

Bullet fragmentation and lead deposition in white-tailed deer and domestic sheep

MARRETT D. GRUND, Minnesota Department of Natural Resources, Farmland Wildlife Research Group, 35365 800th Avenue, Madelia, MN 56062, USA marrett.grund@dnr.state.mn.us

LOUIS CORNICELLI, Minnesota Department of Natural Resources, 500 Lafayette Road, St. Paul, MN 55155, USA

LEAH T. CARLSON, Minnesota Department of Natural Resources, Farmland Wildlife Research Group, 35365 800th Avenue, Madelia, MN 56062, USA

ERIKA A. BUTLER, Minnesota Department of Natural Resources, Wildlife Disease Research Group, 5463-C West Broadway, Forest Lake, MN 55025, USA

Abstract: In February 2008, a private physician in North Dakota radiographed hunter-harvested venison and found that 60 of 100 packages contained metal fragments. This discovery had implications for public-funded venison donation programs, and it prompted several Midwest states to examine their programs. Approximately 500,000 deer hunters harvest >200,000 deer annually in Minnesota, and the state has a donation program similar to North Dakota's program. Therefore, we analyzed fragmentation patterns and lead deposition in carcasses of 8 white-tailed deer (*Odocoileus virginianus*) and 72 domestic sheep (*Ovis aries*). We fired 5 different bullet types from centerfire rifles, and we also fired projectiles from both a shotgun and a black-powder muzzleloader. Centerfire bullets, which are designed to expand quickly upon impacting the animal, left bullet fragments and lead deposits throughout the entire abdominal cavity of carcasses. We also used 2 types of centerfire bullets that were purportedly designed to resist fragmentation. One of these bullet types had fragmentation patterns and lead deposition rates similar to the rapid-expanding bullets; the other bullet type resisted fragmentation, and no lead was detected in muscle tissue that we sampled. Centerfire bullets made from copper resisted fragmentation, and of course did not deposit any lead in muscle tissues. Projectiles fired from the shotgun and black-powder muzzleloader did deposit lead into carcasses but did not fragment as much as bullets fired from centerfire rifles. Our study suggests that rinsing the abdominal cavity may spread the lead contaminant to other areas of the carcass, thereby worsening the contamination situation. We suggest that hunters who use centerfire rifles and are concerned about lead exposure should purchase a bullet type that resists fragmentation.

Key words: bullets, deer, donation, fragmentation, human–wildlife conflicts, hunting, lead, policy, venison

WHITE-TAILED DEER (*Odocoileus virginianus*) populations throughout the United States are a wildlife success story (Woolf and Roseberry 1998), and hunting is the primary tool used to manage deer populations (Stedman et al. 2008). However, there is considerable discussion and legitimate concern about whether or not hunters can control deer populations (Rutberg 1997, Brown et al. 2000, Riley et al. 2003). Given the national decline in hunter numbers (U.S. Department of Interior 2007), the impacts of large deer populations will present future challenges to wildlife managers. In Minnesota, approximately 500,000 hunters harvest >200,000 deer annually; thus, any issue that may contribute to declines in hunter numbers is important given the need to manage deer populations.

Lead is a toxic metal found in the natural environment (Tsuji et al. 1999). It is also the

most common metal used in ammunition for harvesting game species because of its density and malleability. While the toxicological effects associated with lead poisoning of wildlife has been documented (Hunt et al. 2006, Cade 2007), little research has been conducted related to the possible effects on humans consuming animals shot with lead. Johansen et al. (2006) concluded that hunters consuming animals shot with lead had high blood-lead levels. Iqbal et al. (2009) found that people who consumed animals harvested with lead ammunition had blood lead levels 0.30 µg per deciliter higher than did people who did not consume animals shot with lead ammunition. Thus, health concerns exist for humans consuming meat from animals that were harvested using lead-based ammunition, although the relationships and ramifications of consumption are poorly understood.

Although few studies examined impacts of

humans consuming bullet fragments in food, there have been many physiology studies conducted about the toxic effects of lead exposure. Exposure to lead has been found to adversely affect neural systems, kidney structure, bones, blood formation, and nerve transmission (Canfield et al. 2003, Menke et al. 2006). The most significant toxic effects of lead exposure are among children, which include neuro-cognitive and neuro-developmental disorders caused when low blood lead levels were observed (Canfield et al. 2003, Lanphear et al. 2005, Kordas et al. 2006, Menke et al. 2006). Consequently, these physiological studies also demonstrate that exposure to lead bullet fragments pose human health risks for individuals.

White-tailed deer are considered light, thin-skinned game, and ammunition manufacturers market bullets that are designed to expand rapidly upon penetration. Bullets of this type are often marketed for use while hunting mid-sized deer species (*Odocoileus* spp.), pronghorn (*Antilocapra americana*), bighorn sheep (*Ovis canadensis*), and other species typically ranging in weight from 34 to 136 kg. We will refer to these types of bullets as rapid expansion (RE) bullets throughout this paper.

Alternatives to RE bullets exist for larger game animals and are usually marketed as having properties that allow for slower expansion. These bullets are designed to penetrate into the body after striking thick skin, heavy bone, or thick muscle tissue. Bullets of this type usually include lead, but are designed to resist fragmentation and are often described as retaining >90% of their weight after striking the animal. This type of bullet is typically recommended for hunting large mammals such as elk (*Cervus canadensis*), moose (*Alces alces*) and other species weighing >226 kg. We will refer to these types of bullets as controlled-expansion (CE) bullets throughout this paper.

Several manufacturers also market bullets that are not lead-based but are designed for both mid-sized and large mammals. These bullets are made entirely from copper or a copper-based alloy and are presumed to be nontoxic. Throughout this paper refer to these bullets as copper (Cu) bullets.

Hunters often use shotguns that fire slugs and black-powder muzzleloading rifles for deer

hunting. Both weapons fire projectiles of larger mass and at lower velocities than most bullets fired from centerfire rifles and, thus, may have different fragmentation patterns. Lead-based shotgun slugs are the most common type of shotgun projectiles used for deer hunting. Based on our observations over the last 15 years, hunting with black-powder muzzleloaders has been increasing in popularity, and many state wildlife agencies have observed an increased number of deer harvested by this method. There are essentially 2 types of muzzleloader (MZ) bullets. The first is a bullet that equals the size of the caliber and is designed specifically for black-powder muzzleloader firearms. The second type is smaller in diameter and was originally designed for a handgun that is inserted into a plastic jacket so that the size matches the diameter of the bore of the muzzleloader.

To our knowledge, no studies have been published that examined the variability of bullet fragmentation and deposition using different categories of bullet and firearm classifications. The objectives of our study were to: (1) provide a standardized basis of examination of different bullet types; (2) describe general bullet performance, variability, and differences among firearm types; and (3) provide information to hunters so that informed choices can be made about selecting a bullet if lead deposition is a concern.

Background

Several midwestern states have publicly funded venison donation programs. While these programs vary slightly, the primary intent is to provide surplus hunter-harvest venison to the public. In 2007, Minnesota deer hunters donated 1,996 deer to food pantries, which yielded an estimated 35,500 kg of venison. In February 2008, a private physician in North Dakota reported observing radiographic evidence of metal in 60 of 100 samples of donated venison collected from food pantries. The State of North Dakota confirmed the presence of lead in these samples and suspended the state venison donation program. Due to the similarities in state venison donation programs in Minnesota and North Dakota, a decision was made to examine a portion of the venison remaining at Minnesota food pantries.

A random sample of 238 packages of venison was removed from Minnesota food pantries and subsequently examined by radiography to determine the presence of metal. Overall, radiographic evidence revealed 32% of the inspected packages contained metal fragments, and, consequently, the remaining venison at area food pantries was recalled and destroyed (L. Cornicelli, Minnesota Department of Natural Resources, unpublished report). The discovery of lead in venison prompted the Minnesota Department of Natural Resources to examine the broader issue of bullet fragmentation with the goal of providing hunters with a baseline of information regarding the most popular bullet types.

Hunt et al. (2006) used radiographs to study bullet fragmentation patterns in both hunter-harvested deer carcasses and offal piles and confirmed that metal fragments existed within both. While the study demonstrated the presence of bullet fragments, its findings were limited because hunters killed deer under variable conditions. For example, hunters harvested deer using different calibers that had varying bullet weights and bullet velocities, estimated shot distances of 37 to >200 m, and no deer were harvested using shotguns or muzzleloaders. We presume that differences in rifle caliber, bullet weight, design, bullet velocities, shot distances, and shot placement will likely influence bullet fragmentation patterns. Consequently, it was not possible to distinguish fragmentation patterns associated with different bullet types, shot distances, and shot placement based on their results.

Similarly, Dobrowolska and Melosik (2008) analyzed lead concentrations in muscle tissues of wild boar (*Sus scrofa*) and red deer (*Cervus elaphus*) harvested by hunters in Poland. The authors concluded that muscle tissue closer to wounds had higher concentrations of lead. However, their samples were also taken from animals harvested with bullets of different calibers and types. The authors concluded that caliber and bullet type would be an important factor related to the extent of contamination, but their study was designed to confirm that meat derived from animals shot with lead-based bullets would be contaminated with lead. Their study was not designed to address the variability associated with fragmentation

patterns of different types of bullets and firearms.

Hunt et al. (2009) conducted a study where all hunters used a Remington Magnum 7-mm caliber bullet, as well as a bullet of identical mass to harvest white-tailed deer. The authors concluded that individuals risk exposure to lead when they consume venison from deer killed with standard lead-based rifle bullets. However, their study did not test different bullet types. Thus, there is a lack of information about which types of bullets individuals who are concerned about lead exposure should purchase for hunting.

Methods

Our research was conducted in July 2008 with the goal of producing preliminary results before the fall 2008 Minnesota deer season (November 8, 2008). We used euthanized, domestic sheep (*Ovis aries*) as surrogates for white-tailed deer. Domestic sheep are ruminants, anatomically similar to deer, and were readily available. Each sheep carcass was harnessed in a sternal recumbent position and then shot broadside in the thoracic cavity at 50 m. In all cases, the scapula was positioned forward so that the bullet did not strike the scapula. After being shot, sheep were immediately transported to a necropsy laboratory at the University of Minnesota, Veterinary Diagnostic Laboratory (UMN-VDL) for fragmentation analysis.

We tested 2 types of RE bullets (RE1 and RE2), 2 types of CE bullets (CE1 and CE2), and 1 type of Cu bullet to make bullet type comparisons using a centerfire rifle chambered in .308 (7.62mm) Winchester (Table 1). All centerfire rifle bullets were commercially available cartridges, and weighed 10 g (150 grains). For centerfire rifles, 10 sheep were shot for each bullet brand group ($n = 50$ sheep). An additional 10 sheep were shot using a 12-gauge shotgun that fired slugs weighing 28 g (1 ounce). A 0.50 caliber muzzleloader rifle was used to test 2 types of MZ bullets. One type of muzzleloader bullet (MZ1) weighed 16 g (245 grains), and the other type (MZ2) weighed 19 g (300 grains). Six sheep were shot using MZ1 bullets, and 6 sheep were shot using MZ2 bullets.

To make comparisons to deer carcasses, we examined 8 deer that were killed in April 2008 as part of a disease management program

Table 1. Bullet types, average velocity of projectiles in meters per second (\pm SD), weight retention as advertised by manufacturer, and description of lead composition within projectile (Bullet types: RE = rapid expansion; CE = controlled expansion; Cu = copper; MZ = muzzleloader.)

Treatment	Bullet type	Velocity ¹	Advertised weight retention	Lead description
Nosler Ballistic Tip	RE1	876 \pm 10	50%	Lead throughout core
Remington Core Lokt	RE2	885 \pm 17	50%	Lead throughout core
Winchester XP ³	CE1	894 \pm 20	Near 100%	Copper in front half of bullet, lead at base of bullet
Hornady Interbond	CE2	855 \pm 12	>90%	Lead core bonded to jacket
Barnes TSX	Cu	871 \pm 30	Near 100%	No lead
Reminton Foster Slug	Slug	452 \pm 38	N/A	100% lead
Powerbelt Aero-Tip	MZ1	484 \pm 3	N/A	Lead throughout core
Hornady XTP	MZ2	475 \pm 16	N/A	Lead throughout core

¹Bullet velocity determined via chronograph placed 3 meters from the shooting bench.

conducted by the Minnesota Department of Natural Resources. Deer were shot with a .308 (7.62 mm) Winchester using RE1 bullets over bait at an average distance of about 110 m (range = 80–175 m). Deer were killed in variable conditions, and not all bullets struck the thoracic cavity. These intact deer carcasses were frozen until July 2008 and were not eviscerated until they thawed and were examined for this study.

Our intent was to approximate patterns of fragmentation for deer that would be harvested during fall hunting seasons. Therefore, we examined lead deposition in a manner that would be consistent with how a hunter would handle a deer carcass. Thus, we removed the hide and viscera prior to analysis. To determine bullet direction (entry to exit), we inserted a carbon fiber tube through the wound channel then took a ventral-dorsal (VD) view and a lateral view (LV) radiograph image on the exit side of the carcass. When carcass length exceeded the imaging radius of the scanner, we took 2 radiographs of each view then tiled the images together prior to analysis. Fragments were most visible on VD radiographic images. Thus, we used VD radiographic images to enumerate total number of bullet fragments in each carcass. No aids were used to magnify the fragments while the counting was being performed. In addition to total fragment counts, we counted the number of bullet fragments <5cm from the exit wound. All radiographic images were coded, so, the individual observing the image did not know which bullet brand group was being analyzed.

We studied lead contamination levels (ppm) throughout carcasses using similar procedures as those outlined in Dobrowolska and Melosik (2008). We collected muscle tissue samples along the abdominal cavity at perpendicular distances of 5, 25, and 45 cm from the exit wound on each carcass (Figure 1). Tissue samples were taken by cutting through the carcass and entirely removing a 2.5- \times 2.5-cm section of muscle at the aforementioned distances from the exit wound sites. All muscle tissue samples were analyzed by University of Minnesota, Veterinary Diagnostic Laboratory

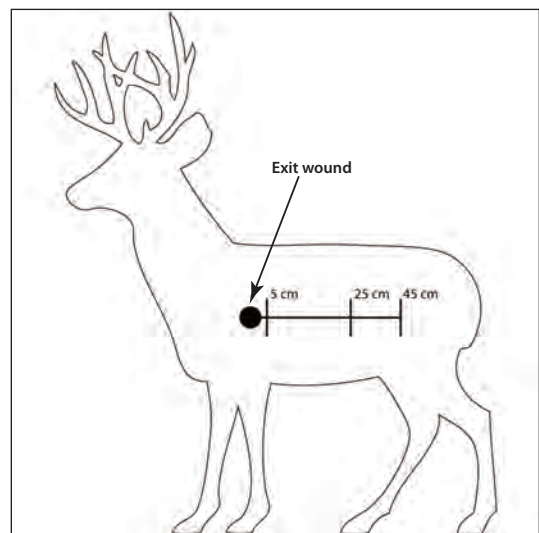


Figure 1. Depiction of tissue extraction sites that were obtained to test for lead contamination (ppm) caused by bullet fragmentation in white-tailed deer and domestic sheep.

Table 2. Average number of fragments counted (SD) within white-tailed deer and domestic sheep in various treatment groups using ventral-dorsal view radiographs. (Bullet types: RE = rapid expansion; CE = controlled expansion; Cu = copper; MZ = muzzle-loader).

Species	Bullet type	N	$\bar{x} \pm SD$	Minimum	Maximum
Deer	RE1	8	60 ± 84	7	261
Sheep	RE1	9	141 ± 135	74	498
Sheep	RE2	10	86 ± 34	28	138
Sheep	CE1	10	9 ± 7	2	28
Sheep	CE2	10	82 ± 62	21	28
Sheep	Cu	10	2 ± 1	1	4
Sheep	Slug	10	28 ± 41	3	127
Sheep	MZ1	6	3 ± 3	1	9
Sheep	MZ2	6	34 ± 36	6	105

staff using their standard operating protocol for measuring concentrations of metals in muscle tissue. Muscle tissue samples were digested in nitric acid then examined for the presence of lead through inductively coupled plasma analysis. The lower detection limit for lead was 1 part per million. We also assessed the effects rinsing the meat had on lead contamination by rinsing the abdominal cavity of each carcass for approximately 30 seconds after the first set of tissues was collected. We then extracted another set of tissue samples at about 5, 25,

and 45 cm from the exit wounds on all carcasses and used the same laboratory procedures described above. were limited to portions of individual carcasses because some fragments were observed along the perimeter of many radiograph images and we concluded that we were not able to count all the fragments that may have been present in carcasses. Because we were unable to enumerate all the fragments, we reported the average number of those observed <5 cm from the exit hole as a standard measure for comparison among bullet brand groups (Table 3).

Similar to our radiograph findings, lead was

Results

We observed a higher number of bullet fragments in sheep shot with both types of RE and CE2 bullets as compared to the CE1 and Cu bullets (Figure 2; Table 2). We observed comparatively fewer fragments in carcasses that were shot using MZ bullets and slugs than RE and CE2 bullets, which was likely due to their greater bullet mass and lower velocities (Table 1). Radiographic images



Figure 2. Radiographic images of a domestic sheep shot with Nosler Ballistic bullet, which is a rapid expansion (RE) bullet. Bullet fragments show up as white spots.



Figure 3. Radiographic image of a domestic sheep shot with a Winchester XP³ bullet, which is a controlled-expansion (CE) bullet. Bullet fragments show up as white spots.

Table 3. Average number of fragments counted (SD) <5cm of exit wound within each white-tailed deer and domestic sheep in various treatment groups using lateral view radiographs. (Bullet types: RE = rapid expansion; CE = controlled expansion; Cu = copper; MZ = muzzleloader).

Species	Bullet type	N	$\bar{x} \pm SD$	Minimum	Maximum
Deer	RE1	8	18 ± 16	2	43
Sheep	RE1	9	41 ± 20	13	86
Sheep	RE2	10	43 ± 23	15	92
Sheep	CE1	10	< 1 ± 1	0	3
Sheep	CE2	10	36 ± 24	11	83
Sheep	Cu	10	< 1 ± 1	0	2
Sheep	Slug	10	12 ± 9	1	31
Sheep	MZ1	6	2 ± 4	0	10
Sheep	MZ2	6	21 ± 22	3	62

detected by assay more frequently in muscle tissues collected from carcasses shot using both types of RE bullets and the CE2 bullet (Table 4). We detected no lead in muscle tissues collected from carcasses shot using CE1 or Cu bullets. We detected lead in 40% of muscle tissues near exit wounds from carcasses shot using slugs. However, our study suggested lead fragments did not travel far throughout abdominal cavities of carcasses shot using slugs because lead was not detected at the 25 or 45 cm intervals.

Our data suggest that rinsing does not eliminate lead from the carcass (Table 4). On the contrary, our data suggest that rinsing the carcass may spread the contaminant to other areas of the carcass. Two of 80 (3%) samples that we collected 45 cm from exit wounds had detectable lead levels prior to rinsing. However, we detected lead in 9 of 80 (11%) samples collected 45 cm from exit wounds after rinsing the carcass.

Discussion

Our study shows there were marked differences in fragmentation patterns and lead deposition rates based on different types of bullets. Wildlife managers should make individuals who are concerned about lead exposure aware that there are bullets available for hunting deer that can minimize the likelihood of being contaminated by lead. It is critical to point out, however, that simply purchasing a bullet that is advertised to retain >90% of its weight may not mean that the bullet

will not fragment and deposit lead into the carcass. Our results also imply that future wildlife studies conducted on lead bullets should attempt to identify the type of bullet used in their study because failure to account for bullet type could greatly bias the results of a study.

There were differences in our results between deer and sheep shot with RE1 bullets. We believe that the angles and distances that deer were positioned from the shooter explain some of these differences. All sheep were perpendicular to the shooter and shot in the thoracic cavity at 50

m at a constant angle. Presumably, all bullets struck light bones and areas of thin muscle at a relatively constant velocity and entry angle. In contrast, the shooters killing deer for our study took shots opportunistically, and several bullets struck the shoulder area where heavier bones (e.g., scapula) and comparably thick muscles are located. Regardless, of the anatomical similarities between species, we are confident that our findings related to fragmentation patterns in sheep carcasses associated with different bullet types would parallel results found on white-tailed deer, and that our recommendations are applicable to deer hunters.

In general, lead was most abundant immediately around the exit hole and its prevalence declined as the distance from the exit hole increased. However, we were not able to recommend a specific distance from the exit hole that would not expose an individual to lead because we found samples that tested positive for lead at a distance of 45 cm from the exit wound. Based on these findings, we conclude that all meat from a deer harvested using a lead bullet has the potential to contain at least some lead.

We are not aware of any published studies that indicate that rinsing the carcass has any benefits in terms of human health. However, some hunters believe rinsing the carcass will eliminate debris and bacteria from the abdominal cavity. Our study suggests introducing water to the carcass may spread a highly concentrated

area of lead immediately around the wound channel to areas where lead did not previously exist. Further research may be warranted to determine if the cost of not rinsing the carcass outweighs the risk of rinsing it.

Avian scavengers may be susceptible to lead poisoning when they ingest fragments in the tissues of deer killed by lead-based bullets (Wayland and Bollinger 1999, Hunt et al. 2006, Cade 2007). Offal piles produced from both harvested and fatally wounded deer not retrieved by hunters provide a substantial amount of lead to avian scavengers. An offal pile is always produced by a harvested deer, which translates into 200,000 to 250,000 piles of offal per year in Minnesota alone. Nixon et al. (1991) reported wounding rates ranged from 21 to 24% in Illinois. Wounding losses represented 24% of the legal harvest in Montana (Dusek et al. 1989) and ranged from 17 to 32% of the harvest in Indiana (Stormer et al. 1979). These values are very difficult to estimate and are likely to vary spatially and temporally. Nevertheless, a substantial amount of lead is made available to scavenging animals via both piles of offal and wounded animals that are not retrieved by hunters. Additional research is required to determine if the short-term exposure of lead in offal piles and deer carcasses has long-term impacts on avian scavenger populations.

Management implications

We conclude that concerned hunters and wildlife managers have options to manage risk of exposure to lead. We believe people concerned about lead exposure should: (1) select a bullet that does not contain lead, such as the Cu bullet used in this study or a bullet that will not expose lead to the animal, such as the copper bullet used in this study; (2) not rinse the carcass; (3) be aware that meat 45 cm from the wound may contain lead; and (4) be

Table 4. Percentage of muscle tissue samples at 5, 25, and 45 cm from exit wounds that had detectable levels of lead, pre- and post-rinse, on white-tailed deer and sheep shot by various types of projectiles. (Bullet types: RE = rapid expansion; CE = controlled expansion; Cu = copper; MZ = muzzleloader).

Species	Bullet type	N	5cm		25cm		45cm	
			Pre	Post	Pre	Post	Pre	Post
Deer	RE1	24	12	25	0	12	0	0
Sheep	RE1	30	50	30	70	50	10	20
Sheep	RE2	30	70	70	40	50	0	20
Sheep	CE1	30	0	0	0	0	0	0
Sheep	CE2	30	50	40	20	30	10	20
Sheep	Cu	30	0	0	0	0	0	0
Sheep	Slug	30	40	30	0	10	0	30
Sheep	MZ1	18	0	0	0	0	0	0
Sheep	MZ2	18	0	0	17	17	0	17

aware that lead-based slugs and MZ bullets will fragment and deposit lead into carcasses.

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MARRETT D. GRUND (right in photo above) is a research scientist at the Farmland Wildlife Populations and Research Group. He received his Ph.D. degree in zoology at Southern Illinois University-Carbondale while working at the Cooperative Wildlife Research Laboratory. He and his team at the research center study deer ecology and management in farmland and urban landscapes. His current research focuses on developing techniques to estimate abundance and evaluating innovative hunting regulations to manage overabundant deer populations.

LEAH T. CARLSON (left in photo above) is earning her B. S. degree in biology at Minnesota State University-Mankato. She has been employed as a paraprofessional researcher at the Farmland Wildlife Populations and Research Group for the past 2 years while attending school. In her current position, she plays a crucial role assisting research scientists conducting daily activities so that projects are completed in a timely manner.



LOUIS CORNICELLI (right in photo above) is the big game program coordinator for the Minnesota Department of Natural Resources. His current position involves setting programmatic direction for white-tailed deer, bear, moose, and elk management. His professional interests range from wildlife diseases and population management to integrating the social sciences into wildlife management policy. He holds a B.S. degree from Cornell University, M.S. degree from Southern Illinois University, and a Ph.D. degree from the University of Minnesota.

ERIKA A. BUTLER (left in photo above) earned her B.S. degree in fisheries and wildlife management from the University of North Dakota and her DVM degree from the University of Minnesota, where she focused her education on wildlife disease detection, surveillance, and management. She currently serves as the wildlife veterinarian for the Minnesota Department of Natural Resources, where she investigates and manages diseases in the state's wildlife populations. Her professional interests include the mysterious decline in Minnesota's moose population, transmission of disease between wildlife, livestock, and human populations, and the role of wildlife as a disease reservoir.