Texas stakeholders' knowledge and perceptions of chronic wasting disease risks: implications for wildlife agency communications

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Abstract: Chronic wasting disease (CWD) is a fatal neurological disease impacting cervids. The disease can move swiftly through populations, making CWD management a priority for wildlife agencies across the United States. Stakeholder perceptions of CWD may shape behaviors that can negatively impact wildlife agencies. Thus, agencies need comprehensive assessments of stakeholder risk perceptions and enhanced understandings of how perceptions are formed to improve communications. Using a mail- and online-based questionnaire to collect data from September 2020 through January 2021, we surveyed 503 hunters throughout the state of Texas, USA, and 481 Texas landowners who owned property in CWD-affected counties to better understand risk perceptions, knowledge of CWD, and relationships between both elements. Furthermore, we compared risk perceptions across multiple host types and wildlife-related diseases. We documented frequent "don't know" responses across perceptions and found a negative or no relationship between factual knowledge and risk perceptions, context dependent. As such, results suggest wildlife agencies should consider communications that emphasize actionable knowledge to better encourage preventive action.

Key words: cervids, chronic wasting disease, communications, CWD, hunter, knowledge, landowner, perceptions, risk, Texas

Chronic wasting disease (CWD) is a fatal, prion-caused neurological disease impacting both wild (i.e., free-ranging) and captive cervids, including deer (*Odocoileus* spp.), red deer (*Cervus elaphus*), elk (*C. canadensis*), moose (*Alces alces*), and reindeer (*Rangifer tarandus*) species (Needham et al. 2017). The disease was first identified in the 1960s in Colorado, USA, and has spread to 26 U.S. states, Canada, Finland, Norway, South Korea, and Sweden (U.S. Geological Survey [USGS] 2021). Chronic wasting disease can move swiftly through wild populations (Edmunds et al. 2016) and even faster through captive populations (Keane et al. 2008). Therefore, CWD management has become a priority for agencies across the United States (Vaske 2010). Although greater risk perceptions of CWD do not necessarily result in significant behavior change (Vaske 2010), research indicates hunter perceptions of CWD can influence hunter attitudes and behavior in a way that negatively impacts agencies (e.g., declines in hunting license sales; Heberlein and Stedman 2009, Miller and Shelby 2009, Vaske 2010, Vaske and Lyon 2011, Haus et al. 2017). Such potential negative impacts make effective management of the disease all the more critical.

Whereas risks are calculated functions of incidence and severity (Quinn et al. 2003), perceptions of risk are judgments about risk (Slovic 1987), rather than technical assessments (Gore and Kahler 2012). The public's risk perceptions do not always align with rational estimates and objective expert judgements. Rather, the former are often based on subjective and emotional responses (Needham et al. 2017).

Wildlife managers have recognized the need to better assess wildlife stakeholder perceptions of risk related to CWD and understand how these perceptions are formed. In addition to familiarity with the risk and overall risk sensitivity (Needham et al. 2017), knowledge (i.e., enhanced understanding) of the risk can also be an influential, although inconsistent, factor in the formation of stakeholders' risk perceptions. Reduced levels of knowledge of CWD may be

associated with either reduced (Vaske et al. 2018) or greater perceptions of risk (Needham et al. 2017). Given agency efforts to develop effective public communication campaigns (Vaske et al. 2018), it is crucial to improve understandings of the relationships between risk perceptions and knowledge of CWD and how messaging can be used to influence both elements.

Most of the published literature available on risk perceptions of CWD focuses on hunter risk perceptions concerning effects on human and deer populations (Cooney and Holsman 2010, Harper et al. 2015, Haus et al. 2017, Oruganti et al. 2018, Holland et al. 2020, Schroeder et al. 2021). Although hunters are a critical CWD stakeholder group, non-hunter stakeholder groups are understudied, despite their impact on CWD management and policy (Vaske and Miller 2018). A shift in research focus will help unearth important understandings about non-hunter stakeholder characteristics, such as levels of concern for effects of wildlife diseases on livestock (Siemer et al. 2007) or perceptions of free-range and captive deer populations. Additionally, few studies have explored CWD risk perceptions juxtaposed to other wildlife-related diseases (Heberlein and Stedman 2009, Miller and Shelby 2009, Needham et al. 2017). Explorations and comparisons of the management of other wildlife-related diseases can ultimately yield valuable lessons learned (Miller and Shelby 2009, Vaske 2010).

We completed a comprehensive, multidimensional assessment of stakeholders' risk perceptions of CWD in Texas, USA, to address these research gaps. Texas serves as an exemplary setting for this type of research because of its strong hunting economy and culture as well as a robust captive deer breeding industry (Kirby 2020), which intersect with the state's domestic livestock sector. Therefore, Texas offers an opportunity to survey and compare CWD stakeholders who hold a range of views. We explored the relationships between risk perceptions and factual knowledge and compared these measurements across stakeholder type, perception measure, disease type, and host type factors. Generating multiple levels of comparisons can help wildlife managers to better understand how stakeholders conceptualize, assign, and respond to perceived risks related to CWD.

Study area

At the time of the survey design and administration, 8 counties in western Texas were affected by chronic wasting disease (i.e., Dallam, El Paso, Hartley, Hudspeth, Kimble, Medina, Uvalde, and Val Verde counties; Figure 1). These rural counties are known for their livestock and captive deer breeding land uses, elevating their importance to CWD management conversations (Kirby 2020). In fact, although the first case of CWD in Texas was discovered in a free-ranging mule deer (*O. hemionus*) in Hudspeth County in 2012, the majority of CWD cases since then has come from 5 captive deer-breeding facilities, including the first case in a deer-breeding facility located in Medina County (Kirby 2020). Increasing cases and the likelihood of CWD transmission to new counties has prompted the Texas Parks and Wildlife Department (TPWD) to explore public perceptions of the disease and its management.

Methods

We developed 2 different survey instruments to administer to key CWD stakeholder groups in Texas: (1) white-tailed deer (*O. virginianus*), mule deer, red deer, elk, and/or sika deer (*C. nippon*) hunters throughout the state of Texas; and (2) landowners who owned approximately 8 or more ha of property in CWD-affected counties. Using screener questions, we ensured hunter respondents resided in Texas, purchased a Texas hunting license in the past 5 years, and had hunted deer in Texas within the past 5 years. Additionally, we used screener questions to ensure landowner respondents owned land in at least 1 of the 8 counties. These 2 groups were not mutually exclusive. Survey instruments included questions regarding factual knowledge of CWD and risk perceptions of wildlife diseases, individual preferences for preventing the spread of CWD, CWD's effects on landowners' land and management practices, CWD's effects on hunters' behaviors, respondents' preferred communication methods, and demographics.

Following Needham et al. (2017), we used a series of questions to measure factual knowledge of CWD: (1) CWD is a degenerative neurological disease similar to bovine spongiform encephalopathy (BSE), also known as "mad cow disease" (options: true/false/I don't know

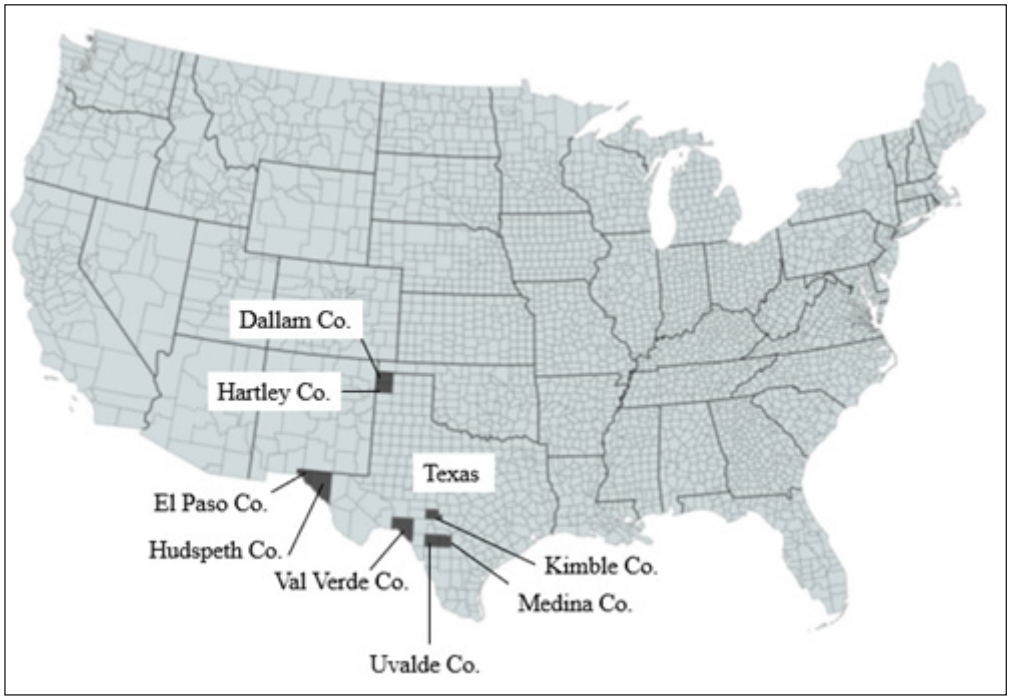

Figure 1. Locations of September 2020 to January 2021 surveying efforts for hunters (Texas, USA, statewide) and landowners (chronic wasting disease-affected counties; shaded in dark gray).

[DK]; correct answer: true); (2) CWD is present in how many counties in Texas? (options: 8/96/168/241/DK; correct answer: 8); and (3) CWD is known to spread from deer to humans (options: true/false/DK; correct answer: false). For analysis, we collapsed the responses to each question into a wrong (0)–right (1) binary and summed the total number of correct answers for each respondent.

We measured risk perceptions using a 3-dimensional approach to generate a comprehensive understanding of how stakeholders perceive risk related to CWD. The first dimension involved the measurement of risk perceptions. We employed 3 distinct measurements of risk perception (perceived seriousness, perceived susceptibility, and concern/extent of anxiety) outlined by the Effective Communication in Outbreak Management project (ECOM), an international initiative aimed at developing evidence-based behavioral and communication packages for use during major outbreaks of infectious diseases (Municipal Public Health Service Rotterdam-Rijnmond 2015). We adapted this protocol to wildlife-related disease. By using ECOM's 3 measurements of risk perception, we were able to separately measure how respondents viewed the physical seriousness of the disease and its consequences (seriousness), the chances of animals contracting the disease in the near future (susceptibility), and the feeling of anxiety and distress associated with the spread of the disease through animal populations (concern). Although these 3 risk perception ideas are related, they represent different concepts and should thus be measured separately (Municipal Public Health Service Rotterdam-Rijnmond 2015).

The second dimension involved comparing perceived seriousness, perceived susceptibility, and concern across 4 wildlife-related diseases (Heberlein and Stedman 2009, Needham et al. 2017): CWD, epizootic hemorrhagic disease (EHD), Lyme disease, and bovine tuberculosis (bovine TB). These diseases were chosen in collaboration with TPWD to represent a range of wildlife-related diseases with which Texas hunters and landowners may be familiar, regardless of their actual threat to Texas deer populations.

Whereas CWD was the disease of primary focus within the study, we included these other

wildlife-related diseases for comparison purposes, allowing us to contrast respondent familiarity with CWD with expected lesser known (e.g., EHD) and better known (e.g., Lyme disease) wildlife-related diseases. The final dimension involved comparing risk perceptions of these wildlife diseases across 3 host types: free-range deer, captive deer, and livestock. It is necessary to differentiate perceptions among these host types because of hunters' and landowners' experiences with each host type.

The Texas State University Institutional Review Board (#7222) approved the survey protocol, and we cognitively pretested the instruments per Alaimo et. al. (1999). We used simple random samples (De Leeuw et al. 2008) of hunters and landowners by employing sampling frames provided by TPWD. Sampling frames were comprised of current hunting license holders throughout Texas (for hunters) and property owners owning approximately 8 ha or greater in the 8 focal counties (for landowners).

Mailings (hunters = 9,492, landowners = 7,545) consisted of an introductory letter with a website to complete the survey online, a hard copy of the survey, and a postage-paid return envelope. We also mailed prospective respondents 2 follow-up postcards approximately 8 weeks apart, reminding the individual to mail the survey back or complete it online. Data collection occurred from September 12, 2020, through January 20, 2021. Upon closing the survey, we mailed an abbreviated survey consisting of mostly demographic questions to 500 nonrespondent hunters and 500 nonrespondent landowners to assess potential nonresponse bias.

We processed and analyzed survey data using STATA statistical software. We first analyzed risk perceptions as nominal variables to compare DK responses and then as continuous variables to calculate mean values (excluding DK responses). We conducted chi-square tests to test for differences of proportions of nominal variables (e.g., DK responses), *t*-tests (e.g., comparing landowner and hunter risk perceptions), 1-way between subjects ANOVA to test for differences of means of continuous variables (e.g., comparing disease risk perceptions among host types), and linear regressions to test for relationships between risk perceptions and factual knowledge (McDonald 2009). We noted statistical significance at the 10%, 5%, and 1% levels.

Results

Response rates and demographics

We collected 503 (51.1%) completed hunter and 481 (48.9%) landowner responses, for a total of 984 responses. These responses represented a total response rate of 5.8% (5.3% for hunters, 6.4% for landowners), and we collected enough responses to make robust statistical inferences at the 95% confidence level for both hunters statewide (379 responses were necessary) and landowners across all 8 counties (377 responses were necessary). Hunters ranged from 18–87 ($\bar{x}$ = 55.03, SD = 16.85) years of age and were younger than landowners ($\bar{x}$ = 65.35, SD = 11.72), ranging from 26–91 years of age, $t(940) = -10.83$, $P < 0.01$, Cohen's $d = 0.71$. The majority of survey respondents were male (hunters = 91.5%, landowners = 79.7%), although a greater proportion of hunters were male compared to landowners, χ^2 (1, $N = 962$) = 27.11, $P < 0.01$, Cramér's V = 0.17.

Most respondents resided in rural settings (n = 514, 53.8%), whereas 30.8% (n = 294) lived in suburban and 15.4% (n = 147) in urban settings. Of all respondents, 61.1% (n = 586) had completed some college or held a bachelor's degree, 23.9% (n = 230) held a graduate degree, and 14.9% (n = 143) had a high school degree or less formal schooling. On average, a greater proportion of landowners had more years of formal education than hunters, χ^2 (4, $n = 959$) = 15.81, $P < 0.01$, Cramér's V = 0.12.

We received 33 hunter and 32 landowner responses to our nonresponse bias survey. There were few differences between respondent and nonrespondent populations for both hunters and landowners (hunter ages: $t[518] = -0.40$, $P = 0.69$, Cohen's $d = 0.07$; landowner ages: $t[481] = -1.10$, $P = 0.27$, Cohen's $d = 0.21$; landowner genders: χ^2 [1, $n = 469$] = 1.36, $P = 0.24$, Cramér's V = 0.05; hunter residential settings: χ^2 [2, $n = 492$] = 4.13, $P = 0.13$, Cramér's V = 0.09; landowner residential settings: χ^2 [2, $n = 463$] = 0.54, $P = 0.77$, Cramér's V = 0.03; hunter formal education levels: χ^2 [4, $n = 494$] = 2.96, $P = 0.57$, Cramér's V = 0.08). Exceptions to this include a fewer number of female respondent hunters (χ^2 [1, $n = 493$] = 6.80, $P = 0.01$, Cramér's V = 0.12) and greater levels of formal education among respondent landowners (χ^2 [4, $n = 465$] = 0.05, $P = 0.14$, Cramér's V = 0.03).

Table 1. Chi-square results comparing the frequency of "I don't know" responses for perceived seriousness, perceived susceptibility, and concern by host type and disease among Texan hunters statewide and landowners who owned approximately 8 or more hectares in chronic wasting disease-affected counties in Texas, USA, as surveyed from September 2020 through January 2021.

			Perceived seriousness				Perceived susceptibility				Concern			
			% I don't know	Count I don't know	χ^2 stat. (*P*-value)	Cramér's V	% I don't know	Count I don't know	χ^2 stat. (*P*-value)	Cramér's V	% I don't know	Count I don't know	χ^2 stat. (*P*-value)	Cramér's V
Host type comparison	Chronic wasting disease (CWD)	Free-range deer	14.53	143	172.53 (<0.01)	0.24	20.33	200	141.62 (<0.01)	0.22	6.81	67	104.76 (<0.01)	0.19
		Captive deer	21.75	214			24.80	244			10.77	106		
		Livestock	39.53	389			43.39	427			21.85	215		
	Epizootic hemorrhagic disease (EHD)	Free-range deer	62.20	612	8.44 (0.01)	0.05	62.70	617	3.90 (0.14)	0.04	44.61	439	64.85 (<0.01)	0.04
		Captive deer	64.63	636			63.62	626			46.34	456		
		Livestock	68.39	673			66.77	657			48.98	482		
	Lyme	Free-range deer	32.42	319	16.40 (<0.01)	0.08	42.48	418	5.77 (0.06)	0.04	24.49	241	8.15 (0.02)	0.05
		Captive deer	38.31	377			45.02	443			28.05	276		
		Livestock	41.06	404			47.87	471			30.18	297		
	Bovine tuberculosis (TB)	Free-range deer	53.46	526	27.84 (<0.01)	0.10	57.42	565	6.15 (0.05)	0.05	37.40	368	8.46 (0.01)	0.05
		Captive deer	54.98	541			58.03	571			39.43	388		
		Livestock	44.00	433			52.95	521			33.23	327		
Disease comparison	Free-range deer	CWD	14.53	143	562.02 (<0.01)	0.38	20.33	200	428.48 (<0.01)	0.33	6.81	67	399.97 (<0.01)	0.32
		EHD	62.20	612			62.70	617			44.61	439		
		Lyme	32.42	319			42.48	418			24.49	241		
		Bovine TB	53.46	526			57.42	565			37.40	368		
	Captive deer	CWD	21.75	214	425.72 (<0.01)	0.33	24.80	244	351.61 (<0.01)	0.30	10.77	106	33.29 (<0.01)	0.29
		EHD	64.63	636			63.62	626			46.34	456		
		Lyme	38.31	377			45.02	443			28.05	276		
		Bovine TB	54.98	541			58.03	571			39.43	388		
	Livestock	CWD	39.53	389	217.36 (<0.01)	0.24	43.39	427	121.57 (<0.01)	0.18	21.85	215	170.58 (<0.01)	0.21
		EHD	68.39	673			66.77	657			48.98	482		
		Lyme	41.06	404			47.87	471			30.18	297		
		Bovine TB	44.00	433			52.95	521			33.23	327		

Table 2. Chi-square results comparing the frequency of "I don't know" responses for perceived seriousness, perceived susceptibility, and concern by Texan hunters statewide and landowners who owned approximately 8 ha or more in chronic wasting disease-affected counties in Texas, USA, as surveyed from September 2020 through January 2021.

		Perceived seriousness				Perceived susceptibility				Concern			
		% Hunter (count)	% Landowner (count)	χ^2 stat.	Cramér's V	% Hunter (count)	% Landowner (count)	χ^2 stat.	Cramér's V	% Hunter (count)	% Landowner (count)	χ^2 stat.	Cramér's V
Chronic wasting disease	Free-range deer	9.34 (47)	19.96 (96)	22.30 (<0.01)	0.15	14.71 (74)	26.20 (126)	20.02 (<0.01)	0.14	2.98 (15)	10.81 (52)	23.75 (<0.01)	0.16
	Captive deer	15.11 (76)	28.69 (138)	26.65 (<0.01)	0.17	18.69 (94)	31.19 (150)	20.59 (<0.01)	0.15	5.77 (29)	16.01 (77)	26.84 (<0.01)	0.17
	Livestock	34.39 (173)	44.91 (216)	11.37 (<0.01)	0.11	39.56 (199)	47.40 (228)	6.15 (0.01)	0.08	18.49 (93)	25.36 (122)	6.81 (0.01)	0.08
Epizootic hemorrhagic disease	Free-range deer	58.65 (295)	65.90 (317)	5.51 (0.02)	0.08	59.64 (300)	65.90 (317)	4.12 (0.04)	0.07	43.34 (218)	45.95 (221)	0.68 (0.41)	0.03
	Captive deer	60.04 (302)	69.44 (334)	9.50 (<0.01)	0.10	60.64 (305)	66.74 (321)	3.95 (0.05)	0.06	43.74 (220)	49.06 (236)	2.81 (0.09)	0.05
	Livestock	65.21 (328)	71.73 (345)	4.83 (0.03)	0.07	65.21 (328)	68.40 (329)	1.13 (0.29)	0.03	47.71 (240)	50.31 (242)	0.66 (0.42)	0.03
Lyme	Free-range deer	26.44 (133)	38.67 (186)	16.78 (<0.01)	0.13	36.98 (186)	48.23 (232)	12.75 (<0.01)	0.11	22.07 (111)	27.03 (130)	3.27 (0.07)	0.06
	Captive deer	31.01 (156)	45.95 (221)	23.20 (<0.01)	0.15	39.36 (198)	50.94 (245)	13.30 (<0.01)	0.12	25.65 (129)	30.56 (147)	2.94 (0.09)	0.06
	Livestock	35.98 (181)	46.36 (223)	10.94 (<0.01)	0.11	42.94 (216)	53.01 (255)	10.00 (<0.01)	0.10	28.63 (144)	31.81 (143)	1.18 (0.28)	0.04
Bovine tuberculosis	Free-range deer	49.70 (250)	57.38 (276)	5.83 (0.02)	0.08	53.68 (270)	61.33 (295)	5.89 (0.02)	0.08	34.99 (176)	39.92 (192)	2.55 (0.11)	0.05
	Captive deer	50.70 (255)	59.46 (286)	7.63 (0.01)	0.09	54.47 (274)	61.75 (297)	5.34 (0.02)	0.07	35.79 (180)	43.24 (208)	5.73 (0.02)	0.08
	Livestock	38.97 (196)	49.27 (237)	10.60 (<0.01)	0.10	48.71 (245)	57.38 (276)	7.42 (0.01)	0.09	29.03 (146)	37.63 (181)	8.20 (<0.01)	0.09

Table 3. Results of t-tests comparing average perceived seriousness, perceived susceptibility, and concern by Texan hunters statewide and landowners who owned approximately 8 ha or more in chronic wasting disease-affected counties in Texas, USA, as surveyed from September 2020 through January 2021.

		Average perceived seriousness					Average perceived susceptibility					Average concern				
		Hunter	Land-owner	Total	*t* stat. (*P*-value)	Cohen's *d*	Hunter	Land-owner	Total	*t* stat. (*P*-value)	Cohen's *d*	Hunter	Land-owner	Total	*t* stat. (*P*-value)	Cohen's *d*
Chronic wasting disease	Free-range deer	3.11 (0.92)	3.13 (0.93)	3.12 (0.93)	-0.30 (0.76)	0.02	3.24 (0.74)	3.15 (0.83)	3.20 (0.78)	1.55 (0.12)	0.11	3.12 (0.95)	3.17 (0.97)	3.15 (0.96)	-0.79 (0.43)	0.05
	Captive deer	3.37 (0.84)	3.41 (0.92)	3.39 (0.87)	-0.66 (0.51)	0.04	3.30 (0.76)	3.26 (0.83)	3.28 (0.79)	0.55 (0.58)	0.04	3.03 (1.01)	3.05 (1.04)	3.04 (1.02)	-0.27 (0.79)	0.02
	Livestock	2.53 (1.16)	2.28 (1.22)	2.42 (1.19)	2.52 (0.01)	0.21	2.65 (0.96)	2.59 (1.06)	2.62 (1.01)	0.66 (0.51)	0.06	2.59 (1.13)	2.71 (1.67)	2.65 (1.15)	-1.36 (0.17)	0.10
Epizootic hemorrhagic disease	Free-range deer	2.89 (0.94)	2.87 (1.02)	2.88 (0.97)	0.18 (0.85)	0.02	2.93 (0.82)	2.91 (0.90)	2.92 (0.86)	0.21 (0.83)	0.02	2.89 (1.02)	2.97 (0.99)	2.93 (1.01)	-0.90 (0.37)	0.08
	Captive deer	2.98 (0.95)	2.94 (1.06)	2.96 (1.00)	0.34 (0.74)	0.04	2.93 (0.86)	3.00 (0.87)	2.96 (0.86)	-0.77 (0.44)	0.08	2.81 (1.03)	2.87 (1.03)	2.84 (1.03)	-0.63 (0.53)	0.06
	Livestock	2.58 (1.15)	2.52 (1.13)	2.55 (1.14)	0.45 (0.65)	0.05	2.65 (0.93)	2.65 (0.96)	2.65 (0.95)	-0.02 (0.99)	<0.01	2.64 (1.12)	2.79 (1.09)	2.71 (1.11)	-1.45 (0.15)	0.13
Lyme	Free-range deer	2.67 (1.01)	2.66 (1.00)	2.67 (1.01)	0.19 (0.85)	0.01	2.77 (0.88)	2.78 (0.88)	2.78 (0.88)	-0.16 (0.87)	0.01	2.68 (1.03)	2.84 (1.02)	2.76 (1.03)	-2.16 (0.03)	0.15
	Captive deer	2.66 (1.02)	2.62 (1.02)	2.64 (1.02)	0.51 (0.61)	0.04	2.79 (0.90)	2.83 (0.86)	2.81 (0.88)	-0.62 (0.54)	0.05	2.58 (1.08)	2.73 (1.03)	2.65 (1.06)	-1.89 (0.06)	0.14
	Livestock	2.48 (1.05)	2.48 (1.09)	2.48 (1.07)	0.02 (0.99)	<0.01	2.61 (0.95)	2.61 (0.95)	2.61 (0.95)	0.08 (0.94)	0.01	2.49 (1.10)	2.73 (1.08)	2.60 (1.10)	-2.86 (<0.01)	0.22
Bovine tuberculosis	Free-range deer	2.40 (1.14)	2.31 (1.17)	2.36 (1.15)	0.80 (0.42)	0.08	2.57 (0.99)	2.52 (0.98)	2.55 (0.98)	0.49 (0.62)	0.05	2.55 (1.12)	2.74 (1.09)	2.64 (1.11)	-2.10 (0.04)	0.17
	Captive deer	2.50 (1.12)	2.34 (1.17)	2.46 (1.15)	1.87 (0.06)	0.18	2.62 (0.98)	2.59 (0.97)	2.61 (0.97)	0.27 (0.79)	0.03	2.54 (1.12)	2.68 (1.10)	2.60 (1.11)	-1.52 (0.13)	0.12
	Livestock	2.86 (1.02)	2.83 (1.10)	2.85 (1.05)	0.33 (0.74)	0.03	2.71 (0.96)	2.70 (0.93)	2.71 (0.94)	0.15 (0.88)	0.01	2.74 (1.07)	2.90 (1.03)	2.81 (1.06)	-1.98 (0.05)	0.16

Table 4. ANOVA results comparing average perceived seriousness, perceived susceptibility, and concern by host type and disease among Texan hunters statewide and landowners who owned approximately 8 or more hectares in chronic wasting disease-affected counties in Texas, USA, as surveyed from September 2020 through January 2021.

			Average perceived seriousness					Average perceived susceptibility					Average concern				
			Sum of squares	df	Mean square	*F* stat.	η^2	Sum of squares	df	Mean square	*F* stat.	η^2	Sum of squares	df	Mean square	*F* stat.	η^2
Host type comparison	Chronic wasting disease	Between groups	319.13	2	159.56	163.80 (<0.00)	0.13	155.17	2	77.58	106.88 (<0.00)	0.09	112.39	2	56.20	51.92 (<0.00)	0.04
		Within groups	2,109.99	2,166	0.97			1,482.32	2,042	0.73			2,737.09	2,529	1.08		
		Total	2,429.12	2,168				1,637.49	2,044				2,849.48	2,531			
	Epizootic hemorrhagic disease	Between groups	29.52	2	14.76	13.79 (<0.00)	0.02	18.09	2	9.04	11.51 (<0.00)	0.02	11.98	2	5.99	5.44 (<0.00)	0.01
		Within groups	1,062.33	993	1.07			799.96	1,018	0.79			1,686.10	1,533	1.10		
		Total	1,091.85	995				818.05	1,020				1,698.08	1,535			
	Lyme	Between groups	12.60	2	6.30	5.94 (<0.00)	<0.00	11.31	2	5.65	6.92 (<0.00)	0.01	9.10	2	4.55	4.04 (0.02)	<0.00
		Within groups	1,918.20	1,809	1.06			1,291.93	1,582	0.82			2,361.50	2,097	1.13		
		Total	1,930.79	1,811				1,303.24	1,584				2,370.60	2,099			
	Bovine tuberculosis	Between groups	67.23	2	33.61	27.22 (<0.00)	0.04	5.59	2	2.79	3.00 (0.05)	<0.00	15.28	2	7.64	6.42 (<0.00)	0.01
		Within groups	1,734.63	1,405	1.23			1,170.49	1,258	0.93			2,171.73	1,825	1.19		
		Total	1,801.85	1,407				1,176.08	1,260				2,187.01	1,827			

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Disease comparison	Free-range deer	Between groups	188.09	3	62.70			129.39	3	43.13			112.63	3	37.55		
		Within groups	2,311.68	2,300	1.01	62.38 (<0.00)	0.08	1,568.21	2,102	0.75	57.81 (<0.00)	0.08	2,891.54	2,780	1.04	36.10 (<0.00)	0.04
		Total	2,499.77	2,303				1,697.59	2,105				3,004.17	2,783			
	Captive deer	Between groups	303.08	3	101.03			136.20	3	45.4			89.23	3	29.74		
		Within groups	2,083.55	2,106	0.99	102.12 (<0.00)	0.13	1,499.47	1,997	0.75	60.46 (0.75)	0.08	2,942.97	2,647	1.11	26.75 (0.75)	0.03
		Total	2,386.63	2,109				1,635.67	2,000				3,032.21	2,650			
	Livestock	Between groups	60.28	3	20.09			2.61	3	0.87			16.30	3	5.43		
		Within groups	2,429.92	1,967	1.24	16.27 (0.75)	0.02	1,677.04	1,801	0.93	0.93 (1.10)	<0.00	3,121.91	2,557	1.22	4.45 (0.75)	0.01
		Total	2,490.20	1,970				1,679.65	1,804				3,138.21	2,560			

CWD knowledge

On average, respondents answered 1.58 out of the 3 questions correctly (SD = 1.07). Hunters tended to answer factual knowledge questions correctly ($\bar{x}$ = 1.72, SD = 1.02) more often than landowners ($\bar{x}$ = 1.44, SD = 1.09), demonstrating statistically significant differences regarding levels of CWD factual knowledge, $t(982) = 4.02$, $P < 0.01$, Cohen's $d = 0.26$.

Risk perceptions of wildlife diseases

Respondents frequently answered DK to risk perception questions, indicating general unfamiliarity with all 4 wildlife-related diseases. We observed differences with small effect sizes in respondents' abilities to provide a response (i.e., not answer DK) based on host type (Table 1), where DK responses increased from free-range deer, to captive deer, to livestock for CWD, EHD, and Lyme questions. However, provided responses pertaining to livestock were most frequent regarding bovine TB (Table 1). There were also differences with small effect sizes in respondents' abilities to provide a response based on disease (Table 1), consistently following the pattern of increasing DK responses from CWD, to Lyme, to bovine TB, to EHD (where DK responses were approximately 50% or greater). Furthermore, in most cases, we noted differences between hunters and landowners, as the latter answered DK more often than hunters (Table 2).

Overall, risk perceptions were almost always above the "neutral" threshold (i.e., 2.5 on the 1–4 scale) for all diseases and host types, indicating respondents found the diseases at least somewhat serious, likely to spread, and concerning (Table 3). In most cases, we did not observe statistical differences between how hunters viewed these risks compared to landowners. A notable exception regarding CWD is that hunters more so than landowners perceived CWD as more serious to livestock (Table 3). There were consistent differences with small effect sizes in average perceived seriousness, susceptibility, and concern across host types for each disease investigated (Table 4). Additionally, we noted differences in average perceived seriousness, susceptibility, and concern across diseases for free-range deer as well as in average perceived seriousness across diseases for captive deer (Table 4).

Table 5. Regressions between knowledge of chronic wasting disease (CWD) and perceived seriousness, perceived susceptibility, and concern by host type and disease among Texan hunters statewide and landowners who owned approximately 8 ha or more in CWD-affected counties in Texas, USA, as surveyed from September 2020 through January 2021. Asterisks denote significance: (***) at the 1% level, (**) 5% level, and (*) 10% level.

	Observations	Knowledge			Hunter			Constant		
		Coefficient	SE	95% CI (LL, UL)	Coefficient	SE	95% CI (LL, UL)	Coefficient	SE	95% CI (LL, UL)
Perceived seriousness of chronic wasting disease (CWD) to free-range deer	836	-0.06*	0.03	-0.12, 0.01	-0.01	0.06	-0.14, 0.11	3.23***	0.07	3.09, 3.37
Perceived seriousness of CWD to captive deer	759	0.05	0.03	-0.01, 0.11	-0.05	0.06	-0.17, 0.08	3.33***	0.07	3.18, 3.47
Perceived seriousness of CWD to livestock	574	-0.30***	0.05	-0.40, -0.21	0.26**	0.10	0.07, 0.45	2.82***	0.11	2.60, 3.04
Perceived seriousness of epizootic hemorrhagic disease (EHD) to free-range deer	365	-0.06	0.05	-0.16, 0.04	0.03	0.10	-0.18, 0.23	2.99***	0.12	2.75, 3.23
Perceived seriousness of EHD to captive deer	333	-0.01	0.05	-0.12, 0.09	0.04	0.11	-0.18, 0.26	2.97***	0.13	2.71, 3.22
Perceived seriousness of EHD to livestock	298	-0.28***	0.07	-0.41, -0.15	0.10	0.13	-0.15, 0.36	3.02***	0.15	2.72, 3.32
Perceived seriousness of Lyme to free-range deer	657	-0.23***	0.04	-0.30, -0.15	0.04	0.08	-0.11, 0.19	3.04***	0.09	2.87, 3.21
Perceived seriousness of Lyme to captive deer	591	-0.23***	0.04	-0.31, -0.15	0.07	0.08	-0.09, 0.23	3.01***	0.09	2.82, 3.19
Perceived seriousness of Lyme to livestock	564	-0.24***	0.04	-0.32, -0.15	0.03	0.09	-0.15, 0.20	2.88***	0.10	2.68, 3.07
Perceived seriousness of bovine tuberculosis (TB) to free-range deer	446	-0.28***	0.05	-0.38, -0.17	0.13	0.11	-0.08, 0.34	2.78***	0.12	2.55, 3.02
Perceived seriousness of bovine TB to captive deer	427	-0.27***	0.05	-0.37, -0.16	0.24**	0.11	0.03, 0.46	2.80***	0.12	2.56, 3.05
Perceived seriousness of bovine TB to livestock	535	-0.11**	0.05	-0.20, -0.02	0.05	0.09	-0.13, 0.23	3.02***	0.10	2.82, 3.22
Perceived susceptibility of free-range deer to CWD	777	0.01	0.03	-0.04, 0.07	0.09	0.06	-0.03, 0.20	3.13***	0.06	3.01, 3.26
Perceived susceptibility of captive deer to CWD	727	0.00	0.03	-0.05, 0.06	0.03	0.06	-0.08, 0.15	3.25***	0.07	3.12, 3.39

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Perceived susceptibility of livestock to CWD	541	-0.33***	0.04	-0.41, -0.25	0.10	0.08	-0.07, 0.26	3.14***	0.09	2.96, 3.32
Perceived susceptibility of free-range deer to EHD	361	-0.11**	0.04	-0.20, -0.02	0.03	0.09	-0.15, 0.21	3.11***	0.10	2.90, 3.31
Perceived susceptibility of captive deer to EHD	347	-0.12**	0.05	-0.21, -0.03	-0.06	0.09	-0.24, 0.13	3.22***	0.11	3.01, 3.43
Perceived susceptibility of livestock to EHD	313	-0.28***	0.05	-0.38, -0.19	0.02	0.10	-0.18, 0.23	3.15***	0.12	2.92, 3.38
Perceived susceptibility of free-range deer to Lyme	558	-0.17***	0.04	-0.24, -0.10	0.00	0.07	-0.14, 0.15	3.07***	0.08	2.91, 3.23
Perceived susceptibility of captive deer to Lyme	528	-0.17***	0.04	-0.24, -0.10	-0.03	0.08	-0.18, 0.12	3.13***	0.09	2.97, 3.30
Perceived susceptibility of livestock to Lyme	499	-0.25***	0.04	-0.32, -0.17	0.02	0.08	-0.14, 0.18	3.04***	0.09	2.85, 3.22
Perceived susceptibility of free-range deer to bovine TB	410	-0.26***	0.05	-0.35, -0.17	0.07	0.09	-0.12, 0.25	2.98***	0.11	2.76, 3.19
Perceived susceptibility of captive deer to bovine TB	399	-0.25***	0.05	-0.34, -0.16	0.04	0.09	-0.14, 0.23	3.04***	0.11	2.83, 2.26
Perceived susceptibility of livestock to bovine TB	452	-0.20***	0.04	-0.28, -0.11	0.05	0.09	-0.13, 0.22	3.03***	0.10	2.84, 3.23
Concern of CWD to free-range deer	909	0.02	0.03	-0.04, 0.08	-0.05	0.06	-0.18, 0.07	3.15***	0.07	3.01, 3.28
Concern of CWD to captive deer	865	0.02	0.03	-0.05, 0.09	-0.02	0.07	-0.16, 0.12	3.02***	0.08	2.87, 3.17
Concern of CWD to livestock	758	-0.26***	0.04	-0.33, -0.18	-0.07	0.08	-0.23, 0.09	3.11***	0.09	2.94, 3.28
Concern of EHD to free-range deer	535	-0.09**	0.04	-0.17, -0.00	-0.06	0.09	-0.23, 0.11	3.10***	0.09	2.92, 3.28
Concern of EHD to captive deer	513	-0.09**	0.04	-0.17, -0.00	-0.04	0.09	-0.22, 0.14	3.01***	0.09	2.82, 3.19
Concern of EHD to livestock	488	-0.23***	0.05	-0.33, -0.14	-0.09	0.10	-0.28, 0.11	3.14***	0.10	2.94, 3.33
Concern of Lyme to free-range deer	734	-0.18***	0.04	-0.25, -0.11	-0.13*	0.07	-0.27, 0.02	3.12***	0.08	2.97, 3.28
Concern of Lyme to captive deer	693	-0.19***	0.04	-0.26, -0.11	-0.11	0.08	-0.27, 0.04	3.03***	0.08	2.86, 3.19
Concern of Lyme to livestock	673	-0.25***	0.04	-0.33, -0.17	-0.19**	0.08	-0.35, -0.03	3.11***	0.08	2.95, 3.28
Concern of bovine TB to free-range deer	606	-0.22***	0.04	-0.30, -0.14	-0.13	0.09	-0.31, 0.04	3.06***	0.09	2.89, 3.24
Concern of bovine TB to captive deer	580	-0.22***	0.04	-0.30, -0.13	-0.09	0.09	-0.27, 0.09	3.00***	0.09	2.82, 3.19
Concern of bovine TB to livestock	642	-0.13***	0.04	-0.21, -0.05	-0.13	0.08	-0.29, 0.04	3.09***	0.08	2.92, 3.26

Risk perceptions and CWD knowledge

There were few relationships between factual knowledge of CWD and perceived seriousness, perceived susceptibility, or concern of CWD regarding free-range or captive deer (Table 5). However, there were consistent negative relationships between factual knowledge of CWD and perceived seriousness, perceived susceptibility, and concern of CWD regarding livestock. In nearly all other instances, there were negative relationships between factual knowledge of CWD and perceived seriousness, perceived susceptibility, and concern across all wildlife diseases and all host types (Table 5). These relationships indicate reduced levels of factual knowledge of CWD were routinely associated with greater perceived seriousness, perceived susceptibility, and concern of other diseases across host types. Additionally, there were few significant relationships between hunter status and perceived seriousness, perceived susceptibility, or concern across wildlife diseases and host types (Table 5).

Discussion

Wildlife agencies often receive limited guidance about the information they should present on their websites or other communication channels for the effective dissemination of information related to CWD (Eschenfelder 2006). Yet, providing effective information and messaging are crucial to stakeholders who rely on agencies for information (Messmer et al. 1997, Brown et al. 2006), particularly when they have no personal experience with CWD (Heberlein and Stedman 2009). Our findings reveal 3 key takeaways that can assist agencies in planning CWD communication strategies.

First, the frequent DK responses indicate there is a general unfamiliarity regarding wildlife diseases across measurements of risk perception. Although these DK responses may be caused by deficits in knowledge, such responses in surveys related to human infectious diseases may also be prompted by a lack of certainty or salience (Ellis et al. 2018), which may be the case here. For example, our research showed trends of DK frequencies increasing from CWD, to Lyme, to bovine TB, to EHD, which may reflect: (1) a genuine lack of knowledge about these diseases, (2) some uncertainty and an associated unwillingness to engage in the cognitive processes needed to offer an educated guess in uncertainty (Orom et al. 2018), or (3) respondent avoidance of information that is not deemed relevant (Ellis et al. 2018).

Study respondents may have felt most certain due to their familiarity with CWD and viewed CWD as a relevant risk, whereas EHD was less known to respondents and perhaps not considered as relevant and, thus, not as worthy of cognitive effort (Ellis et al. 2018, Orom et al. 2018). Among host types, DK responses increased from free-range deer, to captive deer, to livestock across nearly all diseases, where respondents may have again avoided reporting perceptions they considered irrelevant or about which they felt uninformed (Ellis et al. 2018). A potential corollary to this finding is that among those who responded to risk perception questions, the greatest levels of average perceived seriousness, perceived susceptibility, and concern were reported for captive and free-range deer with CWD (i.e., the most seemingly relevant and familiar disease-host type combinations were perceived to carry the greatest levels of risk). A better understanding of why stakeholders are compelled to choose a DK response underscores the importance of improving communications about wildlife diseases and their transmission. Improved understandings can also elucidate how related information, such as disease implications for humans, livestock, and wildlife, needs to be delivered.

Second, although the effect sizes were small, our findings that landowners selected DK responses more so than hunters and that hunters held statistically greater factual knowledge levels of CWD suggest communications may be more effective if they are delivered differently to different groups (Orom et al. 2018). Researchers have found gaps in understanding about diseases are often linked to certain groups' (often unintentional) exclusion from information, influence, and decision-making (Orom et al. 2018). Current one-size-fits-all communications (e.g., CWD-related website updates, social media posts, newsletter articles) may be potential barriers to CWD-related messaging for landowners in terms of targeting and/or accessibility.

Third and finally, our results challenge existing theories exploring the relationships between knowledge of diseases and perceptions

of risk. Several theoretical frameworks incorporate knowledge as a contributing factor to disease risk perceptions and preventative behaviors (Pask and Rawlins 2016, Piltch-Loeb et al. 2017, Hotle et al. 2020). Yet, rather than finding expected positive relationships between factual knowledge and risk perceptions, we found a negative or no relationship, depending on the circumstance.

We documented negative relationships between factual knowledge of CWD (which may serve as a proxy for knowledge of wildlife diseases generally) and risk perceptions across EHD, Lyme, and bovine TB and all host types. These results suggest reduced levels of factual knowledge of CWD are associated with greater perceptions of risk of other diseases. This negative relationship also emerged with reduced levels of factual knowledge of CWD and greater risk perceptions regarding CWD and livestock. Similarly, hunters often perceived significantly greater levels of risk related to livestock and bovine TB than landowners.

Although not explicitly tested, there is good reason to believe hunters are less familiar with and less knowledgeable about livestock and threats to livestock than landowners. Thus, hunters often perceiving greater risks to livestock from CWD in our study is consistent with the pattern we found of reduced knowledge levels being associated with greater risk perceptions. Not only has this negative relationship between knowledge and risk perception been observed in some human infectious disease contexts (e.g., the overestimation of the risk of contracting human immunodeficiency virus and typhoid among business travelers, where reduced knowledge levels were paired with greater perceptions of risk; Wynberg et al. 2013), but this pattern also mimics the one revealed by Vaske et al. (2018). Vaske et al. (2018) noted hunters who were less geographically exposed to CWD had less knowledge of the disease and perceived greater risks of CWD.

Although greater perceptions of risk are often considered more favorable compared to underestimations of risk (Wynberg et al. 2013), such overestimations of risk may cause changes in hunter behavior (e.g., avoiding certain sites, reducing hunting participation) or be detrimental to CWD and other disease management (e.g., stakeholder expectations of unrealistic management goals). As such, management efforts must be accompanied by messaging explaining agency- and individual-level actions that are and can be taken to manage the diseases.

In other circumstances, there were no relationships between factual knowledge of CWD and perceptions of risk. For example, despite current CWD communications on TPWD's website and social media, there was no significant relationship between factual knowledge of CWD and CWD risk perceptions regarding free-range or captive deer. Similarly, we found landowner risk perceptions were consistent with those of hunters (which differed from previous research; Decker et al. 2012, Vaske and Miller 2018). These findings reveal current communication strategies centered on increasing general factual knowledge of CWD are falling short and need to be expanded or refocused to improve their efficacy.

In using the findings from this study to develop communication strategies, we urge agencies to also consider the limitations of this research. First, we want to highlight that we only sampled landowners with property in CWD-affected counties, which likely introduced a bias where landowners in this study were more likely to be familiar with CWD compared to landowners across the rest of the state. Second, we note again that the 2 respondent groups of hunters and landowners are not necessarily mutually exclusive, which may explain the small effect sizes associated with differences between the groups. Third, we recognize the potential for some nonrespondent bias, particularly in the areas of gender and years of formal education, which may have an effect on our results.

Our study contributes a wildlife-based perspective to the growing recognition within the infectious disease communications literature that health experts often overestimate the value of factual knowledge and its role in risk perception models (Piltch-Loeb et al. 2017). As such, we recommend a shift toward practical and actionable knowledge, which have been shown to be effective in strategic communication plans designed for human infectious disease outbreaks (Lwin et al. 2018, Oh et al. 2021). For example, messages focused on preparedness (Lwin et al. 2018) and recommended preventative behaviors (Oh et al. 2021) have successfully produced greater levels of public engagement

during outbreaks. Additionally, messaging that promotes public common responsibility and cooperation for transmission prevention can be helpful during the outbreak, as well as in the long-term regarding education efforts (Lwin et al. 2018).

Targeted communication campaigns specific to hunters and landowners will also likely be helpful in providing stakeholders with personally useful information (Needham and Vaske 2008). For example, hunter-targeted communications can offer actionable individual-level recommendations for the transportation and testing of carcasses. Landowner-targeted messaging can focus on the symptoms of CWD-infected deer and how to report such sightings as well as information regarding concerns about CWD spreading from deer to livestock. While most studies have consistently quantified knowledge as measurements of factual knowledge of CWD (e.g., Needham et al. 2017), future research exploring how practical and actionable knowledge influences risk perceptions may further improve the efficacy of agency communications.

Management implications

This study's insights into stakeholder risk perceptions provide further evidence that efforts to shape perceptions through communication campaigns must be executed strategically. By analyzing risk perceptions across stakeholder types, perception measures, disease types, and host types, we have revealed wildlife agencies would likely benefit from structuring communication plans that emphasize the salience of disease management to stakeholders and deliver targeted messaging to different audiences. Such messaging should effectively promote agency-recommended preventative actions, dispelling erroneous perceptions that may hamper CWD management efforts.

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