IMPACTS OF WILDLIFE DISEASES IN URBAN ENVIRONMENTS

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Abstract: Approximately 60% of diseases causing pathogenic illness in humans originate in animals. Emergence and re-emergence of zoonotic and vector-borne diseases pose considerable public health, environmental, and economic impacts in the U.S. There are over 250 urban areas in the U.S. with populations >100,000. These densely populated centers, with concomitant development of natural areas, greenbelts, and walking trails, are viewed to exacerbate the potential for human-wildlife, pet-wildlife, and pet-human interactions leading to greater risks of zoonotic disease transmission. Wildlife rabies, West Nile virus (WNV), and bovine tuberculosis (bTB) offer illustrations of potential impacts from zoonoses in urban areas. Prevention of wildlife variants of the rabies virus are estimated to cost > $250 million annually; probable transmission in urban environments can involve direct human exposure to rabid coyotes (*Canis latrans*), raccoons (*Procyon lotor*), skunks (*Mephitis mephitis*, *Spilogale putoris*), and red foxes (*Vulpes vulpes*) or indirect exposure to the virus via pet-wildlife contacts with these animals. West Nile virus is a mosquito-borne illness that has killed >785 people in the U.S.; hospitalization costs associated with the outbreak of this disease in Colorado's densely populated Front Range averaged $33,980/admitted patient. The re-emergence of bovine tuberculosis (bTB) in cattle (*Bovidae* spp.) of Michigan's northern Lower Peninsula has resulted in a loss of the State's "TB-accredited free" status costing the state an estimated $22-74 million in five years. Monitoring, preventing, and treating zoonotic diseases pose new challenges for public health, veterinary, and wildlife professionals, with densely populated urban environments likely to exacerbate transmission and impacts.

Key words: bovine tuberculosis, economics, pets, rabies, urban, West Nile virus, wildlife, zoonoses

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INTRODUCTION

Zoonoses are diseases transmitted from animals to humans under natural conditions. Hantavirus, rabies, bovine tuberculosis (bTB), bubonic plague, tularemia, West Nile virus (WNV), and high pathogenic avian influenza are but a few examples.

Zoonoses account for 75% of the world's emerging infectious diseases and account for 61% of human pathogenic illnesses (Taylor et al. 2001). Increased population growth and concomitant encroachment into wildlife habitats, agricultural production of mono-cultural and irrigated crops, and exotic animal translocations via international wildlife trades are only a few of the factors responsible for increased zoonotic infections worldwide (Chomel et al. 2007).

America's rapid, recent urbanization has increased the potential for human-wildlife, pet-wildlife, and pet-human transmission of many zoonotic diseases (Dryden and Ridley 1999). Development of natural areas, greenbelts, and walking trails in many urban settings has provided useable wildlife habitat that is shared with people and their pets. This has led to potentially greater human and pet contacts with diseased wildlife—greater potential for transport of disease and vectors into homes. Monitoring, preventing, and treating these potential zoonotic diseases pose new challenges for public health, veterinary, and wildlife professionals, with densely populated urban environments likely to exacerbate transmissions and impacts.

Here, we examine recent changes in U.S. urbanization, human-pet-wildlife interaction, and zoonosis transmission. Although empirical studies linking increased urbanization with specific economic and health impacts of zoonotic disease are lacking, we review selected literature relevant to wildlife rabies, WNV, and bTB as illustrations of potential public health and economic impacts posed by these diseases in urban areas.

URBANIZATION

The total U.S. population is >300 million, with approximately 80% of citizens living in urban areas (U.S. Census Bureau 2007a, b). In 2005, 253 urban centers in the U.S. had human populations >100,000. California and Texas led this list with 62 and 25 cities, respectively; whereas, 10 small or agrarian states (plus The District of Columbia) contained only one city of >100,000 citizens, i.e., Alaska, Arkansas, Hawaii, Idaho, Maryland, Mississippi, New Hampshire, New Mexico, Rhode Island, and South Dakota (U.S. Census Bureau 2006a).

Increased urbanization has yielded numerous programs to preserve natural areas and to create areas for recreation. For example, in 1948, only 26% of Cuyahoga County (Cleveland area), Ohio, was considered developed; whereas, by 2002, nearly 90% of this county was developed (Cuyahoga County Planning Commission 2007). As this urbanization occurred, planning boards placed greater emphasis on developing green spaces and parks. The Cuyahoga County Planning Commission now promotes green-space protection and restoration throughout the County (Cuyahoga County Planning Commission 2007). Similarly, a recent King County (Seattle area), Washington, proposal allocated over $20 million for the acquisition of green space and trails (King County 2005), and the Atlanta (Georgia) Development Authority ranked the acquisition of more green spaces and parks as a top priority (ADA 2007). These open space, greenbelts, and natural areas form attractive walking areas for pet owners and their pets as well as corridors for wildlife movement among fragmented rural habitats.

HUMAN-PET-WILDLIFE INTERACTIONS

Human Attitudes

In the past 20 years, Americans' attitudes towards animals (domestic and wild) have changed; many people now hold a humanistic view of wildlife compared to the traditional utilitarian view (Hadidian 1992). As evidence, the National Wildlife Federation (NWF) recently announced a program for homeowners titled "Garden for Wildlife," with these landscapes now capable of being certified as "appropriate" wildlife habitat (NWF 2007). This program reflects an increased tolerance for close contact with diverse wildlife, which ultimately may increase the risk of certain zoonotic infections.

Pet Ownership

There are an estimated 73.9 million domestic dogs (*Canis familiaris*) and 90.5 million domestic cats (*Felis catus*) in the U.S owned as pets (APPMA 2006). Today, pet ownership can also entail exotic animals or wildlife (e.g., monkeys, reptiles, rodents), with approximately 40,000 primates, 4 million birds, 640,000 reptiles, and 350 million tropical fish traded annually worldwide (Chomel et al. 2007).

Urban Wildlife

Diverse wildlife species, such as deer (*Odocoileus virginianus*, *O. hemionus*), coyotes (*Canis latrans*), raccoons (*Procyon lotor*), skunks (*Mephitis mephitis*, *Spilogale putoris*), and red foxes (*Vulpes vulpes*), are increasingly observed in urban areas (DeStefano and DeGraafb 2003). Data has shown that raccoon impacts (e.g., damage to structures, pet attacks) are greater in urban environments due to higher sustained densities of these animals (see Riley 1989, Prange et al. 2003). Additionally, a symposium held in conjunction with the current Conference (i.e., 12th Wildlife Damage Management Conference, Corpus Christi, Texas) focused on increased human encounters with urban coyotes, and provided descriptions of fatal attacks on children (Baker 2007), suspected rabies exposures (Farrar 2007), and predation of pets (Berchielli 2007, Carrillo et al. 2007).

THE HUMAN-PET-WILDLIFE AND ZOONOSIS INTERFACE

Demographics alone suggest that the density and close proximity of people aids zoonotic transmission. In 1993, over 400,000 people were infected with cryptosporidiosis in Milwaukee, Wisconsin (Corso et al. 2003). Cryptosporidiosis is a protozoan that can be shed in feces and transmitted to humans, wildlife, and domestic animals via direct or indirect contact. In case of the Wisconsin outbreak, a common resource, the public water supply, was infected due to a failure of one water treatment plant. The source of contamination of cryptosporidiosis could have initiated in either domestic or certain species of wild animals (Duszynski and Upton 2001).

Greater direct and indirect human-pet, pet-wildlife, and human-wildlife contacts yield concomitant increased risks of exposure to zoonotic disease and vectors of disease. For example, large urban populations of waterfowl, especially Canada geese (*Branta canadensis*), which defecate on lawns, golf courses, and parks are potential sources of coliform bacteria contamination (Clark 2003, Kullas et al. 2002). In the western Great Plains and southwestern U.S., summer die-offs of local prairie dog (*Cynomys* spp.) populations from bubonic plague are often reported and in some instances are associated with human cases (CDC 1997). Increased numbers of wild animal feeding stations, especially wild bird feeders, in urban areas also undoubtedly add to numerous undocumented cases of zoonoses as pets contact parasites and excrement.

Regarding exotic pets, a 2003 outbreak of monkeypox infected a suspected 72 people (37 tested positive) in 6 states (CDC 2003b). Monkeypox is a viral disease found mainly in rainforest areas of central and western Africa, and it belongs to a group of viruses that includes the smallpox virus (variola). It was introduced to the U.S. via exotic imports of the giant Gambian pouched rat (*Cricetomys gambianus*) along with other African rodent species by a Texas animal distributor; however, the human cases were traced to infected prairie dogs that had been housed with the rats earlier, but sold as pets in Illinois (CDC 2003a, b). Sale of both prairie dogs and Gambian pouched rats were banned in the U.S. after this incident (CDC 2003a). Still, this outbreak highlights the potential for the exotic pet trade to introduce a wildlife-borne disease that can spread rapidly to native wildlife and infect humans.

Additionally, many zoonoses or vector-borne diseases are difficult to detect and present unique, rare symptoms for physicians. Bubonic plague, when recognized, is a treatable disease; however, without recognition or proper treatment, it is usually fatal (Gasper and Watson 2001). Plague is a disease that may infect humans handling wildlife, usually rodents serving as host for infected fleas, but a person may also become infected by handling a pet that has contacted infected rodents or fleas. Through hunting rodents, cats may be exposed without their owners' knowledge. Cat-associated plague cases accounted for 23 of 297 total cases reported between 1977 and 1998 (Gage et al. 2000). Five of the cases were fatal and for each fatal case, either a misdiagnosis occurred or the patient delayed seeking treatment (Gage et al. 2000). Moreover, between 1957 and 2005, cats were the source of human transmission for 6 out of 55 human cases of plague in Colorado, which included a human fatality in Arizona that involved exposure to an infected cat in Colorado (Colorado Department of Public Health and Environment 2007). Recently, plague was diagnosed in a tree squirrel found in the center of the urban area of Denver, Colorado (Salley 2007).

SOME ZOONOSIS IMPACTS

Review of selected literature on rabies, WNV, and bTB affords examination of public health and economic impacts associated with wildlife-borne diseases in urban situations. These diseases entail unique routes of transmission and impact. Rabies poses direct or indirect risk to humans via primary or secondary (pet) contact with rabid wildlife. West Nile virus poses mainly an indirect vector-borne risk due to wild bird species serving as hosts for the virus that is then spread to humans via mosquitoes during foraging activities for blood (McLean 2006a, 2006b). Bovine tuberculosis poses minor risk to humans, requiring transmission of saliva, meat, or milk consumption from the infected animal to humans.

Rabies

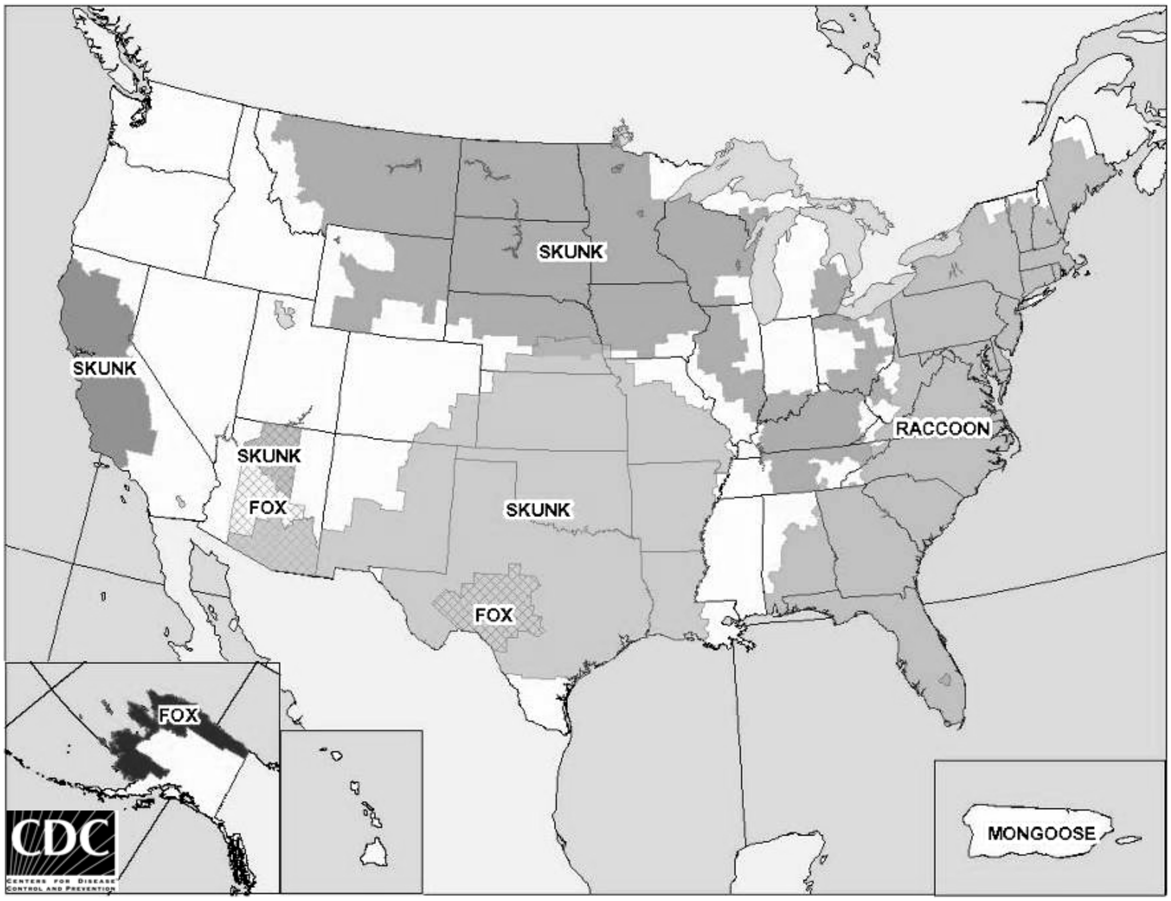
Rabies is a viral encephalomyolitic disease of mammals (Neizgoda et al. 2002). It is almost always fatal following onset of symptoms (i.e., subtle, encephalitis-like events), and the odds of survival remain low if treatment is delayed (CDC 1999). Over 55,000 rabies-related deaths occur annually throughout the world, mostly in Africa and Asia (Knobel et al. 2005), while the U.S. typically reports ≤ 3 deaths per year (Childs 2002). The two main factors contributing to the low U.S. death rate are probably effective post-exposure prophylaxis (PEP) treatment rates and comprehensive pet vaccination programs.

A shift in the composition of animal rabies cases throughout the U. S. occurred during the 1960s (Childs 2002). This shift reflected a collapse of domestic dog cases due to vaccination and control legislation enacted in the 1930s and 1940s, but the subsequent increase in wildlife rabies cases. Domestic dog rabies now accounts for < 200 (i.e., 2-5%) of all animal rabies cases annually in this country (Childs 2002), while cases of rabies in wildlife species exceed 5,000 (i.e., 90-95%) per year (Blanton et al. 2006).

Unique variants of the rabies virus occur within specific regions of the U.S.

(Figure 1). Variants of the disease in bats (*Chiroptera* spp.) are the most widely occurring; however, large areas of raccoon-variant rabies, skunk-variant rabies, and gray-fox-variant (*Urocyon cinereargenteus*) rabies characterize the U.S. distribution of the disease (Childs 2002). Spillover infections (i.e., transmission of rabies to a species that is not a natural host of the disease variant) of rabies occur as a result of interspecies contacts (Niezgoda et al. 2002).

Figure 1. Distribution of major terrestrial reservoirs of rabies in the United States. Image from CDC (2006a).



The total cost for rabies prevention in the U.S. has been grossly estimated at between $230 million and $1 billion dollars annually (Rupprecht et al. 1995). The dispersion in this estimate is attributed to the inclusion or non-inclusion of a number of discrete expenses, e.g., pet vaccinations, human pre-exposure rabies prophylaxes, human post-exposure prophylaxis (PEP), case investigations by public health units, laboratory tests of suspected animals (see Sterner and Sun 2004). Inclusion of more rabies-related cost variables yields greater accumulated estimates (Sterner and Sun 2004).

Any discussion of the likely impacts of rabid wildlife to urban dwellers must be approached cautiously. A probable scenario for human contact with the rabies virus involving urban wildlife is likely to be species specific and involve indirect contact via pet exposures. Shwiff et al. (In Press) found that of 134 human exposures to rabies in Santa Barbara and San Luis Obispo Counties, California, during the 5-year period between 1998 and 2002 (i.e., skunk rabies epizootic), only four PEPs resulted from contacts with skunks—people (not pets) will usually avoid these animals. Bat exposures led to the greatest majority of PEPs, with dog and cat exposures the next most frequent (Shwiff et al. In Press). Conversely, rabid raccoons would probably initiate agonistic human and pet encounters, yielding likely increased frequencies of PEP and pet diagnostic tests (see Uhaa et al. 1992). Similarly, the outbreak of domestic-dog-coyote-variant rabies in rural south Texas during the late 1980s coincided with shifts from 49 (1988) to 176 (1992) PEPs (see Fearneyhough et al. 1998; Sidwa et al. 2005). It has been contended that the potential spread of this variant to San Antonio (or other urban areas) would have produced dramatic increased PEPs and domestic pet cases (Ernest Oertli, Texas Department of State Health Service, personal communication, March 27, 2007) .

Recently, a main component of these impacts has entailed control of raccoon-variant rabies in the Eastern U.S. (Slate et al. 2005). This variant initially occurred in the southeast, but in the 1970's, epizootics started farther north in Mid-Atlantic and New England states due to the translocation of infected raccoons from Florida (Nettles et al. 1979). Before any control measures were implemented, i.e. the USDA/ Wildlife Services, National Oral Rabies Vaccination (ORV) program, the frontlines of the epizootic were spreading at a rate of 30 – 35 miles per year (USDA 2001). To halt the advance of raccoon rabies westward and prevent the epizootic and post-epizootic cost in other urban environments, the ORV Program was implemented, with baits containing Vaccinia-Rabies Recombinant (V-RG) vaccine distributed to create zones of vaccinated animals (i.e., barriers to deter spread). In 2006, 12,412,504 baits were distributed over 224,583 km^2 (WS 2007). The cost for distributing and packing is around $1.20 per bait (Slate et al. 2005).

Regarding benefit-cost studies, the epizootic and post-epizootic costs associated with raccoon-variant rabies cost more than the ORV Program. In Massachusetts, PEP use increased from 1.7 per 100,000 population in pre-epizootic to 45 per 100,000 during an epizootic (Kreindel et al. 1998). The median PEP cost was $2,376 and the range was $1,038-$4,447 per patient. The total health care charges for PEP in Massachusetts during the epizootic were estimated at $2.4 million to $6.4 million (Kreindel et al. 1998).

Costs of distributing vaccine-laden baits are more per unit area in urban environments because these baits are distributed by hand versus from aircraft (public safety issue). Terrestrial (i.e., non-bat) rabies epizootics have been shown to cause the rate of PEPs in a region to increase. Specific studies involving raccoon-variant rabies have reported pre-epizootic rates of PEP treatments at < 4/100,000 residents and epizootic rates of 45/100,000 residents in Massachusetts (Kreindel et al. 1998) and 66/100,000 residents in New Jersey (Uhaa et al. 1992). Additionally, the New Jersey study reported that pet vaccinations were an important impact, with a 20 per cent jump in these vaccinations and costs during the epizootic as formerly negligent pet owners tried to protect their pets. These costs are probably exacerbated in urban environments where human population densities are greater, potentially leading to large numbers of people being exposed from a single event.

West Nile Virus

The WNV is a vector-borne disease spread by *Culex* mosquitoes (McLean

2006a, b). Birds (mainly *Corvus* spp.), horses (*Equus caballus*), and humans are susceptible to the disease. This virus emerged in the U.S. in 1999, where the first human cases occurred in the New York City area, New York. From 1999 to 2001, reported human cases were contained to < 70/year and occurred in ≤ 10 eastern states. However, in 2002 and 2003, the number of cases jumped to > 4,000 and > 9,000, respectively, with 40 states affected (CDC 2006b, McLean 2006a, b). Currently, the disease is present in the 48 contiguous states (McLean 2006a, b).

The rapid spread of WNV throughout the U.S. illustrates the potential public health impacts of zoonoses, as well as the potentially devastating impacts that can occur in urban areas where vectors can quickly infect large segments of the human population. Spread was due mainly to high bird population densities, and the migratory behavior of certain host species (McLean 2006b). Birds are an amplifying host for WNV, with American crows (*Corvus brachyrhynchos*), blue jays (*Cyannocitta cristata*), magpies (*Pica* spp.), house sparrows (*Passer domesticus*) and Common Grackles (*Quiscalus quiscula*) being highly susceptible. Nearly 50,000 dead bird specimens have been found which tested positive for the virus (McLean 2006b).

As areas were hit by WNV disease epidemic, substantial health and economic impacts occurred. For example, Louisiana's outbreak occurred in 2002 and reported 329 human cases out of a total of 4,156 WNV cases in the U.S. (Zohrabian et al. 2004). Key costs involved medical, productivity losses, transportation and public health (epidemic control) outlays. The overall estimated cost for Louisiana was $20.1 million, which included $4.4 million in medical costs, $6.5 million in non-medical costs, and $9.2 million for epidemic control and public health response (Zohrabian et al. 2004).

More significantly, Colorado had the largest outbreak of WNV for the U.S. to date. While 9,862 cases and 263 fatalities occurred in the U.S. during 2003, Colorado experienced 2,947 human cases and 63 fatalities (CDC 2007). Over 66% of the Colorado cases occurred in or near urban centers along the densely populated Front Range (cities of Denver, Colorado Springs, Greeley, and Fort Collins) where over 72% of the State's population lives (U.S. Census Bureau 2006b, USGS 2004). Overall costs for the State have not yet been calculated (John Pape, State Epidemiologist, Colorado Department of Public Health and Environment, personal communication, April 23, 2007), but information from Weld County Department of Public Health and Environment (Sara Evens, Weld County Public Health, personal communication, October 19, 2006) indicated that average cost per patient for emergency room admission was $1,216; whereas, the average per patient cost for an admitted patient was $31,034. Additionally, between $33,980 and $43,980 was spent in 2003 and 2004 for enhanced surveillance of WNV in birds in both rural and urban environments, and between $17,403 and $22,503 have continued to be allocated for this activity since 2005 (Sara Evens, Weld County Public Health, personal communication, October 19, 2006).

Bovine Tuberculosis

In the early 1900s, 200 people per 100,000 suffered tuberculin infections in the U.S., with from 6% to 30% of cases involving the organism, *Mycobacterium bovis* (NRC 1994). Additionally, bTB was a main cause of U.S. farm animal deaths in the early part of the 20th century. The organism causing bTB can be shed in milk, feces, and respiratory secretions (e.g., saliva from cattle). In 1917, a national eradication program of bTB began, and the disease was almost eliminated by mid-century (NRC 1994, VS 2007). Human cases of the disease are now rare (approximalty 0.12% of citizens, NRC 1994) due to the culling of infected cattle herds and the pasteurization of milk products (O'Reilly and Daborn 1995).

Recently, bTB in cattle has re-emerged in Michigan (O'Brian et al. 2006). The re-emergence has been attributed to transmission of *M. bovis* from infected white-tailed deer (*O. virginianus*) to cattle and to humans. Deer were not the only wildlife infected. Testing by Brunning-Fann et al. (2001) resulted in positive red fox, black bear (*Ursus americanus*), and bobcat (*Felis rufus*). Witmer (2006) also found positive grey fox and opossum (*Didelphis virginiana*). The range of prevalence for bTB in the deer population is estimated at 0.7% to 7.7% (O'Brien et al. 2006, VerCauteren et al. In Prep.). Raccoons have also tested positive, with 2.5% to 4.7% of specimens infected (Bruning-Fann et al. 2001, Witmer 2006), as well as coyotes with an estimated 12% to 33% prevalence of bTB (VerCauteren et al. In Prep.). With multiple potential hosts, eradication will be difficult and Michigan will continue to suffer losses as the disease slowly continues to spread across the State.

Michigan was declared "TB-accredited free" in the State's livestock in 1979, but in 1994, a hunter killed a white-tailed deer that was identified as infected. Follow-up tests on sampled animals from the deer population revealed that bTB was endemic in the deer population of the upper third of Michigan's Lower Peninsula (MEDI 2006, O'Brian et al. 2006). Shortly afterwards, cattle herds in the region were found positive (MEDI 2006), which resulted in the depopulation of the affected cattle herds and the loss of unrestricted interstate movement of cattle by the State.

Due to these restrictions, Michigan suffered an estimated economic loss of $22-74 million over the first 5-year period. In 2005, a hunter became infected with bTB from dressing an infected deer (MEDI 2006). The deer population had served as a reservoir that allowed in the disease to re-emerge in cattle and to become a possible source for infecting humans.

The emergence of bTB in Michigan's wildlife of the Lower Peninsula has caused direct and indirect impacts to the urban environments. Indirectly, costs for control and eradication efforts are being borne by all citizens of the State. Directly, many urban dwellers also hunt deer in Michigan with potential of contracting bTB during handling of infected deer (i.e., field-dressing or eating meat which is not properly cooked). Potentially, infected meat and dairy products from unregulated sources could find their way into the human food chain affecting urban consumers.

CONCLUSIONS

Changing views of wildlife have resulted in an increased tolerance or even desire to live in close association with wildlife. Coupled with increasing human population and a rise in human activities that bring humans closer to wildlife, including travel and pet ownership, the chances of human-wildlife interactions have increased along with the possible rapid transmission of a wildlife disease into and within the urban environment. This means that we need to study, understand, and manage the impacts wildlife diseases have on public health and economics. Zoonotic diseases result in enormous impacts in terms of costs of prevention, control, eradication, surveillance, medical treatments, human lives, and psychological impacts to people world-wide. Prevention is the key to reducing impacts. Common sense prevention includes use of tick and flea collars on pets that are exposed to the outdoors, not handling sick or strange acting wild animals, wearing or applying preventive personal protection against vectors such as mosquitoes and ticks and proper hygiene after handling pets or wildlife. Components of prevention also include passage of better laws, regulations, and improved enforcement of present laws and regulations concerning international wildlife importation and domestic wildlife translocations, early detection of zoonotic diseases in animals through quality surveillance and monitoring, and education of policy makers and the general public on the real threats of zoonotic diseases. The magnitude of wildlife disease impacts lies with the society's ability to properly plan, prepare, and cope.

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