RABIES AND RABIES CONTROL IN WILDLIFE: APPLICATION TO NATIONAL PARK SYSTEM AREAS

Purpose

The purpose of this document is to:

1) Review current knowledge on the origins, epidemiology, and management of terrestrial rabies in the United States
2) Answer basic questions that relate to the potential management of terrestrial rabies, including oral rabies vaccination programs, in NPS areas
3) Focus on technical and scientific aspects of these issues rather than the application of NPS policy

Introduction

Rabies is a viral disease of the central nervous system (brain and spinal cord) of warm-blooded animals. Rabies can be transmitted in nature from infected animals to humans so the disease is classified as zoonotic. The disease is almost always fatal in animals or in humans that do not receive post-exposure prophylactic (PEP) treatment. Inoculation of virus-laden saliva from the bite of an infected animal is the most important means of rabies transmission; however, the disease can also be transmitted by exposure to infective body tissues. Rabies has three distinct clinical stages: prodromal, furious, and paralytic (or "dumb"). Onset of clinical disease usually follows exposure by several weeks, although periods of <10 days to several months are well documented. Rabies can be transmitted 3-10 days prior to and during the clinical stages of the disease. Animals usually die a few days after the onset of rabies. Clinical descriptions of the disease may be misleading as considerable variation exists among species and infected individuals of the same population. Infected animals may not display all stages or may vacillate between clinical stages; however, abnormal behavior is the most consistent clinical sign of rabies in any animal (Reviewed by Thorne and McLean 1982, Rupprecht et al. 2001).

Epidemiology

Species that maintain the rabies virus in nature are known as reservoirs. Rabies reservoirs are generally grouped into terrestrial (i.e., land-dwelling) species and bat species. Rabies can occur sporadically in individuals or can exist in an enzootic or epizootic state in animal populations. In an enzootic state rabies is indigenous to a reservoir species in a locality and occurs with a relatively stable incidence rate. An epizootic occurs when the incidence of disease increases markedly in the reservoir species. Rabies that is transmitted sporadically from reservoir to non-reservoir species is said to "spillover".

Technological advances in protein chemistry have enabled researchers to unravel the genomic organization of the rabies virus. Taxonomically, the rabies virus is found in the genus Lyssavirus (called "lyssa" meaning madness), one of three genera from the family Rhabdoviridae. The Lyssarvirus genus contains the rabies virus and a group of related Old World viral species. Different variants, or quasi species, of the rabies virus specific to reservoir

species have been identified throughout the world. For reasons that are not fully understood, these rabies virus variants occur in a given reservoir species and generally only occasionally spillover into other species. When spillover does occur, the variants do not commonly become established in the new species. Over 140 rabies variants have been identified in insectivorous bats. Although bats have been implicated as the reservoir for rabies in terrestrial mammals, detection of isolates of rabies variants have shown distinct differences between the majority of isolates associated with bats and those associated with the common terrestrial reservoir species. In North America, several virus variants have been identified with specific terrestrial reservoir species in known enzootic locations (Fig. 1). These reservoir species are: raccoon (*Procyon lotor),* striped skunk (*Mephitis mephitis*), coyote (*Canis latrans*; infected with the dog variant*)*, gray fox (*Urocyon cinereoargenteus),* and Arctic fox (*Alopex lagopus)* and red fox (*Vulpes vulpes*).

Native or Exotic? The Origin of the Rabies Virus in North America

History

Circumstantial evidence suggests that the rabies virus originated in Africa, although records of rabies in Africa do not occur until the 20th century (Rupprecht et al. 2001). Democritus is thought to be the first person to record a description of canine rabies in the 5th century B.C. Single incidents of rabies were documented throughout the Middle East and Europe in the following 1500 years. The first large outbreak of rabies was documented in wolves in 1271. By 1500, large outbreaks of rabies began occurring quite commonly in dogs in Europe (Steele and Fernandez 1991). In the Americas, a priest in what is now California first reported rabies in 1703 (Steele and Fernandez 1991). Currently, rabies or a clinical entity indistinguishable from classic rabies occurs on all inhabited continents (Rupprecht et al. 2001). In the United States, vaccination programs for companion animals initiated in the 1940's have significantly reduced the occurrence of rabies in dogs and cats. However, rabies in wildlife is a multi-species complex related in part to changes in human demography, animal translocation, environmental alteration, and viral adaptations over time (Rupprecht et al. 2001).

Origin of rabies in North America

The origins of rabies virus in North America remain unclear but it is likely that the present disease is a mosaic of rabies of the Old and New Worlds (Rupprecht et al. 2001). Old World carnivores likely carried rabies across the ancient Bering land bridge to the northern latitudes of North America (Winkler 1975). This natural introduction of rabies has likely persisted as arctic fox rabies in the circumpolar areas (Crandell 1991). Pre-European folklore from the Canadian Pacific Northwest and Alaska tell of rabies-like diseases being transmitted to dogs and Eskimos from foxes. Similar reports are lacking from what are now the contiguous 48 states of the United States. In fact, notable reports from the 1500's and 1600's mentioned the absence of rabies, at least in dogs, in Latin America (Baer et al. 1996). Strong suggestions of the occurrence of rabies in North America did not occur until approximately 200 years after settlement by Europeans. The first report of a rabies outbreak in North America was in Mexico in the early 1700's. In the 1760's rabies was alarmingly common throughout the American colonies, being documented in Boston and other major cities of the time. The first documented epizootic of rabies in the American colonies occurred in dogs and fox from 1768 to 1771 (Steele and Fernandez 1991). Given the available history of rabies in North America coupled with the widespread occurrence

of rabies in Europe from 1500-1900, it appears very likely that the early European settlers introduced new rabies virus variants into North America. Further, the unintentional translocation of infected dogs by European colonists had a major influence on the spread of rabies in the Western Hemisphere (Smith and Seidel 1993). This may have been exacerbated by the translocation of fox for hunting as well (Rupprecht et al. 2001). The origin of rabies variants in current reservoir species in North America will be reviewed individually.

Red Fox and Arctic Fox – Within the fox variant a few virus isolates are significantly different while many others are identical between the two fox species (Rupprecht et al. 1991). Regardless, the variant is distinct from the European red fox variant. Significant information exists to suggest that introduction of this variant may have been by way of the Bering land bridge 30,000 to 75,000 years ago (Winkler 1975). The geographic boundary of the fox variant has been Alaska and northwest Canada; however, fox rabies spread into southern Quebec and Ontario in the 1950's and later to northern New England (Crandell 1991, MacInnes et al. 2001).

Gray fox – This variant is similar to the dog-coyote rabies virus variant found in southern Texas. The variant is found in two isolated populations of gray fox, one in southeastern Arizona and the other in southwestern Texas (Smith and Baer 1988).

Coyote – Rabies in coyotes was detected in southern Texas within the last two decades. The variant is indistinguishable from, and likely originated from, a dog variant from Mexico. At this time it is not known whether the variant will become enzootic or remain an expression of an epizootic event in border dogs (Smith 1989, Smith 1996). Translocation of Texas coyotes also is thought to be responsible for the occurrence of sporadic cases of rabies in dogs in Alabama and Florida (CDC 1995).

Raccoon – The earliest identification of rabies in raccoons was in the late 1930's in California. For the next twenty years rabies in raccoons was reported sporadically across the United States. These cases are thought to be spillover from local reservoir species (i.e., not a raccoon variant). In the late 1940's the first rabid raccoon was identified in Florida, followed by a raccoon rabies epizootic in the early 1950's (Jenkins and Winkler 1991). A unique rabies variant of uncertain origin was responsible for this outbreak (i.e., a raccoon variant). Translocation of infected raccoons from enzootic areas in Florida to the mid-Atlantic region in the late 1970's (Winkler and Jenkins 1991) led to a large raccoon rabies epizootic that is still active. A new outbreak reported from eastern Ohio in 1997 threatens to expand to include the entire upper Midwest (Rupprecht et al. 2001).

Skunk – Rabies in skunks was first documented in 1826 in California. Although the origin of the skunk variant is unknown, it may have been introduced to a California port. Other research suggests that rabies may have resulted from the westward expansion by immigrants and their pets from enzootic areas in the east (Parker 1975). Skunk rabies became a common wildlife disease in the Midwest and west by the 1860's. Currently, three major skunk rabies variants in identifiable enzootic locations can be distinguished: north-central plains, lower mid-western states, and California (Rupprecht et al. 2001). Reports of rabies in skunks from other geographic areas are apparently related to spillover conditions from reservoirs of other rabies variants (e.g., raccoon rabies variant in mid-

Atlantic states). Although all species of North American skunks are susceptible to rabies, the striped skunk is the most common species in areas of enzootic skunk rabies. Therefore, skunk rabies refers to the disease in striped skunks (Charlton et al. 1991).

Bats – The identification of rabies in nonhematophagous bats (i.e., insectivorous or fruit eating bats) was documented in Florida in 1953, approximately 30 years after the first report in the western hemisphere (Brazil). Today, rabies has been identified in 30 of the 39 bat species in the 48 states of the contiguous United States. Unlike the disease in terrestrial species where distinct boundaries of distribution can be mapped, the migrational and highly mobile nature of bats defies identifying discrete boundaries (Smith 1996), although specific bat rabies variants can be traced along migrational routes of most bat species (Rupprecht et al. 2001). Management strategies for bat rabies remain limited because of their mobility and highly variable geographic boundaries. Management is aimed at public education and habitat modification (e.g., excluding bats from human structures; Smith 1996). Because issues surrounding bat rabies and its management differ significantly from terrestrial rabies they will not be discussed here.

Management

General

The overall goal of rabies management is generally to prevent the disease from infecting humans and domestic animals and to reduce the economic and personal costs associated with a rabies outbreak (Uhaa et al. 1992). However, management of rabies also may be used to protect native wildlife species from a non-native pathogen. Passive disease surveillance is an important component of any management program. Surveillance is a management approach that tracks rabies variants in populations providing spatial and temporal distribution information that describes differences in behavior and population dynamics and structure among the major wildlife reservoirs (Hanlon et al. 1999). When deemed appropriate, control programs applied to wildlife populations may be used to limit the spread of a rabies epizootic, prevent the introduction of the disease into a particular area, or eliminate the disease in enzootic or epidemic areas (Wandeler 1991). General approaches to controlling rabies in wildlife are: elimination of the reservoir species, elimination of rabies in the reservoir species, or protection of victim species from rabies infection via a reservoir (Rupprecht et al. 2001). These methods may be applied in combination.

Control

Elimination of a reservoir species is impractical, expensive, ecologically unacceptable (unless an introduced species), and ethically unacceptable (Rupprecht et al. 2001). Population reduction using an array of management techniques (e.g., hunting/bounties, trapping, poison bats, gassing, and trapping) has been used to reduce the population of reservoir species to below a threshold density and thereby restrict the opportunity for the virus to spread among the animal population (Debbie 1991). However, biologists and researchers conclude that the disadvantages of removing mature individuals from the population, the cost of trapping and euthanasia, and the negative perceptions by the public outweigh any advantages (Winkler and Jenkins 1991). Further, lowering the reservoir population below a "transmission threshold" (Wandeler et al. 1988, Anthony et al. 1990, Aubert 1994) may not result in slowing of the progression of rabies or

increase the possibility of it dying-out in the population (MacInnes 1988, Brown et al. 1990, Brietenmoser et al. 1995). In high density reservoir populations the incidence of rabies may be common with the individual cases geographically close to one another. In low-density host populations (i.e., high elevations, carrying capacity, or human control; Wandeler 1988) the individual cases are less numerous and farther away geographically. This potentially results in larger geographic advances with each infection. Therefore, progression of a rabies outbreak over a geographic area does not necessarily move faster in high-density host populations and population reduction efforts do not necessarily lead to a slowing in the rate of disease progression or the likelihood of disease elimination (Aubert 1994, Breitenmoser et al. 1995).

Other management options attempt to protect victim species from reservoir species. Human public health programs and veterinary programs for domestic animals are integral to this approach. Further, management actions that reduce or discourage opportunities for wildlife to interact or contact humans, pets, or their property can be implemented. Examples include garbage management, modification or elimination of habitat, and the storage or removal of human and pet foods (Hanlon et al. 1999).

In contrast to wildlife population control programs, prevention and vaccination programs have been shown to be economically beneficial (Uhaa et al. 1992). The first step with any rabies management program is to clearly identify the objectives. Once done, successful management programs will identify and execute a control method that affects mainly the target (i.e., reservoir) species, is cost-effective and publicly accepted, and maintains the treatment area in a rabies-free status over the long-term (Winkler and Jenkins 1991). However, Hanlon et al. (1999) states that the "Management of rabies in wildlife is complicated by the ecologic and biologic factors associated with wildlife reservoirs, the multiagency approach needed to manage an important public health problem originating in wildlife, the limitations of available control methods, and the broad range of public attitudes toward wildlife".

Two potential methods for rabies control involve vaccination of wildlife reservoir species. In trap-vaccinate-release (TVR) programs targeted reservoir species are live-trapped and manually injected with liquid vaccine (i.e., parenteral vaccination; Wandeler 1991, Hanlon et al. 1999, Rosatte et al. 1992). However, the efficacy of parenteral rabies vaccination in wildlife has not been established and no parenteral vaccine is licensed for use in wildlife in the United States. Conversely, an oral rabies vaccine is currently licensed for use in raccoons in the United States (Jenkins et al. 2001). Oral rabies vaccination (ORV) also may be a more economically and technically feasible alternative for use on a large scale. Although ORV is less invasive to individual animals than TVR, ORV may be more intrusive on the landscape. ORV utilizes baits attractive to targeted reservoir species that once taken (bitten) release an encapsulated, attenuated rabies virus vaccine into the mouth or pharyngeal tissues to elicit an immune response (Wandeler 1991, Hanlon et al. 1998). ORV has been successfully applied, or holds promise for successful application, to control rabies in raccoons, fox, and coyotes in North America; however, numerous questions should be considered prior to implementation of ORV programs. Basic questions about ORV will be addressed here.

Oral Rabies Vaccination (ORV)

Why is ORV used? ORV was developed to vaccinate free-ranging wild animals in geographically large enzootic areas, to control the development and spread of a rabies epizootic, or to establish a rabies-free buffer zone for slowing or halting the advancement of rabies into new areas. Although application of ORV is primarily used as a public health tool, vaccination can also protect native species from infection.

What is the oral rabies vaccine? Although numerous vaccines have been developed and tested since the 1880's, oral immunization was not possible until the discovery of a modified-live rabies virus strain that effectively immunized foxes when given in the mouth (Baer et al. 1971). More recently, recombinant vaccines have been shown to be a safe and efficacious alternative to modified-live vaccines (Rupprecht et al. 1995). The only oral rabies vaccine currently licensed for State and Federal rabies control programs in the United States is the vaccinia recombinant *Raboral V-RG* vaccine manufactured by Merial (Jenkins et al. 2001).

How is ORV delivered? Vaccine is delivered via baits. Baits can be made of many different materials (e.g., fishmeal, dogfood, meat, cheese, fermented egg products, cornmeal; Perry et al. 1989, Hable et al. 1992, Andelt and Woolley 1996, Rosatte et al. 1998). Scents are used with baits (e.g., species-specific scent lures or urines) to attract target species while attempting to be less attractive to not-target species (Hadidian et al. 1989, Perry et al. 1989, Linhart et al. 1994, Andelt and Woolley 1996, Rosatte et al. 1998). The baits can be distributed manually (while walking or from a boat or vehicle) in a random or uniform manner or by direct placement in preferred habitats (Anthony et al. 1990). Baits also may be broadcast by aircraft or by using bait-delivery devices (Andelt and Woolley 1996). Placement of baits in habitats preferred by targeted (rabies reservoir) species, either as a single approach or in combination with other distribution methods, greatly enhances bait uptake by all age classes thus increasing the proportion of the host population that is vaccinated (Trewhella et al. 1991, Nyberg et al. 1992, Vuillaume et al. 1998, Robbins et al. 1998).

Is ORV safe? Safety of baits ingested or contacted by target and non-target species has been tested in Europe and North America. Baits and vaccines have been found to be safe in >50 vertebrate species (Rupprecht et al. 2001) including non-human primates (Rupprecht et al. 1992) and immunocompromised animals (Hanlon et al. 1997). Safety is defined as absence of adverse reactions and disease (from rabies or the vaccine carrier virus) following exposure to vaccine as well as lack of evidence for vaccine-virus and wild-virus recombination. Exposure of non-target species to vaccine may result in an immune response although the resultant level of protection is unknown.

Threats of a public health risk from ORV remain unfounded (McGuill et al. 1998).
Human contact with the baits in the field has been extremely low, especially when information explaining the program has been made available to the public in advance of and during the baiting (Rosatte et al. 1990, McGuill et al. 1997, Robbins et al. 1998). Baits are commonly labeled to identify their purpose and provide contact information. Other outreach programs include the mailing of informational flyers to treatment-area residents, announcements through

the local media, presentations to local groups and schools, and posting warning information notices in treatment areas.

Is ORV effective? In areas with reoccurring rabies epizootics ORV has proven to be cost-effective, attractive and acceptable by the public (Mitchell et al. 1997, Robbins et al. 1998), and efficacious (Hadidian et al. 1989, Brouchier et al. 1996, Robbins et al. 1998, Roscoe et al. 1998, Hanlon et al. 1998). ORV also has been used to eradicate rabies from enzootic area such as eastern Ontario (MacInnes et al. 2001). Control of rabies has been achieved in programs where bait consumption by the target species has attained or exceeded 60% (Wandeler 1988, Anderson 1991, Rosatte et al. 1992, Roscoe et al. 1998, Linhart et al. 1994, Farry et al. 1998, Robbins et al. 1998), although projects with uptake rates above and below this threshold also have reported being successful (Perry et al. 1989, Fearneyhough 1996). Although these programs are successful at stopping or slowing the rate of rabies progression, it is apparent that they may not eradicate the disease in the population in all cases. However, rabies has been eliminated from red fox populations in France (Aubert et al. 1994, Muller 1997) and in eastern Ontario (MacInnes et al. 2001). In Ontario, a well-coordinated aggressive effort eliminated rabies from a 30,000 km^2 study area in 7 years. Fox rabies was absent from the area for 3 years after ending the ORV program but raccoon rabies was then introduced from adjacent areas in the United States (MacInnes et al. 2001). However, some other programs (e.g., Germany) have noted the persistence of rabies in treatment areas and have required continuation of oral vaccination efforts. Additional ORV applications were required to treat individuals immigrating into the area, boost immunity of the population previously treated, and treat that portion of the population added through recruitment (Hadidan et al. 1989, Mitchell et al. 1997). The ability to eliminate fox rabies appeared to be related to fox ecology not simply fox density (MacInnes et al. 2001); however, the influence of gaps in ORV application must also be considered (see below).

What strategies are used in applying ORV? In designing control programs strategies are refined to meet the conditions of the treatment area, nature of the rabies event, location in proximity to human populations, density and dynamics of the host population, and other factors. In large enzootic areas, ORV is used to immunize a significant portion of the population to lower the proportion of the population susceptible to infection thereby causing the disease to be reduced in incidence or die-out. Similarly, buffer zones can be created with ORV to create a line of defense to halt the progression of rabies. Natural and artificial barriers also may limit progression of rabies over a geographic area. ORV may be used alone or with other control strategies (e.g., population control) in response to a point source outbreak of rabies. In this case, immediate action is required in a limited geographic area with a surrounding buffer zone to control a rabies epizootic (Rosatte et al. 1997). This approach is analogous to management of "spot fires" in wildfires when fire is outside of the control lines.

How long must ORV be continued? Models predict that treatment programs should generally be conducted until greater than 70% of the population is vaccinated (this percentage may be lower or higher depending on the reproduction and recruitment rates, mortality rate, emigration or immigration rates, etc.). A simple deterministic model by Coyne et al. (1989) predicted that >95% of raccoons would need to be vaccinated to control rabies in the mid-Atlantic states; however, this model has been criticized for its underlying weak biology and because it did not deal in a stochastic environment (MacInnes and LeBer 2000). In practice, it may be most

feasible to continue a treatment program for one to two years following the last reported rabies case in any terrestrial species. In creating low-incidence or rabies-free areas, programs averaged 4-7 years with 1-2 treatments per year (Rosatte et al. 1992, Hable et al. 1992, Roscoe et al. 1998, Schubert et al. 1998, MacInnes et al. 2001).

Do geographic or temporal gaps in ORV treatment impair success? Little specific data was found describing what constituted a gap or break in a treatment zone. Control programs in the United States and Canada documented how funding reductions or discontinuance of control programs (a temporal break) lead to reinfections of local populations (Rosatte et al. 1992). Also, insufficient baiting within a buffer zone has been noted as being only partially effective in creating or maintaining a buffer zone because an insufficient portion of the host population is protected (Rosatte et al. 1992, Rupprecht et al. 1996, Riley et al. 1998). In Germany, attempts to eliminate fox rabies have not fully succeeded despite repeated efforts. This is likely due to lack of co-ordination between governing agencies of states or adjacent countries (Stohr and Meslin 1996). Similar results may occur in the United States if ORV programs are not uniformly applied because unvaccinated animals from adjacent areas may spread the disease back into previously treated areas.

Will there be a population boom following ORV? During a rabies epizootic population declines are commonly seen in all age classes. This mortality is additive and differs from other mortality factors that routinely affect the juvenile and first year age classes (Blancou et al. 1991). However, specific knowledge about populations prior to an epizootic outbreak is usually lacking further limiting an evaluation of the effects of rabies on a population. Density within a given area is controlled more by food availability (carrying capacity), social regulation, habitat suitability, and to a lesser degree mortality factors. Without knowledge of the specific factors controlling population densities (i.e., carrying capacity, habitat, reproduction-recruitment, mortality factors, and the potential for emigration), predicting post-epidemic population densities may be difficult (Schubert et al. 1998). Specific population information collected prior to rabies introduction is unavailable for most species, including skunks and raccoons. Therefore, a general statement on the effect of vaccination programs on wildlife populations remains controversial reflecting the variety of outcomes (i.e., decreases, increases, no change) reported by rabies control programs in different species and under different conditions. Considerable research remains needed to address this question.

Regardless, an argument made by some state wildlife managers that rabies is a positive force because it is believed to reduce populations of nuisance species is shortsighted and too passive (MacInnes and LaBer 2000). It seems unacceptable to use a zoonotic disease that is likely exotic to species in the contiguous 48 United States as a means to control native populations of animals.

Where has ORV been used? ORV programs have been conducted in Europe (Wandeler et al. 1988, Wandeler 1991, Brochier et al. 1996), Canada (Bachmann et al. 1990, Rosatte et al. 1992, MacInnes et al. 2001), and the United States. In the United States field trials have begun for raccoon rabies control in New Jersey, Massachusetts, New York, Florida, Vermont, and Ohio (Hanlon et al. 1993, Hanlon et al. 1996, Mitchell and Heilman 1996, Robbins et al. 1996, Roscoe et al. 1996, Rupprecht et al. 2001) and for coyote and gray fox in Texas (Fearneyhough 1996). No oral rabies vaccination program has been initiated for skunks because they are largely

refractory (i.e., resistant) to the recombinant oral vaccine licensed in the United States (Rupprecht et al 2001).

Costs Attributed to Rabies

Human Deaths

The loss of human life attributed to rabies throughout the world is estimated to be 50,000 – 100,000 persons per year (WHO 1996). Most human deaths occur in developing countries where dog rabies has not been controlled and where access to post-exposure prophylaxis (PEP) is not available (Rupprecht et al. 2001). In the United States, 32 rabies-related deaths were reported between 1990-2000. Of these, 74% (n=24) were attributed to bat-associated strains and only two attributed to terrestrial rabies acquired within the United States. Six cases were acquired outside the United States (Krebs et al. 2000). In developed countries the economic and emotional impact of evaluating exposure for rabies prophylaxis is much greater than for the disease itself (Rupprecht et al. 2001).

Monetary costs

When rabies becomes established in an area, the number of human PEP treatments increases (CDC 1994). The number of PEP treatments administered annually is not known; however, Meltzer (1999) reported that over the last 40 years in the United States the number of reported cases of human exposure to rabies requiring PEP has nearly doubled from fewer than 5000 to 10,000 per year (Rupprecht et al. 1995 estimated this number to be well over 20,000 PEP treatments per year). The marked increase has occurred since the 1980's and is largely attributable to the human created raccoon rabies epizootic in the mid-Atlantic states (Rupprecht and Smith 1994). During this period there was a shift away from rabies in domestic pets (i.e., mainly dogs) as a result of public education efforts describing the merits of pet vaccination and the enactment of state vaccination laws. The majority of recent incidents have been reported in wildlife (Rupprecht et al. 1995).

Costs associated with enzootic or epizootic rabies include 1) wildlife and domestic animal surveillance and animal control by local officials, 2) public outreach describing the disease and necessary precautions, 3) hospital visits and treatments including PEP, 4) health department investigations and laboratory disgnosis, and 5) public supported vaccinations for pets and livestock (pre-exposure and post-exposure). Rupprecht et al. (1995) estimated the cost of rabies prevention at up to $1 billion per year. The cost estimates for ORV vary ranging from just over $1.6 million for two counties in New Jersey in 1990 to address the raccoon epizootic (Uhaa et al. 1992) to $3.8 million for a program in Ontario to manage enzootic fox rabies and establish a defense strategy against the advancing raccoon epizootic. The cumulative costs in the United States were estimated at $300 million in 1992 (Uhaa et al. 1992, Krebs et al. 1994) and were estimated to be more than $450 million for year 2000 (CDC 2000). Although the figures cited here include a wide variety of activities, with some costs incurred personally and others publically, it is clear that the occurrence of wildlife rabies has had a dramatic financial impact.

Wildlife losses

The loss of wildlife associated with rabies is unknown and little attention has been given this topic. In 1999, 6466 deaths due to rabies in non-domestic species were reported to the CDC

(Krebs et al. 2000). However, many rabid animals are never observed and go untested and undetected (Greenwood et al. 1997). During a rabies epizootic additive mortality from the disease is observed but long-term suppression of the population from the disease is rare. Additive mortality also may result from rabies control programs. Impacts on threatened or endangered species have not been reported but are conceivably detrimental.

Alternative investments

Given these costs and their association with traditional methods of managing rabies, many researchers and public health managers find ORV or TVR programs promising. Their overall success and approval by the public suggests that the costs of ORV programs are merited as a long-term public health initiative (Hanlon and Rupprecht 1997). However, to implement a comprehensive ORV program for the raccoon enzootic and epizootic area (i.e., from Florida to Maine and west to Ohio) would include at minimum four applications of treatment to achieve control or eradication. The estimated bait cost for this program would be $450 million with an associated distribution and education cost ranging between $68 and $120 million. Further, Hanlon and Rupprecht (1997) identified the need for a lead agency staffed with the appropriate expertise and the capability for rabies data analysis and technical advice on zoonotic disease control. Others have supported a similar approach whereby USDA APHIS Wildlife Services would begin working with state and federal agencies, universities, and veterinary service organizations in identifying regional rabies control programs (Lein et al. 1997). These programs would attempt to prevent the continued northward and westward spread of raccoon rabies and direct research and management efforts in defining critical program parameters (i.e., optimal bait application, field applications, cost analyses, and feasibility; Lein et al. 1997).

Rabies remains a feared disease (Johnston et al. 1996, McGuill et al. 1997) by many Americans and imparts a significant economic and emotional toll. It is unrealistic to think that the many state and federal jurisdictions, state laws and local ordinances, and responsible agencies will be able to coordinate a successful management program (Johnston et al. 1996). Because APHIS is charged with providing leadership to ensure health of animals and associated public health concerns, several authors (Uhaa et al. 1992, Lein et al. 1997, Hanlon and Rupprecht 1997) have acknowledged the benefit of this lead organization controlling rabies through their existing wildlife and veterinary services, associations with state and private organizations, and ability to coordinate efforts for diverse landscapes and with different uses and ownership.

In November of 2000, Secretary of Agriculture Dan Glickman declared an emergency regarding the spread of rabies and announced that $4.2 million had been identified to halt the westward progression of raccoon rabies. He specifically identified that the money would be used for ORV programs with the focus being on stopping the westward progression from Ohio. The earmarked money will be a one-year, $2.7 million increase from 1999 and 2000 APHIS expenditures, on rabies control efforts. National Park Service (NPS) lands will likely be included in areas targeted for rabies control programs. The question that remains is "How should the NPS be involved in a rabies management program?"

Conclusions

Rabies is a serious disease threat to humans, domestic animals, and wildlife. Worldwide rabies kills about 50,000 – 100,000 people/year and countless domestic and wild animals. Human deaths due to rabies in the United States are rare (32 deaths in the period 1990-2000) due primarily to control measures in domestics, and more recently, wild species, and a coordinated, aggressive public health program (including an estimated 10,000 to >20,000 PEP treatments per year). Control of rabies in wildlife species seems prudent as a public health measure. Moreover, prevailing data suggest that some, or most, rabies variants currently infecting wildlife species in the 48 contiguous states of the United States were introduced to North America during the post-Columbian period (Rupprecht 2001, pers. comm.). At the least these rabies variants and the reservoir species harboring them have been transported to new geographic areas by humans, and habitats of the reservoir species have been significantly modified. Therefore, rabies management also may be a desirable component of a wildlife management program

Rabies control programs are potentially beneficial to human and animal health, and in the long-term, to restoring or maintaining natural ecosystems. However, critical evaluation should occur before rabies control programs are implemented. Rabies control programs must be warranted and must be well designed to be efficacious, cost effective, be publicly supported, and have negligible negative impact (on wildlife, humans, and landscapes). If control programs for exotic rabies are considered for parklands, park managers should be active participants in the planning, implementation, and evaluation of the program and should reserve decision-making authority.

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Figure 1. Areas in the United States where rabies is currently endemic in terrestrial wildlife (from Krebs et al. 2000).