

**Rabies in Tennessee: Regional Differences and Trends, 1999-2008
and
Human Deaths from Rabies in the United States, 1950-2008**

**Helena Paxton
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The University of Tennessee at Martin
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Master of Science in Agriculture and Natural Resources Systems Management
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Author: _____

Date: _____

Walter R. [Signature]
5 March 2010

Information

Name: Helena Anne Paxton

Date of Degree: December 19, 2009

Institution: The University of Tennessee at Martin

Major Field: Systems Science in Agriculture

Major Professor: Dr. Timothy Burcham

Title of Study: Rabies in Tennessee: Regional Differences and Trends, 1999-2008 and Human Deaths from Rabies in the United States, 1950-2008

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Candidate for Master of Science Degree in Agriculture and Natural Resources Systems Management

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Abstract

Rabies virus is a viral disease of mammals that is primarily transmitted by a bite from a rabid animal. Rabies is deadly but is preventable through vaccination. There are several reservoirs and variants of the rabies virus but only skunk, bat, raccoon, and fox reservoirs are located in Tennessee. Rabies, like most other wildlife diseases, will cause animals to display different symptoms and signs. However, there are no signs that definitely indicate rabies. Death usually occurs after symptoms appear.

The only way to test animals for rabies is to conduct post-mortem tests on brain samples. The direct fluorescent-antibody assay (DFA) is the standard rabies test. The cost and maintenance of a fluorescent microscope limits the use of the DFA, therefore, a direct rapid immunohistochemical test (dRIT) has been developed. Ante-mortem tests are available for detecting rabies in humans but there is no single test; a series of tests must be done. Three labs in Tennessee, located in Nashville, Knoxville, and Jackson, conduct rabies testing. The labs are able to both confirm a positive rabies case and to determine the variant that caused the infection.

Rabies can be prevented through vaccination. There are vaccines present for humans, some domesticated animals, and some species of wildlife.

The main goal of this study was to gather and summarize rabies data in Tennessee from 1999-2008 and to compare the number of rabies cases among the regions of Tennessee. Human rabies deaths across the United States from 1950-2008 was also examined and summarized.

Animal rabies data for Tennessee were obtained for 1999-2008 from the Tennessee Department of Health. Analysis of variance (ANOVA) using a completely randomized design was used to determine the effect of region on the number of rabies cases per county for each year of the study. The Ryan-Einot-Gabriel-Welsch Multiple Range Test (REWQ) was used to separate means. Human rabies death data was obtained from the Zoonosis Control Branch of the Texas Department of State Health Services' Website for 1960-2008. The human rabies data was summarized in contingency tables and the presence or

absence of relationships among gender, location (region), age, and infected species was determined by chi-square analysis and Fisher's Exact Test.

The central region in Tennessee had more animal rabies cases than the western or eastern regions of Tennessee from 1999-2003. The number of rabies cases in the eastern region of Tennessee was equal to the number of rabies cases in the central region of Tennessee by 2007 and 2008. The number of positive cases in West Tennessee remained low throughout the study period.

The number of human deaths from rabies has decreased since the 1950s. Most human rabies deaths in the United States prior to the 1960 were caused by dogs infected with the canine variant of rabies. Presently, most human rabies deaths in the United States are directly or indirectly caused by wildlife. More males have died from rabies than females. The southern region of the United States had more human rabies deaths than the Midwest, West, and Northeast combined. Rabies is 100% preventable, so prevention is key.

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Introduction

Rabies virus “is one of the oldest recognized infectious diseases” (Rupprecht et al., 2001). Rabies is a viral disease of mammals that is primarily transmitted by a bite from a rabid animal, but rabies is preventable through vaccination. It is believed that rabies was first found in Africa (Rupprecht et al., 2001) and rabies is currently found on nearly every continent of the world (WHO, 2006). Wildlife now account for over 90% of all the rabies cases (CDC, 2007a) that are reported to the Centers for Disease Control and Prevention (CDC). There are three main reservoirs of terrestrial rabies in the United States: skunk, raccoon, and fox (Figure 1). A rabies reservoir is an area where a specific variant of rabies is known to exist. There is also a bat variant found in the United States. All four variants of rabies are found in Tennessee (Tennessee Department of Health, 1998-2009). The incubation period for rabies ranges from 10 days – 7 years with the average being 3-7 weeks (The New York Times Health Guide, 2008). Treatment is expensive, so prevention is key. The cost of controlling rabies in the United States exceeds 300 million dollars annually according to the CDC (2007a). The Tennessee Department of Health keeps track of all the rabies information for the state of Tennessee. Tennessee law mandates that all dogs and cats be vaccinated against rabies (ACAT, 2007).

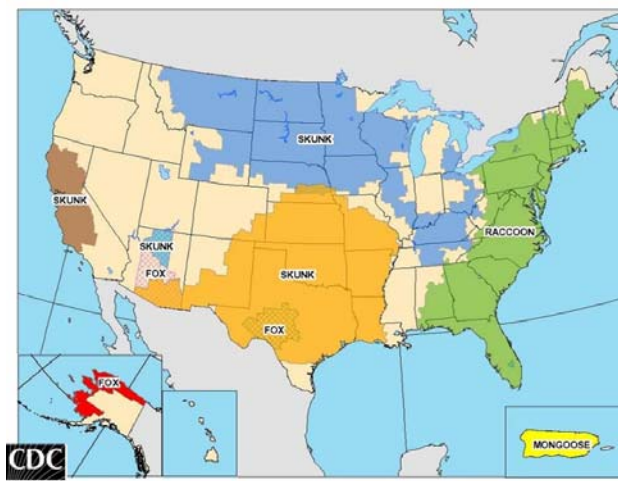


Figure 1. Distribution of United States terrestrial rabies reservoirs. (Blanton et al., 2008)

Objectives

The main goal of this study was to gather and summarize rabies data in Tennessee from 1999-2008 and to compare the number of rabies cases among the regions of Tennessee. This study will additionally examine and summarize data on human rabies deaths across the United States from 1950-2008.

Literature Review

Human Rabies Information

Domesticated animals accounted for the majority of rabies infections in people before 1960 (CDC, 2007a). Since then, wildlife have accounted for the majority of all rabies cases in the United States. More than 99% of all present day human deaths from rabies occur in Africa and Asia (WHO, 2007). The most recent case of a human rabies death in the United States occurred in Indiana in 2009 and the case was caused by a bat bite (MMWR, 2009). Unrecognized exposure to bats that are infected with rabies accounts for the majority of all human rabies infections (Messenger et al., 2003).

The most recent human death caused by rabies in Tennessee occurred in 2002 and was caused by a bat bite. Human rabies cases caused by bats tend to occur more in the southeastern and northwestern parts of the United States than any other part of the United States (Messenger et al., 2003). The Merck Manual of Medical Information (2004) states that a person who is bitten by a skunk, raccoon, fox, most other carnivores, or a bat should consider that animal to be rabid and receive the necessary post exposure vaccines.

Reservoirs and Vectors of Rabies

Domesticated animals and wild mammals are vectors of rabies. Skunks, bats, and raccoons account for the majority of all the rabies cases in the United States. Dogs, cats, and ferrets are the more commonly vaccinated domesticated animals. Inoculation of horses and cattle may be more common in rural and other areas with increased risk of exposure.

Raccoons (*Procyon lotor*) have been a major reservoir for rabies in the southeastern United States since the 1950s (Blanton et al., 2008). The raccoon rabies variant was initially found in Tennessee in 2003 (TWRA, nd). An oral rabies vaccine program was initiated in 2002 to prevent the westward movement of the raccoon variant of rabies (TWRA, nd). Figure 1 shows a map of the terrestrial US

reservoirs of rabies for 2007. This rabies reservoirs map shows where certain species of animals are located and are likely to have rabies infections in those areas.

Symptoms and Signs

Rabies, like most other wildlife diseases, will cause animals to display different symptoms and signs. There are no signs that definitely indicate rabies. Death usually occurs after symptoms appear.

Bats

Rabid bats are usually unable to fly and as a result the bats tend to fall to the ground and are easy prey for cats and other animals to attack (Foster and Smith, 1997). Animals that eat rabid animals can become rabid themselves by coming into contact with infected saliva or infected tissues (Maine Health and Environmental Testing Laboratory, nd).

Cats

The incubation period in a rabid cat varies from two weeks to two months with the variation in incubation time being related to the bite's location (Foster and Smith, 1997). Bites on a cat's head will result in a shorter incubation time than bites located on other parts of the cat's body (Foster and Smith, 1997). Rabid cats may refuse to eat or drink, hide, exhibit depression, drool, struggle swallowing, exhibit violent behavior and spooky eyes, or have wobbly rear legs (Shojai, 1998). A rabid cat will usually die within eight days after becoming sick from rabies (Foster and Smith, 1997). Shojai (1998) found that rabies infections are higher in cats than in dogs across the United States because only about four percent of owned cats are vaccinated against rabies while approximately 40% percent of owned dogs are vaccinated against rabies. Shojai (1998) recommends that both indoor and outdoor owned cats should be vaccinated against rabies. Tennessee law mandates that all pet dogs and cats be vaccinated against rabies each year (ACAT, 2007).

Horses

The most common sign of rabies in horses is a change in behavior (Kentucky Cooperative Extension Service, 1980). Horses infected with rabies tend to show erratic behaviors such as galloping blindly and suddenly falling and rolling (Knightbridge, 2002). They may also chew on their skin (Knightbridge, 2002). Rabid horses will usually die within a few days after appearance of rabies symptoms (Knightbridge, 2002).

Skunks

A rabid skunk will have no fear of humans, will act aggressively or listless, and/or will appear to be sick (Parker, 2002). Oertli et al. (2009) reported that rabid skunks in Texas entered dog pens, made appearances during the day, and attacked pets, all of which are unusual behaviors for skunks. Individual skunks can show one or more of these behaviors.

Raccoons

Raccoons with rabies also have no fear of humans, will act aggressively or listless and will be out during the day (Parker, 2002). Rabid raccoons may not be able to eat or drink, have balance issues, turn around in circles, go into a coma or have seizures (German and McNally, 2007).

Dogs

Restlessness and apprehension are initial signs of rabies in dogs (WebMD, 2009). Rabid dogs may also become aggressive (WebMD, 2009). Rabid dogs typically show the opposite of their normal temperament; i.e., friendly dogs might become more excited and aggressive (WebMD, 2009). A rabid dog may snap or bite when provoked by anything; dogs may lick constantly where they were bitten, and a fever may be present (WebMD, 2009). The signs and symptoms of rabies will typically change once rabies progresses in the dog's body (WebMD, 2009). Sensitivity to touch, sound, and light, an appetite for strange things, a tendency to hide in dark places, paralysis of throat and jaw muscles, disorientation,

seizures, and sudden death are all common symptoms of rabies that has progressed in a rabid dog (WebMD, 2009).

Diagnosis

The only way to test animals for rabies is to conduct post-mortem tests on brain samples. Lembo et al., (2006) recommend that brain tissue samples be collected by either The World Health Organization drinking straw method or by opening up the skull. The direct fluorescent-antibody assay (DFA) is the standard rabies test. A positive DFA will produce fluorescent-apple-green areas in brain tissue samples when viewed with a fluorescence microscope (Figure 2). The cost and maintenance of a fluorescent microscope limits the use of the DFA, therefore, a direct rapid immunohistochemical test (dRIT) has been developed. A positive dRIT would produce a magenta color in brain tissue samples (Figure 3).

Ante-mortem tests are available for detecting rabies in humans, but there is no single test; a series of tests needs to be done. The ante-mortem tests for human detection of rabies include testing saliva, blood serum, and spinal fluid, and taking skin biopsies of hair follicles at the nape of the neck (CDC, 2008).

Three labs in Tennessee, located in Nashville, Knoxville, and Jackson, conduct rabies testing. The labs are able to both confirm a positive rabies case and to determine the variant that caused the infection. The labs can also send samples to either the Atlanta or Kansas CDC labs for a confirmation.

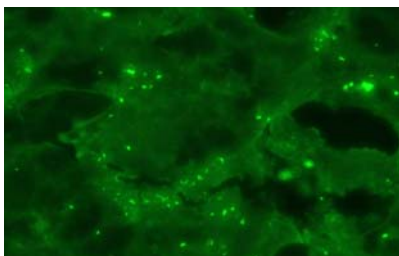


Figure 2. Rabies positive by direct fluorescent-antibody assay (Los Angeles County Public Health Laboratory, 2007)

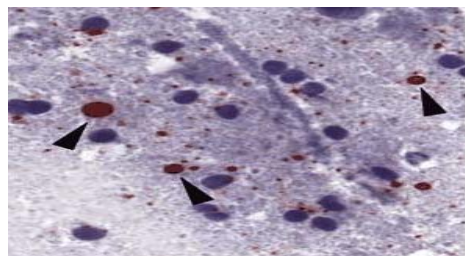


Figure 3. Rabies positive by direct rapid immunohistochemical test. (Lembo et al., 2006)

Vaccines

Louis Pasteur first used the rabies vaccine in 1885 (Hansen, 1998). Since then, there have been several vaccines developed for humans in addition to vaccines developed for some non-human mammals. Human diploid cell vaccine (HDCV), rabies vaccine adsorbed (RVA), purified chick embryo vaccine (PCEC), nerve tissue vaccine, duck embryo vaccine, and live attenuated vaccines are/were the main types of rabies vaccines (Brooks, 2007). The HDCV, the RVA, and the PCEC vaccine are available for human use in the United States (Brooks, 2007). Nerve tissue vaccines, which are made from infected sheep, goat, or mouse brains are used in many developing nations of the world (Brooks, 2007). Multiple doses (up to 23) are required with the nerve tissue vaccines due to the low potency of an individual dose (Brooks, 2007). The duck embryo vaccine was created to offset the adverse reactions of the nerve tissue vaccines but the duck embryo vaccine is no longer manufactured (Brooks, 2007). Live attenuated viruses are used on animals (Brooks, 2007).

Rabies Vaccines for Humans Pre-exposure Vaccines

International travelers, veterinarians, lab workers, animal rehabilitators, and other people who come into contact with animals or environments that are high risks for rabies infection should be vaccinated against rabies as a preventive measure. Pre-exposure prophylaxis (PEP) is the name given to the series of vaccines given to people that work in high rabies exposure environments (CDC, 2007c). The preventive vaccination schedule consists of three doses; the second dose is administered 7 days after the first dose, and the third dose 28 days after the first dose (Brooks, 2007). The cost of the vaccines varies by state but ranges from \$1,000 USD to \$1,500 USD for the full treatment. It is recommended that people who work in high risk environments should get blood drawn to test the antibody level every 2-3 years (Briggs, 2003). The World Health Organization states that a serological titer of 0.5IU/mL is an adequate humeral immune response after vaccination (Briggs, 2003).

Post-exposure Vaccines

A person who has never received rabies vaccines will need to receive five doses of rabies vaccine if they think they were exposed to rabies. The 1st dose should be given immediately with a shot of Rabies Immune Globulin. Additional doses should be given on the 3rd, 7th, 14th, and 28th days following the 1st dose. People who received the PEP vaccines will only need two doses of the rabies vaccine; one immediately and one on the 3rd day after the 1st shot (CDC, 2007b).

Animal Vaccines Domesticated animals

There are vaccines currently available for cats, ferrets, sheep, cattle, and horses (CDC, 2007). Dr. Michael Towns, Trousdale county veterinary services, offers rabies vaccination for cats, dogs, and horses; other animals may also be inoculated. Dog and cat vaccines cost about \$10 USD per vaccine, while horse vaccines cost about \$14 USD per vaccine at this clinic as of 2009 (Dr. Michael Towns, DVM, personal communication, 2009). A horse would require two doses of the Rabvac® 3 TF single dose vials which are manufactured by Fort Dodge. The single dose vials act as a means for quality control. The label can be peeled off the vial and placed directly on the vaccinated animal's vet record. The label can be used for multiple purposes ranging from proof that an animal received a rabies vaccine to checking for recalls, and most importantly if the animal does get rabies, it can be used to check for a pattern or to determine if it is just an isolated case.

Oral Rabies Vaccine

Wildlife Services has established an oral rabies vaccine (ORV) zone from Maine to Alabama to prevent the westward and northward spread of raccoon rabies (Wildlife Services, 2006). The ORV was started in 2002 for Tennessee (Epi-news, 2008). The ORV, Raboral-VRG® rabies vaccine, manufactured by Meril Inc. is placed into either a sachet or plastic packet which is then ready for distribution (Wildlife Services, 2006). The ORV is usually distributed by dropping the packets or sachets from airplanes, but

the ORV is hand baited in areas of high population (Wildlife Services, 2006). The ORV cannot cause rabies and it is safe if a dog or cat eats it (Wildlife Services, 2006).

Methods

Datasets

Animal Rabies Data

The data for animal rabies in Tennessee was obtained from the Tennessee Department of Health. Mr. Lee Wood and Dr. L. Rand Carpenter provided data and advice on how to use some of the rabies data. The Tennessee Department of Health data from 1999-2001 consists of the species name of the rabid animal and the county name in which the animal was found. The 2002 and 2003 data includes a limited number of the rabies virus variant in addition to the species name and the county information. The 2004-2006 data consists of a more complete listing of the rabies virus variant associated with each respective infected animal. Rabies datasets from 2007 and 2008 included: the date the animal was reported, the reported month, the reported year, the control number, the county code associated with each county, the county where the animal was found, the animal code, the type of animal sent for testing, the type of test performed and the result, the lab where the animal was tested, the reported location of the animal sent for testing, and other various data. Only a sub-sample of the skunks processed were tested for the rabies virus variant, because it was believed that the raccoon variant had not migrated from East Tennessee.

Human Rabies Data

The Zoonosis Control Branch of the Texas Department of State Health Services (2008) has compiled human rabies death data from 1946-2008; this dataset was used for the second part of this project.

Data Summary and Analysis

Animal Rabies Data

Numeric data associated with both the species type infected and the variant that caused the infection was analyzed using ArcMap[®], Microsoft Excel[®], and SAS[®]. ArcMap documents were created by combining data from 2007-2008. The 2007-2008 rabies data was used for ArcMap[®] because those

years contained more information than any previous year's data that was obtained for this project. Data for 1999-2006 were obtained from the last weekly reports from the Tennessee Department of Health's website.

Microsoft Excel[®] was used to organize the data and to create graphs to show if there were variations over time involving the type of animal infected with rabies. The rabies variant data could not be included in the summaries and analyses due to lack of information on variants for several years of the study.

Data on rabid animals in Tennessee were divided into regions according to the UT-Extension Service regional divisions of central, western, and eastern (Tables 1 to 3). The data were then further divided by year and by county. Analysis of variance (ANOVA) using a completely randomized design was used to determine the effect of region on the number of rabies cases per county for each year of the study. The Ryan-Einot-Gabriel-Welsch Multiple Range Test (REWQ) was used to separate means. The ANOVA analyses and the mean separation tests were conducted using Proc ANOVA in SAS[®].

Human Rabies Data

The data on human rabies deaths compiled by the Zoonosis Control Branch of the Texas Department of State Health Services (2008) was broken down into regions according to the United States Census Bureau's regional divisions: West, Midwest, Northeast, and South (Table 4). The human rabies data were summarized in contingency tables and the presence or absence of relationships among gender, location (region), age, and infected species was determined by chi-square analysis and Fisher's Exact Test using Proc FREQ in SAS[®].

Table 1. Counties located in West Tennessee (UT-Extension Service)

Western Region Counties		
Benton	Haywood	McNairy
Carroll	Henderson	Montgomery
Chester	Henry	Obion
Crockett	Hickman	Perry
Decatur	Houston	Shelby
Dickson	Humphreys	Steward
Dyer	Lake	Tipton
Fayette	Lauderdale	Wayne
Gibson	Lawrence	Weakley
Hardeman	Lewis	
Hardin	Madison	

Table 2. Counties located in Middle Tennessee (UT-Extension Service)

Central Region Counties		
Bedford	Jackson	Robertson
Cannon	Lincoln	Rutherford
Cheatham	Macon	Sequatchie
Clay	Marion	Smith
Coffee	Marshall	Sumner
Davidson	Maury	Trousdale
DeKalb	Moore	Van Buren
Franklin	Overton	Warren
Giles	Pickett	White
Grundy	Putnam	Williamson
		Wilson

Table 3. Counties located in East Tennessee (UT-Extension Service)

Eastern Region Counties		
Anderson	Greene	Monroe
Bledsoe	Hamblen	Morgan
Blount	Hamilton	Polk
Bradley	Hancock	Rhea
Campbell	Hawkins	Roane
Carter	Jefferson	Scott
Claiborne	Johnson	Sevier
Cocke	Knox	Sullivan
Cumberland	Loudon	Unicoi
Fentress	McMinn	Union
Grainger	Meigs	Washington

Table 4. Regions of United States for human rabies death data (US Census Bureau)

South Region of United States	West Region of United States	Midwest Region of United States	Northeast Region of United States
Alabama	Alaska	Illinois	Connecticut
Arkansas	Arizona	Indiana	Maine
Delaware	California	Iowa	Massachusetts
District of Columbia	Colorado	Kansas	New Hampshire
Florida	Hawaii	Michigan	New Jersey
Georgia	Idaho	Minnesota	New York
Kentucky	Montana	Missouri	Pennsylvania
Louisiana	Nevada	Nebraska	Rhode Island
Maryland	New Mexico	North Dakota	Vermont
Mississippi	Oregon	Ohio	
North Carolina	Utah	South Dakota	
Oklahoma	Washington	Wisconsin	
South Carolina	Wyoming		
Tennessee			
Texas			
Virginia			
West Virginia			

Results and Discussion

Total Numbers of Rabid Animals in Tennessee, 1999-2008

The total number of positive animal rabies cases in Tennessee varied from 95 to 129 from 1999 to 2008 (Figure 4). The highest number of positive rabies cases (132) occurred in 2007, while 2005 had the lowest number of positive rabies cases (48). The total number of cases submitted for rabies testing for Tennessee was available only for 2007 and 2008. There were 2,315 animals in Tennessee that were submitted for rabies testing in 2007, with 132 of the submitted animals testing positive (+). There were 1,918 animals in Tennessee that were submitted for rabies testing in 2008 with 129 of the submitted animals testing positive (+).

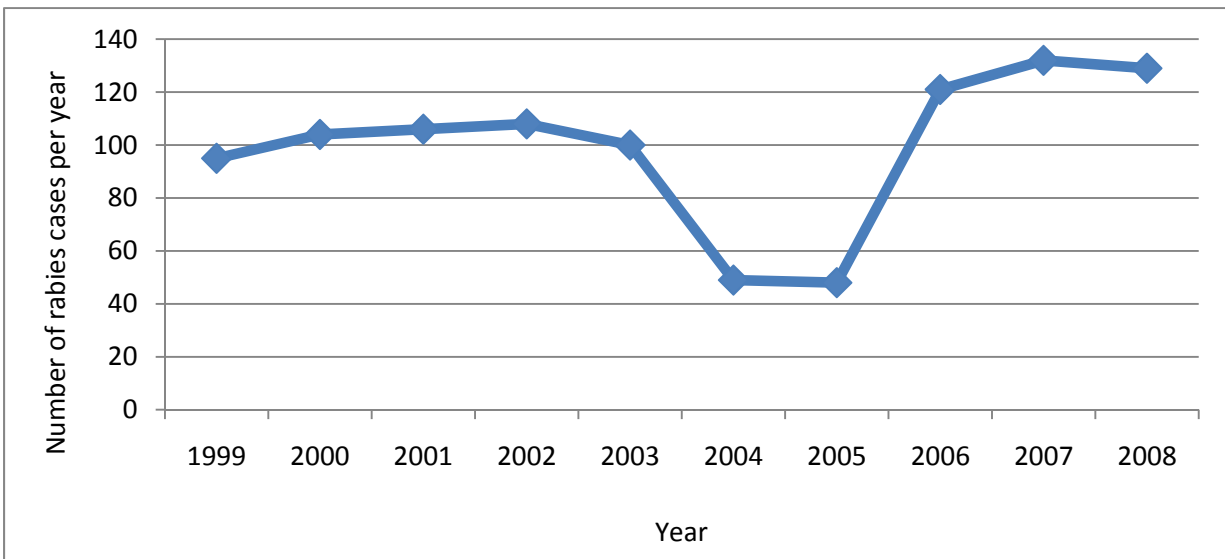


Figure 4. Total number of rabies cases in Tennessee from 1999-2008

The central region in Tennessee had significantly ($P < 0.05$) more animal rabies cases than the western or eastern regions of Tennessee from 1999-2003 (Figure 5). The number of rabies cases in the eastern region was not significantly ($P < 0.05$) different from number of rabies cases in the central region starting with the 2003 rabies data and continuing until 2008. The increase in the number of positive animal rabies cases in eastern Tennessee beginning in 2006 may be due to the spread of skunk

variant rabies into East Tennessee, an increase in the number of animals submitted for testing, seasonal patterns, cyclic animal patterns, or a combination of these. Torrence et al. (1992) referenced a study by Carey et al. (1978) that states that season, weather, and geographic features influence the spread of rabies from rabid animals to non-rabid animals. The number of positive rabies cases in West Tennessee remained low throughout the study period (Figure 5).

Animal Rabies Cases in Tennessee, 2007-2008

There were a total of 261 animals that tested positive for rabies in Tennessee in 2007 and 2008 (Figures 4 and 6). ArcMap® was used to create a graphical representation of the different species of rabid animals that were found in each Tennessee County from January of 2007 until December of 2008 (Figure 7). Some counties had multiple species that were infected with rabies, while others had only one or none. Skunks, raccoons, and bats were the most common species infected in 2007 and 2008 in Tennessee. The number of rabid skunks exceeded all other rabid animals combined (Figure 6). There were fewer cats than dogs that became infected with rabies. This differs from other states that typically have more cats than dogs that become infected with rabies (Shojai, 1998). This is probably due to less stringent laws on vaccination of cats. Tennessee law, on the other hand, mandates both cats and dogs owned as pets be vaccinated against rabies.

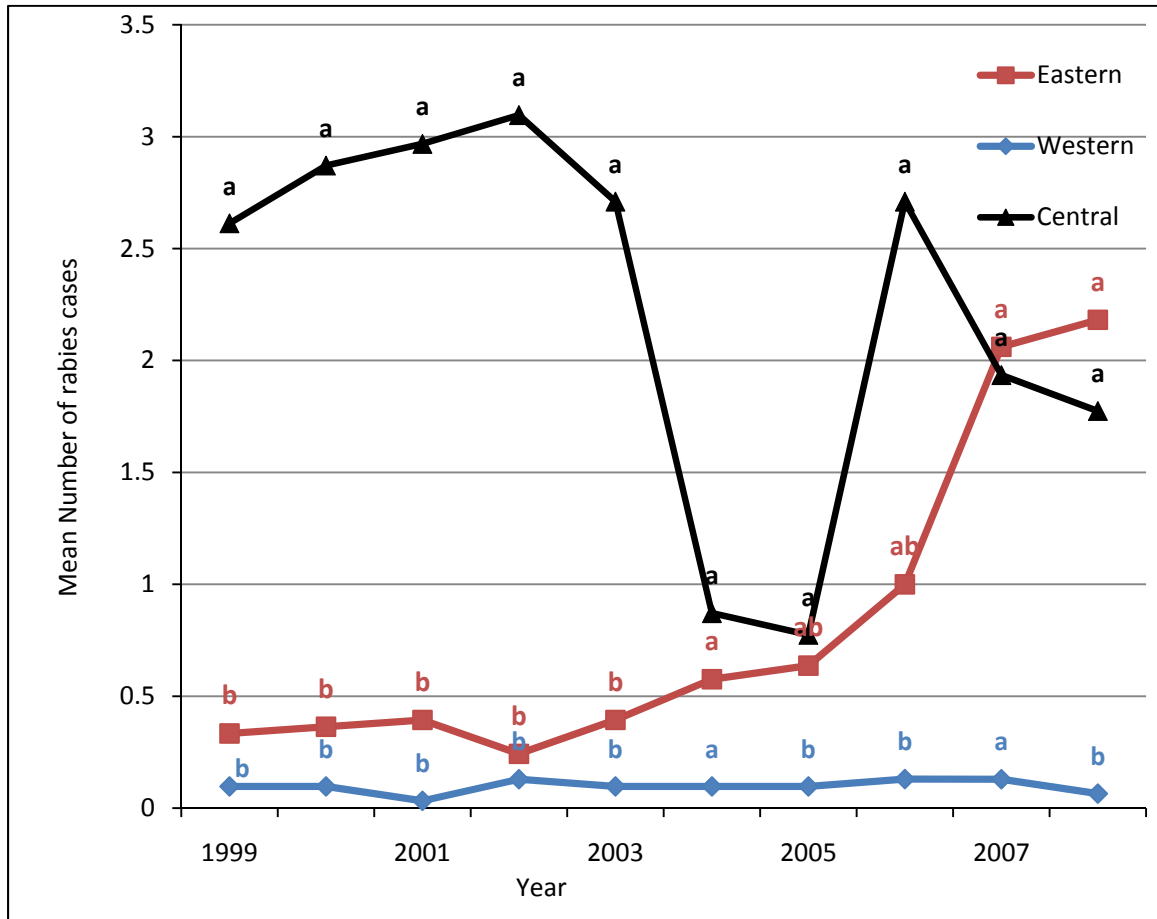


Figure 5. Mean number of rabies cases per county per region of Tennessee from 1999-2008. Within years, means with the same letter are not significantly different by the Ryan-Einot-Gabriel-Welsh Multiple Range Test, $P \leq 0.05$. $n = 31$ and $n=33$.

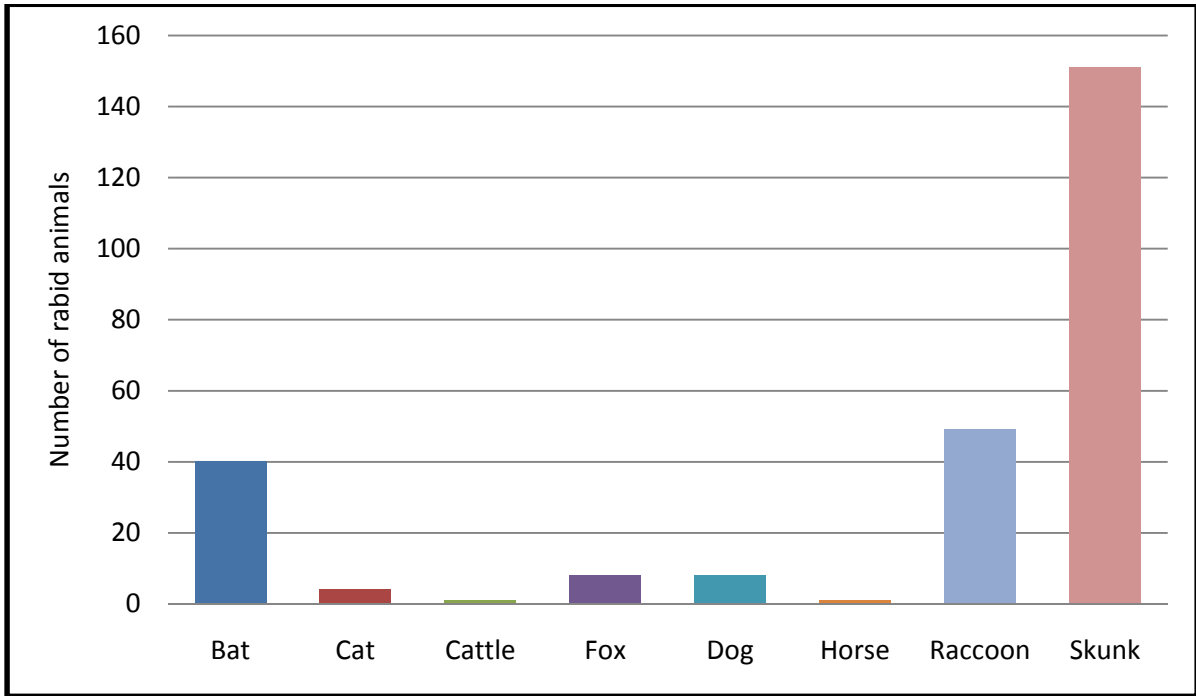


Figure 6. Number of rabid animals by species in Tennessee from 2007-2008

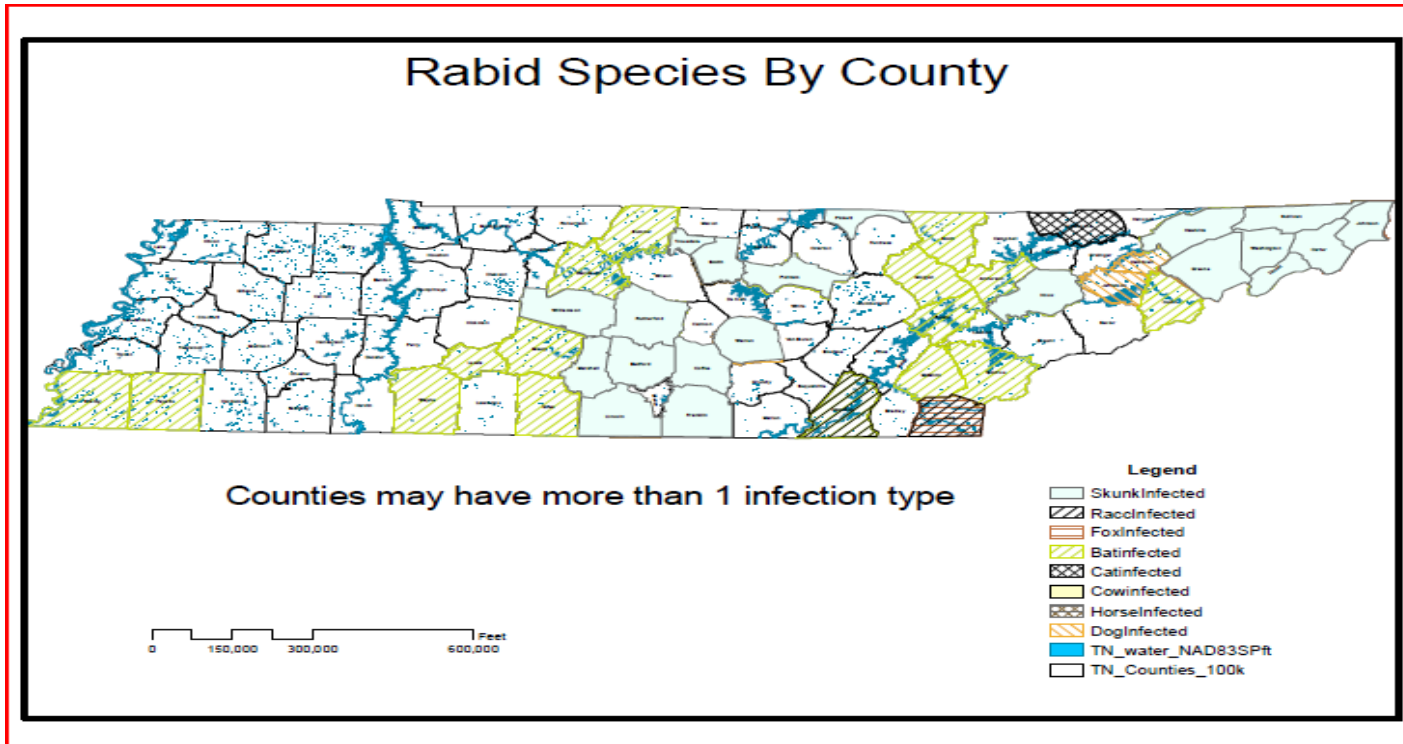


Figure 7. ArcMap® document representing Tennessee county infection rate by species infected from 2007-2008. Major water systems are represented by the blue layer.

Breakdown by Rabid Species, 1999-2008

Individual graphs were created to show the number of rabies cases associated with each of the major mammal species infected in Tennessee from 1999-2008.

Number of Rabid Skunks, 1999-2008

The number of rabid skunks per year in Tennessee (Figure 8) closely followed the trend for the total number of rabid animals per year (Figure 5). This was not surprising, given that skunks made up the majority of animals testing positive for rabies (Figure 6). Oertli et al. (2009) stated that the general trend for the number of rabid skunks increased as the total number of skunks tested for rabies increased. However, the total number of animals tested for rabies in Tennessee was only available for 2007 and 2008, so it was not possible to determine if this occurred in Tennessee.

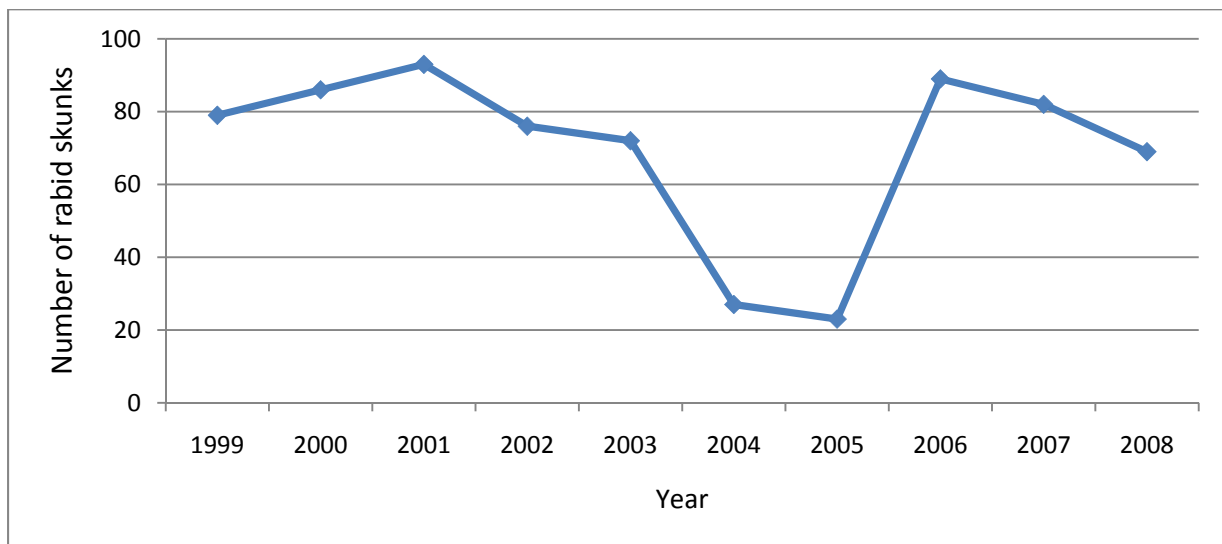


Figure 8. Number of rabid skunks in Tennessee from 1999-2008

Number of Rabid Raccoons from 1999-2008

The number of rabid raccoons in Tennessee remained below 10 per year until 2007 (Figure 9). However, the number of rabid raccoons increased to more than 20 per year in 2007 and 2008. The increase in rabid raccoons in Tennessee maybe due to skunks becoming infected with the raccoon variant of rabies and then coming into contact with non-infected skunks and raccoons (Tennessee Department of Health, 1999-2009). Skunks infected with the skunk variant are also infecting some raccoons with the skunk variant of rabies (Tennessee Department of Health, 1999-2009).

Rabies Numbers for Bats, Dogs, and Foxes from 1999-2008

The number of reported rabid bats in Tennessee has fluctuated between 10 and 27 per year from 1999-2008 (Figure 10). The number of reported rabid dogs in Tennessee remained at five or less from 1999-2008 (Figure 11). The number of reported rabid foxes was less than or equal to four from 1999-2007, but eight were reported in 2008 (Figure 12).

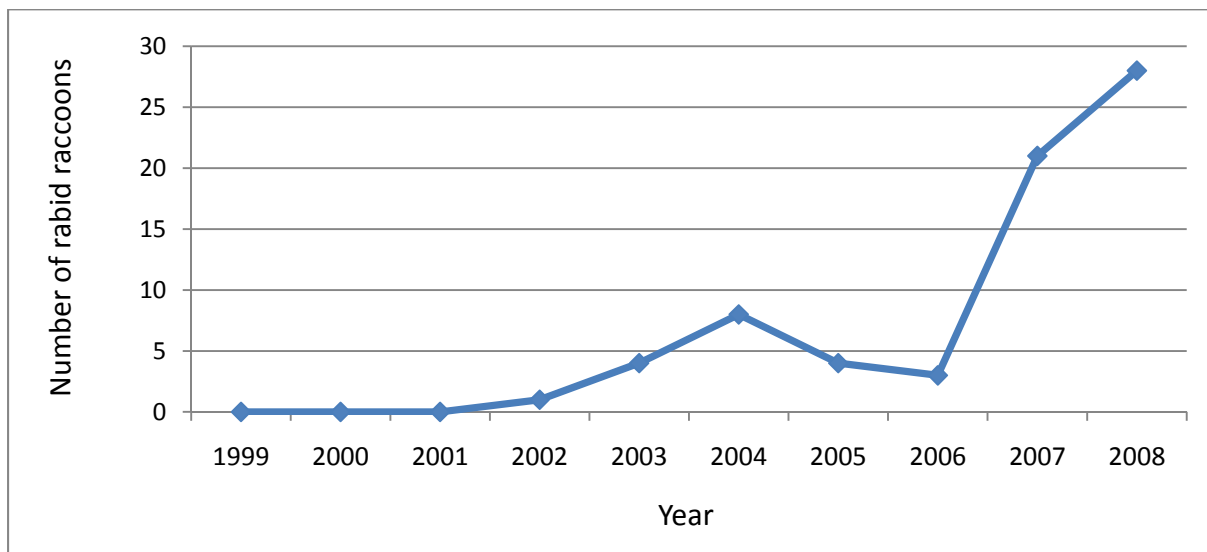


Figure 9. Number of rabid raccoons in Tennessee from 1999-2008

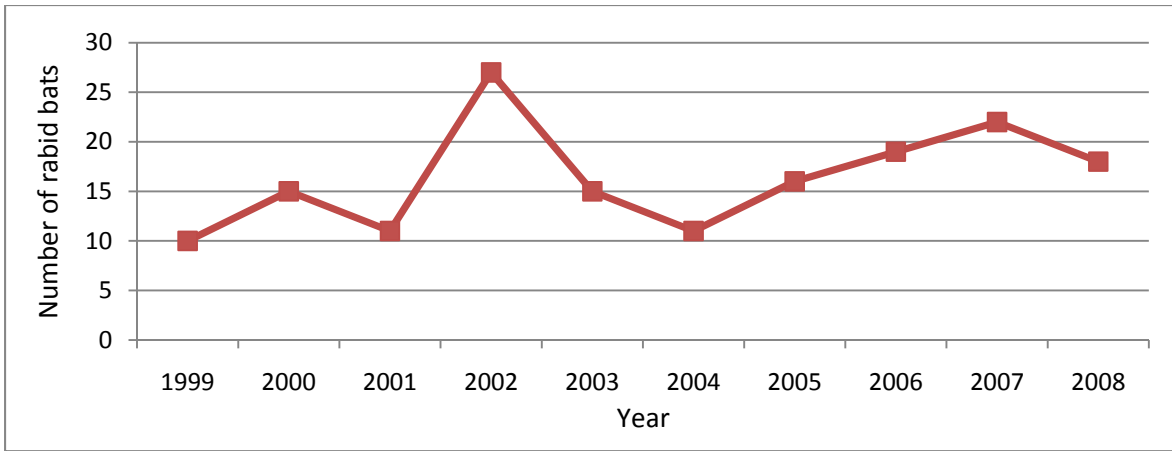


Figure 10. Number of rabid bats in Tennessee from 1999-2008

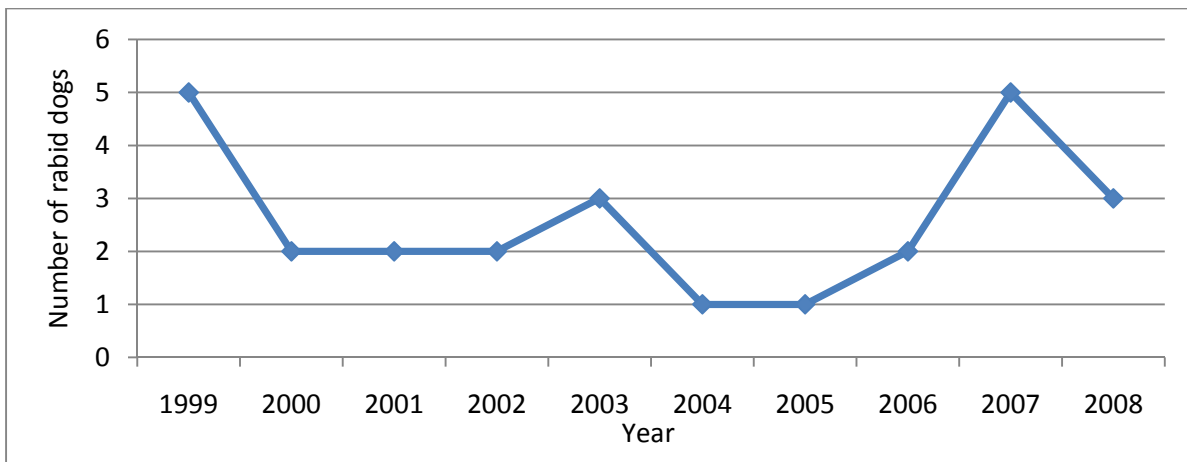


Figure 11. Number of rabid dogs in Tennessee from 1999-2008

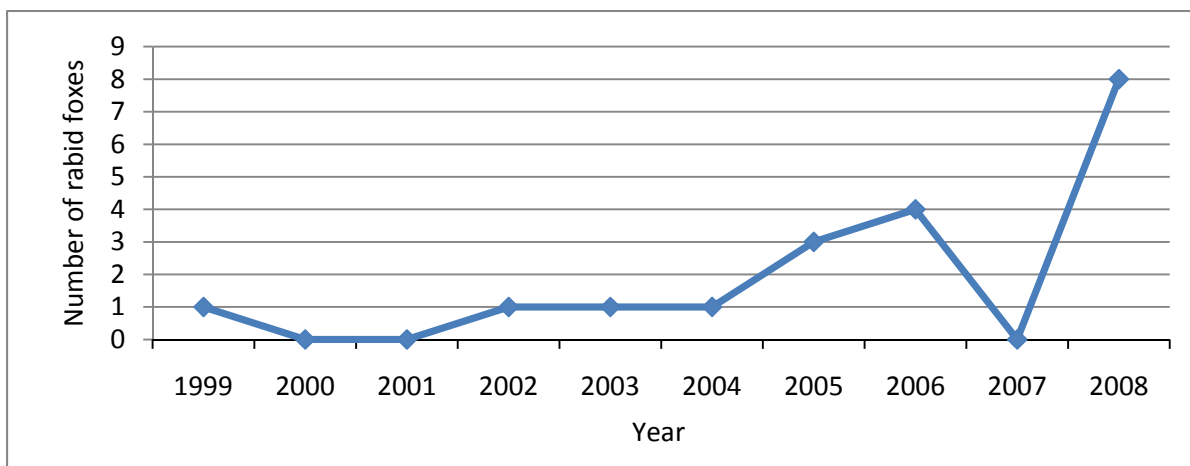


Figure 12. Number of rabid foxes in Tennessee from 1999-2008

Human Rabies Death Results

There were 203 human deaths from rabies from 1950-2008 in the United States (The Zoonosis Control Branch of the Texas Department of State Health Services, 2008). The number of deaths per year decreased in the 1950's and has remained fairly constant, with some variation from 1960 to 2005 (Figure 13). An Indiana man died from a bat bite in October of 2009, since the data from 1960-2008 was collected and analyzed (Weidenbener and Quay, 2009).

The human rabies death data was divided into human deaths that were indirectly or directly caused by domesticated animals or by wildlife (Figures 14-16). Most human rabies deaths prior to 1960 were caused by dogs infected with the canine variant of rabies. Presently, most human deaths are directly or indirectly caused by wildlife.

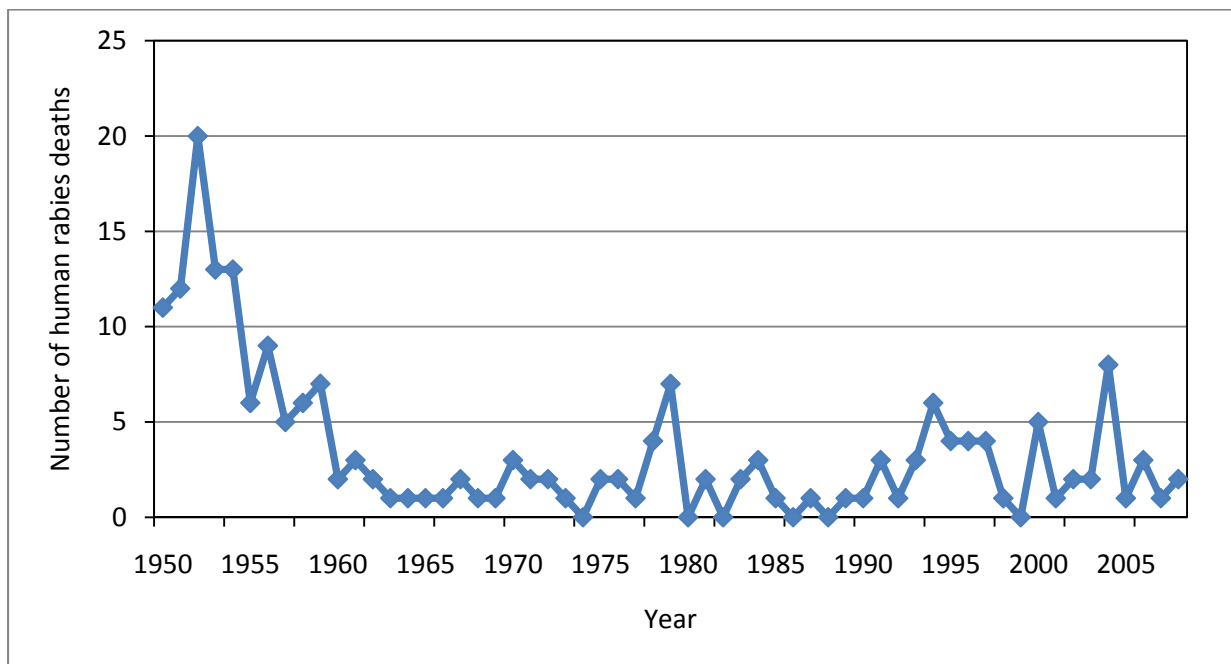


Figure 13. Number of human deaths from rabies in the United States; 1950-2008

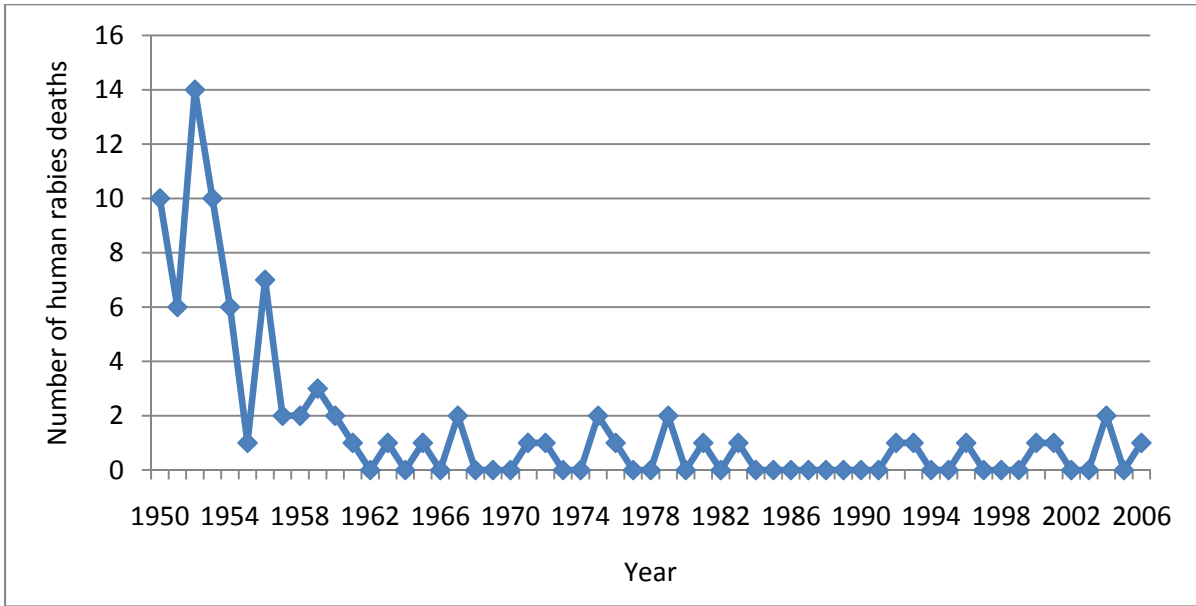


Figure 14. Human rabies deaths caused directly or indirectly by domesticated animals.

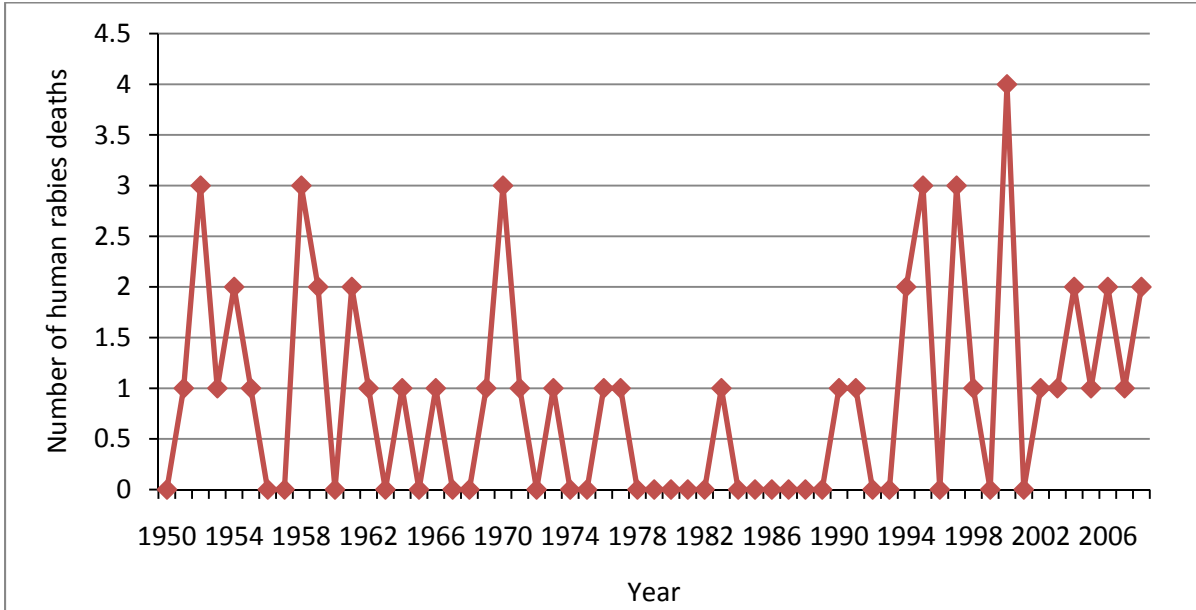


Figure 15. Human rabies deaths caused directly or indirectly by wildlife.

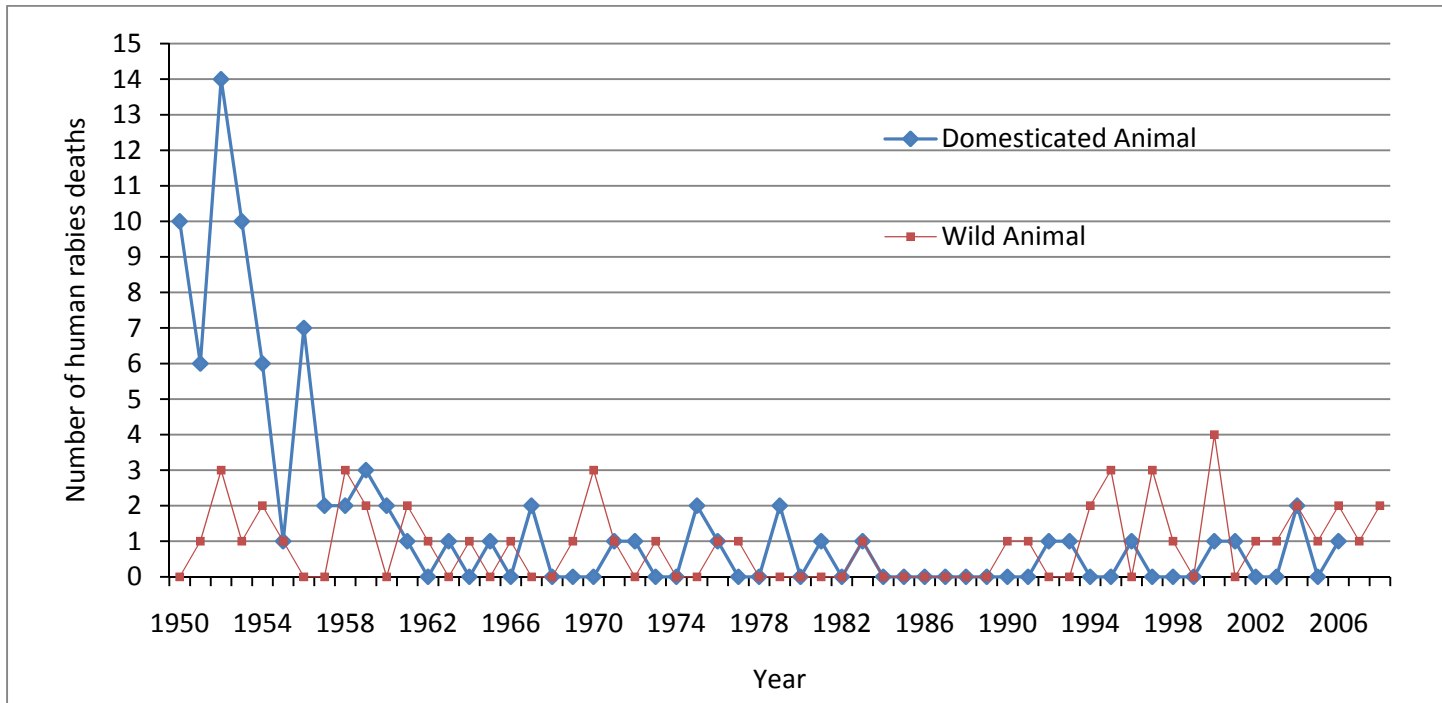


Figure 16. The number of human deaths from rabies by infection agent per region of the United States. There was a significant ($P = 0.00009$, $n = 90$) between infection agent and region.

Regional Breakdown of Human Rabies Deaths across the United States

The south region had the most human deaths (54) of the four United States regions studied (Figure 17). The category designated as 'other' also had many rabies deaths. The other category included deaths that resulted from United States' citizens becoming infected by rabies while visiting foreign countries or people infected with rabies that visited or immigrated to the United States and then died. The N/A category included 80 human rabies cases where little to no data was available.

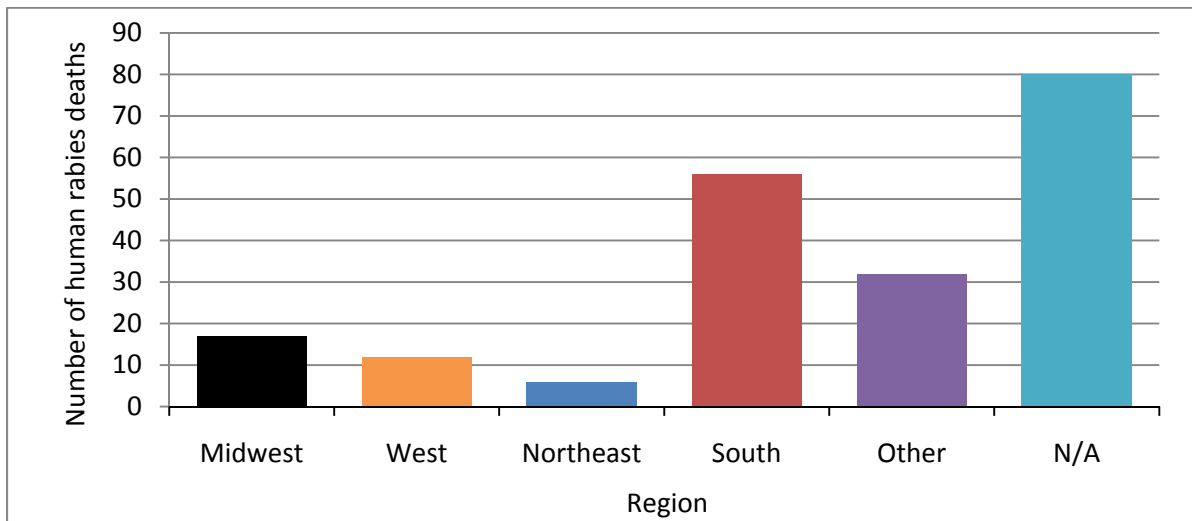


Figure 17. Total number of human death cases per region of the United States; 1950-2008. The 'Other' category includes imported rabies cases; the 'N/A' category includes cases where little or no data were available.

Gender Distribution of Human Deaths from Rabies per Region of United States

The number of human rabies deaths among males living in the Southern region of the United States was higher than the number of deaths associated with any other region of the United States (Figure 18). The number of male deaths outnumbered the number of female deaths in all regions except the Northeast, where they were equal. The relationship between gender and region was not significant (Fisher's Exact Test, $p = 0.7191$).

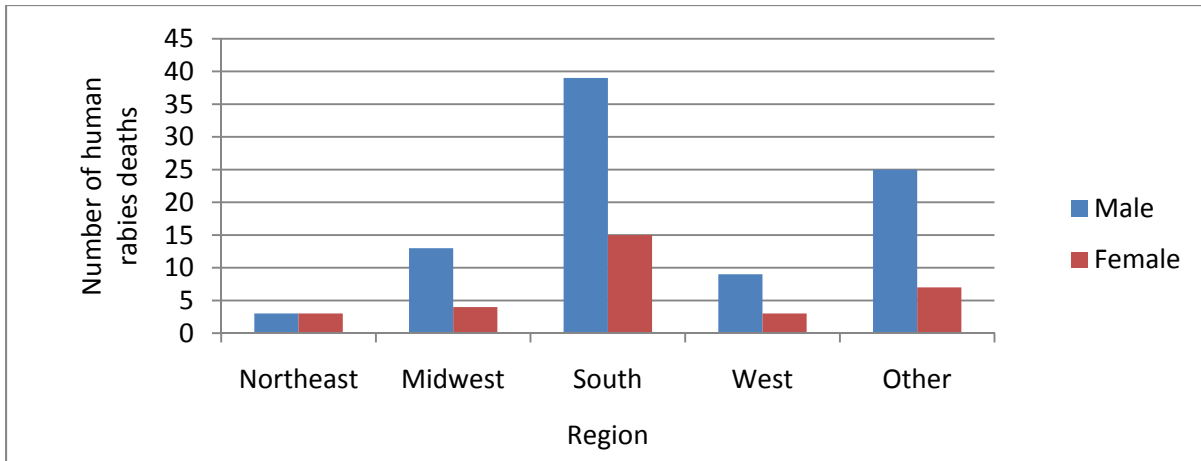


Figure 18. Number of human deaths from rabies in males and females, within regions of the United States, 1950-2008. There was no significant relationship between gender and region according to Fisher's Exact Test ($P=0.7191$, $n = 121$).

Gender Distribution of Human Rabies Deaths among Different Age Categories

Male boys below 10 years old accounted for more deaths caused by rabies than any other age group (Figure 19). There were more males than females that died from rabies in every age category, except the 51 to 60 group, where they were equal. There was no significant ($P = 0.0866$, $n = 137$) relationship between gender and age.

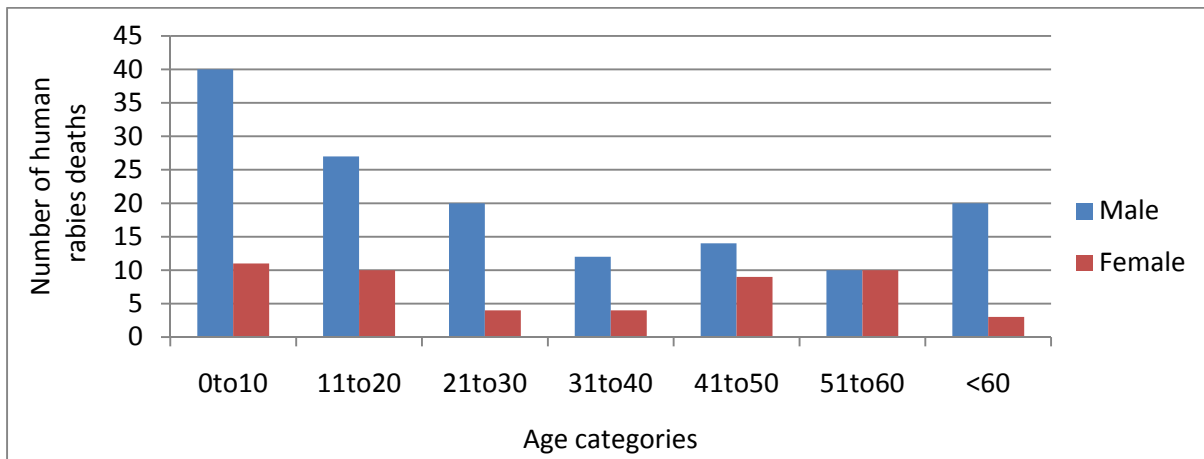


Figure 19. Distribution of human rabies deaths among age categories and gender. There was no significant ($P = 0.0866$, $n = 137$) relationship between gender and age.

Gender Distribution of Human Deaths from Rabies per Infection Agent

Males outnumbered females in every rabies infection category except for death caused by infection from bobcats or foxes, but those two categories were very small (Figure 20). Dogs accounted for the most human rabies deaths. There was no significant ($P = 0.1450$) relationship between gender and infection agent.

Distribution of Infection Agents among U.S. Regions

There was a significant ($P = 0.00009$, $n = 90$) relationship between infection agent and region for number of human deaths from rabies. This analysis was restricted to bat, dog, and fox plus skunk categories, due to the low numbers in the other infection agent categories (aerosol, bobcat, and cat). Dogs caused more deaths in humans than any other infection agent in both the skunk and 'other' regions (Figure 21). However, in the Midwest, West, and Northeast, bats were the main infection agent.

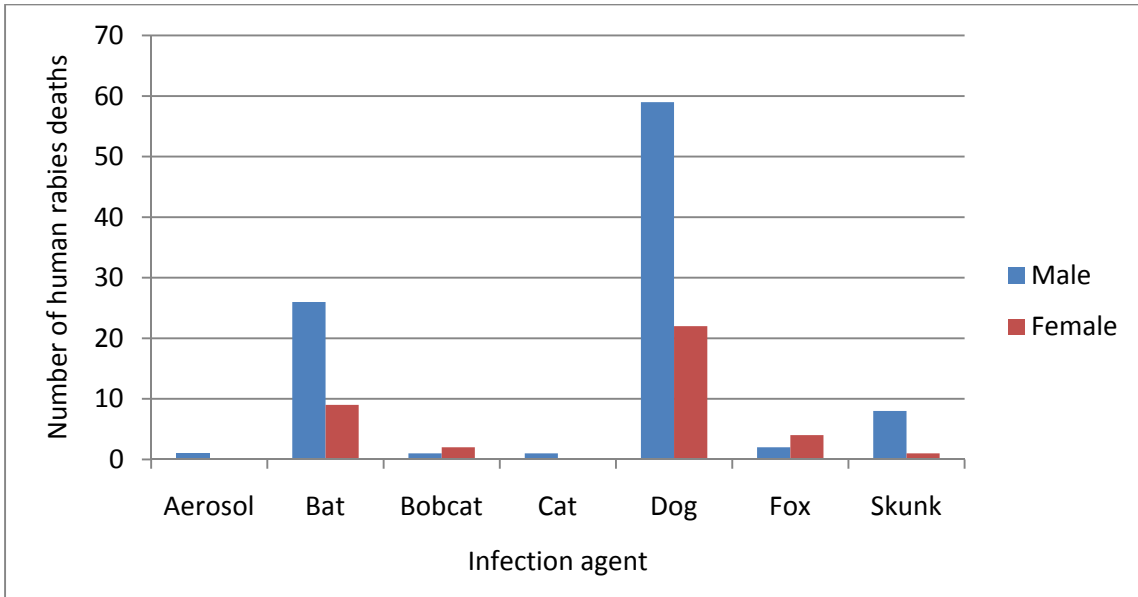


Figure 20. Number of human rabies deaths by gender and infection agent. There was no significant ($P = 0.1450$, $n = 137$) relationship between gender and infection agent.

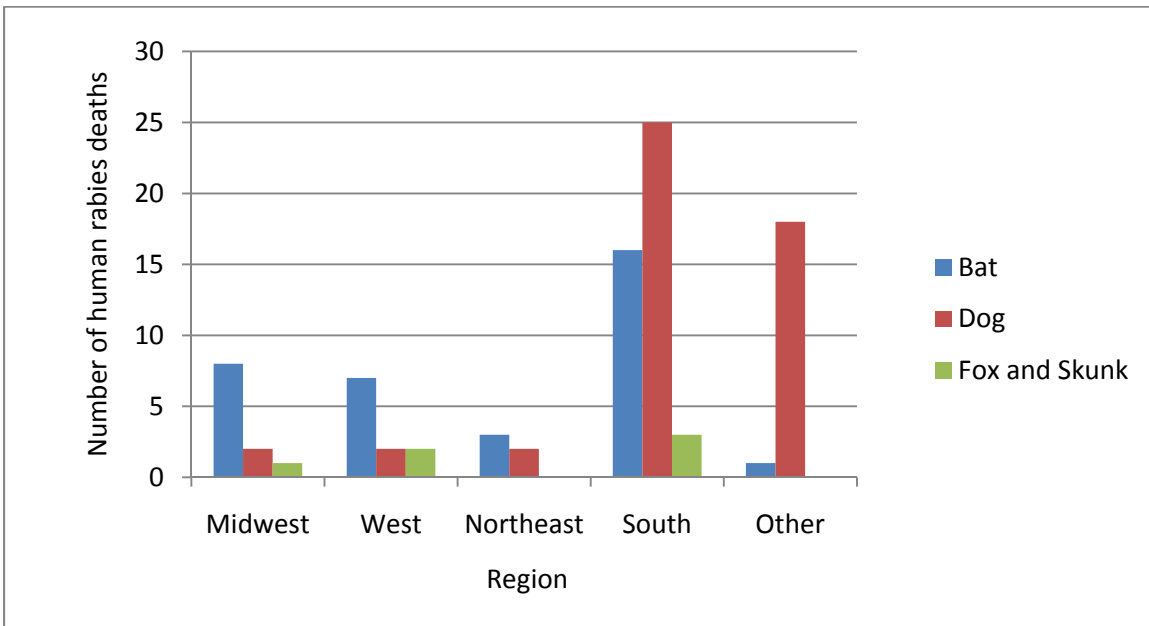


Figure 21. Human rabies deaths caused directly or indirectly by domesticated animals and by wildlife. There was a significant ($P = 0.00009$, $n = 90$) relationship between infection agent and region.

Conclusions

Rabies is still an important disease today even though it is one of the oldest recognized diseases. Rabies is a viral disease of mammals that is primarily transmitted by a bite from a rabid animal. There are several reservoirs of rabies but only skunk, bat, raccoon, and, fox reservoirs are located in Tennessee. There are many symptoms of the disease, but none that definitely indicate rabies. Death usually occurs after symptoms appear. The only way to test animals for rabies is to conduct post-mortem tests on brain samples. Ante-mortem tests are available for detecting rabies in humans, but there is no single test; a series of tests needs to be done. Rabies is preventable through vaccination. There are vaccines present for humans, some domesticated animals, and some species of wildlife.

In this study, the central region of Tennessee had more animal rabies cases than the western or eastern regions from 1999-2003. The number of rabies cases in the eastern region of Tennessee was equal to the number of rabies cases in the central region by 2007 and 2008. Most human rabies deaths in the United States, prior to 1960, were caused by dogs infected with the canine variant of rabies. Presently, most human rabies deaths in the United States are directly or indirectly caused by wildlife. Rabies is 100% preventable, so prevention is key.

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Appendix

A.1. Summary of the ANOVA analysis for the number of rabies cases per county per region of Tennessee from 1999-2008.

Source of Variation	Degrees of Freedom	SS	MS	F	Pr > F
Region	2	22464	11232	26.6	<.0001
Error	27	11401	422		
Total	29	33865.8			

Table A.2. Summary of the ANOVA analysis for the number of rabies cases per county per region of Tennessee in 1999.

Source of Variation	Degrees of Freedom	SS	MS	F	Pr > F
Region	2	120	60.3	4.53	0.0132
Error	92	1223	13.29		
Total	94	1344			

Table A.3. Summary of the ANOVA analysis for the number of rabies cases per county per region of Tennessee in 2000.

Source of Variation	Degrees of Freedom	SS	MS	F	Pr > F
Region	2	146	73.1	4.77	0.016
Error	92	1409	15.3		
Total	94	1556.1			

Table A.4. Summary of the ANOVA analysis for the number of rabies cases per county per region of Tennessee in 2001.

Source of Variation	Degrees of Freedom	SS	MS	F	Pr > F
Region	2	159.9	79.95	6.18	0.003
Error	92	1189	12.93		
Total	94	1349.7			

Table A.5. Summary of the ANOVA analysis for the number of rabies cases per county per region of Tennessee in 2002.

Source of Variation	Degrees of Freedom	SS	MS	F	Pr > F
Region	2	176.9	88.48	7.54	0.0009
Error	92	1080	11.74		
Total	94	1257.2			

Table A.6. Summary of the ANOVA analysis for the number of rabies cases per county per region of Tennessee in 2003.

Source of Variation	Degrees of Freedom	SS	MS	F	Pr > F
Region	2	127	63.8	3.85	0.0248
Error	92	1626	16.5		
Total	94	1654.7			

Table A.7. Summary of the ANOVA analysis for the number of rabies cases per county per region of Tennessee in 2004.

Source of Variation	Degrees of Freedom	SS	MS	F	Pr > F
Region	2	9.47	4.73	1.61	0.205
Error	92	270	2.93		
Total	94	279.7			

Table A.8. Summary of the ANOVA analysis for the number of rabies cases per county per region of Tennessee in 2005.

Source of Variation	Degrees of Freedom	SS	MS	F	Pr > F
Region	2	7.98	3.99	3.29	0.0419
Error	92	111.7	1.21		
Total	94	119.7			

Table A.9. Summary of the ANOVA analysis for the number of rabies cases per county per region of Tennessee in 2006.

Source of Variation	Degrees of Freedom	SS	MS	F	Pr > F
Region	2	107	53.5	3.98	0.0219
Error	92	1235	13.43		
Total	94	1342.8			

Table A.10. Summary of the ANOVA analysis for the number of rabies cases per county per region of Tennessee in 2007.

Source of Variation	Degrees of Freedom	SS	MS	F	Pr > F
Region	2	73.35	36.67	1.96	0.1466
Error	92	311.2	1721		
Total	94	1794.5			

Table A.11. Summary of the ANOVA analysis for the number of rabies cases per county per region of Tennessee in 2008.

Source of Variation	Degrees of Freedom	SS	MS	F	Pr > F
Region	2	79.6	39.8	4.54	0.0131
Error	92	806.19	8.76		
Total	94	885.8			

Table A.12. Mean number of rabies cases per county per region of Tennessee from 1999-2008.

Region	Year									
	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Central	2.6129a*	2.8710a	2.9677a	3.0968a	2.710a	0.8710a	0.7742a	2.7097a	1.935a	1.7742a
Eastern	0.3333b	0.3636b	0.3939b	0.2424b	0.394b	0.5758a	0.6364ab	1.0000ab	2.061a	2.1818a
Western	0.0968b	0.0968b	0.0323b	0.1290b	0.097b	0.0968a	0.0968b	0.1298b	0.129a	0.0645b

*Means followed by the same letter are not significantly different by Ryan-Einot-Gabriel-Welsch Multiple Range Test ($P \leq 0.05$). $n = 31$ for central and western regions and $n = 33$ for eastern region.

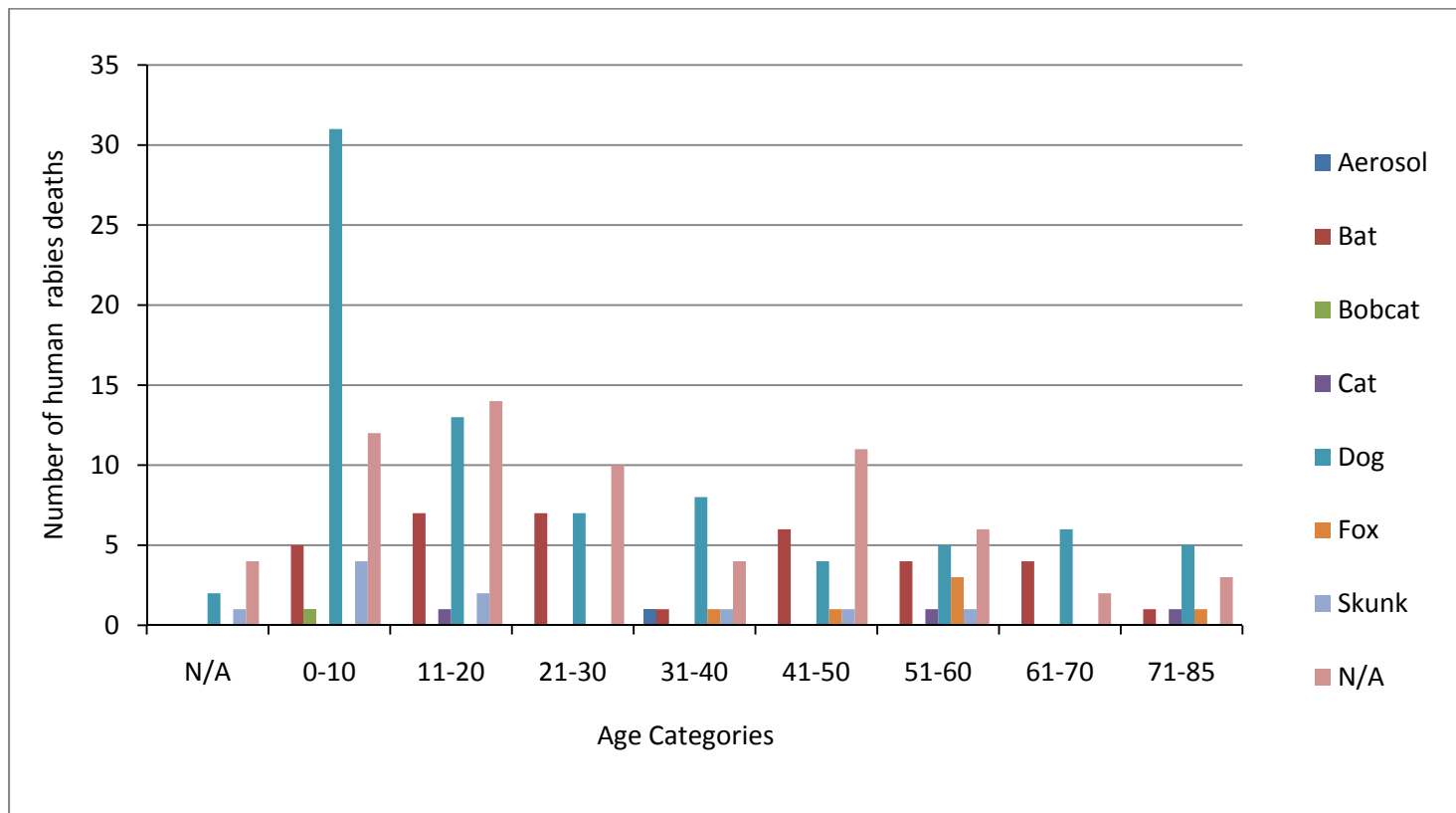
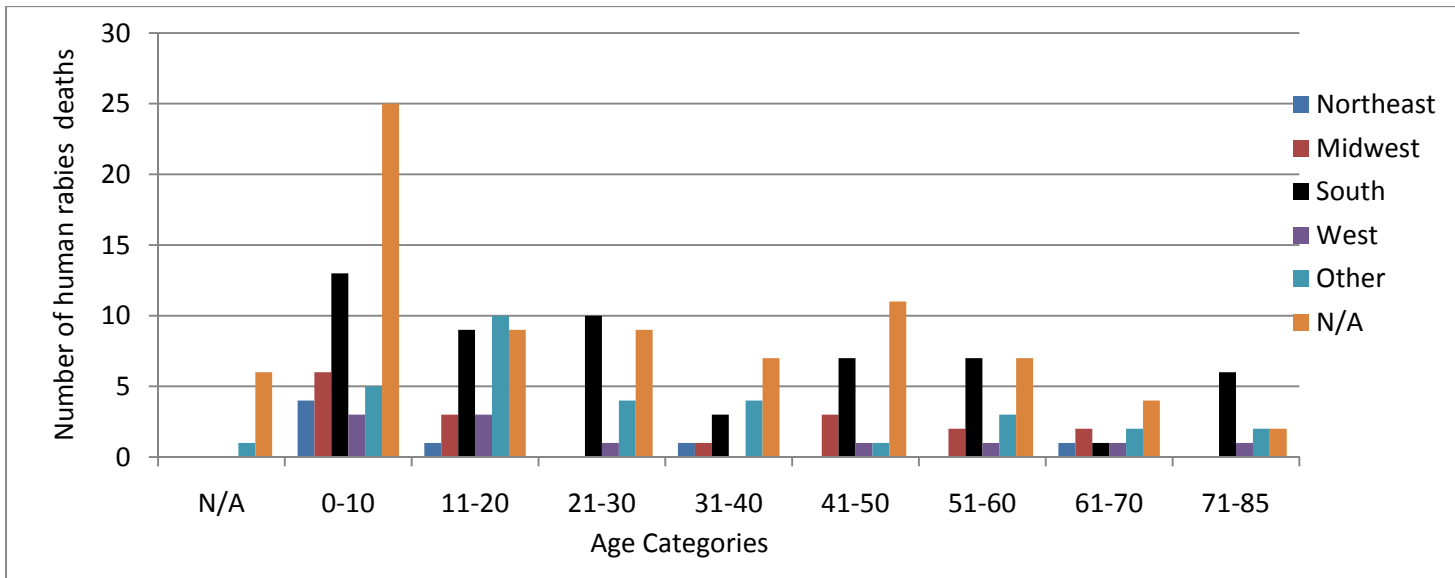
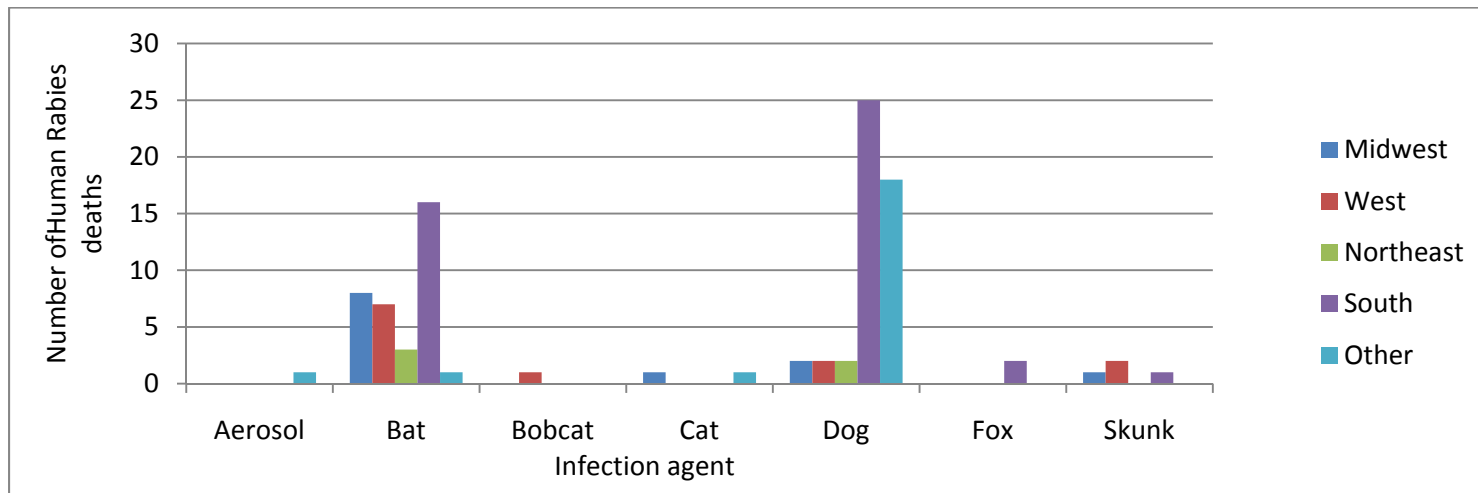


Figure A.1. Number of human deaths from rabies by age category and infection agent.



FigureA.2. Number of human deaths from rabies by age and region of the United States.



FigureA.3. Number of human deaths from rabies by infection agent and region of the U.S.

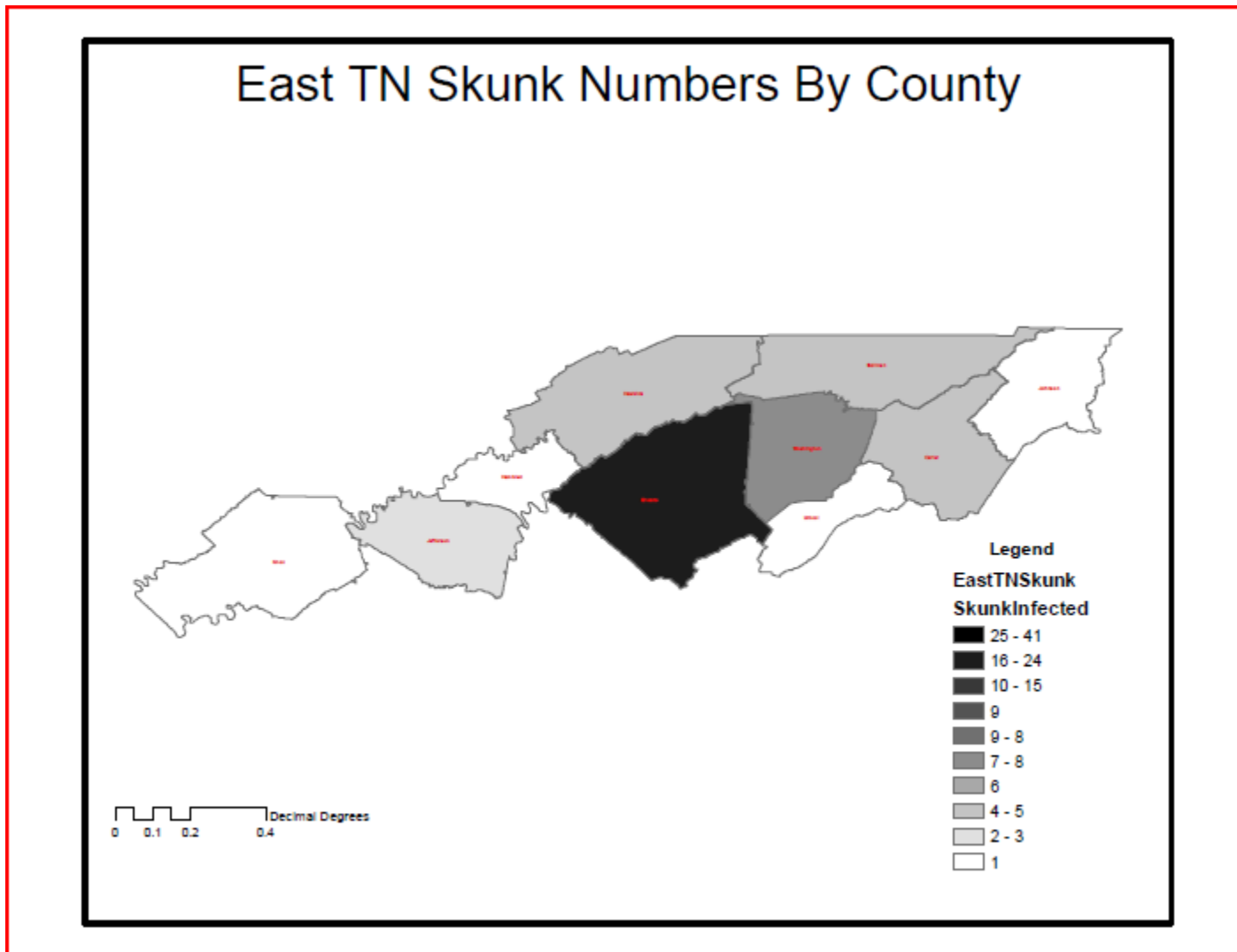


Figure A.4. East Tennessee skunk numbers per county from 2007-2008