SPREAD OF RABBIT HEMORRHAGIC DISEASE VIRUS 2 (RHDV2) IN WILD AND DOMESTIC LAGOMORPHS IN THE WESTERN UNITED STATES

by

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DEDICATION

I would like to dedicate this paper to my rabbits Moony, Padfoot, and Luna, who inspired this topic of study and provided a welcome distraction in my life. I would also like to thank my amazing husband, Paul. His consistent support throughout the process to complete this degree was truly invaluable, from mental support through challenging courses, to physical support as we moved cross-country and allowing me to pursue this degree full time, to his unending love and patience. And a final thanks to my family and in-laws for the support they provided me throughout this process!

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GLOSSARY

ABBREVIATIONS:

ARBA- American Rabbit Breeders Association; a non-profit organization for rabbit breeders.

CVI- Certificate of Veterinary Inspection; a health certificate issued by a federal, state, tribal, or accredited veterinarian certifying that an animal has been inspected, is in good health and meets regulatory requirements to travel within the same state, across state lines, or internationally.

GIS- Geographic Information Systems; used for the mapping of data; commonly used software includes ArcGIS by Esri and QGIS.

RHDV- Rabbit Hemorrhagic Disease Virus; a deadly disease that affects lagomorphs, usually resulting in the death of the animal.

USDA APHIS- United States Department of Agriculture, Animal and Plant Health Inspection Service.

USDA FADDL- United States Department of Agriculture, Foreign Animal Disease Diagnostic Laboratory.

NOMENCLATURE:

Domestic rabbit- a rabbit (*Oryctolagus cuniculus domesticus*) that is descended from the wild European rabbit (*Oryctolagus cuniculus*); commonly referred to as a pet rabbit or house rabbit as they live with or are maintained by humans.

Feral rabbit- A domestic rabbit (or descendant thereof) that was previously domesticated but has escaped or been abandoned in the outdoors; feral rabbits cannot breed with wild rabbits due to genetic differences.

Lagomorph- a mammal within the order *Lagomorpha*, relating to rabbits, hares, and pikas.

Wild rabbit- a rabbit (*Sylvilagus* spp., sometimes referred to as cottontails) or hare (*Lepus* spp.) that lives in the wild and is not classified as a domestic breed or subspecies of the European rabbit to which domestic rabbits are genetically related.

ABSTRACT

Rabbit Hemorrhagic Disease Virus 2 (RHDV2) affects all lagomorphs including domestic and wild rabbits, hares, and pikas. The V2 serotype of the RHD virus first appeared in France in 2010 and as of 2020 has become endemic in North America, particularly in the western United States. RHDV2 and its predecessor RHDV1 have had devastating impacts on wild rabbit populations due to high virulence and lethality, often killing hosts within 72 hours of infection. This analysis focuses on understanding factors related to spread of the virus in the western United States. I utilize data from the USDA APHIS RHDV2 ArcGIS web map to document the spread of confirmed cases in wild, domestic, and feral rabbits in the western states over the last two years. I also analyze the regulatory frameworks and permitting for the RHDV2 vaccine, in addition to an identification of key stakeholders and analysis of risk communication on the virus. My investigation of this virus suggested that RHDV2 poses a greater risk to lagomorph species than RHDV1 due to higher transmission rates and virulence, the ability to infect young rabbits before maturity, and the ability to overcome RHDV1 immunity. Mapping completed for my analysis indicates that both wild and domestic cases spread rapidly throughout the western states in 2020 and 2021, particularly during peak breeding times, with confirmed cases largely centered in California and Arizona and near population centers. In limiting the spread of the virus, current policies and laws need to be more thorough. Monitoring the spread of this disease is difficult due to government and fiscal constraints. A wide range of interested stakeholders from commercial, government, and public sectors are involved in this issue. Without a joint effort focused on obtaining and understanding the necessary data, and considering the limitations of current laws, it has proven difficult to control the spread of RHDV2 and the associated impacts on stakeholders. Increased monitoring by government organizations and citizen scientists can provide necessary data to determine the severity of the problem, and inform measures required to mitigate the impact of RHDV2 on lagomorph populations in the United States.

INTRODUCTION

The United States rabbit industry generates more than $2.2 billion per year, mainly through pet supplies and care of the estimated 6.7 million domestic house rabbits (Cole, 2020). There are also environmental benefits obtained from the expansive wild rabbit populations within the United States that sustain native predator populations. Introduction of Rabbit Hemorrhagic Disease Virus 2 (RHDV2) presents a significant threat to both domestic and wild rabbit populations in North America. Limited research exists on specific risks inherent in RHDV2 virus effects on a population level, as the virus is relatively novel both in the scope of time and biological factors that set it apart from other RHD viruses. My paper identifies (1) a range of risks inherent in the spread of RHDV2 in the western United States, according to a variety of factors from transmissibility and pathways of introductions, ecological and economic impacts, (2) any regulatory frameworks associated with RHDV2, and (3) impact to stakeholders that may be affected as a result of this virus.

My paper will address the following research objectives:

- *Objective 1.a* Identify factors related to the spread of RHDV2, such as transmissibility between rabbit species, pathways for introduction of the virus, and biological elements of the virus.
- *Objective 1.b* Use the United States Department of Agriculture (USDA) Animal Plant Health Inspection Service (APHIS) RHDV2 affected counties web map data to determine the possible spread of the virus over the time span of March 2020 to March 2022, and the extent to which the virus has affected particular states over this time period in cases of domestic, wild, and feral rabbits.

- *Objective 2* Analyze the regulatory framework related to RHDV2 and vaccine licensing and permitting regimes within the United States.
- *Objective 3a* Identify key stakeholders, including commercial, government, and private sectors.
- *Objective 3b* Assess the efficacy of risk communication efforts to mitigate RHDV spread, across the span of reference materials available to the general public through state and federal websites.

History and Background

Wild Rabbits and Lagomorphs in the United States

North America provides habitat for 11 species of cottontails (family Leporidae, genus *Sylvilagus)* and eight species of jackrabbits and hares (family Leporidae, genus *Lepus)*, along with two species of pikas (family Ochotonidae), which are all members of the taxonomic order *Lagomorpha*, commonly referred to as "Lagomorphs" (Shalaway, 2018) (Figure 1). Cottontails are found throughout the United States and Canada, while jackrabbits inhabit prairies, grasslands, and deserts in the western portions of North America. Hares are adapted to and situated in the northern parts of North America, along with some marshes in the southern United States. The most recognizable native rabbit throughout North America is the eastern cottontail (*Sylvilagus floridanus*) known for its white tail (JRank, 2015). Other rabbits include the mountain cottontail (*S. nuttalli*) found in mountainous regions in the west, the desert cottontail (*S. auduboni*) in the arid southwest, the brush rabbit (*S. bachmani*) found in Oregon and California, and the swamp and marsh rabbits (*S. aquaticus* and *S. palustris*) which are known for swimming in the wet habitats of the southeast. The most widespread hare is the snowshoe or

varying hare (*Lepus americanus*), found across the northern United States to the low-arctic tundra, while the arctic hare (*L. arcticus*) inhabits the northern tundra. Jackrabbits include the white-tail jackrabbit (*L. townsendii*) and the blacktail jackrabbit (*L. californicus*). The European hare (*L. europaeus*) has been introduced to North America and is the largest wild lagomorph in America with an average weight of 4.5 kilograms (10 pounds). The two breeds of pika within North America are the collared pika (*Ochotona collaris*) found primarily in Alaska and northern Canada, and the American pika (*O. princeps*) found primarily in the western United States and Canada (The National Wildlife Federation, n.d.).

Wild Lagomorphs of the United States

Snowshoe hare (*Lepus americanus*)

Eastern cottontail rabbit (*Sylvilagus floridanus*)

American pika (*Ochotona princeps*)

Figure 1: A variety of wild lagomorphs found in the United States (Baltana HD Wallpapers, 2020; Canter, 2017; Dulude-de- Broin, 2016)

Domesticated Rabbits

According to the American Rabbit Breeders Association (ARBA), there are 50 unique breeds of domestic rabbit (*Oryctolagus cuniculus domesticus*) recognized in America (ARBA, 2019). However, there are 538 breeds of rabbit worldwide as classified by the Food and Agriculture Organization of the United Nations (FAO, 2017). Domestic rabbits are commonly

thought to have been first domesticated from wild European rabbits (*Oryctolagus cuniculus*) in 600 A.D. by French monks. Historical, anecdotal reports suggest rabbits were domesticated as a result of religious edict; in 600 A.D., Pope Gregory the Great supposedly issued an edict declaring that 'laurices', or rabbit fetuses, were to be classified as fish instead of meat, therefore they could be consumed during Lent (Carneiro et al, 2011; Wei-Haas, 2018). Monks in the south of France started selective breeding of rabbits by weight and coat color to take advantage of this religious exemption, possibly leading to the hundreds of different recognized breeds today. However, these reports were discredited by Irving-Pease (2018) using paleo genomics; Irving-Pease aimed to map the genetic history of modern domesticated and wild animals, and rabbits were an ideal test subject based upon the previous report of them becoming domesticated in 600 A.D. Irving-Pease (2018) revealed that no edict could be found, aside from a 584 A.D. document from St. Gregory of Tours which was seen to be the result of a misinterpreted version of the history. It took roughly 2000 years for differences between wild and domestic rabbits to show up in their skeletal structure, meaning that domestic rabbits were not fully different from their wild counterparts, genetically speaking, for some time (Irving-Pease et al., 2018). It is unknown if there is a specific point in time when rabbits were domesticated; however, Romans were commonly credited with having the earliest historical records of rabbits being kept in hutches and may be responsible for the spread of rabbit populations during the expansion of their empire (University of Oxford, 2018).

Domestic Rabbit Breeds		
		
Dutch rabbit	Cinnamon rabbit	Flemish Giant rabbit

Figure 2: Examples of domestic rabbit breeds in the United States (*Source: Shelbie Hardy*)

Feral Rabbits

Feral rabbits are domesticated European rabbits (non-native rabbit species) that have been released or otherwise introduced into the wild. Rabbits have been considered the most commonly abandoned domestic animal, mostly due in part to their purchase for children during Easter season as gifts, followed by abandonment at shelters or into the wild a few weeks later (when the novelty wears thin, and the work involved in owning them is realized). These 'dumped' rabbits usually are not able to survive in the wild; however, some do survive and form groups with other abandoned rabbits, when available. The issue of feral rabbits can compound quickly, as rabbits reproduce rapidly, with an average 30-day gestation consisting of litters of four to twelve kits, and with the ability to conceive within 24 hours of giving birth (Todd, 2017; McClure, 2020). This can lead to an estimated progeny of more than 800 offspring from one rabbit, since rabbits reach sexual maturity at four to six months. Rescue groups estimate that more than 800 to 1200 feral rabbits reside in Las Vegas, where feral rabbit populations have been an ongoing serious concern since 2012 (Todd, 2017). As feral rabbits are domesticated

breeds, the hunting, trapping, or killing of them is a misdemeanor offense in most states including Nevada; even the common practice used by rabbit rescues of "trap, neuter, return" is technically illegal as it is considered abandonment in Nevada (Todd, 2017).

Rabbit Hemorrhagic Disease

History of RHDV Spread: Rabbit Hemorrhagic Disease was first described in China in 1984 (Liu et al., 1984) after a shipment of commercially bred Angora rabbits imported from Germany entered China and led to 140 domestic rabbit deaths within a year (Abrantes, 2012). The virus then spread in varying forms across Korea and then throughout Europe, starting with Italy in 1986 and extending to Portugal by 1989 (Abrantes, 2012). More recently, the RHDV2 variant of RHDV likely originated in France in 2010 and was dubbed RHDV2 for serotype 2 (USDA, 2020). Interestingly, the virus does not affect human health or the health of any other animals besides lagomorphs. Lagomorphs seem to serve as the only hosts that are able to replicate the virus within the body for further spread, although other animals, such as insects, and humans may serve as fomites for transport of the virus.

The virus finally made its way to Canada and the United States in 2018. Washington state saw an outbreak from July to December of 2019 in pet and feral rabbits. Whole genome sequencing indicated that the RHDV2 virus in Washington was very similar to the 2018 strain found in British Columbia (Cole, 2020). In February 2020, RHDV2 was detected in a domestic rabbit in New York. In this case, the virus was identified, isolated, and eradicated (USDA, 2020). The virus was later found in domestic rabbits in New Mexico on March 24, 2020, and confirmed at the USDA APHIS National Veterinary Services Laboratory (NVSL), Foreign Animal Disease Diagnostic Laboratory (FADDL) as a strain that differed from the British Columbia strain,

indicating a new introduction of the disease from a different source (Cole, 2020). Since 2020, the virus has spread into other states, with confirmed cases reported in Arizona, California, Colorado, Nevada, and Texas (USDA, 2020).

Effective Use as a Biocontrol Measure: The virulence and pathogenicity of the RHD virus has previously been demonstrated in rabbit populations in Australia and New Zealand. When used as a biocontrol measure in these countries, the virus caused a 95% reduction in documented rabbit populations (Abrantes, 2012; Mutze et al, 1998). This virus was tested on Wardang Island in Australia using the RHDV Czech reference strain (Czech V351) for the purposes of addressing the issue of rabbits as pests in the late 1990s. However, while this version of the virus was being tested, it escaped from the testing island (Wardang Island) to the mainland, where there was a 95% reduction in wild rabbit populations, thus proving its pathogenicity and lethality in the short-term management of the abundant rabbit populations (Abrantes, 2012; Mutze et al, 1998). The virus was used as a biocontrol agent to address rabbit destruction of agricultural crops, competition with native wildlife for habitat, and advantageous breeding abilities that resulted in a rabbit population explosion over the span of a few decades following introduction to this geographic region.

METHODS

The following describes the methods adopted to address each of the objectives in my paper:

Objective 1: Factors Contributing to RHDV2 Spread

Objective 1a focuses on identification of hazards inherent in Rabbit Hemorrhagic Disease Virus serotypes 1 and 2, such as transmissibility between rabbit species, pathways for introduction of the virus, and biological elements of the virus. Objective 1b serves to map the spread and range of the virus across the western United States, including the following states: Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Texas, Utah, Washington, and Wyoming between 2020 and 2022.

Objective 1a: Literature-Based Review:

Due to the emerging nature of rabbit hemorrhagic disease virus 2 (RHDV2/RHDVb), a majority of existing published literature focuses on RHDV serotype 1. As a result of the limited literature available for RHDV2, I included resources on both RHDV and RHDV2 in my review. Most of my analysis was completed using the Montana State University Library CatSearch engine (which incorporates all search engines in MSU library's collection). The search was restricted to peer-reviewed articles dating from 1980 to 2022, given the prevalence of RHDV since the 1980s. Boolean search terms entered into the MSU database included the following: [(Rabbit OR Lagomorph OR Hare) AND (Hemorrhagic Disease) AND (Virus)], [Rabbit Hemorrhagic Disease], and [Rabbit Virus]. Relevant in-text citations from these sources were also included in the literature review, as they provided further clarity on points addressed in the original sources and further expanded on topics not found in the original source materials.

Relevant online resources [e.g., factsheets, publications, etc.] were also included in this review to complement peer-reviewed sources.

Objective 1b: GIS mapping:

For objective 1b, the data were mapped using QGIS 3.16.2 and originally encompassed all states that have confirmed RHDV2 cases since March 2020 in the RHDV2 USDA APHIS dataset. Extracting the data from the USDA APHIS "2020-22 Rabbit Hemorrhagic Disease -- Affected Counties as of Mar 20, 2022", I mapped the spread of the virus within the western states (Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Texas, Utah, Washington, and Wyoming), a map was created demonstrating the spread of RHDV2 in domestic, feral, and wild rabbit species. The outbreak in the western states was the principal focus of this analysis, and as such outlying cases in states such as Tennessee, Minnesota, and Florida were not included. Cases identified in the previously identified states were isolated, and the data were parsed into the respective rabbit populations (domestic, feral, or wild) and were further divided into six-month increments. For example, domestic breeds that had confirmed cases from January to June in 2021 were classified together as "Domestic_Early21". The RHDV2 dataset was also turned into a CSV file to better calculate values within the attribute table, such as county counts, and counts by state and year.

Objective 2: Policy and Licensing Impacting RHDV2

Objective 2 focuses on understanding the regulatory framework related to RHDV2, the vaccine licensing and permitting process within the United States. Part of this analysis was

completed using resources found on state websites through individual state departments: Department of Agriculture, Department of Fish and Game, and Wildlife Resources. Federal resources included articles, lectures, and guides found through the USDA and their sectors such as APHIS, FADDL, or other divisions. State law databases were also included to determine relevant laws or regulations in place. For vaccine information, resources were obtained from the supplier of the American vaccine, Medgene Labs, and their partners.

Objective 3: 3a. Identification of Key Stakeholders and 3b. Efficacy of Risk Communication Efforts

Objective 3a includes the identification of key stakeholders, such as those found in the commercial, government, and private sectors. Objective 3b assesses the efficacy of risk communication measures, based on the regulations outlined per state or per agency. My analysis was completed via review of commercial websites such as Oxbow Animal Health, government websites including sites similar to those found for objective 2, and public sector websites such as the House Rabbit Society, a show rabbit podcast, and other sites that update the greater public on issues surrounding RHDV2.

RESULTS

Objective 1a: Factors Contributing to RHDV2 Spread

Transmissibility:

Rabbit hemorrhagic viruses (RHDV2 in particular) have been shown to be most prevalent and deadly shortly after the commencement of lagomorph breeding cycles (Taggart et al, 2022). RHDV2 has three main transmissibility advantages over prior RHD viruses, including the ability to partially overcome immunity to other variants, the ability to infect young rabbits, and a wider host range. Wild rabbits in the Iberian Peninsula have demonstrated the transmissibility of RHDV2 in populations previously inoculated with RHDV1. Prior to 2011, infected rabbits had RHDV strains within the same genotype (G1); however, a 2016 survey showed that all Iberian rabbits only had RHDV2, suggesting that the RHDV2 virus may have completely replaced all other strains of the RHD viruses in the area (Monterroso, 2016). The use of RHDV in Australia in 1995 (and officially in 1996) was a prime opportunity to study the co-evolution of RHDV, as Australia only had one strain of RHDV until 2015 when RHDV2 entered the country. The Czech reference strain (Czech V351), escaped from the Wardang Island testing site in 1995 and was officially released by the Australian government into wild populations in 1996 (Elsworth, 2014). This sole strain in the country allowed for testing to see how the virus and genetic resistance occurred in wild rabbit populations. At first onset of the original RHDV, wild rabbit populations declined by 95% (Abrantes, 2012), and the virus continued to control rabbit populations to varying degrees across Australia. As time progressed, virus lethality decreased in areas with previous high mortality rates, suggesting the development of natural immunity within the populations and subsequent resistance to the RHDV1 strain (Elsworth & Cooke, 2006). In

populations where high mortality rates were not observed, virus lethality over time remained similar to the lethality demonstrated in virgin rabbit populations. The ability of RHDV2 to overcome the previous strains of RHDV poses a significant risk to populations that have previously been inoculated and are now again at significant risk, with a lethality similar to that of RHDV.

Infection of young rabbits:

The ability to clinically infect young rabbits was shown during the Monterroso study on the Iberian Peninsula where most (n = 58; 85.9%) of the animals infected with RHDV2 were found during the mating season for European wild rabbits from November to March (with half of those found dead being less than 6 months old). Extensive and rapid transmission of RHDV2 within young rabbits overcame immunity conferred by seroconversion within the population (Abrantes, 2021). This high viral shedding and subsequent mortality rate caused a flood of virus-laden carcasses. With the significant transmissibility and dissemination of RHDV2 throughout the population in the Iberian Peninsula, the virus caused widespread lethality (Taggart, 2022). The Iberian Peninsula observations illustrate that RHDV2's ability to clinically infect young rabbits is a key advantage in the field that allows it to spread so vigorously.

Host range:

In addition, RHDV2 is considered to have a wider host range than RHDV. RHDV has not adversely affected species outside of domestic European rabbits and European hares, whereas RHDV2 can take hosts in native North American rabbits and hares including jackrabbits, cottontails, and domestic breeds. The virus can also be spread to non-target species, such as in infectious RHDV2 strains found in the liver of a Mediterranean pine vole and two white-toothed

shrews that were in the vicinity of an outbreak area in Europe (Calvete et al, 2019; Abrantes, 2021). The ability to infect a wider range of hosts compared to RHDV is one of the major concerns with RHDV2, as it can infect not only European breeds of rabbit, but also American breeds of hare, rabbit, and pika.

Physiology of the RHD Viruses:

RHDV is a non-enveloped, single-stranded RNA virus in the family Calicivirus of the genus *Lagovirus* that causes rabbit hemorrhagic disease (RHD) in adult European rabbits (*Oryctolagus cuniculus*) (Abrantes et al, 2012; Cole, 2020). RHD has three recognized pathogenic groups: RHDV (or RHDVa), RHDV1 (a subtype of RHDVa), and RHDV2 (or RHDVb) which may be classified as a distinct viral subtype (OIE, 2019). Phylogenetically, there have been four RHDV genotypes (GI) that have been identified: GI.1 through 4 (Abrantes et al, 2021). Commonly called the classical form of RHDV or RHDV1, GI.1 consists of the first strains that were characterized globally and was the only pathogenic genotype in circulation for over twenty years; it also has four subtypes, GI.1a through d where GI.1a has distinct antigenic properties and is mostly associated with outbreaks within rabbitries. GI.2 is what is referred to as RHDV2 and is known for its ability to infect young rabbits. Genotypic differences between GI.1 and GI.2 may explain why GI.1 vaccines do little to help with GI.2 (RHDV2) infections. The final two genotypes, GI.3 and GI.4, correspond to the non-pathogenic forms of RHDV that were recognized as a result of immunohistochemistry tests.

Virulence of the RHD Viruses:

Virulence of RHDV has increased throughout time, possibly as a response to the development of genetic resistance in Australian wild rabbits (Elsworth et al, 2014). This

progressive virulence seems to be favored as rabbit carcasses (as opposed to currently diseased animals) served as a likely source for mechanical insect vectors, which led to a more widespread dispersion of the virus than observed in previous outbreaks (Elsworth, 2014). Most RHDV transmission is via direct contact of the virus particles to mucous membranes, but RHDV2 transmission can also occur via oral, nasal, or conjunctival routes. The virus can be spread through exposure to an infected rabbit's excretions or blood and has environmental retention, giving the virus the ability to infect from carcasses, food, water, and via contaminated materials, along with transmission via clothing and shoes (USDA, 2020). In addition, RHDV2 displays environmental resistance to temperature extremes, both hot and cold, so it is able to withstand the elements and survive in the environment on fomite materials (Cole, 2020; USDA, 2020). The liver, spleen, and kidneys act as the main sites for virus replication, but RHDV/RHDV2 can be detected in major organs and tissues such as the lungs, kidneys, and bone marrow in addition to biological fluids such as serum, feces, and urine (Abrantes, 2021). The virus, even though it is relatively short-lived in most hosts (with death commonly occurring within 72 hours), causes hepatic necrosis, splenomegaly, hyperemia, and hemorrhages in the lungs and trachea (OIE, 2019; USDA, 2020; Abrantes, 2021). The virulence of RHDV2 assures the virus can be spread more rapidly and with greater ease, dependent on the vectors of transport, given the ability of the disease to survive longer in the environment than RHDV or other rabbit viruses, and spread easily via susceptible hosts via oral, nasal, and other mucosal routes.

Trophic cascades:

The increasing prevalence of RHDV2 has also led to trophic cascades in the Iberian Peninsula. With the decline of rabbit populations, those animals on higher trophic levels are

adversely affected as well. This was studied in the Iberian Peninsula in regard to declining populations of highly threatened apex predators such as the Iberian lynx (*Lynx pardinus*) and the Spanish Imperial eagle (*Aquila adalberti*) as a result of mass die-offs of the European rabbit (*Oryctolagus cuniculus*) (Monterroso, 2016). The catastrophic decline in rabbit populations adversely affected fecundity and birth rates in both the lynx and eagle. This was even more pronounced with the entrance of RHDV2 that took over for RHDV. Fecundity and birth rates for predators post-RHDV2 spread declined at much greater rates than those observed with RHDV outbreaks. With the highly threatened status of these two animal species in the Iberian Peninsula at stake, it shows that rabbit disease, especially with the mortality rates of RHDV2, can adversely affect other populations throughout the food chain. When applied to the southwestern United States where this disease is currently endemic, a widespread epidemic of RHDV2 could threaten the health of snake, coyote, owl, and even wolf populations. Similar to the lynx and eagle, rabbits and hares may not be a primary food source for the top-tier predators but may be a food source for mesopredators that are consumed by apex predators. A loss of cottontails and jackrabbits could also lead to devastating effects throughout faunal communities in the southwestern United States.

Objective 1b: GIS mapping

This data set incorporated information from 125 counties in the western United States from March 2020 through March 2022.

Table 1: Overview of case counts, county most affected per state, and the most affected type of rabbit population reported per state.

RHDV2 Data Summary in the Western United States			
State	*Total RHDV2 cases*	*County most affected*	*Type most affected (overall)*
Arizona	74	Cochise (23)	Dom (46)
Cali	87	Los Angeles (20)	Dom (54)
Colorado	52	El Paso (13)	Wild (29)
Idaho	2	Ada (2)	feral/wild 1/1
Montana	10	Yellowstone (10)	feral/wild 5/5
Nevada	17	Clark (4)	Dom (9)
New Mexico	53	Santa Fe (8)	Dom (43)
Oregon	8	Deschutes (4)	Wild (4)
Texas	29	Lubbock (4)	Wild (20)
Utah	15	Iron (3)	Wild (9)
Wyoming	27	Park/Laramie (7 each)	Wild (26)
Total	374		Dom (192)/ Wild (175)

The data set included 374 cases of RHDV2, of which 192 were domestic reports, 175 were wild cases, and 14 were feral rabbit cases. The states with the highest number of cases were California (87) and Arizona (74), with the majority of reported cases occurring in domestic rabbit populations. Arizona had the highest geographical spread of the virus, with 13 of its 15 counties affected, with Cochise County having the most observed cases of any county with 23 positive cases, of which 14 were domestic.

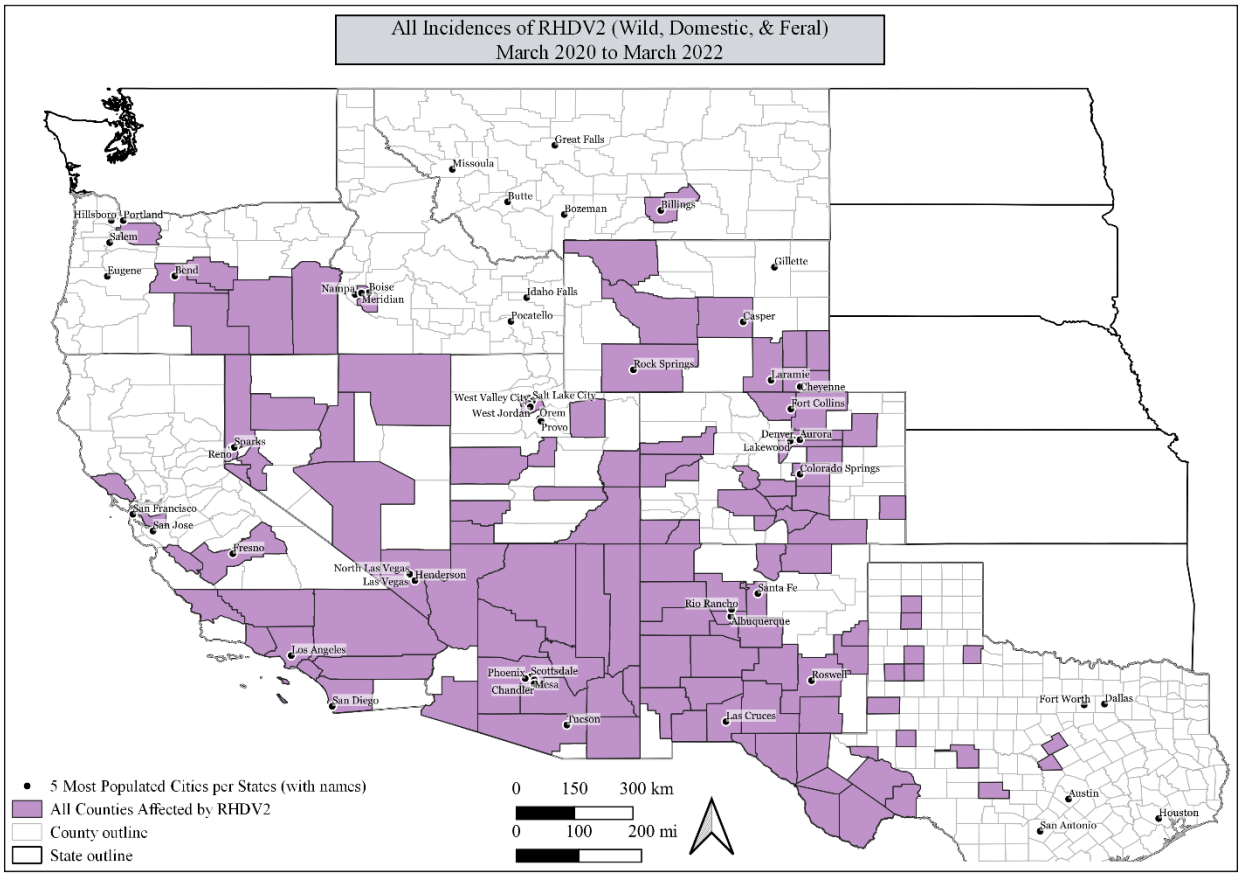

Figure 3: Regional map of the western United States with counties affected by documented incidences of RHDV2 in wild, domestic, or feral rabbits highlighted. Five most populous cities included with tags. (Appendix A-1) (USDA APHIS, 2022)

Domestic rabbit positive case spread (2020 to 2022)

The domestic maps encompass appendices B-1 through B-6. Figure B-1 is a mapping of the overall count of domestic cases reported over the entire timespan of the RHDV2 reporting through APHIS from March 2020 to March of 2022. B-1 shows that the highest incidence of cases appears to be within Arizona and California, which is also true for the overall prevalence of the virus in both wild and domestic cases. Examining the five most populous cities per state, high case numbers per county were observed in the counties containing these urban centers.

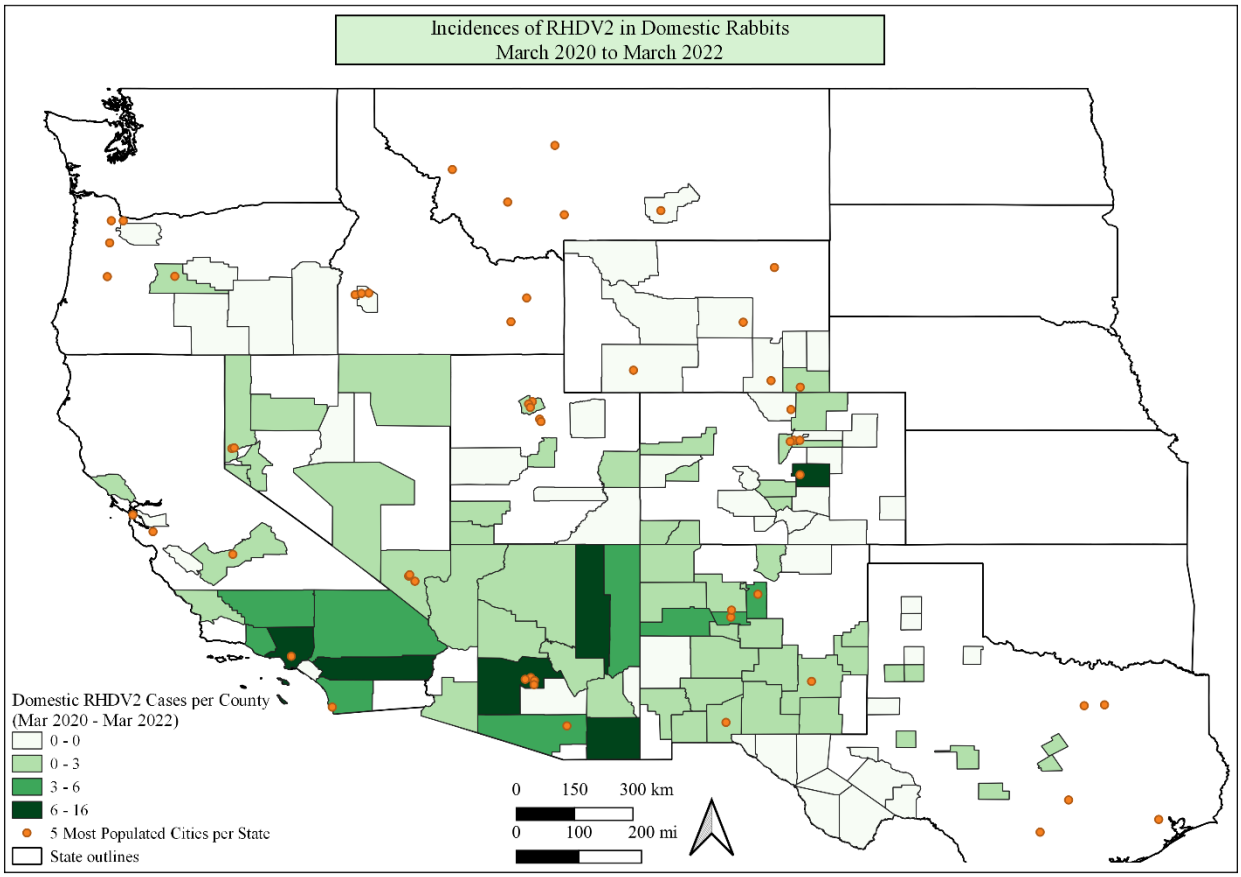

Figure 4: Map of the counties affected by domestic cases of RHDV2 over the entire timespan (March 2020 to March 2022), with darker colors indicating higher incidences of RHDV2 per county. Dots representative of five most populous cities per state. (Appendix B-1) (USDA APHIS, 2022)

2020: In early 2020, the virus was mostly found within the area where it was first confirmed, ranging from southeast Nevada through Arizona and New Mexico with cases up to 38 per state (Arizona). At this point in time, only six of the eleven western states were affected, with two states only having one case each. In late 2020, the virus frequency per county decreased but seemed to spread into California for the first time. During this time, all county counts stayed below four cases, and many were solitary cases. In late 2020, only seven of the eleven states studied had any incidences of the virus in domestic breeds, and in four of those states, only one county was affected.

2021: In early 2021, the case counts in California rose from nine total cases in 2020 to 45 cases across all of 2021. The virus also spread across nine of the eleven states in early 2021 and in all but California stayed below four cases per affected county. In late 2021, the case counts drastically dropped, with only three of the eleven states reporting positive cases and all counties staying below four cases per county. Data for 2022 through March only showed one case in Arizona.

Wild rabbit positive case spread (2020 to 2022)

The domestic maps encompass appendices C-1 through C-6. Figure C-1 is a mapping of the overall count of domestic cases during the entire timespan of the RHDV2 reporting through APHIS. C-1 shows that the highest incidence of cases appears to be in Arizona and California, similar to the domestic cases. California had 32 total wild cases while Arizona had 33 wild cases. For the most populous cities per state, the wild cases in all but four states occurred within hotspot areas near these populous cities.

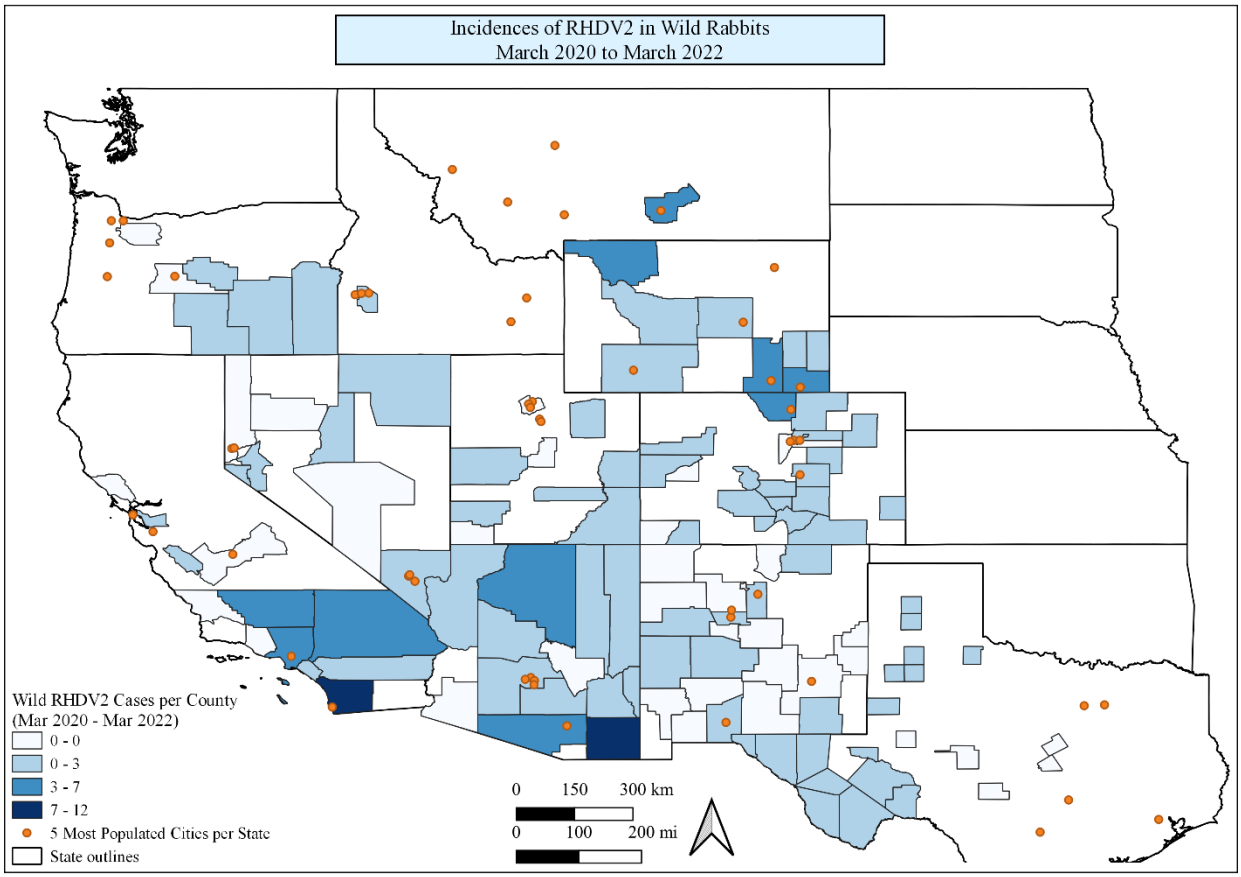

Figure 5: Map of the counties affected by wild cases of RHDV2 over the entire timespan (March 2020 to March 2022), with darker colors indicating higher incidences of RHDV2 per county. Dots representative of five most populous cities per state. (Appendix C-1) (USDA APHIS, 2022)

2020: In early 2020, the virus was primarily found within Arizona, with sporadic cases in California, southeast Nevada, New Mexico, Texas, and Colorado, affecting six of the eleven states. In late 2020, seven of the states were affected but only California had a county case count above four, with eight cases reported from July to December 2020. 25 cases were reported within Arizona for wild species within 2020, followed by Texas with 19 cases that year.

2021: Early 2021 showed outbreaks in Yellowstone County in Montana (5 cases), Wyoming (25 cases from January to June of 2021), and in California (15 cases in early 2021). In early 2021, all eleven states had at least one case of RHDV2 in wild rabbits. In late 2021, only

four states had cases, and all counties reported less than four cases per county during this time period. Wyoming had the largest total of cases, at 25 within the state, followed by California with 18 cases.

Feral rabbit positive case spread (2020 to 2022)

The feral case map is under Appendix D and includes data from the select states that disclosed feral RHDV2 cases to USDA APHIS. Feral cases were reported in the following seven states: California (Ventura County), Colorado (El Paso and Jefferson Counties), Idaho (Ada County), Montana (Yellowstone County), Nevada (Nye County and Lander Counties), Oregon (Clackamas and Deschutes Counties), and Utah (Sanpete County). Most feral cases were reported in the breeding season, normally between March and June (in 9 of 14 cases); four of these cases were reported across different states during April of 2021. Four cases were reported in Yellowstone in February of 2021, and one outlier was the feral case reported in December in Nevada in 2020. Feral cases accounted for half of all reported non-domestic cases in both Idaho and Montana. In four of the seven affected states, at least one major city was within a county reporting feral rabbit infection.

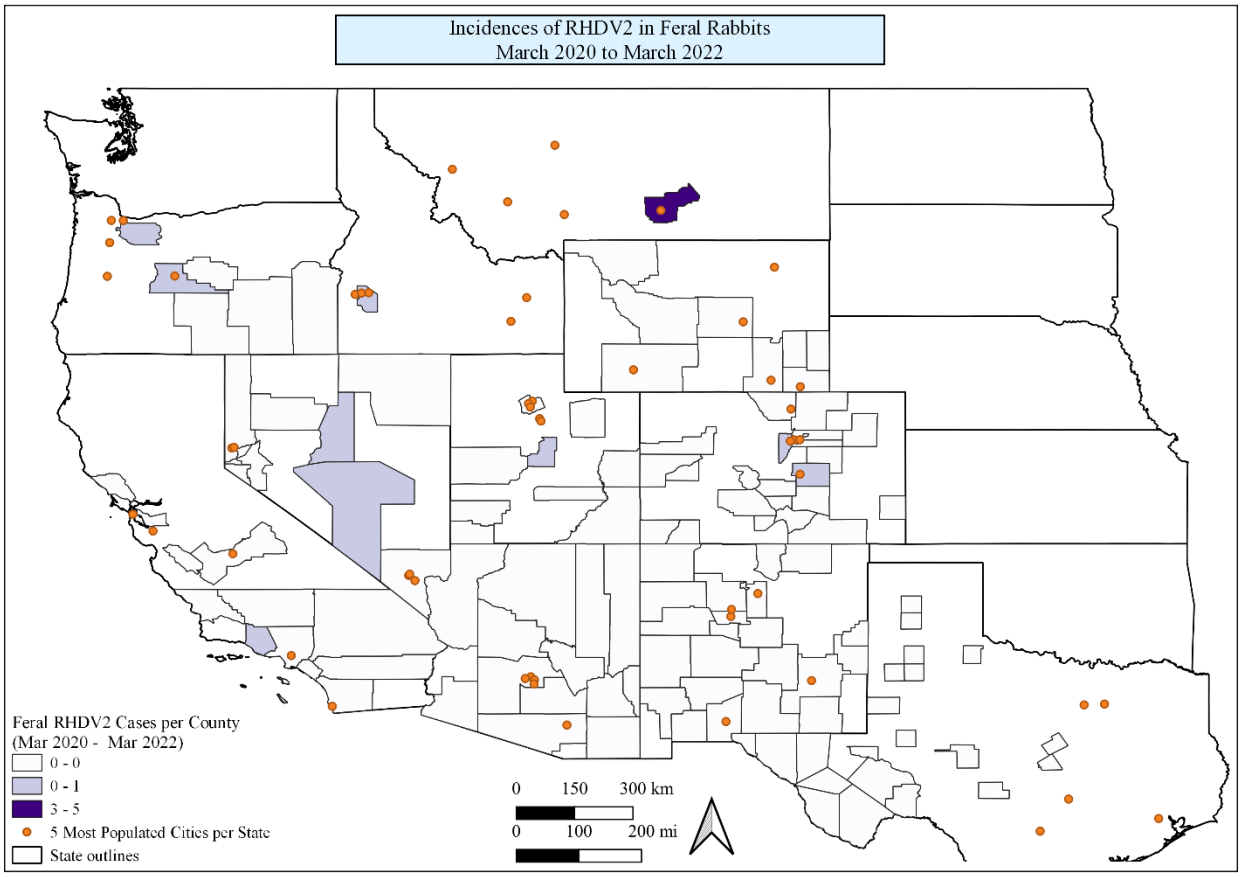

Figure 6: Map of the counties affected by feral cases of RHDV2 over the entire timespan (March 2020 to March 2022), with darker colors indicating higher incidences of RHDV2 per county. Dots representative of five most populous cities per state. (Appendix D-1) (USDA APHIS, 2022)

Objective 2: Policy and Licensing

Regulatory Framework:

The current lack of firm policies and/or laws to minimize the severity of the spread of RHDV2 is limiting efforts to contain the spread of the virus across the United States. One of the major issues with a lack of policy is that there is also a lack of regulatory authority (USDA APHIS, 2020). At the moment, the only control measures are based on generic import regulations and quarantine requirements for all livestock and certain pets. For the eleven states

involved in this study, only nine have import regulations (Arizona, New Mexico, and Texas do not have regulations on file); the majority of these states only require a Certificate of Veterinary Inspection (CVI), which is a document completed within the previous month to show that a rabbit is in good health to travel across state lines. Some states such as Montana, Oregon, Washington, and Idaho require an import permit as well. Other states, such as California and Nevada, require the CVI and a follow-up inspection within 72 hours of entry. Hawaii requires a CVI, 72-hour post arrival inspection, and a quarantine for 30 days (State of Hawaii, 2022). Despite these precautions, there was a case reported in Hawaii in late June 2022 (Cruz, 2022).

Most states, in lieu of defined policies, are opting to publish and teach biosecurity measures to the public and other organizations that are involved with rabbits. Some of these precautions include proper sanitation (cleaning of rabbit enclosures and supplies, cleaning of hands and clothing before moving between rabbit groups, and not sharing equipment), maintenance of feed and hay supply (ensuring sources are virus-free, free of pests or other fomites that can communicate the virus, and not using wild forage), and keeping rabbitries physically isolated so they cannot communicate the disease between domestic groups or between wild and domestic rabbit breeds (Arizona Department of Agriculture, 2020). Other biosecurity measures suggest that any unexplained deaths or illnesses within domestic or feral rabbit herds be brought to the attention of a local veterinarian and the state veterinarian; any unexplained deaths or carcasses of wild rabbits are encouraged to be reported to the local Fish and Game/Parks and Wildlife office for the appropriate state. Based on the findings from Objective 1b, it is evident that the existing regulatory framework is not adequately mitigating the risk of spread of this disease.

Licensing of the RHDV2 Vaccine:

There is currently no fully licensed vaccine for RHDV2 in the United States, but the vaccine from Medgene Labs, based in South Dakota, is allowed for use by veterinarians via an emergency authorization from the USDA. Currently, Medgene Labs is hoping to get full licensure by the end of 2022. Before the Emergency Use Authorization of the Medgene vaccine in October of 2021, the vaccines being used within the United States were those acquired from the European Union using a special permit, which was a long and expensive process. These European vaccines [Filavac VHD K C+V (Filavac) and Eravac RHDV-2 (Eravac)] took up to four months to import and came with associated shipping and importation fees, raising the overall pricing of the vaccine in the United States (McLaughlin, 2020).

Medgene Labs vaccine: RHDV2 cannot be synthesized in an artificial lab environment, so as a result the European vaccines (Filavac and Eravac) created their vaccines from infected rabbit livers and used inactivated purifications of the virus in their vaccines (Mesick & Smith, 2021). While certainly effective, this process required that rabbits be infected and then killed to make the vaccine. In contrast, the Medgene Labs vaccine differs from the European vaccines in that it is an inactivated recombinant subunit protein vaccine which uses genomic sequencing to determine the genetic makeup of the virus and then targets components of the virus that are immunogenic. The protein yielded from this genomic analysis is produced for the vaccine, and then a baculovirus (insect virus that does not affect mammals) is employed to induce a more specific immune response to the target antigen in the vaccine. The Medgene vaccine does not require the use of infected rabbits to create the vaccine and is not sourced from live vaccine copies, making it impossible for a rabbit that receives the vaccine to shed any virus or infect

other rabbits (Medgene Labs, 2021). The vaccine, per Medgene Labs website, includes recombinant RHDV2 protein, saline, gentamicin, thimerosal, and aluminum hydroxide. This recombinant vaccine has a further advantage in that it may be readily adapted to account for genomic drift and mutations that may occur in the RHD viruses as the outbreak persists. This biotechnology is also being used to create an RHDV1 vaccine that is expected to be fully licensed later this year (Mesick & Smith, 2021). The Medgene vaccine is currently approved for use in 44 of the 50 states (including the District of Columbia), with five of the states who have not applied for approval having no reported cases thus far (Alaska, Maine, Massachusetts, New Hampshire, and Vermont) aside from Hawaii which only just had a case reported on a rabbit farm on June 22, 2022 (Cruz, 2022). Based on the findings above, the full licensure of the Medgene Labs vaccine will help to ensure that, in the near future, with high vaccination rates, domestic rabbits will obtain a semblance of herd immunity which can limit the spread of the virus within the United States.

Inoculation of wild rabbits:

Most vaccinations are given via the oral route for wild animals, decreasing invasiveness of the vaccination administration by not requiring wild animals to be captured to be inoculated with a vaccine (Abbott, 2020). This delivery method has worked with many wild animal species for vaccination against rabies, Lyme disease, and other endemic diseases for bats, wolves, rodents, bison, and other wild fauna. For rabbits, there are a variety of factors that must be considered for developing an ideal vaccine for vaccinating wild rabbit populations. Since the RHDV2 virus is novel within the United States, there has not been proper time to conduct research into how to best inoculate rabbits. If an oral route of administration is pursued, methods

to target rabbits specifically while avoiding other animals ingesting the vaccine products are not well understood or designed yet. There is also the issue of the most cost-effective distribution of the vaccine and monitoring to ensure that the vaccine is effective in immunizing wild rabbit populations. One of the largest hurdles to immunizing wild hares, rabbits, and other target species is the cost to produce the vaccine at the current moment; for the Medgene Labs vaccine, the cost per vaccine can range from $60 to $100 depending on the veterinary clinic. To scale this up more broadly would be difficult and is currently cost-prohibitive. The lack of available resources and immunization protocols suggests that the spread of the RHDV2 virus may be exacerbated by wild breeds since these populations will have a slower route to herd immunity compared to if they could receive the vaccine.

Objective 3: 3a. Identification of Key Stakeholders and 3b. Efficacy of Risk Communication Efforts

Objective 3a: Identification of Key Stakeholders

There are a variety of stakeholder groups currently affected by the RHDV2 epidemic, including commercial, government, and private stakeholders.

Commercial: Commercial stakeholders in the incidence of RHDV2 include companies that sell rabbit supplies, feed, or forage such as Oxbow Animal Health, Small Pet Select, or even Kaytee brands, among many others. In light of the spread of the virus and the virulence factors it possesses such as RHD being able to be transmitted via fomite (non-living) objects for up to 90 days, these companies have put forth updated guidance on how they are best managing the disease (Oxbow Animal Health, 2020: Cole, 2020). Oxbow is quarantining hay and grass sources

post-harvest for a minimum of three months, keeping in touch with their growers in terms of native population reporting for any sick animals in their fields, and updating Oxbow's standard quality control procedures (Oxbow, 2020).

Other commercial stakeholder groups include those companies or entities that produce for the rabbit meat and fur markets. Compounding factors contributing to the susceptibility of these industries to damage from RHDV2 outbreaks include the living environments for rabbits in these rabbitries, where they are often either housed outside together in large groups or contiguous hutches or are housed indoors in close proximity to one another. Another theorized virus virulence factor for rabbits who contract RHDV1 (as shown by an experiment in France) relates to rabbit body mass, with higher mass rabbits tending to die from the virus quicker than those with a lower body mass (Cooke & Berman, 2000). In the case of meat and fur rabbits, the primary breed used in these establishments are New Zealand rabbits, which average from nine to twelve pounds (4-5.5 kg) dependent on gender, and were bred to grow quickly (Spencer, n.d.). The fast growth and large size of this rabbit breed may make them particularly susceptible to deleterious effects from RHDV2.

Government: Some of the government agencies that may be adversely affected by this virus include any government sector that deals with livestock, wildlife, or agriculture. The main resource for RHDV2 information is USDA APHIS, and they are responsible for communicating the risks of this disease to their state agency partners, gathering data from surveys on confirmed RHDV2 cases in rabbits, and are responsible for approving the vaccine for use in domestic breeds. The significant financial burden and agricultural impact potential this epidemic brings may have led the USDA APHIS to prioritize research on this disease, pulling limited resources

from other projects and issues facing livestock and other domestic animals in the United States. In addition, those in government agricultural organizations may need to dedicate resources to ensure that foods and grasses are not infected with the RHDV2 virus, or that meat and fur farms are up to code in order to prevent a breakout of the virus within the herds or contain an outbreak should one happen.

Private groups: Private sector groups including breeders and house rabbit owners are one of the most populous groups to be directly affected by possible outbreaks of RHDV2. Breeders may have similar issues with spread of the virus to the rabbitries used for meat and fur production, particularly if their herds rival the size of commercial rabbit meat and fur producers. In response to questions about the vaccine and inoculating these herds of rabbits at significant cost, it was suggested by Dr. Amanda Jones, a veterinarian in Texas, that they "vaccinate what they cannot afford to lose"; this means that they are forced to choose to vaccinate those bucks, does, or breeding lines they cannot afford to lose, as opposed to vaccinating the entire herd (Mesick & Smith, 2021). This may lead to mental distress in these owners having to prioritize which breeding animals they want to protect with the vaccine. For individual pet owners, the prohibitive cost of the vaccine is slightly offset by the low number of rabbits each owner will need to vaccinate, albeit it is still an expense for each owner. Fear surrounding the spread of the virus to their pets also affects individual rabbit owners. At the beginning of the epidemic, it was suggested that house rabbit owners took excessive precautionary measures each time they left the house to decontaminate clothes and shoes upon return, lest the virus be carried to their indoor rabbits from an outside source. This was exacerbated by a lack of vaccine availability until late 2021 when the Medgene vaccine became readily available. Prior to this, the process for acquiring

a vaccine was arduous and not always successful, and sourcing the European vaccines came at a hefty price point. Even if rabbit owners could get the vaccine permitted and imported, the permitting and shipment process regularly took at least four months, delaying immunization efforts (McLaughlin, 2020).

3b. Efficacy of Risk Communication Efforts

Risk communication efforts immediately following the outbreak were widely disseminated by the responsible government organizations. At the start of the outbreak, USDA APHIS quickly released FAQs and answered questions from concerned citizens. Individual state organizations also followed suit with an outpouring of resources, guides, and information on the virus and what people could and should do to prevent or address viral infections in wild or domestic rabbits. Many factsheets, such as the one from the Arizona Department of Agriculture, informed the public on the history and origin of the virus, what animals could be affected, transmission and control of the virus, the signs and symptoms of infection, and guides on what to do if an infection was suspected (Arizona Department of Agriculture, 2020). Many of these factsheets also recommended disinfectants for use in cases where an infection was suspected to have occurred or for those wishing to exercise caution for their rabbits or rabbitries. The key messages from these pamphlets, articles, and blogs appear to be uniform in terms of the best courses of action to be taken in the case of a suspected infection or outbreak; this uniformity was vital, so the general public received consistent messaging regarding the nature of the virus, how to monitor, prevent the spread and respond to suspected infections. Most states recommended a stepwise approach to reports of infections. For private animals, pet owners were recommended to take their pet to a veterinarian as soon as possible, utilizing safety measures to ensure that the

virus was not communicated to other rabbits in the clinic. Upon presentation from a pet owner, individual veterinarians were then encouraged to contact their state veterinarian or APHIS to get laboratory confirmation for suspected virus cases. For rabbits spotted in the wild that appeared sick or dead, publications advised individuals to contact their state's Fish and Game or Wildlife Management divisions who would then investigate the animal and report any findings to the state veterinarian or APHIS. When compiling this research, almost all of the affected states had an exclusive webpage dedicated for RHDV2 documents and updates. This issue was also addressed in major news channels and sources such as the Smithsonian magazine (Gamillo, 2022) and in state-led publications. The substantial government investment in public education on RHDV2 may significantly empower industries, private pet owners, and other persons to take preventative measures to prevent dissemination of RHDV2 and to appropriately respond to suspected RHDV2 infections should they encounter them. It is uncertain whether states and the USDA APHIS will continue to publish these FAQs and RHDV2 informational briefs, since best practices and procedures are expected to stay relatively the same. Updates may be warranted in states with major outbreaks, or in those states that are seeing cases for the first time, to provide the easiest method of access for those currently being affected. The spread of the virus, with the proper communication on this topic being available to the general populace, should be expected to be lessened in house rabbits by the measures suggested in these informative communications, and may also provide good guidance for the control of the spread within wild populations with citizen science measures.

DISCUSSION

Objective 1: Factors Contributing to RHDV2 Spread

Objective 1a:

The three transmissibility factors outlined previously do not bode well for population dynamics of rabbits and other lagomorphs. The ability to overcome immunity to prior RHD viruses, to infect young rabbits results in shortened breeding cycles and the wider host range are concerning facets of the transmissibility of RHDV2. As outlined earlier, this potential reduction in rabbit populations may impact related species and possible trophic cascades as seen in the Iberian Peninsula with RHDV1.

The virus's virulence is also a key factor in the threat it presents to the rabbit population in North America. With the transmission routes being via the mucosal and respiratory routes, there is a high likelihood of spread in rabbit communities through close contact or spread via food and other items that rabbits may smell or taste. With the addition of the virus being so resilient to temperature changes and surviving within the environment possibly for months at a time, the likelihood of spread is increased. Due to the mechanical routes also presented by insects from infected rabbit carcasses to live rabbits, the spread of this virus is difficult to combat. One of the proposed solutions to this problem is to inoculate the rabbit populations, but it is difficult to solely treat rabbit populations due to the prevailing method being administering the vaccine via insertion in rabbit food. The concerning issue with this approach is that many of the foods that rabbits enjoy are also enjoyed and eaten by other animals, so the targeting of rabbit species via food is problematic. The fact that current vaccines only last for a few hours after reconstitution also presents an inoculation challenge.

Objective 1b:

While the virus may have originated in different places (evidenced by documented separate cases in Canada and Washington in 2018 and 2019), and the first confirmation in New Mexico in late March of 2020, it is informative to see how the virus spread throughout these areas and assess whether there is any quantifiable trend to the data. Based on the overall map (Figure A-1), the virus affected 125 counties within this region, not accounting for the cases not shown within Washington state. Figure A-2 shows the overlay of all RHDV2 cases in relation to terrain mapping in order to determine if topography was a factor in RHDV2 case counts or in their surveys; based on this mapping, it can be assumed that sampling was affected by topography and mountainous terrain throughout New Mexico, Colorado, and Nevada, and possibly for Montana and Idaho as well.

The wild and domestic case report maps share a commonality in the hotspots for positive cases, especially in Arizona and California; this may be a result of the virus being active in these states for longer, hence more case counts total. It may be indicative of sampling measures as well, since more populous areas may have more effective governmental and public monitoring of dead rabbits. It was very revealing that the total case counts were almost split between domestic and wild cases. Prior to this analysis, a larger offset would have been an assumed outcome either due to (1) the availability of domestic breeds to be tested for the virus, or (2) higher case counts for wild species due to the larger population of wild breeds represented in one survey.

Domestic rabbit positive case spread (2020 to 2022): The domestic maps for 2020 to 2022 show the highest case counts in Arizona and California and may be the result of overall numbers as opposed to severity. The decrease of reported cases in late 2020 and late 2021 may

have been the result of the breeding season tapering down and less susceptible conditions for transmission of the virus. The 2020 numbers may also be attributed to pandemic quarantines put in place for COVID-19 in humans, where people could not travel outside of their homes, decreasing spread of the disease from their rabbits or wild sources. For the five most populous cities per state, most cases match with high incidences of domestic RHDV2 cases. This could be due to those in more rural areas deliberately choosing to not investigate an uncommon death in their rabbit due to cost or distance, or may be due to higher populations equating to higher frequency of rabbits per area.

Wild rabbit positive case spread (2020 to 2022): The wild case maps for 2020 to 2022, similar to the domestic maps, show higher case counts in California and Arizona with their high population centers. The high number of wild positive cases near city centers could be attributed to these counties having better access to data collection and surveying. The fact that Texas had such high case counts in 2020 (19 cases), coming in second place behind Arizona (25 cases), for wild species since their domestic numbers were relatively low compared to other states was interesting. It is not clear if this was due to an emphasis on wild captures of rabbits within Texas not found within other states. It was also telling that wild case counts were more widespread compared to domestic cases, as there were wild cases in all eleven western states covered in this analysis, as opposed to the nine of eleven shown in the domestic data. This could perhaps be explained by the rurality of the two states affected by wild cases - Montana and Idaho which only had one county affected each (with feral and wild cases).

Feral rabbit positive case spread (2020 to 2022): Feral cases occurred in only seven of the eleven states included in this analysis. One consideration is how these rabbits were determined to

be feral and how long they had possibly been feral. In some cases, it may be that there are established feral herds of rabbits that are wild in every sense aside from genetics. It would be valuable to explore (in a future study) how these rabbits were classified and if they were newly feral or part of established herds. The feral populations occurring within populous cities seems to fit with the predominant trend of dumping feral rabbits within major city centers. Yet another further analysis of the feral rabbit population within Las Vegas, and the number of affected rabbits that may not be monitored, could be revealing.

Uncertainties: This data set covered 125 affected counties of the total 629 counties across this region, excluding Washington. It is unclear why the data for Washington were not included in the original USDA dataset (inquiries made on this point were not adequately answered), so the counties for Washington state were not included in the county count. With the basing of data on county cases, it is important to keep in mind the relative size of counties within varying states to one another. A county in Texas is not the same as one in California and may have vastly different populations per county. For instance, Texas had 21 of its 254 counties affected by the RHDV2 virus but only had 29 total cases; California had 12 of its 58 counties affected but had 87 total cases.

Another source of uncertainty is that the early 2020 data only encompassed March to June of that year, since March was when data collection and the outbreak began, and the 2022 data only includes data from March of 2022; whether the 2022 data was a lump entry for the year so far, or a lack of positive cases from January to February, is unknown. This lack of data from the 2022 entries makes it hard to draw any conclusions, as it was only for March of 2022 and only had three cases total, all wild.

In addition, sampling bias and results may not necessarily be indicative of the true spread of the virus within this region. The COVID-19 virus may have affected the ability of technicians to go into the field to sample for dead rabbits to test for the virus and may have affected those with domestic rabbits getting appointments with their veterinarian at the height of the pandemic. In addition, wild carcasses may have been difficult to find, as the virus does not make the rabbits inedible (thus they still may be a food source for predators and carcasses may be non-existent).

Furthermore, the sampling methods per state may not be uniform. Las Vegas is well known for having a large feral rabbit population, so it was curious that no feral rabbit populations have been either sampled or found with the virus within this dataset. There is also the case of Montana and Idaho, again, where only one county was positive per state, and each only had four to eight cases in three scenarios total.

Objective 2: Policy and Licensing

The lack of laws or regulatory authority on the matter of the RHDV2 virus means the monitoring and control of the spread of the virus is very difficult for governmental and federal agencies. While nine of the eleven states covered in this analysis have import regulations, many of the other states within the United States do not have any import regulations; a minority of states (13 of the 50 states) do not have any form of import regulations that apply to rabbits or other agricultural animals. For the rest of the states that do have regulations, they can vary from simply requiring a Certificate of Veterinary Inspection before entry into the state (Colorado Department of Agriculture, 2021), to requiring the CVI alongside an inspection within 72 hours of entry into the state and no imports from states that have active cases within the last 12 months

(California Department of Food and Agriculture, 2022). Without a standardized regulation on the movement of rabbits, the RHDV2 virus has a high possibility of continuing to spread.

As demonstrated in the GIS mapping, cases tended to occasionally arise in random spots, without a clear entry point or flow of movement through time. The communication of biosecurity measures has most likely proven to be effective within the public realm and may be assisting in halting the spread of RHDV2 across states. The adoption of rabbits across state lines may be contributing to the issue of RHDV2 spread, but most rabbitries are exercising an abundance of caution in this regard, requiring adoptees to have vaccinated rabbits already in the home and to quarantine rabbits before introduction or outdoor exposures.

The licensing of the Medgene Labs vaccine will prove to be helpful in the control of the spread and severity of RHDV2. With a vaccine supplier now within the United States, the wait for a vaccine for house rabbits has shortened from several months to around 1 to 2 weeks, primarily due to veterinarians wanting to vaccinate on specific days to ensure the vaccine vials are used appropriately without waste. With higher levels of vaccinated rabbits, the incidence of rabbit-to-rabbit transmission is lessened and will hopefully lead to herd immunity within domestic rabbits and wild breeds not acquiring the virus from domestic hutches of rabbits. For wild and feral breeds, the question of how best to inoculate or vaccinate these herds remains; it is the hope that an edible, long-lasting form of the vaccine can be created to combat this facet of RHDV2 spread.

Objective 3: 3a. Identification of Key Stakeholders and 3b. Efficacy of Risk Communication Efforts

Objective 3a:

By understanding the key stakeholders and their related interests in regard to the RHDV2 pandemic, communication and mitigation efforts can more effectively address concerns and better inform stakeholders as to best practices for implementation of measures to halt the spread of the virus. For commercial stakeholders such as hay and food suppliers, it is important efforts be made to communicate the need for them to ensure the virus is not spread through their processes and products along to the domestic house rabbit.

Commercial stakeholders in the pet supplies market have thus far been cognizant of the measures they must take to ensure customer satisfaction and security with their products, such as seen with the lengthened quarantine of hay by Oxbow to ensure that the hay they are selling does not carry infected material. For those commercial stakeholders with fur or meat farms, it is important to keep them apprised of any updated guidance or vaccine opportunities. If the Medgene Labs vaccine is allowed to enter the public market, and the price is not driven by veterinary clinics, these operations could afford better opportunities to vaccinate their herds and avoid widespread infections within the herd (thereby avoiding adverse impacts to produce their product).

Governmental stakeholders are an important facet of the management process of the virus; without the aid of USDA APHIS and other governmental organizations, this virus would be difficult to track and study. The manpower, including sampling, inspection, and testing, that these governmental stakeholders offer is vitally important for our collection and understanding of

this information and for key information being disseminated to other stakeholders as it becomes available. Public stakeholders also play a key role in the understanding and control of this virus; without private house rabbit owners bringing in their sick rabbits to be tested, there would be very little data of the impacts of RHDV2 on domestic breeds. Breeders and private owners must be kept in the loop when it comes to the regulation and management of the RHDV2 virus, and the spread of this virus across the United States.

Objective 3b:

The risk communication about this virus seemed to have been handled very well from the outset, with those who wanted more information on the RHDV2 outbreak being able to find a number of informative resources. Communication using factsheets, FAQs, articles, and broadcasts seems to be relatively standardized, without conflicting information source-to-source. While there are great resources for those who know about the virus and want to learn more, there is a deficit in public awareness. Many people do not know about the virus and its possible harm; even those who have house rabbits and have yet to visit with their veterinarians may not have an idea of the danger RHDV2 presents. Public websites such as the House Rabbit Society have done well to try and communicate these dangers, but they can only reach so much of a target audience. In this analysis, there were a few print and online articles but very little public broadcasting such as on live news broadcasts. If public broadcasting systems were able to better inform the public of this issue, it may help to alleviate the spread.

CONCLUSION

Recommended Action

Based on the outcomes of the analysis obtained in this process, the following recommended actions for improved management of the virus within the United States are of important consideration. First and foremost is the continued and improved education of the general populace; while there is a plethora of information for those willing to find it, there is little outreach to inform the general masses. With an increase in public awareness, we may have better opportunities to lessen spread of the virus, whether that be through the increased reporting of sick animals, or the care taken to not transmit the virus through touching of wild or domestic breeds that may be sick and transmission to other rabbits. With an increase of data collection through citizen science, we may be able to better track the spread of the virus, instead of the sporadic cases that occurred within the maps compiled for this analysis. In this same vein, it is important that improved and more expansive sampling be completed by governmental agencies, so that more data can be compiled to garner a better understanding of the overall scope and severity of the virus in wild breeds in the varying states. It is recognized that this objective is difficult to achieve due to lack of governmental funding for such projects, and a lack of regulatory authority to do so.

It will also be important to determine how the full licensure of the Medgene Labs vaccine will affect overall case rates and outcomes for domestic rabbits. With full licensure, it is possible that Medgene could start selling vials of the vaccine through local or commercial retailers; this would lessen the overall cost and effort it takes for breeders and other commercial rabbit growers to get the vaccine and may result in better herd immunity. Further research is warranted on

production of a vaccine with an extended post-reconstitution efficacy and an effective means of delivering that vaccine to wild and feral rabbit populations.

Given the detrimental impact of RHDV2 to rabbit populations and related stakeholders, there is a strong demand for the implementation of mitigation measures to assure the health of our domestic and wild rabbit populations. Although the continued spread of RHDV2 may last for an extended period of time, there is certainly hope that through better sampling, education, and vaccination this virus can be effectively combated.

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APPENDICES

APPENDIX A

ALL RHDV2 CASES (FULL TIMESPAN)

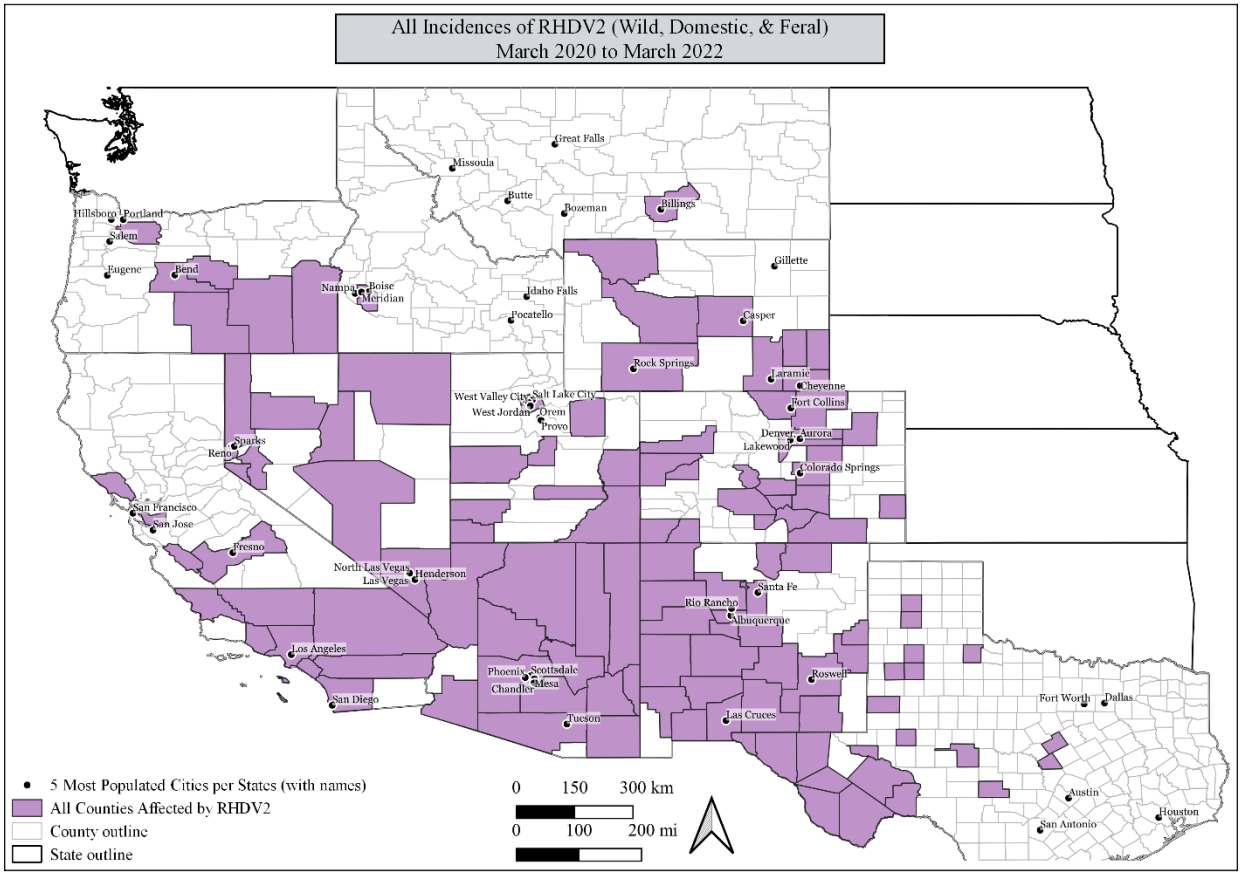

Figure A-1: Regional map of the western United States with counties affected by documented incidences of RHDV2 in wild, domestic, or feral rabbits highlighted. Five most populous cities included with tags. (USDA APHIS, 2022)

ALL RHDV2 CASES (FULL TIMESPAN) WITH TERRAIN MAPPING

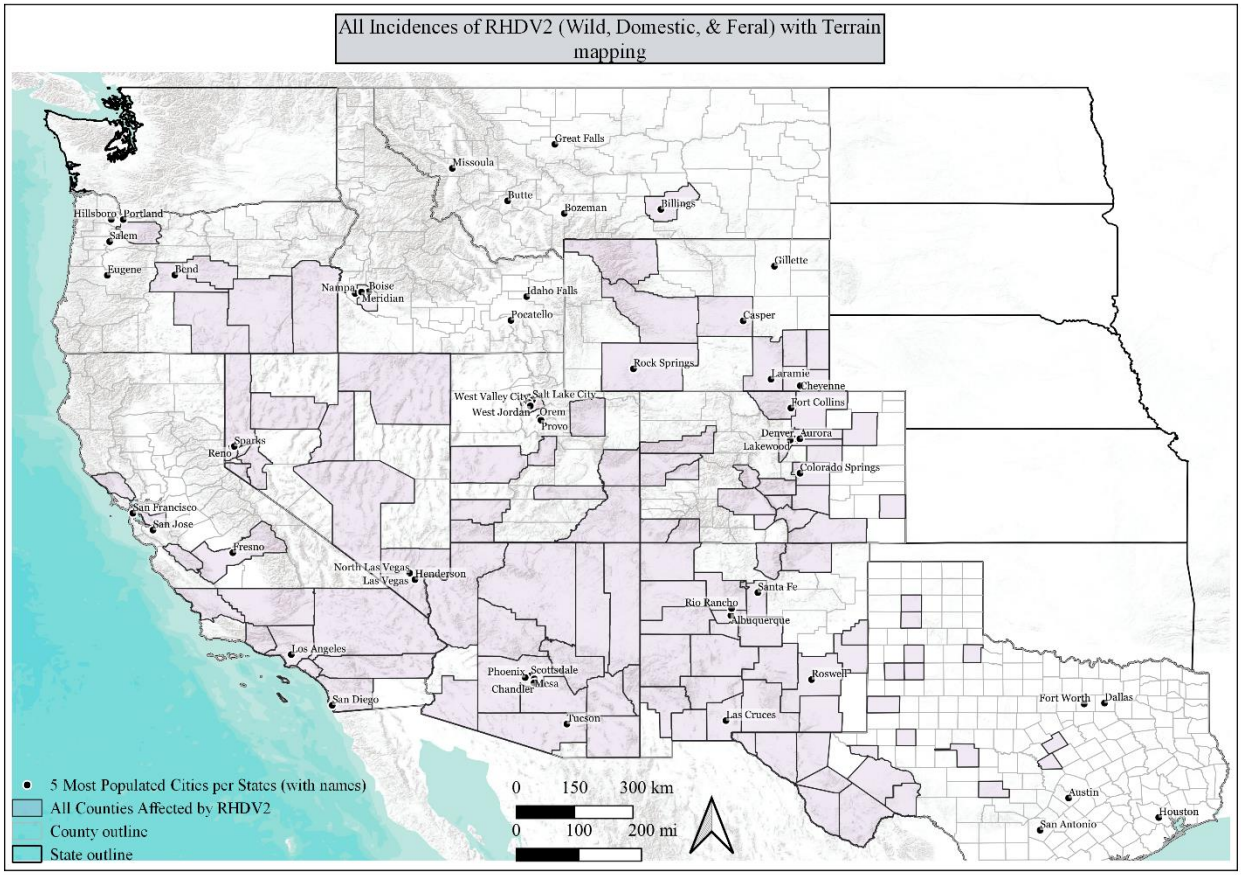

Figure A-2: Regional map of the western United States with counties affected by documented incidences of RHDV2 in light purple, as to allow for view of the underlying terrain. Five most populous cities included with tags. (USDA APHIS, 2022)

APPENDIX B

DOMESTIC INCIDENCES OF RHDV2

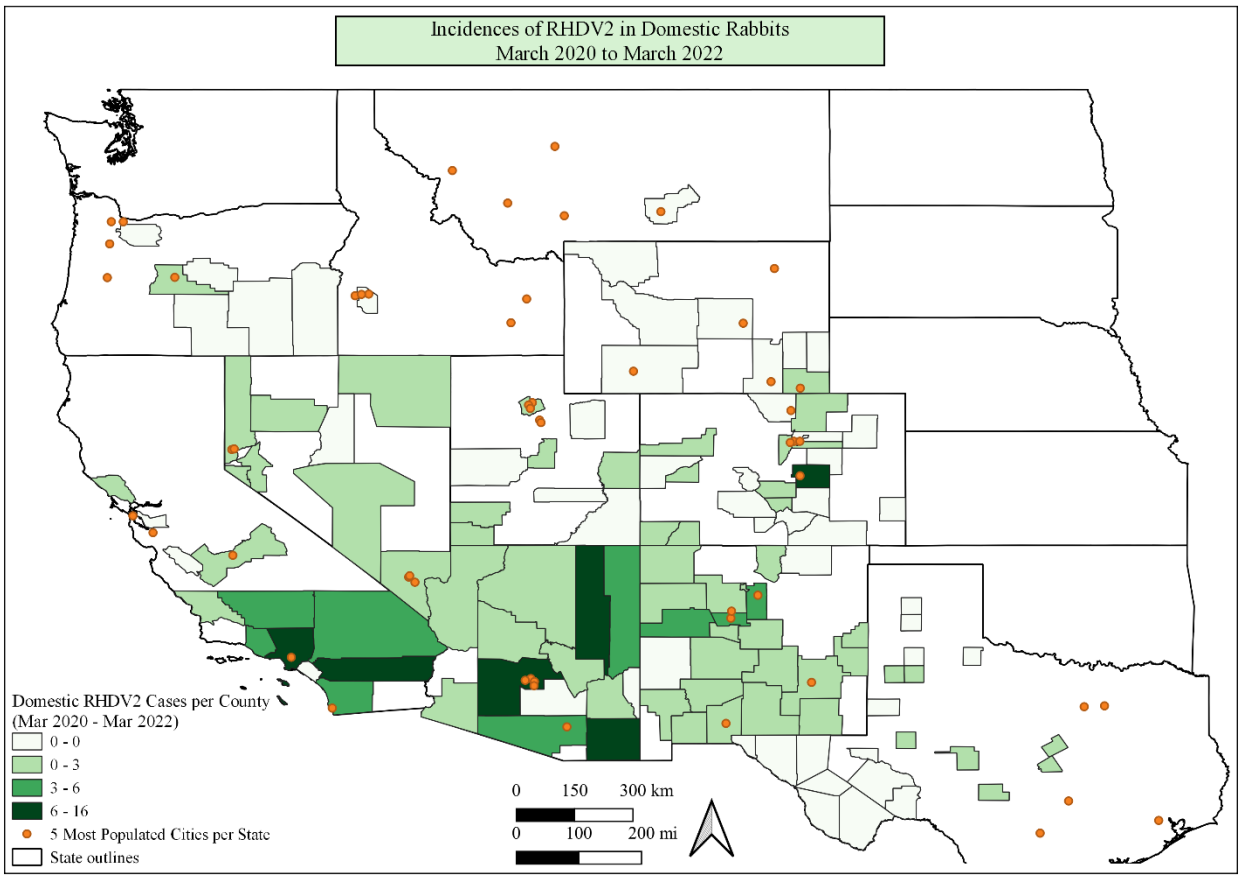

Figure B-1: Map of the counties affected by domestic cases of RHDV2 over the entire timespan (March 2020 to March 2022), with darker colors indicating higher incidences of RHDV2 per county. Dots representative of five most populous cities per state. (USDA APHIS, 2022)

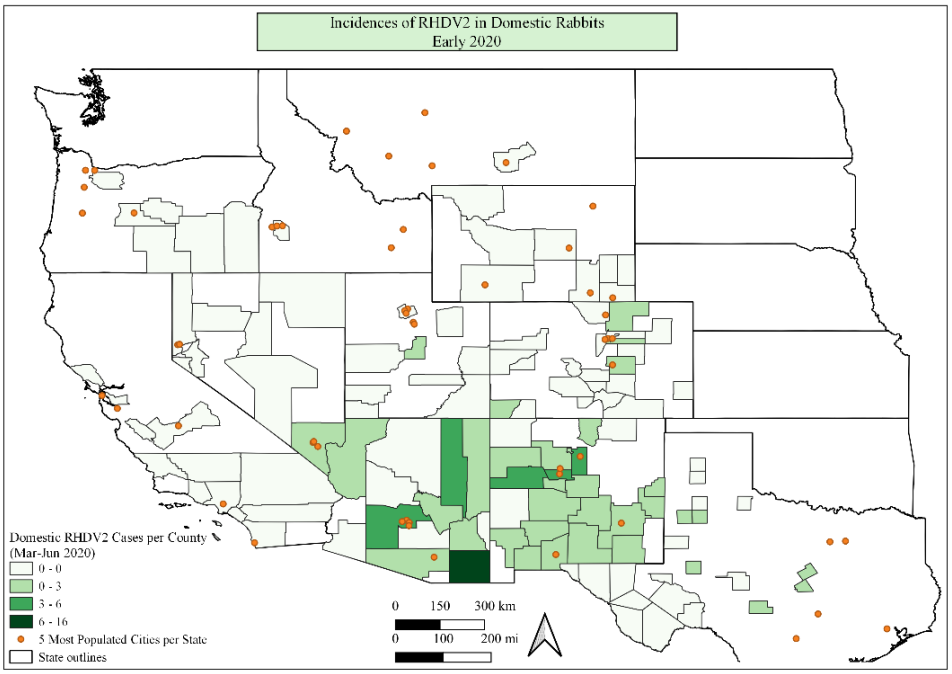

Figure B-2: Map of the counties affected by domestic cases of RHDV2 in early 2020, from March 2020 to June 2020 with darker colors indicating higher incidences of RHDV2 per county. (USDA APHIS, 2022)

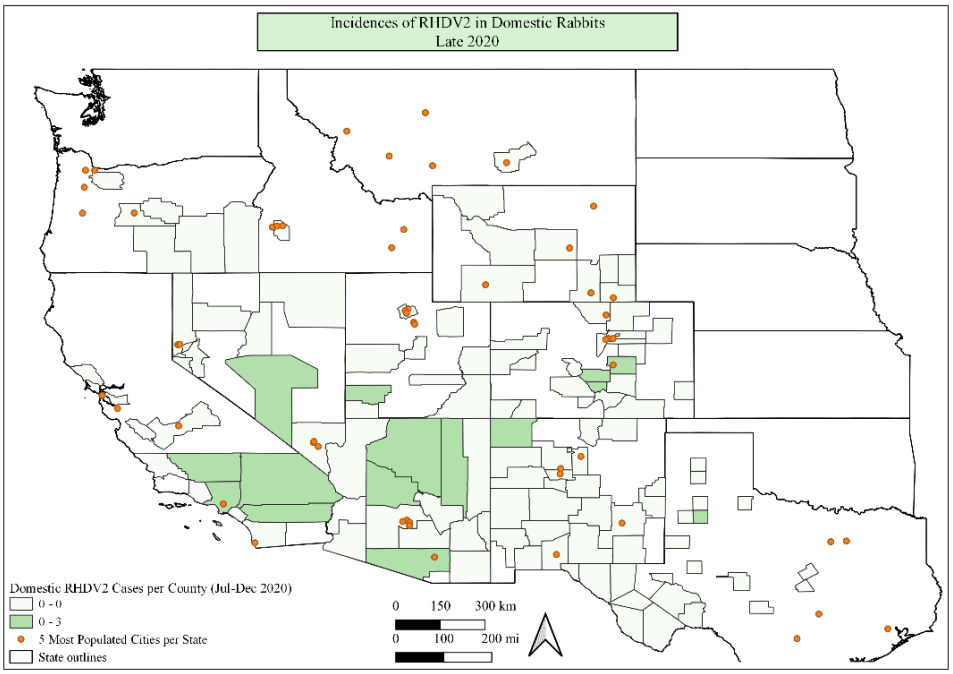

Figure B-3: Map of the counties affected by domestic cases of RHDV2 in late 2020, from July 2020 to December 2020 with darker colors indicating higher incidences of RHDV2 per county. (USDA APHIS, 2022)

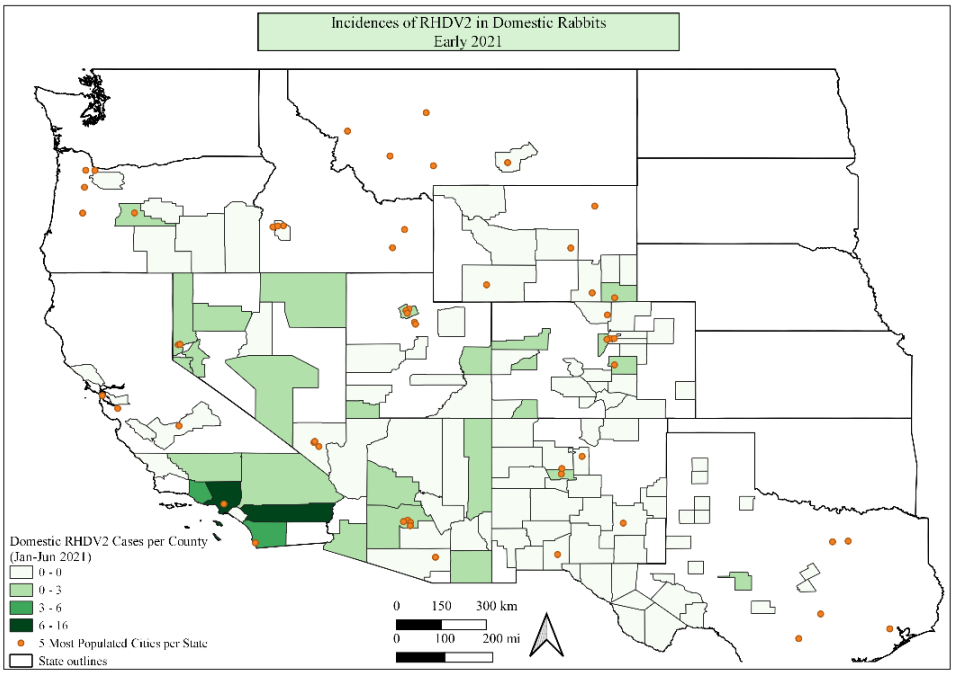

Figure B-4: Map of the counties affected by domestic cases of RHDV2 in early 2021, from January 2021 to June 2021 with darker colors indicating higher incidences of RHDV2 per county. (USDA APHIS, 2022)

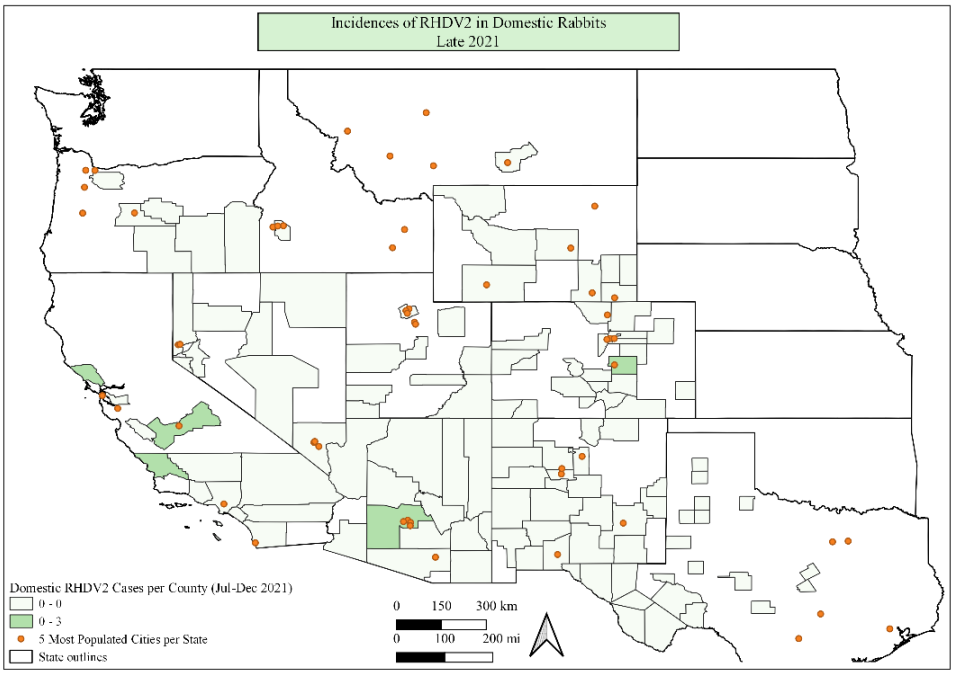

Figure B-5: Map of the counties affected by domestic cases of RHDV2 in late 2021, from July 2021 to December 2021 with darker colors indicating higher incidences of RHDV2 per county. (USDA APHIS, 2022)

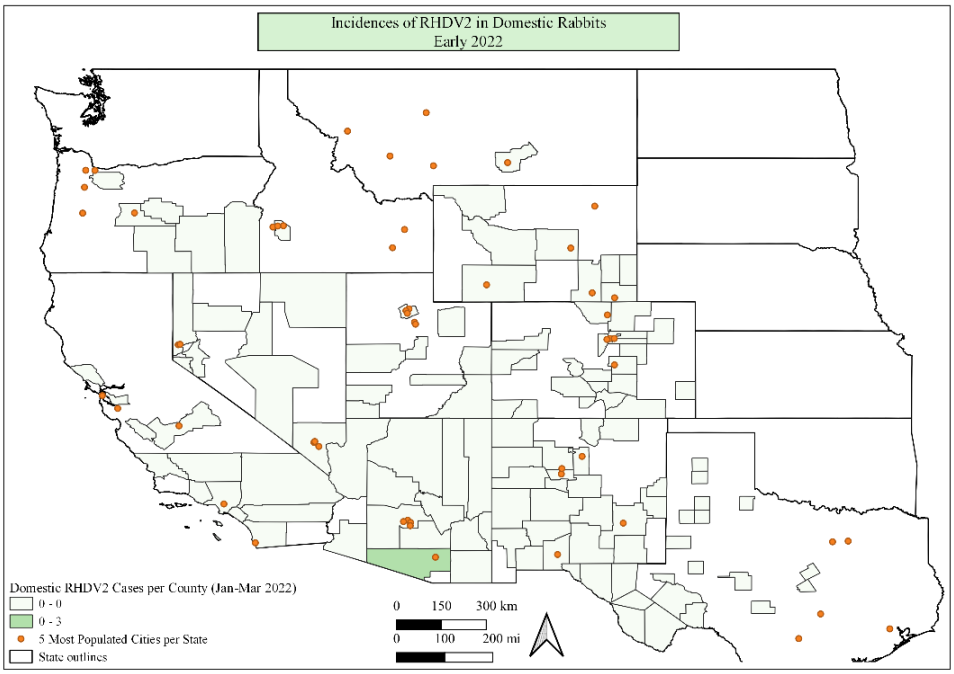

Figure B-6: Map of the counties affected by domestic cases of RHDV2 in early 2022, with values only from March 2022 with darker colors indicating higher incidences of RHDV2 per county. (USDA APHIS, 2022)

APPENDIX C

WILD INCIDENCES OF RHDV2

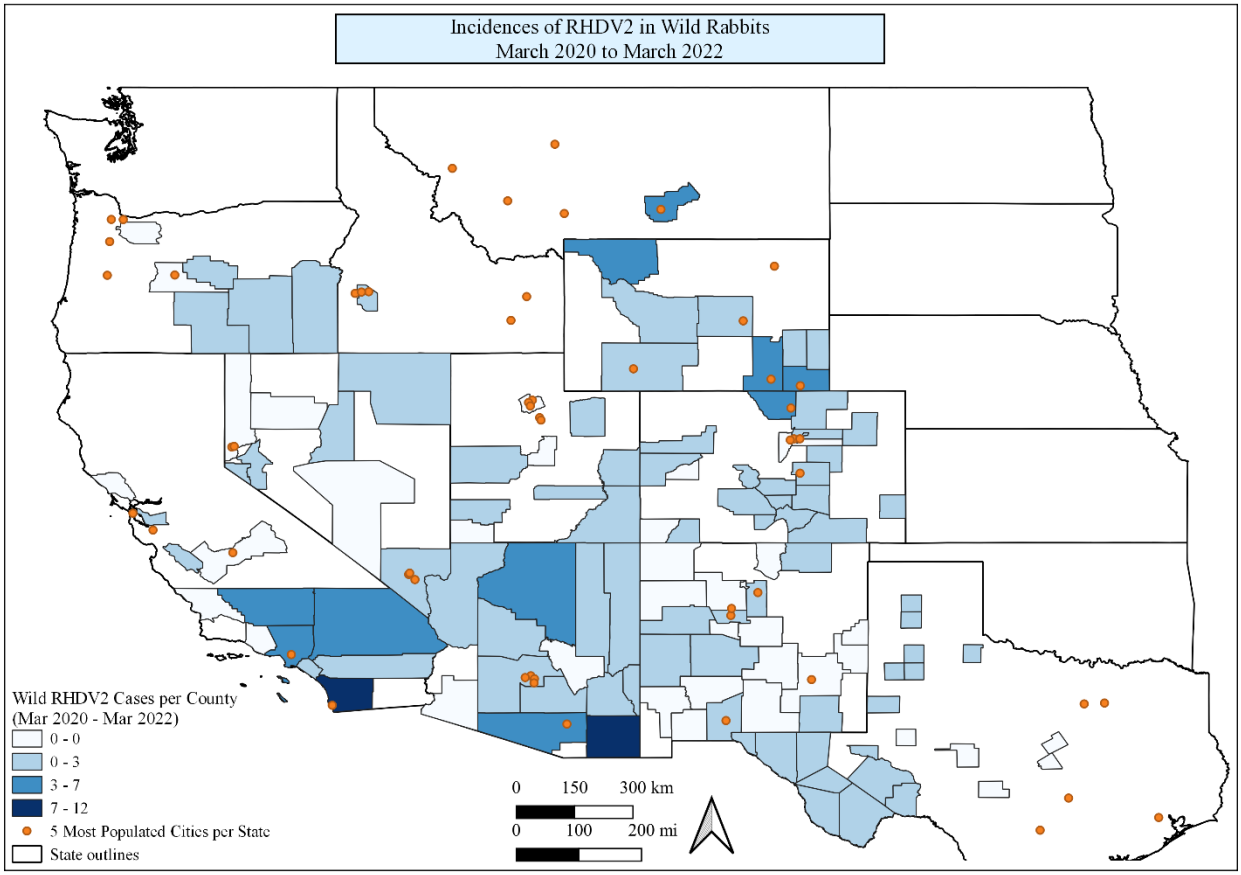

Figure C-1: Map of the counties reporting wild cases of RHDV2 for the entire timespan (March 2020 to March 2022), with darker colors indicating higher incidences of RHDV2 per county. Dots representative of five most populous cities per state. (USDA APHIS, 2022)

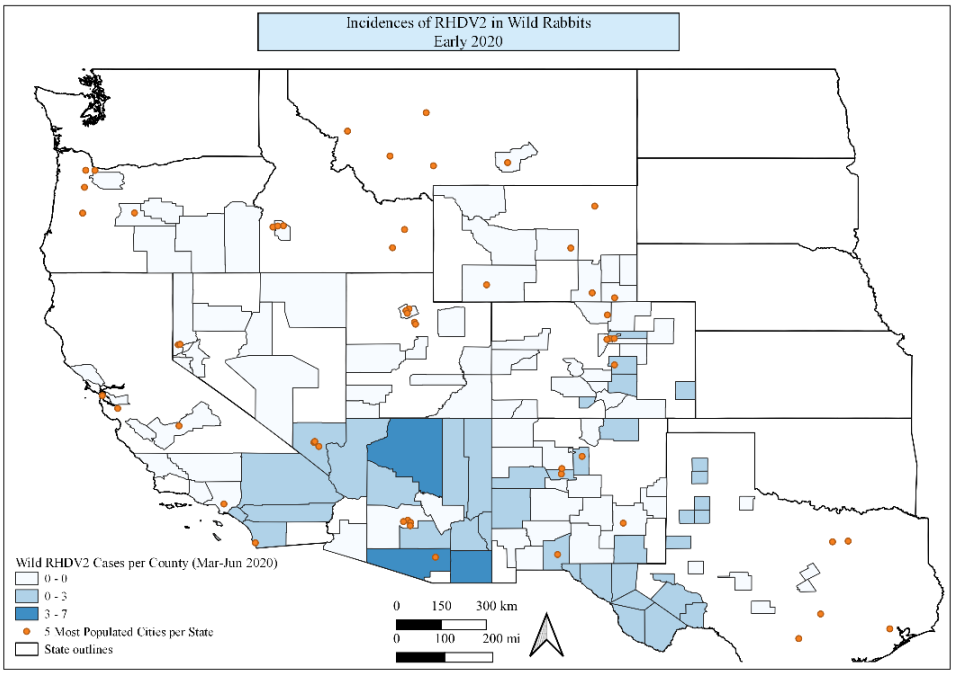

Figure C-2: Map of the counties affected by wild cases of RHDV2 in early 2020, with values only from March 2020 to June 2020, with darker colors indicating higher incidences of RHDV2 per county. (USDA APHIS, 2022)

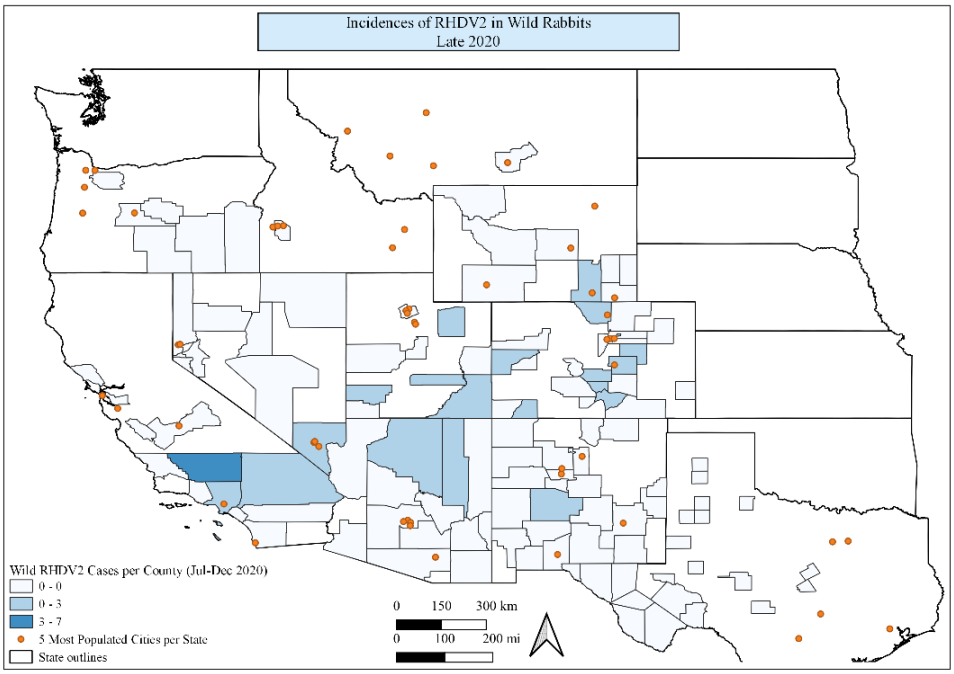

Figure C-3: Map of the counties affected by wild cases of RHDV2 in late 2020, from July 2020 to December 2020 with darker colors indicating higher incidences of RHDV2 per county. (USDA APHIS, 2022)

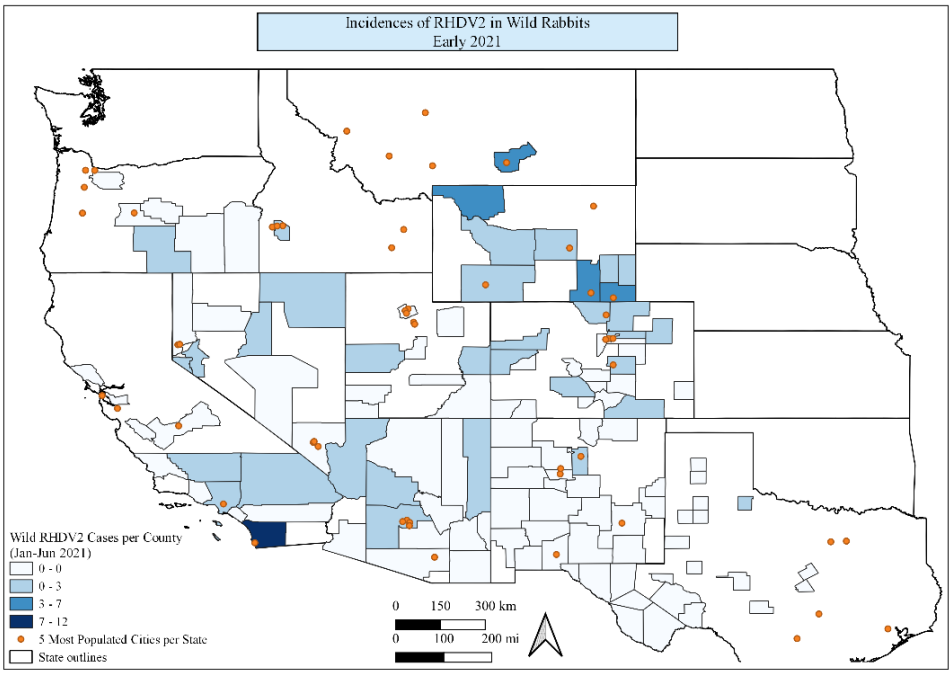

Figure C-4: Map of the counties affected by wild cases of RHDV2 in early 2021, from January 2021 to June 2021 with darker colors indicating higher incidences of RHDV2 per county. (USDA APHIS, 2022)

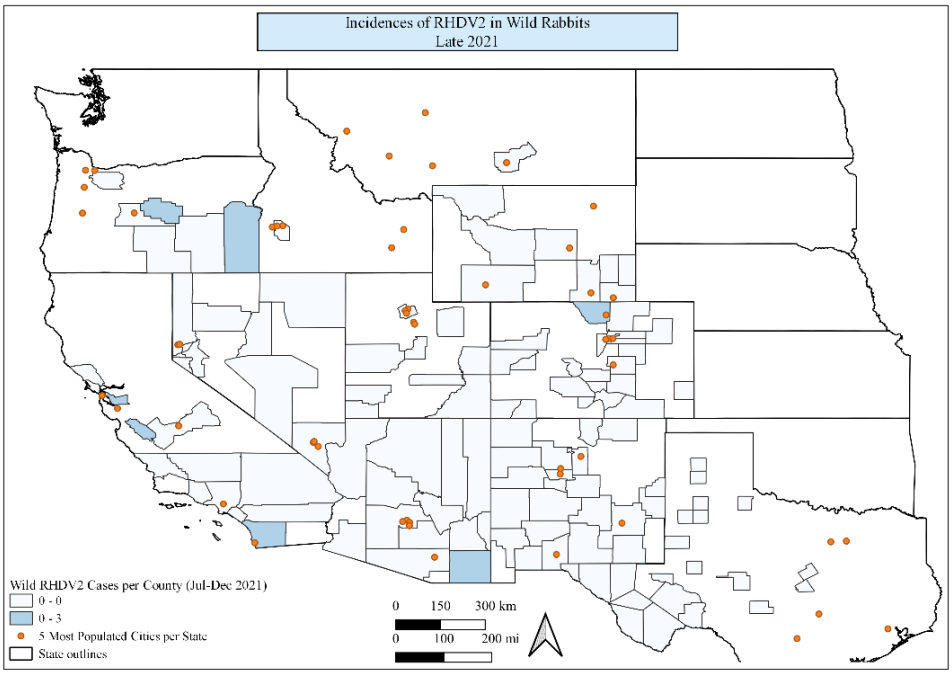

Figure C-5: Map of the counties affected by wild cases of RHDV2 in late 2021, from July 2021 to December 2021 with darker colors indicating higher incidences of RHDV2 per county. (USDA APHIS, 2022)

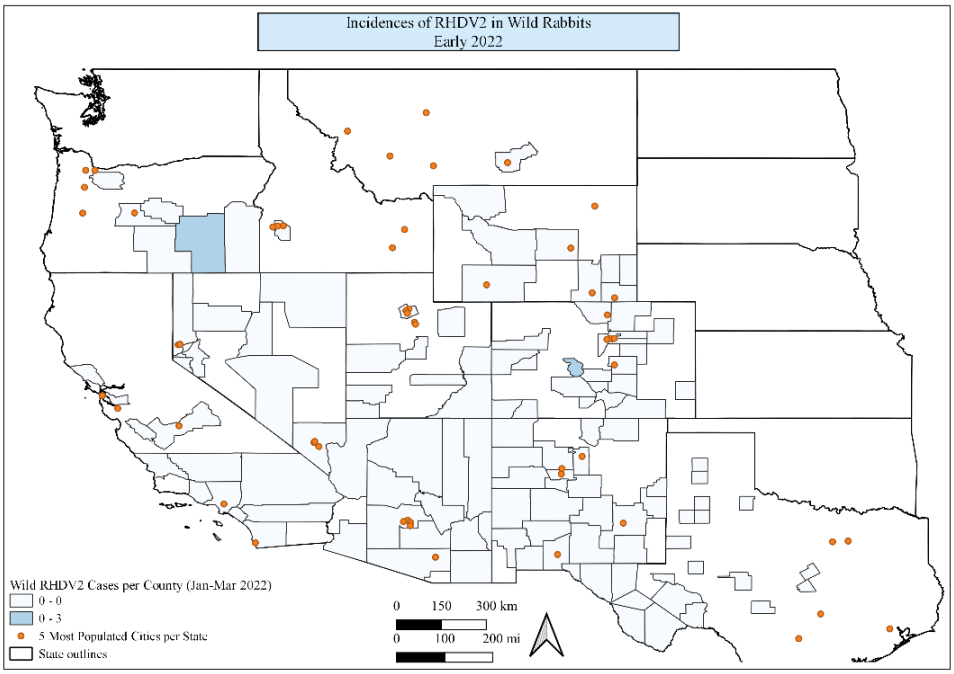

Figure C-6: Map of the counties affected by wild cases of RHDV2 in early 2022, with values only from March 2022 with darker colors indicating higher incidences of RHDV2 per county. (USDA APHIS, 2022)

APPENDIX D

FERAL INCIDENCES OF RHDV2

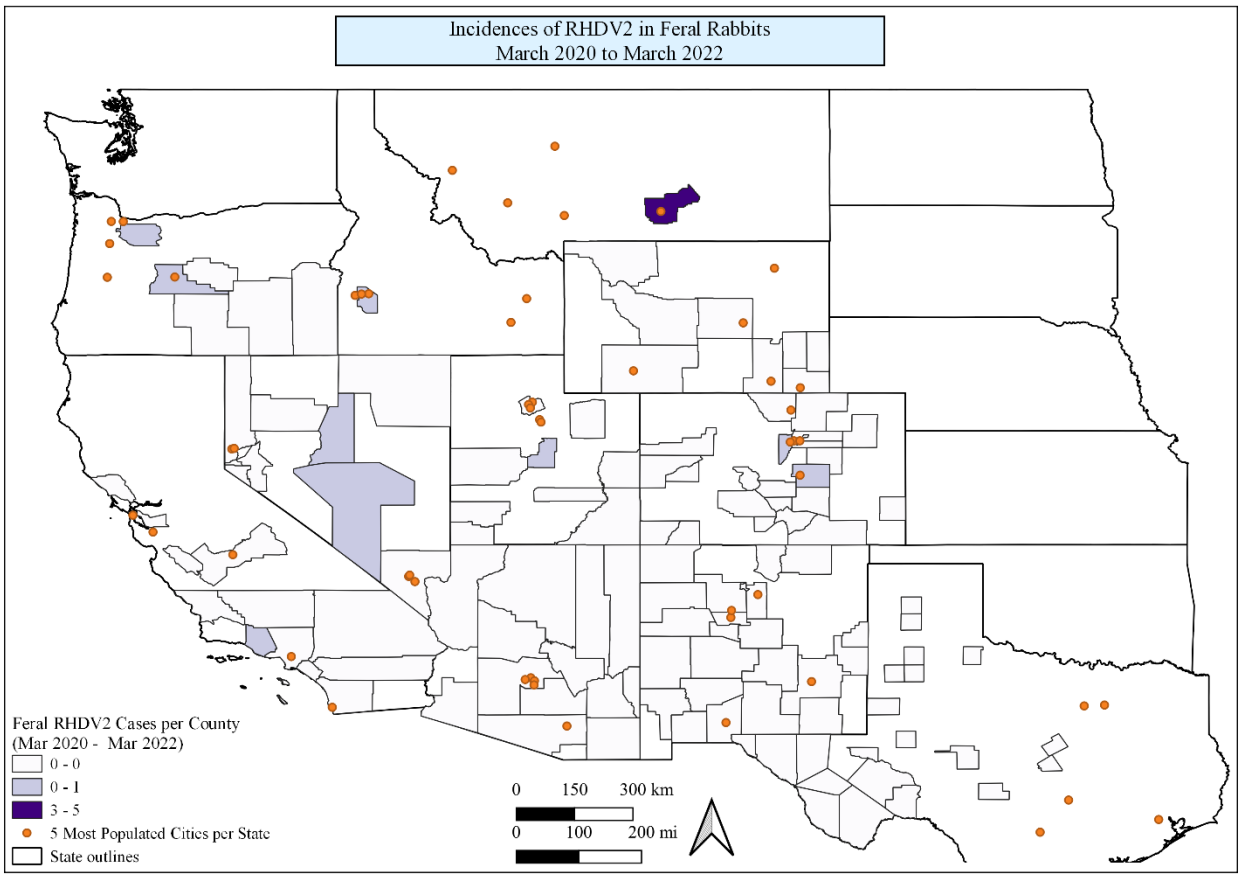

Figure D-1: Map of the counties reporting feral rabbit cases of RHDV2 for the entire timespan (March 2020 to March 2022), with darker colors indicating higher incidences of RHDV2 per county. Dots representative of five most populous cities per state. (USDA APHIS, 2022)