arctic and sub-arctic areas of North America. Human cases are closely associated with contact with infected farm animals, caribou and reindeer, and consumption of unpasteurized dairy products from infected animals.
Epsilon toxin of *Clostridium perfringens*	Bacterial toxin	Enterotoxemia	●	○	●	Foodborne disease; causative agent of gas gangrene.
Food Safety Threats:						
Salmonella spp.	Bacteria	Salmonellosis	●	●	●	Foodborne disease; used in attacks within the USA.
Shigella dysenteriae	Bacteria	Shigellosis	○	●	●	Foodborne disease; used in attacks within the USA.
Escherichia coli O157:H7	Bacteria	Colibacillosis	●	○	○	Foodborne disease.
Burkholderia (Pseudomonas) mallei	Bacteria	Glanders	●	●	●	Primarily a disease of domestic animals (especially horses, donkeys, and mules) within parts of Asia and the Middle East. High human fatality rate among untreated, acute cases (close to 100 percent).
B. pseudomallei	Bacteria	Melioidosis	●[e]	○	○	Primarily a disease of humans and animals in Southeast Asia and Australia but also occurs worldwide in tropical and subtropical areas. Acute infections can be fatal; chronic disease also occurs. Transmission by contact, ingestion, and inhalation of organisms, but rarely due to direct transmission from animals.
Chlamydia psittaci	Bacteria	Ornithosis (psittacosis)	●	○	○	Worldwide distribution involving detection in more than 130 bird species. Transmission to humans generally by inhalation of contaminated dusts or contact with excretions of infected animals.
Coxiella burnetti	Rickettsia	Q fever	●	●	●	Worldwide (except for New Zealand) debilitating disease transmitted by ticks, a wide variety of animals (including some birds), and by airborne dust contaminated with tick feces and dried feces from infected animals.
Ricin	Plant toxin	Toxicosis	○	●	●	Toxin produced from castor beans (*Ricinus communis*); first isolated in 1889. Commercial formulation used as a mole killer.[180] Covert use by assassins and terrorists, including attacks in the USA.[179]
Staphylococcal enterotoxin B	Bacterial toxin	Enterotoxemia	●	○	●	Aerosol and food poisoning potentials as a biological agent.

Table 6.4 Category B (second highest priority) critical biological agents for public health response activities (list is from Levy and Sidel[177])[a]—Continued

Agent	Type	Disease	Zoonoses	Previous[b] use	Weaponized[c]	Comments[d]
Rickettsia prowazekii	Rickettsia	Typhus fever/epidemic typhus	●	○	○	Classical epidemic form has a mortality rate of 10–40 percent. Endemic areas persist in North and Central Africa, South America, and the former USSR; sporadic cases in the USA are associated with flying squirrels. Typically, a louse-transmitted disease. Airborne transmission via inhalation of agent from dried feces of infected lice and other ectoparasites and dead lice.
Alphaviruses	Virus	Venezuelan, eastern, and western equine encephalitis	●	○	●	Mosquito transmitted diseases, primarily of the Americas, involving a variety of animal species. Horses are an important amplification host for virus production and infection of mosquito populations. Encephalitis resulting in mortality, primarily in children, generally occurs in less than 5–10 percent of human infections.
Water Safety Threats:						
Vibrio cholerae	Bacteria	Cholera	○[f]	●	●	Food/waterborne disease. Seventh pandemic began in Indonesia in 1961, and reached South America in the early 1990s.[181,182]
Cryptosporidium parvum	Protozoan parasite	Cryptosporidiosis	●	○	○	Worldwide disease associated with contact with livestock, person-to-person transmission in daycare centers and medical institutions, and contaminated water and food.

[a] Category B agents "include those that are moderately easy to disseminate; cause moderate morbidity and low mortality and require specific enhancements of CDC's diagnostic capacity and enhanced disease surveillance."[178]

[b] Confirmed applications of agent during wartime, by terrorists, and/or as criminal activity.[23,33,37,179]

[c] Agent produced for weapons use by nations with biowarfare programs.[14,22,23,33,52]

[d] For more information, see Beran and Steele,[61] Krauss et al.,[62] Williams and Barker.[183]

[e] Since a vertebrate reservoir host is not required for maintenance of the causative agent in nature, this disease is more appropriately a sapronosis, saprozoonosis, or geonosis.[62]

[f] Non-human vertebrates are not an important aspect of the ecology of cholera.

●= positive; ○= negative

also targets.[22, 110, 111] These events took place in Europe, the USA and South America (Table 6.1). During 1917 to 1918, more than 200 mules intended for export to Allied forces from Argentina died from these attacks.[111] During WWI there are no reports of widespread disease due to any covert uses of infectious disease. Disease agents have been used since then against cattle and horses in Africa and Afghanistan (Fig. 6.4).[26, 112, 113]

Agroterrorism

During the timeframe when the public health community in the USA was raising concern about potential bioterrorism, the U. S. Department of Agriculture (USDA) requested that the National Academy of Sciences evaluate potential impacts of terrorist actions against agriculture. The resulting report, *Countering Agricultural Bioterrorism*, (2002; http://www.nap.edu) concluded that the USA was not adequately prepared to prevent or address such attacks, and that there was enormous potential for economic harm from bioterrorism.[114] The Academy's findings reaffirmed the great vulnerability of agriculture to terrorist attack.[110, 115–117] Criteria have been established for the identification of pathogens considered to pose the greatest threats to domestic animals, and this list consists of 22 agents (Table 6.6).

The agriculture pathogen list is a reflection of diseases whose occurrence is of great economic concern (see Chapter 3). For example, consider the magnitude of the immediate economic losses experienced, first by Canada in mid-2003 and then by the USA at the end of 2003, following single cases in cattle of bovine spongiform encephalopathy (BSE) or mad cow disease. The resulting market impacts associated with human fear of contracting disease from meat from infected cattle illustrates the connectivity between animal disease and human health and the potential for agroterrorism.

A single case of a high profile disease (e.g., BSE) or a small number of cases of more common diseases (e.g., Newcastle disease or bovine tuberculosis) may result in international sanctions that cause major economic losses for agriculture and related industries. The connectivity between many diseases of animals and humans suggests the need for integrated preparedness for addressing the potential for bioterrorism attacks against animals. The 2001 outbreak of foot-and-mouth disease (FMD) in Europe is somber testimony to the costs that can be incurred by agriculture from the introduction of a highly contagious disease. More than 6 million animals were slaughtered to combat this disease.[209] Predicted costs from an FMD outbreak in California alone are at least $13.5 billion.[210]

"Double Agents"

Pathogens that can cause disease in humans and animals can be viewed as "double agents" relative to the populations they can impact. Although the historic use of biological agents in wartime appears to have been specifically focused on either human or animal targets, most of the early uses of microbes as bioweapons involved agents capable of causing serious disease in both (Table 6.1). The interfaces between humans and animals can promote persistence and spread of infectious agents. Thus, careful selection of target situations can enhance the probabilities for disease in both humans and animals, and increase the potential for environmental persistence of the disease agent and disease spread through animal movements.

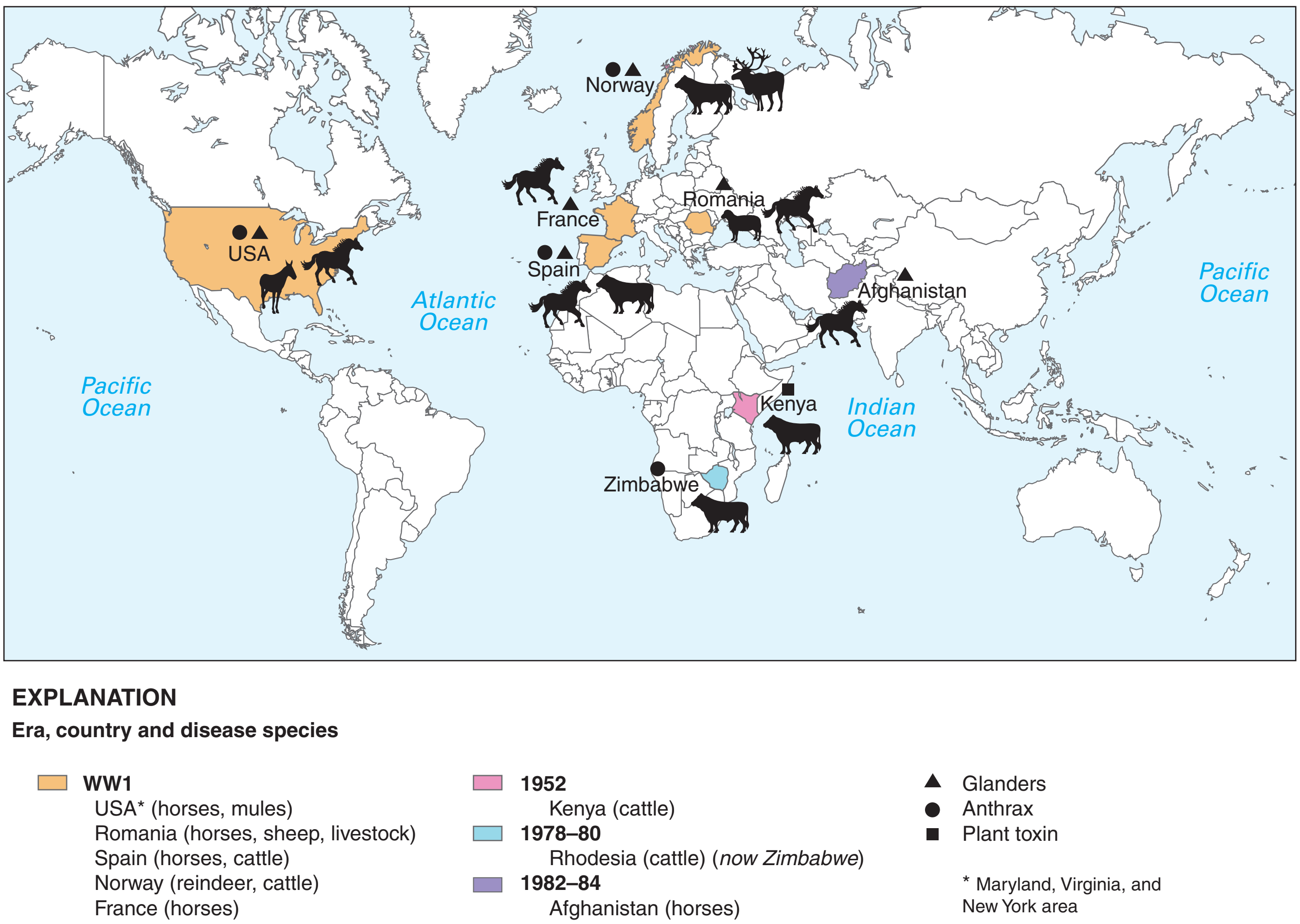


Figure 6.4 Documented war time uses of biological weapons to target livestock (developed from Wilson et al.[110]).

Anthrax is an example of a “double agent.” In 1979, there was an accidental release of anthrax spores from a research facility within the former Soviet Union.[26] According to one report, at least 77 people who lived or worked within 4 km in a narrow zone downwind from the release site became infected and 66 died, making this the largest documented epidemic of inhalation anthrax in history.[22, 118] Livestock deaths from anthrax extended out to 50 km.[119] The final death toll may have been as high as 200 to 1,000 people.[73, 120]

The deliberate uses of anthrax in Africa were even more devastating. Anthrax appears to have been used as a bioweapon in Rhodesia (now Zimbabwe) during the war of independence in the 1970s.[110] Those in power targeted cattle to undermine the morale and food supply of those seeking independence. The breakdown of government administration and veterinary services due to the war aided anthrax’s epizootic nature and disease spread. The ensuing human epidemic resulted in about 10,000 cases of illness and hundreds of deaths. The persistence of anthrax in Zimbabwe since then continues to take a large toll on human life, domestic animals, and wildlife.[110]

Anthrax is only one of several infectious diseases capable of causing severe illness and death in humans and animals alike. Because of this, there is great difficulty in combating such diseases and an increased probability for persistent residual effects.

Characteristics of the Most Dangerous Pathogens in Attacks Against Agriculture

Pathogens that pose the greatest terrorist threat (*Most Dangerous* category) to agriculture were determined by experts who identified combinations of the following characteristics.[110]

Pathogen characteristic	Outcome
Highly infectious and contagious	Low doses able to cause initial infections and disease followed by spread from one animal to another.
Good ability to survive in the environment	Not easily inactivated by ambient temperatures and other physical conditions outside of the host, so that contact with pathogen-contaminated substrates (e.g., water, soil, vegetation) can serve as sources for infection.
Predictable clinical disease pattern, including morbidity and mortality	Allows terrorists to consider specific species targets and strategically plan to produce desired impacts.
Pathogenic for livestock or poultry	May cause severe disease outcomes such as mortality, reproductive failure, and economic losses due to product embargoes.
Available and easy to acquire and produce	Allows use of common agents that are easy to cultivate, have minimum requirements for special handling to retain virulence, and can be obtained easily from natural disease events and other sources.
Attributable to natural outbreak, ensuring plausible deniability	Facilitates covert activities oriented toward disruptive impacts without providing leads for pursuit of the perpetrators.
Not harmful to perpetrator	Exposure to pathogen does not impair the health of perpetrators, thereby facilitating transport of the pathogen, as well as repeated attacks by the perpetrator.
Easily disseminated	Does not require elaborate or cumbersome means for pathogen transport and subsequent exposure of target animals (e.g., contamination of food and water by a small amount of agent).

Concentrated livestock and poultry operations, such as feedlots and poultry houses, facilitate the transmission of infectious disease agents that may be introduced. Also, animal movements associated with commerce facilitate disease spread to other locations. These considerations have great bearing on the effectiveness of a bioterrorist attack.

Table 6.5 Category C (third highest priority) critical biological agents for public health response activities (list is from Levy and Sidel[177]).[a]

Agent	Type	Disease	Zoonoses	Previous[b] use	Weaponized[c]	Comments[d]
Nipah virus (Paramyxo-virus)	Virus	Nipah virus encephalitis	●	○	○	First observed in Malaysia during winter of 1998–1999; high human fatality rate. Fruit bats are the reservoir host, pigs have been the source for human cases.
Hantaviruses (Bunyavirus)	Virus	Hantavirus pulmonary syndrome (HPS) and hemorrhagic fever with renal syndrome (HFRS)	●	○	○	New World infections (HPS) first appeared in USA in 1993 (Sin Nombre disease) causing high fatality rate. Old World infections (HFRS) generally result in low to moderate fatality rates. Small rodents are reservoir hosts and shed agent via feces and urine. Aerosol exposure primary route for human infection.
Tickborne hemorrhagic fever viruses (Bunyavirus)	Virus	e.g., Crimean-Congo hemorrhagic fever (CCHF)	●	○	○	CCHF is present in parts of the former USSR, Europe, Asia, the Middle East, Africa, Australia. Domestic animals and farm-raised ostriches are involved in disease ecology; hedgehogs, horses and mouse-like rodents are reservoir hosts. Transmission generally occurs via tick bites or contact with infected animals. High human fatality rate (up to 30–50 percent).
Tickborne encephalitis viruses (Flavivirus)	Virus	e.g., Kyasamur forest disease, (KFD); Central European encephalitis (CEE); Russian spring-summer meningoen-cephalitis (RSSE).	●	○	○	CEE is the most important human arbovirus infection in Central Europe and RSSE is an even more severe disease where it occurs; both diseases extend into parts of Asia. KFD occurs in parts of India. CEE and KFD can be transmitted through nonpasteurized milk products in addition to tick bites.
Yellow fever virus (Flavivirus)	Virus	Yellow fever	●	○	●	Mosquito transmitted, high human fatality rate, endemic in central Africa and much of South America. Urban and sylvatic disease cycles with monkeys being the sylvatic reservoir host.
Mycobacte-rium tubercu-losis	Bacteria	Multidrug-resistant tuberculosis	●	○	○	Tuberculosis remains an important disease of humanity in much of the world (two million new cases in India in 1999 causing about 450,000 deaths).[177]

[a] Category C agents "include pathogens that could be engineered for mass dissemination in the future because of availability; ease of production and dissemination; and potential for high morbidity and mortality and major health impact." [178]

[b] Confirmed applications of agent during wartime, by terrorists, and/or as criminal activity.[23,33,37,179]

[c] Agent produced for weapons use by nations with biowarfare programs.[14,22,23,33,52]

[d] For more information, see Beran and Steele,61 Krauss et al.,62 Williams and Barker.[183]

●= positive; ○= negative

Table 6.6. Disease agents posing the greatest potential threats from agroterrorism for livestock and poultry in the USA (list is from Wilson et al.[110]).

● = Common; ● (orange) = infrequent; ○ = not known to occur.

Agent	Type	Disease	Zoonoses	Primary hosts			Comments[a]
				Poultry	Livestock	Wildlife	
Foot-and-mouth disease virus (Aphthovirus)	Virus	Foot-and-mouth disease (FMD)	● (orange)	○	●	●	The FMD epizootic that began in the UK during 2001 led to the eradication of 4 million livestock[184] with direct costs of slaughter and disposal estimated at US$7.5 billion and other costs adding additional billions.[41] Although technically a zoonosis, human cases are rare and self limiting. FMD has been eradicated from the USA.
Hog cholera virus (Pestivirus)	Virus	Classical swine fever (hog cholera)	○	○	●	●	Domestic pigs and wild boar are species usually affected; 1997 epizootic among domestic pigs in the Netherlands resulted in direct economic losses of US$2.3 billion and the destruction of more than 11 million pigs.[185] Hog cholera had been eradicated from the USA. It is present in Africa, Asia, Latin America, and in parts of Europe.
African swine fever virus (Asfarvirus)	Virus	African swine fever (ASF)	○	○	●	●	Domestic and wild species of pigs are primary species affected. Enzootic in Africa from the Equator south. Following spread in the 1960s, 1970s and 1980s to parts of Europe, South America, and the Caribbean, most outbreaks have been eliminated by depopulation of infected pig farms.[186] Transmission is by infected ticks, ingestion of infected meat, direct contact, and by aerosol. ASF is not present in the USA; previous introductions into the Dominican Republic, Haiti, Cuba, and Brazil have been eradicated. Portugal, Spain, and Sardinia remain as enzootic foci in Europe.[187]
Rinderpest virus (Morbillivirus)	Virus	Rinderpest	○	○	●	●	Panzootic of 1889–1905 in sub-Saharan Africa due to infected cattle from India killed large numbers of wildlife and cattle.[64] Disease causing greater impacts on humans (social and economic) and domestic livestock than any other animal disease. Present in parts of Africa, Pakistan, southern and possibly central Asia, and parts of the Middle East.[188]
Rift valley fever virus (Phlebovirus)	Virus	Rift valley fever	●	○	●	●	Livestock (including camels) and humans are the primary species impacted by this mosquito-borne disease of the Middle East and Africa.[65]

Table 6.6. Disease agents posing the greatest potential threats from agroterrorism for livestock and poultry in the USA (list is from Wilson et al.[110])—Continued.

Agent	Type	Disease	Zoonoses	Primary hosts			Comments[a]
				Poultry	Livestock	Wildlife	
Influenza virus (Orthomyxovirus)	Virus	Avian influenza	●	●	●	●	Birds, humans, pigs, horses, and seals are species most commonly infected by influenza viruses. Genetic drift and "gene swapping" between influenza viruses produce viruses pathogenic for poultry, humans, and other species. Highly pathogenic strains cost the poultry industry millions of dollars in eradication costs and product embargos.[189,190]
Newcastle disease virus (Rubulavirus)	Virus	Velogenic viscerotropic Newcastle disease (VVND)	●	●	○	●	Eradication of VVND from the USA and Canada occurred during the early 1970s. Periodic reappearances of this disease have been associated with imported birds (pet bird trade). Major mortality from ND has been occurring in double-crested cormorants in the USA and Canada since 1990.[176]
Venezuelan equine encephalomyelitis virus (Alphavirus)	Virus	Venezuelan equine encephalomyelitiis	●	○	●	●	Disease of horses and people in northern South America since the 1930s. 1995 outbreak caused 75,000 human cases and killed an estimated 8 percent of the horse population. Outbreak of 1969–1971 spread 4,000 km northwest through Mexico and into Texas killing more than 44,000 horses. Horses, mules, and donkeys are main vertebrate hosts of this mosquito-borne disease. Sylvatic subtypes of virus (non-epidemic forms) are maintained in wild rodents, bats, and other small mammals rather than horses.[191]
Bluetongue virus (Orbivirus)	Virus	Bluetongue	○	○	●	●	Causes epizootic disease both in wildlife (e.g., deer, bighorn sheep) and livestock. Midges (*Culicoides* spp.) vector this disease. Wildlife have only been affected in North America despite worldwide disease in livestock. Large-scale epizootics can occur.[192]
Goat pox virus, Sheep pox virus (Capripoxvirus)	Virus	Sheep pox; goat pox	○	○	●	○	These viruses cause serious systemic infections and are commonly found throughout the near and Middle East, India, Bangladesh, and North Central Africa. Although wildlife cases are lacking, infection in wildlife of the same genera should be expected to cause similar disease.[193]

Table 6.6. Disease agents posing the greatest potential threats from agroterrorism for livestock and poultry in the USA (list is from Wilson et al.[110])—Continued.

Agent	Type	Disease	Zoonoses	Primary hosts			Comments[a]
				Poultry	Livestock	Wildlife	
Pseudorabies virus (suid herpesvirus 1) (Alphaherpesvirus)	Virus	Pseudorabies (Aujeszky's disease)	○	○	●	○	Important disease of domestic pigs in the USA and much of the rest of the world. Although many wildlife species can be infected, natural cases of clinical diseases are rare. Feral and wild swine are the only known wildlife reservoirs; the domestic pig is the primary reservoir.[194,195]
Vesicular stomatitis virus (Vesiculovirus)	Virus	Vesicular stomatitis	●	○	●	●	Livestock and deer are the primary species affected by this disease; sand flies appear to be the most important vector and likely overwinter the virus in areas of the Southeastern USA. Much of the ecology of this disease remains unknown.[191]
Porcine enterovirus type 1 (Enterovirus)	Virus	Teschen disease (porcine enterovirus type 1)	○	○	●	○	This paralytic disease of domestic pigs occurs nearly worldwide (not in Asia), but serious disease typically only occurs in parts of Europe and Madagascar.[196]
Porcine enterovirus type 9 (Enterovirus)	Virus	Swine vesicular disease (SVD)	●	○	●	○	Disease of domestic swine. Following the initial 1966 detection of SVD in Italy, this disease rapidly spread to many countries in Europe, and to Japan and Taiwan.[196] Italy is the only country where SVD remains enzootic.[62]
Rabies virus (Lyssavirus)	Virus	Rabies	●	○	●	●	Rabies is a major zoonosis of concern because of its public health, veterinary, and economic impacts. Japan, the UK, and some limited areas have eradicated this disease; indigenous cases of disease are absent from much of the Caribbean and Pacific Ocean, but common in much of the remainder of the world.[197]
Lumpy skin disease virus (Capripoxvirus)	Virus	Lumpy skin disease	○	○	●	○	Sub-Saharan Africa and the Middle East are the primary areas where this disease exists. The epizootic that spread through southern and eastern Africa during 1943 to 1945 affected about 8 million cattle. Cattle and buffalo are the primary species affected but other species have died from experimental infections.[196]
Porcine reproductive and respiratory syndrome virus	Virus	Porcine reproductive and respiratory syndrome	○	○	●	○	First reported in USA in 1987; since then outbreaks have been confirmed throughout North America and Europe. This disease is maintained within domestic swine populations.[198]

Table 6.6. Disease agents posing the greatest potential threats from agroterrorism for livestock and poultry in the USA (list is from Wilson et al.[110])—Continued.

Agent	Type	Disease	Zoonoses	Primary hosts			Comments[a]
				Poultry	Livestock	Wildlife	
African horse sickness virus (Orbivirus)	Virus	African horse sickness (AHS)	●	○	●	○	Horses and then mules are the species most susceptible to this midge-transmitted virus; dogs become infected by feeding on infected meat and the virus may be spread by wind. Zebras are reservoir host. AHS is most prevalent in the Middle East and Asia; it is not present in the Western Hemisphere.[192,196]
Bacillus anthracis	Bacteria	Anthrax	●	○	●	●	Anthrax is worldwide in distribution and causes fatal disease in humans, domestic animals and wildlife. Scavenger species relatively resistant to this disease aid its spread by opening the carcasses of animals that have died and releasing large numbers of *B. anthracis* organisms. Ingestion by these species also serves to disperse the spores over broad areas.[199] Anthrax is a highly desired weapon of terrorists and biowarfare programs.
Chlamydia psittaci	Bacteria	Ornithosis/ psittacosis/ chlamydiosis	●	●	○	●	Disease introductions into the USA by pet bird trade (parrots, parakeets); disease exists in some USA waterbirds and pigeon populations.[213]
Cowdria ruminantium	Rickettsia	Heartwater/ Cowdriosis	○	○	●	●	A very important vector-borne disease of livestock (cattle, sheep goats) in Africa. Also present in Madagascar and some islands in the Indian and Atlantic oceans and in the Caribbean.[200] Naturally, occurring wildlife infections are generally subclinical but some mortality occurs in Africa.[201] White-tailed deer are highly susceptible to experimental infections. Importation into the USA of heartwater and exotic *Amblyomma* ticks that vector this disease could cost the livestock industry billions of dollars and result in major epizootics among white-tailed deer.[200]
New World Screwworm *Cochliomyia hominivorax*	Parasite	Myiasis (screw worm)	●	○	●	●	Screwworm fly is native to tropical and subtropical North and South America; cannot overwinter in cold climates and migrates to the north with onset of warm weather. Prior to control, one of the most important pests of livestock in the Southern USA where it caused millions of dollars in economic losses annually.[212]

[a] Species groups generally involved in epizootics.

The Wildlife Factor

> **"...and he that will not apply new remedies must expect new evils; for time is the greatest innovator..." (The Essays by Sir Francis Bacon, 1601)[121]**

Livestock and poultry of today are descendants of wild species that were domesticated, bred, and cultivated over time incorporating sophisticated animal genetics and husbandry programs. Although some species such as reindeer have retained their wildlife characteristics, others such as cattle, sheep, pigs, and some poultry have major appearances, behaviors, and other modifications that differentiate them from their parent stock. Nevertheless, these domesticated animals retain susceptibility to many of the pathogens affecting their wild counterparts.

Domesticated species often share common habitat with their wildlife relatives, have transient contact with wild species, or may have tangential relations that provide direct or indirect opportunities for the harboring and exchange of disease agents and/or arthropod vectors essential for the maintenance and transmission of infectious disease. Therefore, livestock and poultry throughout much of the world, and the diseases that affect them, are often closely linked with diseases of wildlife. Some of these diseases appear to have been transferred from domesticated species to wild populations (e.g., brucellosis in bison and elk of the Greater Yellowstone

Table 6.7. List A diseases from the Office International des Epizooties.[a]

Disease[b]	Agent	Zoonoses[c]	Causes disease in:[d]			Enzootic in USA
			Livestock	Poultry	Wildlife	
Foot-and-mouth disease	Aphthovirus	● (orange)	■	□	■	No
Swine vesicular disease	Enterovirus	● (orange)	■	□	□	No
Peste de petits ruminants	Morbillivirus	○	■	□	□	No
Lumpy skin disease	Capripoxvirus	○	■	□	□	No
Bluetongue	Orbivirus	○	■	□	■	Yes
African horse sickness	Orbivirus	● (orange)	■	□	□	No
Classical swine fever	Pestivirus	○	■	□	■	No
Newcastle disease	Rubulavirus	● (orange)	□	■	■	Yes[e]
Vesicular stomatitis	Vesiculovirus	●	■	□	■	Yes
Rinderpest	Morbillivirus	○	■	□	■	No
Rift Valley fever	Phlebovirus	●	■	□	□	No
African swine fever	Asfarvirus	○	■	□	□	No
Sheep and goat pox	Capripoxvirus	○	■	□	□	No
Influenza[f]	Orthomyxovirus	●	■	■	■	Yes
Contagious bovine pleuropneumonia	*Mycoplasma mycoides* var. *mycoides*	○	■	□	□	No

[a] Reportable diseases for compliance with the International Animal Health Code. These transmissible diseases have the potential to cause serious epizootics; their rapid spread can pose serious socioeconomic or public health consequences and are of major importance in the international trade of animals and animal products.

[b] All of these diseases, except contagious bovine pleuropneumonia (caused by mycoplasma), are caused by viruses.

[c] Classification is based on the Office International des Epizooties: ● = diseases that cause serious illness and/or death in animals and humans; ● (orange) = diseases for which infections have been documented in animals and humans, but for which human infections are rare (except for Newcastle disease), self-limiting, not clinically severe, and generally associated with laboratory exposures (except for Newcastle disease); ○ = diseases not considered to be zoonoses.

[d] ■ = Primary animal species reported to have clinical cases of this disease; □ = disease does not naturally occur in these species, or only rarely so.

[e] Velogenic (highly pathogenic) strains of Newcastle disease as evaluated for chickens have been eradicated from the USA, but strains highly pathogenic for wild birds are present.

[f] Highly pathogenic avian influenza viruses evolve from the virus pool contributed to by pigs, poultry, and wildlife; at this time, only low pathogenic avian influenza exists in the USA. See Krauss et al.[62] for a concise overview of this complex disease.

Table 6.8. Synopsis of List B diseases from the Office International des Epizooties.[a,b]

Primary species	Number of diseases	Type of disease						Number enzootic in USA
		Virus	Bacteria	Rickettsia	Fungal	Prion	Parasitic	
Cattle	15	3	4	1	1	1	5	12
Sheep and goats	11	4	6	0	0	1	0	9
Swine	6	3	2	0	0	0	1	5
Equine	15	8	2	0	1	0	4	7
Birds	13	7	6	0	0	0	0	11
Lagomorphs	3	2	1	0	0	0	0	3
Bees	5	0	2	0	0	0	3	5
Fish	5	5	0	0	0	0	0	3
Mollusks	5	0	0	0	0	0	5	4
Crustaceans	3	3	0	0	0	0	0	1
Other species	11	2	3	2	0	0	4	8

[a] Reportable disease (voluntary) compliance with the International Animal Health Code. See Appendix C for listing of these transmissible diseases of socioeconomic and/or public health importance that are significant for the international trade of animals and animal products.

[b] New World leishmaniases are additional List B diseases that are cutaneous diseases that occur from southern Texas south into South America. Visceral leishmaniasis (Kala-Azar) is a more serious disease and does not occur in the USA, but is present in Central and South America in addition to much of the Old World.[62]

Table 6.9a. Zoonoses being considered by the Ad Hoc Group of State Parties to the Biological and Toxin Weapons Convention (list is from Wilson et al.[110]).

Zoonoses[a]			
Agent	**Type**	**Disease**	**Primary species linkages[b]**
Rift Valley fever virus	Virus	Rift Valley Fever	Cattle, goats, sheep, mosquitoes, humans
Monkeypox virus	Virus	Monkeypox	Rodents, monkeys, humans
Alphaviruses[c]	Virus	Eastern, Western, and Venezuelan equine encephalitis	Rodents, bats, birds, mosquitoes, horses, humans
Bacillus anthracis	Bacteria	Anthrax	Soil, biting flies, scavengers, herbivores, humans
Brucella melitensis	Bacteria	Brucellosis (Malta fever)	Goats, sheep, humans
Brucella suis	Bacteria	Brucellosis	Pigs, European hare, reindeer, caribou, humans
Burkolderia mallei	Bacteria	Glanders	Horses, donkeys, mules, humans
Burkholderia pseudomallei	Bacteria	Melioidosis	Rodents, livestock, humans
Francisella tularensis	Bacteria	Tularemia	Arthropods, voles, aquatic rodents, rabbits, humans
Yersina pestis	Bacteria	Plague	Rodents, fleas, humans

[a] Each causes serious human illness that often leads to death. Animals have major roles in the ecology of each of these diseases and, like humans, also are affected by these disease agents.

[b] Species generally involved in disease maintenance, transmission, and as susceptible hosts; for details see current literature on specific diseases.

[c] Somewhat different species linkages occur for each of the diseases listed; see Yuill and Seymour[191] for details.

Table 6.9b. Animal pathogens being considered by the Ad Hoc Group of State Parties to the Biological and Toxin Weapons Convention (list is from Wilson et al.[110]).

Animal pathogens[a]	
Viral agent/disease	**Primary species linkages**[b]
African horse sickness	Horses, mules, midges, zebras
African swine fever	Domestic and wild pigs, ticks
Avian influenza (influenza)	Waterbirds, poultry, pigs, humans
Hog cholera (classical swine fever)	Domestic and wild pigs
Bluetongue	Wild ungulates, livestock, midges
Foot-and-mouth disease	Cattle, African buffalo, antelope, and other wild ruminants
Newcastle disease	Psittacines, poultry
Pestes des petitis ruminants	Sheep and goats
Porcine enterovirus type 1	Domestic pigs
Rinderpest	Cattle, cloven-hoofed wildlife (e.g., African buffalo)
Vesicular stomatitis	Livestock, sand flies, black flies, deer, antelope, humans

[a] Human infections do not occur for most of these viruses and the agents that do infect humans are generally infrequent causes of disease; clinical disease in humans typically is mild and self limiting (except for influenza).

[b] Species generally involved in disease maintenance, transmission, and as susceptible hosts; for details, see Williams and Barker[183] and current literature on specific diseases.

Table 6.9c. Plant pathogens being considered by the Ad Hoc Group of State Parties to the Biological and Toxin Weapons Convention (list is from Wilson et al.[110]).

Plant pathogens[a]			
Agent	**Type**	**Disease**	**Plant target**
Colletotrichum coffeanum var. *virulans*	Fungus	Coffee berry disease	Coffee
Dothistroma pini	Fungus	Dothistroma needle blight	Pine trees
Erwinia amylovora	Bacteria	Fire blight	Apple, pear
Ralstonia solanacearum	Bacteria	Bacterial wilt	Potato
Puccinia graminis	Fungus	Stem rust	Wheat
Sugarcane Fiji disease virus	Virus	Sugarcane Fiji disease	Sugarcane
Tilletia indica	Fungus	Karnal bunt	Wheat
Xanthomonas albilneans	Bacteria	Sugarcane leaf scald disease	Sugarcane
Xanthomonas campestris pr. citri	Bacteria	Citrus canker	Grapefruit, lemon, lime, trifoliate orange
Sclerotinia sclerotiorum	Fungus	Sclerotinia stem rot (pink rot, white mold, water soft rot)	Vegetable row crops, soybeans, citrus, melons, and others
Claviceps purpurea	Fungus	Ergot	Rye, other cereal grains, and pasture grasses
Peronospora hyoscyami de Bary f. sp *Tabacina* (Adam) *skalicky*	Fungus	Blue mold	Tobacco

[a] Disease agents within this category are pathogens of agricultural crops. Anticrop agents within the USA arsenal of bioweapons that were destroyed by the U.S. Military during 1971–1973 were rice blast, rye stem rust, and wheat stem rust.[22] Plant pathogens also were components of the bioweapons programs of the former USSR, Iraq, and other nations.[14,37]

Basin, USA). These wildlife are now a threat for transmitting disease back to domestic animal populations (Table 6.2). In other situations, wildlife are reservoirs for disease agents or arthropod vectors that are of less consequence for wildlife, but are of major consequence for domestic animals (e.g., avian influenza viruses).

Wildlife and Bioterrorism

In general, wildlife populations are more vulnerable to biological terrorist attacks than are domesticated species. Access to free-ranging wildlife is largely unrestricted, chances of a perpetrator being noticed are very low, and wildlife disease surveillance activities are minimal in most areas. Thus, disease introductions may take hold and become major epizootics before detection occurs, facilitating spread and impacts of the disease. Targeting wildlife, at least in North America, may inflict fewer economic losses or species extinctions than in other geographic areas where wildlife are primary protein sources and/or a major means of revenue for local and regional economies. Secondary disease spread following the release of infectious agents capable of causing disease in multiple species raises concerns about the effects of bioterrorism on the biodiversity of wild species[41] and on rare breeds of domestic animals.[13, 41, 110, 122, 123]

The wildlife conservation community has not conducted any in-depth evaluations on the potential consequences from bioterrorist attacks, despite the apparent vulnerability of wildlife. With the release of the U.S. Department of Homeland Security's National Response Plan (NRP) in October 2004 (http://www.dhs.gov/dhspublic/interapp/editorial/editorial_0566.xml), the wildlife factor in detection of and response to emerging diseases is recognized under Emergency Support Function #11 (ESF #11). Within the NRP, natural resources are defined as "land, fish, wildlife, domesticated animals, plants, biota, and water…." The U.S. Department of the Interior and the U.S. Department of Agriculture are designated to be prepared for and to respond to any biological emergencies, intentionally or unintentionally introduced, involving wildlife. During 2005, NRP mock tabletop preparedness exercises included plague and avian influenza, and the wildlife factor within each of those responses.

More NRP exercises and training are needed to further improve responses, actions, and communications among agricultural, wildlife, and public health entities. Major strategic planning also is ongoing for protecting wildlife and for responding, should wildlife be involved in terrorist activities. Such planning is important because of the connectivity between wildlife and other species.

The capability to use wildlife as vehicles for the spread of infectious agents has been demonstrated by biological control activities in the USA and elsewhere (Box 6–2). This concept could be exploited by bioterrorists who focus on livestock, poultry, or human impacts, because wildlife are readily available launch vehicles for the transport and delivery of infectious disease agents. For bioterrorists using wildlife to succeed, they must have knowledge of species ecology and population movements, along with knowledge of the ecology of the diseases they desire to introduce. A successful application could include introduction of a disease launched either from distant locations or from on-site introductions.

Closing the Gap

In many ways, combating an infectious disease outbreak in humans, domestic animals, or wildlife is like combating a forest fire. Early detection of the outbreak is critical. Equally important are adequate response capabilities and an infrastructure that, on short notice, provides personnel, supplies, and specialized equipment. Efficient communications,


Photo by Milton Friend

Figure 6.5 Large concentrations of wildlife are often found on public lands due to diminishing habitat.

information flow, and reporting are crucial. Also, surveillance to detect flare-ups and persistent efforts are required for containment to be realized. Appropriately trained and experienced personnel must guide, coordinate, and carry out all of these and associated activities; these attributes are especially important for first responders in order to minimize event impacts.

Early Detection and Response

Early detection and response to minimize illness and death from bioterrorist attacks are important aspects of public health[39, 45, 50] and domestic animal disease fields.[13, 41, 110] A recent evaluation within the USA by scientists at the CDC "confirmed that the most critical component for bioterrorism outbreak detection and reporting is the frontline healthcare professional and the local health departments."[77] Similarly, a National Academy of Sciences evaluation of the threat of bioterrorism to agriculture recommended better training for frontline responders, such as farmers and other agricultural workers, on how to recognize and report a disease outbreak and thus provide early detection. Because of the rapid global movement of agricultural products and live animals, enhanced monitoring of emerging diseases in other countries is also necessary. A final recommendation was that laboratories collaborate to facilitate rapid testing of large numbers of samples.[114]

Table 6.10. Jurisdiction and regulatory authorities for stewardship of free-ranging wildlife[a] (USA).

Species type	Regulatory agency[b]			Comments
	DNR[c]	FWS[c]	NOAA[c]	
Endangered (federal)	▲	●	▲	As defined by Federal Endangered Species Act. Involves federal regulatory listing through due process by FWS.
Endangered (state)	●	▲	■	As defined by formal listing involving due process by State DNR; state cannot usurp federal regulations.
Migratory birds	▲	●	■	As established by the Migratory Bird Treaty Act and its amendments; includes virtually all birds that have seasonal movement patterns between distant locations. States can have more stringent, but not less stringent regulations.
Anadromous fish	▲	●	■	Salmonids (salmon, trout) only; populations that spend part of their life cycle in the oceans and part in freshwater rivers and other water bodies.
Oceanic fish	●	■	●	Species dictates jurisdiction; nearshore fish generally under authorities of State DNR.
Marine mammals	▲	●	●	As defined by Marine Mammal Protection Act. FWS responsible for polar bear, walrus, sea otter, and manatee; remainder of species under primary jurisdiction of NOAA.
Resident wildlife	●	▲	■	All species that are localized in their life cycle by generally having minimal movements across State boundaries. Includes shellfish, finfish, amphibians, reptiles, mammals, and birds.

[a] Each land management agency is responsible for the management of species on its lands and waters, but must abide by laws and regulations established by regulatory agencies for the harvest and possession of wildlife. Special provisions that extend rights for native peoples exist. Also, species management is often a collaborative venture involving agencies and the private sector.

[b] Agencies empowered to promulgate binding regulations for harvest, methods of take, possession, and use of free-ranging wildlife and products from these species. Also have enforcement responsibilities for those laws and regulations.

[c] DNR=State Departments of Natural Resources or State Fish and Game Agencies; FWS=Fish and Wildlife Service, U.S. Department of the Interior; NOAA=National Oceanographic and Atmospheric Administration, U.S. Department of Commerce.

●= Agency with primary regulatory and law enforcement responsibilities for the species.

▲= Agency with secondary regulatory and law enforcement responsibilities associated with the management of the species on agency lands and waters. Species protections generally can be more stringent, but not more lenient, than that of the agency with primary responsibilities.

■= Agency with limited to no regulatory responsibilities for the species.

Box 6–2 Wildlife as Disease Delivery Systems

"Bacteriological warfare is science stood on its head…a gross perversion." -from an official paper published by the Soviet Union in 1951[26]

In the past, wildlife have been used as delivery systems for biological warfare, where these free-ranging animals were captured, infected, and released back into the wild to transmit disease to others of their kind, as well as to other susceptible species. Terrorists could use diseased wildlife to convey pathogens to wildlife and other species.

During the 19th, and into the 20th century, Montana Livestock Sanitary Board (USA) veterinarians used mange mites (*Sarcoptes scabiei*) as a means for reducing coyote and wolf numbers to protect livestock from depredation. Healthy coyotes and wolves were trapped, infested with mange mites, and released in attempts to initiate mange epizootics.[149,150] Similar practices targeting dingoes (**wild dogs**) took place in Australia.[151]

Although mange has long been recognized as a human pathogen, the mange mites infesting coyotes and wolves posed little human health risk because the mites were host-specific (to **canids**).[152,153] The situation differed for ranchers who attempted to employ tularemia (*Francisella tularensis*) as a biological weapon.

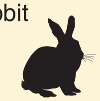
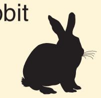
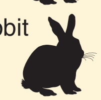
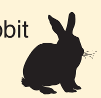
Tularemia is a category A disease (highest priority) within the current ranking of critical biological agents for public health response (Table 6.3). Ranchers in California (USA) considered any human disease risks for this disease as acceptable, as long as they could achieve their objective of reducing small rodent populations. These ranchers believed the small rodents were competing with livestock for forage on range and grasslands. So they employed **ground squirrels** infected with tularemia as vehicles to help decimate the rodent populations.[154,155] Other notable examples of wildlife being used as vehicles to initiate infectious disease epizootics in free-ranging wildlife populations include myxomatosis and viral hemorrhagic disease of rabbits (Table A).

Certain infectious diseases used for biological control can combat unwanted vertebrate species but are seldom employed because of low success rates and inherent risks to those releasing the agents.[156–158] Today, there is the capability to develop genetically modified disease agents that may target just a single species, thus reducing the potential for unwanted effects. Yet, these capabilities can go astray. Recently, a killer mousepox virus (highly virulent strain) emerged from a laboratory that genetically engineered the virulent strain to be a vector-borne contraceptive for reducing rodent populations. This unexpected killer virus outcome caused alarm because of the potential for similar outcomes in viruses that infect humans. This potential has implications for the development of new biological weapons.[54,159]

Photos by Milton Friend

The frequent movement of pathogens through the illegal and legal transportation of wildlife attests to the need for concern regarding wildlife as potential vehicles for bioterrorism.

Table A. Examples of infectious disease used for biological control of vertebrates.

Disease	Agent	Type	Targeted species	Country	Comments
Sarcocystis	*Sarcocystis singaporensis*	Protozoan parasite	Wild rats 	Thailand	Mortality of 58–92%.[156,160]
Capillariasis	*Capillaria hepatica*	Nematode (roundworm) parasite	House mouse 	Australia	Results unclear.[161]
Feline panleucopaenia	Parvovirus	Virus	Feral cats 	Oceanic Islands	Estimated populations of 3,400 cats on sub-Antarctic Marion Island reduced to about 620[156,162,163] successful in reducing cat populations in most cases.[156,164]
Myxomatosis	Myxoma virus	Virus	European rabbit 	France	Deliberate 1952 introduction on an estate resulted in unintentional spread leading to death of 90–98% of French rabbit population and spread of disease to other countries in Europe.[156,165]
Myxomatosis	Myxoma virus	Virus	European rabbit 	Australia	Initial reductions greater than 95% of populations; classic example of biological control by a pathogen.[156,165–167]
Rabbit hemorrhagic disease	Calicivirus	Virus	European rabbit 	Australia	Escaped from experimental biological control studies on an island in 1995 and invaded mainland; spread at rates of up to 414 km/month with initial mortality reaching 95% in some areas.[156,168–170]
Rabbit hemorrhagic disease	Calicivirus	Virus	European rabbit 	New Zealand	Illegal, intentional 1997 introduction resulted in high mortality and rapid spread among rabbit population.[156,171,172]
Mange	*Sarcoptes scabiei*	Metazoan parasite	Coyote 	USA	Anecdotal reports of infected coyotes being released to initiate epizootics causing reductions in coyote populations early in the 20th century.[150]
Tularemia	*Francisella tularensis*	Bacteria	Ground squirrels 	USA	Anecdotal reports of infected ground squirrels being released to initiate epizootics to help reduce small rodent populations during the early 1900s.

The frontline personnel for detecting disease outbreaks in free-ranging wildlife populations are the biologists and other field personnel providing management and oversight of the well-being of wildlife on public lands. These individuals may unknowingly be the first to encounter diseased wildlife associated with bioterrorist activities. Their knowledge of what is "normal" wildlife mortality in an area relative to species involved, season and location of occurrence, and magnitude of losses is useful in the identification of unusual events that may merit further investigation. It is prudent and serves the interests of national security for unusual wildlife mortality events to be referred to wildlife disease investigation personnel from whom assistance is normally obtained. Timely reporting and follow-up evaluations are important for maximizing the potential to contain the spread of infectious disease, a need that is driven by the potential for subsequent or concomitant disease spread to humans and domestic animals.

Within the USA and in most other countries, networks of national parks, wildlife refuges, game management areas, and other holdings provide key habitats for sustaining free-ranging wildlife populations and could be prime areas targeted by bioterrorists (Fig. 6.5). Many of these areas are managed to accommodate multiple uses, such as grazing by livestock, hunting, and other outdoor recreational activities. Natural occurrences of diseases, such as plague, tularemia, and ornithosis, has resulted in temporary closures of public land areas as a disease prevention measure (USGS National Wildlife Health Center records). In other situations, the well-being of livestock is challenged by disease in wildlife, such as brucellosis in elk and bison of the Greater Yellowstone Area of the western USA.[124–127] These situations attest to the natural movement of infectious disease between species groups in wildlife areas and suggest that bioterrorists could successfully use these areas as pathways for attacks against humans and agriculture.

The speed of detection and identification of the cause for disease events in wildlife differ greatly from that with humans or domestic animals. Capabilities are limited for disease surveillance, diagnosis, reporting, field response, and for other critical activities needed for effective disease containment and often hinder wildlife agency personnel from obtaining the assistance that they may need for investigating wildlife mortality events. In the USA, few wildlife stewardship or wildlife resource agencies have any internal capacity for diagnosing or combating disease events. Also, in the USA, stewardship responsibilities and regulatory authorities for different types of wildlife are distributed across different federal and state agencies (Table 6.10). Nevertheless, within North America there are three major, relatively long-standing wildlife disease programs that have considerable capacity and capabilities to serve wildlife resource agencies and bridge differences in responsibilities and regulatory authorities (see Chapter 3).

Within the USA, the Southeastern Cooperative Wildlife Disease Study (SCWDS) has been in existence since 1957 at the University of Georgia, Athens. This program primarily serves member state wildlife agencies in the Southeastern USA and a number of other nearby states. Project work is also done for USDA and other contractors. The National Wildlife Health Center (NWHC) in Madison, Wisconsin, became an entity within the U.S. Fish and Wildlife Service in 1975 and during the 1990s was transferred to the U.S. Geological Survey as part of science consolidation within the Department of the Interior (DOI). This program primarily serves the field units of the DOI (e.g., National Wildlife Refuge System, National Parks), is national in scope, and also carries out collaborative investigations with the Public Health Service (e.g., West Nile virus) and others. Canadian wildlife biologists are assisted by the Canadian Cooperative Wildlife Health Centre (CCWHC) in Saskatoon, Saskatchewan, and have been since its establishment in 1992. Each of the Canadian Provincial Schools of Veterinary Medicine maintains a component of this program.

All of these programs are at the forefront for early detection of new and emerging diseases of wildlife, have large databases on diseases of free-living wildlife, are staffed with a broad spectrum of specialists needed for disease investigation, and actively collaborate with one another. Their combined resources exceed the total resources for all of the other wildlife disease programs maintained by State and Provincial wildlife agencies and those within the university community, but overall are only a small fraction of the investments in human and domestic animal disease programs.

Wildlife disease capabilities need to be better developed throughout the USA and other nations in order to bridge the current gaps between wildlife and domestic animal health and between diseases that affect wildlife and humans. This would help bring wildlife disease capabilities to a level where they are a major force for addressing potential bioterrorist attacks. Enhancements of infrastructure and capabilities, as well as additional cooperation, collaboration, and coordination among wildlife disease programs are necessary components. Unlike public health and agricultural programs, currently there is no national infrastructure network within the USA for wildlife disease diagnosis, research, reporting, information exchange, or response to wildlife disease emergencies. Strategic planning for response to major wildlife disease events has begun, but more internal and interagency communication and cooperation is needed to delineate clear lines of authority, responsibilities, and response capabilities, particularly when disease outbreaks occur in urban and suburban environs. Because of increased interaction between wildlife and humans (Fig. 6.6) and the connections among wildlife, domestic animals, and public health, there is an elevated need to move informal wildlife disease networks into a coordinated, formal infrastructure.

Photo by Milton Friend

Figure 6.6 The close proximity between humans and urban wildlife provides a "bridge" for the delivery of infectious disease that easily could be exploited by bioterrorists because of inadequate disease surveillance and monitoring of these wildlife.

Surveillance and Monitoring

Public health and agricultural agencies in most nations organize disease surveillance and monitoring systems to track specific diseases. These systems serve to identify unusual disease events, patterns, and trends. A network of field programs, diagnostic laboratories, research, reporting systems, and a list of reportable diseases are the cornerstones that support disease surveillance and monitoring. In addition, routine testing of human patients and domestic animals provides continuous and consistent sampling that augments findings from clinical cases of disease. Such findings are expeditiously communicated within local communities and are combined with regional and national findings to provide important perspectives that help to evaluate disease risks, guide investigations, and serve regulatory and other purposes.

In contrast to the structured programs of public health and agriculture, wildlife disease surveillance and monitoring is largely ad hoc. There are no reportable requirements for wildlife diseases in most countries (beyond those of public health and agricultural importance), nor is there any methodical sampling of wildlife populations to provide insights of disease activity. Data gathered during independent scientific investigations may or may not be published, and may not be reported for one or more years after collection. Often these data are not readily accessible to many that could benefit from the findings and analyses. Exceptions include collaborative surveillance activities such as those developed in the USA for West Nile fever.[128–130] Voluntary reporting in program newsletters like those issued by the SCWDS and the CCWHC and the quarterly summary of wildlife die-offs compiled by the NWHC and published in the Wildlife Disease Association Newsletter provide highlights of current events but are not comprehensive in coverage or timely enough (Fig. 6.7).

Designing standardized spatial, temporal, and trophic level matrices of sampling to establish functional baselines for broad-based wildlife disease surveillance and monitoring could be of great value. Despite the current absence of structured, national wildlife disease surveillance and monitoring programs, they would be relatively easy to develop in most countries. Wildlife commonly are live-trapped for wildlife management purposes. Non-lethal sampling could become a component of many of these activities (Fig. 6.8). Other sampling could be done in conjunction with wildlife harvests and population reduction programs. Independent disease studies have commonly used all of these opportunities. Incorporating evaluation of suitable carcasses from the large numbers of wildlife found dead, as well as samples from wildlife rehabilitation programs, could augment other disease diagnostic data in a planned manner to enhance disease surveillance and monitoring.

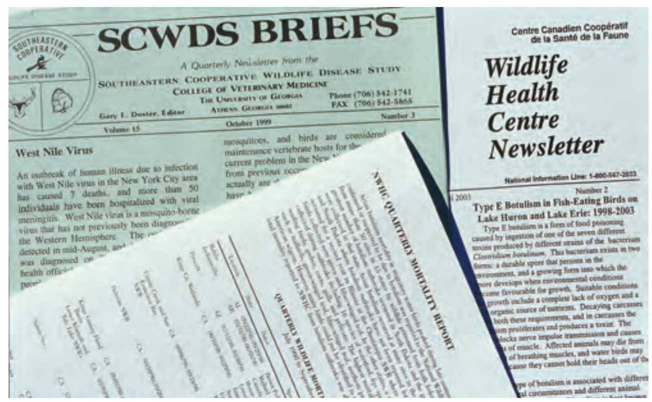


Photo by Milton Friend

Figure 6.7 Newsletters and Web sites of major wildlife disease programs are good sources for information about current wildlife disease issues.

Photo by Milton Friend

Figure 6.8 Sampling of wildlife for disease surveillance can be done in conjunction with wildlife management activities. Exposure to a broad spectrum of disease agents will be evaluated from the non-lethal sampling being done on these geese.

In the USA, current available resources for personnel, facilities, and sample processing do not as yet allow for development of sustainable wildlife disease monitoring and surveillance programs. Correcting this situation would serve national security by enhancing early warning systems for detecting unusual disease activity and trends in disease activity over time. Findings also would contribute to national efforts to combat emerging diseases that pose threats to human and domestic animal health.

Knowledge and Networks

Existing wildlife disease programs, although currently limited in size, number, and fiscal resources are rich in knowledge gained from decades of experience. Also, there are extensive networks of collaborators within the wildlife conservation community that can be called upon by the public health and agricultural communities to play a role in disease surveillance and monitoring that serve national homeland security. This collaboration is continuing to develop because it is essential for major improvements in surveillance and response capabilities (Fig. 6.9). We must be prepared to rapidly respond to bioterrorists who could capitalize on the current inadequacies of wildlife disease surveillance, monitoring, and response capabilities. Global efforts to combat emerging infectious disease at the wildlife-human and wildlife-domestic animal interfaces could help overcome existing deficiencies and in the end benefit national homeland security.

Reality in a Changing World

Although society has limited ability to prevent bioterrorist attacks, there still is a need to take preventative steps to reduce potential risks for such attacks. Increased laboratory security for disease agents, greater controls for investigations involving these pathogens and other security measures implemented since the fall of 2001, are necessary to restrict access to dangerous pathogens. A protective curtain of sorts has been drawn around us that will more readily restrict terrorists from obtaining pathogens that could be used as bioweapons. However, this protective curtain is not impermeable. Enhanced surveillance activities for early detection of

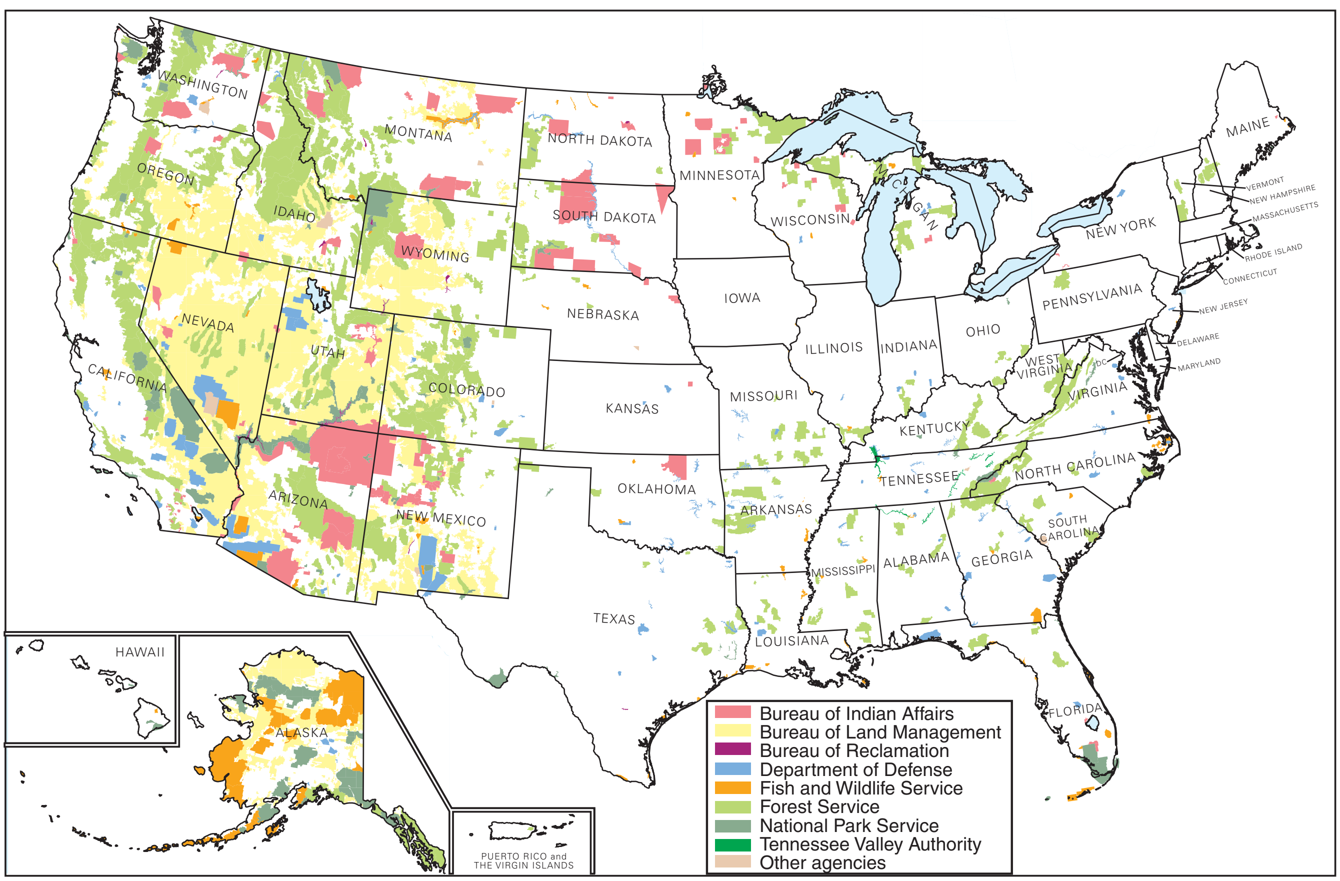


Figure 6.9 The extensive network of federal lands provides an appropriate grid for wildlife disease surveillance and monitoring to detect emerging diseases in wildlife and attendant threats for domestic animals and humans.

flaws in this protective curtain will be bolstered by enhanced strategic planning, infrastructure development, and rapid response capabilities that minimize impacts and quickly repair damage that may occur. Furthermore, the current curtain assumes frontal attacks by known enemies using familiar tactics for exposing humans and domestic animals to dangerous pathogens. The vulnerability of the curtain to unconventional attacks also needs to be addressed.

Wildlife have a great capability to breach the protective curtain and easily pass through its fabric. Examples include infectious diseases transported by wildlife that caused major economic and/or human health impacts, such as Nipah virus in Malaysia,[131,132] SARS in China,[133–137] monkeypox in the USA,[138] and current concerns associated with the role of migratory birds in global movement of highly pathogenic H5N1 influenza virus. Wildlife and the diseases that they can transport represent flaws in the fabric of this protective curtain and can be exploited by terrorists in attacks against society. The protective curtain can be greatly strengthened by fully incorporating the wildlife factor into its fabric. This refurbishment and enhancement can serve society well in many ways, including contributions to the larger issue of infectious disease emergence and resurgence worldwide.

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Chapter 7

How to Find and Access Published Information on Emerging Infectious Diseases

"Books are the carriers of civilization. Without books, history is silent, literature is dumb, science crippled, thought and speculation at a standstill. Without books, the development of civilization would have been impossible. They are the engines of change." (Tuchman)[1]

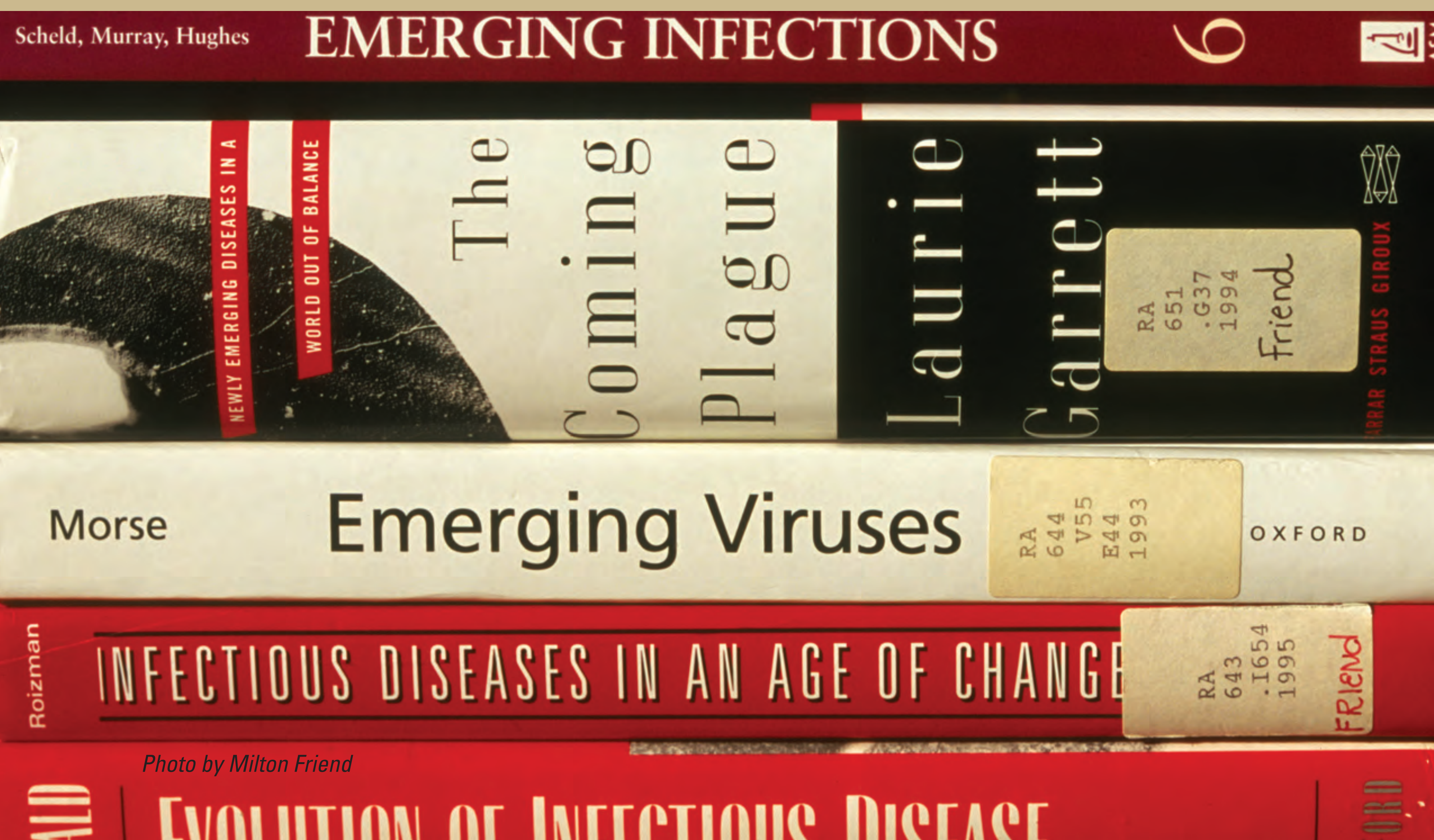

Photo by Milton Friend

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Chapter 7

How to Find and Access Published Information on Emerging Infectious Diseases

During the last two decades of the 20th century, and continuing today, there has been a global emergence and resurgence of infectious disease of humans and other species. The "exotic" nature and serious consequences of many of these diseases results in media attention and public interest, in addition to the scientific exploration and efforts associated with combating these diseases. Finding and accessing information about diseases and keeping informed about current events and new discoveries is a daunting task because of the diversity of information sources and the great volume of published materials. This chapter provides guidance for effectively traveling the information highway and efficiently negotiating the information maze.

Information and More Information

Technological advances have provided access to enormous information resources. Consider this scenario: In 1968, a British librarian researched the topic of bubonic plague to illustrate how reference work was done. He did this research by using specialized paper indexes in one library and identified 14 books, which he used as a starting point for his research. These books provided sufficient leads to allow the researcher to adequately compile resources and publish a small book titled *The Black Death* that depicted plague events in Europe between the 14th and 17th centuries.[2]

A similar search was done in 2004, with the use of readily available electronic resources. The term "plague" was entered into an Internet **search engine** and the search netted nearly 2 million results (also referred to as hits). The search for "black death" resulted in over 7 million hits. A "Bubonic plague" search resulted in the fewest at 72,000. Results that number in the thousands and millions may seem unmanageable, but there are ways to focus a search to get the most useful material. In this chapter, emerging infectious diseases, primarily zoonoses and other diseases affecting wildlife, are the topics used for illustrating information pathways. General strategies for negotiating the information maze are also provided. Although primarily intended for those unfamiliar with how to find and access information, this chapter may also benefit those unfamiliar with the literature on zoonoses and on wildlife disease.

Traversing the Information Maze

In this chapter, the subject is approached by taking the reader on two journeys into the information maze (Fig. 7.1). The first journey highlights the evolution in content of the scientific literature and includes major information sources addressing zoonoses and wildlife diseases. The second journey is more extensive and identifies the primary types of information sources available, methods for identifying and acquiring specific information, and strategies for monitoring information sources for new developments. The examples provided in the tables focus on zoonoses and other diseases of wildlife, but are representative of the general types of information sources available. They do not constitute comprehensive coverage for specific subject areas. Nevertheless, these examples provide primary access to the abundant information available within the general area of emerging infectious diseases.

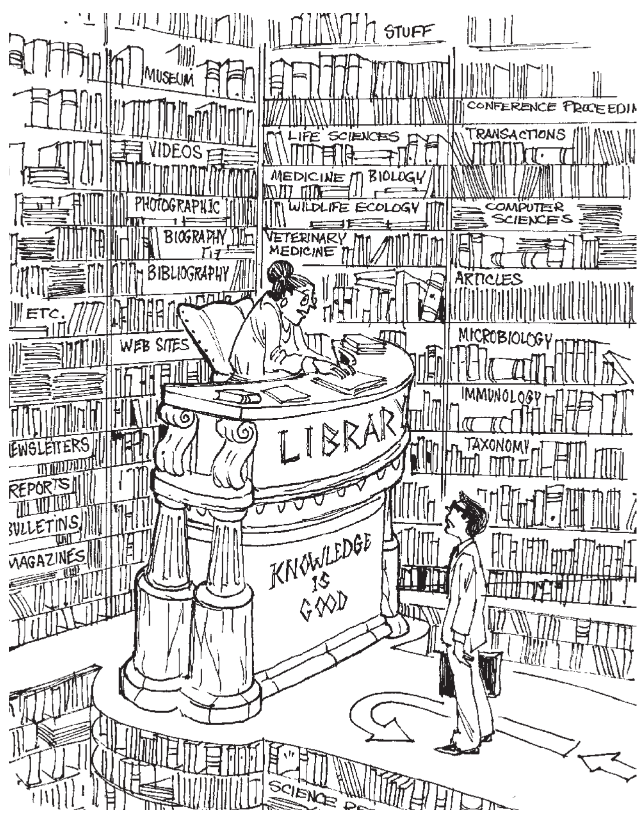

Illustration by John M. Evans

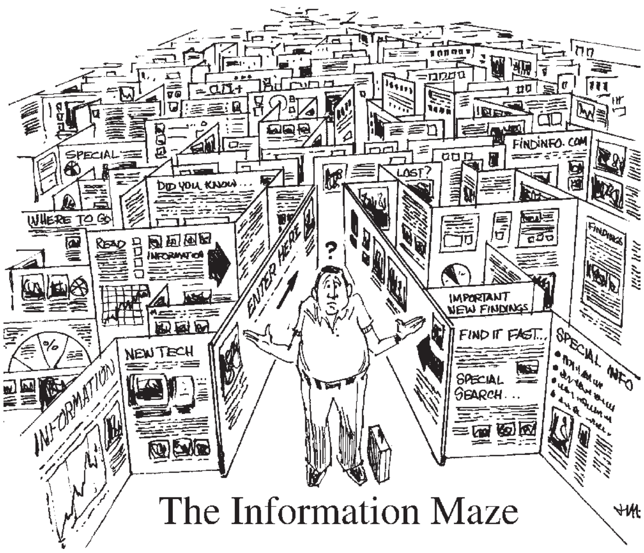

Illustration by John M. Evans

Figure 7.1 Navigating the information maze is a daunting task that requires pretravel planning for a successful journey.

Information Transitions

Today, an increasing amount of information is provided electronically through computer technology. Major scientific journals publish on-line, and various Web sites provide nearly instant postings of information on current disease events. Just as information formats change over time, so does the content of information typically found in scientific publications. Advancement of scientific knowledge has increased the rigor of how science is conducted and, along with competition for journal space and publication costs, has adjusted what type of information appears in peer-reviewed scientific publications. The richness and robustness of information published today differs greatly from that of past centuries. For example, the advanced technology and knowledge of current times allows highly sophisticated investigations, a great deal of control over experimental conditions, and complex statistical and mathematical evaluations of findings. However, while the associated publications may be rich in technical detail and scientifically robust, some aspects of these publications often have less "richness" than historic publications (Box 7.1).

New information about a subject over time reflects advances in knowledge; however, increases in knowledge do not necessarily translate to increases in wisdom. For example, about 2,400 years ago, Hippocrates (c. 400 B.C.) displayed great wisdom about the relations between landscape and disease in humans (environmental or ecosystem health) in his writing "On Airs, Waters, and Places" (see Chapter 1), even though the "germ theory" would not be scientifically proposed until the 1860s. Much can be learned by revisiting the historic literature in addition to reviewing current knowledge, and such excursions often are more rewarding than might be expected. For instance, a wealth of early information about disease outbreaks in animals can be found in two summaries, *Animal Plagues*[3] and *History of Animal Plagues of North America*,[4] published in the late 19th century and just prior to World War II, respectively. The latter is a publication that the U.S. Department of Agriculture republished 35 years later because of its value.

Increases in scientific knowledge have been accompanied by a continuum of specialized focus areas within the broader areas of health and disease. This specialization results in discrete bodies of literature embedded within those broader areas. For example, many emerging infectious diseases are zoonoses, and many of these are associated with wildlife (see Chapter 2). The **etiologic** agents involved are focus areas for specialists in the fields of bacteriology, virology, parasitology, immunology, epidemiology, and other disciplines, in addition to specialists pursuing the ecology and control of these diseases in humans, domestic animals, and wildlife. Therefore, the connectivity among related areas of literature is highlighted here to assist in the quest for information.

Infectious Disease Through the Ages

Infectious disease has existed as a human malady throughout human history. Descriptions and accounts of infectious disease have been extracted from archeological studies, historical writings, and even from fossilized skeletal remains.[5,6] Zoonoses, such as rabies, have been prominent among the earliest known infectious diseases.[7,8] Highlighted here are some of our choices for books addressing infectious disease through the ages (Table 7.1). In doing so, our primary focus is on broad-based publications rather than hallmarks of discovery or individual diseases. The history of infectious disease is not addressed here, as this has been done by others. [3,4,9,10–13]

Zoonoses

Publications about the relation between infectious diseases of animals and humans have surfaced over time (Table 7.1); however, by the late 1920s, zoonoses became an increasing focus for study. At that time, sufficient understanding of these relations existed and books on zoonoses began to appear, even though the term was not coined and defined until later.[14] Since then, zoonoses have become a specific area for investigation within the broader area of infectious disease. A substantial and ever increasing body of literature exists

Table 7.1 Selected books on infectious disease (pre-1980).

Title	Date first published	Comments
Animal Plagues[3]	1871	Reports the history of animal diseases from 1490 B.C. to the beginning of the 19th century.
Tropical Diseases[47]	1898	A "classic" early publication by a physician-scientist who in 1913 was formally acclaimed "The Father of Tropical Medicine." This manual on tropical diseases deals with a broad spectrum of human health issues and was intended as a practical reference for those traveling or living in tropical areas.
The Grouse in Health and in Disease[48]	1912	A classic early investigation into the causes of mortality in red grouse and the determination that the nematode *Trichostrongylus* spp. is a major factor; 2 volumes.
Rats, Lice, and History[49]	1935	A historical account and classic study of typhus in regard to the organism's impact upon humans and the response of modern medicine; a biography of disease as seen by the organism.
Natural History of Infectious Disease[50]	1940	General presentation about infectious diseases. Offers intriguing facts and ideas along with biological descriptions written to appeal to laymen, scientists, and physicians with an interest in this topic. Revised editions in 1953, 1962, and 1972.
World-Atlas of Epidemic Diseases Vol.1–3[51]	1952–1961	An atlas of oversized, worldwide maps showing the distribution of epidemics. The text explores relationships in time and place between disease prevalence, spread, and geographical features. Written in German and English.
Mirage of Health[52]	1959	A historical account of the human struggle against disease from a perspective of "Utopias, Progress, and Biological Change."
Myxomatosis[53]	1965	A classic study in the evolution of host-parasite relations following the introduction of *Myxoma* virus to infect European rabbits in Australia.
Natural Nidality of Transmissible Diseases[54]	1966	A 1964 Russian publication translated to English that advanced Pavlovsky's "doctrine" of natural nidality of disease; that is, that certain diseases occur naturally in wildlife and are transmitted to humans by arthropods when humans enter the territory of wildlife.
The Biology of Animal Viruses[55]	1968	A comprehensive description of broad biological principles of viruses of warm-blooded vertebrates that builds upon *Principles of Animal Virology*.[56] Revised in 1974.
Plagues and Peoples[13]	1976	Explores the shifting balance between human hosts and infectious organisms. A "classic" and often cited book most recently reissued in 1998 with a new preface.
Zoonoses and the Origins of Ecology of Human Disease[5]	1978	Builds upon established zoonotic literature by examining how human relationship to the environment effects disease patterns.

Box 7–1 Transitions in the Reporting of Science

"…modern scientific writing is quite unlike that of the past. Pressed into a 'conventional format', the scientific article of today is deprived of all subjective elements, stripped of all that is extraneous to the conclusions reached, and shorn of the human activity underlying the conclusions it presents" (Holmes).[36]

The style and content of scientific articles have changed over time; many scientific investigators may not give much thought to these changes. Nevertheless, these changes reflect editorial practices and the scientific community standards that affect what does and does not get published. Conventions that have evolved for presenting scientific information are valuable for helping readers screen the increasing volume of available information. However, these conventions are not without information costs and raise questions related to motives underlying those changes. The rhetoric of science both informs and structures the scientific process itself,[37] thereby restricting the type of information provided and approaches to scientific inquiry. Some contend that the standards for presenting arguments and conclusions for scientific information (rhetoric) have bearing on the soundness of scientific writing.[38] Therefore, changes in scientific reporting are not only of interest to historians and literary scholars, but also to working scientists.

Evolution of the Science Article

The modern journal article has evolved from a form that emerged during the late 17th and early 18th centuries, along with the "learned" journal, as the forum for reporting scientific investigations.[36] Some evaluators contend that the current style for scientific writing equates to "literary Novocain,"[39] as it is devoid of the spontaneity characteristic of earlier scientific writing.[36] Early scientific writing usually included "…something about the nature of scientific endeavor—its difficulties, the prospects for failure and the flexibility necessary to do scientific work."[39] Today's scientific article is far more "crisp" in presentation. As a result, "…some of the range of expression allowable in the scientific writing of the past finds no place in the specialized scientific literature of today.…"[36,38] Despite less scientific rigor, the "ancillary" information common to earlier presentations often enhanced the "richness" of those presentations, and they may contain important observations and perspectives worthy for further investigation.

The scientific article is not a static means "…for communicating the conceptual system of science and, in the case of argument, is a developing means for creating that system." Despite its changing nature, it is "…the canonical form for the communication of original scientific results."[38] Contemporary scientific articles are expected to state a problem, present evidence, weigh supporting or conflicting evidence, and reach a conclusion.[36] Transitions over time, in format and content, reflect external changes associated with styles of thinking and making decisions that occur within any society or culture.[40,41] Style, presentation, and argument for the purpose of analysis are the primary aspects of this system. These components have associated standards that have evolved over time in response to selective pressures for change (Fig. A).

During the late 17th and early 18th centuries, scientists used detailed narrative accounts of scientific investigations and observations to attain "authority" for their assertions. These accounts often contained extensive details of time, place, and other supplementary information to convince the reader that the events described and conclusions drawn represented real and faithful reporting.[36] The use of scientific terminology was minimal, little quantitative data was provided, and the narrative approach for argument commonly used analogies with common things that most people could visualize. Also, these reports were intended for a diverse audience of amateurs and some professionals, rather than the audiences currently targeted, which consist almost exclusively of other professionals engaged in similar research.[38]

In general, the substantial changes in the format and content of the scientific article have improved the conduct and the reporting of science. These changes "…favor a style that represents science as an objective enterprise, foster more efficient communication, and produce stronger, more flexible argument strategies"[38] (Table A). The advent of electronic publishing brings along other external factors.

Development of the Scientific Journal

The development and importance of "learned journals" was elevated by changes in world views fostered by the discoveries of new continents and observations about the natural world. The resulting information challenged the beliefs of learned people. For example, at the beginning of the 16th century, all scholars believed that all important truths and knowledge were contained in authoritative texts,[42] but this viewpoint was discarded between 1550 and 1650 by most educated Europeans. This change was aided by Baconism (philosophy of Francis Bacon), a revolt against ancient authority by its advocacy for induction from facts as the basis for scientific investigation. In general, the advancement of science in England was fostered by the 1660 founding of the Royal Society to formulate the principles of doing science and shaping knowledge.[41] "Learned journals" became the vehicle for advancing these goals.

The first "learned journals" reporting scientific inquiry were the French Journal des Scavans (Journal of the Learned) and the British Philosophical Transactions. Both began publication in 1665, when science was a fledgling enterprise.[38] Philosophi-

Table A. General characteristics involving the style and content of the scientific article during earlier times (developed from Gross et al.[38]).

<table>
<tr><th>17th Century</th><th>18th Century</th><th>19th Century</th><th>20th Century</th></tr>
<tr><td></td><td colspan="2">• English, French, and German are the major languages of science</td><td></td></tr>
<tr><td>• Mostly brief, observational reports of encounters wtih nature (biological and physical)
• Baconian advocacy of induction from facts
• Use of testimony and qualitative experience to establish authors' cred-ibility</td><td></td><td></td><td>• "Scientific English" becomes the international disclosure of science
• Growth of format uni-formity across national boundaries and disciplines
• Focus readers' atten-tion on issue rather than on the text itself or the authors</td></tr>
<tr><td colspan="3">• Scientific style changes from the occasionally and overtly social and personal to the mostly impersonal
• Scientific style becomes more nominal (use of nounlike words) than verbal (use of words derived from a verb)
• Sentence syntax (e.g., length and clausal density) becomes simple
• Presentational features change from letter and news item format to include headings, figure captions, and introductions that provide context for article</td><td rowspan="2">• Relatively short, syntacti-cally simple sentences
• Technical abbreviations, quantitative expressions and equations, and cita-tional traces
• Intended audience almost exclusively other profes-sionals engaged in similar research
• Few sciences (e.g., plant and animal taxonomy) rely heavily on naked-eye observations to support claims; epistemic hedging common part of interpre-tation
• Preference for comparison of large data sets
• Mathematics/statistics applied whenever possible
• Increasing visual content results in interpretation of figures and tables being important aspect of inter-preting the findings</td></tr>
<tr><td colspan="2">• Intended audience includes public as well as scientific peers
• Hedging infrequent as claims are stated as fact</td><td></td></tr>
</table>

cal Transactions established a precedent in using rapid publication to provide credit for priority claims of new knowledge.[43] Science and Nature are prominent among current scientific journals that serve this purpose today, along with the numerous discipline-oriented journals and others that continue to emerge (see Fig. 7.2).

Perspective

Changes in scientific writing and presentation have become a focus for study, interpretation, and debate.[37,38,44,45] Despite these transitions, "…the scientific article will remain the medium of choice for establishing new knowledge claims.…"[38] Opinions such as the following, support that claim:

> "Against widespread opinion to the contrary, we contend that the current scientific article is, on the whole, an accurate reflection of the world as science conceives it, an effective means of securing the claims of science, and an efficient medium for communicating the knowledge it creates. Our conclusions thus challenge the critiques of stylistic 'purists' who insist that modern scientific prose is a communicative scandal."[38]

Most important relative to the scientific article is the question of how scientists will cope with the never-ending stream of information. Will the volume of flow "…tempt scientists to narrow rather than broaden the scope of their reading, leading to a "balkanization of the global village"?[46] This chapter provides suggestions to help scientists and others in developing strategies that enhance, rather than reduce, their ability to screen scientific information involving a broad spectrum of subject matter. Such strategies are important so that the knowledge gained through specialization remains connected with the broader areas of related science.

Table 7.2 Examples of general compendiums on zoonoses.

Title	Date first published	Comments
		Major summaries
Diseases of Animals in Relation to Man[15]	1926	Informs public about diseases shared by humans and animals to promote healthy living conditions and to minimize transmission. Also, debunks common myths and fallacies.
Diseases Transmitted from Animals to Man[16]	1930	First major summary of disease common to animals and humans. Prepared in part to encourage collaboration between veterinarians, physicians, laboratory researchers, and health officials to reduce disease transmission from animal to man. Revised editions were issued until 1975 (6th edition) when there was a change of editorship to W.T. Hubbert et al.
Zoonoses[57]	1964	Summary presentation of zoonoses at the time that address the history, biology, and the importance of certain diseases.
Diseases of Man Acquired from his Pets[58]	1967	A guide to zoonotic diseases intended for students and practitioners, in both human and veterinary medicine. The chapters are organized according to the types of animals kept as pets, such as carnivores, birds, and ungulates.
Zoonoses of Primates: The Epidemiology and Ecology of Simian Diseases in Relation to Man[59]	1967	A collection of writings by world authorities selected to provide research workers and students a foundation of knowledge on which to build further research.
CRC Handbook Series in Zoonoses[17–20]	1979–1982	Published in three sections, each with multiple volumes and a fourth section addressing treatment; Section A: Bacterial, Rickettsial and Mycotic Diseases (2 volumes). Section B: Viral Zoonoses (2 volumes). Section C: Parasitic Zoonoses (3 volumes). Section D: addresses antibiotics, sulfonamides, and public health.
Zoonoses and Communicable Diseases Common to Man and Animals[23]	1980	Written for medical professionals, this comprehensive work has been updated and expanded with each edition. The third edition consists of three volumes.
Handbook of Zoonoses[21,22]	1994	Two volume revision of the CRC handbook series in zoonoses.
Zoonoses: Recognition, Control and Prevention[61]	1995	Provides information about the field study of zoonoses, including historical background, current principles, predictions of future changes, and the present knowledge base in human and veterinary medicine.
Zoonoses: Biology, Clinical Practice, and Public Health Control[24]	1998	A medical textbook that describes zoonotic diseases, focusing on transmission, prevention, and treatment.
Dogs, Zoonoses, and Public Health[62]	2000	A diverse collection of works from different fields of study that provide a comprehensive examination of the human-dog relationship, ranging in topics from the human-dog bond to the major zoonotic diseases humans are exposed to by dogs.
Zoonoses: Infectious Diseases Transmissible from Animals to Humans[25]	2003	Based on the German edition first published under the title *Zoonosen*: *von Tier zu Mensch ubertragbare Infecktionskrankheiten* in 1986 and in 1997; this 3rd edition provides physicians and travelers concise presentations for well-known and rare zoonoses and other infectious diseases.

Table 7.2 Examples of general compendiums on zoonoses—Continued.

Title	Date first published	Comments
North American Parasitic Zoonoses[63]	2003	A brief summary of pertinent information on parasitic zoonotic diseases.
Waterborne Zoonoses: Identification, Causes, and Control[138]	2004	A comprehensive assessment of waterborne zoonoses that stresses the need for anticipating and controlling future emerging water-related diseases. Much of the emphasis is on diseases transmitted by domestic animals. Published on behalf of the World Health Organization and available at http://www.who.int/water_sanitation_health/diseases/zoonoses/en/
	Outline presentations	
An Outline of the Zoonoses[64]	1981	Concise desktop reference to the zoonotic diseases that provides brief, basic information about diagnosis, treatment, transmission, prevention, and control.
Bacterial and Viral Zoonoses[14]	1982	Summary report of a WHO Expert Committee that outlines the health and direct and indirect economic impact of bacterial and viral zoonoses.
The Zoonoses: Infections Transmitted from Animals to Man[65]	1988	A handbook providing a comprehensive list of over 100 zoonoses.
Veterinary Public Health Reports: Notes on the Role of Wildlife in the Epidemiology of Zoonoses[66]	1992	Provides guidance for assessing zoonotic transmission by local wild animals to humans in relation to the type of human activities within an area (e.g., dwelling, farming, tourism, and hunting).

under this designation, including a continuum of excellent books that synthesize available information about zoonoses (Table 7.2).

Disease of Animals in Relation to Man[15] is considered a zoonoses literature milestone; it is an early book that focuses on infectious diseases common to humans and animals. That small book, published in the UK, was followed by *Diseases Transmitted from Animals to Man*,[16] a USA publication that endured as a major reference for at least 50 years. Revisions published in 1941, 1947, 1955, 1963, and 1975 kept the contents current. The history, prevalence, causative agent, disease manifestations in animal and humans, and disease prevention are summarized and concisely presented. The first volume of the *CRC Handbook Series in Zoonoses*,[17] published in 1979 and completed in 1982,[18–20] set a new standard because of its comprehensive coverage of zoonotic diseases and its international authorship by recognized experts. The second edition of the CRC series has less detail than the original publications, but remains highly useful.[21,22]

Zoonoses and Communicable Diseases Common to Man and Animals[23] (1980) is another important publication. This book includes symptoms, etiology, geographic distribution, disease occurrence in man and in animals, source of infection, mode of transmission, disease diagnosis, and control for 166 different zoonoses. Originally published as a single volume, the third edition requires three volumes. The recent single-volume publications, *Zoonoses*[24] and *Zoonoses: Infectious Diseases Transmissible from Animals to Humans*[25] are other excellent books in this subject area (Table 7.2). These types of books are good starting points for delving into the literature on specific diseases. Greater detail is found in disease-specific monographs, books, and other publications (Table 7.3). Screening Web sites and high-profile weekly scientific journals provides a means to remain updated on research about diseases (Table 7.4).

Publication of the presentations from scientific symposiums and the annual meetings of professional societies is another important source of information on zoonoses and infectious disease (Table 7.5). Reports from annual meetings such as the U.S. Animal Health Association and the *Transactions of the North American Wildlife and Natural Resource Conference* typically contain presentations on current wildlife disease issues. Meetings about specific diseases often attract recognized authorities to address and debate that disease, and the resulting publications are often good sources of current knowledge. Examples include the periodic conferences on avian influenza[26] and on rabies.[27,28] Also, during recent years, popular literature and media have become important sources for information. Zoonoses are prominent among diseases that are often a focus in popular literature on emerging infections (Table 7.6).

Table 7.3 Examples of zoonoses-specific publications.

Title	Date first published	Comments
Rocky Mountain Spotted Fever[67]	1990	A history of this rickettsial disease during the 20th century with retrospective evaluations for the 19th century.
The Natural History of Rabies[7]	1991	This is an update of the original 2 volume treatise originally published in 1975 that presents the history and ecology of this disease in animals and humans and fundamental aspects of the rabies virus including morphology, chemistry, physical makeup, and relationship to related viruses.
Human Schistosomiasis[68]	1993	Covers the complex immunological reactions, epidemiology and control, the parasite and the snail as intermediate host, as well as clinical aspects of the disease. This is the third summary of information that first appeared in 1969 under this same title, and then again in 1982 as *Schistosomiasis: Epidemiology, Treatment, and Control.*
Tuberculosis[69]	1994	A comprehensive review of human tuberculosis (*Mycobacterium tuberculosis*).
Giardia: From Molecules to Disease[70]	1994	A comprehensive review of this common waterborne protozoan disease of humans.
Echinococcus and Hydatid Disease[71]	1994	A major publication addressing this important tapeworm of carnivores and often fatal infection in humans.
From Consumption to Tuberculosis: A Documentary History[72]	1994	A collection of papers written between 1850 and 1992 that document and interpret historic contests with human tuberculosis.
Brucellosis in the Greater Yellowstone Area[73]	1998	A publication by the National Research Council examining *Brucella abortus* infection, transmission, vaccination, and approaches to combating this disease in wildlife.
Mycobacterial infections in domestic and wild animals[74]	2001	OIE Scientific and Technical Review special issue that addresses bovine tuberculosis and associated *Mycobacterium* infections in wildlife and domestic animals and their relation to human infections.
Biology of Plagues[75]	2001	A historic, epidemiological, and social evaluation of bubonic plague events that have ravaged humankind.
Anthrax[76]	2002	A broad survey of the ecology, epidemiology, clinical manifestations, pathology, and bacteriology of anthrax.
Ebola and Marburg Viruses: A View of Infection Using Electron Microscopy[77]	2004	Consolidation of recent literature and personal studies to tell the story of filoviruses and how they invade and conquer their hosts.
Ebola and Marburg Viruses: Molecular and Cellular Biology[78]	2004	Summarization of advances in molecular and cellular biology of Marburg and Ebola viruses.

Table 7.4 Examples of information sources providing rapid reporting of outbreaks of zoonotic and other infectious diseases.

Information Source	Type	Comments
Science	Journal	Published weekly by the American Association for the Advancement of Science. Content includes news items, policy articles, and subject evaluations all written for general understanding and highly technical research articles and reports directed at subject matter specialists. Also available electronically at http://www.scienceonline.org/.
Nature	Journal	Similar in content and frequency to *Science*. Published since 1869 by Macmillian Journals. Available electronically at http://www.nature.com/.
New England Journal of Medicine	Journal	A long-standing, prestigious journal publishing a broad spectrum of papers addressing diseases affecting human health including emerging disease issues, such as SARS and monkeypox; published weekly.
Science News	Report	Published weekly for subscribers. Contains news items abstracted from journals such as *Science* and *Nature,* and from major newspapers.
Morbidity and Mortality Weekly Report (MMWR)	Report	Weekly reporting of specific diseases and other health concerns by state and territorial health departments and by the Centers for Disease Control (CDC); international events of importance are also reported. Available online at http://www.cdc.gov/mmwr/.
Disease Information	Report	A weekly compilation of emergency messages and animal health follow-up reports provided to the Office International des Epizooties (OIE) by 166 member countries in order to inform the international community about significant epidemiological events; distributed every Friday afternoon to http://www.oie.int/eng/info/hebdo/A_INFO.HTM.
ProMed-mail	Report	The global electronic reporting system for outbreaks of emerging infectious diseases and toxins, a program of the International Society for Infectious Diseases. Available at http://www.promedmail.org/

Wildlife Disease Literature

Scientists have been investigating disease in free-ranging wildlife populations for many years, but wildlife disease has only recently become a topic that has generated its own body of literature. In 1951, the Wildlife Disease Association (WDA) formed and began to publish the *Journal of Wildlife Diseases* (originally called the *Bulletin of Wildlife Diseases*), the first journal addressing this topic. The WDA also sponsors an annual meeting, periodically sponsors international meetings, and publishes a quarterly newsletter, which contains reports of wildlife mortality. Familiarity with the wildlife disease literature is worthwhile because many zoonoses have wildlife origins, and an increasing number of diseases appearing in humans (e.g., AIDS, SARS, monkeypox, and others) involve agents with wildlife origins. A substantial number of noteworthy wildlife disease publications exist despite the recent origin of this field and relatively small number of investigators involved. Table 7.7 lists some of these publications. Entering the names of some contributors to these publications into search engines can provide a gateway to many other important scientific publications.

The first of a benchmark series of books on diseases of wildlife appeared in 1970 with the publication of *Infectious Diseases of Wild Mammals*[29] and was followed by *Parasitic Diseases of Wild Mammals*,[30] *Infectious and Parasitic Diseases of Wild Birds*,[31] and *Noninfectious Diseases of Wildlife*.[32] These publications provided the most comprehensive coverage up to that time of diseases affecting free-ranging

Table 7.5 Examples of zoonoses and other infectious disease information sources associated with scientific symposia, conferences, and meetings.

Title	Date first published	Format	Comments
Psittacosis[79]	1955	Book	Proceedings of a symposium. Papers provide state of knowledge for that time.
Animal Disease and Human Health[89]	1958	Journal	A New York Academy of Sciences monograph addressing a comparative medicine conference that provides a 10-year progress report on zoonoses of concern.
Newcastle Disease Virus: An Evolving Pathogen[80]	1964	Book	Symposium proceedings with papers by leading experts of different disciplines from around the world; clearly provides state of knowledge at that time.
Rabies[27]	1971	Book	Proceedings of Working Conference on Rabies sponsored by the Japan-United States Cooperative Medical Science Program. Internationally recognized experts in this disease provide state of knowledge along with summaries of rabies in Asia, Japan, and the Philippines.
Wildlife Diseases[81]	1976	Book	Proceedings of the Third International Wildlife Disease Conference; papers by internationally known wildlife disease specialists.
Wildlife Diseases of the Pacific Basin and Other Countries[82]	1981	Book	Proceedings of the 4th International Conference of the Wildlife Disease Association.
Rabies in Europe[28]	1989	Report series	Collection of papers from the Second Joint Meeting on Rabies Control in Europe; updates the findings from the First Joint Meeting (1985).
Bovine Tuberculosis in Cervidae: Proceedings of a Symposium[86]	1992	Agency publication	Proceedings from a conference to formulate recommendations for dealing with disease emergence in captive deer and elk; published by USDA.
Implications of Infectious Disease for Captive Propagation and Reintroduction of Threatened Species[90]	1993	Journal	Proceeding papers from an international conference with a focus on how to develop and implement disease prevention for the well-being of free-ranging wildlife populations.
Ecology of Infectious Diseases in Natural Populations[83]	1995	Book	Developed from a 1993 Isaac Newton Institute workshop on epidemic models to focus on disease in natural systems (fauna); largely mathematical evaluations.
Infectious Diseases in An Age of Change[84]	1995	Book	Developed from a Natural Academy of Sciences' colloquium entitled "Changes in Human Ecology and Behavior: Effects on Infectious Diseases."
Brucellosis, Bison, Elk, and Cattle in the Greater Yellowstone Area: Defining the Problem, Exploring Solutions[87]	1997	Agency publication	Papers presented at a national symposium sponsored by the Greater Yellowstone Interagency Brucellosis Committee.
Public Health Systems and Emerging Infections[88]	2000	Independent publication	Summaries of presentations from a Workshop of the Forum on Emerging Infections. Published by the National Academy of Sciences.
Proceedings of the Fifth International Symposium On Avian Influenza[26]	2003	Technical society publication	One of a continuing series of proceedings of meetings of international experts in influenza providing state of knowledge of this disease.
Coral Health and Disease	2004	Book	A comprehensive global evaluation of emerging disease in coral reef systems; derived from an international meeting held in Eilat, Israel, April 2003.

Table 7.6 Examples of recent popular literature focused on emerging infectious diseases.

Title	Year of publication	Comments
The Restless Tide: The Persistent Challenge of the Microbial World[140]	1981	A series of essays about the challenges microbes pose for human health. This book is of special interest because it was published at a time when it was believed that the era of infectious diseases in humans was ending.
Disease for Our Future[91]	1989	A *BioScience* article highlighting the outcome from discussions and presentations from among 200 scientists attending a workshop focused on emerging viral diseases.
The Coming Plague: Newly Emerging Diseases in a World out of Balance[92]	1994	A highly readable account of the emergence of several high profile diseases such as AIDS and Ebola fever; author was awarded a Pulitzer prize for this book.
The Killers All Around[93]	1994	Illustrated article in *Time* magazine helped bring the issue of infectious disease emergence before the general public.
The Emergence of New Diseases[94]	1994	A good overview of global disease emergence and resurgence prepared by several members of the Harvard University Working Group on New and Resurgent Diseases; published in *American Scientist*.
The Hot Zone[95]	1995	Story of Ebola fever; adapted for the movie, *Outbreak*.
Biohazard, the Hot Zone and Beyond: Mankind's Battle Against Deadly Disease[96]	1997	Examines the rise in resistant diseases and speculates on humanity's chances for survival against them.
Virus X: Tracking the New Killer Plagues: Out of the Present and Into the Future[97]	1997	Presents a radical theory about the origin of deadly microbes and discusses past outbreaks and the dangerous work researchers are conducting in attempts to prevent them.
Guns, Germs, and Steel[98]	1998	A popular book exploring disease in humans over the last 13,000 years and the affects of widespread pathogens.
Outbreak Alert: Responding to the Increasing Threat of Infectious Diseases[99]	2000	A layman's guide about infectious diseases and how to minimize exposure; past outbreaks are used to provide context.
Bioinvasion[100]	2000	*Business Week* article that focuses on the global movement of disease as a by-product of travel and commerce and the economic consequences associated with disease introductions.
Killer Germs: Rogue Diseases of the Twenty-First Century[101]	2001	Analyses the impacts of infectious disease during the 20th century; also explores the potential use of disease as a biological weapon.
The New Killer Diseases[102]	2003	Presents high profile diseases such as SARS and reviews what is being done about them.
Six Modern Plagues and How We Are Causing them[137]	2003	Focuses on mad cow disease, AIDS, salmonella DT104, Lyme disease, hantavirus, and West Nile virus. Connects these health risks and their ecological origins.
Dinner, Pets, and Plagues by the Bucketful[103]	2004	Article in *The Scientist* that is focused on the wild animal trade as a source of pathogen introductions.

Table 7.7 Examples of books primarily focused on disease in free-ranging wildlife.

Title	Date first published	Comments
	General publications	
Parasites of North American Fishes[104]	1967	An illustrated key with descriptive information about this group of parasites; a major work of its time.
Infectious Diseases of Wild Mammals[29]	1970	First in a series of books published by Iowa State University Press summarizing information about disease in free-ranging wild mammal populations. A benchmark publication prepared by wildlife disease specialists. An expanded and updated 3rd edition published in 2001 is edited by Williams and Barker.
Parasitic Diseases of Wild Mammals[30]	1971	Another in the series published by Iowa State University Press, an expanded and updated 2nd edition was published in 2001 under the editorship of Samuel et al.
Infectious and Parasitic Diseases of Wild Birds[31]	1971	Publication of a revised edition of this component of the original set of four books developed under the guidance of J.W. Davis is pending; separate volumes for infectious diseases and for parasites will be published under the editorship of Thomas et al.
Diseases of the Reptilia[105]	1981	Volume 1 covers infectious diseases and Volume 2, non-infectious diseases. This was the first book on this subject written by specialists in diseases of reptiles and provides a good baseline for comparative evaluations.
Diseases and Parasites of White-tailed Deer[106]	1981	Compendium about diseases and parasites of one of North America's most important and favorite game species.
Noninfectious Diseases of Wildlife[107]	1982	A 2nd edition of was published in 1999 under the editorship of Fairbrother et al.; focus is on environmental contaminants, lead poisoning, mycotoxins, and other non-infectious sources of disease.
Diseases of Amphibians and Reptiles[108]	1984	Infectious and noninfectious diseases of free-ranging and captive "herp-tiles"; primarily organized by disease.
Investigation and Management of Disease in Wild Animals[109]	1994	First book devoted to the control and management of disease in free-ranging wildlife populations. The author has a great deal of practical experience provided by his role as Director of the Canadian Wild Animal Disease Centre.
Fish Diseases and Disorders[110–112]	1995–1999	A three volume set: Vol. 1, *Protozoan and Metazoan Infection, Vol. 2, Non-infectious disorders, and Vol. 3, Viral, Bacterial, and Fungal Infections* providing comprehensive coverage of the biology and ecology for the diseases addressed.
Handbook of Trout and Salmon Diseases[113]	1997	Third edition of a well-illustrated publication initially intended as a guide for trout and salmon farmers in the 1970s.
Diseases of Wild Waterfowl[114]	1997	First published in 1981, the updated and expanded 2nd edition remains an important standard reference for obtaining information about the diseases of free-ranging waterfowl.
Fish Disease Diagnosis and Treatment[115]	2000	Highly illustrated guide addressing the diagnostic methods and treatment of fish diseases.
Amphibian medicine and captive husbandry[116]	2001	Addresses amphibian medicine and captive husbandry; includes a focus on the pathology of diseases of amphibians.
Diseases of Marine Mammals[117]	2001	The 2nd edition is a comprehensive assembly of diseases affecting this group of species; an important standard reference for anyone with interests involving diseases in marine mammals.

Table 7.7 Examples of books primarily focused on disease in free-ranging wildlife—Continued.

Title	Date first published	Comments
Infectious Diseases of Wildlife: Detection, Diagnosis and Management[118]	2002	Two part Scientific and Technical Review of OIE addressing disease in farmed and free-ranging wildlife. High profile diseases of mammals are the primary orientation along with management of disease in wildlife.
	Regional publications	
Diseases of Wildlife in Wyoming[135]	1956	An illustrated compendium of diseases and disease agents found in Wyoming wildlife and other disease agents of concern. Updated, expanded, and published in 1982 as a 2nd edition edited by Thorne et al.
Alaskan Wildlife Diseases[119]	1981	A compendium of diseases of Alaskan wildlife (including fish and invertebrates).
Parasites and Diseases of Wild Mammals in Florida[120]	1992	A thorough, comprehensive presentation of disease agents and conditions affecting Florida's mammalian wildlife. Presented by animal species and includes established introduced species (e.g., sambar deer) and feral species (e.g., wild hogs).
Parasites and Diseases of Wild Birds in Florida[121]	2003	A complementary and equally thorough companion publication to the 1992 mammal publication. These two books provide a rare, in-depth assemblage of information about the diseases of wildlife within a single state and serves as an important baseline for disease investigations involving Florida wildlife.

wildlife. Subsequent editions for all but the wild bird volume have been updated. Additional publications that have since appeared further expand the sources of information (Table 7.7).

A number of field guides illustrating gross lesions associated with various diseases of wildlife also have been published (Table 7.8). Typically, a synopsis about each disease is included. More extensive information and illustrations are provided by the field guides published by the National Wildlife Health Center.[33,34] Bibliographies on wildlife disease, scientific journals devoted to diseases of wildlife, and various special reports and conference proceedings add to the publications available. Newsletters prepared by several wildlife disease programs, such as the Southeastern Cooperative Wildlife Disease Study in Georgia and the Canadian Cooperative Wildlife Health Centre, and subscription-based wildlife health modules are also important data sources (Table 7.9). Other useful resources are the National Wildlife Health Center's Web site (http://www.nwhc.usgs.gov) and Wildpro® (http://www.wildlifeinformation.org), a fee-based electronic information system that includes wildlife disease modules, such as those for chronic wasting disease and West Nile virus. During recent years, the Paris-based Office International Des Epizooties (OIE) has become an important source addressing wildlife disease (http://www.oie.int) through their OIE Scientific and Technical Reviews. The orientations for these reviews, most of which provide an international perspective, are primarily the direct and indirect interactions between domestic animals and wildlife, and those between animals and humans.

Pathfinding

Finding and extracting the desired information from among the many sources is the next task in negotiating the information maze. Major libraries often provide a variety of tools to locate information. These tools include general and specialized guides to the scientific literature, guides called pathfinders that focus on a specific subject at a specific library, and reference books that explore the literature of a particular field.

Getting Started

Many university libraries offer excellent general discussions about their information resources and are a good starting point for information searches. For example, a basic guide to resources at the library homepage of the University of Illinois at Springfield (http://library.uis.edu/findinfo/types.html) provides the following suggestions for focusing a search. For:

- a brief summary or background information, try an encyclopedia;
- a comprehensive analysis of your topic, look for books;
- a detailed analysis on some aspect of your topic, look for articles;
- objective accounts of an event, look for newspaper articles;
- obscure or esoteric information or historic primary documents, look for Web sites.

Table 7.8 Examples of illustrated field guides on wildlife disease.

Title	Date first published	Comments
Manual of Common Parasites, Diseases and Anomalies of Wildlife in Ontario[122]	1964	Pocket-sized (6"x 8") ring binder intended to be taken into the field. Color photographs of gross lesions accompanied by brief description of the disease, 1 to 3 selected references for more detailed information, and a form for documenting occurrences of each disease. An expanded second edition was published in 1969.
Manual of Common Wildlife Diseases in Colorado[123]	1981	Similar size, and basic content as the Ontario and Southeastern U.S. manuals.
Handbook of Diseases of Saskatchewan Wildlife[124]	1985	Addresses causative agent, species affected, occurrence in Saskatchewan, general ecology, clinical disease, pathology, specimens for diagnosis, and general significance for wildlife. Color photographs illustrate each disease.
Field Guide to Wildlife Diseases—General Field Procedures and Diseases of Migratory Birds[33]	1987	A highly illustrated guide written for field biologists. Tables synopsize information. The most detailed presentation of information for any field guide previously published. The first part of the book addresses field procedures for combating disease. The remainder of the text is disease specific and addresses synonyms, cause, species affected, geographic distribution of disease, seasonality, field signs, gross lesions, diagnosis, control, and human health considerations.
Field Manual of Wildlife Diseases in the Southeastern United States[125]	1988	Information is arranged by species and then disease. Color photographs illustrate the disease condition/parasite. Information is arranged by causative agent, clinical signs, lesions, hosts, diagnosis, ecology, wildlife management significance, and public heath implications. An expanded second edition was published in 1997.
Field Manual of Wildlife Diseases—General Field Procedures and Diseases of Birds[34]	1999	An expanded revision of the 1987 Field Guide to incorporate additional diseases. Basic format and type of information presented is similar to the 1987 Field Guide; available on-line at http://www/nwhc.usgs.gov/

Once initial needs are determined, certain strategies can be applied to each information source in order to retrieve the most useful items in each category. A variety of guides exist to help direct searchers to appropriate information; one example is a "pathfinder." Basically, pathfinders define a subject and then systematically list all the resources in the library that fall into that category. The University of Guelph has posted an excellent pathfinder that deals with diseases of wildlife: http://www2.uoguelph.ca/library/lib/pathfinder/index.cfm?code=wzdiseases. When available, pathfinders are recommended for initial searches because their listings often include information resources previously unknown to those conducting the search. Pathfinders are limited in that they only direct the searcher to items held by one particular library.

Other useful literature guides are compiled to direct searchers to primary and secondary resources. For example, the library at the University of Illinois, Urbana–Champaign developed *Using the Biological Literature: A Practical Guide*,[35] which evolved from a series of handouts prepared for biology students and covers over 3,000 major books, journals, and biology-related Web sites. It does not specifically cover applied sciences, such as medicine or veterinary medicine; however, it covers basic foundations of biology such as taxonomy, ecology, animal behavior, and many other areas of interest to biologists. Further, the authors comment on the constantly changing nature of the electronic literature and have extracted the entire set of Web resources listed in the guide and posted them at: http://door.library.uiuc.edu/bix/biologicalliterature/ (updated regularly).

Search Methods

Books

A basic method for compiling a knowledge base on a subject is to begin with books. The presentation of the material can range from brief information found in dictionaries and encyclopedias to extensive coverage of a single subject, typical of a monograph.

Encyclopedias and handbooks (e.g., *The Merck Veterinary Manual*, also online at http://www.merckvetmanual.com) can be used to find basic information. Bibliographies often appear in book form. Sometimes they include abstracts, but mostly they function to point the reader to a listing of works on a particular subject. The most authoritative works are monographs, which attempt to systematically and completely cover a subject area..[3]

The library catalog, the traditional library tool used to find books, is a listing of every book owned by a particular library. Prior to the Internet, one had to actually be at the library to search a catalog. Now many catalogs for university libraries are accessible via the Web. More productive searches will result from libraries at universities that have strong academic programs in the subject area of interest and from specialty libraries, such as the National Library of Medicine. Library catalogs can be checked routinely for new titles. A method to remain current on books about zoonoses might involve accessing a university's on-line catalog and routinely entering applicable search terms. Search engines have a limiting capacity in regard to publication date, so it is easy to see which books have been recently published.

In electronic library catalogs, search engines often provide for a subject search along with author, title, or keyword searches. Including subject headings from the Library of Congress that correspond to the subject area can facilitate searching electronic library catalogs. When the exact subject headings from the Library of Congress are entered, a listing of every item that contains that subject matter is listed. "Zoonoses" has been designated as a subject heading in the Library of Congress, and using this keyword will retrieve a comprehensive listing of materials. The use of specific keywords, such as tularemia or rabies, may narrow the list, but the use of a designated heading will provide the broadest approach possible to the topic.

Another search option available at many university and public libraries is called *WorldCat*, a catalog of more than 56 million books, serials, audiovisual media, maps, archives, manuscripts, scores, and computer files owned by more than 9,000 member libraries around the world. Database searching was previously limited to member libraries, but now *WorldCat* records are accessible through common search engines and through selected on-line booksellers (e.g., BookPage.com, ABE Books, Alibris for Libraries, and the Antiquarian Booksellers' Association of America). Search results include how to locate libraries that own the desired material.

Publishers' catalogs of recent and forthcoming titles provide information on new publications. These catalogs may be requested on a regular basis from publishing companies or may be accessed on-line at the publishers' Web sites. A few examples of scientific publishing houses are Blackwell, Springer-Verlag, Elsevier, Saunders, CABI, OIE, and the Iowa State Press. Searchers can also peruse catalogs of Internet booksellers. New books are often listed with a table of contents and may include a sample chapter.

Journals (Periodicals)

Scientific journals are another important source of information and are typically more current than books. Journals often take the form of a periodical, which contains news, proceedings, transactions, and reports of work carried out in a particular field. The number of journals in which information on zoonoses and other infectious diseases can be found continues to expand. For example, a database tally of periodicals publishing papers on communicable diseases disclosed 32 records (18 in English) during 1940 to 1949 and 199 (172 in English) during 1990 to 1999 (Fig. 7.2). Many current journals (Table 7.10) also publish on-line and can be screened as each volume is published, but a more effective way is to search their contents through an abstracting and indexing service.

Abstracting and Indexing Services

Whereas library catalogs are used to identify sources of published information, titles of journal articles and conference proceedings are compiled by indexing and abstracting services. Some of these services are available for free (usually as a government service) and others are fee-based. An indexing service provides only basic information, such as journal name, volume, date, author, and title, along with keywords and subject headings. An abstracting service provides this information plus a brief summary of the content of the article. Many of these services specialize in a variety of fields, including medical, veterinary, and wildlife sciences. The primary products of these services are title listings. For the full text, the article might be obtained through interlibrary loan, as a reprint from the author, through a document delivery service, or from the Internet.

Keywords are a prime portal for finding information. A thesaurus can be helpful for finding search terms. Some common keywords for the topic of zoonoses are zoonotic disease and animals and public health. Also, specific zoonotic diseases, such as tularemia and rabies, can be used as search terms, alone or in combination with another term. For example, a search for information about tularemia in rabbits may be aided by keywords defining the causative agent (*Francisella tularensis*) and the host species (e.g., *Sylvilagus floridanus* and *Lepus californicus*).

Free on-line databases that can be accessed through the Internet include PubMed, Agricola, and Ingenta (Table 7.11). These sources can be used as a starting point to become familiar with on-line databases. A useful database for searching zoonotic literature is PubMed, which is the version of Medline available to the general public. This service provides access to over 12 million Medline citations, some beginning in the early 1960s. The National Library of Medicine produced the broad range of citations for Medline from over 4,500 different biomedical journals. The National Agricul-

Table 7.9 Examples of other types of special publications focused on wildlife diseases.

Title	Source	Comments
Journal of Wildlife Diseases	Wildlife Disease Association	Papers on all aspects of disease and health associated with the survival of free-living or captive populations of wild animals, including fish; published quarterly.
Journal of Zoo and Wildlife Medicine	American Association of Zoo Veterinarians	Papers on research findings, clinical observation, case reports in the field of veterinary medicine dealing with captive and free-ranging wild animals; published quarterly.
Journal of Fish Diseases	Blackwell Science Ltd	Information on original research into all aspects of disease in both wild and cultured fish and shellfish; international scope and published quarterly.
Journal of Aquatic Animal Health	American Fisheries Society	Published under the guidance of the American Fisheries Society's Fish Health Section. An international journal, published quarterly that focuses on papers addressing the causes, effects, treatments, and prevention of diseases of marine and freshwater organisms, particularly fish and shellfish.
Diseases of Aquatic Organisms	Inter-Research	Research articles, reviews, notes, and other information about health issues associated with all forms of life (animal, plant, microorganisms) in marine, limnetic, and brackish habitats.
SCWDS Briefs	Southeastern Cooperative Wildlife Disease Study (SCWDS)	Quarterly newsletter providing information on current issues involving diseases of wildlife and SCWDS activities.
Canadian Cooperative Wildlife Health Centre Newsletter (CCWHC)	CCWHC	Quarterly newsletter providing information on current issues involving diseases of wildlife and CCWDS activities.
Quarterly Wildlife Mortality Report	National Wildlife Heath Center (NWHC)	This report compiles North American Wildlife mortality events and appears within the larger *Supplement to the Journal of Wildlife Diseases* issued with the Journal and is also posted on the National Wildlife Health Center Web site (http://www.nwhc.usgs.gov).
A Bibliography of References to Diseases of Wild Mammals and Birds[126]	American Veterinary Medical Association	A 1955 compilation of the literature in this subject area published as Part 2 of Volume 16 of the American Journal of Veterinary Research. An important reference for access to earlier scientific literature on diseases of wildlife.
Avian Cholera and Related Topics: An Annotated Bibliography[127]	NWHC	A 1988 updating of the 1979 bibliography on this subject by Wilson and Jensen, containing 1,416 references of this important disease of wild birds and some other species.
A Partial Bibliography on Duck Plague[128]	Unpublished NWHC Internal Report	Developed shortly after duck plague erupted for the first time in wild waterfowl in the USA, this internally produced bibliography helped to focus scientific investigations by scientists within the U.S. Fish and Wildlife Service.
Annotated Bibliography of Helminthes of Waterfowl[129]	Bureau of Sport Fisheries and Wildlife (now the U.S. Fish and Wildlife Service)	A compilation of the world literature that remains as a valuable reference despite its 1969 publication as a Special Scientific Report of the Bureau of Sport Fisheries and Wildlife (now the U.S. Fish and Wildlife Service).
A Partly Annotated Bibliography on Infections, Parasites, and Diseases of African Wild Animals[130]	Kenyan International Development Research Centre	Because of the close interface between African wildlife and livestock, diseases shared between these species have economic consequences for both. This bibliography was developed to bring together literature citations of benefit for combating these diseases.

Table 7.9 Examples of other types of special publications focused on wildlife diseases—Continued.

Title	Source	Comments
Bibliography of Ticks and Tickborne Diseases: From Homer (about 800 B.C.) to 31 December 1984[136]	United States Naval Medical Research Unit Number Three	A bibliography compiled by Harry Hoogstrall which covers historical papers on tickborne diseases many of which are transported by migrating birds.
Steel Shot and Lead Poisoning in Waterfowl: An Annotated Bibliography of Research[131]	Natural Wildlife Federation	A compilation of literature associated with lead shot poisoning and alternative shot shell types for addressing this issue.
Bibliography of References To Avian Botulism: Update[132]	NWHC	An update of the 1977 bibliography published by Allen and Wilson in response to a high volume of requests to the Fish and Wildlife Service's Bear River Research Station for information on avian botulism. In general, citations are primarily focused on avian botulism as a disease, not on the biology of *Clostridium botulinum*.
Zoo and Wild Animal Medicine[133]	W.B. Saunders Co.	A highly useful, long-standing textbook developed for veterinarians and first published in 1978; the 2003 edition covers the diagnosis and treatment of zoo and exotic wildlife including their husbandry, maintenance, and diseases.
Use of Lead Shot for Hunting Migratory Birds in the United States[134]	U.S. Fish and Wildlife Service	Final Supplemental Environmental Impact Statement providing data on lead poisonings in waterfowl, alternative shot shell types, comments received, and other insights into this issue; also contains extensive literature citations.
WildPro®	Wildlife Information Network	A fee-based electronic program providing information on the natural history, husbandry, and management of captive and free-ranging wild animals, including their diseases. Full texts of various guidelines, books, manuals, and documents are components of this electronic encyclopedia and library for wildlife, as are comprehensive, subject specific modules.

tural Library produces the database Agricola. Agricola is a bibliographic database of agricultural literature citations that contains references from the 1970s to the present. The subject area covers all aspects of agriculture, including animal and veterinary sciences, so zoonotic diseases are also included.

Another way to identify new articles is to browse through the table of contents of recent journals. Ingenta (www.ingenta.com) is a company that provides a way to do this for free, although a fee is charged if the entire article is needed. Users can search Ingenta by recent table of contents or by subject. This database only covers materials published since 1997.

Universities and research agencies often purchase licenses that allow users free access to fee-based databases (Table 7.12). These are also available to individuals privately, but in most cases the costs are prohibitive. Many fee-based databases can be used to identify articles on the topic of wildlife and zoonotic diseases. Some examples include *Wildlife and Ecology Worldwide*, *Biological Abstracts*, and *Zoological Record* (the latter two are provided by BIOSIS, an information service company).

Wildlife and Ecology Worldwide is a compilation of extensive citations from scientific literature related to information on wildlife. The print version, known as *Wildlife Review*, was started in 1935 for the benefit of the U.S. Bureau of Biological Survey and continued under the stewardship of the U.S. Fish and Wildlife Service until 1995. This service has been privatized and is currently offered by the National Information Services Corporation (NISC). Major topic areas include studies of individual species, habitat types, hunting, economics, wildlife behavior, management techniques, diseases, parasites, and others.

Biological Abstracts provides comprehensive coverage of resources worldwide in the biological and biomedical sciences. *Zoological Record* focuses on zoological literature. With coverage extending back to 1874, *Zoological Record* is the oldest continuing database covering publications on animal biology. The emphasis is on systematic/taxonomic

Table 7.10 Other examples (in addition to those in other chapter tables) of journals commonly publishing scientific papers addressing the ecology and control of zoonotic diseases.

Journal	Source	Year of first issue	Comments
The Journal of Infectious Diseases	Infectious Diseases Society of America	1904	A frequently cited publication focusing on original research involving the pathogenesis, diagnosis, and treatment of infectious diseases, the microbes that cause those disease, and disorders of host immune mechanisms; published semimonthly.
American Journal of Epidemiology	Johns Hopkins University School of Hygiene and Public Health	1921	Formerly the American Journal of Hygiene and the Journal of Hygiene. Covers empirical research findings, methodological developments in the field of epidemiologic research and opinion pieces. Aimed at both epidemiologists and those who use epidemiologic data, including public health workers and clinicians; published monthly.
American Journal of Tropical Medicine and Hygiene	American Society of Tropical Medicine and Hygiene	1921	Serves as a communication bridge between the application of new laboratory science technologies and the control of human disease in the developing tropics; published monthly.
Avian Diseases	American Association of Avian Pathologists, Inc.	1957	Quarterly publication of research articles, notes, and case reports addressing disease in domestic, captive, and wild birds.
Zoonoses Research	Lyceum Press	1960	This short-lived international journal of epidemiology and epizootiology issued papers in serial form. Volume 1 covered the period of 1960-1962; Thereafter, one volume per year, composed of separate numbers issued irregularly as they became available, was published. Despite its short tenure, numerous important papers of that time by leading scientists appear within this journal.
International Journal of Zoonoses	International Laboratory for Zoonoses, Research Foundation	1974	This quarterly journal ceased publication in 1987; published in Chinese, it is noted here as an example of the sources in other languages that often contain local and regional information not reported elsewhere.
Epidemiological Bulletin	Pan American Health Organization	1980	Provides brief summaries about epidemiological activity of communicable, non-communicable and emerging and reemerging diseases of priority public health concern as well as information regarding technical aspects involved in disease surveillance, prevention and control programs worldwide. Published quarterly and available online: http://www.paho.org/English/DD/AIS/beindexe.htm.
OIE Scientific and Technical Review	Office International des Epizooties (OIE)	1982	Publishes reviews containing up-to-date information of scientific and technical progress associated with the control of animal diseases and zoonoses. Two of the three issues published each year are devoted to a specific theme, such as infectious diseases of wildlife (vol. 21) and prion diseases in animals (vol. 22). The remaining issue publishes non-thematic papers.
Emerging Infectious Diseases	Centers for Disease Control and Prevention	1995	Established expressly to promote the global recognition of new and reemerging infectious diseases; the purposes include understanding the factors involved and providing information to guide disease prevention and control actions. Published monthly and available on-line: http://www.cdc.gov/eid.
Vector Borne and Zoonotic Diseases	Mary Ann Liebert, Inc.	2001	Vector-Borne and Zoonotic Diseases is the first peer-reviewed scientific journal to primarily focuses on diseases transmitted to humans by arthropods or directly by other animals; published quarterly.

Table 7.11 Examples of free on-line databases useful for searching information on zoonoses.

Name	Source	URL	Comments
Agricola	National Library of Agriculture (NAL)	http://www.nal.usda.gov/ag98/ag98.html	Bibliographic database of citations to the agricultural literature created by the NAL and its cooperators. Production of these records in electronic form began in 1970, but the database covers materials in all formats, including printed works from the 15th century.
Agris	Food and Agriculture Organization of the United Nations (FAO)	http://www.fao.org/agris/	AGRIS is the international information system for the agricultural sciences and technology created in 1974 to facilitate information exchange and to bring together world literature dealing with all aspects of agriculture. Free searching from 1975–1997. Current years available through for-profit vendors.
Ingenta	Publicly traded company	http://www.ingenta.com/	A for-profit corporation that allows free searching of a comprehensive collection of academic and professional publications available for online, fax and Ariel delivery.
Medline	National Library of Medicine	http://www.ncbi.nlm.nih.gov/entrez/query.fcgi/	A service of the National Library of Medicine, includes over 14 million citations for biomedical articles back to the 1950s. These citations are from medical journals and additional life science journals. Free through Pubmed.gov.
PrimateLit	National Center for Research Resources, National Institutes of Health, Grant RR15311, "Coordinated Information Services to Support Primate Research."	http://primatelit.library.wisc.edu/	The PrimateLit database provides bibliographic access to the scientific literature on nonhuman primates for the research and educational communities. Coverage of the database spans 1940 to present and includes all publication categories and many subject areas.

information for various animal groups, including protozoa, nematoda, pisces, reptilia, aves, and mammalia. Table 7.12 provides examples of fee-based databases in which information on zoonoses can be found.

Individuals can also order documents directly from the National Library of Medicine and the National Agricultural Library; some articles are free, others charge a fee. Interlibrary loan and document delivery services are available from a university or research library, possibly for a fee. Documents and books requested through a local public library may be less costly, but are the least timely. If the library is not able to fulfill a patron's request, the next step would be to contact the particular state's reference and loan library. The lending library may charge the patron, but in most cases, this service is free. Information about state-run lending libraries can be found at the Web site for the State of Wisconsin's Reference and Loan Library (http://www.dpi.state.wi.us/dltc/rll/). Staff at this library will either fill the requests or direct patrons from other states to similar facilities in their area.

Information brokerage services are another potential resource when time is limited. Fee-based information brokerage services, such as Wisconsin Tech Search and Instant Library, fill information needs by providing literature searches and document retrieval. Service can be as immediate as the next day, but involves a fee. To view a typical schedule of fees go to http://www.wisc.edu/wendt/wts/ (the homepage for Wisconsin Tech Search).

News Media

Newspapers and major news magazines are common sources of information on emerging infectious diseases and major epizootics affecting free-ranging wildlife populations. One method for finding this type of information is to use an Internet news reader service, which is a software program that

Table 7.12 Examples of fee-based online databases useful for searching information on zoonoses.

Name	Source	Web Address	Comments
Biological Abstracts (BA)	BIOSIS	http://www.biosis.org/products/ba/	Comprehensive worldwide coverage of resources in the biological and biomedical sciences. BA indexes articles from over 4,000 serials
CAB Abstracts	CAB International	http://www.cabi-publishing.org/AbstractDatabases.asp?SubjectArea=&PID=125	Containing over 4 million abstracts; one of the world's largest bibliographic databases covering international research in the applied life sciences. Coverage is especially strong in the field of parasitology. Also, the strong human health component makes CAB well-suited as a source of zoonotic information.
Web of Science	Thomson ISI	http://www.isinet.com/products/citation/wos/	Provides access to current and retrospective multidisciplinary information from about 8,500 of the world's most prestigious research journals.
Zoological Record	BIOSIS	http://www.biosis.org/products/zr/	Oldest continuous coverage of animal biology with references dating as far back as 1864; represents every area of animal biology, from biodiversity and the environment to taxonomy and veterinary sciences.
Wildlife Worldwide	National Information Services Corporation	http://www.nisc.com/frame/NISC_products-f.htm	The world's largest index to literature on wild mammals, birds, reptiles, and amphibians; over 618,975 bibliographic records, many include abstracts. The databases in this exclusive collection offer a global perspective and collectively form the ultimate resource on wildlife information.
Current Contents	Thompson ISI	http://www.isinet.com/products/cap/ccc/	A multidisciplinary current awareness Web resource providing access to complete bibliographic information from over 8,000 of the world's leading scholarly journals and more than 2,000 books. Users also can search a premium collection of scholarly evaluated Web sites and access evaluated full-text Web documents.
Fish and Fisheries Worldwide	National Information Services Corporation	http://www.nisc.com/frame/NISC_products-f.htm	This exclusive collection of databases is indispensable for researchers of fish and fish culture. Files from around the world provide more than 413,540 citations and some abstracts on all aspects of ichthyology, fisheries, and related aspects of aquaculture. Major topics include culture and propagation, limnology and oceanography, genetics and behavior, natural history, parasites, diseases, habitat management, fish processing/marketing, general research, and fisheries.
Aquatic Sciences and Fisheries Abstracts (ASFA)	Food and Agriculture Organization of the United Nations	http://www.fao.org/fi/asfa/asfa.asp	ASFA is an International Cooperative Information System which comprises an abstracting and indexing service covering the world's literature on the science, technology, management, and conservation of marine, brackish water, and freshwater resources and environments, including their socio-economic and legal aspects. The ASFA bibliographic database is the principal output of the system and it contains over 900,000 references, with coverage since 1971.

searches for stories and provides capabilities for following or deleting threads of information. An example of a news reader can be found at http://www.newsisfree.com, which is a Web site that allows access to nearly 10,000 sources that range from well-known newspapers and magazines to more obscure sources related to specific topics. This site is mainly useful for current information; older material is not archived.

Lexis/Nexis Academic Universe, an on-line service composed of about 5,000 legal, news, reference, and business sources, is the ultimate compilation of archived newspaper information. International and U.S. newspapers, ethnic and regional news sources, magazines, wire services, newsletters, trade journals, company and industry analyst reports, and broadcast transcripts are included and most are full text. Costs for a subscription may be prohibitive for individuals, but access may be possible from an academic library or, possibly, from an information brokering service.

Conclusion

Events of the past quarter century clearly indicate that emerging infectious diseases are a global issue and likely will remain so for the foreseeable future (see Chapter 2). The information maze associated with this subject area is growing, as are the advances in technology that attempt to manage both the cataloguing of this information and access to it. In general, an increasing amount of today's literature is being published electronically and only can be found and accessed through computer-based systems. The ability to efficiently locate, select, and access available information in paper or electronic form is often a function of how well the searcher understands information systems used to catalogue and inventory the types of information needed. Regardless of the systems used, a useful approach is to consider the subject area as a series of keywords that help to further define the types of information sought.

A general overview of major components of the information maze is provided in this chapter, including systems involved with those components, and some guidance for negotiating the information pathways. The experiences one gains through exploration will dictate what works best for each individual and the type of information needed. Each of the other chapters in this manual provides a wealth of literature citations specific for that subject. Collectively, these citations illustrate the volume of information available and the importance of knowing how to find those of greatest value and interest.

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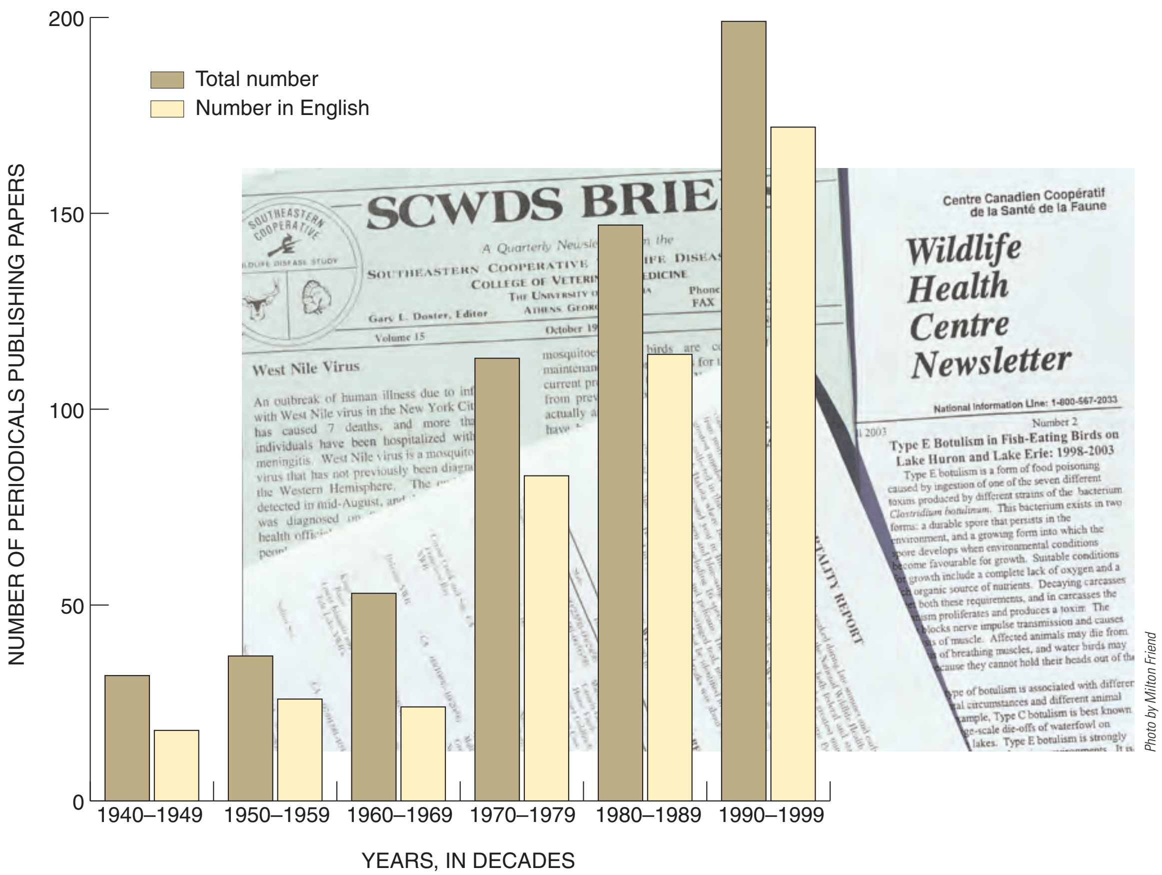

Figure 7.2 Number of periodicals publishing papers on communicable diseases.

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Conclusion

"Few ideas have been so ingrained in the literature of medicine and parasitology as the idea that parasites [i.e., all infectious pathogens] should evolve toward benign coexistence with their hosts. Few ideas in science have been so widely accepted with so little evidence. And few ideas are so at odds with the fundamental principles on which they are supposedly based, with such a great potential for missed opportunity…. In recent years both theoretical and empirical studies have led to a rejection of obligate evolution to benignness, yet it is still presented in well-respected journals and medical texts as the foundation upon which evolutionary arguments are built …" (Ewald)[1]

During recent times, much of society has believed that evolutionary processes, like those noted in the above quote, will minimize the effects of individual infectious diseases on humans in the long term and that advances in technology can provide much of the short-term protection needed. Tuberculosis and rabies, two diseases of antiquity, are examples of the fallacy in these perspectives and are prominent in the current era of global emergence and resurgence of infectious diseases that began during the 1980s. Both of these diseases are zoonoses, as are many of the other emerging and resurging diseases.[2] The importance of zoonoses as a continuing challenge to human well-being is associated with human lifestyles (work and leisure) that bring people into contact with animals (wild and **domestic**) and with other environmental reservoirs of infectious agents.[3] Wildlife are an increasingly important aspect of infectious disease emergence and resurgence, as evidenced by recent events of pathogens crossing species barriers and the rapid spread of West Nile fever across the USA (see Box 2–3).[4–8] The need to better understand the ecology of diseases of free-ranging wildlife has never been greater. Public health; the global economies of the livestock, poultry, and aquaculture industries; and the economies associated with wildlife ventures (e.g., tourism and other recreational pursuits) require enhanced efforts to obtain this understanding and are factors that stimulated the development of this publication.

This project began as an overly ambitious effort to bring together timely overviews for many of the diseases of free-ranging wildlife that have zoonotic implications. A primary consideration for this project was depicting the ecological aspect of these diseases in a highly illustrated manner, allowing nonspecialists a basic understanding of these diseases. Each module was designed to have an introductory chapter providing an overview for the subject area (e.g., viral diseases) followed by chapters for primary diseases (e.g., rabies) and completed by a chapter on other diseases within that category (e.g., miscellaneous viral zoonoses). Numerous chapters developed by subject experts have been prepared to meet this goal. However, a variety of circumstances have delayed completion of other chapters that are essential components of the disease modules.

With great apology to the authors that completed their zoonoses chapters, time delays in completing all of the chapters for each module resulted in separating those components from the more general information presented here. Even with this separation, the time required to reach publication for this part of the project has resulted in the emergence of additional diseases of concern that are not included within these chapters. Highly pathogenic avian influenza H5N1 is the most notable of these diseases, because it poses a significant threat for a global pandemic akin to that which resulted in millions of human deaths between 1918 and 1919. A unique aspect of this influenza virus strain is its potency for some species of migratory waterbirds, in addition to poultry and humans.[9–11] The involvement of wildlife, domestic animals and humans emphasizes the concepts stressed throughout this publication. Specifically, there is a continuing need for enhanced wildlife disease surveillance and monitoring, and collaborative approaches between public health, **domestic animal**, and wildlife interests to address infectious disease emergence and resurgence.

Other recent noteworthy disease events include an outbreak in China of *Streptococcus suis* that killed 38 humans and more than 600 pigs. This outbreak of a rare, and rarely fatal, bacterial disease may involve a new, more virulent form of the bacterium.[12] Concern also has arisen that pigs in South Korea may have become infected with a research influenza strain (WSN133) not known to occur in nature, and there are potential human health effects associated with exposure to this virus.[12,13]

The information provided in this publication is sufficiently independent, currently relevant, and sufficient in scope and volume to be issued as a stand-alone document. The value in doing so is associated with continuing concerns about increases in emerging infectious diseases and global unrest that could result in **bioterrorism** activities. The information provided in this publication offers perspectives for combatting these threats if wildlife are involved and will be enhanced by the subsequent publication of the supplemental circulars on specific zoonotic diseases.

Milton Friend

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Glossary, Appendixes, and Index

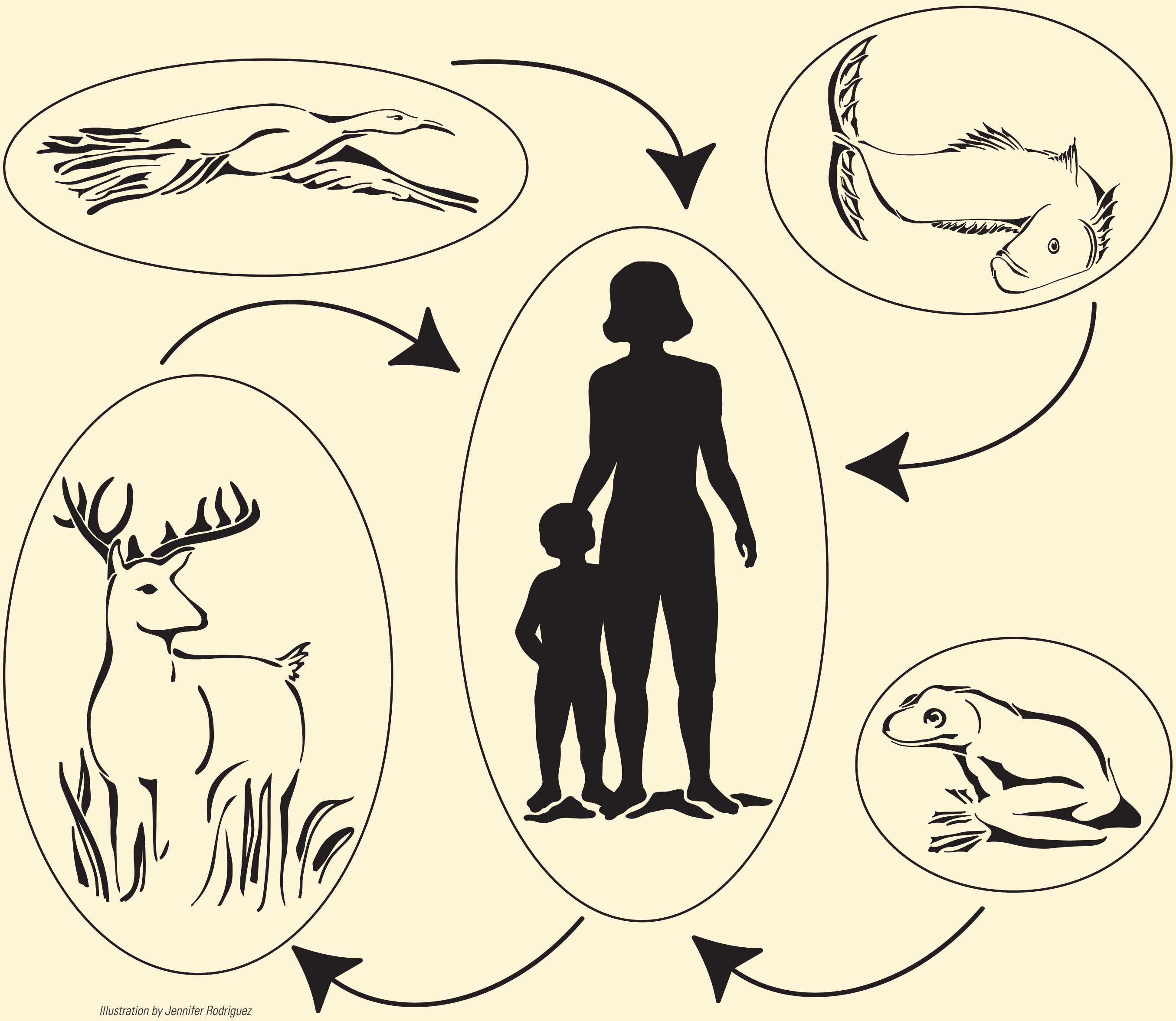

Illustration by Jennifer Rodriguez

Glossary

Abalone — Edible, rock-clinging shellfish with flattened shells that appear cup-shaped and depressed, with a slightly spiral form. The shell is lined with mother-of-pearl (hard, pearly iridescent covering of the inner portion of the shell).

Acroporids — Branching types of corals.

Ad hoc — Spontaneous and/or opportunistic evaluations and investigations (e.g., wildlife disease response) rather than established, coordinated program activities.

Aerosolized — The dispersal of ultramicroscopic solid or liquid particles suspended in air or gas.

AIDS — Acquired Immunodeficiency Syndrome, an infectious disease complex resulting from infection with Human Immunodeficiency Viruses (HIV).

Altricial — Pertaining to birds whose young are hatched or born in an immature and helpless condition requiring parental care (e.g., feeding and protection from the elements) for an extended period of time.

Amphibians — Cold-blooded vertebrates that live both on land and in water, have limbs instead of fins, have no claws on their toes, and have moist skin unprotected by external covering (e.g., scales, feathers, or hair); salamanders, newts, frogs, and toads.

Anemone (sea anemones) — Predatory, nonmobile marine invertebrates that are usually solitary (not attached together in colonies) and capture their prey by tentacles and special stinging cells (nematocysts) of the oral disk protruding from their stalk-like body.

Antelope — Deer-like mammal with true horns rather than antlers; in North America the pronghorn antelope, in the Old World numerous species (e.g., eland, blackbuck, and impala).

Anurans — Frogs and toads.

Apes — Primarily gibbons, orangutans, chimpanzees, and gorilla; tails are generally absent in apes.

Aquaculture — Collectively, the farming of finfish, shellfish (mariculture), crustaceans (e.g., shrimp), and aquatic plants.

Aquatic rodents — Rodents whose primary habitat is aquatic; North American examples are beaver, muskrat, and nutria.

Arthropods — Invertebrates belonging to the Phylum Arthropoda; here referring to members of the Classes Arachnida (spiders, ticks, mites, and scorpions) and Insecta (e.g., mosquitoes, flies, lice, fleas) that are disease vectors (e.g., mosquitoes and West Nile fever; ticks and tularemia).

Artiodactyls — Cloven-hoofed mammals with an even number of digits of the feet; includes ruminants (e.g., cattle) and nonruminants (e.g., pig).

Asclepiadae — An order of Greek physicians and priests who claimed to be descendants of Asclepius, the god of healing and medicine in Greek mythology.

Avian — Pertaining to birds.

Bats — Exceeded only by rodents in number of species, bats are the only mammals that fly (some other species of mammals are able to glide because of membranes attached to their body).

> **Insectivorous bats** — Those that primarily feed on insects while in flight.
>
> **Fruit-eating bats** — Feed almost entirely on fruit and some green vegetation.
>
> **True vampire bats** — Feed on blood obtained from mammals while the animal is asleep.

Bears — Large carnivorous mammals within the Family *Ursidae*; in North America, the black, brown, grizzly, and polar bears.

Bees — Winged, hairy-bodied, and, often, stinging, insects in the Superfamily Apoidea that use chewing and sucking mouth parts to gather pollen and nectar.

Biological community — The assemblage of living organisms (microscopic to macroscopic) that interact to shape the appearance and function of an area.

Bioterrorism — The use of biological agents, such as pathogenic organisms or agricultural pests, for terrorist purposes.

Biowarfare — Biological warfare; the use of biological weapons by one nation against another.

Bioweapons — Any weapon usable in biological warfare.

Birds — Warm-blooded vertebrates with wings and feathers (although the wings are poorly developed for some species and they are flightless); belonging to the Class Aves.

Birds of prey — Birds that primarily feed on the flesh of animals (from amphibians and reptiles to mammals and birds). Typically hawk-like birds, owls, eagles, condors, and vultures.

Biting flies — Insects of the Order Diptera with mouthparts adapted to biting and piercing vertebrate animals; examples include deer flies and horse flies.

Blackbirds — A general term that collectively refers to species such as blackbirds, cowbirds, and grackles or specifically to a single species.

Blackflies — Small, dark-colored biting flies in the Family Simuliidae whose larvae attach to rocks in flowing water; important vectors of *Leucocytozoan* spp., blood parasites of birds.

Bovidae — The ox family of ruminants, including domestic cattle, sheep and goats in addition to wild buffalos, bison, and many types of antelope.

Budding — Reproduction of some unicellular organisms, such as yeasts, by growth and specialization followed by the separation by constriction of a part of the parent.

Buffalo — African buffalo.

Caddisflies — Insects of the Order Trichoptera with four membranous wings, slender antennae, and aquatic larvae; important food source for fish and birds.

Camels — Primarily domesticated species of one-humped (*Camelus dromedarius*) and most two-humped camels; the only two-humped camel in a wild state (*C. bactrianus*) inhabits the Gobi Desert in Mongolia.

Canids — Mammals within the Family Canidae (e.g., wolves, coyote, jackals, foxes, and other dog-like animals).

Carnivores — Mammals with teeth and other body adaptions for feeding on flesh; primarily species belonging to the Order Carnivora (e.g., wolves, bears, raccoons, weasels, civets, hyenas, and tigers).

Carp — Medium-sized bottom-feeding finfish belonging to the minnow Family Cypriniformes and typically found in warm, relatively shallow water bodies.

Cat — Domestic cat.

Catfish — Bottom-feeding finfish with a scaleless skin, a broad, flat head and a strong single spine associated with both the dorsal and pectoral fins; barbels (fleshy appendages) are present on the face area. North American species include catfish, bullhead, stonecat, and madtoms.

Cervids — Mammals belonging to the deer family (e.g., deer, elk, moose, and caribou).

Cetaceans — Marine mammals that are commonly known as whales, dolphins, and porpoises.

Chlamydial — Pertaining to infections caused by bacteria of the Genus *Chlamydia*.

Chorus frogs — Small, highly vocal, arboreal frogs within the Family Hylidae that during some times of the year are choristers described as "voices in the swamp."

Civet cats — Any one of the multiple genera of medium-sized carnivores within the Family Viverridae. Utilized as food in some parts of Asia and thought to be the source of the virus causing SARS in humans.

Clams — Typically, largely sedentary filter-feeding marine mollusks with two shells (bivalves) joined at the hinge by ligament and held together by one or two strong muscles.

Companion animals — Animals maintained by humans as pets (e.g., dogs, cats, caged wildlife, horses).

Conjunctiva — The mucous membrane that lines the inner surface of the eyelid and the exposed surface of the eyeball.

Contagion — The direct cause, such as a bacterium or virus, of a communicable disease.

Containment — The concept of arresting the spread of communicable disease.

Coral reef fish — Fish species utilizing coral reef habitat (e.g., grouper, moray eel, parrotfish).

Coral reefs — Assemblages of the calcareous or horny skeletal deposit produced primarily by anthozoans (marine coelenterates having polyps with radial partitions). The reefs formed are the most complex and biologically diverse marine ecosystems that exist.

Cougar — Mountain lion, puma, Florida panther, panther.

Crabs — Pertaining to the true crabs, invertebrates with a short body form that is as wide as or wider than it is long; a sideways gait is usually well developed for locomotion.

Cranes — Long-legged wading birds; within North America, the sandhill and whooping cranes.

Crayfish — A freshwater crustacean that resembles a lobster in appearance except for its small size.

Crows — Primarily the American and fish crows in North America.

Crustaceans — Fauna with a chitinous exoskeleton such as crabs, lobsters, and shrimps and also including barnacles, sow bugs, water fleas, and beach hoppers.

Cyprinids — Fish within the minnow family (e.g., carp, minnows, goldfish, shiners, chubs, and dace).

Cysticercosis — Disease caused by encystment of cysticercus larvae of some tapeworms (*e.g., Taenia solium* or *T. saginata*) in subcutaneous, muscle, or central nervous system tissues; typically developed in swine and cattle, producing measly pork and beef.

Cytoplasm — The aqueous part of the cell that is outside of the nucleus but that is contained within the cell wall. The cytoplasm is the site of most of the chemical activities of the cell.

Deer — Pertaining to the white-tailed deer (including subspecies) and mule deer (black-tailed deer) as native species in North America. The European red deer, axis deer (chital) from Asia, and fallow deer (Europe and Asia minor) are exotic species maintained in captive herds.

Diatoms — Minute planktonic unicellular or colonial algae with silicified (impregnated with silica) skeletons that form diatomaceous earth (used especially as filter material).

Dinoflagellates — Single-celled planktonic organisms that are important food-web components (foundational in marine systems); some forms cause red tide.

Disarmament — The act of laying down arms, especially the reduction or abolition of a nation's military forces and armaments.

Disease carriers — Animals infected with infectious agents and showing no clinical signs of disease but are capable of transmitting the infection.

Dogs — Domestic dog.

Dolphins — Marine mammals of the Family Delphinidae; they are small whales, usually with teeth in both jaws and a blowhole far back from the snout. (Do not confuse with dolphin, which are marine finfish, also called mahi-mahi).

Domestic animals — Livestock (e.g., cattle, sheep), poultry (e.g., chicken, turkey), domestic waterfowl (e.g., Pekin duck, goose), and companion animals of domesticated species (e.g., horse, dog, and cat).

Domestic ducks — Primarily the white Pekin duck.

Domestic pigs — Hogs domesticated from wild members of the same species and bred for specific genetic characteristics that have somewhat altered the appearance of the animals.

Donkeys — Domesticated horse-like animals within the Family Equidae and same genus (*Equus*) as horses, zebras, mules, and several other species. Extremely surefooted animals with high endurance and capacity to survive on a minimum of food; often used for work under hot, difficult conditions.

Doves — Pigeon-like birds belonging to the Family Columbidae. The domestic pigeon is often referred to as the rock dove. Within North America, the mourning dove and the white-winged dove are the most abundant wild species.

Ducks — Webbed-footed waterbirds with short legs that along with geese and swans form the Order Anseriformes.

Ecotourism — In general, travel to natural areas rich in various forms of biota and natural beauty for the purposes of viewing, cultural enrichment, and other nonconsumptive uses carried out in a manner that is ecologically sound and sustains the well-being of local peoples.

Eel — Snakelike, voracious, and elongated bony fishes with a smooth slimy skin and lacking pelvic fins.

Egret — Wading birds within the heron/bittern family (Ardeidae) including the reddish egret, cattle egret, and other species.

Elephant shrews — Small African mammals of the Family Macroscelididae with long, prehensile noses used for finding insects and other food items.

Endemic — A disease that commonly is present within a human population or a geographical area.

Enzootic — An animal disease that commonly is present within a population or a geographical area.

Epidemic — An outbreak of disease affecting a disproportionately large number of humans within a population, community, or region during a period of time.

Epizootic — A disease affecting a greater number of animals than normal; typically, involving many animals in the same region at the same time.

Equine — Pertaining to horses.

Eradication — The elimination of an exposed population of animals during disease control activities attempting to prevent the establishment of a highly infectious pathogen (e.g., depopulation of poultry to combat highly pathogenic influenza and Newcastle disease viruses).

Estuarine fish — Fish that live in coastal areas where the tide ebbs and flows, often at the wide mouth of a river where the tide meets the current.

Etiologic — Assigning or seeking to assign a cause or discover the origins of disease.

Eutrophication — The process by which a body of water becomes enriched in dissolved nutrients (e.g., nitrates and phosphates) that stimulate the growth of planktonic and other aquatic plant life usually resulting in the depletion of dissolved oxygen.

Fairy shrimp — Transparent freshwater branchiopod crustaceans of the Order Anostraca.

Felidae — A family of carnivora including the domestic cat and wild species, such as lion, tiger, leopard, lynx, cheetah, and many other wild cats. Civet cats are not part of this family; they are in the Family Viverridae along with mongooses and several other species.

Felids — Pertaining to members of the cat family.

Feral — Typically, animals that have descended from tame stock and are now sustaining themselves in nature.

Feral swine — Domestic swine that have reverted to a wild state and are living free in nature.

Fibropapillomas — A papilloma (small wart-like growth) characterized by a conspicuous amount of fibrous connective tissue at the base and forming the cores upon which the neoplastic epithelial cells are massed.

Filter feeders — Animals such as clams that obtain their food by filtering organic matter from the aquatic environment in which they live. Baleen whales filter minute organisms from the current of water around them.

Finfish — Scaled fish with a caudal (tail) fin and multiple other fins along the dorsal (top), ventral (bottom), and other body areas.

Fleas — Small, wingless, bloodsucking insects within the Order Siphonaptera with laterally compressed bodies and legs adapted for jumping; some are important vectors of zoonotic diseases such as plague.

Flies — Two-winged insects belonging to the Order Diptera (flies, gnats, and mosquitoes).

Foxes — In North America pertaining to arctic, red, kit (swift), and gray fox.

Free-ranging wildlife — Wildlife living unconfined in nature.

Freshwater fish — Finfish normally in freshwater environments (e.g., bass, crappie, and trout).

Frogs — Amphibians that, along with toads, are within the Order Anura. Adult specimens of both have short, squat bodies, powerful hind legs, and lack a tail (see Toads).

Gallinaceous birds — Birds belonging to the Order Galliformes; chicken-like birds including grouse, partridge, ptarmigan, pheasants, prairie chickens, quail, and turkeys.

Geese — Medium-sized waterbirds that along with ducks and swans form the Order Anseriformes.

Gnathostomiasis — Disease caused by ingestion and subsequent tissue migration of immature roundworms (*Gnathostoma* spp.).

Gnats — Small, biting flies within the Order Diptera.

Gorgonians — Corals belonging to the Genus *Gorgonia*; usually colonial species with a horny and branching axial (having a trunk and a head) skeleton.

Ground squirrels — Typically, burrowing small rodents of the Family Sciuridae (e.g., in the USA, thirteen-lined ground squirrel, rock squirrel, and antelope ground squirrel) but this term often also includes species in other genera such as chipmunks and prairie dogs.

Gulls — Long-winged aquatic birds with webbed feet and, usually, gray and/or white plumage; primarily scavengers.

Hard clams — Clams with stout, hard shells that close completely (e.g., littleneck, cherrystone, and sweet butter clams).

Hard corals — Corals within the Order Scleractina, including branching corals (e.g., staghorn and elkhorn); encrusting, mound and boulder corals (e.g., star, and starlet); brain corals (e.g., knobby brain) and others.

Hard ticks — Arthropods of the Family Ixodidae that are important for disease transmission; includes ticks of the genera *Dermacentor*, *Amblyomma*, *Ixodes*, and *Haemaphysalis*.

Hatchery fish — Finfish being reared in captivity for food and for release into nature.

Hawaiian honeycreepers — Multiple species of brightly colored singing birds of the Subfamily Drepanidinae found in forested areas of the Hawaiian Islands.

Hedgehogs — Small, nocturnal insectivores of the Subfamily Erinaceinae with spines on their backs, which they present outwards when they roll into balls for protection.

Herbivores — Mammals that feed almost exclusively on plants (e.g., cattle, sheep, manatee).

Herons — Long-legged wading birds within the Family Ardeidae (e.g., great blue heron, green heron, and black-crowned night-heron).

Hippocrates — Medical practitioner who is regarded as the father of medicine; author of the Hippocratic Oath (circa 460–377 BC).

HIV — Human Immunodeficiency Viruses, the agents resulting in AIDS.

Honeybees — Social, honey-producing insects of the Family Apidae; often kept in hives for the honey and beeswax they produce.

Hosts — Species that harbor or nourish microbes, viruses, and metazoan parasites.

Hounds — Pertaining to domestic dogs used to track and chase (run) foxes, coyotes, and other wildlife as part of a hunt.

Hummingbirds — Brightly colored, small, New World birds within the Family Trochilidae with long, slender bills and rapid wing movements that allow them to hover.

Hyenas — Dog-like but not closely related carnivores within the Family Hyaenidae; found in the general geographic regions of the Old World inhabited by jackals. Primarily scavengers with powerful jaws and teeth for feeding on the bones of large animal carcasses.

Iguanas — Lizards of the reptile Family Iguanidae.

Immunocompromised — A condition in which the immune system is not functioning normally.

Index case — The earliest documented case of disease in an outbreak or the first identified case of a new disease syndrome.

Invertebrates — Animals lacking a spinal column (e.g., insects, crustaceans).

Jackals — Dog-like carnivores within the Family Canidae; primarily feed on carrion but also prey on small mammals and insects and eat plant material. Jackals are found in Africa, the Middle East, and some other countries of that region.

Kangaroos — Herbivorous marsupials of the Family Macropodidae from Australia and adjacent islands with long tapered tails, short forelimbs, and strong hind limbs adapted for leaping.

Lagomorphs — Mammals within the Order Lagomorpha (rabbits, hares, and pikas).

Lampreys — Jawless fishes whose circular mouth appears as rings of teeth, which are actually horny spines adapted for sucking blood; they feed by attaching to live fish such as lake trout and northern pike.

Lions — The African lion.

Livestock — Collectively, mammals raised for agriculture (e.g., cattle, sheep).

Mammals — Warm-blooded vertebrate animals that possess hair during some part of their life and suckle their young.

Manatee — Large, herbivorous, aquatic mammal with a rounded body, a small head, and a squarish snout. Primarily found in warm coastal waters and adjacent sluggish rivers of South America, north to the southeastern USA, and in western Africa.

Mariculture — The cultivation of finfish, shellfish, or aquatic plants in a saltwater environment (i.e., marine aquaculture).

Marine mammals — Aquatic species of mammals living in the oceans and nearshore saltwater environments (e.g., polar bear, walrus, seals, whales).

Marsupials — Mammalian species having an external abdominal pouch (marsupium) for carrying their young until their development is complete; young of these species are born in a very underdeveloped state and must be carried and nourished for a prolonged period of time (e.g., opossums, kangaroos, koala, and wombats).

Mice — Any of numerous small rodents of the Family Muridae having pointed snouts, long nearly hairless tails, and small rounded ears.

Microbes — Microscopic living organisms, especially those capable of causing disease and including bacteria, viruses, protozoa, and fungi.

Migratory birds — Species of birds that undertake seasonal geographic movements to meet their living and life-cycle requirements (e.g., waterfowl, shorebirds, many passerines).

Mole salamanders — Salamanders within the Family Ambystomatidae; except for a brief period during breeding these species stay underground most of their lives.

Mollusks — In general, shell-bearing invertebrates that have soft, unsegmented bodies (e.g., snails, clams, conchs, shells, scallops, oysters); also highly specialized carnivores often lacking an external shell and having long flexible tentacles, eyes, and a powerful beak (e.g., squid and octopi).

Monkeys — Any of various long-tailed mammals of the Order Primates, including the families Cebidae (New World monkeys) and Cercopithecidae (Old World monkeys).

Morbidity — A diseased condition, or the severity or incidence of a disease.

Mosquitoes — Blood-sucking, small dipteran insects of the Family Culicidae that are important vectors for disease transmission (e.g., West Nile fever, malaria).

Mules — The typically sterile offspring of a male donkey and a female horse.

Mycosis — A fungal infection.

Neotenic salamanders — Salamander species that retain gills throughout their entire life.

Newts — Brightly colored species of salamanders, generally with thick warty skins and an absence of some anatomical features of other salamanders (e.g., grooves in the skin in the vicinity of the nose (nasolabial) and vertically along the body (costal)).

Nonhuman primates — Context in this book: the great apes, monkeys, langurs, and other monkey-like mammals; the Order Primates also includes a variety of other species.

Nosocomial — Disease/infections of humans originating or taking place in a hospital.

Ornamental fish — Finfish traded, reared, and maintained for home aquaria (e.g., goldfish, koi, tropical fishes).

Oysters — Bivalve mollusks having a rough, irregular, and asymmetrical shell closed by a single adduction (to draw toward) muscle.

Parakeets (budgerigars) — Small, brightly colored, slender parrots of the Genus *Melopsittacus* having long, tapered tails.

Parasitic infection — A successful invasion of a host by an organism that uses the host for food and shelter.

Parr — Typically, young anadromous salmon that have reached a stage of development where they feed in freshwater.

Parrotfish — Brightly colored marine tropical fish of the Family Scaridae with fused teeth resembling a parrot's beak.

Parrots — Brightly colored tropical and semitropical birds of the Family Psittacidae with short hooked bills.

Partridge — Small to medium size gallinaceous birds; the chukar partridge and gray (Hungarian) partridge are established exotics in North America.

Passerines — Perching birds belonging to the Order Passeriformes; primarily includes songbirds requiring extended parental care after hatching (altricial). Examples include flycatcher, swallows, waxwings, warblers, finches, and thrushes.

Pathogens — Typically, microorganisms capable of inducing disease, but broadly includes all disease-inducing agents.

Pelicans — In North America, the American white and the brown pelican.

Penaeid shrimp — Edible shrimp; members of the Genus *Penaeus*.

Pheasant — Long-tailed and often brightly colored Old World gallinaceous birds of the Family Phasianidae.

Pigeon — Common street pigeon, rock pigeon, or rock dove; introduced into North America from Europe, often feral as well as human maintained.

Pinnipeds — Seals, sea lions, and walruses.

Plant community — The assemblage of plant life that constitutes the flora of a specific area, region, or other geographic designation.

Porcine — Relating to swine (pigs, hogs).

Poultry — Domestic species of chicken-like birds (e.g., chicken, turkey).

Primates — Mammals of the Order Primates with shortened snouts and highly developed hands and feet; includes humans, monkeys, apes, and lemurs.

Prion — A protein particle that lacks nucleic acid and is believed to be the cause of various infectious diseases of the nervous system (e.g., bovine spongiform encephalopathy, Creutzfeldt-Jakob disease, and chronic wasting disease).

Propagated — Reared under human-controlled conditions (e.g., captive rearing of pheasants for release into nature).

Psittacines — Relating to parrots; includes New World and Old World species (e.g., parrots, macaws, parakeets, budgerigars, cockatoos, and lovebirds).

Public domain — Land and other natural resources held in stewardship for society by the government (term also extends to unprotected property rights that belong to society and can be appropriated by all).

Quail — Any of various small, short-tailed gallinaceous birds of the Family Phasianidae.

Rabbits — Small, long-eared mammals within the Family Leporidae (hares and rabbits) of the Order Lagomorpha (pikas, rabbits, and hares). Rabbits are born naked, blind, and helpless in a fur-lined nest; hares are born fully haired, with open eyes, and are able to run within minutes after birth. Some species commonly referred to as rabbits are actually hares (e.g., jack rabbit and snowshoe rabbit) while the Belgian hare is actually a rabbit.

Raptors — Birds of prey; hawk-like birds, eagles, owls, condors, and vultures.

Reptiles — Vertebrates of the Class Reptilia that breathe by means of lungs and have external coverings of scales or bony plates; includes snakes, lizards, crocodiles, turtles, and dinosaurs.

Reservoir host — The host that maintains the disease agent in nature and that provides a source of infection to susceptible hosts.

Retropharyngeal pouches — Pouched areas at the rear of the pharynx, the muscular tubular passage of vertebrates extending from the back of the nasal cavity and mouth to the esophagus.

Rickettsial — Any of various bacteria of the Genus *Rickettsia* carried as parasites by many ticks, fleas, and lice; they cause diseases such as typhus, scrub typhus, and Rocky Mountain spotted fever in humans.

Rodents — A diverse group of mammals characterized by incisor teeth that grow throughout life and must be worn away by cutting and gnawing hard materials. Species within the Order Rodentia include squirrels, mice, rats, voles, chipmunks, gophers, lemmings, beaver, porcupines, and many others.

Ruminants — Even-toed, hoofed mammals that chew the cud and have complex four-chambered stomachs; includes cattle, sheep, goats, and deer.

Salamanders — Essentially voiceless amphibians that possess a tail throughout their lives (can regenerate a lost tail or limb), usually have moist, relatively smooth skin, no external ear openings, and not more than four toes on their front feet.

Salmon — Predatory finfish within the Family Salmonidae (whitefish, grayling, salmons, trouts, and chars). Saltwater species are anadromous (enter freshwater streams to spawn). Some live exclusively in fresh or saltwater; others spend part of their life in both.

Salmonids — Typically, salmon and trout finfish; the Family Salmonidae also includes other species.

Saltwater fish — Finfish typically found in marine habitat (e.g., tuna, grouper, sharks, halibut, and herring).

Sandflies — Small, biting dipteran flies of the Family Psychodidae—especially in the Genus *Phlebotomus*—that are important vectors for disease transmission (e.g., leishmaniasis).

SARS — Severe Acute Respiratory Syndrome, a recently emerged viral disease often lethal to humans. The causative virus is believed to be harbored by civet cats.

Scallops — Mollusks with two valves (shells), which may or may not be of equal size, radiating ribs along the valves, and scalloped edges; one of the few mollusks that swim.

Scavengers — Animals that feed on dead carcasses, other carrion, and refuse (e.g., vultures, crows, hyenas, and jackals).

Schistosomiasis — Generally tropical diseases caused by parasitic invasion with schistosomes. Widespread in rural areas of Africa, Asia, and Latin America through contact with contaminated water; infections commonly lead to gradual destruction of the tissues of the kidneys, liver, and other organs.

Scleractinian family — The hard corals; the basic building blocks of tropical coral reefs including encrusting, mound, boulder, brain, branching, and numerous other types of corals.

Seabirds — Bird species that utilize ocean environments as primary habitat (e.g., gulls, albatross, brown pelicans, fulmars, petrels, shearwaters, and many other species).

Seagrass — Nearshore marine grasses (e.g., turtle grass and manatee grass) that often form dense beds serving as important habitat for a wide variety of marine life forms.

Seagrass community — The nearshore assemblage of seagrasses and associated plants that comprise the seagrass beds of some warm water marine areas.

Sea turtles (marine turtles) — Turtles of the Family Cheloniidae; unlike other turtles, sea turtles are only on land to lay eggs and have a lighter weight shell and a short, heavy neck that cannot be completely drawn back into the shell.

Sea urchins — Globular-shaped marine invertebrates characterized by their radial symmetry (echinoderms) and including starfish, serpent stars, sea urchins, sand dollars, sea cucumbers, and sea lilies. Sea urchins are covered with tubercles having long and heavy movable spines so dense as to give the appearance of the urchins being "furred."

Seals — Carnivorous marine mammals that belong to the Families Phocidae and Otariidae and have webbed flippers.

Search engine — A computer program designed to use keywords entered by users to locate Web sites that contain the requested information.

Serotype — A group of closely related microorganisms distinguished by a characteristic set of antigens.

Sharks — Large finfish with cartilaginous rather than bony skeletons.

Shellfish — Aquatic invertebrate animals with a shell; typically edible mollusks (e.g., clams, oysters) and crustaceans (e.g., lobster, crabs, and shrimp).

Shrimp — Pertaining to the edible shrimp of the Genus *Penaeus*; shrimp, along with lobsters and crabs, are the most highly organized (morphologically) crustaceans.

Skunk — Several species of carnivores within the Family Mephitidae; specifically, the striped, hooded, spotted, and hog-nosed skunk.

Smolt — Typically, young salmon and steelhead trout that are about 2 years old and have developed the silvery adult coloration.

Snails — Mollusks of the Class Gastropoda; most have a single enclosing shell or valve (usually spiral). Snails are a mobile, predatory species (often carnivores) that are important developmental hosts for pathogens causing several major parasitic diseases.

Snakes — Scaled, limbless, often venomous reptiles of the Suborder Serpentes having long, cylindrical tapering bodies.

Snapping turtles — Any of numerous large, freshwater turtles within the Family Chelydridae that have rough shells and powerful hooked jaws capable of closing suddenly.

Soft corals — Commonly, the gorgonians (e.g., sea rods, sea whips, feather plumes, and sea fans) because their colonies lack hard, rigid, permanent skeletons; specifically corals belonging to the Family Nephtheidae (corals resembling branched trees with thick trunks).

Soft ticks — Eight-legged arthropods of the Family Argasidae characterized by their soft, membranous external shells.

Soft-shelled clams — Clams with thin, brittle shells and a long rubbery neck (siphon) that extends beyond the edge of the shell preventing closure (e.g., razor, steamer, and geoduck clams).

Songbirds (passerines) — Primarily, altricial perching birds that commonly sing and many have specialized vocal apparatus for song.

Sponges — Marine invertebrates that are the most primitive of all multicellular animals, essentially being a mass of porous tissue organized around a system of water canals; sponges are attached to a substrate, have no front end, no head, no mouth or gut.

Sportfish — Finfish such as marlin, salmon, trout, and bass that are pursued by recreational fisherman.

Squirrels — Small- to medium-sized arboreal rodents of the Family Sciuridae having long bushy tails and strong hind legs.

Stable flies — Biting dipteran flies of the Family Muscidae common around stables.

Sucking lice — Wingless insects of the Suborder Anoplura that are parasites to birds and mammals.

Swans — Large web-footed waterbirds with long, slender necks that along with ducks and geese form the Order Anseriformes.

Swine — The domestic pig or hog.

Ticks — Blood-sucking, parasitic arthropods that have a hard body (ixodid ticks) or a soft body (argasid ticks); ticks are important disease vectors.

Toads — In general, anurans with less smooth skin than that of most frogs; toads are also more terrestrial than frogs and hop rather than jump.

Translocation — Human capture of wildlife at one geographic area and their transportation and release at a different geographic area.

Transmission — The spread of infectious agents from one individual to another by direct and indirect means (e.g., contaminated environment or fomites).

Trout — Salmon-like finfish within the Family Salmonidae; typically found in well-aerated, cool, freshwater habitat and generally of smaller size than salmon.

True frogs — Those within the Family Ranidae; generally long-legged, slim-waisted anurans and the only frogs with teeth in the upper jaw, large distinct eardrums, and broadly webbed hind feet.

Turtles — Reptiles with shells that cover the body; some species are found in freshwater habitats, others in marine environments (sea turtles), and still others are terrestrial (tortoises).

Ungulates — Mammals having hooves. The even-toed hoofed species (Artiodactyla) include deer, antelope, cattle, and sheep; the odd-toed hoofed mammals (Perissodactyla) include horses, tapirs, and rhinoceroses.

Upland game birds — Chicken-like terrestrial birds commonly hunted for sport and food (i.e., chachalacas, grouse, partridges, pheasants, prairie-chicken, ptarmigan, quail, and turkeys).

Vector-borne — Denoting a disease or infection that typically is transmitted by the bite of an arthropod (e.g., mosquitoes and ticks).

Vertebrates — All animals having spinal columns; mammals, birds, reptiles, amphibians, and fishes.

Vibrios — Any of various short, motile, S-shaped or comma-shaped bacteria of the Genus *Vibrio*, especially *V. cholerae,* which causes cholera in humans.

Virulence — The degree or ability of a pathogenic organism to cause disease.

Vole — Small, mouse-like rodent.

Vultures — Carrion-feeding, soaring birds within the raptor/birds of prey group. In North America, the California condor, turkey vulture, and black vulture.

Waterbirds — Bird species that utilize water environments as primary habitat (e.g., waterfowl, wading birds, gulls and terns, cormorants, and many others).

Waterborne pathogens — Disease agents transmitted to susceptible hosts through contaminated surface and drinking water (e.g., giardiasis and cryptosporidiosis).

Waterfowl — Ducks, geese, and swans.

Whales — Large, marine mammals of the Order Cetacea with forelimbs modified to form flippers, tails with horizontal flukes, and blowholes for breathing.

Wild dog — Typically, a general term referring to free-ranging wild canids such as the African hunting dog, the dhole in India, and the dingo in Australia.

Wild hogs — See feral swine, wild swine, and wild pigs.

Wild pigs — Domestic swine that have become feral.

Wild rat — Nonlaboratory species of rats including indigenous species, such as the wood rat (USA) and exotic species, such as Norway and roof rats (USA).

Wild ruminants — Nonlivestock species of animals that chew the cud (e.g., bison, deer, giraffe, antelope).

Wild swine — See feral swine, wild hogs, and wild pigs.

Wild ungulates — Nonlivestock species of hoofed mammals (e.g., deer, antelope, moose, peccary, and rhinoceros).

Wildlife rehabilitation — Restoration of a state of health suitable for the release of sick, injured, and otherwise impaired wildlife brought into captivity for care and treatment.

Wolves — The gray or timber wolf and the red wolf.

Wombats — Medium-sized burrowing animals that carry their young inside a pouch (marsupials) until they are fully furred; found in Australia, Tasmania, and on Flinders Island in Bass Strait.

Zebras — Horse-like striped animals within the Family Equidae; found in Africa.

Zoanthids — Small, marine invertebrates of the Order Zoanthidae.

Zoonoses — Infectious diseases transmissible between animals and humans, and vice versa.

Zoonosis — An animal disease that can be transmitted to humans.

Zoonotic — Pertaining to a zoonosis.

Zooplankton — Minute living animal organisms within the upper portion of water bodies; these organisms drift within the current and are an important component of natural food chains.

Appendix A. Some emerging and resurging pathogens causing disease in fauna and the geographic areas most affected.[a]

(Y, yes; N, no; U, unlikely; I, insufficient information for determination.)

Pathogen	Disease	Zoonosis[b]	Primary fauna affected	Primary geographic area affected	References[c]
VIRUSES					
Adenovirus hemorrhagic disease virus	Adenovirus hemorrhagic disease	U	Mule deer	USA (central California)	262, 263
Adenovirus	Adenovirus infection	N	Long-tailed duck (oldsquaw)	Beaufort Sea (northern Alaska, USA)	123
Avian pox virus	Avian pox	N	Bald eagle, Hawaiian honeycreepers, passerines, waterfowl	USA	58, 86, 105
Canine distemper virus	Canine distemper	N	Baikal and Caspian seals	Lake Baikal, Caspian Sea (Russia), Kazakhstan	56, 86, 134, 136, 166, 176, 231
			African lion, African wild dog, black-footed ferret, wide range of carnivores (including foxes, raccoons, skunks)	Tanzania, North America	2, 8, 29, 54, 58, 135, 179, 216
Canine parvovirus	Canine parvovirus infection	N	Coyote, gray wolf, other canids	Worldwide	14, 54, 172, 180
Classical swine fever virus	Classical swine fever (hog cholera)	N	Wild boar	Europe	10
Dolphin morbillivirus	Dolphin morbillivirus infection	U	Atlantic bottlenose, striped, Pacific common, and Black Sea common dolphins	Northwestern Atlantic Ocean (eastern USA coast), Mediterranean Sea, Black Sea, South Pacific Ocean	3, 18, 53, 64, 65, 67, 136, 160, 176, 237
Duck enteritis virus	Duck virus enteritis (duck plague)	N	Waterfowl	USA, Canada	29, 49, 58, 84, 86, 145, 146
Eastern equine encephalitis virus	Eastern equine encephalitis	Y	Various birds	North America	58
Ebola virus	Ebola virus hemorrhagic fever	Y	Nonhuman primates	Sub-Saharan Africa, Indonesia, Philippines	54, 148
Herpesviruses	Elephant herpesvirus infections	N	Asian and African elephants	Globally (captive collections)	212
EHD viruses, or bluetongue viruses	Epizootic hemorrhagic disease (EHD)	N	Deer, bighorn sheep	North America	58
Calicivirus (European brown hare syndrome virus)	European brown hare syndrome	N	European brown hare	Eastern and Western Europe	147
Feline immunodeficiency virus	Feline immunodeficiency virus infection	N	African lion	Tanzania, South Africa, Botswana	135, 180
Feline leukemia virus	Feline leukemia virus infection	N	European wildcat, cougar	UK (Scotland), USA (California)	135
Herpesvirus	Fibropapillomatosis	N	Marine sea turtles	Gulf of Mexico, Caribbean Sea, Pacific Ocean, western Atlantic Ocean, Indian Ocean	13, 86, 115, 116, 201, 247, 248

Appendix A. Some emerging and resurging pathogens causing disease in fauna and the geographic areas most affected[a]—Continued.

(Y, yes; N, no; U, unlikely; I, insufficient information for determination.)

Pathogen	Disease	Zoonosis[b]	Primary fauna affected	Primary geographic area affected	References[c]
Infectious bursal disease virus	Infectious bursal disease (Gumboro disease)	N	Emperor and Adelie penguins, spectacled and common eiders, herring gull	Antarctica, Baltic Sea, USA (western Alaska)	90, 91, 122
Infectious pancreatic necrosis virus	Infectious pancreatic necrosis	N	Trout, Atlantic salmon	UK (Northern Ireland, Scotland)	181, 198
Infectious salmon anemia virus	Infectious salmon anemia	N	Atlantic salmon	USA (Maine), Canada (New Brunswick)	23, 58
Influenza A virus	Influenza A	Y	Harbor seal	USA (Cape Cod, Massachusetts)	34, 242
Influenza B virus	Influenza B	Y	Gray and harbor seals	North Sea (Dutch coast)	136, 176, 193
Koi herpesvirus	Koi herpesvirus infection	N	Common carp, koi	USA (mid-Atlantic states, southern California)	96
Largemouth bass virus	Largemouth bass virus infection	N	Largemouth bass	USA (17 southeastern and southwestern states)	58, 101, 195, 259
Malignant catarrhal fever virus	Malignant catarrhal fever	N	White-tailed deer	Northcentral USA (captive collection)	151
Marburg virus	Marburg hemorrhagic fever	Y	Nonhuman primates	Sub-Saharan Africa, Indonesia, Philippines	54
Measles virus	Measles	Y	Mountain gorilla	Africa	54, 74
Monk seal morbillivirus-G	Monk seal morbillivirus-G infection	U	Mediterranean monk seal	Northeastern Atlantic Ocean (western Saharan coast of Africa)	176
Monk seal morbillivirus-WA	Monk seal morbillivirus-WA infection	U	Mediterranean monk seal	Northeastern Atlantic Ocean (western Saharan coast of Africa)	176
Myxoma virus	Myxomatosis	N	Rabbits	Australia, UK, Europe	54, 180
Newcastle disease virus	Newcastle disease	Y	Double-crested cormorant, pelicans, gulls	USA, Canada	29, 54, 58, 59, 86, 256
Nipah virus	Nipah virus infection	Y	Fruit bats	Malaysia, Singapore	11
Phocine herpesvirus-1 and -2	Phocine herpesvirus-1 and -2 infection	U	Harbor seal	Northeastern Pacific Ocean (California coast), northwestern Atlantic Ocean (eastern USA coast), Wadden Sea (coastal ecosystem of the North Sea)	136, 176
Phocine morbillivirus (phocine distemper virus)	Phocine morbillivirus infection	U	Harbor, harp, hooded, ringed and gray seals, Atlantic walrus	Canadian Arctic Ocean, western Atlantic Ocean, European seas (Danish, Swedish, Dutch, Norwegian, German, UK and Irish waters)	29, 114, 130, 136, 165, 176, 180, 192
Pilchard herpesvirus	Pilchard herpesviral disease	N	Pilchard	Australia and New Zealand coasts	125, 244
Pilot whale morbillivirus	Pilot whale morbillivirus infection	U	Long-finned pilot whale	Northwestern Atlantic Ocean (eastern USA coast)	176
Ophidian paramyxovirus	Ophidian paramyxovirus infection	N	Snakes	USA and Europe (captive collections)	54

Appendix A. Some emerging and resurging pathogens causing disease in fauna and the geographic areas most affected[a]—Continued.

(Y, yes; N, no; U, unlikely; I, insufficient information for determination.)

Pathogen	Disease	Zoonosis[b]	Primary fauna affected	Primary geographic area affected	References[c]
Polio virus	Polio	Y	Nonhuman primates	Africa	54, 240, 258
Porpoise morbillivirus	Porpoise morbillivirus infection	U	Atlantic bottlenose dolphin, harbor porpoise	Northwestern Atlantic Ocean (eastern USA coast), Gulf of Mexico, coast of Northern Ireland, northeastern Atlantic Ocean	136, 159, 176, 237
Rabbit hemorrhagic disease virus	Rabbit hemorrhagic disease	N	European rabbit	Europe, Australia	50, 182
Rabies virus	Rabies	Y	Raccoon, Ethiopian wolf (endangered), wide range of other mammals	USA (eastern states), Ethiopia	38, 42, 58, 78, 86, 204, 219, 250
Ranavirus	Ranavirus infection	N	Green python	Indonesia	126
Other ranaviruses (variants)	Ranavirus infections (variants), other[d]	N	True frogs, chorus frogs, mole salamanders, newts	USA (10 states)	62, 98, 99
Red sea bream iridovirus	Red sea bream iridoviral disease	N	Red sea bream, yellowtail, sea bass, Japanese parrotfish	Japan	184
Redwood Creek ranavirus	Redwood Creek ranavirus infection	N	Northern red-legged frog, stickleback fish	USA (California)	167
Rift Valley fever virus	Rift Valley fever	Y	Ruminants	Egypt/East Africa	29
Rinderpest virus	Rinderpest	N	Ruminants	Africa	180
Salmon sarcoma virus	Salmon sarcoma virus infection	N	Atlantic salmon	North America	58
Soft-shelled turtle iridovirus	Soft-shelled turtle iridovirus infection	N	Soft-shelled turtle	China	44
Spring viremia of carp virus	Spring viremia of carp	N	Carp	USA (North Carolina, Wisconsin, Mississippi River drainage)	191, 253
St. Louis encephalitis virus	St. Louis encephalitis	Y	Various birds	North America	58
Tadpole edema virus	Tadpole edema virus infection	N	Northern leopard frog, bullfrog, wood frog, spotted salamander	USA (upper Midwest and Eastern states)	98, 99, 257
Taura syndrome virus	Taura syndrome	N	Penaeid shrimp	Virtually all shrimp farming regions of the Americas	109, 152, 153, 155, 156
Tiger salamander virus	Tiger salamander virus infection	N	Tiger salamander	USA (western states), Canada (Saskatchewan)	21, 99, 128
Unknown type of morbillivirus, first in baleen whale	Unknown type of morbillivirus infection	U	Fin whale	North Sea (Belgian coast)	176
Unnamed English ranaviruses	Unnamed English ranaviral infection	U	Common European frog	UK (England)	51

Appendix A. Some emerging and resurging pathogens causing disease in fauna and the geographic areas most affected[a]—Continued.

(Y, yes; N, no; U, unlikely; I, insufficient information for determination.)

Pathogen	Disease	Zoonosis[b]	Primary fauna affected	Primary geographic area affected	References[c]
Usutu virus	Usutu virus infection	U	Eurasian blackbird, barn swallow	Austria	243
Wallal and possibly Warrengo viruses	Viral chorioretinitis (kangaroo blindness)	N	Kangaroos	Australia	54
Papillomavirus	Viral papillomatosis	N	Atlantic and Pacific bottlenose and dusky dolphins, harbor and Burmeister's porpoises	Southeastern Pacific Ocean (Peruvian coast), North Sea	136, 176, 237
Viral hemorrhagic septicemia virus	Viral hemorrhagic septicemia (Egtved disease)	N	Rainbow trout, Pacific cod, Pacific herring	North America	53, 57, 87, 175, 218
West Nile virus	West Nile fever	Y	American crow, numerous other avian spp., bats	USA (national)	58, 86, 171
Western equine encephalitis virus	Western equine encephalitis	Y	Various birds	North America	58
White spot syndrome virus	White spot disease	N	Penaeid shrimp	North, Central and South Americas, East Asia	154
White sturgeon herpesvirus	White sturgeon herpesvirus infection	N	White sturgeon	USA (Oregon, California)	241
White sturgeon iridovirus	White sturgeon iridovirus infection	N	White sturgeon	USA (Oregon, Idaho, California)	113
Woodcock reovirus	Woodcock reovirus infection	N	American woodcock	USA (eastern states)	60, 61
PRIONS					
Chronic wasting disease agent	Chronic wasting disease	I	Mule deer, white-tailed deer, elk	USA, Canada	15, 58, 86, 180, 197, 249
BACTERIA					
Aeromonas caviae	*Aeromonas caviae* infection	U	Atlantic salmon, rainbow trout	Kenya, Turkey (Black Sea)	12
Aeromonas jandaei	*Aeromonas jandaei* infection	U	Eel	Spain	12
Pasteurella multocida	Avian cholera	N[e]	Waterfowl	USA, Canada	29, 58, 83, 86
Bacillus cereus	*Bacillus cereus* infection	U	Common carp, striped bass	USA	12
Bacillus mycoides	*Bacillus mycoides* infection	U	Channel catfish	USA	12
Bacillus spp.	*Bacillus* infection	U	Various freshwater fish	Nigeria	12
Renibacterium salmoninarum	Bacterial kidney disease	N	Salmonid fish	Worldwide	53, 163
Brucella spp.	Brucellosis	Y	Striped, common, and Atlantic white-sided dolphins, harbor porpoise, harbor, hooded, and gray seals	North Sea	69, 118, 176

Appendix A. Some emerging and resurging pathogens causing disease in fauna and the geographic areas most affected[a]—Continued.

(Y, yes; N, no; U, unlikely; I, insufficient information for determination.)

Pathogen	Disease	Zoonosis[b]	Primary fauna affected	Primary geographic area affected	References[c]
Brucella spp.	Brucellosis	Y	Elk, mule deer, buffalo	North America	58
Campylobacter-like bacterium	*Campylobacter*-like infection	U	New Zealand sea lion	Auckland Islands	176
Chlamydia pneumoniae	Chlamydiosis	Y	Giant barred frog	Australia	17
Chlamydia psittaci	Chlamydiosis	Y	Gulls, waterfowl, American white pelican, double-crested cormorant	Canada, USA	254, 255
Erysipelothrix rhusiopathiae	Erysipelas	Y	Eared grebe, brown pelican	Western USA	132, 185
Escherichia vulneris	*Escherichia vulneris* infection	U	Balloon and silver molly, Caucasian carp	Turkey	12
Aeromonas salmonicida	Furunculosis	N	Trout	North America	58
Helicobacter spp.	*Helicobacter* infection	U	Atlantic white-sided dolphin	Northwestern Atlantic Ocean	69, 176
Mycoplasma conjunctivae	Infectious keratoconjunctivitis	N	Ibex, chamois, mouflon, thar	Europe	93
Leptospira spp.	Leptospirosis	Y	California sea lion, Pacific harbor and northern fur seals	Northeastern Pacific Ocean (Oregon and California coasts), Bering Sea	69, 103, 108, 118
Leptospira spp.	Leptospirosis	Y	Various rodents	North America	58
Listeria ivanovii	Listeriosis	Y	Harbor seal	Northeastern Pacific Ocean (California coast)	176
Borrelia burgdorferi	Lyme disease	Y	White-footed mouse, white-tailed deer	USA	54, 58, 180
Moritella marina	*Moritella marina* infection	U	Atlantic salmon	Iceland	12
Mycobacterium marinum and other *M.* spp.	Mycobacteriosis	Y	167 freshwater and saltwater fish spp.	USA (all coastal waters)	207
Mycobacterium abscessus	*Mycobacterium abscessus* infection	U	Japanese maduka	USA	12
Mycobacterium poriferae	*Mycobacterium poriferae* infection	U	Snakehead	Italy	12
Mycoplasma gallisepticum	Mycoplasma conjunctivitis	N	House finch, other birds	USA, Canada	29, 58, 77, 106
Clostridium perfringens	Necrotizing enteritis	N	Waterfowl	USA, Canada	86
Salmonella typhimurium	Salmonellosis	Y	Various passerines, egret and heron colonies	USA, Canada, England, New Zealand	6, 58, 85, 86, 137, 138, 236
Streptococcus difficilis	*Streptococcus difficilis* infection	N	Saint Peter's fish, rainbow trout	Israel	12
Streptococcus iniae	*Streptococcus iniae* infection	Y	Coral reef fish, tilapia, dusky spinefoot, hybrid striped (sunshine) bass, rainbow trout	Worldwide	12, 29, 37, 75

Appendix A. Some emerging and resurging pathogens causing disease in fauna and the geographic areas most affected[a]—Continued.

(Y, yes; N, no; U, unlikely; I, insufficient information for determination.)

Pathogen	Disease	Zoonosis[b]	Primary fauna affected	Primary geographic area affected	References[c]
Streptococcus parauberis	*Streptococcus parauberis* infection	N	Turbot	Spain	12
Streptococcus zooepidemicus	Streptococcosis	Y	Eared grebe	Western USA	131
Yersinia pestis	Sylvatic plague	Y	Prairie dog, black-footed ferret, wide range of mammals (especially rodents)	Worldwide	24, 54, 58, 232
Treponema spp.	Treponemal infection	N	European brown hare	The Netherlands	164
Mycobacterium tuberculosis complex	Tuberculosis	Y	Southern and Australian sea lions, South American, Subantarctic, and New Zealand fur seals	Indian Ocean (western Australia), New Zealand waters, Southwestern Atlantic coast (coast of Argentina)	69, 118, 176
Mycobacterium tuberculosis complex	Tuberculosis	Y	Nonhuman primates, big cats, banded mongoose, meerkat	India, Africa	4, 238, 240, 258
Mycobacterium bovis	Bovine tuberculosis	Y	Wild cervidae, canidae, bovidae, felidae, white-tailed deer, African buffalo, Chacma baboon	North America, South Africa	55, 58, 86, 180, 224
Mycobacterium avium	Avian tuberculosis	Y	Cranes, other birds	USA (New Mexico)	86, 180
Francisella tularensis	Tularemia	Y	Rabbits, hares	USA (Wyoming), Europe	185, 206
Mycoplasma agassizii	Upper respiratory tract disease	N	Desert and gopher tortoises	USA (California, Nevada, Utah, Arizona)	30, 31, 58, 86, 127, 170
Vibrio ichthyoenteri	*Vibrio ichthyoenteri* infection	N	Japanese flounder	Japan	12
Vibrio logei	*Vibrio logei* infection	N	Atlantic salmon	Iceland	12
Vibrio parahaemolyticus	*Vibrio parahaemolyticus* infection	Y	Iberian toothcarp	Spain	12
Vibrio pelagius	*Vibrio Pelagius* infection	N	Turbot	Spain	12
Vibrio trachuri	*Vibrio trachuri* infection	N	Japanese horse mackerel	Japan	12
Vibrio viscosus	*Vibrio viscosus* infection	N	Atlantic salmon	Iceland, Norway, Scotland	12
Yersinia intermedia	*Yersinia intermedia* infection	U	Atlantic salmon	Tasmania	12
RICKETTSIA					
Coxiella burnetii	Coxiellosis	Y	Pacific harbor seal	Northeastern Pacific Ocean (California coast)	143, 176

Appendix A. Some emerging and resurging pathogens causing disease in fauna and the geographic areas most affected[a]—Continued.

(Y, yes; N, no; U, unlikely; I, insufficient information for determination.)

Pathogen	Disease	Zoonosis[b]	Primary fauna affected	Primary geographic area affected	References[c]
Psiscirickettsia salmonis	Piscirickettsiosis	N	Coho salmon, rainbow trout, Chinook, Atlantic, and pink salmon	Waters of southern Chile, western Canada, Norway, Ireland	53, 86, 87, 88
Rickettsia-like organism	Rickettsia-like infection	N	Mozambique, Nile, blue, red-belly, and wami tilapia, Atlantic salmon	Taiwan, Chile	45, 87, 88
FUNGI					
Batrachochytrium dendrobatidis	Chytridiomycosis	N	Various amphibians, including anurans and salamanders	Worldwide	16, 54, 58, 97, 98, 178
Coccidioides immitis	Coccidioidomycosis	Y	Pacific bottlenose dolphin, California sea lion, southern sea otter	Northeastern Pacific Ocean (California coast)	58, 86, 118, 176, 205, 233, 235
Aphanomyces astaci	Crayfish plague	N	Crayfish	Europe	54
Dermosporidium	*Dermosporidium* infection	N	Toads	USA (California and eastern USA)	97, 99, 129
Aphanomyces invadans	Epizootic ulcerative syndrome	I	Estuarine fish, Atlantic men-haden	USA Atlantic coast	20
Ichthyophonus spp.	*Ichthyophonus* infection	N	Frogs, newts, salamanders	USA (eastern), Canada	99, 117
Lacazia loboi	Lobomycosis	Y	Atlantic bottlenose dolphin	Gulf of Mexico, Atlantic Ocean	110, 118, 176, 205
Fusarium semitectum	Necrotizing scute disease	N	Texas tortoise	USA	217
Aspergillus sydowii	Sea fan disease	N	Sea fan corals	Caribbean Sea	5, 183, 227, 228
Saprolegnia	Water mold infection (saproleg-niasis)	N	Toad eggs	USA (Oregon)	19
PROTOZOAL PARASITES					
Plasmodium relictum	Avian malaria	N	Hawaiian honeycreepers	USA (Hawaiian Islands)	54, 58
Ceratomyxa shasta	*Ceratomyxa shasta* infection	N	Salmon, trout	USA (California, Pacific northwest), Canada (Pacific northwest)	53, 87
Cryptobia branchialis	*Cryptobia branchialis* infection	N	Tilapia	USA (California's Salton Sea)	140
Cryptosporidium spp.	Cryptosporidiosis	Y	California sea lion	Northeastern Pacific Ocean (California coast)	176
Perkinsus marinus	Dermo disease	N	Oysters	USA (Gulf coast and east coast)	80, 142
Giardia spp.	Giardiasis	Y	Ringed, harp, harbor, and gray seals, California sea lion	Canada (western arctic region, Gulf of St. Lawrence and St. Lawrence estuary), USA (northern California coast)	52, 176
Labyrinthula spp.	Green sea urchin disease	N	Green sea urchin	Nova Scotia	70
Haplosporidium nelsoni	Haplosporidiosis (multinucle-ated spore unknown [MSX])	U	Eastern oyster	USA (north- and central eastern coast)	71, 120

Appendix A. Some emerging and resurging pathogens causing disease in fauna and the geographic areas most affected[a]—Continued.

(Y, yes; N, no; U, unlikely; I, insufficient information for determination.)

Pathogen	Disease	Zoonosis[b]	Primary fauna affected	Primary geographic area affected	References[c]
Heterosporis spp.	*Heterosporis* infection	N	Lake and yellow perch	North America	58, 252
Mikrocytos mackini	Mikrocytosis	N	Pacific oyster	USA (Washington), Canada (British Columbia)	190, 202
Perkinsus-like organism	*Perkinsus*-like infection	N	Tadpoles of true frogs	USA (Alaska, Virginia, Minnesota, Mississippi, North Carolina, New Hampshire)	99
Quahog parasitic unknown (QPX)	Quahog parasitic unknown (QPX)	U	Quahogs	Canada (New Brunswick, Prince Edward Island), USA (Massachusetts, New Jersey)	139, 246
Sarcocystis neurona	*Sarcocystis neurona* infection	U	Southern sea otter	Northeastern Pacific Ocean (California coast)	52, 157, 158, 176, 233
Sarcocystis neurona-like organism	*Sarcocystis neurona*-like infection	U	Pacific harbor seal	Northeastern Pacific Ocean (California coast)	52, 176
Steinhausia sp.	Steinhausiosis	N	*Partula* snails	UK (captive collection)	54
Toxoplasma gondii	Toxoplasmosis	Y	Southern sea otter	Northeastern Pacific Ocean (California coast)	48, 52, 58, 176, 177, 233
Myxobolus cerebralis	Whirling disease	N	Various salmon and trout, including Rainbow trout	USA (at least 21 states, including mountainous west)	29, 53, 58, 73, 87, 119, 196, 200
METAZOAL PARASITES					
Acanthocephalan parasites (primarily *Polymorphus* spp.)	Acanthocephaliasis	N	Southern sea otter	Northeastern Pacific Ocean (California coast)	52, 58, 176, 233
Anchorworms	Anchorworm infection	N	Bullfrog tadpoles	Worldwide?	79
Bothriocephalus acheilognathni (Asian tapeworm)	Bothriocephaliasis	N	Humpback chub, many native cyprinids, carp, and some catfish	USA (continental)	46, 86
Contracaecum corderoi	*Contracaecum corderoi* infection	N	California sea lion	Northeastern Pacific Ocean (California coast)	52, 176
Dirofilaria immitis	Heartworm disease	N	Wolves	USA	26
Gyrodactylus salaries	Gyrodactylosis	N	Atlantic salmon, other salmonids	Russia, Norway, Sweden	189
Ribeiroia ondatrae	*Ribeiroia ondatrae* infection	N	Frogs, toads, salamanders	USA, Canada	79, 225
Sarcoptes scabiei	Sarcoptic mange	Y	Foxes, wombats, and other mammals	Australia, UK, Sweden	54
Leyogonimus polyoon	Trematodiasis	N	American coot	USA (Wisconsin)	47, 86
Varroa jacobsoni	Varroasis	N	Honeybees	Worldwide except Australasia and central Africa	54

Appendix A. Some emerging and resurging pathogens causing disease in fauna and the geographic areas most affected[a]—Continued.

(Y, yes; N, no; U, unlikely; I, insufficient information for determination.)

Pathogen	Disease	Zoonosis[b]	Primary fauna affected	Primary geographic area affected	References[c]
BIOTOXINS					
Type C botulinum toxin	Avian botulism, type C (classical)	N	Waterfowl	USA, Canada, Mexico	58, 86, 214
Type C botulinum toxin	Avian botulism, type C in fish-eating birds	N	American white pelican, brown pelican	USA (California's Salton Sea)	86, 215
Type E botulinum toxin	Avian botulism, type E	N	Ring-billed gull, red-breasted merganser, common loon, long-tailed duck	USA (Lake Erie, Lake Michigan)	25, 27, 63, 66, 185
Brevetoxin	Brevetoxicosis	N	Lesser scaup, Florida manatee	Gulf of Mexico (Gulf coast of Florida)	22, 81, 176, 188, 226
Domoic acid	Domoic acid	N	Northern anchovy, brown pelican, Brandt's cormorant	USA (Santa Cruz California)	264
Mycotoxins	Mycotoxicosis	N	Sandhill crane	USA (Texas, New Mexico)	86, 251
Pfiesteria piscicida toxin	*Pfiesteria piscicida*	N	Estuarine fish	USA (east coast estuaries)	29, 33, 70, 94, 186, 220, 230
Other biotoxins	Other biotoxins	N	California sea lion	Northeastern Pacific Ocean (California coast)	176
MIXED ETIOLOGIES					
Multiple	Malformations	U	Frogs, toads, salamanders	USA, Canada	7, 99, 133, 173, 174, 225
Multiple	Coral diseases	U	Soft and hard corals	Global	9, 28, 32, 35, 39, 40, 41, 92, 95, 102, 107, 111, 112, 141, 161, 162, 168, 187, 208, 209, 210, 211, 213, 221, 229, 260, 261, also see Chapter 2
PHARMACEUTICAL AGENTS					
Non-steroidal anti-inflammatory medication	Diclofenac	N	Indian white-backed and Indian long-billed vultures	India, Pakistan, Nepal	121, 199, 203
UNDETERMINED ETIOLOGIES[f]					
Not determined	Angiomatosis	U	Atlantic bottlenose dolphin	Gulf of Mexico (Gulf coast of Texas, USA)	176
Not determined	Avian vacuolar myelinopathy	I	Bald eagle, American coot, waterfowl	USA (Arkansas, North and South Carolina, Georgia)	76, 234

Appendix A. Some emerging and resurging pathogens causing disease in fauna and the geographic areas most affected[a]—Continued.

(Y, yes; N, no; U, unlikely; I, insufficient information for determination.)

Pathogen	Disease	Zoonosis[b]	Primary fauna affected	Primary geographic area affected	References[c]
Not determined	Damselfish neurofibromatosis	U	Bicolor damselfish	Caribbean and Florida (USA) coral reefs	222, 223
Not determined	Disseminated neoplasia	U	Soft-shelled clam	USA (New England, Chesapeake Bay)	68, 72
Not determined	Florida loon mortality	I	Loon	USA (Gulf coast of Florida)	185
Not determined	Galapagos Islands giant tortoise mortality	U	Giant tortoise	Ecuador (Galapagos Islands)	43
Not determined	Immunoblastic malignant lymphoma	U	Atlantic bottlenose, Atlantic spotted, and pantropical spotted dolphins	USA (Florida coastal waters)	176
Not determined	Juvenile oyster disease	U	Eastern oyster	USA (northeastern coast)	144, 150
Not determined	Leporine dysautonomia	U	Hares	UK	100, 245
Not determined	New Jersey Atlantic brant mortality	I	Atlantic brant	USA (New Jersey coast)	185
Not determined	Ophthalmic condition	U	Hawaiian monk seal	Northern Pacific Ocean (northwestern Hawaiian Islands, USA)	176
Not determined	Pulmonary carcinoma	U	Atlantic bottlenose dolphin	Northwestern Atlantic Ocean (northern Puerto Rican coast, USA)	176
Not determined	Renal adenoma	U	Atlantic bottlenose dolphin	Gulf of Mexico	176
Not determined	Salton Sea eared grebe mortality	I	Eared grebe	USA (California's Salton Sea)	185
Not determined	Sea urchin disease	U	Black long-spined sea urchin	Caribbean Sea	36, 95, 124, 149
Not determined	Seabird mortality	I	Seabirds	USA (Alaska, Washington, and Oregon coasts)	185
Not determined	Shell disease	U	Lobster, several crab spp.	USA (northeastern coast)	239
Not determined	Sponge disease	U	Large barrel sponge, other barrel sponges	Caribbean Sea	95, 194
Not determined	Ulcerative stomatitis-obstructive rhinitis-pneumonia complex	U	Green sea and loggerhead turtles	Farmed and oceanarium-reared	89
Not determined	Unspecified neoplasias	U	California sea lion	Northeastern Pacific Ocean (central California coast)	176
Not determined	Wisconsin bald eagle mortality	I	Bald eagle	USA (Wisconsin)	185
Not determined	Withering syndrome	U	Black abalone, red abalone	USA (California's Channel Islands)	82, 104, 169
Not determined	Zoanthid disease	U	Zoanthids	Brazilian coast	1

[a] Based on summary papers by selected authors and selected reports focusing on individual diseases.

[b] Based on current information relative to human infection.

[c] Citations refer to diseases.

[d] Amphibian ranaviruses not specified elsewhere in the table.

[e] Not all *Pasteurella multocida* serotypes cause zoonotic disease; most human cases result from bite wound infections involving small mammals (domestic and wild).

[f] Diseases of unknown etiology.

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Appendix B. Common and scientific names of animals and plants in text.[a]

Common name	Scientific name
AMPHIBIANS	
African clawed frog	*Xenopus laevis*
American pig frog	*Rana grylio*
Boreal toad	*Bufo boreas boreas*
Bullfrog	*Rana catesbeiana*
Chiricahua leopard frog	*Rana chiricahuensis*
Chorus frogs	*Pseudacris spp.*
Common European frog	*Rana temporaria*
Edible frog	*Rana esculenta*
Giant barred frog	*Mixophyes iteratus*
Green frog	*Rana clamitans*
Harlequin frog	*Atelopus varius*
Marsh frog (lake frog)	*Rana ridibunda*
Mole salamander	*Ambystoma talpoideum*
Northern leopard frog	*Rana pipiens*
Northern red-legged frog	*Rana aurora*
Ornate burrowing frog	*Limnodynastes ornatus*
Spotted salamander	*Ambystoma maculatum*
Tiger salamander	*Ambystoma tigrinum*
True frogs	*Rana* spp.
Wood frog	*Rana sylvatica*
ARTHROPODS	
American dog tick	*Dermacentor variabilis*
Asian tiger mosquito	*Aedes albopictus*
Bedbugs	*Cimex* spp.
Bird tick	*Haemaphysalis chordeilis*
Black-legged tick	*Ixodes scapularis (formerly Ixodes dammini)*
Brown recluse spider	*Loxosceles reclusa*
Deer flies	*Chrysops* spp.
Deer tick	*Ixodes scapularis* (formerly *Ixodes dammini*)
European castor bean tick	*Ixodes ricinus*
Gamasid mites	*Hirstionyssus* spp.
Horse flies	*Tabanus* spp.
Lice	*Pediculus humanus*
Lone star tick	*Amblyomma americanum*
Mange mite (itch mite, scabies)	*Sarcoptes scabiei*
Marsh tick (ornate cow tick)	*Dermacentor reticulatus*
Meadow tick	*Dermacentor pictus*
Midges	*Culicoides* spp.
Moose tick (winter tick)	*Dermacentor albipictus*
New World screwworm	*Cochliomyia hominivorax*

Appendix B. Common and scientific names of animals and plants in text[a]—Continued.

Common name	Scientific name
None	*Aedes cinereus*
None	*Aedes excrucians*
None	*Chrysops aestuans*
None	*Chrysops discalis*
None	*Chrysops fulvaster*
None	*Chrysops relictus*
None	*Haemaphysalis concinna*
None	*Haemaphysalis flava*
None	*Ixodes angustus*
None	*Ixodes apronophorus*
None	*Ixodes dentatus*
None	*Tabanus bromius*
None	*Chrysozona pluvialis*
None	*Ixodes nipponensis*
None	*Rhipicephalus pumilio*
None	*Rhipicephalus rossicus*
None	*Tabanus autumnalis*
Ornate sheep tick	*Dermacentor marginatus*
Pacific Coast tick	*Dermacentor occidentalis*
Rabbit dermacentor	*Dermacentor parumapertus*
Rabbit tick	*Haemaphysalis leporispalustris*
Taiga tick	*Ixodes persulcatus*
Western black-legged tick	*Ixodes pacificus*
Wood tick (Rocky Mountain wood tick)	*Dermacentor andersoni*
BIRDS	
Adelie penguin	*Pygoscelis adeliae*
American coot	*Fulica americana*
American crow	*Corvus brachyrhynchos*
American robin	*Turdus migratorius*
American woodcock	*Scolopax minor*
Atlantic brant (brant)	*Branta bernicla*
Azure-winged magpie	*Cyanopica cyanus*
Bald eagle	*Haliaeetus leucocephalus*
Band-tailed pigeon	*Columba fasciata*
Barn swallow	*Hirundo rustica*
Black kite	*Milvus migrans* (formerly *Milvus korschun*)
Black-billed magpie (common magpie)	*Pica pica*
Black-headed gull	*Larus ridibundus*
Blue grouse	*Dendragapus obscurus*
Bobwhite quail (northern bobwhite)	*Colinus virginianus*
Brandt’s cormorant	*Phalacrocorax penicillatus*

Appendix B. Common and scientific names of animals and plants in text[a]—Continued.

Common name	Scientific name
Brown pelican	*Pelecanus occidentalis*
Brown skua	*Catharacta antarctica*
California gull	*Larus californicus*
Canada goose	*Branta canadensis*
Cape cormorant	*Phalacrocorax capensis*
Capercaillie	*Tetrao urogallus*
Chicken, domestic	*Gallus domesticus*
Chukar partridge (chukar)	*Alectoris chukar*
Common eider	*Somateria mollissima*
Common loon	*Gavia immer*
Common moorhen	*Gallinula chloropus*
Common noddy (brown noddy)	*Anous stolidus*
Common tern	*Sterna hirundo*
Copper pheasant	*Syrmaticus soemmerringii*
Cormorants	*Phalacrocorax* spp.
Corncrake	*Crex crex*
Crows	*Corvus* spp.
Double-crested cormorant	*Phalacrocorax auritus*
Eared grebe	*Podiceps nigricollis*
Eastern screech-owl	*Megascops asio* (formerly *Otus asio*)
Emperor penguin	*Aptenodytes forsteri*
Eurasian blackbird	*Turdus merula*
Eurasian buzzard (common buzzard)	*Buteo buteo*
Franklin's gull	*Larus pipixcan*
Goshawk (northern goshawk)	*Accipiter gentilis*
Gray moorhen (common moorhen)	*Gallinula chloropus*
Gray partridge (Hungarian partridge)	*Perdix perdix*
Great black-backed gull	*Larus marinus*
Great gray owl	*Strix nebulosa*
Great horned owl	*Bubo virginianus*
Green-winged teal	*Anas crecca*
Herring gull	*Larus argentatus*
Hooded crow	*Corvus cornix*
Horned lark	*Eremophila alpestris*
House finch	*Carpodacus mexicanus*
Indian long-billed vulture	*Gyps indicus*
Indian white-backed vulture	*Gyps bengalensis*
Japanese quail	*Coturnix coturnix*
Lesser scaup	*Aythya affinis*
Loggerhead shrike	*Lanius ludovicianus*
Long-tailed duck	*Clangula hyemalis*

Appendix B. Common and scientific names of animals and plants in text[a]—Continued.

Common name	Scientific name
Loons	*Gavia* spp.
Mallard (mallard duck)	*Anas platyrhynchos*
Mourning dove	*Zenaida macroura*
Ostrich	*Struthio camelus*
Oystercatchers	*Haematopus* spp.
Pekin duck	*Anas platyrhynchos*
Pigeon	*Columba livia*
Pine siskin	*Carduelis pinus*
Prairie falcon	*Falco mexicanus*
Raven (common raven)	*Corvus corax*
Red-breasted merganser	*Mergus serrator*
Redhead duck (redhead)	*Aythya americana*
Red-shouldered hawk	*Buteo lineatus*
Red-tailed hawk	*Buteo jamaicensis*
Ring-billed gull	*Larus delawarensis*
Ring-necked pheasant	*Phasianus colchicus*
Rockhopper penguin	*Eudyptes chrysocome*
Rough-legged buzzard (rough-legged hawk)	*Buteo lagopus*
Ruffed grouse	*Bonasa umbellus*
Sage grouse	*Centrocercus urophasianus*
Sandhill crane	*Grus canadensis*
Sharp-tailed grouse	*Tympanuchus phasianellus* (formerly *Pedioecetes phasianellus*)
Snow goose	*Chen caerulescens*
Sooty tern	*Sterna fuscata*
Sparrowhawk (Eurasian sparrowhawk)	*Accipiter nisus*
Spectacled eider	*Somateria fischeri*
Starlings (European starling)	*Sturnus vulgaris*
Tawny owl	*Strix aluco*
Turkey, domestic	*Meleagris gallopavo*
Ural owl	*Strix uralensis*
White pelican (American white pelican)	*Pelecanus erythrorhynchos*
White tern	*Gygis alba*
White-capped noddy	*Anous* spp.
White-winged dove	*Zenaida asiatica*
White-winged scoter	*Melanitta fusca*
Whooping crane	*Grus americana*
Wild turkey	*Meleagris gallopavo*
Willow ptarmigan (willow grouse, red grouse)	*Lagopus lagopus*
CORALS	
Blushing star coral	*Stephanocoenia michelini*
Brain coral (boulder brain coral)	*Colpophyllia natans*

Appendix B. Common and scientific names of animals and plants in text[a]—Continued.

Common name	Scientific name
Elkhorn coral	*Acropora palmata*
Fire coral	*Millepora alcicornis*
Massive starlet coral	*Siderastrea siderea*
Mountainous star coral	*Montastraea faveolata*
Sea fan corals	*Gorgonia* spp.
Staghorn coral	*Acropora cervicornis*
Star coral (great star coral)	*Montastraea cavernosa*
ECHINODERMS	
Black (long-spined) sea urchin	*Diadema antillarum*
Green sea urchin	*Strongylocentrotus droebachiensis*
FINFISH	
Amago salmon	*Oncorhynchus rhodurus*
Atlantic cod	*Gadus morhua*
Atlantic halibut	*Hippoglossus hippoglossus*
Atlantic herring	*Clupea harengus*
Atlantic menhaden	*Brevoortia tyrannus*
Atlantic salmon	*Salmo salar*
Bicolor damselfish	*Stegastes partitus*
Bighead carp	*Hypophthalmichthys nobilis* (formerly *Aristichthys nobilis*)
Blue tilapia	*Oreochromis aureus* (formerly *Tilapia aurea*)
Bluefish	*Pomatomus saltatrix*
Brown trout	*Salmo trutta*
Carp	*Cyprinus carpio*
Catfish	*Ictalurus* spp.
Catfish (European) (black bullhead)	*Ameiurus melas* (formerly *Ictalurus melas*)
Channel catfish	*Ictalurus punctatus*
Char	*Salvelinus alpinus*
Chinook salmon	*Oncorhynchus tshawytscha*
Chum salmon	*Oncorhynchus keta*
Cod	*Gadus morhua*
Coho salmon	*Oncorhynchus kisutch*
Common carp	*Cyprinus carpio*
Crucian carp	*Carassius carassius*
Dolphin (mahi-mahi)	*Coryphaena hippurus*
Dusky spinefoot	*Siganus fuscescens*
European brown trout (brown trout)	*Salmo trutta*
Goldfish	*Carassius auratus*
Grass carp	*Ctenopharyngodon idella*
Grayling	*Thymallus thymallus*
Haddock	*Melanogrammus aeglefinus*
Herring	*Clupea* spp.

Appendix B. Common and scientific names of animals and plants in text[a]—Continued.

Common name	Scientific name
Humpback chub	*Gila cypha*
Hybrid striped (sunshine) bass	*Morone chrysops* x *Morone saxatilis*
Iberian (Spanish) toothcarp	*Aphanius iberus*
Japanese flounder	*Paralichthys olivaceus*
Japanese horse mackerel	*Trachurus japonicus*
Japanese madaka	*Oryzias latipes*
Japanese parrotfish	*Oplegnathus fasciatus*
Koi	*Cyprinus carpio*
Kokanee salmon	*Oncorhynchus nerka*
Lamprey	*Lampetra* spp., *Ichthyomyzon* spp., *Petromyzon* spp.
Largemouth bass	*Micropterus salmoides*
Mackerel	*Scomber* spp.
Macquarie perch	*Macquaria australasica*
Masu salmon	*Oncorhynchus masou*
Menhaden	*Brevoortia tyrannus*
Mosquito fish	*Gambusia affinis*
Mountain galaxias	*Galaxias olidus*
Mozambique tilapia	*Oreochromis mossambicus*
Nile tilapia	*Oreochromis niloticus*
Northern anchovy	*Engraulis mordax*
Northern pike	*Esox lucius*
Pacific cod	*Gadus macrocephalus*
Pacific herring	*Clupea harengus pallasi*
Pacific salmon	*Oncorhynchus* spp.
Pike	*Esox* spp.
Pilchard	*Sardinops neopilchardus*
Pink salmon	*Oncorhynchus gorbuscha*
Rainbow trout	*Oncorhynchus mykiss*
Red sea bream	*Pagrus major* (formerly *Chrysophrys major*)
Redbelly tilapia	*Tilapia zillii*
Redfin perch	*Perca fluviatilis*
Rockling	*Ciliata mustela* (formerly *Onos mustelus*)
Round goby	*Neogobius melanostomus*
Saint Peter's fish	*Tilapia* spp.
Sea bass	*Dicentrarchus labrax*
Sheatfish	*Silurus glanis*
Silver carp	*Hypophthalmichthys molitrix*
Silver perch	*Bidyanus bidyanus*
Snapper	*Chrysophrys auratus* (formerly *Pagrus auratus*)
Sockeye salmon	*Oncorhynchus nerka*
Sprat	*Sprattus sprattus*

Appendix B. Common and scientific names of animals and plants in text[a]—Continued.

Common name	Scientific name
Steelhead trout	*Oncorhynchus mykiss*
Stickleback fish	*Gasterosteus* spp.
Striped bass	*Morone saxatilis*
Tench	*Tinca tinca*
Tilapia	*Oreochromis mossambicus* (fomerly *Tilapia mossambica*)
Tilapid	*Oreochromis* spp. (formerly *Tilapia* spp.)
Tuna	*Thunnus* spp.
Turbot	*Psetta maxima* (formerly *Scophthalmus maximus*)
Wami tilapia	*Oreochromis urolepis*
White sturgeon	*Acipenser transmontanus*
Whitefish	*Coregonus* spp.
Whitefish (lake whitefish)	*Coregonus clupeaformis*
Yamame salmon	*Oncorhynchus masou*
Yellow perch (lake perch)	*Perca flavescens*
Yellowtail	*Seriola quinqueradiata*
MAMMALS	
African elephant	*Loxodonta africana*
African green monkey	*Chlorocebus aethiops*
African lion (lion)	*Panthera leo*
African wild dog	*Lycaon pictus*
American alligator	*Alligator mississippiensis*
American badger	*Taxidea taxus*
American black bear (black bear)	*Ursus americanus*
Antelope squirrel	*Ammospermophilus* spp.
Arctic fox	*Vulpes lagopus*
Asian elephant	*Elephas maximus*
Atlantic bottlenose dolphin	*Tursiops truncatus*
Atlantic spotted dolphin	*Stenella frontalis*
Atlantic walrus	*Odobenus rosmarus*
Atlantic white-sided dolphin	*Lagenorhynchus acutus*
Australian sea lion	*Neophoca cinerea*
Axis deer	*Axis axis*
Baikal seal	*Pusa sibirica* (formerly *Phoca sibirica*)
Banded mongoose	*Mungos mungo*
Beaver	*Castor canadensis*
Bighorn sheep	*Ovis canadensis*
Bison (American bison)	*Bison bison*
Black Sea common dolphin	*Delphinus delphis*
Blackbuck antelope	*Antilope cervicapra*
Black-footed ferret	*Mustela nigripes*
Black-tailed jackrabbit	*Lepus californicus*

Appendix B. Common and scientific names of animals and plants in text[a]—Continued.

Common name	Scientific name
Blue hare (mountain hare, varying hare)	*Lepus timidus*
Bobcat	*Lynx rufus*
Brush rabbit	*Sylvilagus bachmani*
Brush-tailed possums	*Trichosurus* spp.
Buffalo (African buffalo, cape buffalo)	*Syncerus caffer*
Burmeister's porpoise	*Phocoena spinipinnis*
Bushy-tailed woodrat	*Neotoma cinerea*
California ground squirrel	*Spermophilus beecheyi* (formerly *Citellus beecheyi*)
California meadow vole	*Microtus californicus*
California sea lion	*Zalophus californianus*
California sea otter	*Enhydra lutris*
California vole	*Microtus californicus*
Camel	*Camelus* spp.
Canyon mouse	*Peromyscus crinitus*
Cape hare (European hare)	*Lepus capensis*
Capybara	*Hydrochaeris hydrochaeris*
Caribou	*Rangifer tarandus*
Caspian seal	*Pusa caspica* (fomerly *Phoca caspica*)
Cat, domestic	*Felis silvestris* (formerly *Felis catus*)
Cattle, domestic	*Bos taurus*
Chacma baboon	*Papio ursinus*
Chamois	*Rupicapra rupicapra*
Chimpanzee	*Pan troglodytes*
Chinchilla	*Chinchilla* spp.
Chisel-toothed kangaroo rat	*Dipodomys microps*
Cliff chipmunk	*Tamias dorsalis*
Coatimundi	*Nasua narica*
Collared peccary	*Pecari tajacu*
Columbian ground squirrel	*Spermophilus columbianus*
Common dolphin	*Delphinus delphis*
Cotton rats	*Sigmodon* spp.
Cottontail rabbit (Eastern cottontail)	*Sylvilagus floridanus*
Cottontail rabbits	*Sylvilagus* spp.
Cougar (mountain lion, puma)	*Puma concolor* (formerly *Felis concolor*)
Coyote	*Canis latrans*
Cynomolgus macaque	*Macaca fascicularis*
Deer mouse	*Peromyscus maniculatus*
Delmarva Peninsula fox squirrel	*Sciurus niger cinereus* (formerly *Sciurus cinereus*)
Desert bighorn sheep	*Ovis canadensis*
Desert cottontail	*Sylvilagus audubonii*
Desert woodrat	*Neotoma lepida*

Appendix B. Common and scientific names of animals and plants in text[a]—Continued.

Common name	Scientific name
Dingo	*Canis lupus* (formerly *Canis dingo*)
Dog, domestic	*Canis lupus* (formerly *Canis familiaris*)
Dusky dolphin	*Lagenorhynchus obscurus*
Dusky-footed woodrat	*Neotoma fuscipes*
Eastern chipmunk	*Tamias striatus*
Eastern spotted skunk	*Spilogale putorius*
Elk	*Cervus elaphus*
Ethiopian wolf	*Canis simensis*
European badger	*Meles meles*
European brown hare (brown hare, European hare)	*Lepus europaeus*
European rabbit	*Oryctolagus cuniculus*
European red squirrel	*Sciurus vulgaris*
European wildcat	*Felis silvestris*
Fallow deer	*Dama dama*
Feral swine	*Sus scrofa*
Fin whale	*Balaenoptera physalus*
Florida manatee	*Trichechus manatus latirostris*
Flying squirrels	*Glaucomys* spp.
Forest rabbit	*Sylvilagus brasiliensis*
Fox squirrel	*Sciurus niger*
Gambian rat	*Cricetomys gambianus*
Giraffe	*Giraffa camelopardalis*
Goat, domestic	*Capra hircus*
Golden lion tamarin	*Leontopithecus rosalia*
Grasscutter	*Thryonomys swinderianus*
Gray fox	*Urocyon cinereoargenteus*
Gray seal	*Halichoerus grypus*
Gray squirrel	*Sciurus carolinensis*
Gray wolf (timber wolf)	*Canis lupus*
Great Basin kangaroo rat	*Dipodomys microps*
Great Basin pocket mouse	*Perognathus parvus*
Great fruit-eating bat	*Artibeus lituratus*
Great gerbil	*Rhombomys opimus*
Gunnison's prairie dog	*Cynomys gunnisoni*
Harbor porpoise	*Phocoena phocoena*
Harbor seal	*Phoca vitulina*
Hare	*Lepus* spp.
Harp seal	*Pagophilus groenlandicus* (formerly *Phoca groenlandica*)
Hawaiian monk seal	*Monachus schauinslandi*
Hooded seal	*Cystophora cristata*
Horse, domestic	*Equus caballus*

Appendix B. Common and scientific names of animals and plants in text[a]—Continued.

Common name	Scientific name
House mouse	*Mus musculus*
Hyenas	*Crocuta* spp. or *Hyaena* spp.
Ibex	*Capra ibex*
Jackal	*Canis* spp.
Japanese hare	*Lepus brachyurus*
Kit fox	*Vulpes macrotis*
Least chipmunk	*Tamias minimus*
Lemming	*Lemmus* spp.
Lesser kudu	*Tragelaphus imberbis*
Llama	*Lama glama*
Long-finned pilot whale	*Globicephala melas* (formerly *Globicephala melaena*)
Long-tailed pocket mouse	*Chaetodipus formosus*
Macaque	*Macaca* spp.
Manatee	*Trichechus manatus*
Masked palm civet	*Paguma larvata*
Meadow vole	*Microtus pennsylvanicus*
Meadow vole (meadow mouse)	*Microtus pennsylvanicus*
Mediterranean monk seal	*Monachus monachus*
Meerkat	*Suricata suricatta*
Mink	*Mustela vison*
Montane vole	*Microtus montanus*
Moose	*Alces alces*
Mouflon	*Ovis aries* (formerly *Ovis musimon*)
Mountain cottontail rabbit	*Sylvilagus nuttallii*
Mountain goat	*Oreamnos americanus*
Mountain gorilla (gorilla)	*Gorilla gorilla*
Mountain hare (blue hare, varying hare)	*Lepus timidus*
Mule deer	*Odocoileus hemionus*
Muntjac deer	*Muntiacus* spp.
Muskrat	*Ondatra zibethicus*
New Zealand fur seal	*Arctocephalus forsteri*
New Zealand sea lion	*Phocarctos hookeri*
Northern fur seal	*Callorhinus ursinus*
Norway rat	*Rattus norvegicus*
Old World rabbit	*Oryctolagus cuniculus*
Olive baboon	*Papio hamadryas anubis*
Opossum (Virginia opossum)	*Didelphis virginiana*
Ord's kangaroo rat	*Dipodomys ordii*
Osgood white-footed mouse	*Peromyscus* spp.
Pacific bottlenose dolphin	*Tursiops truncatus*
Pacific common dolphin	*Delphinus delphis*

Appendix B. Common and scientific names of animals and plants in text[a]—Continued.

Common name	Scientific name
Pacific harbor seal	*Phoca vitulina richardsi*
Pantropical spotted dolphin	*Stenella attenuata*
Pig, domestic	*Sus scrofa*
Pine marten	*Martes* spp.
Pinyon mouse	*Peromyscus truei*
Piute ground squirrel	*Spermophilus mollis*
Polar bear	*Ursus maritimus*
Porcupine	*Erethizon dorsatum*
Prairie dog	*Cynomys* spp.
Pronghorn (pronghorn antelope)	*Antilocapra americana*
Pygmy rabbit	*Brachylagus idahoensis* (formerly *Sylvilagus idahoensis*)
Rabbit, domestic	*Oryctolagus cuniculus*
Raccoon	*Procyon lotor*
Red deer	*Cervus elaphus*
Red fox	*Vulpes vulpes* (formerly *Vulpes fulvus*)
Red squirrel	*Tamiasciurus hudsonicus*
Red wolf	*Canis rufus*
Red-backed vole	*Clethrionomys* spp.
Redwood's white-footed mouse	*Peromyscus* spp.
Reindeer	*Rangifer tarandus*
Rhesus macaque	*Macaca mulatta*
Richardson's ground squirrel	*Spermophilus richardsonii*
Ringed seal	*Pusa hispida* (fomerly *Phoca hispida*)
River otter	*Lontra canadensis* (formerly *Lutra canadensis*)
Rope squirrel (Thomas's rope squirrel)	*Funisciurus anerythrus*
Rusa deer (Timor deer)	*Cervus timorensis*
Sambar deer (sambar)	*Cervus unicolor*
Sawatch Meadow vole	*Microtus pennsylvanicus*
Sea otter	*Enhydra lutris*
Sheep, domestic	*Ovis aries*
Snowshoe hare (varying hare)	*Lepus americanus*
Sonoran white-footed (deer) mouse	*Peromyscus maniculatus sonoriensis*
Sooty mangabey	*Cercocebus torquatus atys*
South American fur seal	*Arctocephalus australis*
Southern sea lion	*Otaria flavescens* (formerly *Otaria byronia*)
Southern sea otter	*Enhydra lutris nereis*
Steller's sea lion	*Eumetopias jubatus*
Stoat (ermine)	*Mustela erminea*
Striped dolphin	*Stenella coeruleoalba*
Striped skunk	*Mephitis mephitis*
Subantarctic fur seal	*Arctocephalus tropicalis*

Appendix B. Common and scientific names of animals and plants in text[a]—Continued.

Common name	Scientific name
Tahr	*Hemitragus* spp.
Tiger	*Panthera tigris*
Townsend's ground squirrel	*Spermophilus townsendii*
Tree squirrels	*Sciurus* spp.
Tundra vole	*Microtus oeconomus*
Uinta ground squirrel	*Spermophilus armatus*
Vole (meadow vole, meadow mouse)	*Microtus pennsylvanicus*
Voles	*Microtus* spp.
Walrus	*Odobenus rosmarus*
Wandering shrew (vagrant shrew)	*Sorex vagrans*
Wapiti	*Cervus elaphus*
Water buffaloes	*Bubalus* spp.
Water vole	*Arvicola terrestris*
West Indian manatee	*Trichechus manatus*
Western harvest mouse	*Reithrodontomys megalotis*
Western jumping mouse	*Zapus princeps*
White-footed mouse	*Peromyscus leucopus*
White-lipped deer (Thorold's deer)	*Cervus albirostris*
White-tailed deer	*Odocoileus virginianus*
White-tailed jackrabbit	*Lepus townsendii*
White-tailed prairie dog	*Cynomys leucurus*
White-throated woodrat	*Neotoma albiqula*
Wild boar	*Sus scrofa*
Wild hogs	*Sus scrofa*
Wild pigs	*Sus scrofa*
Wild rats	*Rattus* spp.
Wild swine	*Sus scrofa*
Wind River pine squirrel	*Tamiasciurus hudsonicus ventorum*
Woodchuck	*Marmota monax*
Wyoming ground squirrel	*Spermophilus elegans*
Yellow-bellied marmot	*Marmota flaviventris*
PLANTS	
Coralline algae	*Porolithon* spp.
Eelgrass (seawrack)	*Zostera marina*
Turtlegrass	*Thalassia testudinum*
REPTILES	
Bullsnake	*Pituophis catenifer*
Crocodiles	*Osteolaemus* spp. and *Crocodylus* spp.
Desert tortoise	*Gopherus agassizii* (formerly *Scaptochelys agassizii*)
Giant tortoise (Galapagos tortoise)	*Geochelone nigra*
Gopher tortoise	*Gopherus polyphemus* (formerly *Testudo polyphemus*)

Appendix B. Common and scientific names of animals and plants in text[a]—Continued.

Common name	Scientific name
Green iguana	*Iguana iguana*
Green python	*Morelia viridis*
Green turtle (green sea turtle)	*Chelonia mydas*
Loggerhead turtle	*Caretta caretta*
Royal python	*Python regius*
Soft-shelled turtle (Chinese softshell turtle)	*Pelodiscus sinensis* (formerly *Trionyx sinensis*)
Spectacled caiman	*Caiman crocodilus*
Texas tortoise	*Gopherus berlandieri* (formerly *Xerobates berlandieri*)
SHELLFISH	
Black abalone	*Haliotis cracherodii*
Blue mussel	*Mytilus edulis*
Eastern oyster (American oyster)	*Crassostrea virginica*
Freshwater crab	*Potamon potamios*
Freshwater shrimp	*Gammarus spp.*
Lobster (American lobster)	*Homarus americanus*
New Brunswick oyster	*Crassostrea virginica*
Pacific oyster	*Crassostrea gigas*
Penaeid shrimp	*Penaeus* spp.
Quagga mussel	*Dreissena bugensis*
Quahog (northern quahog, hard clam)	*Mercenaria mercenaria*
Red abalone	*Haliotis rufescens*
Red swamp crayfish	*Procambarus clarkii*
Soft-shelled clam (softshell clam)	*Mya arenaria*
Zebra mussel	*Dreissena polymorpha*
SPONGES	
Barrel sponges	*Xestospongia* spp.
Large barrel sponge (giant barrel sponge)	*Xestospongia muta*

[a]Literature Cited:

1. Integrated Taxonomic Information System, 2004, Integrated Taxonomic Information System on-line database, accessed March 1, 2005, at URL *http://www.itis.usda.gov*.
2. Clements, J.F., 2000, Birds of the world: a checklist (5th ed.): Vista, Calif., Ibis Publishing Company, 867 p.
3. Nowak, R.M., and Paradiso, J.L., 1983, Walker's Mammals of the world (4th ed.): Baltimore, Md., The Johns Hopkins University Press, 2 v.

Appendix C. Agents that require specific government approval for scientific investigations within the USA.[a]

Select agents, U.S. Department of Health and Human Services only[b]	High consequence pathogens and agents, U.S. Department of Agriculture only[c]	HIgh consequence livestock pathogens and toxins, overlap agents and toxins[d]
Crimean-Congo hemorrhagic fever virus	***Livestock pathogens and toxins***	*Bacillus anthracis*
Coccidioides posadasii	Akabane virus	*Brucella abortus*
Ebola viruses	African swine fever virus	*Brucella melitensis*
Cercopithecine herpesvirus 1 (Herpes B virus)	African horse sickness virus	*Brucella suis*
Lassa fever virus	Avian influenza virus (highly pathogenic)	*Burkholderia mallei* (formerly *Pseudomonas mallei)*
Marburg virus	Bluetongue virus (exotic)	*Burkholderia pseudomallei* (formerly *Pseudomonas pseudomallei)*
Monkeypox virus	Bovine spongiform encephalopathy agent	Botulinum neurotoxin producing species of *Clostridium*
Rickettsia prowazekii	Camel pox virus	*Coccidioides immitis*
Rickettsia rickettsii	Classical swine fever virus	*Coxiella burnetii*
South American hemorrhagic fever viruses	*Cowdria ruminantium* (heartwater)	Eastern equine encephalitis virus
Junin	Foot and mouth disease virus	Hendra virus
Machupo	Goat pox virus	*Francisella tularensis*
Sabia	Lumpy skin disease virus	Nipah virus
Flexal	Japanese encephalitis virus	Rift Valley fever virus
Guanarito	Malignant catarrhal fever virus (exotic)	Venezuelan equine encephalitis virus
Tick-borne encephalitis complex (flavi) viruses	Menangle virus	Botulinum neurotoxin
Central European tick-borne encephalitis	*Mycoplasma capricolum*/ M.F38/ *M. mycoides capri*	*Clostridium perfringens* epsilon toxin
Far Eastern tick-borne encephalitis	*Mycoplasma mycoides mycoides*	Shigatoxin
Russian spring and summer encephalitis	Newcastle disease virus (VVND)	Staphylococcal enterotoxin
Kyasanur forest disease	Peste des petits ruminants virus	T-2 toxin
Omsk hemorrhagic fever	Rinderpest virus	
Variola major virus (smallpox virus)	Sheep pox virus	
Variola minor virus (alastrim)	Swine vesicular disease virus	
Yersinia pestis	Vesicular stomatitis virus (exotic)	
Abrin	***Plant pathogens***	
Conotoxins	*Liberobacter africanus*	
Diacetoxyscirpenol	*Liberobacter asiaticus*	
Ricin	*Peronosclerospora philippinensis*	
Saxitoxin	*Phakopsora pachyrhizi*	
Shiga-like ribosome inactivating proteins	Plum pox potyvirus	
Tetrodotoxin	*Ralstonia solanacearum* race 3, biovar 2	
	Schlerophthora rayssiae var *zeae*	
	Synchytrium endobioticum	
	Xanthomonas oryzae	
	Xylella fastidiosa (citrus variegated chlorosis strain)	

[a] http://www.cdc.gov/od/sap/docs/salist.pdf

[b] The U.S. Department of Health and Human Services (HHS) oversees agents of primary concern for public health.

[c] The U.S. Department of Agriculture (USDA) oversees agents of primary concern for domestic animal and plant health.

[d] HHS and USDA share oversight responsibility for agents of concern for both public and domestic animal health.

Appendix D. Pathogens of focus for biowarfare and bioterrorist activity.[1,2,3,4]

(●, Disease occurs in a species or is listed by a government agency or an internationl organization; ○, disease does not occur in a species or is not listed by a government agency or an international organization; ***A***, highest priority; ***B***, second-highest priority; ***C***, third-highest priority)

Pathogen	Disease	Zoonosis	Primary species affected						Established in USA	Agency or organization[a] and priority						
			Humans	Livestock	Poultry	Other domestic	Plants	Wild biota		CDC *A*	CDC *B*	CDC *C*	USDA	OIE *A*	OIE *B*	BWC
VIRUSES																
African horse sickness virus	African horse sickness	○	○	●	○	○	○	○	○	○	○	○	●	●	○	●
African swine fever virus	African swine fever	○	○	●	○	○	○	●	○	○	○	○	●	●	○	●
Junin virus	Argentine hemorrhagic fever	●	●	○	○	○	○	●	○	●	○	○	○	○	○	●
Avian infectious bronchitis virus	Avian infectious bronchitis	○	○	○	●	○	○	○	●	○	○	○	○	○	●	○
Avian infectious laryngotracheitis virus	Avian infectious laryngotracheitis	○	○	○	●	○	○	○	●	○	○	○	○	○	●	○
Influenza virus	Avian influenza (fowl plague)	●	●	●	●	○	○	●	●	○	○	○	●	●	○	●
Avian pox virus	Avian pox (fowl pox)	○	○	○	●	○	○	●	●	○	○	○	○	○	●	○
Bluetongue virus	Bluetongue	○	○	●	○	○	○	●	●	○	○	○	●	●	○	●
Machupo virus	Bolivian hemorrhagic fever	●	●	○	○	○	○	●	○	●	○	○	○	○	○	●
Caprine arthritis/encephalitis virus	Caprine arthritis/encephalitis	○	○	●	○	○	○	○	●	○	○	○	○	○	●	○
Classical swine fever virus	Classical swine fever (hog cholera)	○	○	●	○	○	○	●	○	○	○	○	●	●	○	●
Crimean-Congo haemorrhagic fever virus[c]	Crimean-Congo haemorrhagic fever (CCHF)	●	●	●	●	○	○	●	○	○	○	●	○	○	○	●
Duck enteritis virus	Duck virus enteritis (duck plague)	○	○	○	●	○	○	●	●	○	○	○	○	○	●	○
Duck hepatitis virus	Duck virus hepatitis	○	○	○	●	○	○	○	●	○	○	○	○	○	●	○
Eastern equine encephalitis virus	Eastern equine encephalitis	●	●	●	○	○	○	●	●	○	●	○	○	○	●	●
Ebola virus	Ebola hemorrhagic fever	●	●	○	○	○	○	●	○	●	○	○	○	○	○	●
Bovine leukemia virus	Enzootic bovine leukosis	○	○	●	○	○	○	○	●	○	○	○	○	○	●	○
Epizootic hematopoietic necrosis virus	Epizootic hematopoietic necrosis	○	○	○	○	○	○	●	○	○	○	○	○	○	●	○
Equine infectious anemia virus	Equine infectious anemia	○	○	●	○	○	○	○	●	○	○	○	○	○	●	○
Equine influenza virus	Equine influenza	●	●	●	○	○	○	○	●	○	○	○	○	○	●	○
Equine rhinopneumonitis virus	Equine rhinopneumonitis	○	○	●	○	○	○	○	●	○	○	○	○	○	●	○
Equine viral arteritis virus	Equine viral arteritis	○	○	●	○	○	○	○	●	○	○	○	○	○	●	○
Foot-and-mouth disease virus	Foot-and-mouth disease	○	○	●	○	○	○	●	○	○	○	○	●	●	○	●

Appendix D. Pathogens of focus for biowarfare and bioterrorist activity[1,2,3,4]—Continued.

(●, Disease occurs in a species or is listed by a government agency or an internationl organization; ○, disease does not occur in a species or is not listed by a government agency or an international organization; ***A***, highest priority; ***B***, second-highest priority; ***C***, third-highest priority)

Pathogen	Disease	Zoonosis	Primary species affected						Established in USA	Agency or organization[a] and priority						
			Humans	Livestock	Poultry	Other domestic	Plants	Wild biota		CDC ***A***	CDC ***B***	CDC ***C***	USDA	OIE ***A***	OIE ***B***	BWC
Hantaviruses[d]	Hantavirus pulmonary syndrome and hemorrhagic fever with renal syndrome	●	●	○	○	○	○	●	●	○	○	●	○	○	○	●
Horse pox virus	Horse pox	○	○	●	○	○	○	○	○	○	○	○	○	○	●	○
Bovine herpesvirus-1	Infectious bovine rhinotracheitis/infectious pustular vulvovaginitis	○	○	●	○	○	○	●	●	○	○	○	○	○	●	○
Infectious bursal disease virus	Infectious bursal disease (Gumboro disease)	○	○	○	●	○	○	●	●	○	○	○	○	○	●	○
Infectious hematopoietic necrosis virus	Infectious hematopoietic necrosis	○	○	○	○	○	○	●	●	○	○	○	○	○	●	○
Japanese encephalitis virus	Japanese encephalitis	●	●	●	○	○	○	●	○	○	○	○	○	○	●	○
Lassa virus	Lassa fever	●	●	○	○	○	○	●	○	●	○	○	○	○	○	●
Lumpy skin disease virus	Lumpy skin disease	○	○	●	○	○	○	○	○	○	○	○	●	●	○	○
Maedi-visna virus	Maedi-visna	○	○	●	○	○	○	○	●	○	○	○	○	○	●	○
Malignant catarrhal fever virus	Malignant catarrhal fever	○	○	●	○	○	○	●	●	○	○	○	○	○	●	○
Marburg virus	Marburg hemorrhagic fever	●	●	○	○	○	○	●	○	●	○	○	○	○	○	●
Marek's disease virus	Marek's disease	○	○	○	●	○	○	○	●	○	○	○	○	○	●	○
Monkeypox virus	Monkeypox	●	●	○	○	○	○	●	●	○	○	○	○	○	○	●
Myxoma virus	Myxomatosis	○	○	○	○	○	○	●	●	○	○	○	○	○	●	○
Nairobi sheep disease virus	Nairobi sheep disease	○	○	●	○	○	○	○	○	○	○	○	○	○	●	○
Nipah virus	Nipah virus encephalitis	●	●	●	○	○	○	●	○	○	○	●	○	○	○	○
Oncorhynchus masou virus	*Oncorhynchus masou* virus disease	○	○	○	○	○	○	●	○	○	○	○	○	○	●	○
Jaagsiekte sheep retrovirus	Ovine pulmonary adenomatosis (jaagsiekte)	○	○	●	○	○	○	○	●	○	○	○	○	○	●	○
Peste de petits ruminants virus	Peste des petits ruminants	○	○	●	○	○	○	○	○	○	○	○	○	●	○	●
Porcine reproductive and respiratory syndrome virus	Porcine reproductive and respiratory syndrome	○	○	●	○	○	○	○	●	○	○	○	●	○	●	○
Pseudorabies virus	Pseudorabies (Aujeszky's disease)	○	○	●	○	○	○	○	●	○	○	○	●	○	●	○
Rabbit hemorrhagic disease virus	Rabbit hemorrhagic disease	○	○	○	○	○	○	●	●	○	○	○	○	○	●	○

Appendix D. Pathogens of focus for biowarfare and bioterrorist activity[1,2,3,4]—Continued.

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Pathogen	Disease	Zoo-nosis	Primary species affected						Estab-lished in USA	Agency or organization[a] and priority						
			Humans	Live-stock	Poultry	Other domes-tic	Plants	Wild biota		CDC *A*	CDC *B*	CDC *C*	USDA	OIE *A*	OIE *B*	BWC
Rabies virus	Rabies	●	●	●	○	●	○	●	●	○	○	○	●	○	●	○
Rift Valley fever virus	Rift Valley fever	●	●	●	○	○	○	●	○	○	○	○	●	●	○	●
Rinderpest virus	Rinderpest	○	○	●	○	○	○	●	○	○	○	○	●	●	○	●
Sheep and goat pox viruses	Sheep and goat pox	○	○	●	○	○	○	○	○	○	○	○	●	●	○	○
Variola major	Smallpox	○	●	○	○	○	○	○	○	●	○	○	○	○	○	●
Spring viremia of carp virus	Spring viremia of carp	○	○	○	○	○	○	●	●	○	○	○	○	○	●	○
Sugarcane Fiji disease virus	Sugarcane Fiji disease	○	○	○	○	○	●	○	●	○	○	○	○	○	○	●
Porcine enterovirus type 9 (swine vesicular disease virus)	Swine vesicular disease	○	○	●	○	○	○	○	○	○	○	○	●	●	○	○
Taura syndrome virus	Taura syndrome	○	○	○	○	○	○	●	○	○	○	○	○	○	●	○
Porcine enterovirus type 1	Teschen disease (enterovirus encephalomyelitis)	○	○	●	○	○	○	○	○	○	○	○	●	○	●	●
Transmissible gastroenteritis virus	Transmissible gastroenteritis	○	○	●	○	○	○	○	●	○	○	○	○	○	●	○
Tickborne encephalitis viruses	Various (e.g., Kyasamur forest disease; Central European encephalitis; Russian spring-summer meningoencephalitis)	●	●	●	○	○	○	●	○	○	○	●	○	○	○	●
Newcastle disease virus	Velogenic viscerotropic Newcastle disease	○	○	○	○	○	○	●	●	○	○	○	●	●	○	●
Venezuelan equine encephalomyelitis virus	Venezuelan equine encephalomyelitis	●	●	●	○	○	○	●	●	○	●	○	●	○	●	●
Vesicular stomatitis virus	Vesicular stomatitis	○	○	●	○	○	○	●	●	○	○	○	●	●	○	●
Viral hemorrhagic septicemia virus	Viral hemorrhagic septicemia (Egtved disease)	○	○	○	○	○	○	●	●	○	○	○	○	○	●	○
Western equine encephalitis virus	Western equine encephalitis	●	●	●	○	○	○	●	●	○	●	○	○	○	●	●
White spot syndrome virus	White spot disease	○	○	○	○	○	○	●	●	○	○	○	○	○	●	○
Yellow fever virus	Yellow fever	●	●	○	○	○	○	●	●	○	○	●	○	○	○	●
Yellowhead virus (gill-associated virus)	Yellowhead disease	○	○	○	○	○	○	●	○	○	○	○	○	○	●	○
PRIONS																
Bovine spongiform encephalopathy agent	Bovine spongiform encephalopathy	●	●	●	○	○	○	○	●	○	○	○	○	○	●	○

Appendix D. Pathogens of focus for biowarfare and bioterrorist activity[1,2,3,4]—Continued.

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Pathogen	Disease	Zoo-nosis	Primary species affected						Estab-lished in USA	Agency or organization[a] and priority						
			Humans	Live-stock	Poultry	Other domes-tic	Plants	Wild biota		CDC *A*	CDC *B*	CDC *C*	USDA	OIE *A*	OIE *B*	BWC
Scrapie agent	Scrapie	○	○	●	○	○	○	○	●	○	○	○	○	○	●	○
BACTERIA																
Paenibacillus larvae larvae	American foulbrood	○	○	○	○	○	○	●	●	○	○	○	○	○	●	○
Bacillus anthracis	Anthrax	●	●	●	○	○	○	●	●	●	○	○	●	○	●	●
Pasteurella multocida[e] +/- *Bordetella bronchiseptica*	Atrophic rhinitis of swine	○	○	●	○	○	○	○	●	○	○	○	○	○	●	○
Pasteurella multocida[e]	Avian cholera (fowl cholera)	○	○	○	●	○	○	●	●	○	○	○	○	○	●	○
Mycoplasma gallisepticum	Avian mycoplasmosis	○	○	○	●	○	○	●	●	○	○	○	○	○	●	○
Mycobacterium avium	Avian tuberculosis	●	●	○	●	○	○	●	●	○	○	○	○	○	●	○
Ralstonia solanacearum	Bacterial wilt	○	○	○	○	○	●	○	●	○	○	○	○	○	○	●
Campylobacter fetus	Bovine genital campylo-bacteriosis	●	●	●	○	○	○	○	●	○	○	○	○	○	●	○
Mycobacterium bovis	Bovine tuberculosis	●	●	●	○	○	○	●	●	○	○	○	○	○	●	○
Brucella abortus, B. meliten-sis, and *B. suis*	Brucellosis	●	●	●	○	●	○	●	●	○	●	○	○	○	●	●
Chlamydia psittaci	Chlamydiosis (ornithosis or psittacosis)	●	●	○	●	○	○	●	●	○	●	○	●	○	●	○
Vibrio cholerae[f]	Cholera	○	●	○	○	○	○	○	●	○	●	○	○	○	○	○
Xanthomonas campestris pv. Citri	Citrus canker	○	○	○	○	○	●	○	○	○	○	○	○	○	○	●
Mycoplasma spp.	Contagious agalactia	○	○	●	○	○	○	○	●	○	○	○	○	○	●	○
Mycoplasma mycoides var. *mycoides*	Contagious bovine pleuro-pneumonia	○	○	●	○	○	○	○	○	○	○	○	○	●	○	●
Mycoplasma capricolum	Contagious caprine pleu-ropneumonia	○	○	●	○	○	○	○	○	○	○	○	○	○	●	○
Taylorella equigenitalis	Contagious equine metritis	○	○	●	○	○	○	○	○	○	○	○	○	○	●	○
Chlamydia psittaci	Enzootic abortion of ewes (ovine chlamydiosis)	●	●	●	○	○	○	○	●	○	○	○	●	○	●	○
Escherichia coli O157:H7	*Escherichia coli* O157:H7 infection	●	●	●	○	○	○	○	●	○	●	○	○	○	○	○
Melissococcus pluton	European foulbrood	○	○	○	○	○	○	●	●	○	○	○	○	○	●	○
Erwinia amylovora	Fire blight	○	○	○	○	○	●	○	●	○	○	○	○	○	○	●
Salmonella gallinarum	Fowl typhoid	○	○	○	●	○	○	○	○	○	○	○	○	○	●	○

Appendix D. Pathogens of focus for biowarfare and bioterrorist activity[1,2,3,4]—Continued.

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Pathogen	Disease	Zoonosis	Primary species affected						Established in USA	Agency or organization[a] and priority						
			Humans	Livestock	Poultry	Other domestic	Plants	Wild biota		CDC *A*	CDC *B*	CDC *C*	USDA	OIE *A*	OIE *B*	BWC
Burkholderia mallei	Glanders	●	●	●	○	○	○	○	○	○	●	○	○	○	●	●
Pasteurella multocida[e]	Hemorrhagic septicemia	○	○	●	○	○	○	●	●	○	○	○	○	○	●	○
Leptospira spp.	Leptospirosis	●	●	●	○	○	○	●	●	○	○	○	○	○	●	○
Burkholderia pseudomallei	Melioidosis	●	●	●	○	○	○	○	●	○	●	○	○	○	○	●
Multidrug-resistant *Mycobacterium tuberculosis*	Multidrug-resistant tuberculosis	●	●	○	○	○	○	●	●	○	○	●	○	○	○	○
Mycobacterium paratuberculosis	Paratuberculosis (Johne's disease)	○	○	●	○	○	○	○	●	○	○	○	○	○	●	○
Yersinia pestis	Plague	●	●	○	○	○	○	●	●	●	○	○	○	○	○	●
Salmonella pullorum	Pullorum disease	○	○	○	●	○	○	○	○	○	○	○	○	○	●	○
Salmonella spp.	Salmonellosis	●	●	●	●	●	○	●	●	○	●	○	○	○	●	○
Shigella dysenteriae	Shigellosis	○	●	○	○	○	○	○	○	○	●	○	○	○	○	○
Xanthomonas albilineans	Sugarcane leaf scald disease	○	○	○	○	○	●	○	●	○	○	○	○	○	○	●
Francisella tularensis	Tularemia	●	●	●	○	○	○	●	●	●	○	○	○	○	●	●
RICKETTSIA																
Anaplasma marginale	Bovine anaplasmosis	○	○	●	○	○	○	○	●	○	○	○	○	○	●	○
Cowdria ruminantium (Ehrlichia ruminantium)	Cowdriosis (heartwater)	○	○	●	○	○	○	●	○	○	○	○	●	○	●	○
Coxiella burnetti	Q fever	●	●	●	○	○	○	●	●	○	●	○	○	○	●	●
Rickettsia rickettsii	Rocky Mountain spotted fever	●	●	○	○	●	○	●	●	○	○	○	○	○	○	●
Rickettsia prowazekii	Typhus fever (epidemic typhus)	●	●	○	○	○	○	●	●	○	●	○	○	○	○	●
FUNGI																
Peronospora hyoscyami de Bary f. sp. *Tabacina (Adam) skalicky*	Blue mold	○	○	○	○	○	●	○	●	○	○	○	○	○	○	●
Colletotrichum coffeanum var. virulans (Colletotrichum kahawae)	Coffee berry disease	○	○	○	○	○	●	○	○	○	○	○	○	○	○	●
Dermatophytes	Dermatophilosis	●	●	●	○	○	○	●	●	○	○	○	○	○	●	○
Dothistroma pini (Scirrhia pini)	Dothistroma needle blight	○	○	○	○	○	●	○	●	○	○	○	○	○	○	●
Histoplasma capsulatum var. *farciminosum*	Epizootic lymphangitis	●	○	●	○	○	○	○	○	○	○	○	○	○	●	○

Appendix D. Pathogens of focus for biowarfare and bioterrorist activity[1,2,3,4]—Continued.

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Pathogen	Disease	Zoonosis	Primary species affected						Established in USA	Agency or organization[a] and priority						
			Humans	Livestock	Poultry	Other domestic	Plants	Wild biota		CDC *A*	CDC *B*	CDC *C*	USDA	OIE *A*	OIE *B*	BWC
Claviceps purpurea	Ergot	○	○	○	○	○	●	○	●	○	○	○	○	○	○	●
Tilletia indica	Karnal bunt	○	○	○	○	○	●	○	○	○	○	○	○	○	○	●
Sclerotinia sclerotiorum	Sclerotinia stem rot (white mold)	○	○	○	○	○	●	○	●	○	○	○	○	○	○	●
Puccinia graminis	Stem rust	○	○	○	○	○	●	○	●	○	○	○	○	○	○	●
PROTOZOAL PARASITES																
Bonamia exitiosus, B. ostreae, Mikrocytos roughleyi	Bonamiosis	○	○	○	○	○	○	●	●	○	○	○	○	○	●	○
Babesia spp.	Bovine babesiosis	●	●	●	○	○	○	○	○	○	○	○	○	○	●	○
Cryptosporidium parvum	Cryptosporidiosis	●	●	●	○	○	○	●	●	○	●	○	○	○	○	○
Trypanosoma equiperdum	Dourine	○	○	●	○	○	○	○	○	○	○	○	○	○	●	○
Babesia equi (or *Theileria equi)* and *Babesia caballi*	Equine piroplasmosis	●	●	●	○	○	○	○	○	○	○	○	○	○	●	○
Haplosporidium nelsoni	Haplosporidiosis (MSX disease)	○	○	○	○	○	○	●	●	○	○	○	○	○	●	○
Leishmania spp.	Leishmaniasis	●	●	○	○	●	○	●	●	○	○	○	○	○	●	○
Marteilia refringens, M. sydneyi	Marteiliosis (Aber disease)	○	○	○	○	○	○	●	○	○	○	○	○	○	●	○
Mikrocytos mackini	Mikrocytosis	○	○	○	○	○	○	●	●	○	○	○	○	○	●	○
Naegleria australiensis[g]	*Naegleria australiensis* infection	○	○	○	○	●	○	○	●	○	○	○	○	○	○	●
Nosema apis	Nosemosis of bees	○	○	○	○	○	○	●	●	○	○	○	○	○	●	○
Perkinsus marinus, P. olseni/ atlanticus	Perkinsosis	○	○	○	○	○	○	●	●	○	○	○	○	○	●	○
Naegleria fowleri	Primary amebic meningo-encephalitis	○	●	○	○	○	○	○	●	○	○	○	○	○	○	●
Trypanosoma evansi	Surra	○	○	●	○	○	○	●	○	○	○	○	○	○	●	○
Theileria parva and *Theileria annulata*	Theileriosis	○	○	●	○	○	○	●	○	○	○	○	○	○	●	○
Tritrichomonas foetus	Trichomonosis	○	○	●	○	○	○	○	●	○	○	○	○	○	●	○
Trypanosoma spp.	Trypanosomosis (tsetse-transmitted)	●	●	●	○	○	○	●	○	○	○	○	○	○	●	○
METAZOAL PARASITES																
Acarapis woodi	Acariosis of bees	○	○	○	○	○	○	●	●	○	○	○	○	○	●	○
Taenia saginata	Bovine cysticercosis	●	●	●	○	○	○	○	●	○	○	○	○	○	●	○

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Pathogen	Disease	Zoonosis	Primary species affected: Humans	Livestock	Poultry	Other domestic	Plants	Wild biota	Established in USA	Agency or organization[a] and priority: CDC *A*	CDC *B*	CDC *C*	USDA	OIE *A*	OIE *B*	BWC
Echinococcus spp.	Echinococcosis (hydatidosis)	●	●	●	○	○	○	●	●	○	○	○	○	○	●	○
Sarcoptes scabiei var. *equi*	Horse mange	●	●	●	○	○	○	○	●	○	○	○	○	○	●	○
New World screwworm (*Cochliomyia hominivorax)*	Myiasis	●	●	●	○	○	○	●	○	○	○	○	●	○	●	○
Old world screwworm (*Chrysomya bezziana*)	Myiasis	●	●	●	○	○	○	○	○	○	○	○	○	○	●	○
Taenia solium	Porcine cysticercosis	●	●	●	○	○	○	○	●	○	○	○	○	○	●	○
Trichinella spp.	Trichinellosis (trichinosis)	●	●	●	○	○	○	●	●	○	○	○	○	○	●	○
Varroa jacobsoni	Varroasis	○	○	○	○	○	○	●	●	○	○	○	○	○	●	○
BIOTOXINS																
Abrins	Abrin intoxication	○	●	○	○	○	○	○	○	○	○	○	○	○	○	●
Anatoxins	Anatoxin intoxication	○	●	○	○	○	○	○	●	○	○	○	○	○	○	●
Clostridium botulinum toxin	Botulism	○	●	●	●	●	○	●	●	●	○	○	○	○	○	●
Bungarotoxins (snakes)	Bungarotoxin intoxication	○	●	○	○	○	○	●	○	○	○	○	○	○	○	●
Ciguatoxins	Ciguatera fish poisoning	○	●	○	○	○	○	○	●	○	○	○	○	○	○	●
Epsilon toxin of *Clostridium perfringens*	*Clostridium perfringens* enterotoxemia	○	●	●	●	○	○	●	●	○	●	○	○	○	○	●
Shiga toxins	Enterohemorrhagic *Escherichia coli* infection	○	●	●	○	○	○	●	●	○	○	○	○	○	○	●
Saxitoxins	Paralytic shellfish poisoning	○	●	○	○	○	○	○	●	○	○	○	○	○	○	●
Ricin toxin	Ricin intoxication	○	●	○	○	○	○	●	●	○	●	○	○	○	○	●
Staphylococcal enterotoxin B	Staphylococcal enterotoxemia	○	●	●	●	○	○	○	●	○	●	○	○	○	○	●
Trichothecene toxins (*Fusarium* spp.)	Trichothecene intoxication	○	●	○	○	○	○	●	●	○	○	○	○	○	○	●

[a] CDC, Centers for Disease Control and Prevention; USDA, United States Department of Agriculture; OIE, Office International des Epizooties; BWC, Ad Hoc Group of State Parties to the Biological and Toxins Weapons Convention.

[b] Human infections have occurred but are not common and generally have minimal to no public health importance.

[c] CDC, Category C includes "tickborne hemorrhagic fever viruses," of which CCHF is one example.

[d] Refers to Sin Nombre virus; many other hantaviruses occur in the world.

[e] Not all *Pasteurella multocida* serotypes cause zoonotic disease; most human cases result from bite wound infections involving small mammals (domestic and wild).

[f] Sometimes associated with undercooked or raw seafood consumption.

[g] Disease in experimentally infected mice; potentially a human pathogen.

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