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ABSTRACT: Rabies transmitted by the common vampire bat is a major public health concern in subtropical and tropical areas of Latin America, and there is some concern that the species will eventually spread into south Texas. The objective of this study was to estimate the total economic impact of the potential spread of vampire bats into south Texas. Data on livestock populations and values in the relevant counties was combined with expected mortality rates to calculate livestock losses. An IMPLAN model of the regional economy was then used to estimate the secondary impacts experienced by other businesses in the region. These impacts were combined with estimates of increased expenditures on post-exposure prophylaxis and animal tests to derive the total economic impact. We estimated the total economic impact would be $7 million to $9.2 million annually if vampire bats spread to south Texas.

KEY WORDS: cattle, *Desmodus rotundus*, diease, economics, livestock, rabies, Texas, vampire bat

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INTRODUCTION

Rabies transmitted by the common vampire bat (*Desmodus rotundus*) is a major public health concern in subtropical and tropical areas of Latin America (World Health Organization 2005). Infected vampire bats can transmit rabies to domestic mammals and humans through their haematophagous behavior (Turner 1975). In this region of the world, although transmission of rabies from bats to humans is less common than transmission by feral dogs (Schneider et al. 2005), vampire bats have been the main vector species to spread rabies to livestock (Acha and Málaga Alba 1988, World Health Organization 2005, World Health Organization 2007).

In Mexico, the common vampire bat has a vast range and is abundant in local concentrations (Lord 1988). The expansion of villages and livestock range and the subsequent construction of wells, buildings, tunnels, and mines have opened areas as roosts that were previously unavailable, resulting in an increase in the transmission of rabies to livestock and humans (Flores-Crespo and Arellano-Sota 1991). The damage caused by vampire bat-transmitted rabies to cattle (e.g., damaged hides, weight loss, decreased milk production, death) and humans (post-exposure prophylaxis, death) have economic consequences for cattle producers and communities in the rabies endemic region of Mexico (Acha and Málaga Alba 1988). Anderson et al. (2014) conducted a benefit-cost analysis of a management program in Mexico to reduce the economic consequences of vampire bat-transmitted rabies. Though it was determined that the net benefit of such a program was positive, the study highlighted the high costs associated with vampire bat-transmitted rabies and its control.

The vampire bat is currently found in Mexico as far north as the states of Sonora and Tamaulipas. However, there is some evidence (e.g., Mistry and Moreno 2008) that future range expansion may extend into south Texas over the coming decades as the climate in that region warms. This concerns ranchers, whose livestock may become susceptible to rabies transmitted by vampire bats. In addition to livestock losses, there are other negative impacts of this potential expansion of vampire bats' range. It is likely that use of post-exposure prophylaxis (PEP) and animal tests (AT) will increase. Shwiff et al. (2007) estimates the cost of PEP at $3,816 per person, implying that even small increases in PEP rates will lead to significant economic impacts. These direct economic impacts (livestock losses, PEP and AT costs) are not the only economic impacts. When livestock producers lose revenue and resources are diverted to PEP and AT, other businesses in the region suffer. A complete estimate of the economic impact of the spread of vampire bats into south Texas should account for these secondary impacts.

The purpose of this study was to estimate the total economic impact of the potential spread of vampire bats into south Texas. Data on livestock populations and values in the relevant counties was combined with expected mortality rates to calculate livestock losses. An IMPLAN model of the regional economy was then used to estimate the secondary impacts experienced by other businesses in the region. These impacts were combined with estimates of increased expenditures on PEP and AT to derive the total economic impact of vampire bats in south Texas.

METHODS

There are three types of regional economic impacts to be measured: direct, indirect, and induced. All of these can be measured in terms of income loss and employment loss. Measurement in terms of income loss gives the regional equivalent of gross domestic product (GDP).

One type of direct economic impact is the impact on livestock producers. Revenue loss experienced by livestock producers is equal to the number of animals lost multiplied by the market value of those animals when they are lost. These prices may differ from the prices of finished animals, because animals can be lost at any time in the production cycle. When an animal is killed before the production cycle has ended, the rancher will not realize the revenue from selling that animal when it is finished. But the costs associated with the remainder of the production cycle are also unrealized. This is why basing revenue loss on the market value at time of death is appropriate.

The revenue loss experienced by livestock producers may be expressed as the difference in expected revenue with and without the presence of vampire bats. With vampire bats, the annual revenue realized by producers of livestock type j in county i is given by

$$R_i = P_j\left[Q_i - Q_i\left(\frac{M_j}{100}\right)\right]$$

where P_i is the market price of livestock, Q_{ij} is the inventory of livestock, and M_j is the annual mortality rate without rabies vaccination. The total revenue lost by all producers in all counties affected is therefore given by

$$T \quad R \quad L = \sum_{i=1}^{I}\sum_{j=1}^{J}\left(Q_i P_j - R_i\right).$$

Because producers have already incurred costs associated with the production of the lost livestock up to the point of loss, total revenue loss is equal to total income loss. The lost income is the direct economic impact experienced by livestock producers.

Calculating the direct impact requires estimating the range expansion of vampire bats into Texas. This is necessary because the extent of the range expansion determines the size of the livestock population at risk. Two approaches were used to estimate the range expansion of vampire bats into south Texas. The counties included in each scenario are shown in Table 1 and Figure 1. The first approach (Scenario 1) identified a proxy bats species that currently resides in Texas and that requires natural habitat similar to that required by vampire bats. The proxy species identified, Peter's ghost-faced bat (*Mormoops megalophylla*), roosts in caves and exists in 20 Texas counties along the Mexican border. A second approach (Scenario 2) is based on a recent study (Mistry and Moreno 2008) that modeled the changes in the vampire bat range by examining changes in the 10°C minimum January isotherm. The northern limit of the vampire bat range is partially determined by winter temperature, so as the 10°C isotherm shifts northward it is predicted that the bats' range will also shift northward. Scenario 2 includes the Texas counties that encompass the northern expansion of the vampire bat range according to this second method.

In Texas, livestock susceptible to vampire bat rabies include cattle, hogs, sheep, and goats. County-level data on susceptible livestock in the expansion area were obtained from the USDA National Agricultural Statistics Service (NASS 2010). The value of an animal at the time of death depends on where it is in the production cycle. To account for variability in the production cycle, cattle were divided into several types and age groups, including 500-lb calves, 725-lb feeder cattle, 1,100-lb live cattle, beef cows, and milk cows. Hogs were divided into two categories based on the size of the operation (e.g., small operations of less than 25 head, and large operations). Only hogs on small operations were included in the analysis, based on the assumption that biosecurity on large hog operations would be sufficient to prevent exposure to vampire bats. Division of other types of livestock was not possible due to data limitations. These various types of livestock were valued based on market prices reported by the Livestock Marketing Information Center (LMIC 2010). LMIC, however, does not report equine prices, so the value of a horse was based on the value recommended by the USDA Livestock Indemnity Program (USDA 2009). Table 2 presents the values used in this analysis.

Table 1. Texas counties in predicted expansion of vampire bat range.

	Scenario 1	
Bandera	Jeff Davis	Starr
Brewster	Kinney	Terrell
Cameron	Maverick	Uvalde
Culberson	Medina	Val Verde
Dimmit	Presidio	Webb
Edwards	Real	Zapata
Hidalgo	Reeves	
	Scenario 2	
Aransas	Hidalgo	Refugio
Bee	Jim Hogg	San Patricio
Brooks	Jim Wells	Starr
Calhoun	Kennedy	Victoria
Cameron	Kleberg	Webb
Duval	Matagorda	Willacy
Goliad	Nueces	Zapata

Figure 1. Counties locations in predicted expansion of vampire bat range.

Table 2. Livestock values used in the analysis.

Livestock Type	$ / cwt	$ / head
500-lb calf	$107.13	$535.64
725-lb feeder	$100.26	$726.87
1,100-lb fed	$91.99	$1,011.84
beef cow	*NA*	$755.98
milk cow	*NA*	$1,798.12
finished hog	$47.93	$117.43
goat	$70.64	$70.64
sheep	$111.68	$111.68
horse	NA	$850.00

Livestock mortality rates are based on the cattle mortality rate derived in Anderson et al. (2014) for Mexico. During the 10-year period between 1997 and 2006, 2,769 cattle sent from the endemic region in Mexico to a national laboratory tested positive for rabies (SAGARPA 2007). Numerous studies have reported that this is a substantial underestimate of the actual number of cattle that contracted and subsequently died from vampire bat-transmitted rabies (Prieto and Baer 1972, Baer 1991, World Health Organization 2005). Conservatively, the official mortality rate as reported by the Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación (SAGARPA) was more than double the mortality rate indicated by the number of animals that tested positive in a laboratory. Published estimates of cattle mortality due to vampire bat rabies exposure indicated that between 90,000 to 100,000 head of cattle died each year in Mexico (approximately 1% mortality rate) (Acha 1967). Additional reports related to specific study sites or recent epizootics estimated the mortality rate ranges from 4% to greater than 20% (Prieto and Baer 1972, Baer 1991, Martínez-Burnes et al. 1997). Given the wide range of published estimates, a conservative estimate of 1% was the assumed mortality rate in this study for all livestock types.

Estimates of the costs associated with animal post-exposure prophylaxis (PEP) and animal tests (AT) were also developed. These may be interpreted as additional direct economic impacts. A range of PEP costs was developed based on two estimation methods. According to Belotto et al. (2005), there were 62 cases of human rabies attributable to vampire bats from 1993 to 2002 in the Americas. Over that same time period and in the same regions, there were 8 cases of human rabies attributable to non-vampire bats, for a ratio of 7.75 vampire cases to every 1 non-vampire case. Using this ratio to extrapolate to the predicted expansion counties in Texas indicates that for the 11.5 non-vampire cases from 2000 to 2005, there would be 2.94 PEP cases per 100,000 people related to vampire bats.

A second method to estimate PEP use was based on Mexican data. In the vampire bat endemic regions of Mexico, approximately 1.23 people per 100,000 received PEP each year. This was based on data from 2000 to 2005. Combining the result of this and the previous method yields a range of PEP use of 21 to 50 applications annually in Scenario 1 counties and 27 to 64 in Scenario 2 counties. Using the midpoint of the Scenario 1 range and the estimate of $3,816 per person from Shwiff et al. (2007), the total cost of PEP in Scenario 1 counties would be $135,468. The same calculation for Scenario 2 yields an estimate of $173,628.

Animal test costs represent a significant cost due to the large number of livestock lost. It is assumed that all livestock lost to rabies from vampire bats will be tested. While the actual number of tests will exceed this, such a method provides a conservative estimate of the total cost of testing animals for rabies. Gordon et al. (2005) estimated the cost of a positive animal test to be $85 to $305. This includes costs associated with transporting the specimen to a lab, lab work, and notifying persons who may have been exposed. The midpoint of this range ($195) multiplied by the number of livestock lost yields a cost estimate of $1,676,098 for Scenario 1 and $1,600,496 for Scenario 2.

Direct economic (primary) impacts create secondary (indirect and induced) impacts due to the multiplier effect. When livestock producers suffer losses, they have less revenue available to purchase inputs and/or their own income falls. This implies lower income for other businesses in the region. The loss in income suffered by other business is the secondary economic impact of the livestock losses. The indirect impacts are the changes in income associated with businesses that supply inputs to livestock production. When income associated with these supplying businesses and with livestock production falls, less is spent on other goods and services (restaurants, car repair, etc.). Thus, income associated with those businesses also falls; this is the induced effect. The IMPLAN (Implan Group LLC 2011) model was used to estimate these secondary economic impacts. IMPLAN is a widely-used, computer-based model of the regional economy based on the known linkages between various sectors.

RESULTS AND DISCUSSION

The direct economic impacts of the spread of vampire bats into south Texas are shown in Table 3. The majority of the direct economic impact in both scenarios is the income loss experienced by livestock producers. Animal tests are also a significant cost, particularly given that the estimates developed here are highly conservative. It is somewhat counterintuitive that the livestock losses in Scenario 1 are lower than in Scenario 2, yet the AT costs are higher. This is due to the relatively larger amount of high-value cattle present in Scenario 2 counties.

Table 3. Direct economic impacts (annual).

	Scenario 1	Scenario 2
Livestock Losses	$3,727,982	$5,232,055
PEP Costs	$135,468	$173,628
AT Costs	$1,676,098	$1,600,496
Total Direct Impact	**$5,539,548**	**$7,006,179**

The IMPLAN model was used to estimate the secondary economic impacts associated with livestock losses. Table 4 presents the secondary impacts along with the total direct economic impact and total economic impact. The impacts are expressed in dollar terms and are interpreted as the reduction in aggregate income in the region or the reduction in regional output. The results of this analysis indicate that the economic impact of the spread of vampire bats into south Texas would likely be $7 million to $9.2 million. IMPLAN also allowed estimation of the job losses that are associated with the impacts (Table 4).

Table 4. Indirect and total economic impacts (annual).

	Scenario 1	Scenario 2
Indirect Impact	$1,080,671	$1,631,770
Induced Impact	$344,484	$512,847
Total Secondary Impact	$1,425,155	$2,144,617
Total Direct Impact	$5,539,548	$7,006,179
Total Economic Impact	**$6,964,703**	**$9,150,796**
Employment Impact	63 jobs	92 jobs

Our estimates of the impacts of the potential spread of vampire bat rabies into Texas are conservative. Incorporating more rabies-caused impacts (i.e., pet vaccinations, rabies educational programs, human deaths, pet replacements, etc.) as sources of potential impacts would have undoubtedly increased the overall economic impact. Additionally, several factors related to the methodology used in the analysis contribute to the conservative nature of the results. First, the methodology used to derive the number of animal tests given annually was based solely on the number of livestock that would test positive for rabies. As vampire bats move into Texas, many animals will be tested for rabies, including bats and myriad other wildlife. Additionally, many animals (including livestock) will be tested for rabies but will be negative for the virus. Costs incurred for testing wildlife (positives and negatives) and livestock (negatives) were not included in this analysis and necessarily make the results conservative. Second, the secondary impacts are based only on the direct impact of livestock losses because the IMPLAN model is limited in its ability to capture secondary impacts associated with other direct impacts. Although some of the spending on PEP and AT occurs in the regional economy, the secondary impacts of it should not be interpreted as beneficial to the region. Presumably, in the absence of vampire bat rabies, people would allocate their money to more desirable uses.

Despite the conservative nature of our estimates, the estimated impacts represent a significant burden on counties in south Texas that depend on livestock production. The human population in the counties included in this analysis is relatively small, and economic activity is limited relative to some other parts of Texas. Thus, an annual impact in excess of $7 million may be intolerable. Future analyses of the potential spread of vampire bats into Texas should focus on two areas. First, there should be an attempt to more precisely estimate the economic impact by incorporating some of the previously mentioned factors that we were unable to account for (e.g., human mortality risk, pet vaccinations). Additionally, the cost-effectiveness of livestock vaccination should be investigated. If livestock vaccinations are cost effective, the total burden of vampire bat rabies can be reduced but not eliminated.

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