15 Disease management through influencing human activities

> "*Public sentiment is everything. With public sentiment nothing can fail; without it, nothing can succeed*". Quote attributed to Abraham Lincoln by (Gilbert 1964)

That wildlife management consists largely of managing people is an axiom among biologists. Almost anything done to control or prevent disease in wild species involves a considerable amount of people management. While involvement of people in disease management has always been important, it will become ever more urgent as the global human population continues to grow, adding about 76 million persons each year to the current level of about 6.4 billion. This growth in human population will necessitate the movement of people into new ecologic regions and uninhabited areas for exploitation of natural resources. There will be expanded cultivation, development of roads, dams and irrigation, all of which will have effects on the occurrence of disease in wild animals and will lead to enhanced transmission of infectious diseases among wild animals, domestic animals and humans. An ever-increasing proportion of humans will live in urban areas. About 30% of humans lived in urban areas in 1950, in 2000 this reached 47%, and by 2030 it is expected that 60% of humans will live in cities (United Nations 2004). This trend is even more advanced in the most developed countries. One consequence is that, increasingly, the human population will be removed from direct contact and understanding of natural processes and much of their understanding will come from sources such as 'nature' television. This will mean that more effort will be needed to explain disease management.

A major problem in trying to manage disease in wild animals through influencing human behavior lies in convincing people that changing their actions is in their own best interest. Short-term gains from ecosystem alteration, such as increased employment and better returns on investment, are much easier to demonstrate than benefits from protecting biodiversity or fresh water. Many human-induced changes in ecosystems, such as increased food production in agricultural systems, improve human health locally at the expense of other systems such as preserving freshwater, and displace the detrimental effects temporally or spatially (Weinstein 2005). For instance, irrigation usually is beneficial locally, at least in the short-term, but may lead to increased disease transmission (Jardine et al. 2004), soil salinization, accumulation of toxicants in drainwater, and depletion of aquifers, in the longer term. As Weinstein (2005) observed, draining swamps and replacing forests with concrete may be helpful in eliminating human malaria but it is short-sighted if you or someone else runs out of water as a result.

I will not discuss the over-arching problem of human population growth and appetite, nor will I discuss the type of management needed to obtain funding necessary for disease control programs, although that is an essential skill if a program is to succeed; instead I will discuss forms of action more directly related to technical management of disease. I have mentioned at various places earlier in the book that many of the most serious disease problems in wildlife are directly related to some human activity. These usually result from habitat modification or loss, artificial manipulation of animal populations, or because of direct introduction of disease agents or risk factors into the environment. Much of what can be done to control or prevent disease consists of recognizing the potential effects of such activities and trying to prevent or mitigate the effects before they occur, or of trying to reduce or control the effects of some existing activity.

The most simple situations are those in which some man-made element is a direct cause of morbidity or mortality and management consists of removing or neutralizing this factor. For instance, some large birds are particularly prone to collide with overhead wires passing over wetlands, e.g., 38% of mute swans found dead during a long-term study in England died as a result of such collisions (Owen and Cadbury 1975). Care in the location of overhead lines in relation to areas of bird movement and concentration, alterations in the configuration of the wires, and marking of the wires, are modifications that may reduce mortality as a result of collision (Anderson 1978, Meyer 1978). Electrocution on electrical transmission lines also is an important cause of mortality for some birds. Electrocution was the third most common cause of death of bald eagles in the U.S.A. and killed approximately as many eagles as did infectious diseases and intoxication of all types combined (Reichel et al. 1984). Modification of the spacing and arrangement of the wires makes towers carrying such wires more safe as roosting sites by large birds (Miller et al. 1975) and could substantially reduce mortality.

The solution to most anthropogenic problems is less direct. In this chapter, I will deal with three major areas: (i) problems associated with the movement of animals and disease agents, (ii) legislative or regulatory means to reduce or curb disease, and (iii) public education and planning of human activities, to reduce the impact of diseases not manageable in other ways.

15.1 Movement of animals and disease

Humans are compulsive and inveterate movers and transporters of biological materials. We do this consciously to ‘enrich’ the fauna of an area with exotic wild species, such as the house sparrow and the starling, and inadvertently as, for example, when *Aedes albopictus*, a mosquito vector of many arboviral diseases of man, was introduced to the Western Hemisphere from Asia in used tires (Hawley et al. 1987). In some cases, wild animals may be translocated to promote recovery of populations decimated by disease (Dullum et al. 2005). In transporting biologic materials about the globe we circumvent natural geo-physical barriers that have determined the distribution of animals and disease agents. This process of human-assisted movement has occurred for centuries but the risk of successful translocation of animals and diseases has increased dramatically with developments in transportation. In the past, the rigors of transport were such that many disease agents, vectors, and hosts failed to survive the trip and this, in itself, was a barrier to the spread of disease. However, not all agents are equally susceptible to the rigors of prolonged travel and some diseases such as plague were transported widely about the world in sailing ships and in the baggage of armies and caravans. The situation is now much more conducive to effective translocation of disease, with travel time between any two points on earth, even by commercial airlines, being within the lifespan of most arthropod vectors and shorter than the incubation period of most infectious diseases. This time period often is so short that even fragile agents may survive in the relatively inhospitable environment of soil clinging to boots or equipment. Much of what I will be discussing in this section deals with creation of artificial barriers to replace the natural barriers to disease movement that can now be circumvented so easily.

The movement of agents and/or animals may create at least three types of disease problem. The first problem, and the most obvious, occurs when a disease agent is introduced into an area where it did not previously occur. If the disease agent becomes established at the new site it may have a serious impact on indigenous species, including humans and domestic animals. A second, less obvious problem occurs when highly susceptible animals are introduced into an area where a disease agent, to which they are vulnerable, already exists in the native fauna. The indigenous disease may have a serious impact on the introduced species, although it may cause little or no detectable problem in native animals. The third potential problem occurs when the introduction of a new species changes the ecology of an existing disease or host–parasite relationship, so that it becomes more of an issue. The first of these three potential problems is by far the most serious but the second may result in the failure of costly transplantation exercises. In both the second and third situations, the introduction of new animals may result in management becoming necessary for a disease that was previously of no particular significance.

15.1.1 Introduction of novel disease agents

Many examples are available of diseases that have become established in new areas as a result of translocation of wild animals (Table 15.1) and it is worthwhile considering a few of these in detail.

Table 15.1 Examples of diseases that have been moved through the translocation of wild animals

Disease or agent	Type of movement
Bovine tuberculosis	Alberta to Wood Buffalo National Park with bison.[1]
Oedemagena tarandi	Norway to Greenland with reindeer[2]
Malignant catarrhal fever	Africa to North America with wildebeest[3]
Raccoon rabies	Florida, Georgia to Virginia with raccoons[4]
Elaphostrongylus cervi	Europe to New Zealand with red deer[5]
	New Zealand to Australia with elk[6]
Echinococcus multilocularis	Northern to southeastern USA with foxes[7]
Dog rabies	Texas to Florida with coyotes[8]
Exotic ticks	Tropical areas to North America with reptiles[9]
Plague	China to western North America with rats[10]
Elaphostrongylus rangiferi	Norway to Newfoundland with reindeer[11]
Fascioloides magna	North America to Europe with elk[12]
Squirrel parapoxvirus	North America to Britain with grey squirrels[13]
Aleutian mink disease	North America to Europe with mink[14]
Avian influenza (H5N1)	Thailand to Belgium with smuggled eagles[15]

[1]Fuller (2002), [2]Clausen et al. (1980), [3]Castro et al. (1982), [4]Baer (1985), [5]Watson and Gill (1985), [6]Presidente (1986), [7]Davidson et al. (1992), [8]Anonymous (1995), [9]Burridge et al. (2000), [10]Gaspar and Watson (2001), [11]Lankester (2001), [12]Pybus (2001), [13]Tompkins et al. (2003), [14]Fournier-Chambrillon et al. (2004), [15]van Borm et al. (2005)

Nematodes of the genus *Elaphostrongylus* have a wide distribution in cervids in Eurasia (Steen and Rehbinder 1986; Lankester 2001) and utilize a variety of gastropods as intermediate host. The adult worms may invade the nervous system of cervids and cause severe neurologic disturbance, including paralysis and blindness. Neurologic disease caused by *Elaphostrongylus* occurs in red deer (Borg 1979; Watson 1983), reindeer (Kummeneje 1974), caribou (Lankester and Northcott 1979), sika and maral deer (Watson and Gill 1985) and moose (Steen and Rehbinder 1986; Lankester 1977). In addition to the propensity to cause neurologic disease, the parasite may also cause interstitial pneumonia (Sutherland 1976). Carcasses of farmed red deer have been condemned because of lesions in the intermuscular fascia caused by *E. cervi* (Mason et al. 1976) and the carcass weight of adult moose infected with *E. alces* is significantly lower than that of uninfected animals (Stuve 1986). This is not the type of parasite that one would knowingly transplant into new areas where susceptible cervid species are present; however, there is a growing history of that having been done.

Elaphostrongylus cervi was recognized to be present in New Zealand in 1975, when infection was found in red deer (Mason et al. 1976) and elk (Mason and McAllum 1976); neither of which is native to New Zealand. Watson and Gill (1985) suggested that the parasite could have been introduced to New Zealand either with elk from North America or with red deer from Scotland. The latter source is far more likely, as *E. cervi* is enzootic in red deer in Scotland but has not been found in elk in North America. Introduction probably occurred at about the turn of the 20th century, before the parasite had been discovered.

In 1986, *E. cervi* infection was diagnosed in one of a group of 33 elk being held in quarantine in Australia after importation from New Zealand. The infected animal was destroyed and further importation of live deer from New Zealand was suspended (Presidente 1986). This case is notable for two reasons. The first is that it represents one of the few documented examples in which an exotic disease agent was recognized during the transplantation process and dealt with before release of the animals. It also is important because of the extent of the measures that had been taken to ensure that the animals were not infected with the parasite prior to importation. All 170 deer on the farm of origin in New Zealand had been examined and were negative for larvae of *E. cervi* when tested prior to selection of animals for export to Australia. The animals selected for export were then quarantined on pasture for 6 months, separate from other deer, then treated each day for 5 days with an anthelmintic and, finally, held in quarantine off pasture for a further 42 days prior to export. After arrival in Australia, the elk were placed in quarantine for 100 days and feces were examined from each animal on three occasions (4, 40, and 69 days after arrival). Larvae were detected only on the third examination.

The second occurrence involved 1,597 red deer in four groups imported into Canada from New Zealand (Gajadhar et al. 1994). Feces were collected from each animal within 30 days of arrival in quarantine. A total of six animals in three of the herds were found to be infected with *E. cervi*. When repeated fecal samples were taken from these animals, larvae could not be detected consistently. All four herds were depopulated and importation of cervids from countries where *E. cervi* is known or suspected to occur was suspended (all of the red deer had been negative on one to three tests done while in quarantine prior to leaving New Zealand).

Many factors, including a long prepatent period [up to 206 days, Gajadhar et al. (1994)], intermittent shedding of larvae, and suppression of larval output by anthelmintic treatment, may have been involved in these cases, but they serve to illustrate several points. The first is the extreme difficulty in detecting and preventing entry of certain diseases when live animals are translocated. **A living animal cannot be readily separated from its microflora and microfauna for purposes of translocation and it is impossible to sterilize a living animal**. The measures required by the Australian government, in particular, were very rigorous and, no doubt, were considered excessive by those interested in moving the animals. But the measures were not sufficiently rigorous to prevent movement of the parasite. The second point worth noting is that drug treatment was ineffective in ridding the Australian animals of the infection, although it may have stopped larval output temporarily and, hence, made the parasite even more difficult to detect. Chemotherapeutic agents are seldom 100% effective, even under ideal conditions. To complicate the matter further, very few drugs have been tested specifically in wild species. Fortunately in both cases described above the parasite was recognized prior to its release. This demonstrates the value of an extended quarantine period, with careful monitoring prior to release. It must be noted that the measures used to prevent introduction of *E. cervi* into Australia were markedly more stringent than those required in most instances in which wild animals are transplanted into new areas.

An incident involving another parasite in the same genus is worth reviewing. *Elaphostrongylus rangiferi* was detected in wild caribou on Newfoundland, Canada in 1976 (Lankester and Northcott 1979, Lankester 2001). It is thought to have been brought with reindeer from Norway to the island in the early years of the 20th century. Cases of neurological disease have been found in naturally infected caribou in Newfoundland, and a moose infected experimentally with parasites derived from caribou developed neurologic disease (Lankester1977). *Elaphostrongylus rangiferi* is not known to occur elsewhere in North America, although caribou from Newfoundland were transplanted to Maine in the 1960s and in 1987. The early introduction failed and the animals died. The animals moved in 1987 were treated with an anthelmintic prior to translocation but larvae, that may have been those of *E. cervi*, were shed by two animals after arrival in Maine. The animals were then treated rigorously with anthelmintic and held in quarantine (M.W. Lankester, personal communication). The ultimate fate of the animals and worms is unclear. It must be noted that transplantation of caribou to Maine in 1987 occurred despite knowledge of the presence of the parasite in Newfoundland caribou and after the results of the Australian experience with *E. cervi* had been published, so that the indifference of those involved in the transplantation cannot be excused.

There have been multiple translocations of rabies virus with wild animals. The best known of these was introduction of rabies with wild-caught raccoons purchased from animal dealers in the southeastern USA that were transported and released by hunting clubs in more northern areas. The success of the release programs was extremely poor. In one survey, only 3.1% of the released animals were recovered by hunters, at a cost of $640/animal. Most animals died shortly after release (from a disease-management perspective, failure of the transplants was likely a desirable result, but the unnecessary death of the animals cannot be condoned). Many disease agents were documented in the translocated raccoons, including protozoa (Schaffer et al. 1978), helminths (Schaffer et al. 1981), parvovirus (Nettles et al. 1980) and rabies virus (Nettles et al. 1979). Many of these disease agents were not present in indigenous raccoons at the proposed release sites. The introduced rabies virus resulted in a major epizootic involving many states and southern Canada. Two other examples of translocated rabies are the establishment of rabies on several Caribbean islands with introduced Indian mongooses and movement of dog-strain rabies in coyotes moved from Texas to Alabama and Florida for hunting preserves (Rupprecht et al. 2001).

The experience with *E. cervi*, described earlier, demonstrates the value of a strict quarantine period, during which the animals are monitored closely, after they reach their destination but before they are released. The value of such a quarantine period was also evident in New Zealand where the winter tick *Dermacentor albipictus* was detected on two occasions on elk imported from Canada, while they were being held in quarantine (Heath 1986). **For quarantine to be effective, animals must be held for at least as long as the maximum known incubation period for any of the diseases that they might be carrying**. Thus, if the maximum recorded prepatent period (the period from infection until eggs or larvae are passed) of a parasite is 100 days, animals suspected to carry the parasite must be held in quarantine, and examined regularly, for at least 100 days. Calvete et al. (2005) made a number of suggestions for improving quarantine, from the perspective of increasing the survival among quarantined animals.

It is appropriate to prohibit or prevent the translocation of any wild animal until the risks of disease transfer have been assessed fully. Corn and Nettles (2001), Leighton (2002), and Armstrong et al. (2003) provide detailed information on doing a risk assessment. If translocation is still considered to be desirable after such an assessment, it should proceed only when suitable diagnostic and quarantine measures are available and can be applied. This is not an area where policy can be flexible if the aim is to prevent disease introduction. Rigid application of this basic principle has been the backbone of control measures to prevent the international spread of livestock diseases and it has proven to be remarkably efficient for that purpose.

15.1.2 Introduction of animals susceptible to indigenous disease agents

Serious disease may occur among exotic animals introduced into an area where a disease agent is indigenous. Examples in which this has happened are shown in Table 15.2. *Parelaphostrongylus tenuis*, a nematode closely related to *E. cervi*, will be discussed as an example. The normal host of *P. tenuis* is the

Table 15.2 Examples in which an indigenous disease in wild animals at the release site has had a negative effect on translocated wild animals

Disease or agent	Introduced species	Source of infection
Aspergillosis	Penguins	Temperate zone birds[1]
Avian malaria	Penguins	Temperate zone birds[2]
Parelaphostrongylus tenuis	Reindeer/caribou	White-tailed deer [3]
	Black-tailed deer	White-tailed deer [4]
Elaphostrongylus cervi	White-tailed deer	Red deer [5]
Schistosomiasis	Atlantic brant	Indigenous waterfowl[6]
Eastern equine encephalitis	Ring-necked pheasant	Indigenous birds[7]
	Whooping crane	Indigenous birds [8]
	African penguin	Indigenous birds [9]

[1]Kageruka (1967), [2] Griner and Sheridan (1967), [3]Anderson and Prestwood (1981), [4]Nettles et al. (1977), [5]Kotrly and Ehrardova- Kotrla (1971), [6]Wojcinski et al. (1987), [7]Beaudette et al. (1952), [8]Dein et al. (1986), [9]Tuttle et al. (2005)

white-tailed deer, in which the worm causes little or no clinical disease. However, the parasite produces severe and often fatal neurologic disease in a variety of other cervids, as well as in some domestic ruminants. Some attempts to establish populations of other cervids, notably caribou and reindeer, in areas where the parasite is enzootic have failed because the introduced animals died of neurologic disease caused by the worm (Anderson and Prestwood 1981). The llama also is very susceptible to the parasite and parasite-induced neurologic disease is common in llamas in areas where the parasite occurs in deer (Baumgartner et al. 1985).

Changes in habitat in eastern North America that occurred with settlement allowed expansion of the range of both the white-tailed deer and of the parasite with serious consequences for other cervids in these areas (Anderson and Prestwood 1981). Caribou were particularly affected. In this situation, the parasite moved and affected indigenous animals. This parasite must be considered seriously in any program involving the transplantation of cervids in North America, because of: (i) the risk of transplanting the parasite to areas where it currently does not occur, and (ii) its probable effect on exotic animals introduced into areas where the parasite is enzootic. *Parelaphostrongylus tenuis* is enzootic in white-tailed deer in Maine, so that the transplantation of caribou from Newfoundland, described earlier, is a good example of doubly bad practice. The introduced caribou were likely to succumb to *P. tenuis*, perhaps before the exotic nematode, *E. rangiferi*, which might be introduced with the caribou, became a problem for native cervids.

Occurrence of an indigenous disease affecting introduced animals hampered efforts to propagate whooping cranes in captivity. The virus of eastern equine encephalitis is transmitted by mosquitoes and is enzootic in many areas of eastern North America, where it produces transient, sub-clinical, infection in native birds. However, the virus produces fatal disease in a variety of introduced species, most notably whooping cranes and ring-necked pheasants. An outbreak of encephalitis in 1984 killed whooping cranes in a captive propagation program at the Patuxent Wildlife Research Center in Maryland. The discovery that the disease is enzootic in the area was considered a serious risk to the propagation program for this endangered species and led to development of a vaccine (Clark et al. 1987). It will never be possible to predict all such effects in advance, but the presence of diseases in native fauna of the recipient area always should be considered in any plan to translocate wild animals.

15.1.3 Introduction of a species that alters the ecology of an indigenous disease

This aspect of translocation has received relatively little attention but addition of a new species that acts as a host for an existing disease agent can have major effects on disease. The most dramatic example of this has been the introduction of brushtail possums to New Zealand and the subsequent impact on bovine tuberculosis. Bovine tuberculosis has been controlled effectively or eliminated in many parts of the world by measures directed at domestic cattle; primarily through test and slaughter. However, tuberculosis has proven impossible to control in some countries, because of the existence of an alternate wild host for the disease. Tuberculosis occurred in cattle in New Zealand prior to the introduction of the brushtail possum from Australia as a potential fur-bearing animal. Possums became a serious environmental pest, because of damage to native forests and because it became the primary reservoir for *M. bovis*. The population of possums is estimated to be about 70 million animals. Control measures that have been effective in other parts of the world for eliminating tuberculosis from cattle have failed in New Zealand and continuing transmission of *M. bovis* from possums to cattle is the single greatest barrier to eliminating the disease in domestic livestock (O'Neil and Pharo 1995).

A less dramatic example of the impact of an introduced species occurred on the arctic archipelago of Svalbard. Although arctic foxes were present, including winter migrants infected by the adult stage of the tapeworm *Echinococcus multilocularis*, this zoonotic agent did not become established, because of lack of a suitable rodent intermediate host. However, when sibling voles were introduced, perhaps in forage for livestock, all of the required elements were present and the parasite became established. "*This is an interesting example of how an accidental introduction of an intermediate host can contribute to the establishment of a dangerous parasite*" (Hentonnen et al. 2001).

Introduced animals may alter an established disease in other ways. Introduction of a less competent host species may reduce the prevalence of certain diseases in the primary host through a "*dilution effect*" (Ostfeld and Keesing 2000). This only pertains to diseases that require an intermediate host. An example that appears to fit this hypothesis has been reported by Telfer et al. (2005). Native wood mice in Ireland are infected with two species of *Bartonella* that are transmitted by fleas. The introduced bank vole is infested by the same flea species as the wood mouse but has not been found to be infected with *Bartonella* in Ireland. In areas where bank voles have become established, the prevalence of *Bartonella* in wood mice is lower than in areas without bank voles, and the prevalence in wood mice is inversely proportional to the density of bank voles.

15.1.4 General comments about translocation

It is impossible to move or transfer live animals without also transferring potential disease agents. Fortunately, many introduced diseases fail to become established in the new environment and others, that have become established, may be of little recognizable consequence at this time. However, good fortune is no substitute for good management and one should always be conscious that imported diseases have had disastrous consequences in the past. Probably the most dramatic documented example was the introduction of rinderpest into Africa with Zebu cattle from India. This resulted in a devastating epizootic among wild ungulates that swept the length of the African continent. "*It was estimated, for example, that 90 percent of the buffalo in Kenya died, and that the bongo were almost exterminated*" (Henderson 1982). An important indirect result of rinderpest introduction was that the reduction in another disease, trypanosomiasis, that occurred in association with the absence of game animals lead to a policy of systematic "*game destruction*" in southern Africa for the control of that disease in livestock (Henderson 1982).

It is nearly impossible to totally prevent inadvertent introduction of vectors or agents that may travel as passengers in old tires, on peoples' shoes, or in or on other fomites, except by the stringent type of controls now in effect to prevent introduction of human and domestic animal diseases. Sanitation measures, such as inspection of the belongings of immigrants and control of garbage from ships and aircraft, also protect wild animals, although that is not their intended purpose. It is possible; however, to reduce or prevent the introduction of new diseases that may travel with transplanted wild animals. The simplest, and the best way to prevent introduction of diseases is to disallow importation of live animals from any area where an exotic disease might, or is known to, occur. However, this requires knowledge of the occurrence of specific diseases in individual species and of the geographic distribution of diseases. This information often is not available for wild species.

If no information is available on the occurrence of disease in the donor population, there are a number of choices. The first and most obvious option under such circumstances is to decide that the risk of introducing a disease outweighs the potential benefits and forego transplantation. Another option would be to import only reproductive products (fertilized ova and/or semen) rather than live animals. This method circumvents many of the problems associated with certain types of disease and has been used extensively for transfer of genetic material from domestic livestock, as well as from deer for game farming. However, it is likely not appropriate for many situations in wild animals. A third option would be to screen the donor population carefully to ensure that the individual animals chosen for translocation are free of specific diseases. However, as discussed earlier, **one can never be certain that a population is free of disease without testing every individual using a test that is 100% reliable**. In most circumstances, the only available option, where translocation is considered to be necessary and unavoidable, is to sample each individual animal that is a candidate for translocation. For this to be effective, a reliable and highly sensitive method for detecting infected individuals must be available. This often is not the case in wild animals and the efficacy of most screening techniques is unknown. For some diseases, such as rabies, there is no suitable method for testing live animals.

In many cases it is logistically impossible to test all of the individual animals that might be moved and the best that can be done is to examine a sample. It is critical that the disease specialist explain, in advance, that **negative results on a sample do not guarantee freedom of disease**. All that can be reported is the maximum prevalence of disease that can be detected using the sample examined. For example, assume that 350 wild birds are to be translocated but it is only possible to obtain samples from 30 birds (8.6%). If none of these 30 birds tests positive, the minimum prevalence of disease that could be detected at the 95% confidence interval with this sample size is 10%. Stated in another way, the disease specialist could report that based on the sample it is possible to be 95% confident that the prevalence in the entire group is not greater than 10% (see Chap. 8 for discussion of the methodology). In addition, this prevalence is the apparent prevalence rather than the true prevalence, unless the specificity and sensitivity of the tests are known for the species. Thus, the test is not an assurance of absence of disease but it can be helpful in estimating the degree of risk inherent in the translocation.

In addition to problems in detecting known diseases, one always must be cognizant that disease agents that are currently unrecognized also may be translocated. "*It is relatively easy to legislate for known disease, especially where there is a thorough knowledge of its epizootiology, but impossible to do so for unknown disease or those where knowledge of the epizootiology is lacking*" (Biggs 1985).

No movement of animals should proceed until these questions have been answered and suitable methods have been established to prevent the occurrence of disease as a result of the translocation. Most biologists would not proceed with translocation of animals without understanding how the animals would affect and be affected by the flora and fauna at the release site.

However, translocations are often made without consideration of the microfloral and microfaunal organisms that may cause disease.

15.2 Modifying human activities by regulation and legislation

Any attempt to control disease in wild animals inevitably involves people in some way. In much of the world, most wild animals belong to the people and are managed in the public interest, so that an agency must have support from the public to succeed in any management program. People must know and understand what is being done, how it will be done, and why it is being done, before they will support the action. There are two basic ways of modifying human activities and behavior, either through some form of compulsion, such as legislation or regulation, or by education and persuasion. Although the two methods may seem distinct, it is important to remember that regulations are created by elected officials who respond to public opinion and who need to be educated about the need for regulations, and that unpopular regulations will be ignored or flaunted. Thus, it is important that the public is informed and supportive of the action. A large segment of the general public is interested in wild animals and "*many of these people will react if they think wildlife is being mistreated or if they think some agency is planning to do something detrimental to the resource*" (Shay 1980). Public opinion can be very much of a double-edged sword in regard to management of wildlife diseases. Public support has been used effectively to promote legislation and regulations to reduce or control a number of serious disease problems caused by environmental pollutants, such as mercury and certain pesticides. However, there may be marked negative public reaction to management that requires population control or severe habitat manipulation through techniques such as prescribed burning or clearing. Such instances require extensive advance education of the public so that they understand how and why the action will be taken.

The severe controversy that erupted when an 'emergency' population reduction of deer was attempted in Florida serves as a case-study of problems that can occur when there is no time for such education. Torrential rains during the summer of 1982 confined the large deer herd to small islands of habitat in the Everglades. "*Based on projected water levels and past experience with the deer herd under similar circumstances, Commission biologists predicted extensive deer mortality unless the herd could be quickly reduced to a level commensurate with the habitat conditions*" (Florida Game and Fresh Water Fish Commission 1983). Emergency hunts were authorized to reduce the herd from 5,550 to 2,300, a level considered appropriate for the resources available. There was immediate opposition from groups who wished to stop the hunt and use capture/relocation or feeding of deer as alternative remedies, although these had proven unsuccessful during similar circumstances in previous years. After extensive legal delays, opponents were allowed to attempt rescue of deer on a portion of the area while a hunt proceeded in the remainder of the area. During hearings, potential rescuers had testified that 2,000 deer could be removed in 8 days but the rescue was halted after 1 ½ days when only 18 deer had been captured. The rescuers admitted that it was impossible to remove enough deer to have an impact on the population. About 67% of deer present in the area where rescue was attempted died, while about 23% of deer in the hunted area died of natural causes or were killed by hunters. It was concluded that: "*wildlife management practice, no matter how well-founded on biology and management principles, can become highly controversial if it is not understood and accepted by the media and the general public*" (Florida Game and Freshwater Fish Commission 1983).

Public acceptance and approval usually is high for short-term remedial actions, such as feeding starving deer or rehabilitation of injured or oiled birds. However, it can be argued that this type of emergency disease response may be deleterious to sound management, because it diverts attention and funding away from the more basic factors, such as too many deer in too little habitat, that caused the problem. Promoting actions such as emergency feeding also may create a perception that the problem is under control and that the short-term emergency response is the appropriate way to deal with the situation. Some types of emergency treatment provide an opportunity to educate the public about the cause and nature of disease. This can be used to make the public more receptive to management designed to prevent disease recurrence. For example, sportsmen who participated in an emergency winter feeding program for deer in Saskatchewan became aware that the root cause was insufficient winter habitat. They then became strong proponents for habitat improvement. Similarly, while the number of birds saved and returned to the wild during a cleanup operation after an oil spill may be insignificant biologically, the publicity and surveillance that results may have some deterrent effect on potential polluters. Public concern generated by the exercise also may be a powerful tool to convince legislators of the need for more stringent preventive regulations.

Legislation has been particularly effective for the control of environmental toxicants and for preventing importation of exotic diseases with introduced domestic animals, as was discussed earlier. Very few regulations have been drafted specifically to prevent introduction of diseases of wildlife. A few examples are available of regulations related directly to wildlife diseases. These include a longstanding policy of not allowing importation of hares into Denmark to prevent introduction of tularemia (Bendtsen et al. 1956), decisions not to introduce and release Arabian oryx with bluetongue antibodies into Oman, or to release captive orangutans exposed to human tuberculosis in Indonesia (Jones 1982). The continuing movement of wild animals, often for trivial purposes, emphasizes the need for more such regulations.

Legislation may also be used to reduce the risk of exposure of the public to certain zoonotic diseases of wild animals. A law was introduced in Oklahoma in 1977 that made it illegal to remove the scent glands or to vaccinate skunks for the purpose of domestication, after three pet skunks exposed 42 people to rabies. Legislation was enacted in 1995 prohibiting movement of foxes, coyotes, and raccoons within or out of Texas as part of a program to control rabies (Sidwa et al. 2005).

15.3 Modifying human activities through education

Legislation must be accompanied by appropriate public education to ensure that the reason for the control is understood and that the regulations will be obeyed. Almost any procedure to manage disease in wild animals will benefit if the public understands why and how the program will be done. In many instances public education and acceptance may be critical to the success of a program and, in other situations, modification of human activity may be the most efficient method for managing a disease. Management of hydatid disease (infection with the larval form of the tapeworm *Echinococcus granulosus*) in various parts of the world provides an example of the value of education in a disease control program. This parasite has a two host lifecycle, with the adult tapeworm occurring in the intestine of a carnivore and the larval form (hydatid) in tissues of a herbivore. Humans may become infected with the larval stage, which forms large cysts in tissue, including in lung, brain and liver. The disease is a serious zoonosis in many parts of the world. In most areas, the parasite cycles between domestic livestock, particularly sheep, and dogs. Control consists largely of measures to prevent dogs from gaining access to infected sheep tissues and hygiene to block transmission from dog to man. During the 19th century, the disease was enzootic in sheep and dogs in Iceland and approximately one-sixth of the human population was infected (Schantz and Schwabe 1969). The first measure taken for control of the disease was distribution of a pamphlet describing the nature, cause and means of prevention of the parasite to every family in 1864. The same information was taught at all levels in schools, so that every individual in the country became fully familiar with the disease. This resulted in voluntary control measures that were so effective that the prevalence of infection in humans fell from 15–22% to 3% by 1890, when compulsory control was introduced. The parasite was eradicated from Iceland by the early 1950s.

In contrast, early attempts to control hydatid disease in New Zealand involved only sporadic educational efforts and were based on legislation that made it illegal to feed raw sheep tissue to dogs. This was regulation with only limited explanation of the reasons for the regulation. These measures had little effect on the prevalence of the disease, probably as a result of failure of people to comply with the regulations. A more intensive educational campaign, that involved teaching about the parasite in schools and stressing zoonotic aspects to farm wives led to voluntary farmer-initiated hydatid eradication campaigns. These were coordinated by the government and resulted in a very marked reduction in prevalence of the disease. New Zealand was able to declare provisional freedom from hydatid disease after a campaign the lasted >50 years (Pharo 2002).

In reviewing the management of hydatid disease, Schantz and Schwabe (1969) stated that "*control is largely a question of people's determination. In effect, the local population must be educated to the dangers of the disease and motivated to do something about it*". This statement could be applied to almost any disease-management program. It is important to remember that technical knowledge is usually far ahead of public knowledge and acceptance.

Once a disease-management program has been accepted and begun, continual feedback of information is necessary to maintain enthusiasm for the program. This feedback must be to those involved directly in the program, to the politicians responsible for funding the work, and to the public. Information on progress of the project becomes particularly important in the latter stages of a successful campaign, when the disease has nearly been controlled and it is no longer highly visible. Under these circumstances, the management program may no longer appear to be a priority for funding, and general enthusiasm and effort may wane, allowing recrudescence of a partially vanquished disease. This appears to have occurred during a program to control rabies in skunks in Alberta. A population reduction campaign had reduced the population density of skunks and the prevalence of rabies in a focal area but had not eradicated the disease. Attention was then shifted to a new problem area, with a concomitant decrease in effort in the original focus. Both the skunk population and the prevalence of disease rebounded in the original area.

Public education can be used in other ways to reduce the **effect** of a disease, without having to control or reduce its prevalence in wild species. This is particularly appropriate for many zoonotic diseases, such as rabies, trichinosis, giardiasis, plague, and some arthropod-borne viral infections that are enzootic in wild animals. These disease agents present little or no problem when confined to animals but become a problem when people are exposed. Education in such situations is usually directed toward acquainting people with the occurrence and nature of the disease in wild animals, and to suggesting methods for avoiding potentially hazardous situations and preventing disease transmission. In the case of rabies, such an educational program might include advising the general public to: (i) avoid wild animals that seem tame, friendly or that are otherwise acting abnormally, (ii) report animals of this type to appropriate authorities, (iii) consult a physician immediately if they think they have been exposed to such an animal, (iv) encourage regular vaccination of domestic pets, and (v) discourage keeping of wild animals, particularly skunks and raccoons, as pets. In the case of arthropod-borne diseases, education is usually directed at methods to reduce exposure by encouraging use of insect repellents, the wearing of appropriate clothing, protecting susceptible infants from insects, and treatment of pets to prevent them introducing rodent fleas and ticks into the home.

Special programs may be needed to reach and educate particular groups within the population that are at greater risk than the general public. For example, a special education program might be used to advise bear hunters of the occurrence of *Trichinella spiralis* in bear meat and of appropriate methods for caring for the meat. An information package of this type could be distributed directly with the license for hunting bears. Trappers might be advised of special precautions, such as not skinning animals found dead and wearing rubber gloves while handling animals, to reduce the risk of contracting tularemia and rabies. Conservation officers and pest control officials, who may have to deal with rabid animals, should receive intensive instruction on how to avoid exposure to the disease and should be vaccinated prophylactically. Campers and hikers using areas where zoonotic diseases, such as plague and giardiasis, occur might be provided with specific information to reduce the likelihood of exposure. The objective of such education is to reduce the risk of exposure without creating hysteria or aversion to outdoor activities.

The same basic educational methods can be used to reduce transmission of disease from wild to domestic animals. For example, a program to educate farmers about the risk of feeding hare viscera (potentially infected with *Brucella suis* biotype 2) to swine, was proposed as the best method of controlling porcine brucellosis in Denmark (Christiansen and Thomsen 1956). Promotion of isolation of domestic poultry from contact with wild birds has been recommended for many years as part of the program for control of influenza in poultry (Wood et al. 1985) and continues as part of the current programs to deal with H5N1 influenza. In these instances, the education campaign is intended to reduce the risk of transmission to livestock without having to reduce the prevalence of disease in wild species.

15.4 Integrating disease management in planning

An important aspect of disease management is the use of features of the ecology of both the disease agent and the wild animals in planning human activities, in order to reduce disease risk. The features that often are of greatest value in this regard are the spatial and temporal distribution of the agent and of the hosts. Many diseases are distinctly seasonal and have a high degree of nidality. As an example, avian botulism is strongly associated with hot weather, so that management procedures, such as alterations of water level, which might provoke an outbreak, should be avoided in the high-risk summer period. One would not recommend a rough-fish poisoning program on a botulism-prone marsh during warm weather, as the dead fish could provide abundant substrate for growth and toxin production by *C. botulinum*. Similarly, public use of a campground might be scheduled to avoid the seasonal occurrence of large numbers of ticks in areas where tick-transmitted zoonoses, such as Lyme disease, are a problem.

Disease-management activities, such as closure of campgrounds or public information campaigns, can be timed more precisely to coincide with periods of high risk if the occurrence of the disease is monitored in wild or sentinel animals. The latter technique, employing groups of sentinel chickens, has been used for many years to provide early warning of an increase in the amount of certain arthropod-borne viral diseases present in an area (e.g., Nichols and Bigler 1967; Morgante et al. 1969). When increased viral activity is detected by increased infection rate among sentinel birds, appropriate preventive measures, such as a public advisory, can be put in place. Similarly, Valtonen et al. (1980) suggested that the probability of epizootics of tularemia in Finland could be predicted by monitoring fluctuations in the number of wild rodents.

Knowledge of the biology of wild species that may be affected also can be used in planning human activities that might result in disease among wild animals. For example, Yom-Tov (1980) proposed a method of timing bird control operations in irrigated fields that was both efficacious in terms of reducing pest species, and had a minimal probability of causing secondary poisoning of raptors. The simple principles outlined by Yom-Tov should be applicable to many other uses of pesticides in agriculture. Unfortunately, most applications of pesticide are timed with the pest in mind and with little or no consideration of the phenology of events in other species that may be affected adversely.

If a zoonotic disease has a known nidality, it may be possible to direct human activities away from such sites. McLean et al. (1981) characterized the landscape epidemiology of Colorado tick fever (CTF) and found that one nidus containing "*the most rodents, ticks, and CTF virus*" was located within a large public campground. They concluded that there was "*a high risk of CTF exposure to campers, especially in May and June*". This information could be used to direct campers away from such areas during periods of high risk and also in choosing sites for future campgrounds. Human activities often unintentionally create a nidus for disease. Human artifacts, such as rock walls, refuse heaps, and streamside rip-rap, created habitat for rock squirrels in towns of the southwestern U.S.A. This increased both the population density of squirrels and the risk of human plague (Barnes 1978). In this case, a program to reduce the risk of plague might require an extensive public education program to explain the relationship among habitat, squirrel density, and the disease. The squirrels were considered an attractive part of the fauna and it was thought that any direct attempt to reduce their numbers would be resisted (Barnes 1978).

15.5 Disease transmitted from humans to wildlife

A few diseases are transmitted directly from humans to wild animals in nature. Examples of this type of situation include *Mycobacterium tuberculosis* infection in suricates and banded mongoose in South Africa, likely as a result of exposure to infectious human sputum (Alexander et al. 2002) and cryptosporidiosis in non-human primates in Sri Lanka (Ekanayake et al. 2006). In these situations, the occurrence of the disease in the wild animals usually is a minor problem compared to occurrence of the disease in humans, and it is probable that management directed to reduce infection in humans also will be beneficial for wild animals. Occasionally it may be possible to control or prevent disease transfer directly. Ferrer and Hiraldo (1995) found that the occurrence of *Staphylococcus aureus* infection in nestling eagles could be reduced greatly by requiring that handlers banding the birds wear disposable gloves.

15.6 Summary

- Management of disease in wild animals usually involves a high degree of people management.
- The public must understand the reason for the management and how it will be done if they are to support it. Public education should be a part of any major program.
- Management programs should include continual feed-back to all involved, and to the public, to maintain enthusiasm for the project. This is particularly important in the later stages of successful campaigns, when disease management may cease to be a priority and the disease may be allowed to re-emerge.
- Translocation of wild animals is a management activity that involves a high degree of risk from disease.
- Translocated animals may introduce exotic diseases that will adversely affect indigenous species, or translocated animals may be affected adversely by disease agents present in indigenous animals.
- Introduced animals may alter the ecology of an existing disease.
- Animals should not be translocated without an understanding of the potential disease agents present at both the site of origin and the release site. Every translocation should be subject to a formal risk assessment.
- It is impossible to separate living animals from their microflora and microfauna.
- Treatment with drugs prior to translocation reduces but does not eliminate the risk of transferring disease agents.
- Animals that are translocated should always be held in strict quarantine with regular monitoring after they have been moved but before they are released.
- Knowledge of the spatial and temporal features of wild populations and their diseases can be used in planning human activities to reduce risks to people from zoonoses, and risks to the animals from activities such as pesticide application and human infections.