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ABSTRACT: A comprehensive cost model of wildlife rabies is presented. A total of 11 factors were viewed to comprise the diverse agricultural, insurance, medical, and veterinary expenses associated with rabies (i.e., pet vaccinations, livestock vaccinations, pet replacements, livestock replacements, pre-exposure prophylaxis for humans, post-exposure prophylaxis for humans, adverse medical reactions, animal control activities, public health charges, quarantine costs, and human death settlements). These factor costs form the basis of potential savings to be gained from rabies control activities. Irrespective of incidence, per unit costs and ranges were found to be greatest for livestock replacement, post-exposure prophylaxis, adverse medical reactions, and human death settlements, with substantial costs of adverse medical reactions and human deaths occurring infrequently but due to potential insurance or litigation claims. Empirical studies are needed to document the incidence of these factors during pre-epizootic, epizootic, and post-epizootic phases of wildlife rabies.

KEY WORDS: costs, disease, economics, model, rabies, savings, wildlife

INTRODUCTION

The median number of annual human deaths from rabies in the U. S. is low– less than 3 per year (Childs 2002, Krebs et al. 2003). Still, this disease poses a major economic and public health concern due to diverse costs incurred from human or domestic animal contacts with suspected rabid animals (Meltzer and Rupprecht 1998a,b).

Recent data (Childs 2002) show that rabies cases involving dogs (*Canis familiaris*) and cats (*Felis catus*) account for only 5 - 10% (<500/year) of all animal rabies cases. Conversely, the incidence of rabies in wildlife has increased dramatically in the past 25 years, with 7,967 positive cases reported in 2002 (Krebs et al. 2003). Multiple variants of the rabies virus occur in this country: bat (e.g., *Eptesicus fuscus, Lasionycterus noctivagans*), coyote (*Canis latrans*), fox (e.g., *Vulpes vulpes, Alopex lagopus*), raccoon (*Procyon lotor*), and skunk (e.g., *Mephitis mephitis, Spilogale putoris*) (Childs 2002). Mammals infected with these variants occupy prescribed geographical regions, with bat-variant rabies overlapping many regions (Childs 2002). Interestingly, during the 1990s bats accounted for three-fourths of the 32 human cases of rabies (Niezgoda et al. 2002).

Uncertainty characterizes the economic costs of rabies throughout the U.S. While several studies have attempted to quantify individual medical (see Kreindel et al. 1998, Shwiff et al. *In Manuscript*, Uaaa et al. 1992) and veterinary (Meltzer 1996) costs, estimates of other potential costs associated with the disease remain unknown. Here, we describe a comprehensive model of the costs attributed to rabies. Minimum-maximum estimates of the individual event costs (i.e., per unit cost) related to 11 factors were derived using Internet sites, published reports, statistical data services, and personal inquiries. This information helps to reduce the uncertainty of economic costs linked with rabies and to identify key sources of potential savings that could result from wildlife rabies control activities, especially oral rabies vaccination (ORV) programs.

COSTS-SAVINGS MODEL OF RABIES
Theoretical Description

In recent reviews, Meltzer and Rupprecht (1998a, b) stated that rabies impacts the global economy as mainly human and domestic animal health costs– prevention and treatment. We extend this view and identify diverse agricultural, insurance, medical, and veterinary costs that can be attributed to outbreaks of the disease. The potential saving of all or a portion of these costs is the benefit of rabies control.

Meltzer (1996) published a cost-savings model of raccoon-variant rabies that viewed expenditures and savings from ORV to vary with stages of an epizootic (i.e., pre-, during-, and post-epizootic). He discussed pet vaccinations and post-exposure medical treatments as the two main factors determining the economic impacts of raccoon-variant rabies epizootics. During an epizootic, disease costs are driven by increased rates of animal vaccination and human treatment. As pet owners become focused on the protection of their animals from rabies, pet vaccinations increase; and, as individuals learn of a rabies epizootic, they want more liberal dispensing of medical treatments for practically any suspicious animal bite or secondary contact with another exposed victim.

Meltzer (1996) attributed potential savings from a raccoon-variant ORV Program to the difference between pre-epidemic (baseline) versus epidemic and post-epidemic costs for these vaccinations and medical treatments. We agree with Meltzer's (1996) model, but we contend that numerous cost variables behave similar to these two costs. Because few empirical data are available for these variables, the significance of these costs in wildlife rabies epizootics is largely unknown.

Cost Equation

The following equation describes our view of the costs and potential savings associated with wildlife rabies:

$$C_R = PV + LV + PR + LR + PreEP + PEP + AR + PH + AC + Q + HD$$

where C_R is the additive cost ($US) of a multi-year epizootic of some wildlife-variant of rabies. This cost is attributed to 11 main independent variables: PV – pet vaccinations ($n \times$ $US/vaccination), LV – livestock vaccinations ($n \times$ $US/vaccination), PR – pet animal replacements ($n \times$ $US/animal for rabies-caused deaths), LR – livestock replacements ($n \times$ $US/head by species), PreEP – human pre-exposure-prophylaxis ($n \times$ $US/ vaccination), PEP – human post-exposure-prophylaxis ($n \times$ $US/treatments), AR – Adverse reaction charges ($n \times$ $US/event), PH – public health charges ($n \times$ $US/event for case investigations and laboratory tests), AC – animal control costs ($n \times$ $US/event), Q – quarantine of suspected rabid animals ($n \times$ $US/event), HD – insured human death claims ($n \times$ $US/death).

RELATIVE PER-UNIT COST ESTIMATES

We gleaned low and high cost data for each factor in our model from Internet sites, published reports, statistical data services, or personal inquiries. Descriptive paragraphs were used to explain the nature of these empirical values and a graph was prepared to show the relative minimum-maximum difference in these factor costs (see Figures 1a and 1b). We converted reported cost values to present values based on the intervening annual reported Consumer Price Indices (International Monetary Fund 2003).

Pet Vaccination (PV)

Prices for rabies vaccine and animal examination varied from a low of $5.00 and $0.00 at cost-of-vaccine-only or "free" clinics (Humphrey 1971, Uaaa et al. 1992) to a high of $15.00 and $43.00, respectively (i.e., personal phone call by RTS to a veterinarian in New York, with the examination fee for a booster shot usually waived). A well-derived mean estimate of PV is $19.36 in 2003 US$ (see Meltzer 1996). During epizootics, many municipalities underwrite some PV costs and hold clinics that typically charge $5.00 for the vaccine, with local veterinarians volunteering their time to administer the injections. The recommended regimen for rabies PV is annually or triennially based upon the chosen vaccine, the prior immunization history, and local regulations (National Association of State Public Health Veterinarians Committee 2004). Many pet owners opt for annual PV, especially if a rabies epizootic occurs in their area.

Livestock Vaccination (LV)

Rabies vaccines for cattle, equines, and sheep are available; no vaccines for swine or goats are currently approved (Briggs et al. 2002, National Association of State Public Health Veterinarians Committee 2004). Preventative vaccinations must be given to livestock annually; therapeutic vaccinations after onset of symp-
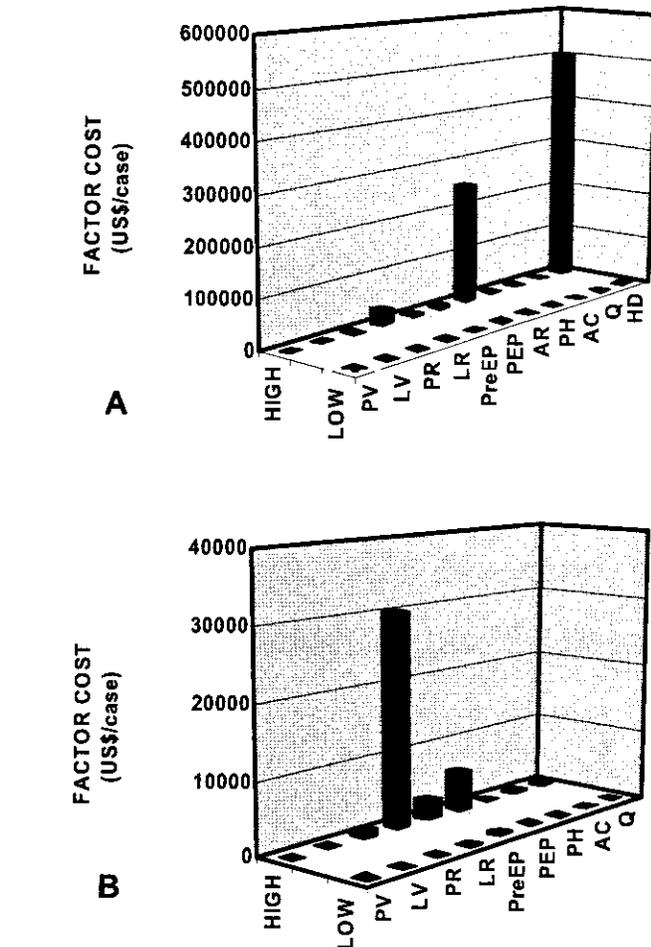

Figure 1. (A) Bar graph of low and high factor costs obtained for the 11 factors in the rabies-cost model; (B) bar graph of low and high factor costs with AR and HD removed (9 factors).

toms (e.g., unusual behavior, unexplained choking, partial paralysis) are rarely effective due mainly to the slow onset of pathogenic signs and the progression of the disease before treatment (Humphrey 1971, Childs 2002). Few states maintain records of preventative or therapeutic rabies LV, with Texas a noteworthy exception (Wilson and Clark 2001).

Charges for rabies LV also varied widely. Low and high charges ranged from $10.00 for the vaccine (rancher administering shot) to $50.00 for the vaccine and examination by a veterinarian and a $1.00 per mile "call charge", respectively. Assuming a 20-mile trip for the veterinarian, this higher cost would be $70.00. While authorization to purchase and to administer the vaccine is limited to veterinarians in many states, enforcement is poor; ranchers in some states can buy the vaccine directly from a veterinary supply store and administer the shots.

Pet Replacement (PR)

The cost of replacing a pet depends upon pedigree and lineage of the animal. We arbitrarily set the minimum and maximum PR costs for a non-pedigreed and

pedigreed dog at $25.00 (i.e., local pound animal) and $1,000.00 (i.e., exclusive breeder and pedigreed animal with lineage documents), respectively. Replacement of a cat, ferret, or rodent would be priced within these values.

Livestock Replacement (LR)

The costs of LR can be derived from current market data. Granted, ranchers/farmers could contend that this underestimates the investment in each animal due to life-long veterinary charges or long-term genetic breeding investments in an animal. Still, these market price valuations afford useful minimum and maximum cost estimates for livestock. [*Note* – The reader may verify suggested prices by checking available internet sites using diverse search engines; here, we provide representative example sites.] Replacement of a representative steer/ heifer at current market value would cost $825 (i.e., 1,000 lb. @ $82.50/cwt; http://usda.mannlib.cornell.edu/reports /nassr/price/pap-bb/2004/agpr 0304.txt), replacement of a representative calf would cost $111 (i.e., 100 lb. @ $111.00/cwt; usda.marinlib.cornell.edu/reports/nassr /price /pap-bb/soo4/agpr 0304.txt), and replacement of a representative dairy cow would average $1,130 (http:// usda.mannlib.cornell.edu/reports/nassr/price/pap-bb/2004 /agpr 0304.txt). Replacement of a sheep and lamb would cost approximately $62 (i.e., 150 lb. @ $41.20/cwt; http:// usda.mannlib.cornell.edu/reports/nassr/price/pap-bb/2004 /agpr 0304.txt) and $65 (i.e., 60 lb. @ $107.00/cwt; http:// usda.mannlib.cornell.edu/reports/nassr/price/pap-bb/2004 /agpr 0304.txt), respectively. Horse prices varied with lineage and breed; we estimated this replacement cost at between $1,000.00 (i.e., riding horse) and $30,000.00 (i.e., dressage or event mount; http://www.hhhorse.com /show/horses.phporderby=price).

Pre-Exposure Prophylaxis (Pre-EP)

Preventative rabies prophylaxis is typically provided to some animal control, veterinary, and animal research professionals (Briggs et al. 2002, CDC 1999, Uaaa et al. 1992). The treatment regimen involves three 1.0-ml intramuscular (IM) doses of Human Diploid Cell Vaccine (HDCV), Purified Chick Embryo Cell Vaccine (PCEC), or Rabies Vaccine Adsorbed (RVA) on days 0, 7, and either 21 or 28; serologic monitoring then determines the use of booster shots usually once every 0.5 to 2 years depending upon risk of exposure (CDC 1999, Murray and Arguin 2000).

Kreindel et al. (1998) estimated the median HDCV dose cost at $328 (i.e., $221 in 1998 dollars) with a minimum-maximum of $119 - $716 (i.e., $80 - $483 in 1998 dollars). Based on these data and the prescribed 3-dose series for PreEP, we estimated that the current low and high charges for PreEP would be $357 and $2,148, respectively (i.e., excluding possible physician charges). Murray and Arguin (2000) reported a mean Pre-EP 3-dose intramuscular (IM) cost as $563 or $188/dose (i.e., $468 and $156/dose in 2000), with an additional $83 (i.e., $71 in 2000) for serologic verification of immunization– a mean total cost of $646. Interestingly, Uaaa et al. (1992) estimated the mean cost of Pre-EP at $2,683 ($1,860 reported for 1988 pre-epizootic phase with physician costs included) per treatment series (i.e., no

variance reported).

Post-Exposure Prophylaxis (PEP)

A typical human PEP regimen is somewhat similar to Pre-EP; however, the wound is infiltrated with 20 I.U./kg Human Rabies Immune Globulin (HRIG) at the time of initial treatment and the rabies vaccine regimen entails 5 repeated IM injections of HDCV, PCEC, or RVA on days 0, 3, 7, 14, and 28 (CDC 1999).

A number of studies have provided empirical costs for PEP; high variance has characterized these estimates (Kreindel, et al. 1998, Shwiff et al. *In Manuscript*, Uhaa et al. 1992). Kreindel et al. (1998) reported a median PEP cost of $2,688 ($2,376) that varied from a low of $1,174 to a high of $5,031 (i.e., $1,038 to $4,447 reported for 1996). Shwiff et al. (*In Manuscript*) reported a mean $2,254 PEP, minimum and maximum costs of $257 and $5,673, respectively (i.e., this low value was reported by one clinic and may have represented a partial PEP). Uhaa et al. (1992) reported a mean PEP cost of $1,586 ($1,138 in 1990; no variance reported). Thus, using these empirical data, the minimum and maximum direct cost for a human PEP treatment today is $257 and $5,673, respectively, but typical direct PEP costs would be between $1,586 and $2,688.

Adverse Reactions (AR)

Adverse medical effects are linked with both PreEp and PEP (CDC 1999). Prior studies have shown that 30 - 74% of HDCV recipients note local pain, redness, swelling, and itching at injection sites, 5 - 40% of HDCV recipients develop systemic reactions (e.g., headache, nausea, abdominal pain, dizziness), and 3 cases developed neurologic effects resembling Guillain-Barré syndrome which alleviated in ≤12 weeks (CDC 1999). Infiltration of a wound with HRIG has also been linked with localized pain and fever (CDC 1999).

Studies to estimate the actual costs of these AR effects are non-existent. Individuals experiencing localized and mild systemic effects would probably rely on inexpensive "over-the-counter" analgesics or possibly make one or two additional visits to a primary care physician. We arbitrarily estimated these costs as between $5.00 (e.g., aspirin, skin ointment) and $150.00 (e.g., 2 physician visits with no health insurance), respectively. Obviously, the few patients that experience neurologic side effects might seek some kind of insurance or malpractice remuneration; this could be sizable, depending upon the severity of the syndrome. We arbitrarily estimated these claims at between $00 and $250,000.

Additionally, Shwiff et al. (*In Manuscript*) estimated the indirect patient costs of a rabies exposure at $680 (no variance reported), with alternative medicines, lost wages, travel, and other (e.g., day care, therapy) costs of $57, $140, $12, and $471, respectively (no variances reported). Some AR costs were probably contained in these indirect estimates.

Public Health (PH)

To our knowledge, only Shwiff et al. (*In Manuscript*) have attempted to estimate a per unit case cost for public health intervention to deal with rabies. They reported a

mean $121 cost (no variance reported) for personnel and related investigatory activities.

Animal Control (AC)

Shwiff et al. (*In Manuscript*) also reported an AC estimate, but this did not separate AC and Q charges. The mean combined AC and Q cost was reported as $290 (no variance reported).

Quarantine (Q)

Current national recommendations for a dog, cat, or ferret that bites a human require a 10-day isolation and observation period (National Association of State Public Health Veterinarians Committee 2004). For animals potentially exposed to a suspected or confirmed rabid animal, recommendations involve a 45-day isolation and observation period assuming that the biting animal is currently vaccinated; this isolation and observation period is extended to 6 months if the animal is not currently vaccinated for rabies (National Association of State Public Health Veterinarians Committee 2004).

Of course, the capture of pets is common following a suspected exposure, whereas the capture of wildlife is rare. Despite the cited recommendations and circumstances, most municipal or county governments impose the 10-day period in all cases– a questionable policy considering the long incubation period of rabies virus– ≥ 13 days (Niezgoda et al. 2002). Most of these municipal and county governments use their own pound or local Humane Society facilities for holding animals; fees are billed to the pet owner or, in the case of captured wildlife, incurred by the municipality. Representative charges consist of a $40.00 impound fee and an $18.00/day maintenance fee ($220.00 total) for dogs and cats (pers. commun., Scott Temple, Larimer County, CO Humane Society, 2003). Pets that were vaccinated for rabies and bite a person are usually confined (quarantined) at the owner's property for observation (no cost)– the risk of losing track of the pet is low. Livestock involved in suspected rabid wildlife exposures are usually corralled and observed at the stockman's ranch or farm (no cost).

Human Death (HD)

Obviously, it is difficult to place a monetary valuation on a human life; nevertheless, these deaths must be counted as rabies-incurred impacts. To quantify low and high impacts from these deaths, we arbitrarily assumed that costs are attributed simply to payment from life insurance policies at a low of $00 (uninsured) and a high of $500,000 per HD. This is a conservative valuation; many actuarial estimates would include loss of lifetime future income in HD settlements.

CONCLUSIONS

Wildlife rabies has increased dramatically in the past decade. Economic impacts from epizootic outbreaks of specific variants of this disease are exerted upon diverse agricultural, insurance, medical, and veterinary interests. Due to greater incidences, PV and human PEP have been cited traditionally as the major cost impacts of the disease; however, of the 11 factors included in our model, the maximum and largest ranges of per unit costs were

associated with LR, PEP, AR, and HD, with the potential occurrence of high AR and HD costs rare events. Empirical studies to determine pre-epizootic, epizootic, and post-epizootic incidences for the factors are sorely needed to allow improved economic projections of actual costs of the disease. Determination of these incidences and relative cost components will reduce the uncertainty of economic impacts linked with wildlife rabies and will allow improved policy decisions involving the development and distribution of ORV for wildlife.

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