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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**Bolded words** within the text indicate terms that are defined in the Glossary.

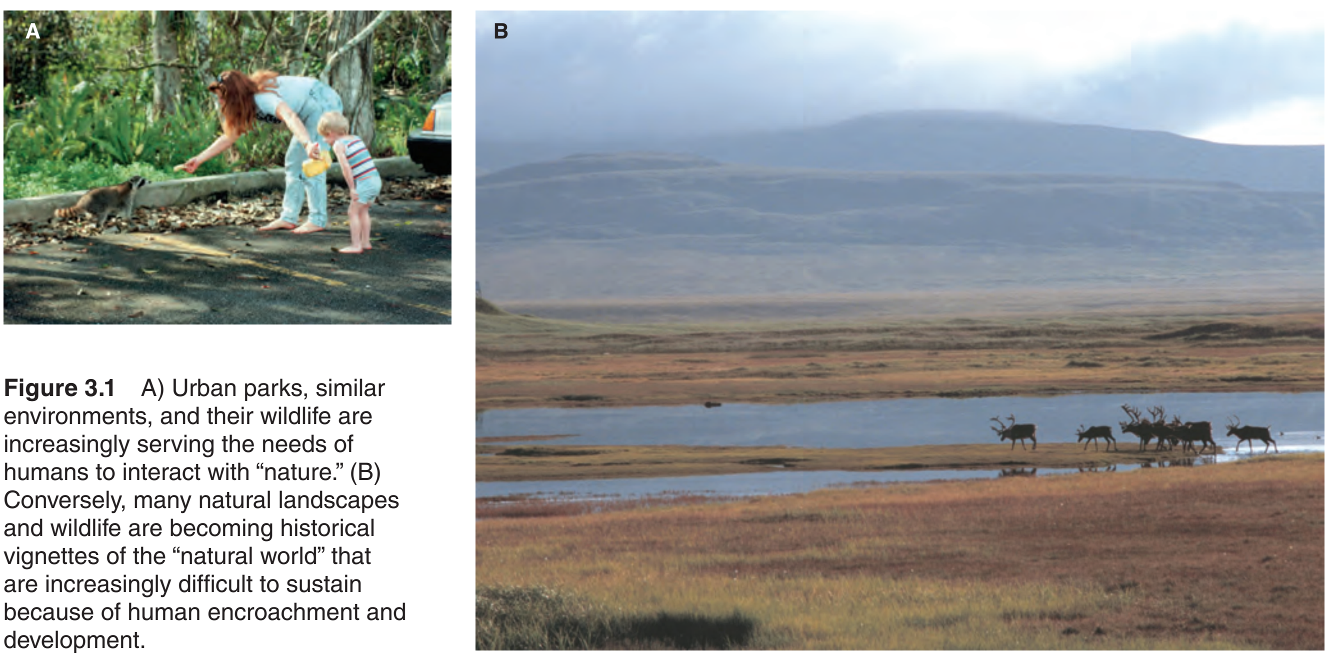
Chapter 3

# 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,

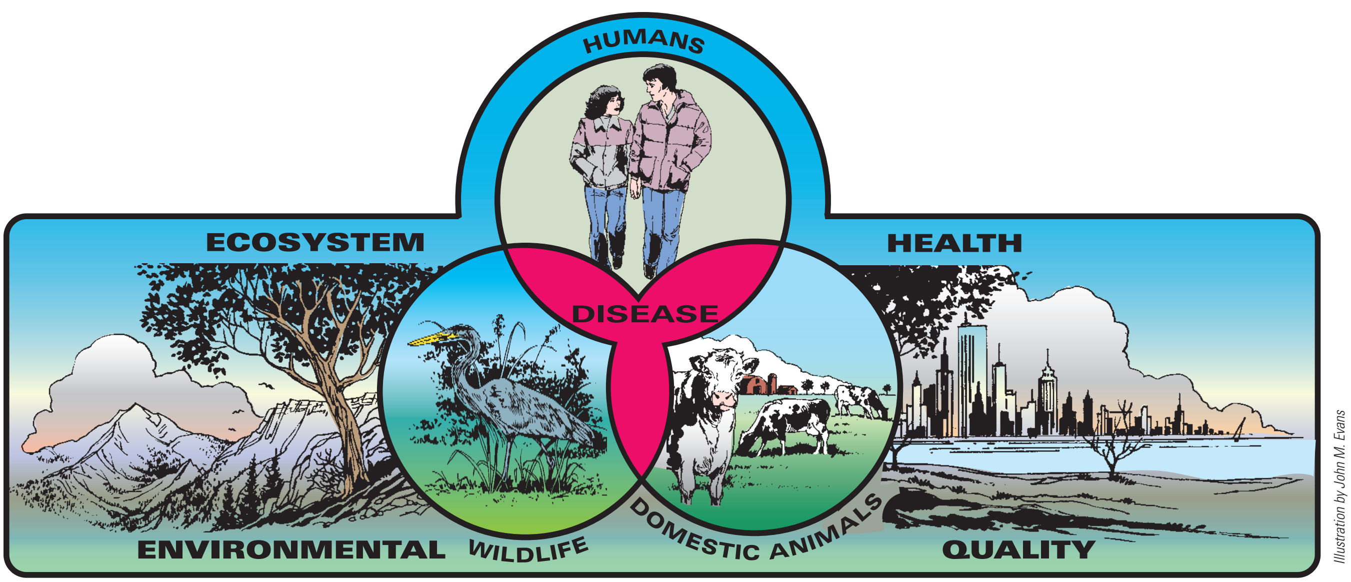



**Figure 3.2** Ecosystem health is a reflection of environmental quality, an important factor in the well-being of humans, domestic animals, and wildlife alike. The interfaces that commonly occur between all of these components support the need for a holistic approach of "one medicine" for the benefit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

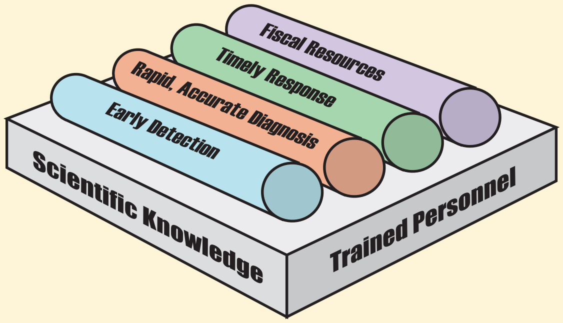



**Figure A.** **Basic pillars and support platform for combating disease.**

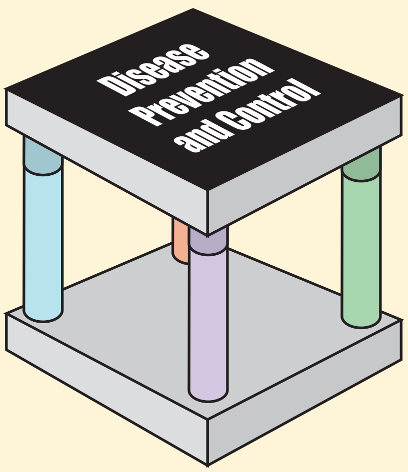



**Figure B.** **Disease prevention and control requires a sound foundation of basic components.**

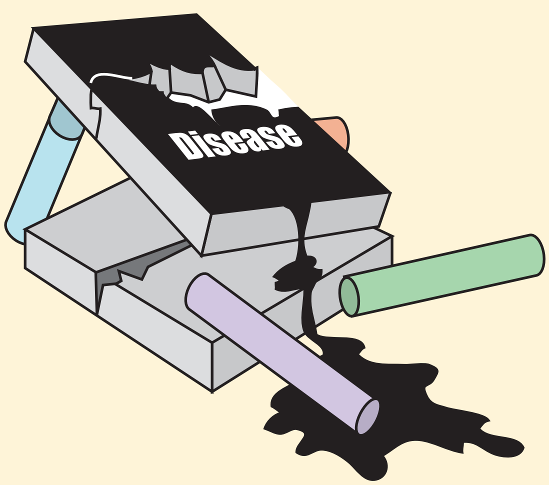



*Illustration by John M. Evans*

**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

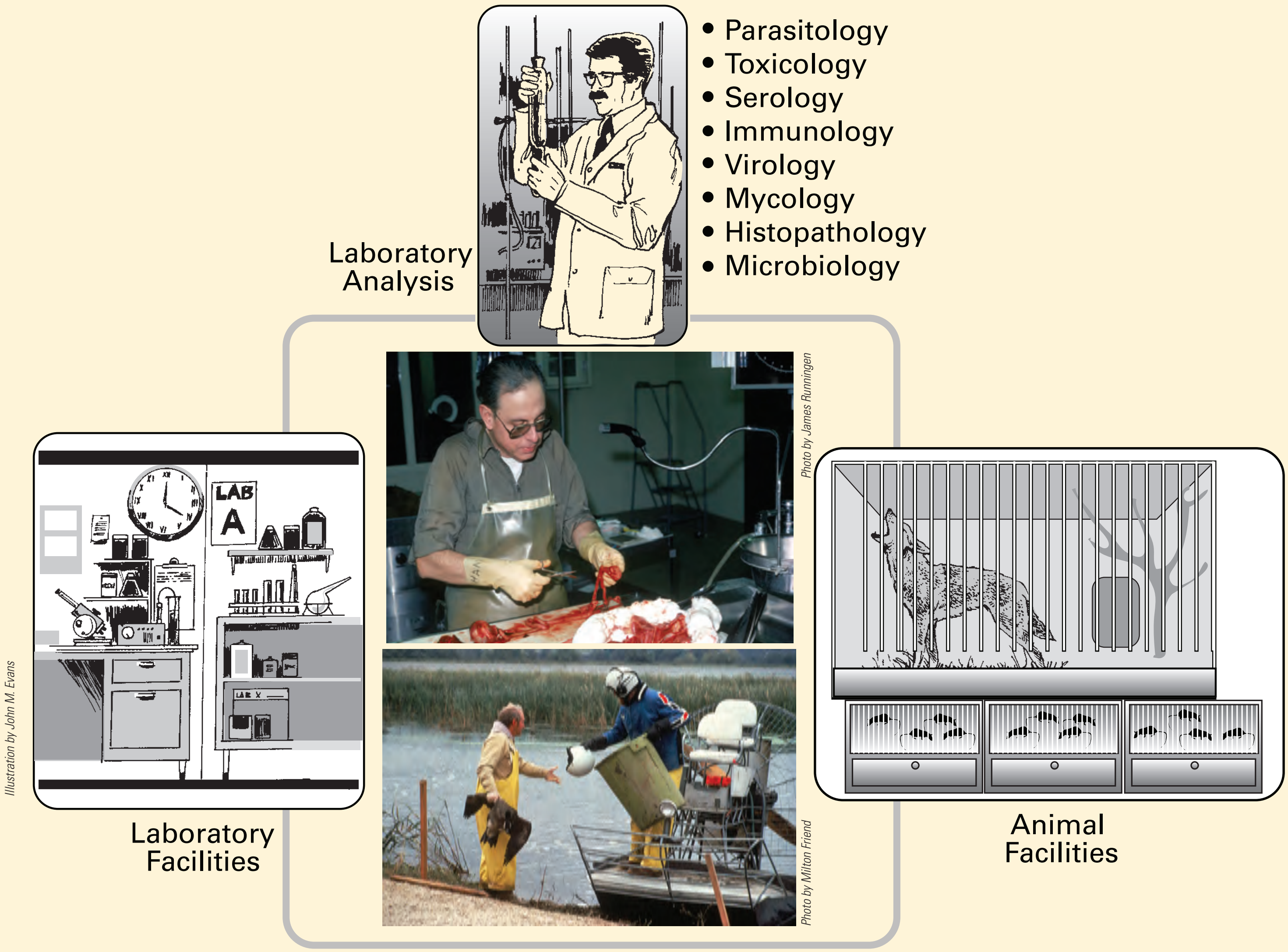



**Figure D.** **A broad spectrum of expertise, technical assays, and facilities are needed to provide timely, accurate diagnosis of disease occurrence and support disease prevention and control in wildlife populations.**

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.

**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.**

*Photos by Milton Friend*

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

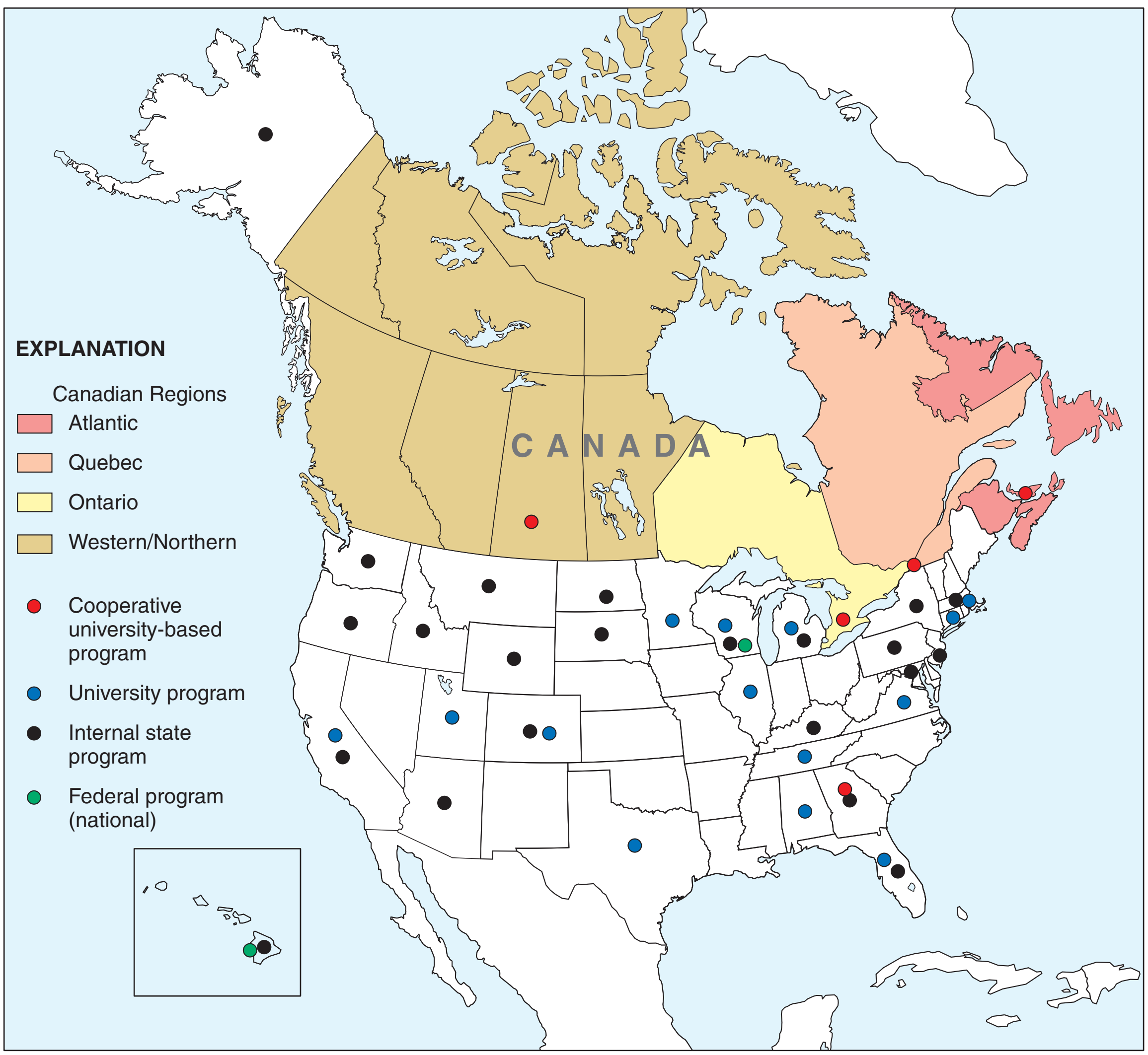
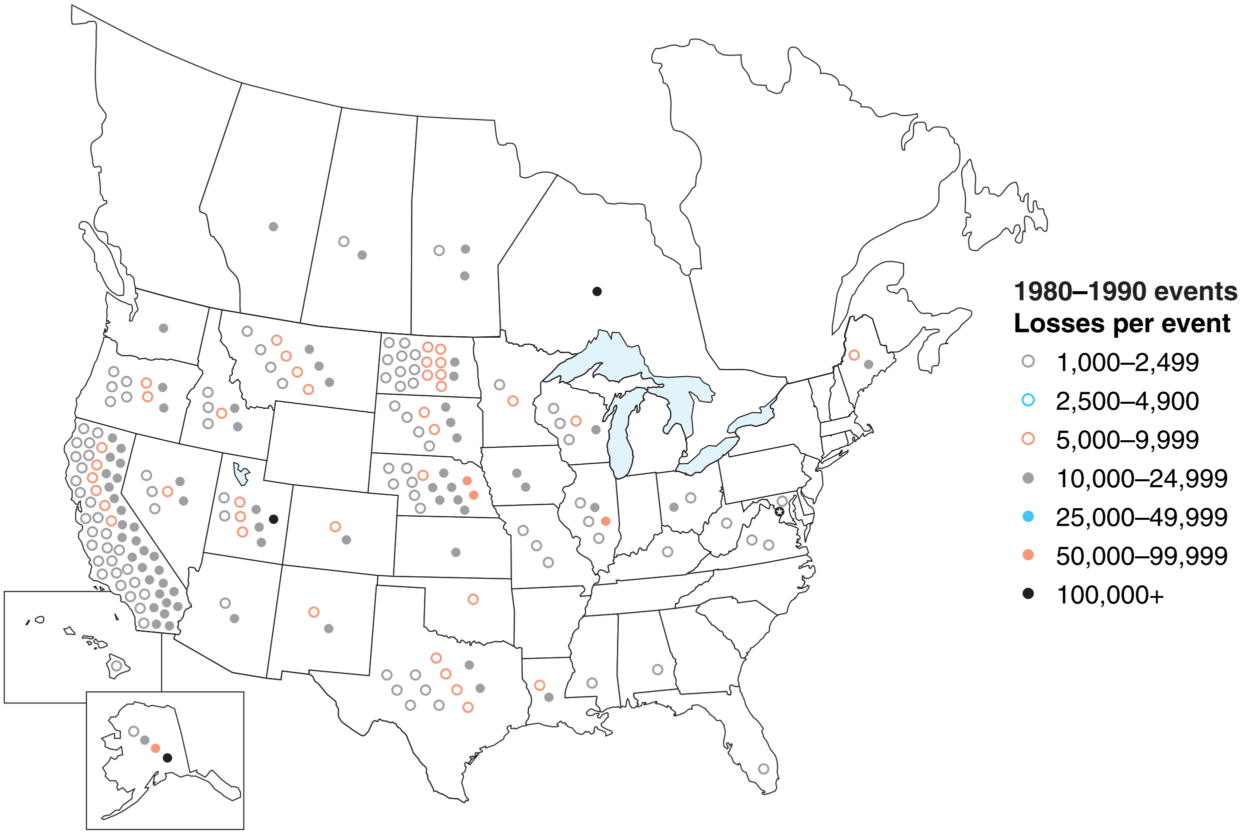



**Figure 3.3** Locations and sponsorship of North American programs devoted to disease investigations involving free-ranging fauna (state, federal, University cooperative programs).



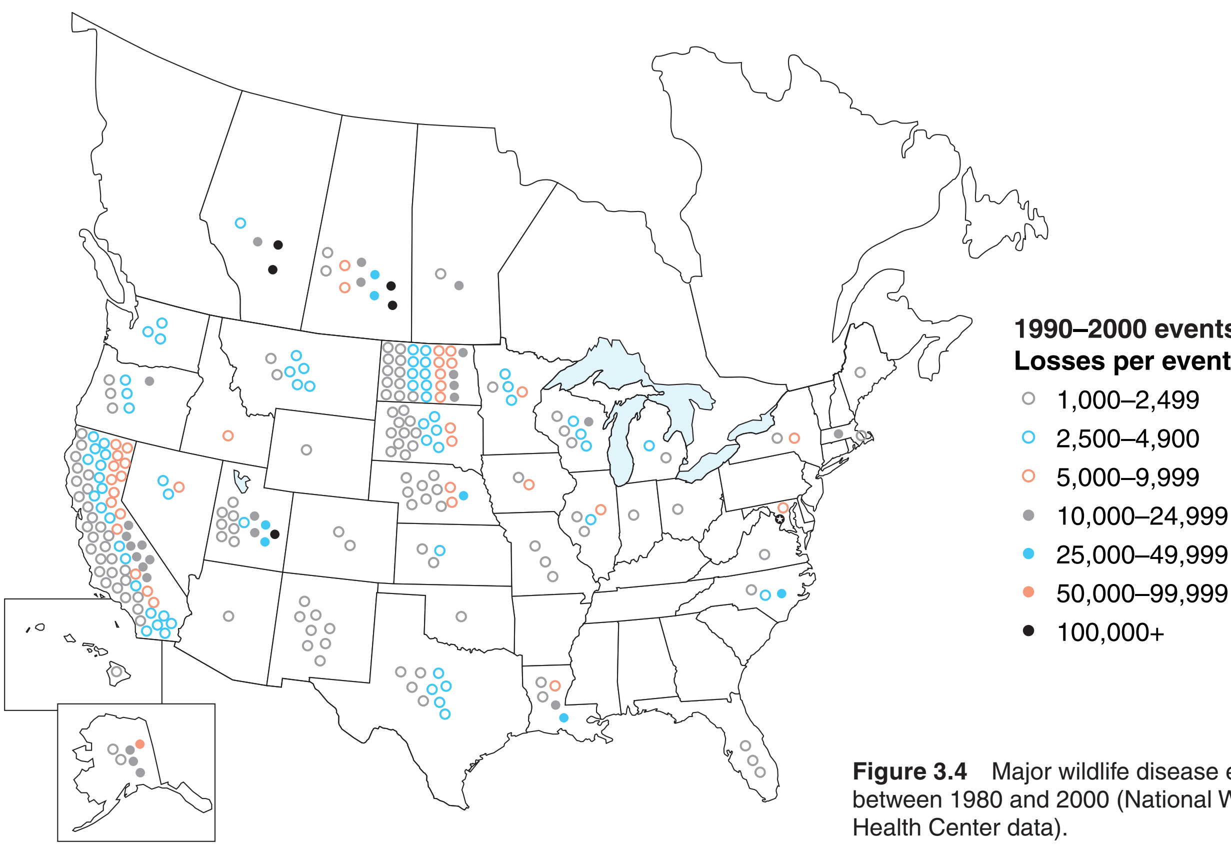




**Figure 3.4** Major wildlife disease events between 1980 and 2000 (National Wildlife Health Center data).

**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 | 21.5 | million | Annual costs to USA.[168] |
| | Forest trees/plants | 2.1 | million | |
| | Livestock | 9 | million | |
| | Humans | 6.5 | million | |
| 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


**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).


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.

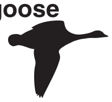
Wildlife in captive-propagation programs (including aquaculture) can bring pathogens from nature into propagation facilities. Some of these pathogens may emerge as causes of significant diseases within the propagation program and/or for species they share environments with once propagated stock are released. 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 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.<br>• A 2001 Harris poll identified recreational fishing as American's top outdoor leisure time activity.<br>• 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.<br>• 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.

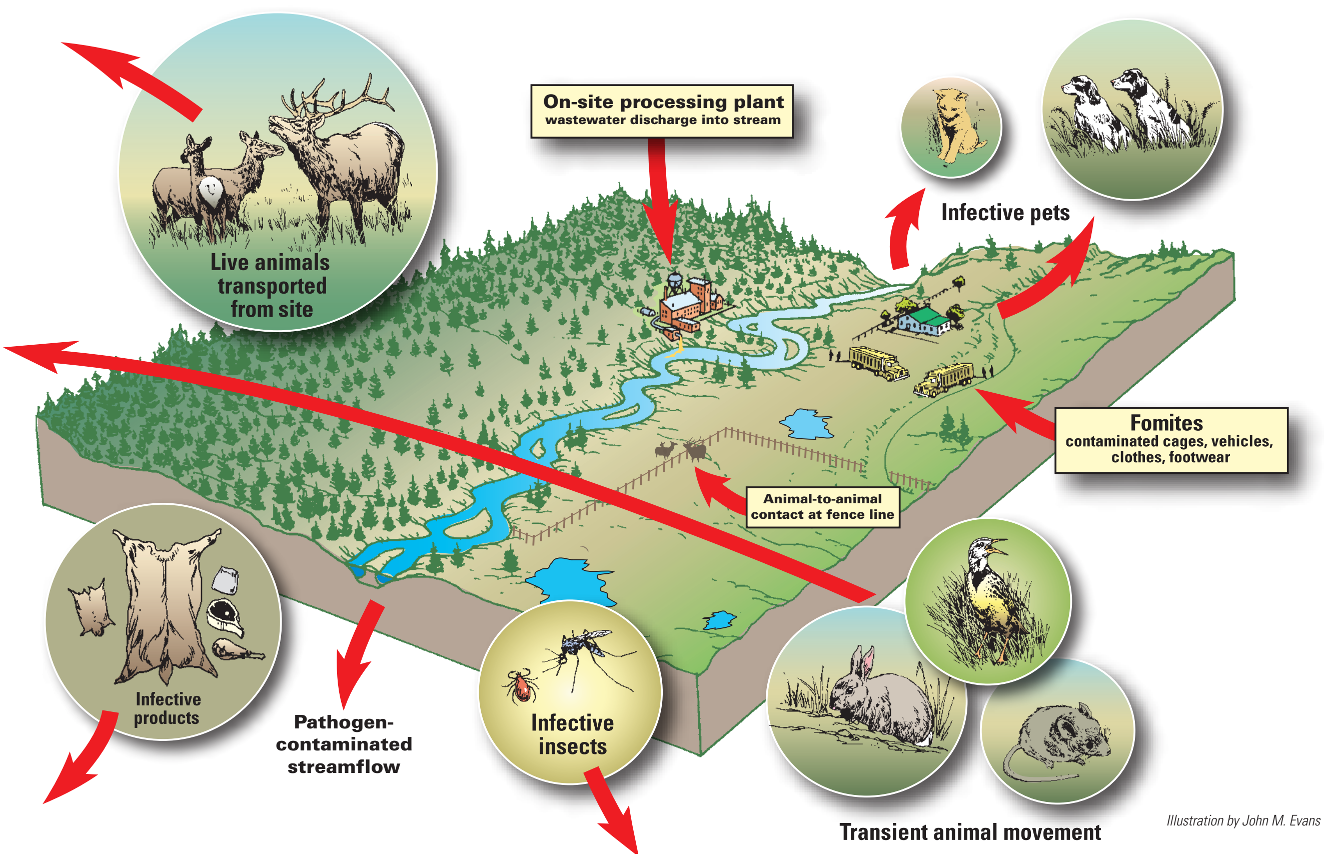



**Figure 3.10** Numerous pathways exist for the potential movement of pathogens between wildlife propagation facilities, surrounding environments, and other locations. Sound management of these facilities requires an emphasis on disease prevention.

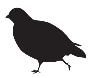
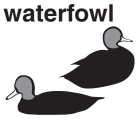
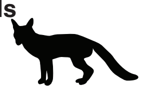
**Table 3.5** Examples of socioeconomic effects of recreational hunting.[38]

| 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<br>• $61 billion in overall economic output<br>• 704,000 jobs |
| **Canada**[202]  | • 5.1% of population hunt | • $824 million in total estimated expenditures by hunters<br>• $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<br>• Euro $9.88 billion (not $US) financial flux generated by hunting in the European Union<br>• 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<br>• $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 | Releases | 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

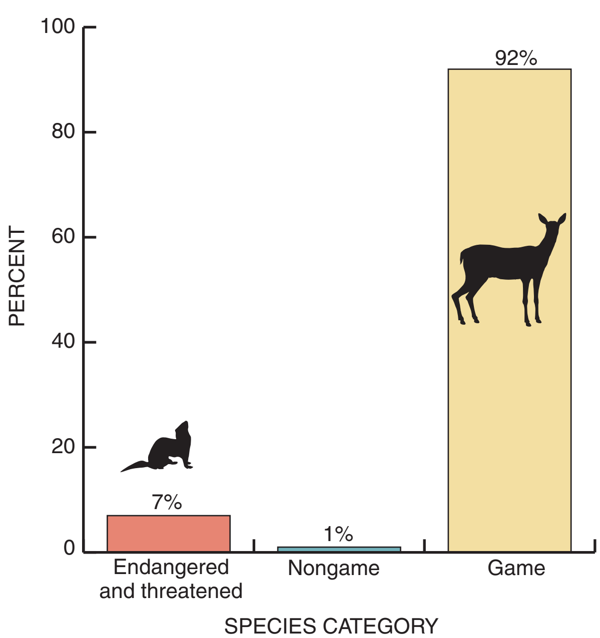



**Figure 3.14** Wildlife translocations within the USA, Canada, New Zealand, and Australia, 1973–1989.[19]

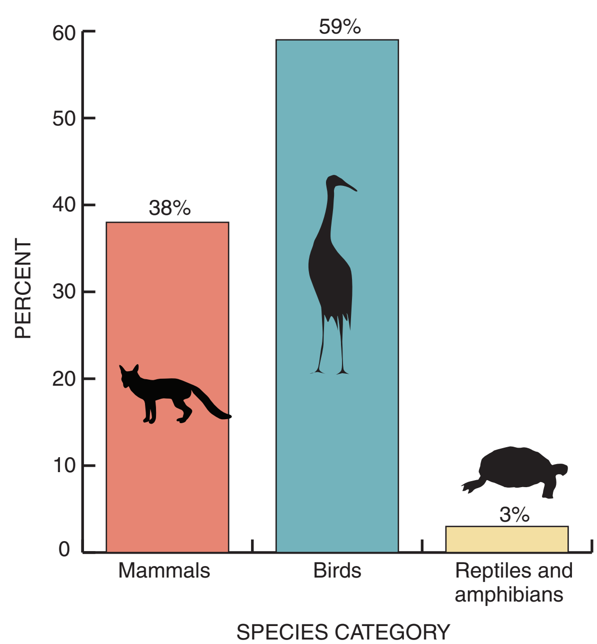



**Figure 3.15** Percentage of translocations by wildlife type, 1971–1986.[19, 23]

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]

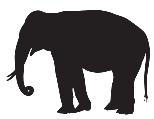
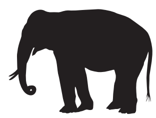
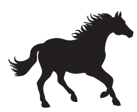
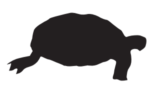
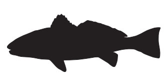
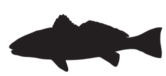
The focus of this chapter is wild stocks of animals not yet genetically altered for the selection of traits that serve the ranching industry. Wildlife ranching is a growing industry of considerable local and regional economic importance for many developing countries.[38] The changing values resulting 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-

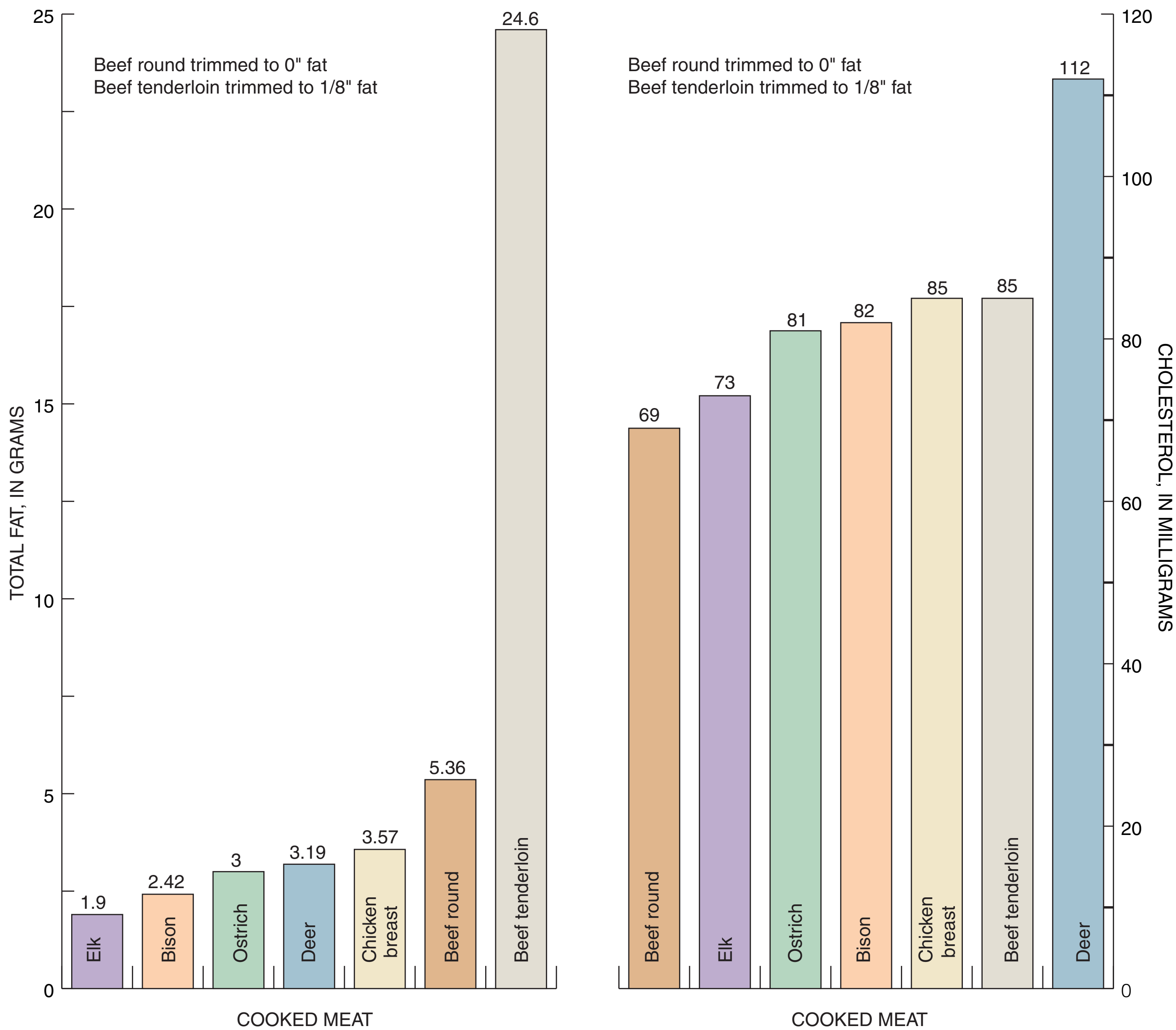
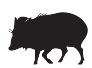
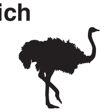



**Figure 3.17** Total fat and cholesterol per 100 grams of edible portion of cooked meats.[60]

**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] |
| **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 | Food[a] | Fiber[b] | Medicinals[c] | Scents[d] | Bone[e] | Burden[f] | Hunting[g] | Pets[h] | Comments

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Waterfowl Ducks, geese, swans** | ● | ● | ○ | ○ | ○ | ○ | ● | ● (secondary) | 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** | ● | ● | ○ | ○ | ○ | ○ | ○ | ● (secondary) | |
| **Iguana** | ● | ● | ○ | ○ | ○ | ○ | ○ | ● | |
| **Turtles** | ● | ● | ○ | ○ | ● (secondary) | ○ | ○ | ● | 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 (orange) ○ 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]

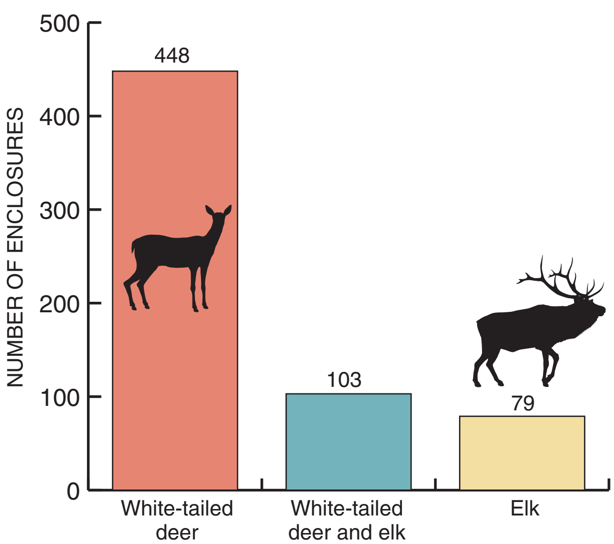



**Figure 3.18** Licensed enclosures with captive cervids in Michigan, 1999.[67]

### 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]

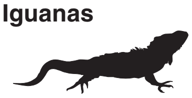
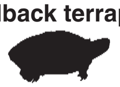
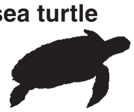
| Species | Countries | Primary uses | Comments |
|---|---|---|---|
| **Iguanas**  | South and Central America | Meat, skins, pet trade | Iguana lizards and boas are integrated with crocodile farming in Colombia; in Panama and Costa Rica farming of green iguanas is being promoted. |
| **Monitor lizards**  | 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] |

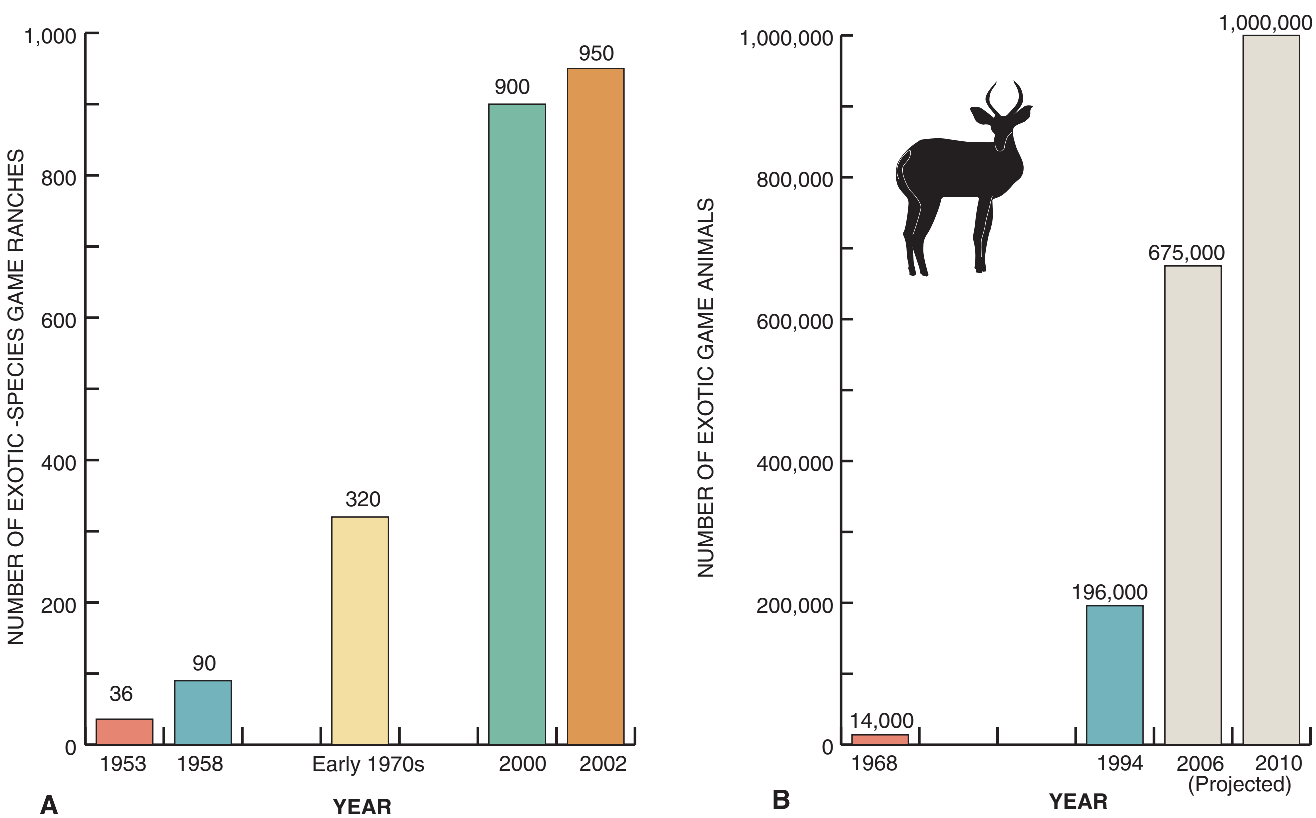



**Figure 3.19** (A) Trends in numbers of exotic-species game ranches and (B) numbers of exotic game animals in Texas.[65]

# 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.

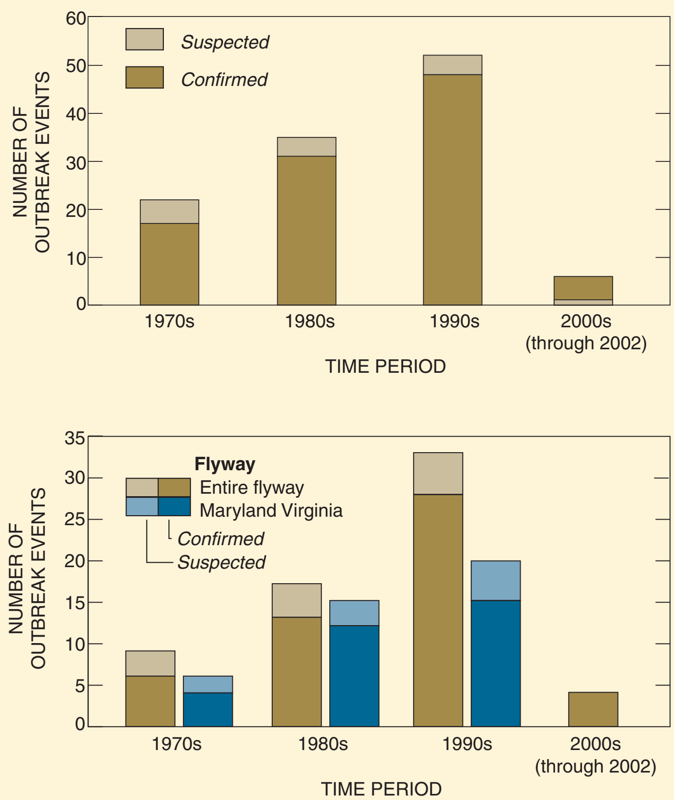



**Figure C. Number of duck plague outbreaks occurring in the USA.**

**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.

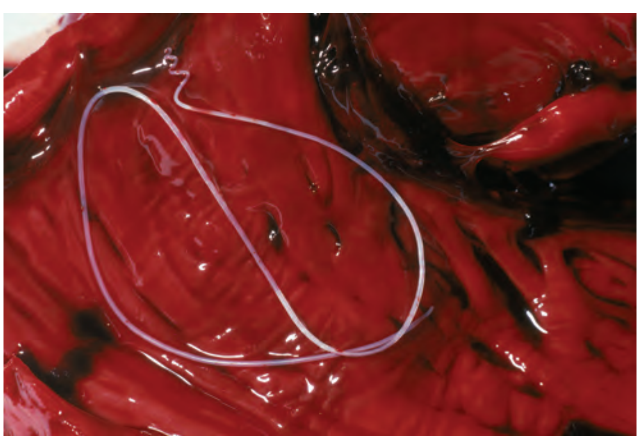



**Figure 3.20** Heartworm in an endangered red wolf. This parasite of dogs is transmitted by mosquitoes and has been responsible for wolf mortality in the USA.

### 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 Wawrzynczyk, 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*<br>• Humans may become infected with *M. bovis* from cattle/milk and then retransmit TB to other species<br>• Major problem in India |
| **"Polio"** | Poliovirus and/or polio-like virus | Chimpanzee  | 1964, 1966 | • Six deaths and at least 6 other chimps paralyzed for life during outbreak in Gombe National Park, Tanzania (1966)<br>• 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<br>• 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 | Chimpanzee  | 1968, 1975, 1978, 1987, 1996 | • Warnings published since 1920s of high susceptibility of apes for human respiratory infections<br>• Gombe National Park outbreaks (1968–1996) have killed 1 to 11 animals per event and left others clinically ill<br>• *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, chimpanzee   | 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<br>• An outbreak in Gombe National Park (1997) killed 3 chimpanzees of 19 infected |
| **Parasitism** | Endoparasites | 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<br>• 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]).

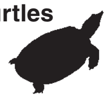
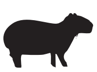
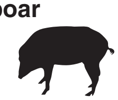
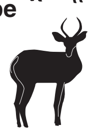
| Type of meat | Producer countries | Comments |
|---|---|---|
| **Crocodile, alligator**  | Southeast Asia, Zimbabwe, Colombia, Australia, USA | Crocodile meat is a highly prized export commodity in South America and Africa, and is a primary purpose for farming these species in Asia).[248] Alligator 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

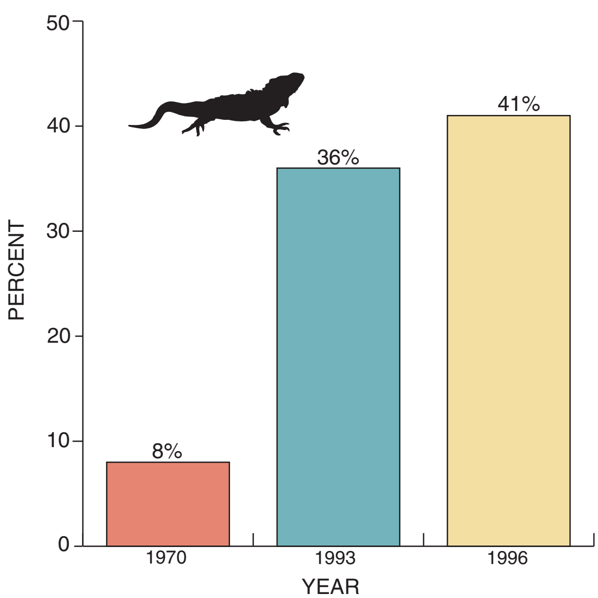



**Figure 3.21** Iguanas imported into the USA as a percentage of total imported reptiles.[243]

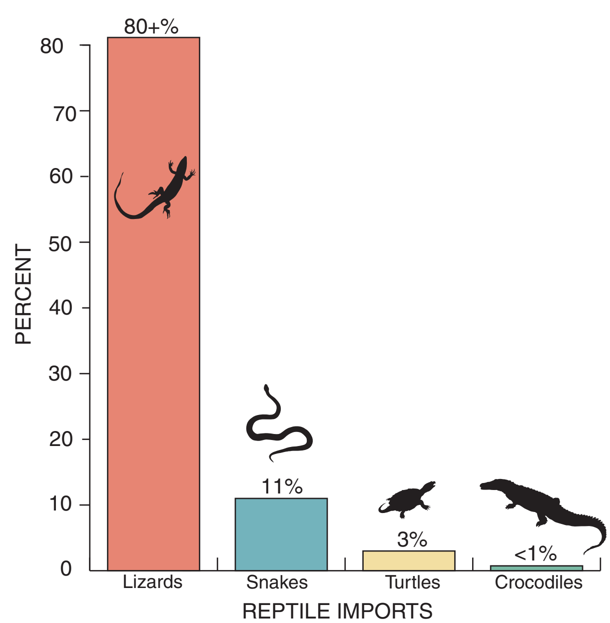



**Figure 3.22** Percentages of live reptiles imported into the USA during the mid- to late 1990s.[90]

# 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]

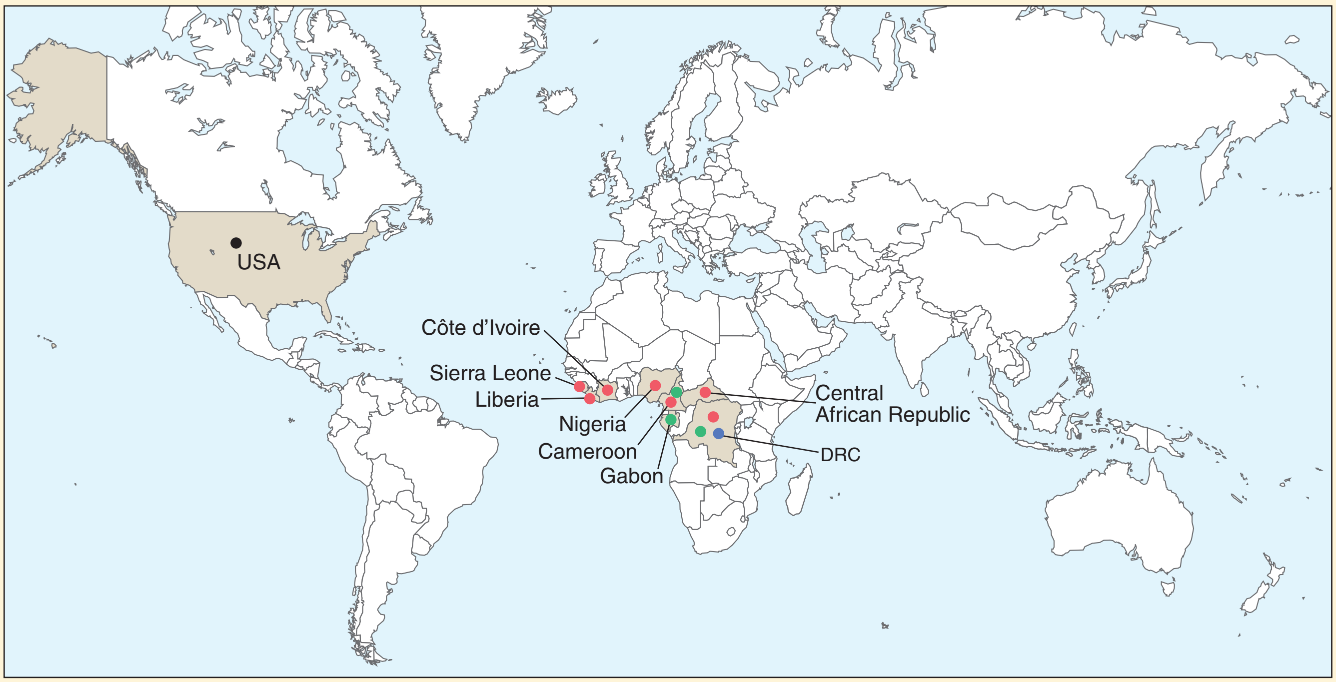
The human index case in the USA was a 3-year-old child who was hospitalized. Her parents developed milder forms of the disease.[155] Subsequent cases were reported from Wisconsin, Illinois, Indiana, Ohio, Kansas, and Missouri.[154] More than 80 human cases, 32 of which had been confirmed by laboratory 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<br>Kuhl's tree squirrel<br>Thomas's tree squirrel<br>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]**

Entry of Monkey Pox into the United States


**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

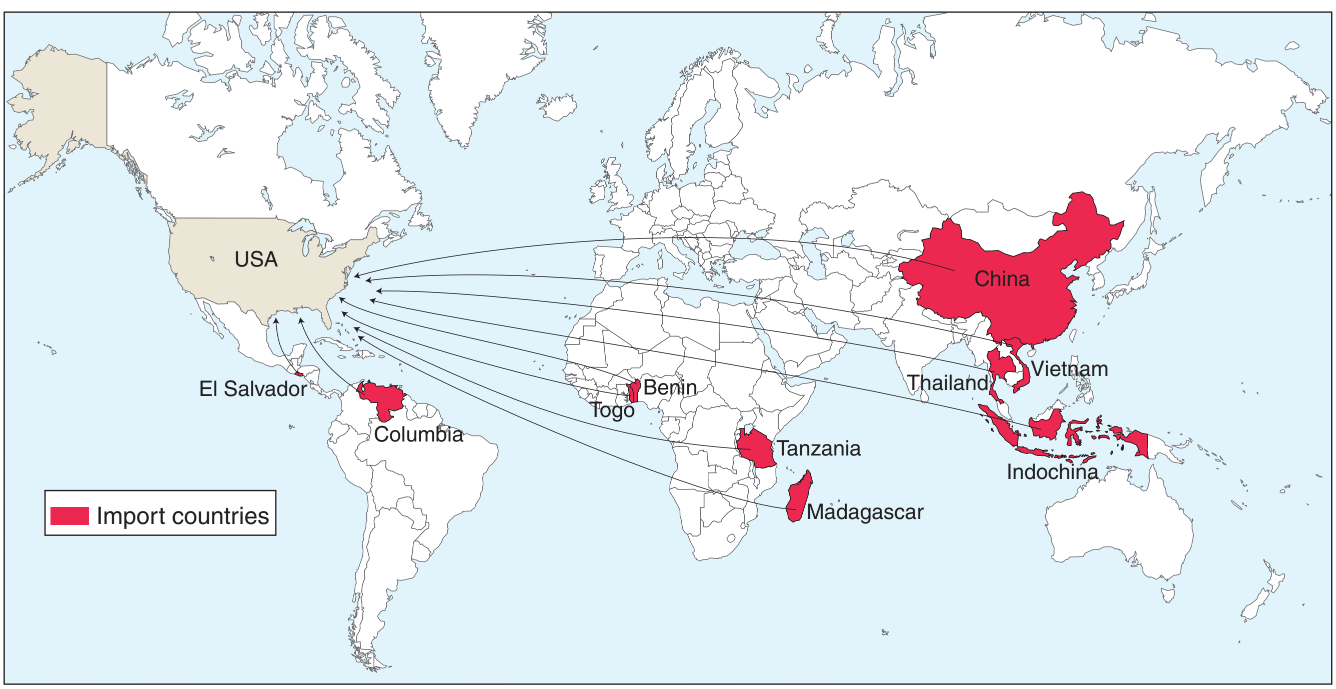



**Figure 3.23** Countries of origin for reptiles imported into the USA during 1998.

**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.


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


**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.

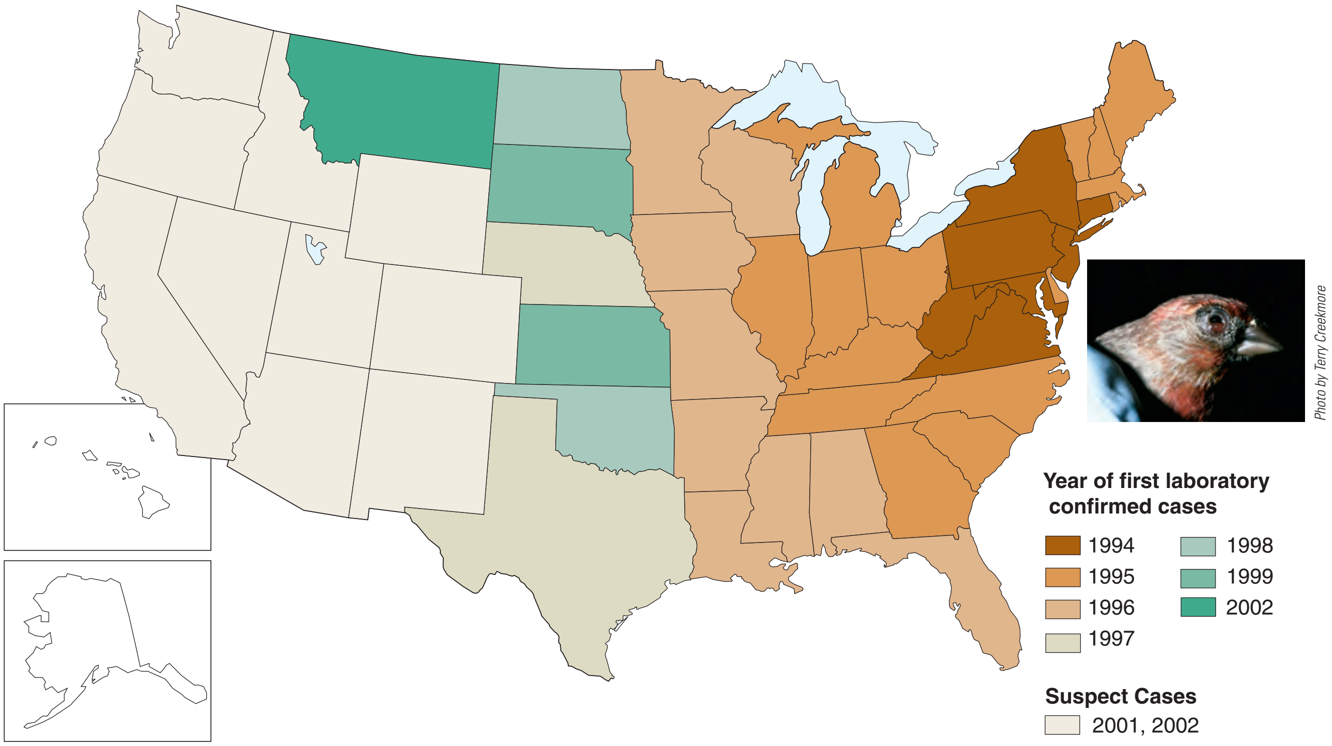



**Figure 3.27** The spread of housefinch conjunctivitis within the USA.[71,239,254,255,256]


**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;

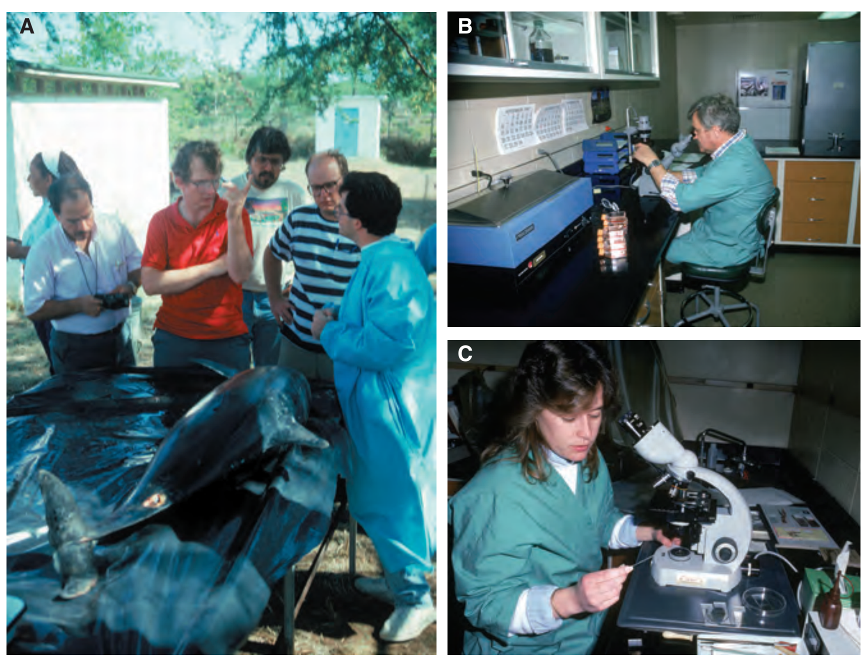
Linkage for zoonotic diseases with national human health disease surveillance reporting systems;

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




Photos by Milton Friend

**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.

*Milton Friend*

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