

Down the Rabbit Hole: Domestic Rabbit Owners' Perceptions of Rabbit Hemorrhagic Disease Virus 2

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Abstract

Rabbit hemorrhagic disease virus 2 (RHDV2) is a highly contagious pathogen that infects wild and domestic rabbits and hares (lagomorphs). Globally, RHDV2 has resulted in substantial economic losses for commercial rabbit trade and caused wild lagomorph population declines. Previous research on RHDV2 suggests that human-mediated movement of rabbits may contribute to the spread of RHDV2. We conducted the first survey of individuals who own or interact with domestic rabbits to identify their rabbit husbandry behaviors and knowledge of, and concerns about, RHDV2. In 2021, we surveyed 1807 rabbit owners, breeders, and rescue staff in the USA. Respondents had a high level of knowledge about RHDV2. Respondents believed RHDV2 posed a high risk to rabbit-related activities and were concerned about its economic and ecological impacts. Nearly half of respondents always kept their rabbits indoors, but 10.7% of respondents allowed their rabbits outside frequently on properties used by wild lagomorphs. Respondents with five rabbits or less were generally willing to vaccinate their rabbits, but respondents with larger herds argued that vaccines were cost prohibitive. Given respondents' concerns about RHDV2, communication about disease prevention should highlight the adverse ecological and economic consequences of RHDV2.

Keywords: breeders, human dimensions of wildlife conservation, knowledge, lagomorphs, pet owners, rescues, RHDV2, vaccine

Introduction

Rabbit hemorrhagic disease virus 2 (RHDV2) is a highly contagious and lethal pathogen that infects both domestic and wild lagomorphs (rabbits and hares). RHDV2 is a non-enveloped, icosahedral, single-stranded RNA virus of the genus *Lagovirus*, family *Caliciviridae* (Asin et al. 2021). The virus typically has a three- to nine-day incubation period and can cause fatal disease (up to 80% mortality rate) within two to four days of infection, and infected animals often show no obvious signs of disease before death (Le Gall-Reculé et al. 2013; OIE 2019). RHDV2 was first detected in France in 2010 and, in the 12 years since its discovery, has spread across five continents (Rouco et al. 2019; Hu et al. 2021; Katayama et al. 2021). It is hypothesized that the human-mediated movement of rabbits is partly responsible for the

dissemination of RHDV2 globally (Mahar et al. 2018; Marschang et al. 2018; Rouco et al. 2019).

The rapid spread of RHDV2 is attributable to the fact that the virus is transmitted by direct or indirect contact with infected lagomorphs (e.g., oculonasal secretions, urine, feces, blood), lagomorph carcasses or carcass parts, insect vectors, and environments or materials contaminated by infected lagomorphs (e.g., bedding, forage; OIE 2019). The virus can survive up to 15 weeks in dry conditions and over 90 days in decaying animal tissue outdoors (OIE 2019). RHDV2 poses a substantial risk to wild and domestic lagomorph populations globally (Asin et al. 2021), especially since vaccinations may not be effective in young animals (Carvalho et al. 2017). Studies that have evaluated RHDV2's impact in Europe found that RHDV2 (1) resulted in substantial economic losses for the commercial rabbit trade and hunting industries (Rouco et al. 2019), (2) caused significant population declines (60–70%) of wild lagomorphs and associated declines in rabbit specialist predators (e.g., Iberian *lynx pardinus* and Spanish Imperial eagle *Aquila adalberti*; Monterroso et al. 2016), and (3) is an important cause of disease in pet rabbits (Marschang et al. 2018). Intensive, costly management efforts may be required to recover ecosystems that are impacted by RHDV2 due to significant alterations to ecosystem structure and function (Guerrero-Casado et al. 2013; Delibes-Mateos et al. 2014).

Efforts to control or prevent the spread of RHDV2 must address potential pathogen transmission through the husbandry and movement of domestic rabbits, as vaccination may not prevent infection or viral shedding (National Assembly RHDV2 Subcommittee 2020). To the best of our knowledge, no studies have been conducted on whether individuals who own or interact with domestic rabbits are aware of, or concerned about, RHDV2. This is an important oversight because voluntary behavioral changes by individuals who own or interact with domestic rabbits (e.g., preventing contact between domestic and wild lagomorphs, and not transporting lagomorphs from regions with RHDV2) are essential to prevent potential human-mediated spread of RHDV2.

In the USA, a diverse group of stakeholders own or interact with domestic rabbits, including people who own rabbits as pets companion animals, breed rabbits, show rabbits at exhibitions, work at rabbit or animal rescues, and raise rabbits for meat or fur. It is estimated that there are over two million pet or companion rabbits in the USA (American Veterinary Medical Association 2018), and in 2017, nearly 500,000 rabbits were sold nationally for commercial use (US Department of Agriculture (USDA 2019). Despite rabbits' popularity as companion mammals and show animals, recent studies suggest that many rabbit owners lack knowledge about proper rabbit care and welfare (Welch et al. 2017; Rioja-Lang et al. 2019; The Veterinary Record 2019; Pérez-Fuentes et al. 2020; McMahon and Wigham 2020). While none of these studies focused on rabbit diseases, rabbit owners' lack of understanding about rabbit welfare needs may be accompanied by incomplete knowledge of disease threats to rabbits and engagement in appropriate behaviors that reduce the risk of pathogen transmission between domestic and wild lagomorphs (e.g., keeping rabbits inside, vaccinating rabbits). Since the outbreak of RHDV2 in domestic and wild lagomorphs in New Mexico in March 2020 (USDA 2021), the virus has spread to 28 US states (Fig. 1). RHDV2 has been confirmed in eight wild lagomorph species in the USA and poses a risk to all 15 native lagomorph species, including several threatened and

endangered species or species of conservation concern (e.g., the riparian brush rabbit *Sylvilagus bachmani riparius*). The detection of RHDV2 in eastern states highlights the role that individuals who own or interact with domestic rabbits may play in the geographic spread of this virus. In 2021, we surveyed US residents who own or interact with domestic rabbits to better understand their husbandry and movement of domestic rabbits, knowledge of RHDV2, and risk perceptions pertaining to RHDV2.

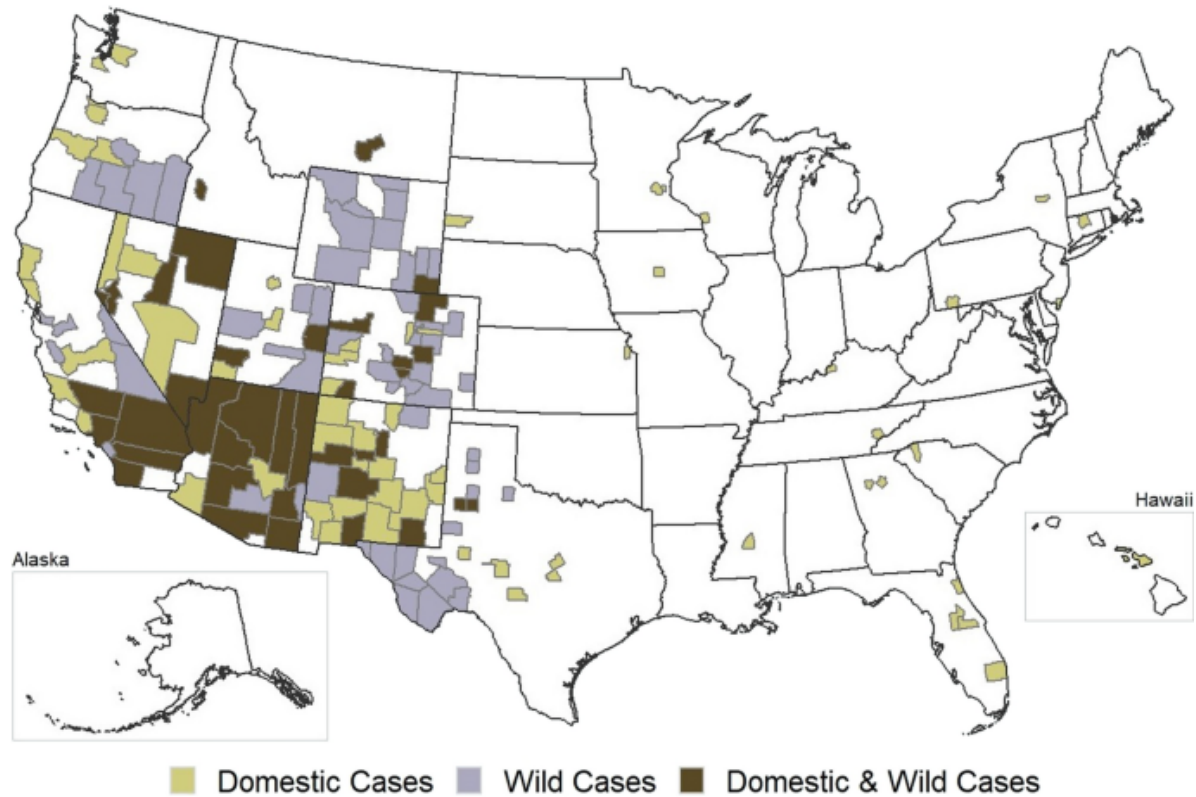


Figure 1. RHDV2 occurrence in the USA. The map does not include the recent detection of RHDV2 in domestic rabbits in Connecticut (09/11/22) or South Carolina (09/15/22). Map last updated on September 1, 2022. Data source: USDA APHIS. Supplemental data reports that have been verified using press releases were used to update the map between USDA reporting periods. Domestic cases include both domestic and feral rabbit cases. Note: in July 2021 (at the time of this study), RHDV2 had been detected in California, Oregon, Idaho, Nevada, New Mexico, Arizona, Utah, Montana, Wyoming, Colorado, Texas, South Dakota, and Georgia. Map credit: M.T. Kohl, University of Georgia.

Methods

We designed a quantitative survey instrument to measure how respondents interact with domestic rabbits, how many rabbits they own, their husbandry and movement of domestic rabbits, their knowledge of RHDV2, their risk perceptions pertaining to RHDV2, and their opinions on mitigating the spread of RHDV2. Prior to implementing the survey, we pretested the survey instrument with five veterinary medicine and animal disease specialists, two wildlife biologists, three human dimensions experts, and 10 stakeholders who interact with domestic and wild lagomorphs, including members of the House Rabbit Society (a rabbit rescue organization) and the American Rabbit Breeders Association (ARBA). The University of Georgia's Institutional Review Board characterized our study as non-human subjects

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.

We implemented surveys online from April to August 2021. We invited 3632 rabbit breeders to participate in this research. We paid a company that administers online surveys (Qualtrics Research Services) to survey 220 people who own rabbits as pets. The House Rabbit Society e-mailed a link to the survey to 7996 e-mail subscribers and 367 House Rabbit Society educators. ARBA posted a link to the survey on the RHDV2 page of their website. We used the statistical analysis software SPSS 27.0 (SPSS Statistics for Windows, Version 27.0, Armonk, NY: IBM Corp.) to conduct descriptive and comparative analyses.

Table 1. Demographic characteristics of individuals who own or interact with domestic rabbits who responded to a survey about their rabbit husbandry behaviors and knowledge of, and concerns about, RHDV2, USA, 2021 ($n = 1807$).

	Number	Percent
<i>Gender</i>		
Female	1447	80.1
Male	311	17.2
Prefer not to say	49	2.7
<i>Age</i>		
18–24 years	195	10.8
25–34 years	356	19.7
35–44 years	389	21.5
45–54 years	434	24.0
55–64 years	229	12.7
65–74 years	185	10.2
75 years or over	19	1.1
<i>Education level</i>		
Less than 12th grade of high school	11	0.6
High school graduate or GED (high school equivalency diploma)	160	8.9
Some college, associate degree, or technical degree	487	27.0
Bachelor's degree	595	32.9
Graduate or professional degree	554	30.7

Results

Overall, 2291 people started the online survey, and 1861 people completed the survey (81.3% completion rate). We removed 54 people from the dataset because they were under 18 years of age or lived outside of the USA for a total of 1807 respondents. Respondents' median age range was 35–44 years, and their median education level was a bachelor's degree (Table 1). Most respondents owned rabbits as pets or companion animals (72.6%) and 561 respondents (31.0%) bred rabbits (Table 2). On average, respondents owned 2–5 rabbits, although breeders owned an average of 21–50 rabbits. Respondents who owned rabbits most frequently acquired their rabbits in state (86.0%), from a rabbit rescue or animal shelter (46.9%), or from a private rabbit breeder (36.8%). Rabbit rescue groups often take in abandoned rabbits, neuter these animals before adopting them out, and educate the public about owning domestic rabbits.

Table 2. Ownership and housing of rabbits by individuals who interact with domestic rabbits in the USA, 2021 ($n = 1807$).

<i>Engagement with lagomorphs (select all that apply)</i>		
Own a rabbit as a pet	1312	72.6
Breed rabbits	561	31.0
Volunteer/work at a rabbit rescue or animal shelter	337	18.6
Raise rabbits for meat and/or fur	265	14.7
Purchased a rabbit for their family	185	10.2
Hunt wild rabbits/hares	30	1.7
Other	153	8.5
<i>Number of rabbits owned</i>		
0	17	0.9
1	505	27.9
2–5	637	35.3
6–10	121	6.7
11–20	143	7.9
21–50	204	11.3
51–100	112	6.2
101–500	68	3.8
<i>Where did you acquire the rabbit(s) you currently own?[†]</i>		
Rabbit rescue or animal shelter	839	46.9
Private rabbit breeder	659	36.8
I breed my own rabbits	460	25.7
Family or friends	191	10.7
Pet shop	139	7.8
Other	130	7.3
<i>Where did you acquire the rabbit(s) you currently own?[†]</i>		
The state I live in	1539	86.0
Another state	567	31.7
Another country	30	1.7
Other	45	2.5
<i>Rabbit housing (select all that apply)</i>		
Indoors (e.g., house, barn)	1562	86.4
Outdoors, but contained on a man-made surface (e.g., a concrete slab)	219	12.1
Outdoors and the rabbits have contact with the ground/natural environment	131	7.2
Other	98	5.4
<i>How often do your rabbit(s) go outside?[†]</i>		
My rabbit(s) are always outside	190	10.6
Multiple times a day	93	5.2
Once a day	53	3.0
Multiple times a week	75	4.2
Once a week	56	3.1
Occasionally (e.g., once a month or a few times a year)	312	17.4
Never	887	49.6
Other	124	6.9

[†]17 people who responded to the survey volunteered or worked at rescue organizations but did not own rabbits at the time they took the survey, hence $n = 1790$ for this question.

We asked respondents how they housed their rabbits because interactions between wild lagomorphs and domestic rabbits increase the risk of RHDV2 transmission and spread to new regions. Most respondents who owned rabbits (78.0%) only housed their rabbits indoors, and approximately half of respondents ($n = 887$, 49.5%) never let their rabbits outdoors. In total, 194 respondents (10.7%) who allowed their rabbits outside frequently (rabbits were kept outdoors or allowed outside daily or weekly) also saw wild lagomorphs on their property daily or weekly.

In total, 530 respondents (29.6%) were members of ARBA or an affiliated breeder club, and 498 respondents (27.8%) participated in rabbit shows (i.e., competitions where rabbits are judged based on breed and physical appearance) in the past 5 years (mean: 11 shows/year; median: 8 shows/year). Almost one-third of respondents ($n = 583$, 32.6%) traveled out of state with their rabbits, primarily to attend rabbit shows ($n = 379$). Respondents also traveled out of state to sell their rabbits ($n = 135$) or for other reasons (e.g., vacation, moving, veterinary appointments; $n = 211$). Respondents who bred rabbits ($n = 561$) primarily sold rabbits from their property (68.8%; Table 3).

Table 3. Locations at which survey respondents who bred domestic rabbits (including for the meat or fur markets) sold their rabbits, USA, 2021 ($n = 561$).

	Number	Percent
<i>Where do you sell your rabbits?</i>		
From my property	386	68.8
At rabbit shows/expositions	367	65.4
At live animal auctions	51	9.1
Through pet stores	46	8.2
Other	81	14.4
I do not sell my rabbits	43	7.7

Table 4. Information about rabbit rescues at which respondents to a RHDV2 survey volunteered or worked, USA, 2021 ($n = 337$).

	Number	Percent
<i>What do you do at the rabbit rescue or animal shelter?</i>		
Educate people on owning rabbits as a pet	236	70.0
Interact with rabbits at the shelter (e.g., socialize, clean cages, feed them, etc.)	234	69.4
Discuss rabbits with potential adopters	208	61.7
Transport rescued rabbits to the shelter	158	46.9
Fundraise money or materials for the shelter	151	44.8
Market or advertise rescued rabbits that are available for adoption	132	39.2
<i>Where do rabbits at your rescue come from?</i>		
Within the state	172	51.0
Both within and outside of the state	144	42.7
From other states	0	0.0
I do not know	21	6.2
<i>What types of rabbits are kept at the rescue or shelter you work/volunteer at?</i>		
Rescued rabbits (e.g., rabbits removed from a harmful situation)	317	94.1
Returned rabbits	290	86.1
Stray rabbits	280	83.1
Feral rabbits	100	29.7
Other	40	11.9
I do not know	9	2.7

Respondents who worked or volunteered at rabbit rescues or animal shelters (hereafter referred to as rescue staff; $n = 337$) primarily interacted with rabbits at the shelter or educated people on owning rabbits as pets (Table 4). In total, 144 of these respondents (42.7%) indicated that rabbits were rescued from both within and outside the state. Rabbits

within the rescues and animal shelters were most frequently rescued, returned, or stray animals.

Table 5. Knowledge of RHDV2 demonstrated by individuals who own or interact with domestic rabbits, USA, 2021 ($n = 1627$). This table only includes responses from people who indicated they had heard of RHDV2 prior to taking the survey.

	Number	Percent
<i>Before today, did you know that RHDV2 infects...</i>		
Wild rabbits and hares	1607	98.8
Domestic rabbits	1596	98.1
Respondents who correctly answered the question: To the best of your knowledge, has RHDV2 been confirmed in your state?	1332	81.9
<i>Are the number of states with RHDV2 infected rabbits higher or lower than you thought?</i>		
Higher than I thought	603	37.1
About what I thought	894	54.9
Lower than I thought	123	7.6
I did not know that RHDV2 was in the USA before taking this survey	7	0.4
<i>To the best of your knowledge, how likely is it that rabbits infected with RHDV2 show signs of the disease before they die?</i>		
Very unlikely	197	12.1
Unlikely	484	29.7
Neither unlikely nor likely	178	10.9
Likely	345	21.2
Very likely	215	13.2
I don't know	208	12.8
<i>Who or what can spread RHDV2? Select all that apply</i>		
Domestic rabbits	1559	95.8
Wild rabbits or hares	1582	97.2
Other domestic animals (e.g., dogs)	1057	65.0
People	1156	71.1
Animals that eat rabbits	1051	64.6
Insects	894	54.9
Other	191	11.7
I don't know	34	2.1
<i>How does RHDV2 spread? Select all that apply</i>		
Contact with infected wild or domestic rabbits that are still alive	1550	95.3
Contact with wild or domestic rabbits that have died from RHDV2	1498	92.1
Contact with the meat or fur of infected rabbits	1327	81.6
Contact with the urine, feces, and/or saliva of infected rabbits	1486	91.3
Contact with items that infected rabbits have used (e.g., food, forage, bedding)	1443	88.7
Other	76	4.7
I don't know	55	3.4

Table 6. Current and preferred sources of information on rabbit health and RHDV2 for individuals who own or interact with domestic rabbits, USA, 2021 ($n = 1807$).

	Number	Percent
<i>Who do you obtain information about rabbit health from?</i>		
Veterinarian	1374	76.0
Rabbit rescue or animal shelter	901	49.9
Press media/news	740	41.0
ARBA or an affiliated breeder club	534	29.6
State agency/department	386	21.4
Federal agency	318	17.6
4H or agricultural extension	260	14.4
Pet store	128	7.1
Other	376	20.8
I have never looked for information on rabbit health	7	0.4
<i>How did you find out about RHDV2?</i>		
Rabbit rescue or animal shelter	754	41.7
Press media/news	738	40.8
ARBA or affiliated breeder club	459	25.4
Veterinarian	362	20.0
State agency/department	271	15.0
Federal agency	212	11.7
4H or agricultural extension	121	6.7
Pet store	16	0.9
Other	317	17.5
<i>From which of the following organizations would you prefer to receive current information and updates on RHDV2?</i>		
State wildlife agency	1172	64.9
Rabbit rescue or animal shelter	1088	60.2
Federal agencies	1088	60.2
State agricultural agency	946	52.4
In-state university/extension services	820	45.4
ARBA or an affiliated breeder club	714	39.5
Local pet store	315	17.4
Other	178	9.9
None of the above	16	0.9
<i>How would you prefer to receive current information and updates on RHDV2?</i>		
E-mail	1427	79.0
Media/news (e.g., articles in newspapers or online, magazines)	964	53.3
Social media	909	50.3
Agency or organization's website	905	50.1
Newsletter	731	40.5
Word of mouth (i.e., information from other rabbit owners or breeders)	444	24.6
Other	40	2.2

Respondents could select multiple options for all questions.

Knowledge of RHDV2

Most respondents (90.0%) had heard of RHDV2 prior to taking the survey. Of these respondents, most knew that RHDV2 infects wild lagomorphs (98.8%) and domestic rabbits (98.1%), and that RHDV2 may be spread by both wild lagomorphs (97.2%) and domestic rabbits (95.8%; Table 5). Over three quarters of these respondents knew that RHDV2 can spread through contact with live (95.3%) and dead lagomorphs (92.1%), the urine, feces, and saliva of infected lagomorphs (91.3%), items that infected lagomorphs have used (88.7%), and the meat or fur of infected lagomorphs (81.6%). A minority of respondents

(41.9%) correctly answered that rabbits infected with RHDV2 are unlikely to show signs of disease before they die. Most respondents (81.9%) correctly identified the RHDV2 status of their state at the time of the survey. We calculated respondents' knowledge of RHDV2 by determining what proportion of the 15 knowledge questions they answered correctly by dividing the number of correct answers they provided by 15 to generate a score of zero to one. Respondents who were not previously aware of RHDV2 scored zero for their knowledge of RHDV2. Pet owners (0.66 ± 0.34) were less knowledgeable about RHDV2 compared to breeders (0.82 ± 0.23) and rescue staff (0.82 ± 0.22 ; $F(1,1626) = 60.52$; $p < 0.001$; $\eta^2 = 0.07$). Although most respondents (76.0%) obtained information about rabbit health from veterinarians, respondents were more likely to have heard about RHDV2 from rabbit rescues (41.7%), the press media or news (40.8%), and ARBA or a breeder organization (25.4%) than from veterinarians (Table 6).

Risk Perceptions Pertaining to RHDV2

Only 16 respondents (0.9%) stated that any of their rabbits had been infected with RHDV2, but 192 respondents (10.6%) indicated that they know someone whose rabbits had been infected with RHDV2. On average, respondents were concerned that RHDV2 would negatively affect the health of their rabbits and other domestic rabbits and wild lagomorphs in their state, or would cause a loss of biodiversity from the disease-related deaths of native lagomorphs (median = strongly agree; Fig. 2). Most respondents believed that RHDV2 poses a high risk to the rabbit pet trade, rabbit shows or expositions, rabbit rescues or animal shelters, the rabbit meat market, and the sport of rabbit hunting (median = high risk; Fig. 3). Respondents expressed greatest concern about the impact of RHDV2 on rabbit rescues or animal shelters and least concern about the impact of RHDV2 on the sport of rabbit hunting (Fig. 4). There were statistically significant differences in respondents' concern about the risk that RHDV2 poses to lagomorph populations and rabbit-related activities; however, the effect size for these differences was small, indicating that the differences were driven by large sample sizes rather than real differences in concern between the stakeholder groups. Rescue staff expressed highest concern about the impacts of RHDV2 on rabbit rescues or animal shelters ($H(2) = 343.99$; $p < 0.001$; $\eta^2 = 0.21$) and breeders expressed highest concern about the impacts of RHDV2 on rabbit shows or expositions ($F(2,1624) = 98.01$; $p < 0.001$; $\eta^2 = 0.11$), the rabbit meat market ($F(2,1624) = 108.59$; $p < 0.001$; $\eta^2 = 0.11$) and the sport of rabbit hunting ($F(2,1624) = 74.51$; $p < 0.001$; $\eta^2 = 0.08$).

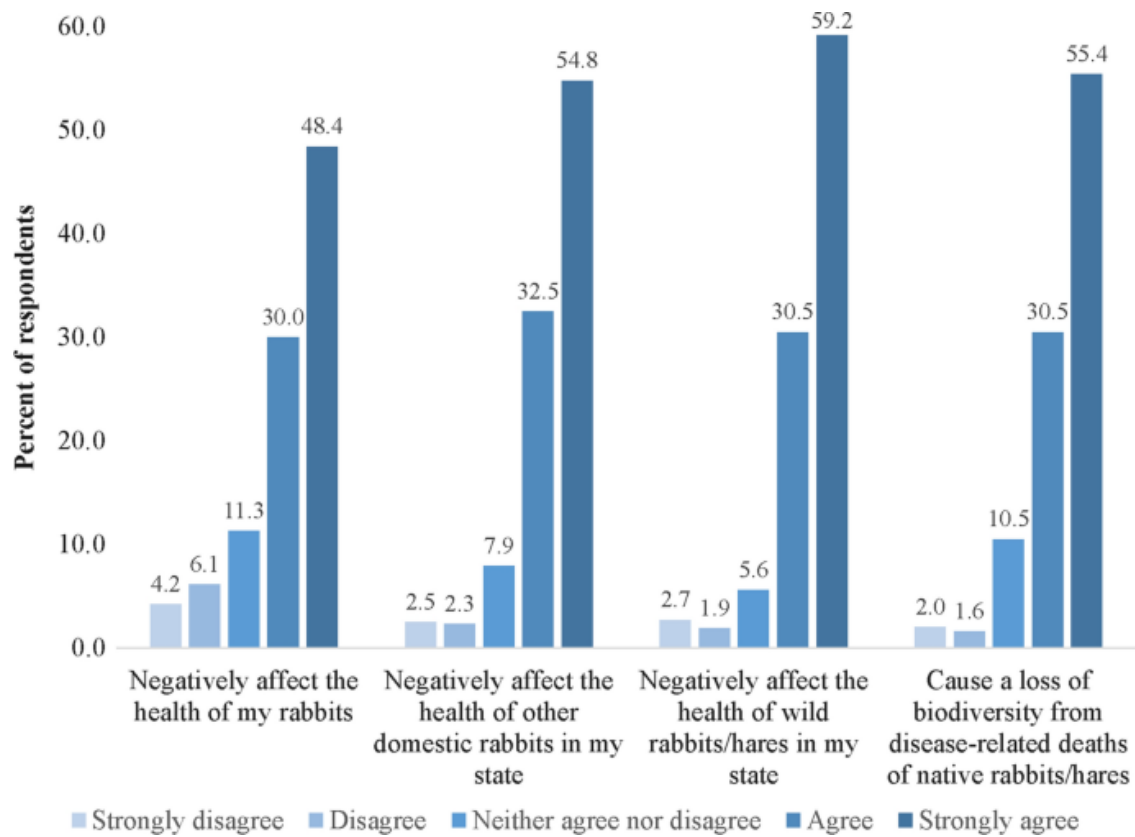


Figure 2. Survey respondents' level of agreement with the statements "I am concerned that RHDV2 will negatively affect (1) the health of my rabbits, (2) the health of domestic rabbits, (3) the health of wild lagomorphs, and (4) cause a loss of biodiversity from the disease-related deaths of native lagomorphs" ($n = 1807$).

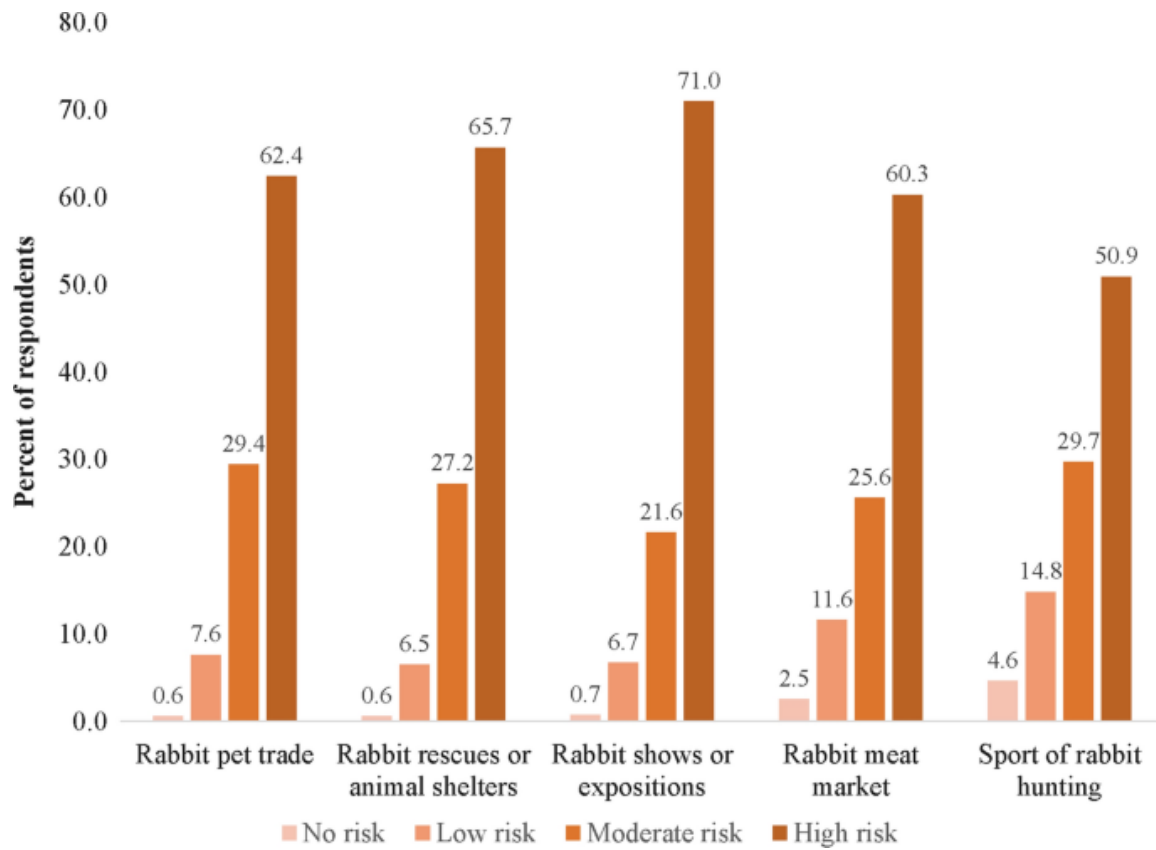


Figure 3. Responses to the question: “How much risk do you think RHDV2 poses to the following activities?” ($n = 1807$).

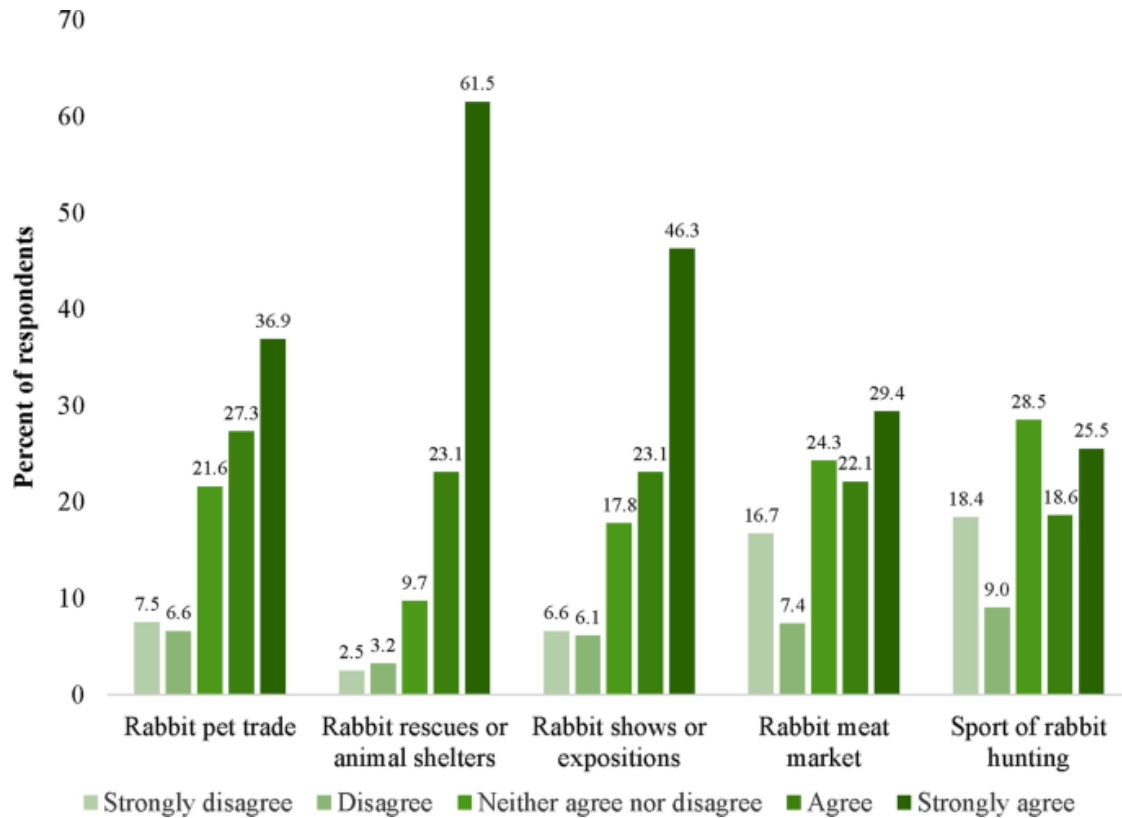


Figure 4. Survey respondents' level of agreement with the statement "I am concerned about the impact of RHDV2 on (1) the rabbit pet trade, (2) rabbit rescues or animal shelters, (3) rabbit shows, (4) the rabbit meat market, and (5) the sport of rabbit hunting" ($n = 1807$).

Preventing the Spread of RHDV2

On average, respondents agreed that transporting rabbits between states increases the probability of RHDV2 spreading (Fig. 5). Most respondents strongly agreed that rabbit owners must engage in measures to prevent RHDV2 from spreading to areas without the disease, engaging in measures to prevent the spread of RHDV2 is important both in states with RHDV2 cases and states with no confirmed cases, and engaging in these measures is important even if rabbits have been vaccinated for RHDV2. Breeders (3.98 ± 1.01) expressed less agreement with the statement "transporting rabbits between states increases the probability of RHDV2 spreading" compared to rescue staff (4.58 ± 0.66) and pet owners (4.44 ± 0.75 ; $H(2) = 120.18$; $p < 0.001$; $\eta^2 = 0.07$; strongly disagree = 1; disagree = 2; neither agree nor disagree = 3; agree = 4; strongly agree = 5).

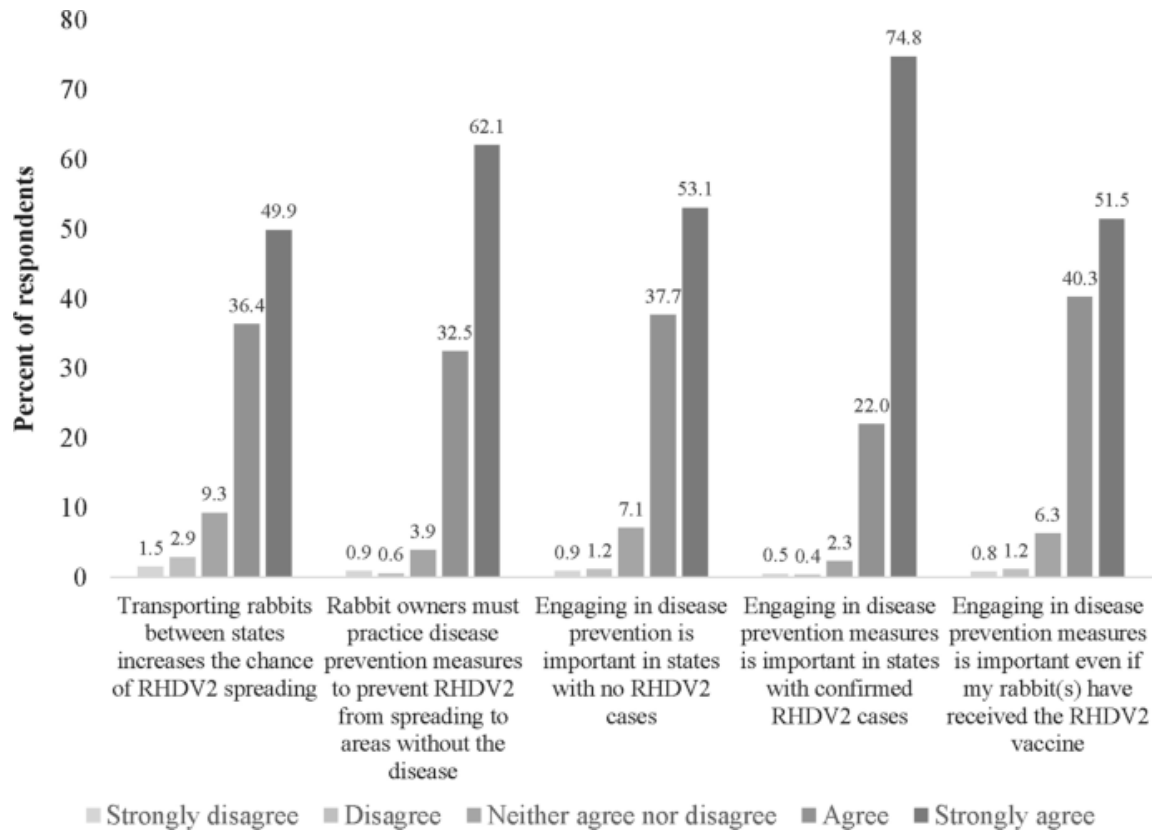


Figure 5. Survey respondents' level of agreement with statements on how spread of RHDV2 may be mitigated ($n = 1807$).

We presented each respondent with a price per dose of a RHDV2 vaccine (each respondent was randomly presented with one of the four potential prices: \$50/vaccine; \$75/vaccine; \$100/vaccine; \$125/vaccine) and asked if they would be willing to vaccinate their rabbits. Respondents who stated they would vaccinate their rabbits at that price were asked how many rabbits they would vaccinate. Over half of respondents stated they would vaccinate all their rabbits, but we note that most of these individuals owned one to five rabbits (Fig. 6). As the price of the vaccine increased, the percentage of respondents who stated they would not vaccinate any of their rabbits increased from 16.4% (\$50 per vaccine) to 25.5% (\$125 per vaccine). In written comments, breeders stated that these prices were cost prohibitive for owners with large rabbit herds. Other rabbit owners expressed ethical concerns about inactivated vaccines (e.g., Filavac VHD K C + V, Filavie Laboratories, France), imported from Europe, which require infection of rabbits for vaccine production (Florida Department of Agriculture and Consumer Services 2002).

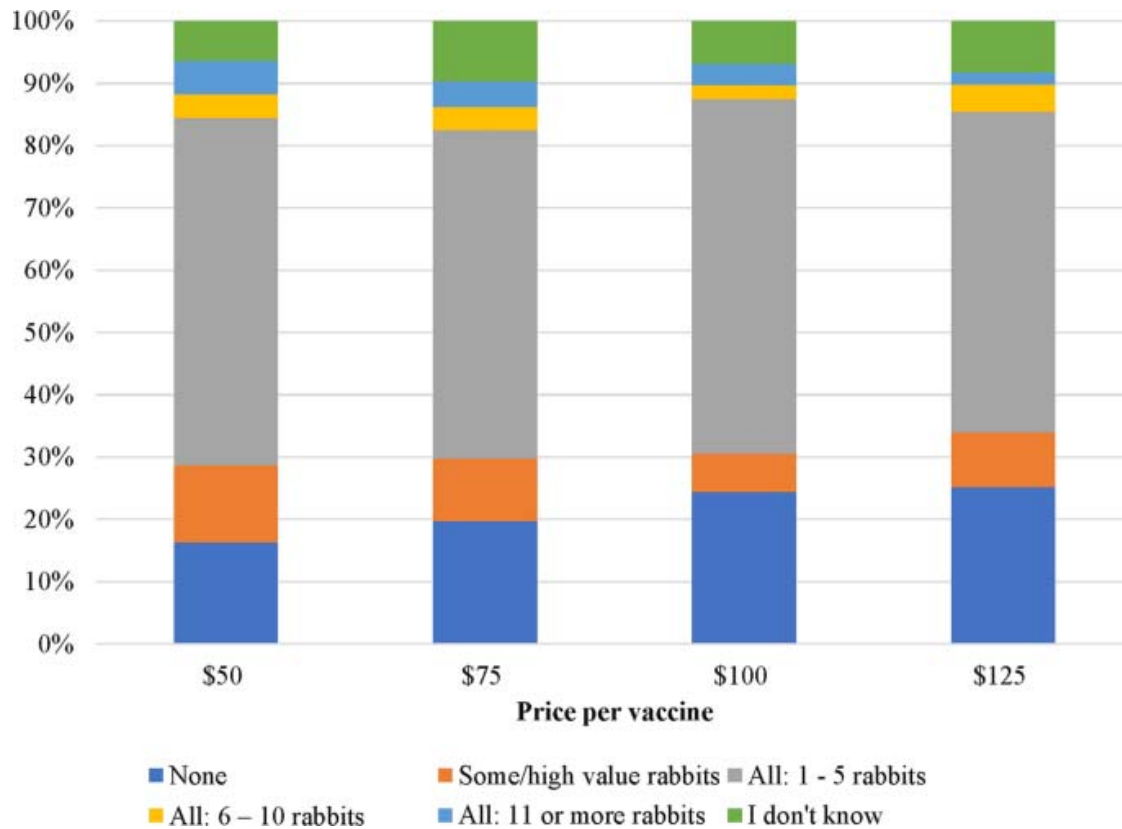


Figure 6. Survey respondents' willingness to vaccinate their rabbits against RHDV2 (292 respondents presented with a vaccine price of \$50 per dose; 269 respondents presented with a vaccine price of \$75 per dose; 281 respondents presented with a vaccine price of \$100 per dose; 265 respondents presented with a vaccine price of \$125 per dose).

When asked what the penalty for intentionally releasing domestic rabbits into the wild should be, 1030 respondents (57.0%) stated that the people releasing rabbits should pay a fine of over \$500 for each animal released. Only 104 respondents (5.8%) stated that there should be no penalty for deliberately releasing rabbits into the wild. In total, 165 respondents (9.1%) stated that a small fine (< \$100 for each animal) should be imposed and 377 respondents (20.9%) considered a medium fine (\$100–\$500 for each animal released) to be appropriate.

Over 60% of respondents indicated that they would prefer to receive current information on RHDV2 from state wildlife agencies, federal government agencies, or rabbit rescues and animal shelters (Table 6). Respondents preferred to receive e-mails about RHDV2. At least half of respondents also preferred to receive RHDV2 information through the news media, social media, and by accessing websites for agencies and organizations.

Limitations

Although we implemented best practices in conducting this research, our sample may not be representative of the larger population of domestic rabbit owners in the USA. Unfortunately, we cannot determine if we have a representative sample because rabbit owner and breeder demographics have been poorly described in the USA. We recognize

that by partnering with rabbit specialist groups to distribute surveys, our sample may be more knowledgeable about RHDV2 than other rabbit owners because these groups have actively engaged in outreach and education about RHDV2.

Discussion

Rabbit owners' and rescue staff's willingness to engage in measures that prevent RHDV2 transmission through direct and indirect contact between infected and healthy lagomorphs is essential for limiting or preventing potential human-mediated spread of RHDV2 and protecting vulnerable wild lagomorph populations. We note that RHDV2 mortalities in domestic rabbits have occurred in 16 US states that lie outside the region with confirmed wild lagomorph mortalities (Fig. 1). Fortunately, in these instances, rabbit owners and rescues reported RHDV2 cases quickly and surveillance efforts revealed that RHDV2 likely did not transmit to wild lagomorph populations (New York State Department of Agriculture and Markets 2021; Florida Department of Agriculture and Consumer Services 2022). However, it is unknown whether there are other instances of RHDV2 infection and mortality in domestic rabbits that were not reported to the appropriate agencies. Detection of RHDV2 in domestic rabbits in the eastern United States reveal the distances over which RHDV2 can spread outside of endemic areas, highlighting the importance of engaging rabbit owners and rescues across the USA in disease prevention strategies.

It is therefore encouraging that respondents were already engaging in, or willing to support, three RHDV2 prevention strategies, namely: (1) keeping rabbits inside; (2) penalizing people who intentionally release domestic rabbits into the wild; and (3) vaccinating rabbits. Nearly half of respondents kept their rabbits indoors at all times, thereby reducing the risk of RHDV2 transmission through environmental contamination or exposure to free-roaming lagomorphs. Nonetheless, we note that 10.7% of respondents allowed their rabbits outside frequently on properties where wild or feral lagomorphs were observed, which is concerning given the length of time that RHDV2 may persist on the landscape. Importantly, breeders with larger rabbit herds were more likely to keep their rabbits outdoors, which may increase the probability of RHDV2 transmission between the domestic herd and free-roaming wild or feral lagomorphs through direct contact between lagomorphs, or exposure to fomites such as contaminated materials and forage.

Most respondents supported penalizing people who intentionally release domestic rabbits into the wild, which may help deter rabbit abandonment and potential disease risks. The number of rabbits abandoned in the USA is currently unknown (Daly 2017), but one study showed that most rabbits in four animal shelters were surrendered pets or stray (Cook and McCobb 2012). Anecdotal evidence from rescue groups indicates that a significant proportion of rescued rabbits are strays (Daly 2017). Several RHDV2 outbreaks have occurred in large feral rabbit colonies in the western United States (Fig. 1; Asin et al. 2021; Williams et al. 2021). Thus, additional studies are needed to understand how many rabbits are abandoned, the reasons people abandon rabbits, and the potential RHDV2 transmission risks that stray, feral rabbits pose to wild lagomorphs and domestic rabbits.

Most respondents were willing to vaccinate some, if not all, of their rabbits, although we note that most respondents owned one to five rabbits only. Prior to October 2021 (during

data collection), RHDV2 vaccines could only be imported from Europe by states with confirmed cases of RHDV2. In September 2021, a domestically produced vaccine received emergency use authorization from the USDA (Medgene Labs 2021), and as of December 2022, most states approved the use of this vaccine. Both the European and US vaccines have been found to be effective at preventing disease from RHDV2 infection. However, the European vaccines do not prevent infection in all rabbits (Le Minor et al. 2019; National Assembly RHDV2 Subcommittee 2020; Sanchez-Matamoros et al. 2021), and the ability of the US vaccine to prevent infection or viral shedding has not yet been documented. Vaccinated rabbits may potentially spread RHDV2 if they are transported to new areas. Moreover, these vaccines are expensive (\$30–\$125 per dose depending on the veterinarian), and the US vaccine requires two doses (as opposed to a single dose for the European vaccines). Respondents were less willing to vaccinate their rabbits as the price of the vaccine increased, especially if they had large herds. Prior to the widespread distribution of the domestically produced RHDV2 vaccine, some veterinarians and rabbit interest groups hosted RHDV2 vaccination clinics to vaccinate rabbits at a greatly reduced cost. However, these clinics were not widespread and had the potential to inadvertently increase the risk of human-mediated RHDV2 spread, as rabbit owners may have traveled between areas with and without RHDV2 to obtain the vaccine. Thus, while the vaccines are a valuable tool for protecting domestic rabbit health and welfare, additional disease prevention strategies (e.g., creating secure barriers between domestic and wild lagomorphs, preventing the transport of rabbits from states that have RHDV2 to areas where the virus has not been detected) are required to reduce the risk of RHDV2 spreading to wild lagomorphs.

Given respondents' generally high levels of knowledge about RHDV2, it is unlikely that lack of knowledge is the limiting factor for voluntary adoption of, or support for, disease prevention by breeders and rescue staff. Rescue groups and breeder organizations have actively disseminated information about RHDV2 to their members. However, while our findings suggest that respondents were largely aware of the existence of RHDV2, most respondents did not realize that rabbits often show no signs of infection before death. This is concerning because owners may then inadvertently transport RHDV2-infected rabbits or contaminated equipment or materials to new areas. Pet owners who were not members of a rabbit interest group were also less informed about RHDV2, which highlights the need for effective outreach to pet owners by trusted sources. Improved education of potential pet owners about rabbits' husbandry and welfare needs may be an important component of RHDV2 outreach to prevent naïve consumers purchasing animals that they are unable to care for or releasing unwanted or sick pets that may transmit RHDV2 (Edgar and Mullan 2011; Rioja-Lang et al. 2019; McMahon and Wigham 2020).

RHDV2 educational and outreach materials targeted at rabbit owners and other stakeholders who interact with domestic rabbits should highlight the risks this pathogen poses to domestic rabbits, wild lagomorphs, biodiversity, and rabbit-related industries, as respondents expressed concern about the economic and ecological impacts of RHDV2. Previous studies have shown that risk perceptions are an important determinant of people's engagement in, or support for, disease prevention, and that articulating both the ecological and economic impacts of pathogen transmission is more likely to engage an array of people with different values in disease prevention (Hanisch-Kirkbride et al. 2013; Pienaar et al. 2022). It is thus important to ensure that rabbit owners are informed about the multiple

adverse impacts associated with RHDV2 spread. However, the source and content of these communications are crucial to prevent panic. At the time of the southwestern RHDV2 outbreak in 2020, several media articles dubbed RHDV2 “rabbit or bunny Ebola” (Orlean 2020; Woodward 2020). Sensationalism in these articles is concerning, as many respondents indicated one of their preferred communication methods was through the news media. While increased coverage in the media can generate short-term behavioral changes in response to increased risk sensitivity (Heberlein and Stedman 2009), sensationalizing RHDV2 could lead rabbit owners to engage in behaviors that increase the risk of RHDV2 spread (e.g., traveling to a RHDV2-positive area to obtain a vaccine). The creation and dissemination of accurate, concise, and clear information by trusted sources about how owners can protect their rabbits and prevent the spread of RHDV2 that speaks to rabbit owners’ values and beliefs is more likely to generate long-term behavior change.

Although previous studies have identified veterinarians and places where people acquire rabbits as trusted sources for information pertaining to rabbit welfare (Edgar and Mullan 2011; Welch et al. 2017), we found that most respondents (~ 65%) would like to receive RHDV2 information from state wildlife agencies. Fewer respondents (52.4%) preferred to receive RHDV2 information from state agricultural agencies. This is surprising because state wildlife agencies have no jurisdiction over domestic rabbits. It is possible that respondents’ preference for receiving RHDV2 information from wildlife agencies may stem from a desire to better understand how RHDV2 is impacting wild lagomorph populations or whether RHDV2 has been detected on the landscape. An alternative explanation is that individuals who own rabbits as pets or companion animals are unaware that in many cases, state agricultural agencies have jurisdiction over domestic rabbits, depending on whether domestic rabbits are classified as livestock within the state (Shapiro et al. 2022). However, since the RHDV2 outbreak, state agricultural agencies have been responsible for responding to domestic rabbit RHDV2 mortalities, importing vaccines from Europe, and communicating with individuals who interact with domestic rabbits about disease prevention. Rescue groups and breeder organizations may complement outreach by government agencies by directly disseminating RHDV2 information to their members.

Despite the importance of educational efforts in encouraging disease prevention measures, we caution against the assumption that improved communication will result in widespread adoption of disease prevention measures by rabbit owners. As already noted, vaccines may be cost prohibitive for rabbit owners, especially if they have large herds. Limited access to veterinarians who treat rabbits, the higher costs of treatment for exotic pets such as rabbits, and the need to transport rabbits (for commercial or personal reasons) may be major constraints to adopting disease prevention measures. Although respondents agreed that transporting rabbits increases the risk of RHDV2 transmission and that rabbit owners should adopt appropriate measures to prevent RHDV2 spread, individuals who rely on the sale of domestic rabbits for their income will still transport rabbits. Individuals who have a strong affinity for rabbits may also transport rescued rabbits across state borders, despite RHDV2 risks. Improved monitoring of RHDV2 transmission by the commercial rabbit trade and rabbit rescues is needed, especially if animals are being transported across borders. Timely reporting of suspected RHDV2 cases to the appropriate government agencies may facilitate accurate diagnosis through professional postmortem examinations. It is therefore important that individuals who own or interact with domestic rabbits report suspected RHDV2 cases to

the appropriate authorities and that agencies report the results of any postmortem examinations to rabbit owners, rescue groups, rabbit interest groups, and veterinarians. We recognize that it is naïve to assume that agencies have the resources to monitor movement of companion animals by individual owners. As such, more research is needed on how to engage rabbit owners in voluntary disease prevention behaviors (e.g., isolating new rabbits, using proper disinfectants, creating secure barriers between domestic and wild lagomorphs), in order to complement agency efforts to prevent the geographic spread of RHDV2.

Conclusion

The movement and husbandry of domestic rabbits may be contributing to the spread of RHDV2 in the USA. Although rabbit owners can protect their rabbits through vaccination, they must engage in additional behaviors (e.g., ensuring that domestic rabbits do not come into direct or indirect contact with wild lagomorphs) to prevent the spread of RHDV2 to new areas, as vaccination may not prevent infection or viral shedding. In this first look at rabbit owners' and rescue staff's responses to RHDV2, we found that most respondents were concerned about RHDV2, about half of respondents kept their rabbits inside and isolated from wild lagomorphs at all times, and rabbit owners with five or fewer rabbits were likely to vaccinate their rabbits. However, the ability to house rabbits inside and vaccinate them may be cost prohibitive for breeders, owing to large herd sizes. Moreover, breeders rely on the sale and transport of rabbits to generate income. Communication on the need for disease prevention behaviors should emphasize the ecological and economic impacts of RHDV2. Improved monitoring of RHDV2 transmission by government agencies should be complemented by studies on how to better engage rabbit owners in voluntary measures to prevent the spread of RHDV2.

Data availability

Data generated or analyzed during this study are included in this article and its supplementary information files.

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Ethics declarations

Conflict of interest

The authors declare that they have no conflict of interest.

Ethical approval

The University of Georgia's Institutional Review Board characterized our study as non-human subjects research because we elicited no identifiable or sensitive private information from research participants. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

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