Human–Wildlife Interactions 13(1):167–175, Spring 2019 • digitalcommons.usu.edu/hwi

Control efforts and serologic survey of pseudorabies and brucellosis in wild pigs of Tennessee

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Abstract: European wild pigs (*Sus scrofa*) are an introduced invasive species that now constitute a major threat to agriculture and the natural ecology of the environments they now inhabit. Wild pigs also carry many diseases known to infect wildlife, humans, and livestock. Two of these diseases, pseudorabies (PRV) and brucellosis, constitute major diseases in the United States. Better data are needed regarding the prevalence of these diseases in wild pigs to understand and manage the potential risks to wildlife, humans, and livestock. From July 1, 2011 to June 30, 2017, Tennessee Wildlife Resources Agency personnel trapped and euthanized 4,727 wild pigs, of which 2,991 were tested for PRV and brucellosis. Of the wild pigs successfully tested and county recorded, 2.52% (73/[2,829+73]) were positive for PRV antibodies and 2.09% (59/[2,768+59]) were positive for brucellosis antibodies. Although the overall incidence of PRV and brucellosis seropositive wild pigs was low across the state, there were counties with high prevalence of past exposure. Disease issues will likely increase as wild pig populations expand across Tennessee. Efforts to educate the public regarding the disease potential of wild pigs should be increased and options made available for control.

Key words*:* brucellosis, disease management, disease surveys, pseudorabies, *Sus scrofa*, Tennessee, wild pigs, zoonosis

European wild pigs (*Sus scrofa*) were introduced into a North Carolina, USA game preserve around 1912, and in 1920, about 100 escaped and became feral within the Great Smoky Mountains National Park (GSMNP; Stegeman 1938). A tradition of wild pig hunting encompassed the surrounding lands, and accidental release or escape of domestic pigs promoted 2 main populations of wild pigs in Tennessee (around South Cherokee and Catoosa Wildlife Management Area; Conley et al. 1972). Since the 1990s, these populations have expanded due to illegal translocation of pigs (Yoest et al. 2013). Jerrolds et al. (2014) reported the presence of wild pigs at 89 of the 95 counties in Tennessee in 2013. As wild pig populations have expanded across the state, public concerns regarding the effects of non-native wild pigs on the environment, potential disease transmission to wildlife, humans, and livestock, and destruction of agricultural crops have increased.

Wild pigs carry many diseases known to infect wildlife, humans, and livestock. Miller et al. (2017) reviewed the literature on wild pig disease studies in North America and found 87% of listed pig diseases can cause clinical disease in livestock, poultry, wildlife, and humans. Currently, 57% of farms with 77% of agricultural animals occur where wild pigs are found. Therefore, there is great potential for cross-species transmission of pathogens, which should be monitored as populations increase.

Two of these diseases, pseudorabies (PRV) and brucellosis, have been of particular interest in the United States. A herpesvirus (*suid herpesvirus* 1), PRV (also known as Aujeszky's disease) has become a significant pathogen of concern for domestic pigs (Stallknecht and Howerth 2001). The virus can cause respiratory distress or even death in young pigs. Some adults appear to be asymptomatic, but PRV may cause abortion or mummified fetuses in pregnant sows. Adult pigs, generally considered carriers of PRV, can shed the virus while appearing clinically normal. Although pseudorabies does not seem to affect wild pig populations and is not a threat to humans, it

Table 1. Wild pigs (*Sus scrofa*) collected the Tennessee Wildlife Resources Agency (TWRA) and mean number of wild pigs shot by landowners, Tennessee, USA, July 1, 2011 to June 30, 2017.

Fiscal year (July 1 to June 30)	Estimated mean and (total number) of wild pigs shot per landowner	Number of wild pigs collected by TWRA	Number and (%) of wild pigs tested for pseudorabies or brucellosis
2011–2012	4.16 (3,162)	800	789 (98.6)
2012–2013	3.41 (3,801)	720	500 (69.4)
2013–2014	4.22 (4,561)	552	483 (87.5)
2014–2015	3.21 (3,121)	951	392 (41.2)
2015–2016	5.04 (6,059)	1031	234 (22.7)
2016–2017	3.73 (4,013)	673	216 (32.1)
Total	$\bar{x}$ 3.96, 24,717	$\bar{x}$ 788, 4,727	2,614

Table 2. Wild pigs (*Sus scrofa*) collected by sex and age, Tennessee, USA, January 17, 2011 to August 2, 2017.

	Age[a]		
Sex	Adult	Juvenile	Total
Female	638 (29.4%)	488 (22.5%)	1,126 (51.8%)
Male	544 (25.1%)	502 (23.1%)	1,046 (48.2%)
Total	1,182 (54.4%)	990 (45.6%)	2,172 (100%)

[a]Age determined by tooth replacement (Matschke 1967).

may be transmitted by adult wild pigs to other wildlife (e.g., carnivores) or domestic animals (e.g., livestock; Stallknecht and Howerth 2001).

Swine brucellosis is caused by the bacteria *Brucella suis* and is primarily a disease of the reproductive tract in pigs (Thorne 2001). Although some pigs may not exhibit signs of illness, the classic signs include abortion, infertility, and lameness. Bevins et al. (2014) found 4.3% seroprevalence for brucellosis in wild pigs nationwide from 2006 to 2012. However, population effects of brucellosis on wild pigs have not been studied (Davidson 2006). Transmission of brucellosis from wild pigs to livestock and humans is a serious concern. Humans can develop flu-like symptoms from handling and field dressing infected wild pigs (Thorne 2001). Mortality rates for humans are low, but the disease can be prolonged and cause a recurrent fever (Davidson 2006, Brown et al. 2017).

In 2011, the Tennessee Wildlife Resources Agency (TWRA) started wild pig control operations which included testing for pseudorabies and brucellosis across the state. Poudyal et al. (2017) estimated damage from wild pigs in Tennessee to be as high as $26 million with $2 million also spent on controlling populations. We wanted to evaluate the prevalence of PRV and brucellosis exposure in wild pig populations of Tennessee using serology surveys. These data are needed to better elucidate the prevalence of these pathogens across the state of Tennessee to better understand potential risks to wildlife, humans, and livestock.

Methods

Starting in January 2011, TWRA personnel controlled wild pig populations across the state of Tennessee by trapping and shooting. The numbers of wild pigs shot by landowners were also estimated based on required landowner reports from exemptions issued by TWRA (hunting without a license because they are the resident landowner) to provide estimates of the total number of wild pigs harvested in the state annually. Field personnel recorded location (wildlife management area or county), sex and age (adult or juvenile) based on tooth eruption (Matschke 1967), and collected a blood sample from pooled blood in the body cavity or

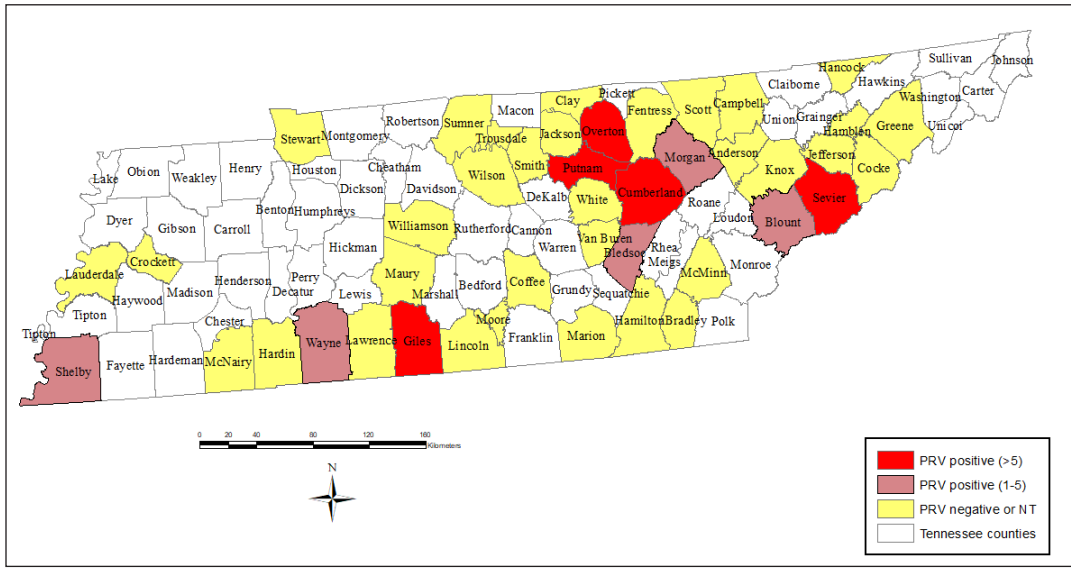

Figure 1. Wild pigs (*Sus scrofa*) collected for serological testing for pseudorabies (PRV), Tennessee, USA, January 17, 2011 to August 2, 2017. Counties are colored according to PRV seroprevalence in wild pigs.

directly from the heart of all wild pigs that were shot. Blood samples were kept in a cooler and refrigerated (if needed) before being sent to the C. E. Kord Animal Health Diagnostic Laboratory of the Tennessee Department of Agriculture in Nashville, Tennessee. Sera were tested for PRV antibodies using an enzyme-linked immunosorbent assay (IDEXX PRV/Aujeszky's Disease (ADV) gB AbTest, IDEXX, Westbrook, Maine, USA) and *Brucella abortus/suis* antibodies using buffered acidified plate antigen (BAPA) test (using standard operating procedures from U.S. Department of Agriculture, Animal Plant Health Inspection Service, National Veterinary Services Laboratory, Ames, Iowa, USA). We considered pathogen exposure to be a proxy for disease transmission risk in the population.

We used SAS 9.3 (SAS Institute, Cary, North Carolina, USA) to tabulate frequency counts of wild pigs killed by county, year, sex, age, and total across the state of Tennessee. Prevalence of exposure was calculated by (number positive pigs/[number positive + number negative pigs])*100. We did not compare demographics of positive and negative pathogen exposure because of the low incidence of positive pigs. We did not include pig records when no county was recorded. The counts of positive and negative wild pigs were mapped by county using ArcMap10 (ESRI, Redlands, California, USA).

Results

Personnel trapped and euthanized 4,727 wild pigs from July 1, 2011 to June 30, 2017 (Table 1). During the same time period, landowners with wild pig exemptions reported an estimated mean of 3.96 wild pigs shot per year at their properties (Table 1) with an estimated total of 24,717 wild pigs removed.

Of the wild pigs killed by TWRA, 2,991 (January 17, 2011 to August 2, 2017) were tested for PRV and brucellosis exposure with sex and age recorded for 2,172 pigs. No county was recorded for 35 of the records so they were not included in the maps or analysis (n = 2,956; Table 2). The number of pigs tested (Table 1) and distribution of collection differed across years due to funding, logistics, and emphasis areas.

For the entire state, 2.52% (73/[2,829+73]) of the wild pigs tested were positive for PRV antibodies (49% male and 51% female; 53% adult and 47% juvenile). Counties with high prevalence of PRV positive wild pigs were Giles (31.37%; 16 of 51 pigs) and Putnam (25.97%; 20 of 77 pigs). The highest number of PRV seropositive (>5) wild pigs occurred in Cumberland, Giles, Overton, Putnam, and Sevier counties (Figure 1).

Overall, 2.09% (59/[2,768+59]) of the wild pigs were positive for brucellosis antibodies

Table 3. Wild pigs (*Sus scrofa*) collected the Tennessee Wildlife Resources Agency (TWRA) and mean number of wild pigs shot by landowners, Tennessee, USA, July 1, 2011 to June 30, 2017.

County	Total number of wild pigs tested	PRV				Brucellosis			
		Not satisfactory for testing	Negative	Positive	Incidence	Not satisfactory for testing	Negative	Positive	Incidence
Anderson	28	0	28	0	0.00	0	28	0	0.00
Bledsoe	133	3	125	5	3.85	3	128	2	1.54
Blount	37	0	36	1	2.70	1	36	0	0.00
Bradley	11	0	11	0	0.00	0	7	4	36.36
Campbell	110	4	106	0	0.00	2	108	0	0.00
Clay	1	0	1	0	0.00	0	1	0	0.00
Cocke	22	1	21	0	0.00	2	20	0	0.00
Coffee	1	0	1	0	0.00	1	0	0	0.00
Crockett	8	0	8	0	0.00	0	8	0	0.00
Cumberland	335	2	327	6	1.80	31	269	35	11.51
Fentress	14	4	10	0	0.00	1	13	0	0.00
Giles	51	0	35	16	31.37	1	50	0	0.00
Greene	22	0	22	0	0.00	0	22	0	0.00
Hamblen	1	0	1	0	0.00	0	1	0	0.00
Hamilton	5	0	5	0	0.00	0	5	0	0.00
Hancock	28	0	28	0	0.00	2	26	0	0.00
Hardin	25	0	25	0	0.00	0	25	0	0.00
Jackson	13	0	13	0	0.00	0	13	0	0.00
Jefferson	28	1	27	0	0.00	4	24	0	0.00
Knox	10	1	9	0	0.00	1	9	0	0.00
Lauderdale	23	0	23	0	0.00	0	23	0	0.00
Lawrence	7	0	7	0	0.00	0	7	0	0.00

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Lincoln	4	0	4	0	0.00	0	4	0	0.00
Marion	5	0	5	0	0.00	0	5	0	0.00
Maury	118	0	118	0	0.00	3	115	0	0.00
McMinn	14	0	14	0	0.00	0	14	0	0.00
McNairy	12	0	12	0	0.00	2	9	1	10.00
Moore	2	0	2	0	0.00	0	2	0	0.00
Morgan	226	0	223	3	1.33	13	207	6	2.82
Overton	84	1	77	6	7.22	13	69	2	2.82
Putnam	77	0	57	20	25.97	0	76	1	1.30
Scott	208	16	192	0	0.00	16	192	0	0.00
Sevier	121	4	105	12	10.25	4	117	0	0.00
Shelby	30	1	28	1	3.45	13	16	1	5.88
Smith	2	0	2	0	0.00	0	2	0	0.00
Stewart	8	0	8	0	0.00	0	8	0	0.00
Sumner	44	0	44	0	0.00	0	44	0	0.00
Trousdale	5	0	5	0	0.00	0	5	0	0.00
Van Buren	25	6	19	0	0.00	5	20	0	0.00
Wayne	961	5	953	3	0.31	3	951	7	0.73
White	74	3	71	0	0.00	7	67	0	0.00
Williamson	5	1	4	0	0.00	0	5	0	0.00
Wilson	18	1	17	0	0.00	1	17	0	0.00
Total	2,956	54	2,829	73	2.52	129	2,768	59	2.09

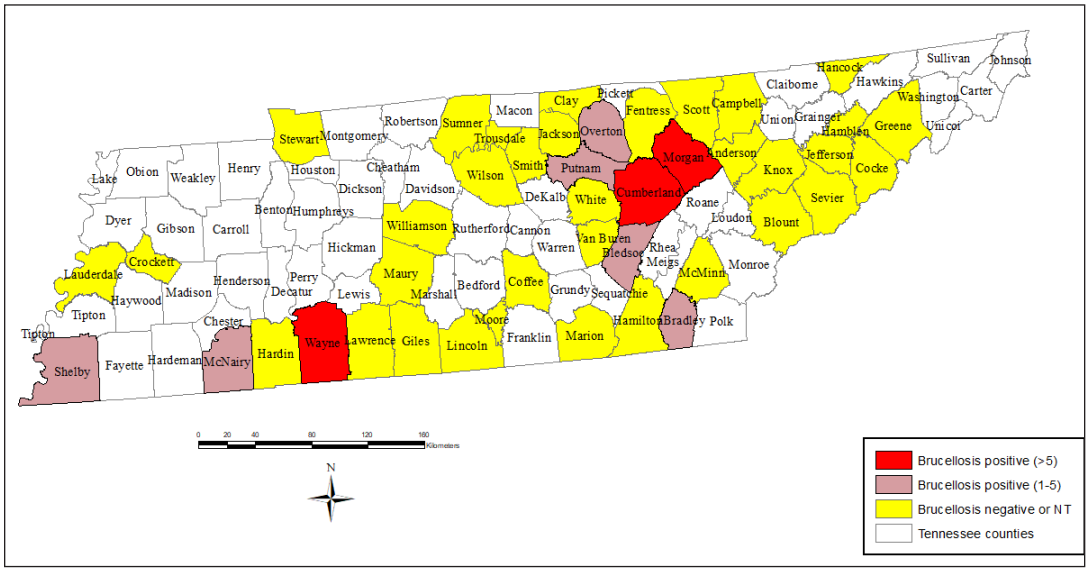

Figure 2. Wild pigs (*Sus scrofa*) collected for serological testing for brucellosis Tennessee, USA, January 17, 2011 to August 2, 2017. Counties are colored according to brucellosis seroprevalence in wild pigs.

(56% male and 44% female; 71% adult and 29% juvenile). Bradley County had the highest prevalence (36.36%; 4 of 11 pigs) followed by Cumberland (11.51%; 35 of 304 pigs) and McNairy (10.00%; 1 of 10 pigs; Table 3). Cumberland, Morgan, and Wayne counties had >5 brucellosis seropositive wild pigs (Figure 2).

Discussion

Overall incidence of PRV (2.52%) and *B. suis* (2.09%) seropositive wild pigs was low across the state, but there were counties with high prevalence of past exposure. One area centered on Catoosa Wildlife Management Area between Cumberland and Morgan Counties, which was an area of high positive serology for both PRV and brucellosis. This area was among the original locations of wild pig introductions in Tennessee (Yoest et al. 2013).

Historically, wild pigs have been managed through harvest and classified as big game. However, wild pig numbers continued to increase, and in 2011, wild pigs were declared as a statewide non-protected species and considered as wildlife deemed destructive (Yoest et al. 2013). The change in regulations was to limit incentive for establishing populations for hunting and also to open pig control statewide. The TWRA implemented tighter restrictions on transportation of wild-appearing pigs and more options for controlling or eliminating wild pigs (e.g., shooting over bait and at night). The TWRA is now using lethal control methods to minimize the impacts of wild pigs, and disease testing should continue, especially in new locations where they occur.

Nearby wild pig populations in the GSMNP were surveyed for PRV and brucellosis (New et al. 1994, Cavendish et al. 2008). These pig populations have been long established but exist in a national park where no domestic pigs are raised except on the periphery. No antibodies to PRV and brucellosis were found in wild pigs by 1990 (New et al. 1994), but PRV exposure was detected in 2005 and thought to be related to illegal movement of wild pigs near the park perimeter (Cavendish et al. 2008).

Across the United States, seroprevalence of PRV was 15.5 % from 2007 to 2012, and brucellosis was 4.3% from 2006 to 2012 (reviewed in Bevins et al. 2014). However, there seems to be a wide variation in pathogen exposure by locality. Pedersen et al. (2013) reported exposure to PRV in 25 of 35 states where wild pigs were sampled. Recently established wild pig populations in North Carolina that occur with high-density commercial pork production did not have evidence of exposure to PRV or brucellosis during 2006 to 2007 (Corn et al. 2009). These commercial operations for pig production are managed to prevent contact with wild pigs. In contrast, long-established

wild pig populations in South Carolina with more opportunity to interact with captive pigs were positive for antibodies against PRV (20%) and *Brucella suis* (14%; Corn et al. 2009). Gresham et al. (2002) found 61% of wild pigs were positive for PRV and 44% for brucellosis in a population in coastal South Carolina, USA in 1999. Across Florida, USA, 51% of wild pigs sampled were seropositive for PRV (Hernández et al. 2018).

We only tested for past exposure to PRV and brucellosis through serology and did not test for the actual pathogenic organisms. Hernández et al. (2018) found serology may underreport the risk of PRV in wild pigs. Wild pigs positive for the viral DNA had the potential to shed the virus through blood, nasal, oral, or genital routes, and 7% of the PRV-seronegative wild pigs were found to also shed the virus. Therefore, our numbers may be conservative for PRV considering some of the negative tests may have been for an animal with the pathogen. Similar to PRV testing, more in-depth analysis of brucellosis would be needed to determine the actual *Brucella* species and biovar present in the population (Leiser et al. 2013); however, the serosurvey showed that *Brucella* spp. is present in select areas of Tennessee. We were not able to evaluate the change in exposure for either pathogen over time since there were variable numbers of animals tested (Table 1) and the location of harvest concentration differed by year.

However, even if our numbers of positive pigs are conservative and low, finding any positive animals may negatively affect human and animal health and the pork industry. Both PRV and brucellosis are part of a U.S. federal eradication program, and eradication may be affected by pathogens spread by wild pig populations (reviewed in Miller et al. 2013). In 2016, the National Agricultural Statistics Service reported gross income from domestic pig production in Tennessee was $74.5 million (https://quickstats.nass.usda.gov). While PRV and brucellosis have been declared eradicated from domestic pigs (reviewed in Corn et al. 2004, Leiser et al. 2013), pathogens transmitted by wild reservoirs could infect farming operations, greatly reduce profits, and pose a risk for animal or human health. Gaskamp et al. (2016) recommended pork producers continue disease surveillance and establish risk zones and spatial control efforts surrounding their operations. Efforts to educate the public regarding ecological impacts and disease potential of wild pigs should be increased.

Disease issues will likely increase as pig populations increase across Tennessee (Jerrolds et al. 2014) and the United States (Corn and Jordan 2017). There has been a relatively constant effort each year to kill pigs in Tennessee by landowners and TWRA personnel (Table 1) because of concerns about disease and damage. Caplenor et al. (2017) sampled Tennessee households in 2015 to determine property owners' knowledge of pig presence in their land and/or community, the type of damage, and perception of feral population trends and risk of pathogen transmission. A companion study estimated the economic value of damage attributable to wild pigs in Tennessee to be as high as $26 million, with an additional $2 million spent in control measures (Poudyal et al. 2017).

Management implications

Although the overall incidence of PRV and brucellosis seropositive in the wild pigs tested in our study was low across the state, there were counties with high prevalence of past exposure. Disease issues will likely increase as wild pig populations expand across Tennessee. Landowners that raise domestic pigs have supported state regulations to control wild pigs because of concerns about interbreeding between domestic and wild pigs or pathogen transmission to their livestock. Efforts to educate the public regarding the disease potential of wild pigs should be increased and options made available for control.

Acknowledgments

Numerous personnel of TWRA trapped and collected samples from wild pigs. The study was encouraged and supported by the Tennessee Department of Agriculture and state veterinarian C. Hatcher, who is currently serving as the commissioner for the Tennessee Department of Agriculture. The staff of C. E. Kord Animal Health Laboratory conducted the serology tests. Comments provided by J. Beasley, HWI associate editor, and 2 anonymous reviewers greatly improved the manuscript.

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