Received: 31 August 2022 | Revised: 5 November 2022 | Accepted: 10 November 2022

DOI: 10.1111/csp2.12858

Conservation Science and Practice
A journal of the Society for Conservation Biology
Open Access
WILEY

CONTRIBUTED PAPER

Engaging stakeholders in wildlife disease management: Hunters' willingness to adopt and support biosecurity actions to prevent the spread of rabbit hemorrhagic disease

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Funding information
United States Department of Interior; Multistate Conservation Grant Program, Grant/Award Number: F21AS00004

Abstract

Rabbit hemorrhagic disease virus 2 (RHDV2) is a highly contagious virus that primarily infects rabbits and hares (lagomorphs) and poses a serious threat to lagomorph populations and hunting. Wildlife agencies in the United States rely on hunters to report RHDV2-related mortalities and engage in voluntary biosecurity actions to prevent the spread of RHDV2. From April 2021 to April 2022, we conducted a nationwide survey of 22,511 hunters to ascertain their willingness to engage in voluntary biosecurity actions and support government-mandated biosecurity measures. Respondents expressed greatest willingness to report suspicious lagomorph deaths to wildlife agencies. Respondents' willingness to engage in or support biosecurity actions was positively correlated with their risk perceptions pertaining to lagomorph deaths and the economic impacts of RHDV2, perceptions of the importance of biosecurity, and trust in state agencies to manage RHDV2. We found evidence that respondents' willingness to engage in or support biosecurity actions was also positively correlated with their knowledge of RHDV2. Wildlife agencies should clearly communicate about RHDV2 and its adverse impacts on lagomorphs, biodiversity, and hunting to engage hunters in biosecurity measures. Hunters can provide valuable information about lagomorph population trends and mortality events in the areas they hunt, a cost-effective method to augment agency surveillance.

KEYWORDS

foreign animal disease, human dimensions of wildlife conservation, hunting, quantitative surveys

1 | INTRODUCTION

Loss of wildlife to environmental change (habitat loss, climate change, species invasions, and overexploitation) is being exacerbated by the introduction and spread of pathogens (Smith et al., 2009). One of the greatest conservation challenges that wildlife agencies face is to prevent the introduction of foreign animal pathogens into naïve wildlife populations. This is a task that is complicated by the growing global trade in live animals and associated pathogen transmission at the wildlife–domestic animal interface (e.g., avian influenza, chronic wasting disease; Shapiro et al., 2022). Accordingly, international organizations (e.g., The World Organization for Animal Health) have called for government investment in defensible and reliable surveillance systems and biosecurity measures to prevent pathogen transmission at the wildlife–domestic animal interface (Portier et al., 2019; Ryser-Degiorgis, 2013; Stephen et al., 2019). Active surveillance is needed to provide early warning of emerging infectious diseases, but wildlife health surveillance is typically based on sampling of dead or visibly sick animals or convenience sampling (e.g., hunter-harvested animals; Ryser-Degiorgis, 2013; Stephen et al., 2019). Targeted (active) wildlife health surveillance is uncommon because high sample sizes are needed to provide reliable pathogen prevalence estimates that account for relevant biological, spatial, and temporal variables (Ryser-Degiorgis, 2013). Furthermore, surveillance and disease management efforts by wildlife agencies are often hampered by incomplete knowledge of wildlife populations at risk, pathogen persistence or transmission outside of vertebrate hosts (i.e., vector-borne pathogens), insufficient diagnostic facilities and staff, funding constraints, and political backlash by environmental groups, hunters, or the public (Portier et al., 2019; Ryser-Degiorgis, 2013; Stephen et al., 2019). To help overcome these obstacles, key stakeholders need to be engaged in participatory disease management and appropriate communication is required to obtain their support for government-mandated biosecurity measures.

We focus on the role of hunters in the United States in preventing the spread of a foreign animal pathogen, rabbit hemorrhagic disease virus 2 (GI.2/RHDV2/b; Le Pendu et al., 2017). Rabbit hemorrhagic disease virus 2 (hereafter, RHDV2) is a highly contagious virus that causes rabbit hemorrhagic disease primarily in wild and domestic rabbits and hares (lagomorphs), although there is evidence of spillover to Eurasian badgers (*Meles meles*; Abade dos Santos et al., 2022). Mortality rates may be as high as 80% (Le Gall-Reculé et al., 2013; Mutze et al., 2018). Detection in wild lagomorphs is challenging because infected animals often show no obvious signs of disease before death (Williams et al., 2021), lagomorphs may die in burrows, and scavengers and predators rapidly consume lagomorph carcasses. Preventing the spread of RHDV2 is further complicated because the virus is transmitted through direct or indirect contact with infected lagomorphs (oculonasal secretions, urine, feces, and blood), lagomorph carcasses or carcass parts, insect vectors (Asgari et al., 1998), and environments or materials contaminated by infected lagomorphs (e.g., clothing and equipment). Moreover, the virus can remain viable up to 15 weeks in dry conditions and over 90 days in decaying animal tissue outdoors (Henning et al., 2005). In Europe, RHDV2 resulted in population declines (60%–70%) of wild lagomorphs, triggering ecological disruptions, trophic cascades, and declines of rabbit-specialist predators, including the endangered Iberian lynx (*Lynx pardinus*) and the vulnerable Spanish Imperial eagle (*Aquila adalberti*; Monterroso et al., 2016). Intensive, costly management efforts may be required to recover ecosystems that are impacted by RHDV2 due to significant alterations to ecosystem structure and function (Delibes-Mateos et al., 2014; Guerrero-Casado et al., 2013).

In the United States, an RHDV2 outbreak occurred in domestic and wild lagomorphs in New Mexico in March 2020 (U.S. Department of Agriculture [USDA], 2022). As of October 2022, RHDV2 has been detected in wild and/or domestic lagomorphs in 28 states (Figure 1). RHDV2 has infected 8 wild lagomorph species, including the endangered riparian brush rabbit (*Sylvilagus bachmani riparius*), and poses a risk to all 15 native lagomorph species in the United States. RHDV2 is likely to place additional strain on both imperiled (e.g., white-tailed jack rabbits *Lepus townsendii*; Brown et al., 2020) and once common lagomorph species (e.g., cottontail rabbits in Wyoming; Corr, 2022) whose populations are threatened by habitat loss, increasing predator populations, climate change, and species invasions (Bosch et al., 2016; Diefenbach et al., 2016; McCleery et al., 2015). Moreover, RHDV2 poses a threat to hunting. Lagomorphs are the fourth most popular game animal in the United States, with ∼1.3 million individuals hunting lagomorphs annually (U.S. Fish and Wildlife Service and U.S. Census Bureau, 2018).

In an effort to control RHDV2, state wildlife agencies have worked with agricultural agencies to investigate suspected RHDV2 mortalities, implemented temporary management or rule changes (e.g., prohibitions on movement of wild lagomorph carcasses from RHDV2-positive areas; Pennsylvania Game Commission, 2021), and created outreach and educational materials. State wildlife agencies rely on hunters to report suspicious rabbit deaths (passive disease surveillance) and to adopt appropriate biosecurity actions to mitigate RHDV2 transmission (e.g., removing

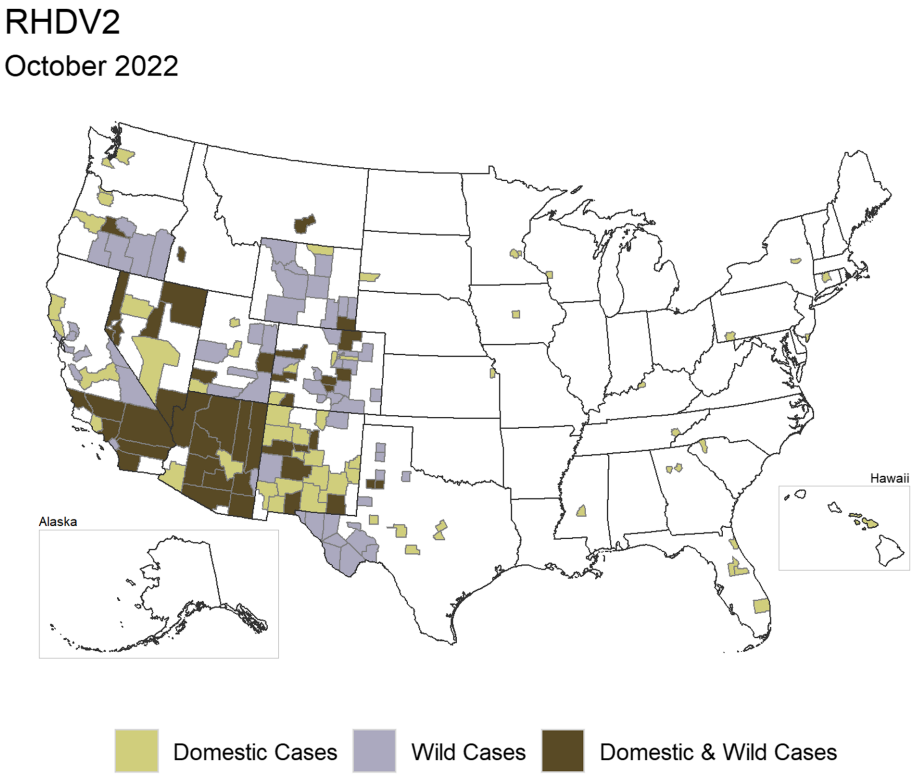


FIGURE 1 Counties with confirmed rabbit hemorrhagic disease virus 2 (RHDV2) cases in domestic, wild, and feral domestic rabbits from March 2020 to October 2022. Domestic cases include both domestic and feral rabbit cases. This map does not include isolated RHD cases in Ohio (2018), Washington (2019), and New York (2020). *Data source*: USDA APHIS. Supplemental data reports that have been verified using press releases were used to update the map between USDA reporting periods. Data visualization: Dr. Michel T. Kohl. Map publicly available at: rhdv2.org

carcasses from the field; Shapiro et al., 2022). Lagomorphs exploit seasonal habitats during periods of optimal conditions (Heldstab, 2021). Hunters pursuing lagomorphs target specific habitat characteristics and use specialized techniques including cooperative hunting parties with multiple hunters and trained scenting hounds. Both rabbit and nonrabbit hunters are well positioned to assist agencies in disease management because they travel into areas not frequented by the public. Moreover, hunters are likely to notice changes in lagomorph populations even if they hunt other species (Dusek et al., 2014). However, to date, hunters' willingness to change their behaviors to prevent the spread of RHDV2 or to support management strategies has not been examined. We investigated hunters' willingness to participate in agency recommended RHDV2 biosecurity actions and their support for biosecurity measures that could be implemented by wildlife agencies. To the best of our knowledge, this study is novel in three respects. This study forms part of the first social sciences investigation of rabbit hemorrhagic disease. Second, we conducted the first nationwide study of hunters in the United States to ascertain their willingness to engage in disease surveillance and mitigation. Third, we surveyed both small and large game hunters because we recognized that all hunters play an important role in disease surveillance, irrespective of whether they target particular species at risk.

We predicted that hunters' willingness to engage in or support biosecurity actions would be positively correlated with their knowledge of RHDV2 (Oruganti et al., 2018), their risk perceptions (Hanisch-Kirkbride et al., 2013; Harper et al., 2015; Pienaar et al., 2022), their trust in state agencies to manage RHDV2 (Hanisch-Kirkbride et al., 2014; Harper et al., 2015; Vaske et al., 2018), their evaluation of whether biosecurity measures are necessary, and whether they hunt in a state with confirmed RHDV2 cases. Risk perceptions are subjective judgments that vary across individuals and influence their behavior under uncertainty (Hanisch-Kirkbride et al., 2013; Needham et al., 2017; Vaske et al., 2018). Risk perceptions are measured in terms of severity and susceptibility (perceived likelihood of occurrence; Hanisch-Kirkbride et al., 2013). People's risk perceptions depend on the specific hazards being evaluated (e.g., RHDV2 transmission at the wild-domestic lagomorph interface), their familiarity with or knowledge of these risks, their risk sensitivity (i.e., weight they place on risk), and their attitudes towards the agents generating risk (e.g., the domestic trade in lagomorphs; Hanisch-Kirkbride et al., 2013; Needham et al., 2017). People may respond differently to the ecological and economic impacts of pathogen transmission, depending on whether they are concerned about loss of wild species or how pathogen transmission impacts domestic industries (e.g., the pet trade, hunting; Pienaar et al., 2022). Women and older individuals tend

to have higher risk perceptions related to pathogens, whereas more educated individuals may have lower risk perceptions, which in turn influences support for, or engagement in, biosecurity actions (Hanisch-Kirkbride et al., 2013; Needham et al., 2017; Pienaar et al., 2022). Trust in state agencies to manage disease risks (hereafter, social trust) encompasses hunters' perceptions of whether state wildlife agencies have the necessary expertise and resources to take appropriate actions to manage disease (Siegrist & Cvetkovich, 2000). Social trust is particularly relevant to hunters' behaviors when they lack knowledge about a hazard (i.e., RHDV2 transmission; Siegrist et al., 2005; Vaske, 2010). For example, previous studies found that most hunters reported trusting wildlife agencies to manage chronic wasting disease to the best of their abilities (Needham & Vaske, 2008), even if controversial actions were taken to address this threat (Stafford et al., 2007).

2 | METHODS

2.1 | Survey design

The objectives of this research were to (1) assess hunters' stated willingness to engage in voluntary actions to prevent the spread of RHDV2 and to support government management of RHDV2, and (2) identify determinants of hunters' willingness to engage in or support biosecurity measures. To attain our second objective, we focused on hunters' awareness and knowledge of RHDV2, risk perceptions pertaining to RHDV2, perceptions of the importance of engaging in biosecurity actions, social trust (i.e., trust in state agencies to manage RHDV2), hunting behaviors (e.g., game species targeted, hunting with dogs), and demographics.

We implemented online questionnaires to elicit hunters' stated willingness (very unlikely = 1; unlikely = 2; neither likely nor unlikely = 3; likely = 4; very likely = 5) to engage in six voluntary biosecurity actions, specifically: (1) reporting suspicious lagomorph deaths to their state wildlife agency; (2) wearing disposable gloves when handling lagomorph carcasses; (3) placing remains of cleaned lagomorphs in a bag, sanitizing the bag, and either burying the bag or disposing of it in the trash; (4) waiting to clean lagomorph carcasses until they had returned home, rather than cleaning lagomorphs in the field; (5) cooking lagomorphs to an internal temperature of 165 °F (73.9°C); and (6) sanitizing all tools, equipment, or other items used to hunt or clean lagomorphs before and after contact with wild lagomorphs (Association of Fish and Wildlife Agencies, 2020; National Assembly of State Animal Health Officials [NASAHO], 2020). Respondents had the option to indicate if any of these biosecurity actions were not applicable to them (e.g., they do not eat lagomorphs). We also asked respondents whether they would support (strongly oppose = 1, oppose = 2, neither oppose nor support = 3, support = 4, and strongly support = 5) four potential government measures to prevent the spread of RHDV2, namely: (1) relocation of field trials for hunting dogs ≥150 miles (241.4 km) from counties with RHDV2 cases; (2) restrictions on lagomorph hunting in areas with threatened or endangered lagomorphs; (3) a ban on the transport of live and dead lagomorphs from states with confirmed RHDV2 cases; and (4) a ban on the transport of lagomorphs between states until a domestic vaccine was produced and distributed. Field trials are outdoor competitions for hunting dogs. Many field trials rely on the presence of naturally occurring, free-ranging lagomorphs, while some include capture and release of wild or domestic lagomorphs into fenced enclosures. Depending on state regulations, permits may be required for certain practices associated with field trials.

Prior to measuring respondents' willingness to engage in or support biosecurity actions, we first asked them to provide us with information on their hunting behaviors (i.e., whether they hunted rabbits in the past 5 years, which game species they hunt). We then measured respondents' prior awareness of RHDV2 (binary variable coded as one if the respondent had previously heard of RHDV2) and their prior knowledge of RHDV2 (i.e., which lagomorphs are susceptible to RHDV2, the RHDV2 status of their state, vectors for pathogen transmission, and the likelihood that lagomorphs show signs of infection before death). After answering these knowledge questions, respondents were presented with identical information on RHDV2 mortality rates, vulnerable species, and available vaccines to ensure that each individual responded to subsequent questions based on accurate understanding of RHDV2.

We measured respondents' risk susceptibility by asking them how much risk they believed RHDV2 poses to the domestic rabbit trade (pet trade, rabbit rescues, rabbit shows, meat production) and lagomorph hunting (no risk = 1, low risk = 2, moderate risk = 3, and high risk = 4). Note, we tested hunters' perceptions of the risk that RHDV2 poses to the domestic rabbit trade because RHDV2 transmits at the wildlife–domestic animal interface and may adversely impact the domestic rabbit trade. We measured respondents' sensitivity to the ecological and economic risks of RHDV2 spread by asking them whether they were concerned about the impact of RHDV2 on the domestic rabbit trade, lagomorph hunting, the health of domestic and wild lagomorphs in their state, and biodiversity (strongly disagree = 1, disagree = 2,

neither agree nor disagree = 3, agree = 4, and strongly agree = 5). To measure respondents' evaluation of whether biosecurity measures are important, we asked whether they agreed that transporting lagomorphs increases the probability of RHDV2 transmission, hunters should engage in measures to prevent RHDV2 spreading, and that disease prevention measures are important in states with and without RHDV2 cases (strongly disagree to strongly agree). We measured social trust by asking respondents whether they agreed that their state agencies have the knowledge, resources, and sufficiently skilled people to manage RHDV2, and have been effective in managing RHDV2 (strongly disagree to strongly agree). Finally, we elicited respondents' gender, age, and education levels.

We conducted expert review of the survey instrument with five veterinary medicine and animal disease specialists, two wildlife biologists, and three human dimensions experts. We used cognitive testing to pretest the survey instrument with 10 members of key stakeholder groups who interact with wild and/or domestic rabbits (including hunters). We adjusted the survey based on the expert reviews and pretests to ensure that the RHDV2 and hunting information we presented in the survey was factually accurate, and we had minimized any potential response bias in the survey (i.e., our questions were appropriately designed and framed to ensure that respondents provided accurate, thoughtful responses that reflected their true opinions and behavioral intentions).

The University of Georgia Institutional Review Board reviewed all research materials and protocols and characterized our study as non-human subject research because we elicited no identifiable or sensitive private information from research participants. We informed all research participants in writing that they were not obligated to participate in this study, and that they could stop taking the survey at any time without penalty.

2.2 | Survey implementation

We implemented online questionnaires from April 2021 to April 2022 using University of Georgia's Qualtrics license (Qualtrics.com). We recruited research participants by cooperating with 27 state wildlife agencies and the Northeast Beagle Gundog Federation. We either obtained licensed hunters' email addresses from these organizations (so that we could email individuals directly) or we asked these organizations to send the survey invitation to licensed hunters in their state (if they were unwilling or unable to share contact details for hunters with us owing to data sharing rules). Our sampling strategy was tailored to each state depending on whether they had records of small game hunters (e.g., hunters who target lagomorphs, squirrels, foxes, racoons, quail, grouse). If states kept records of small game hunters, we asked them to send survey invitations to ≥5000 of these individuals, depending on the total population of small game hunters in their state. If states had <5000 small game hunters or they did not have records of small game hunters, we asked them to send survey invitations to ≥10,000 hunters in each state. This sample comprised as many small game and rabbit hunters as the states could identify (often through prior small game surveys), with the rest of the sample being comprised of a random selection of hunting license holders (excluding waterfowl hunters when possible). Hunters received one reminder to participate in the research 2 weeks after the initial invitation if they were recruited by a state wildlife agency or hunting organization. We adopted this strategy to reduce the administrative burden on states and hunting organizations. In those instances where state wildlife agencies provided us with their list of hunters, we sent three reminders at weekly intervals to survey recipients after they received the initial invitation. Regardless of recruitment method used, survey recipients were informed that this research was being conducted in collaboration with their state wildlife agency or hunting organization. The survey link remained active for 1 month after the final reminder.

2.3 | Data analysis

We used the statistical analysis software SPSS 27.0 (SPSS Statistics for Windows, Version 27.0, Armonk, New York: IBM Corp.) to run descriptive analyses, parametric and non-parametric tests, and conduct principal factor analysis. We tested for any differences in responses to questions between rabbit hunters and those hunters who did not target rabbits using independent *t*-tests and Mann–Whitney *U* tests. If effect sizes were small (Cohen's $d \leq 0.2$ or $\eta^2 \leq 0.01$), we considered any differences to be negligible, and attributable to large sample sizes rather than true differences between rabbit and non-rabbit hunters. We used principal factor analysis with Varimax rotation to test whether ordinal survey items could be combined to generate composite variables (e.g., by averaging individual items to generate unweighted scores that measured respondents' risk perceptions, social trust, and importance they placed on engaging in biosecurity measures). We used Cronbach's alpha (Cronbach, 1951) to measure the inter-item reliability of items used to generate these constructs (scores). Survey items that loaded onto factors with an eigenvalue≥1 and Cronbach's alpha ≥ .7 (Gliem & Gliem, 2003) were combined to generate composite variables. We generated an RHDV2 knowledge score (no correct responses = 0; all correct responses = 15) by summing the number of correct

responses research participants provided to the knowledge questions. We converted this score into a proportion by dividing the total number of correct responses by 15 (i.e., the knowledge score ranged from 0 to 1). Respondents who were not previously aware of RHDV2 scored zero for their knowledge of RHDV2.

We used ordinal logistic regression models to analyze respondents' willingness to engage in biosecurity behaviors and their support for government strategies to control RHDV2. We included risk sensitivity, risk susceptibility, social trust, the perceived importance of engaging in biosecurity measures, awareness of RHDV2, knowledge of RHDV2, hunting behaviors, and sociodemographic variables in the full models. We used the polr package in R 4.1.2 (R Core Team 2021) to estimate the ordinal logistic regression models. Both stepwise reduction and comparison of all possible models using the MuMIn package were conducted to determine the best-fit models. We identified the best-fit models based on the Akaike Information Criterion (AIC; Burnham & Anderson, 2004), whereby the best-fit model had the lowest AIC. We conducted model averaging when there were multiple models that were within AIC ≤ 2 of the lowest AIC. We considered a coefficient to be statistically significant at $p \leq .05$.

3 | RESULTS

We collected 33,213 surveys from hunters in all 50 states (i.e., hunter lists for the various states included both resident hunters and hunters from other U.S. states). Incomplete responses and responses by people who indicated they were <18 years old were removed, resulting in 22,511 completed responses. Our sample of hunters (including lagomorph hunters) exceeded the number needed to ensure we attained a 95% confidence level and 5% margin of error.

Most respondents (n = 20,476; 91.0%) were male (Table S1). The median age range for respondents was 55–64 years, and the median education level was some college or an associate degree (Table S1). On average, respondents hunted 4 game species in the past 5 years, primarily deer (n = 18,420; 81.8%), game birds (n = 10,384; 46.1%), turkey (n = 10,318; 45.8%), and squirrels (n = 9170; 40.9%). Rabbits were the fifth most commonly hunted animal (n = 8602; 38.2%; Table S1). Approximately one-third of respondents lived in a state that had confirmed RHDV2 cases (n = 7214; 32.0%).

3.1 | Biosecurity measures

Most respondents were likely or very likely to engage in all recommended biosecurity behaviors (50.1%–87.9% of respondents depending on the behavior; Table 1). They expressed greatest willingness to report suspicious lagomorph deaths, which would increase the effectiveness of current passive disease surveillance efforts by state wildlife agencies. On average, respondents also expressed support for agency actions to prevent or control RHDV2 by relocating field trials (57.6% of respondents supported this action), banning the transport of lagomorphs from areas with RHDV2 (65.3% of respondents) or until a domestic vaccine had been produced (55.5% of respondents), and restricting hunting in areas with imperiled lagomorphs (64.2% of respondents; Table 2). Taking effects sizes into account, we found no real differences between rabbit hunters and nonrabbit hunters in terms of their willingness to engage in or support biosecurity measures (Table S2).

3.2 | Awareness and knowledge of RHDV2

Most respondents had not heard of RHDV2 before taking the survey (n = 17,877; 79.4%). Respondents who had heard about RHDV2 prior to taking the survey exhibited moderate knowledge about the pathogen (median = 0.53; 0.48 $\pm$ 0.24; range of 0–1). These respondents were most aware that RHDV2 infects (n = 4437; 95.7%) and can be spread by wild lagomorphs (n = 3738; 80.7%; Table S3). Few of these respondents (n = 517; 11.2%) knew that lagomorphs infected with RHDV2 are unlikely to show signs of the disease before death. Taking effects sizes into account, we found no real differences between rabbit hunters and nonrabbit hunters in terms of their awareness and knowledge of RHDV2 (Table S2).

3.3 | Risk perceptions

Respondents expressed risk sensitivity to lagomorph deaths caused by RHDV2, with most respondents expressing concern for the negative impacts of RHDV2 on domestic rabbits (66.4%), wild lagomorphs (76.9%), and biodiversity loss from the disease-related deaths of native lagomorphs (73.2%). Principal factor analysis (eigenvalue = 2.39; Cronbach's alpha = .87) confirmed that respondents' concerns about the impact of RHDV2 on domestic rabbits, wild lagomorphs, and biodiversity represented a single construct "risk sensitivity to lagomorph deaths" (median = 4.00; 3.88 $\pm$ 0.82; range = 1–5; Figure 2 and Table S4).

Respondents demonstrated lower risk sensitivity to the economic impacts of RHDV2. Less than half of respondents were concerned about the impacts of

TABLE 1 Respondents' willingness to engage in voluntary biosecurity measures to prevent the spread of rabbit hemorrhagic disease virus 2 (RHDV2; $n = 22{,}511$).

Biosecurity actions	Median	Very unlikely[a] No. (%)	Unlikely No. (%)	Neither likely nor unlikely No. (%)	Likely No. (%)	Very likely No. (%)	N/A No. (%)
Report suspicious rabbit deaths to your state wildlife agency	Very likely	793 (3.5)	508 (2.3)	1158 (5.1)	6639 (29.5)	13,140 (58.4)	273 (1.2)
Wear disposable gloves when handling rabbit carcasses	Very likely	998 (4.4)	1984 (8.8)	2184 (9.7)	5256 (23.3)	10,459 (46.5)	1630 (7.2)
Place remains of cleaned rabbits in a bag, sanitize the bag, and either bury the bag or dispose of it in the trash	Likely	1140 (5.1)	1665 (7.4)	2202 (9.8)	5607 (24.9)	9752 (43.3)	2145 (9.5)
Wait to clean rabbit carcasses until you have returned home	Likely	2002 (9.0)	2744 (12.2)	2292 (10.2)	4885 (21.7)	6398 (28.4)	4170 (18.5)
Cook rabbits to an internal temperature of 165 °F	Very likely	667 (3.0)	235 (1.0)	1117 (5.0)	3781 (16.8)	12,496 (55.5)	4215 (18.7)
Sanitize all tools, equipment, or other items used to hunt/clean rabbits before and after contact with wild rabbits	Very likely	670 (3.0)	601 (2.7)	1462 (6.5)	4696 (20.9)	11,148 (49.5)	3934 (17.5)

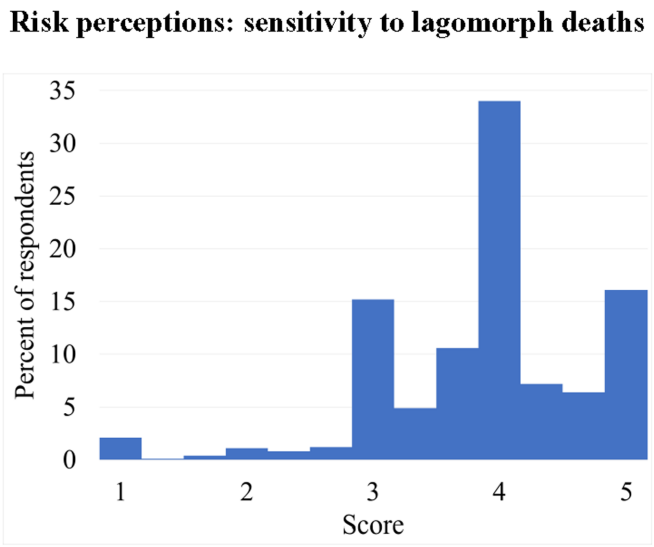
Note: Respondents answered the question "How likely are you to engage in the following behaviors?"
[a]Very unlikely = 1, unlikely = 2, neither likely nor unlikely = 3, likely = 4, and very likely = 5.

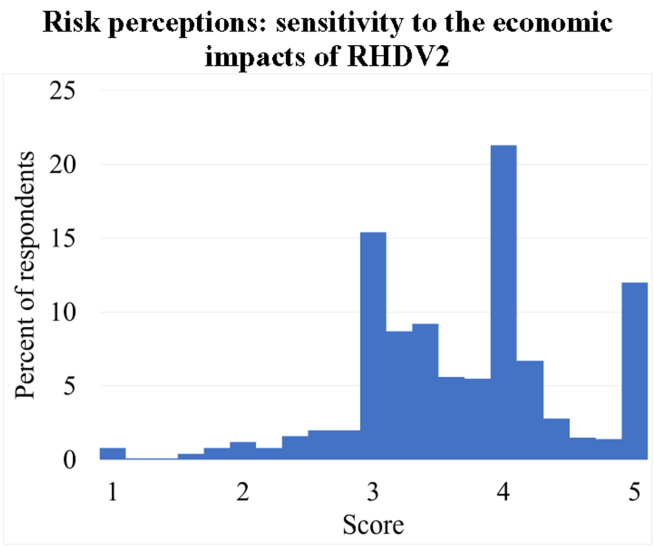
TABLE 2 Respondents' support for agency actions to mitigate the spread of rabbit hemorrhagic disease virus 2 (RHDV2; $n = 21{,}834$[a]).

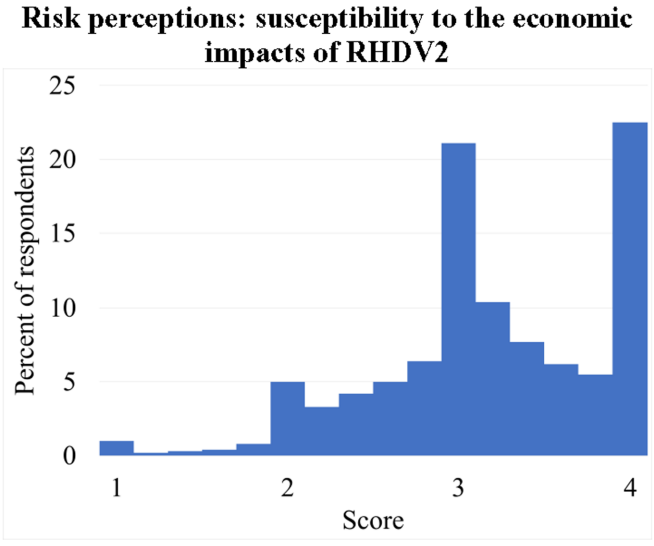
	Median	Strongly oppose[b] No. (%)	Oppose No. (%)	Neither oppose nor support No. (%)	Support No. (%)	Strongly support No. (%)
Relocate field trials that use rabbits at least 150 miles from counties with RHDV2	Support	490 (2.2)	1205 (5.5)	7566 (34.7)	8622 (39.5)	3951 (18.1)
Restrict rabbit hunting in areas with rabbits that are threatened or endangered	Support	1036 (4.7)	1947 (8.9)	4839 (22.2)	9020 (41.3)	4992 (22.9)
Ban the transport of rabbits (alive and dead) that come from states with confirmed RHDV2 cases	Support	595 (2.7)	1724 (7.9)	5264 (24.1)	8331 (38.2)	5920 (27.1)
Ban transport of rabbits (alive and dead) between states until domestic RHDV2 vaccine is produced and distributed	Support	867 (4.0)	1959 (9.0)	6896 (31.6)	7496 (34.3)	4616 (21.1)

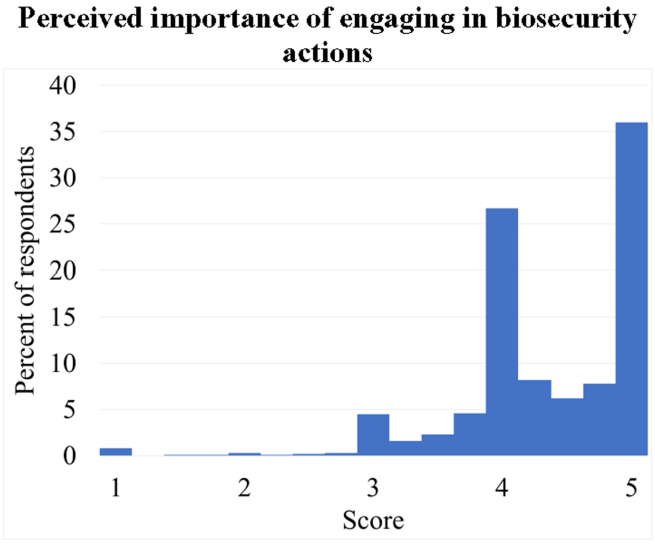
Note: Respondents answered the question "Please indicate if you oppose or support the following potential regulations designed to prevent the spread of RHDV2."
[a]South Carolina asked us to remove these questions from the survey before implementing the survey in their state ($n = 677$).
[b]Strongly oppose = 1, oppose = 2, neither oppose nor support = 3, support = 4, and strongly support = 5.

RHDV2 on the rabbit pet trade (49.6% were concerned or very concerned). A greater share of respondents was concerned about RHDV2's impact on rabbit rescues and animal shelters (55.7% of respondents were concerned or very concerned), rabbit exhibitions (50.7% of respondents), and the rabbit meat market (59.5% of respondents). Respondents were most concerned about the impact of RHDV2 on the sport of rabbit hunting (77.3% of respondents were concerned or very concerned). Principal factor analysis (eigenvalue = 3.62; Cronbach's alpha = .90) confirmed that respondents' concerns about the impacts of RHDV2 on the domestic









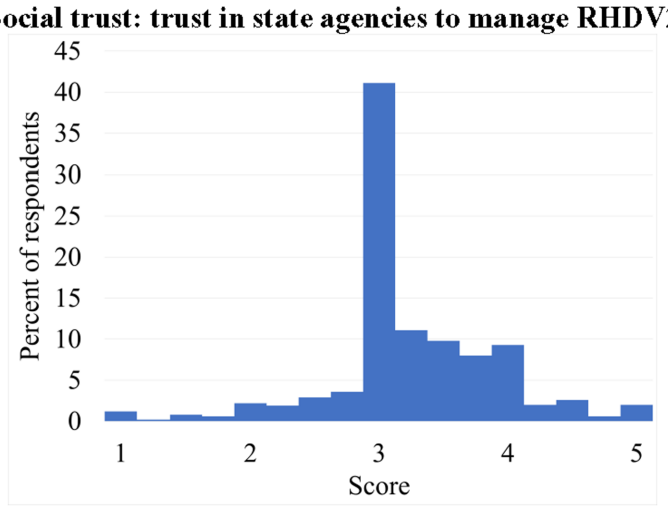


FIGURE 2 Distribution of scores used to measure respondents' risk perceptions, trust in state agencies to manage rabbit hemorrhagic disease virus 2 (RHDV2) and perceptions of the importance of biosecurity actions for the prevention of RHDV2

rabbit trade, rabbit rescues, and hunting represented a single construct, "sensitivity to the economic impacts of RHDV2" (median = 3.80; 3.68 ± 0.79; range = 1–5; Figure 2 and Table S4).

Most respondents believed that RHDV2 poses a risk to the rabbit pet trade (80.2% of respondents considered RHDV2 a moderate or high risk), rabbit rescues (83.5% of respondents), rabbit shows (78.6% of respondents), the rabbit meat market (80.6% of respondents), and the sport of rabbit hunting (83.9% of respondents). Principal factor analysis (eigenvalue = 3.54; Cronbach's alpha = .90) confirmed that respondents' assessment of the risk of RHDV2 to the domestic rabbit trade and hunting measured a single construct, "susceptibility to the economic impacts of RHDV2" (median = 3.20; 3.18 ± 0.66; range = 1–4; Figure 2 and Table S4). Taking effects sizes into account, we found no real differences between rabbit hunters and nonrabbit hunters in terms of their risk perceptions (Table S2).

3.4 | Perceived importance of engaging in biosecurity actions

The majority of respondents agreed or strongly agreed on the importance of engaging in disease prevention measures, recognizing that (1) RHDV2 may be spread through transport of rabbits between states (86.1% of respondents agreed or strongly agreed with this statement), (2) hunters should practice measures to prevent RHDV2 spread (90.8% of respondents), and that (3) disease prevention measures are important in states with no RHDV2 cases (89.5% of respondents) and in states with RHDV2 cases (92.4% of respondents). The items used to measure the perceived importance of biosecurity loaded onto a single factor (eigenvalue = 3.10; Cronbach's alpha = .90; Table S5). Respondents' perceptions of the importance of engaging in biosecurity actions skewed left (median = 4.25; 4.35 ± 0.69; range = 1–5; Figure 2). Taking effects sizes into account, we found no real differences between rabbit hunters and nonrabbit hunters in terms of their perceptions of the importance of biosecurity (Table S2).

3.5 | Social trust

The largest share of respondents neither agreed nor disagreed that their respective state agency had the knowledge (55.8% of respondents provided this response), resources (58.2% of respondents), or skilled employees (52.6% of respondents) to prevent RHDV2 transmission or had been effective (75.7% of respondents) in preventing or controlling the spread of RHDV2. The four items used to measure respondents' "social trust" loaded onto a single factor (eigenvalue = 2.66; Cronbach's alpha = .83; Table S6). Social trust was approximately normally distributed (median = 3.00; 3.24 ± 0.65; range = 1–5; Figure 2). Taking effects sizes into account, we found no real differences between rabbit hunters and non-rabbit hunters in terms of their social trust (Table S2).

3.6 | Ordinal logistic regression analysis of hunters' willingness to engage in or support biosecurity actions

Respondents' willingness to engage in voluntary biosecurity actions or support agency-mandated biosecurity measures was positively correlated with their sensitivity to the economic impacts of RHDV2, perceptions of the importance of biosecurity, and social trust (Table 3). Respondents' willingness to engage in or support biosecurity actions was positively correlated with their perceived susceptibility to the economic impacts of RHDV2 (with the exception of cleaning rabbit carcasses until returning home) and sensitivity to lagomorph deaths (with the exception of sanitizing their hunting tools, equipment, and items).

Respondents who were aware of RHDV2 prior to taking the survey were less likely to report suspicious rabbit deaths if they had low levels of knowledge of RHDV2 (i.e., a knowledge score <0.2). However, respondents with moderate or high levels of knowledge of RHDV2 were more likely to report suspicious lagomorph mortalities. Respondents' willingness to wear gloves when handling lagomorph carcasses, cook rabbits to the appropriate temperature, and sanitize hunting tools and equipment was positively correlated with their knowledge of RHDV2. Respondents with greater knowledge of RHDV2 were less likely to support banning the transport of rabbits until a domestic RHDV2 vaccine was produced.

Although respondents who hunted lagomorphs in the past 5 years were less likely to wear gloves when handling lagomorph carcasses, respondents from RHDV2-positive areas were more likely to engage in this behavior. Both lagomorph hunters and respondents from RHDV2-positive areas were more likely to properly dispose of lagomorph remains, cook rabbits properly, and sanitize their hunting equipment. Respondents who hunted multiple game species were more likely to report suspicious lagomorph mortalities, clean lagomorphs at home, and cook rabbits properly, but were less likely to wear gloves when handling lagomorphs and to properly

TABLE 3 Ordinal logistic regression analysis of respondents' support for and willingness to engage in biosecurity actions.

	Report suspicious rabbit deaths	Wear gloves when handling carcasses	Bag remains, sanitize/ dispose of bag	Clean carcasses at home	Cook rabbits to 165°F	Sanitize hunting tools, equipment, items	Relocate field trials	Restrict hunting in areas with threatened/ endangered rabbits	Ban rabbit transport from RHDV2 states	Ban rabbit transport until vaccine produced
Prior awareness of RHDV2	−0.198**	−0.121	−0.008	0.026	0.025	0.002	−0.100	−0.019	0.028	0.017
Knowledge of RHDV2	0.761***	0.331*	0.027	−0.123	0.397***	0.216*	0.214	−0.048	0.056	−0.180*
Perceived importance of biosecurity	0.841***	0.632***	0.740***	0.331***	0.810***	0.830***	0.810***	0.774***	0.851***	0.678***
Risk perceptions										
Susceptibility to economic impacts of RHDV2	0.275***	0.221***	0.198***	0.037	0.100***	0.087**	0.404***	0.297***	0.397***	0.388***
Sensitivity to economic impacts of RHDV2	0.188***	0.266***	0.304***	0.201***	0.202***	0.306***	0.191***	0.215***	0.120***	0.264***
Sensitivity to lagomorph deaths	0.213***	0.090***	0.128***	0.124***	0.169***	0.040	0.145***	0.106***	0.073***	0.053**
Social trust	0.233***	0.266***	0.256***	0.196***	0.113***	0.186***	0.221***	0.268***	0.183***	0.243***
Rabbit hunter	0.020	−0.232***	0.075*	0.013	0.578***	0.284***	−0.092**	−0.162***	−0.043	−0.065*
Number of species hunted	0.040***	−0.059***	−0.042***	0.029***	0.030***	<0.001	−0.009	−0.062***	−0.004	−0.029***
Gender[a]	−0.070*	−0.160***	−0.176***	−0.109***	−0.021	−0.120**	0.045	−0.130***	0.054*	0.039
Age[b]	0.001	0.005***	0.001	−0.006***	−0.012***	−0.012***	0.002*	−0.002	0.026***	0.022***
Education[c]	0.006	0.019**	0.001	−0.012	0.018*	−0.009	0.041***	0.010	−0.026***	−0.037***
RHDV2 status of the state	−0.072*	0.287***	0.223***	−0.911***	0.128***	0.154***	−0.685***	−0.492***	−0.939***	−0.663***
Intercepts										
β_1	−3.532	−3.083	−3.329	−3.001	−3.509	−4.159	−3.740	−3.889	−3.342	−3.332
β_2	−2.980	−1.811	−2.273	−1.904	−3.175	−3.442	−2.352	−2.648	−1.767	−1.935
β_3	−2.215	−1.060	−1.480	−1.276	−2.223	−2.516	0.139	−1.219	0.004	0.031
β_4	−0.229	0.210	−0.089	−0.079	−0.729	−0.990	2.253	0.874	1.985	1.847
N	22,238	20,881	20,366	18,341	18,296	18,577	21,834	21,834	21,834	21,834
Log likelihood	−21,013	−25,390	−25,045	−26,631	−15,786	−18,869	−25,727	−28,236	−26,772	−28,007
AIC[d]	42,054	50,815	50,117	53,293	31,601	37,766	51,488	56,502	53,572	56,047

Abbreviations: AIC, Akaike Information Criterion; RHDV2, rabbit hemorrhagic disease virus 2.

[a]Coded as female = −1; prefer not to answer = 0, male = 1.

[b]Coded as 18–24 years old = 21, 25–34 = 30; 35–44 = 40; 45–54 = 50; 55–64 = 60; 65–74 = 70; 75 years old and over = 75.

[c]Coded as less than 12th grade = 10; high school graduate = 12; some college or an associate degree = 14; Bachelor's degree = 16; graduate degree = 18.

[d]Reported AIC and log likelihood from the model with the lowest AIC. Model averages calculated for models within AIC ≤ 2 of the model with the lowest AIC.

*$p < .05$; **$p < .01$; ***$p < .001$.

dispose of lagomorph remains. Respondents from RHDV2-positive areas were less likely to report suspicious lagomorph mortalities and prepare rabbit carcasses at home.

Lagomorph hunters were less likely to support the relocation of field trials. Both lagomorph hunters and respondents who hunted multiple game species were less likely to support restrictions on lagomorph hunting in areas with endangered or threatened lagomorphs and a ban on the interstate movement of lagomorphs until the production and distribution of a domestic RHDV2 vaccine. Respondents from RHDV2-positive areas were less likely to support all agency-mandated biosecurity actions.

Older respondents and respondents with higher education levels were more likely to wear gloves when handling lagomorph carcasses. Older respondents were less likely to clean lagomorphs at home, cook rabbits properly, and sanitize hunting equipment. They were also more likely to support the relocation of field trials and bans on the transport of lagomorphs from RHDV2-positive areas or interstate movement of lagomorphs until the production and distribution of a domestic vaccine. Respondents with higher education levels were more likely to cook rabbits properly and to support the relocation of field trials but were less likely to support bans on the transport of lagomorphs. Female respondents were more likely to report suspicious rabbit mortalities, wear gloves when handling lagomorph carcasses, clean lagomorphs at home, properly dispose of lagomorph remains, and sanitize their hunting tools and equipment. Female respondents were also more likely to support restrictions on lagomorph hunting in areas with threatened or endangered lagomorph species but were less likely to support bans on the movement of lagomorphs from RHDV2-positive areas.

4 | DISCUSSION

Most hunters who participated in this study were willing to engage in or support biosecurity actions, notably reporting wild lagomorph mortality events to wildlife agencies, which is critical to preventing the spread of RHDV2. Importantly, nonrabbit hunters were willing to engage in biosecurity and report evidence of RHDV2 on the landscape, which suggests that agencies should engage both rabbit and nonrabbit hunters in efforts to detect and manage RHDV2. Hunters have valuable technical knowledge that may assist agencies in understanding epidemiological scenarios, and participatory approaches have been successfully applied to surveillance for wildlife diseases (Ryser-Degiorgis, 2013). Hunters also expressed willingness to engage in behaviors that would prevent environmental contamination (e.g., properly disposing of lagomorph remains) and indirect transmission of RHDV2 (e.g., sanitizing hunting equipment). Based on the RHDV2 information we provided in the survey, research participants recognized the importance of biosecurity actions, which increased their willingness to participate in biosecurity (see similar findings for other pathogens or stakeholder groups by Cooney & Holsman, 2010; Schemann et al., 2012).

Unfortunately, both rabbit and nonrabbit hunters had low levels of knowledge about RHDV2 and its transmission, which would hamper their active engagement in biosecurity actions. Although some state wildlife agencies have connected with stakeholder groups, created educational materials, recommended biosecurity behaviors for hunters, and instituted rule changes to protect lagomorph populations from RHDV2, these efforts vary greatly between states (Shapiro et al., 2022). Inconsistencies in agency management and communication about RHDV2 have likely contributed to respondents' low level of awareness and knowledge about RHDV2 and their lack of opinion about agencies' effectiveness in managing RHDV2. This is concerning because respondents' trust in wildlife agencies' ability to manage RHDV2 was positively correlated with their likelihood of engaging in or supporting biosecurity measures (see similar findings by Hanisch-Kirkbride et al., 2014; Harper et al., 2015; Vaske et al., 2018).

It is important for state wildlife agencies to communicate and engage more effectively with hunters about RHDV2 to bolster efforts to prevent its spread. Wildlife agencies should provide hunters with consistent updates about RHDV2 (e.g., location, impacted species, transmission pathways) and how actively engaging in biosecurity will help contain the spread of RHDV2. Wildlife agencies are an important, often trusted, source of information for hunters about wildlife health and disease, and the information they provide influences hunter behaviors (Oruganti et al., 2018; Vaske, 2010; Vaske et al., 2022). Based on our findings, agencies should also consider the RHDV2 status of their state and target their outreach to all hunters, not just to individuals who indicated they hunted for rabbits in the past.

Importantly, agencies should consider risk perceptions when designing communication and outreach strategies. Respondents reported sensitivity to both the ecological and economic risks associated with RHDV2, as well as recognizing the susceptibility of the domestic rabbit trade and hunting to RHDV2. Consistent with previous studies, respondents' willingness to engage in or support biosecurity actions was positively correlated with their risk perceptions (Gramza et al., 2016; Pienaar et al., 2022; Slunge & Boman, 2018). Outreach and

education pertaining to RHDV2 should articulate the adverse impacts of RHDV2 on lagomorph populations, biodiversity, hunting, and other economically important domestic rabbit industries. When explaining the need to clean lagomorphs at home and dispose of carcasses correctly, it might be important to inform hunters that dogs and predators (e.g., foxes) may spread RHDV2 in their scat (Chiari et al., 2016; Henning et al., 2006), and hence hunters should not feed lagomorph parts to their dogs. We note that two commonly recommended biosecurity actions that we included in our study (i.e., cooking rabbits to an appropriate temperature and wearing gloves when handling lagomorph carcasses) are consistent with protecting human health against zoonoses, but there is no evidence that RHDV2 transmits to humans. It is important not to suggest that RHDV2 poses human health risks because this may inflate RHDV2 risk perceptions for hunters with low knowledge and undermine knowledgeable hunters' trust in agencies (Needham & Vaske, 2008; Vaske, 2010; Vaske & Miller, 2018). If outreach materials do include recommendations that primarily pertain to human health and are not related to RHDV2 prevention, then the caveat should be added that there is no evidence of human health risks from RHDV2 exposure. If human health precautionary messages are needed, wildlife agencies should highlight that these messages are general public health and/or food safety guidelines and are not related to RHDV2 prevention (Vaske et al., 2022).

While outreach and education are important components of RHDV2 management, wildlife agencies should more actively engage hunters in the management of RHDV2 rather than assuming hunters will report potential RHVD2 cases (Cretois et al., 2020; Shapiro et al., 2022). Hunters can act as citizen scientists who provide valuable information about population trends and mortality events in the areas they hunt, regardless of the wildlife species they are pursuing (Cretois et al., 2020). Hunters may also mark and report locations where they have found potential RHDV2 mortalities, which would allow agency staff to better detect RHDV2 on the landscape and may also allow researchers to monitor viral recombinants and variants (Le Gall-Reculé et al., 2003; Mahar et al., 2018; Silvério et al., 2018). Engaging hunters in RHDV2 detection is a cost-effective method to augment agency surveillance (Cretois et al., 2020), an important consideration because agencies are already operating with limited knowledge of lagomorph populations (Shapiro et al., 2022), limited resources and budgets, and are under political pressure to prioritize chronic wasting disease (Belsare et al., 2020; Portier et al., 2019; Ryser-Degiorgis, 2013; Stephen et al., 2019). Agency efforts to proactively engage hunters in the detection and management of wildlife diseases are critically important. Such efforts can increase the efficiency of surveillance and mitigation approaches, thereby actively engaging hunters in securing wildlife health.

AUTHOR CONTRIBUTIONS

All authors were responsible for conceptualization of this research and review and editing of the article. Hannah G. Shapiro and Elizabeth F. Pienaar were responsible for the methodology, formal analysis, investigation, data curation, visualization, and writing the original draft of this article. Elizabeth F. Pienaar was responsible for providing resources, supervision, and project administration. Gino D'Angelo, Mark G. Ruder, and Elizabeth F. Pienaar secured the funding for this research.

ACKNOWLEDGMENTS

We thank the Northeast Beagle Gundog Federation and the following agencies for their help in distributing the surveys: Alabama Department of Conservation and Natural Resources; Arizona Game and Fish Department; Arkansas Game and Fish Commission; California Department of Fish and Wildlife; Colorado Parks and Wildlife; Florida Fish and Wildlife Conservation Commission; Georgia Department of Natural Resources; Indiana Department of Natural Resources; Iowa Department of Natural Resources; Kansas Department of Wildlife and Parks; Michigan Department of Natural Resources; Mississippi Department of Wildlife, Fisheries, and Parks; Missouri Department of Conservation; Nebraska Game and Parks Commission; New Mexico Department of Game & Fish; New York Department of Environmental Conservation; North Carolina Wildlife Resources Commission; North Dakota Game and Fish Department; Ohio Department of Natural Resources; Pennsylvania Game Commission; South Carolina Department of Natural Resources; Tennessee Wildlife Resources Agency; Texas Parks and Wildlife Department; Vermont Department of Fish and Wildlife; Washington State Department of Fish and Wildlife; Wisconsin Department of Natural Resources; Wyoming Game and Fish Department.

DATA AVAILABILITY STATEMENT

Deidentified data that support the findings of this study are available at Hannah G. Shapiro and Elizabeth F. Pienaar (2022). Hunters' Willingness to Adopt and Support Biosecurity Actions to Prevent the Spread of Rabbit Hemorrhagic Disease (Version 1) [Data set]. Zenodo. https://doi.org/10.5281/zenodo.7335728.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Shapiro, H. G., D'Angelo, G., Ruder, M. G., & Pienaar, E. F. (2023). Engaging stakeholders in wildlife disease management: Hunters' willingness to adopt and support biosecurity actions to prevent the spread of rabbit hemorrhagic disease. *Conservation Science and Practice*, *5*(1), e12858. https://doi.org/10.1111/csp2.12858