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Texas professionals are employing a one health approach to protect the United States against biosecurity threats

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ABSTRACT

Texas is a geographically large state with large human and livestock populations, many farms, a long coastal region, and extreme fluctuations in weather. During the last 15 years, the state of Texas has frequently suffered disasters or catastrophes causing extensive morbidity and economic loss. These disasters often have complicated consequences requiring multi-faceted responses. Recently, an interdisciplinary network of professionals from multiple academic institutions has emerged to collaborate in protecting Texas and the USA using a One Health approach. These experts are training the next generation of scientists in biopreparedness; increasing understanding of pathogens that cause repetitive harm; developing new therapeutics and vaccines against them; and developing novel surveillance approaches so that emerging pathogens will be detected early and thwarted before they can cause disastrous human and economic losses. These academic One Health partnerships strengthen our ability to protect human and animal health against future catastrophes that may impact the diverse ecoregions of Texas and the world.

1. Introduction

Texas, the second-largest U.S. state in both population and geography, leads the nation in number of farms (>248,000 in 2021) and in multiple agriculture and natural resource commodities. A catastrophic event in Texas has potential to affect the entire nation's supply chains. When a catastrophic event disrupts infrastructure or damages environmental ecology, it may be associated with infectious disease threats to human or livestock health. [1] This report examines how academic professionals in Texas are working together to mitigate naturally occurring and manmade catastrophic events in Texas through a One Health (OH) approach via research, training, policy, and practice. The lessons demonstrated by these collaborative initiatives have applicability beyond Texas, to the rest of the United States and our

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Table 1
Recent disasters or catastrophic events in Texas.

Date	Event	Comments
Jun 2022 - present	Monkeypox in humans	Numerous cases detected in Texas
April 2022	Highly pathogenic avian influenza detected	First detected in pheasants in Texas
March 2022	Texas wildfire	Estimated to have burned 64,000 acres
Feb 2022	*Cronobacter sakazakii* and *Salmonella* Newport infections in children	Associated with powdered infant formula
Sept 2021	Hurricane Nicholas (cat 1)	National insured losses estimated at $2.2 billion [50] The storm left 503,000 without power in Texas.
June 2021	Increased interseasonal respiratory syncytial virus activity among humans in Texas	Likely associated with COVID-19 pandemic
May-Aug 2021	Cyclosporiasis outbreak in humans	Increased awareness called for as >500 reported cases were reported in Texas during 2020.
May 2021	Chronic Wasting Disease	Chronic Wasting Disease Discovered at Deer Breeding Facilities in Matagorda and Mason Counties
Feb 2021	Severe Winter Storm Uri	Severe weather impacting all 254 Texas counties and caused widespread power grid failure. Texas suffered billions of dollars of damage including an estimate $600 million in agricultural losses.
Jan 2021	Drug-resistant *Candida auris* outbreak in humans	First cases in Texas of this notifiable condition
Dec 2020	Hurricane Laura (cat 4)	Declared a state of emergency for 23 counties in eastern Texas
Mar 2020 - present	COVID-19 pandemic in humans and animals	Texas leads nation since the start of pandemic in number of confirmed animal infections. 7,049,853 confirmed cases and 88,517 deaths as of June 15, 2022 [51]
Oct 2019	Tropical Storm Imelda	Massive flooding in Texas. Seventh-wettest tropical cyclone in U.S. history.
Aug 2019	Copper Breaks Fire	A wildfire approximately 7206 acres in size burned in Hardeman County. Declared Texas disaster
July 2019	Measles outbreak in Texas	At least 17 cases were detected in 12 Texas counties
June 2019	Texas Severe Storm and Flooding DR-4454	Major disaster declared in South Texas
April – May 2019	COVID-19 impact on meat production	Marked losses in meat production with >$13.6 million in losses to beef industry alone [2,52]
Feb 2019	Texas Severe Storm and Flooding DR-4416	Severe flooding in large areas near Texas Brazos, Trinity, and Nueces Rivers.
Jan 2019	Mumps outbreak	Multiple cases at Texas immigration center
Nov 2018	Outbreak of infant botulism	Associated with ingesting raw honey
Oct 2018	Acute flaccid myelitis outbreak in humans	Now thought to be associated with enterovirus infections
Aug 2017	Hurricane Harvey (cat 4)	Texas suffered an estimated 300,000 damages structures and damage 500,000 vehicles. U.S. damage cost estimates $125 billion
Sept 2008	Hurricane Ike (cat 4)	U.S. coastal and inland area damages were estimated at $30 billion [53]

Some elements were adapted from www.tdem.texas.gov/disasters, www.texasagriculture.gov, and en.wikipedia.org.

interconnected world.

1.1. Recent catastrophic events in Texas

Since 2000, Texas has suffered multiple catastrophic events (Table 1): massive storms, epidemics, largescale power disruption, food contamination, drought, epizootics, and crop failure. These have resulted in major economic loss for Texas and the nation. For the purposes of this paper, "catastrophic events" will be used to encompass all the aforementioned threats.

1.2. Catastrophic events often have complex impacts

Catastrophic events are disruptors with complex etiologies, and thus require multidisciplinary solutions. Texas' experience with COVID-19 is illustrative. As of July 15, 2022, the virus has infected >5.8 million Texans and killed >87,000. Additionally, the pandemic has caused profound disruptions to Texans' productivity and commerce. Major outbreaks among meat processing–plant workers resulted in national food security issues [2,3]. As of summer 2022, Texas had nearly one-third (108/381) of the documented cases of SARS-CoV-2 infection in companion animals [4]. Recent detection of SARS-CoV-2 in Texas' wild and captive white-tailed deer [5,6] has created concerns about epizootics in other species [7], and through mutation or recombination, further human morbidity and death.

1.3. Mitigating catastrophes requires interdisciplinary cooperation

Catastrophes frequently have complex origins (e.g., food contamination, environmental pollution, antimicrobial resistance). Preventing and responding to catastrophes requires cooperation among multiple organizations and disciplines.

The OH approach addresses the root causes of catastrophic events affecting humans, animals, and the environment in an integrated fashion, uniting professionals from disparate disciplines (e.g., public, animal, and environmental health) to solve complex health problems (e.g., zoonotic disease epidemics, antimicrobial resistance, food safety). The OH approach has been endorsed by numerous academic [8–13], professional [14–18], and governmental organizations, including the WHO, Food and Agriculture Organization (FAO), World Organization for Animal Health (OIE), World Bank, G7, and G20.

1.4. Mitigating catastrophes requires international cooperation

Texas's subtropical climates and geopolitical location lead to a constant cross-border movement of people, animals, vectors, and goods that contributes to the circulation of neglected tropical diseases (NTDs) [19]. Texas researchers have used an OH approach to identify the transmission of zoonotic NTDs and evaluate interventions. For example, the College of Veterinary Medicine and Biomedical Sciences, School of Public Health, and College of Architecture at Texas A&M University (TAMU) have evaluated domestic dogs as sentinels for human Chagas disease in Hispanic low-SES border neighborhoods [20] and identified aspects of the housing and peridomestic environments that are risk-factors for infection [21]. This guided community outreach with a focus upon reducing risk factors, as well as a series of interactive workshops focused on kissing bugs and Chagas disease with continuing education for the promotoras (community health workers) that provide care to the residents of these communities.

2. Training professionals to respond to catastrophes

2.1. UTMB Keiller building and Galveston National Laboratory (GNL)

UTMB has prioritized educating research scientists about high consequence pathogens since hosting we inaugurated the first full-sized

Fig. 1. Description of One Health courses, which include virtual, classroom-based, and field-based experiences to help teach a One Health approach to a diverse array of learners from across Texas and beyond. Artwork by Kara McArthur (The Institute for Collaboration in Health).

BSL-4 facility within a US university, the Galveston National Laboratory (GNL). The GNL works jointly with a vast network of collaborators from various sectors and countries. Trainees are familiarized with Good Laboratory practices and Animal Rule procedures for FDA licensure as well as receiving direct oversight and close mentoring from highly experienced investigators.

In addition, as one of only two university-based BSL4s, UTMB has a clear mandate on education and training in biosafety and biosecurity. UTMB provides biosafety training in BSL3 and BSL4 principles for research involving both animal and bench techniques. These processes and protocols are shared with regional, national, and international collaborators to help them improve their field and facility operations.

2.2. Training young professionals to employ the OH approach

Addressing the dynamics of zoonotic disease transmission at the human-animal interface requires an approach spanning considerations of socioeconomics to biophysical mechanisms. OH programs have developed within schools of veterinary medicine and public health, but incorporation into clinical medical training has lagged as has cross disciplinary exposure.

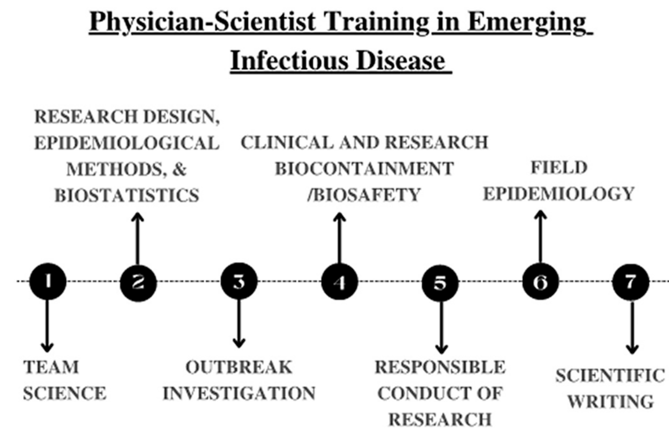

Fig. 2. Graphic summary of UTMB's Physician Scientist Training in Emerging Infectious Diseases program. Graphic by Peter Melby (UTMB).

Recognizing the need and the opportunity to establish integrative OH education in Texas, in 2017 an interprofessional team of clinicians, scientists, and educators from UTMB, University of Texas at Rio Grande Valley (UTRGV), and TAMU developed a cross-disciplinary, scenario-based zoonotic outbreak simulation course. We applied the OH competency framework and multiple pedagogical methods to actively engage learners from diverse post-bachelors training programs (MD, DVM, PhD, MS, MPH, RN, veterinary technology). Initially, the course took place entirely in the field as learners followed an evolving outbreak across Texas, actively learning animal health, vector dynamics, laboratory diagnostics, clinical management, field epidemiology, and communication with the public.

Since 2020, the course has been a virtual/field hybrid (Fig. 1), which allows in-person time to be focused on application and demonstration of skills rather than lectures [22,23].

The online, facilitated case/problem-based learning engages interprofessional teams in real-world situations to apply newly learned skills and concepts [24]. They must negotiate team dynamics, understand professional roles, and build consensus [25]. These teams then undergo in-person training, featuring simulated and real-world fieldwork [26,27].

Beyond the initial instruction, a Community of Practice on OH and Pandemic Preparedness and Response has sustained continued learning and professional development, including peer-support and networking, for >5 years now.

2.3. Training physician-scientists in emerging infectious diseases

Recent outbreaks highlight inadequacies in the global capacity for outbreak prevention, detection, and response [28,29]. Even before the SARS-CoV-2 pandemic, a CDC taskforce identified a critical public-health surveillance workforce shortage [30]. There is an urgent need for broadly-trained physician-scientists with transdisciplinary skills in clinical medicine, epidemiological and field investigation, laboratory science, and biocontainment [31,32]. To address this need, UTMB's Division of Infectious Diseases and Center for Tropical Diseases established a program to train physician-scientists in emerging infectious diseases, which included an OH approach. The program capitalizes on world-class faculty expertise and resources that include BSL3 and BSL4 biocontainment. Fig. 2 shows the program components. Trainees receive intensive scientific and career mentorship through a novel Team Science framework.

2.4. Training interdisciplinary medical teams to care for patients with dangerous infections

In 2015 UTMB was named one of 10 Regional Emerging and Special Pathogens Treatment Centers (RESPTCs). The UTMB BioContainment Care Unit (BCU) is a six-room specialized hospital unit with the facilities and trained staff to care for patients with the world's most highly infectious pathogens. Alongside other RESPTCs and the National Emerging and Special Pathogens Training and Education Center (NETEC), the UTMB BCU and the Special Pathogens Excellence in Clinical Treatment, Readiness, and Education Program (SPECTRE) engage in a diverse range of OH-oriented preparedness activities, including training, education, scientific writing, networking, and development of research infrastructure to facilitate clinical research during an outbreak. For COVID-19 and more recently for monkeypox, BCU and SPECTRE facilitated institutional response by training healthcare workers in personal protection equipment (PPE), formulating clinical-care and pharmaceutical guidelines, establishing a biospecimen repository for research, onboarding UTMB as a site for therapeutic trials, and collaborating with basic-science colleagues to incorporate clinical considerations and relevance into experimental design and publications.

SPECTRE additionally provides opportunities for trainees and young faculty to forge a professional pathway focused on high consequence pathogens. The clinical care focus of SPECTRE activities provides an additional lens through which to view preparedness for outbreaks. Exposure to biocontainment care principles and requirements has been incorporated into the OH outbreak simulation course, clinical infectious diseases training, biosafety and infection control training, and public health education.

2.5. Cross-training young professionals and graduate students in entomology

Because Texas is at high risk for incursions of vector-borne diseases, UTMB provides specialized entomological training is provided for Texas public health and veterinary health professionals through two TAMU training programs. Undergraduates who earn a *Certificate in Public Health Entomology* learn about the major disease vector and reservoir insects and arthropods. Graduate students can earn a *Certificate in Vector Biology and Vector-Borne Disease Response in Human and Animal Systems.*

2.6. Training public health professionals in OH

In 2008, the Association of Schools and Programs in Public Health (ASPPH) estimated an additional 250,000 US public-health professionals would be required by 2020 [33]. The SARS-CoV-2 pandemic revealed the devastating impact of this deficiency on communities and on public-health workers with 1 in 3 public health workers planning to soon leave their jobs [34]. In response, in 2021, Texas approved three new public health schools, including one based at UTMB. The creation of a Department of Global Health and Emerging Diseases in UTMB's new School of Public and Population Health will leverage the institution's expertise in emerging infectious diseases, its network of regional and international partnerships, and its well-established training programs to develop OH-oriented transdisciplinary research, education, and public-health practice.

3. Conducting OH-oriented research to mitigate future catastrophic events

3.1. UTMB's emerging infectious disease research centers and programs

Since the early 2000s with the UTMB-led, Western Regional Center of Excellence in Biodefense and Emerging Infectious Diseases, Texas has housed several major efforts in vector-borne and other emerging zoonotic diseases, including the UTMB-led Western Gulf Center for

Table 2
UTMB major laboratories, institutes, centers, and programs playing important roles in disaster mitigation.

Year Established	Entity	Mission
1994	Center for Tropical Diseases	To alleviate suffering caused by tropical diseases through basic, applied and field research, education, and service.
2003	Center for Biodefense and Emerging Infectious Diseases	The CBEID has two main objectives: • To reduce the vulnerability of the US and other nations to the use of biological weapons for warfare and terrorism. • To alleviate suffering from emerging infectious diseases through application of basic, translational, and field research, and through education.
2004	Institute for Human Infections and Immunity	To coordinate, facilitate and enhance the activities of UTMB's research centers and programs that focus on advancing the fields of infection and immunity.
2007	Institute for Translational Sciences	To develop, evaluate and disseminate best practices for novel training and leadership programs in translational science.
2008	Galveston National Laboratory	To assist the National Institute of Allergy and Infectious Diseases and the nation in the development of an improved means for the prevention, diagnosis and treatment of potentially life-threatening diseases caused by naturally emerging and purposefully disseminated infectious agents.
2018	Center for Global and Community Health	To improve community world health through innovative and collaborative partnerships utilizing interprofessional education, research, clinical care and service learning.
2018	Sealy Institute for Vaccine Sciences	To improve human health by: • Conducting research focused on the development and use of vaccines • Developing public policy and education programs to foster vaccine acceptance • Training investigators in the field of vaccine research
2020	Center for Vector-borne and Zoonotic Diseases	To enhance vector-borne research efforts in the U.S. and worldwide as well will leverage CREATE-NEO's vast network of partnerships to offer basic training in vector handling and rearing, virus identification and characterization, as well as establish exchange training programs for physicians and basic researchers in Vector borne and zoonotic infectious diseases.
2020	West African Center for Emerging Infectious Diseases	To address critical scientific gaps through field studies of animal to human disease transmission and clinical studies of human exposure with resulting disease outcome.
2020	Coordinating Research on Emerging Arboviral Threats	To provide a nimble and flexible network of surveillance sites in

(*continued on next page*)

Table 2 (*continued*)

Year Established	Entity	Mission
	Encompassing the Neotropics (CREATE-NEO)	Central and South America coupled to cutting-edge modeling approaches in order to anticipate and counter emerging arboviruses.
2021	UTMB One Health Research and Training Program	To address complex health problems through the One Health approach, microbiology, and epidemiology methods.

Excellence for Vector-Borne Diseases (WGCVBD), with major collaborations at TAMU and UTRGV. WGVBD focuses on regional surveillance for arboviral diseases in mosquitoes, especially West Nile, dengue, Zika, and tick-borne viruses.

The West African Center for Emerging Infectious Diseases performs surveillance in Senegal, Sierra Leone, and Nigeria on humans, wild and domesticated animals, and vectors to better understand the spatial and ecologic determinants of known and as-yet-undiscovered pathogens. Work in Nigeria includes investigation of zoonotic reservoirs and both spillover and human-to-human transmission of monkeypox virus, which has been introduced repeatedly into Texas [35] with the threat of becoming enzootic or endemic.

The integrated operations of the Keiller-Galveston National Laboratory (Keiller-GNL) represent over a decade of interdisciplinary support of the OH approach. To combat highly-infectious diseases, Keiller-GNL leverages a global and intersectoral network of collaborators to address the biomedical, epidemiological, environmental, and social aspects of infectious outbreaks.

UTMB maintains multiple infectious disease research centers, institutes and programs (Table 2). Through mentorship and coworking relationships, they facilitate work on high-consequence pathogens resulting in >100 publications/year. Furthermore, UTMB houses the World Reference Center for Emerging Viruses and Arboviruses (WRCEVA)—a repository of >8000 strains encompassing 21 viral families, with complementary sera and diagnostic antigens, and short-term training of international scientists.

To combat the complexities of catastrophic outbreaks, over 120 faculty scientists, representing a host of disciplines, research infectious diseases, including immunologic diagnostics, therapeutics, and vaccines to combat emerging/reemerging diseases. UTMB's research promotes understanding of transmission and pathogenesis of emerging viruses and their disease vectors as well as development of medical countermeasures, particularly those against pathogens with the highest mortality rates, most limited options for treatment, and greatest potential as bioweapons.

UTMB's interdisciplinary collaborative history includes responding to national and international epidemics, including the 2009 influenza A H1N1 pandemic, the 2016 Zika threat, and the 2014–2016 West African Ebola outbreak. After the arrival in 2002 of West Nile virus in Texas, WRCEVA staff in collaboration with Harris County Public Health, [36] implemented dead bird and mosquito monitoring to detect its arrival in the Houston area and to identify high-risk enzootic foci for mosquito control interventions. As part of the WGCVBD, TAMU and WRCEVA scientists also identified in Houston the widespread presence of insecticide resistance as well as host feeding patterns of the main enzootic vector, *Culex quinquefasciatus* to further refine interventions. [37,38] In 2022 UTMB developed a Nipah vaccine, a priority virus for the US CDC and Department of Defense (DOD).

A Clinical Research Center, operating under the Institute for Translational Sciences (ITS), integrates academic, clinical, and basic sciences, focusing on holistic solutions "from bench to bedside." As the lead institution for the NIH Centers of Excellence for Translation Research "Advancement of Vaccines and Treatments for Ebola and Marburg Virus Infections," Keiller-GNL research led to the rVSV vaccine for Ebola-Zaire.

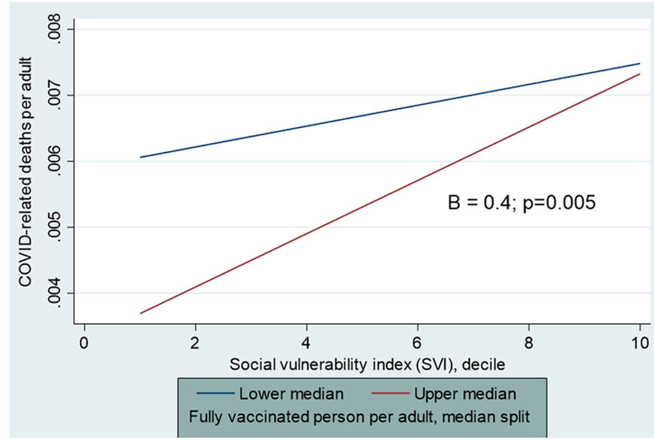

Fig. 3. COVID-19 related deaths per adult capita, social vulnerability, and vaccine uptake across 254 Texas counties. The blue line represents counties where the number of people who were fully vaccinated per adult was in the lower median in Oct. 2021 (0.21–0.51 fully vaccinated persons per adult); the red line represents counties where the number of people who were fully vaccinated per adult was in the higher median in Oct. 2021 (0.51–1.05 fully vaccinated persons per adult). The X-axis represents the decile category of the Social Vulnerability Index (SVI), and the Y-axis represents the number of COVID-19 deaths per adult by July 2022. The interaction term for this moderated association was significant ($p = 0.004$) with a medium effect size ($\beta = 0.4$). SVI decile and vaccination median remained significantly associated with COVID-19 deaths per adult after including the interaction term. Artwork by Michael Goodman (UTMB). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

The OH approach positioned UTMB to well respond to COVID-19, including developing animal models for screening candidate drugs and efficiently testing potential vaccines and therapeutics. UTMB contributed dozens of studies and publications on immunogenicity of the Pfizer/BioNTech and Moderna vaccines, and also developed novel therapeutics, monoclonal antibodies, and diagnostic tools.

3.2. UTMB OH strategic task force

In 2021, a group of UTMB faculty, staff, and students united to promote OH-oriented research and training activities (*UTMB One Health Strategic Taskforce)*, including a website on UTMB's OH research and training activities (www.utmb.edu/one-health), a monthly newsletter *(One Health)* emailed to >5000 scholars around the world, and a podcast, *Infectious Science*. A key objective of the Taskforce has been to promote current research and seek new research opportunities. For instance, UTMB OH collaborators recently won a pair of 5-year NIH-funded contracts to establish a GEOHealth Center of research and training in Mongolia to study the interaction of air pollution and respiratory virus infections.

3.3. Academic and public health professionals partner in emerging infectious disease research

UTMB and Galveston County Health Department (GCHD) are developing a Geographical Information System (GIS) app that monitors the COVID-19 pandemic. It plots multiple data sources like COVID-19 cases, vaccinations, hospitalizations, and deaths. This is overlayed with the CDC Social Vulnerability Index (SVI), a composite measure incorporating poverty, chronic disease burden, and availability to healthcare. In a study of 254 Texas counties, the team plotted the links among vaccine uptake, social vulnerability, and COVID-19 deaths per adult (Fig. 3). In both highly-vaccinated and less-vaccinated groups,

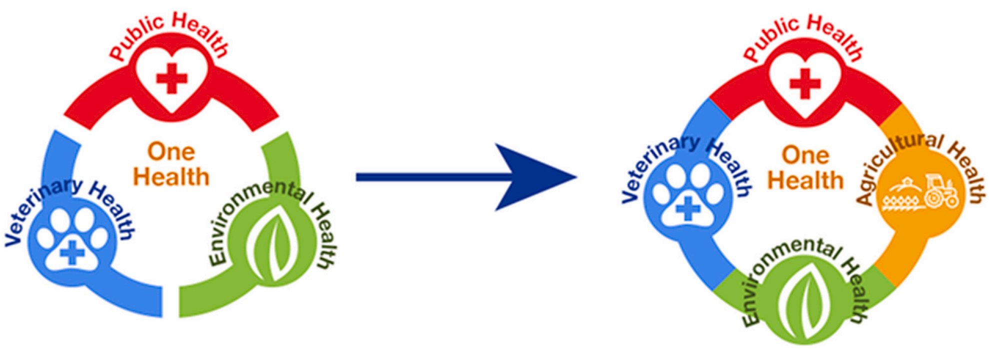

Fig. 4. For some complex problems, One Health consortiums often miss the important partnership of agriculture. This is an unfortunate omission as agricultural industries may serve a nidus of complex problem generation (e.g. food contamination, environmental pollution, and antimicrobial resistance) and as well as suffer great consequences from the complex problem. We posit that for many complex problems, we need to find ways to engage agricultural partners in One Health planning. This will require creative thinking to protect the interests of agricultural industries as presently agricultural industry cooperation with human and environmental health is viewed as a high-risk venture. Artwork by Mary Jo Singleton (UTMB).

high SVI was associated with high COVID-19 death per adult. This proof-of-concept shows that UTMB and GCHD can identify geographical regions at highest risk for COVID-19-related deaths using GIS data. The app is being deployed for community health workers to target interventions and track activities and outcomes in real-time.

Future iterations will include all reportable diseases, vital statistics, and environmental exposures, augmenting an already powerful tool to track and monitor disease outbreaks in real-time and allow for rapid analysis and response to future public health threats.

3.4. Texas occupational health professionals mitigate emerging infectious disease threats to agriculture industries by studying zoonotic disease transmission risks among animal workers

Using a OH research framework includes a recognition that human health is connected to the health of animals and the environment, including the health and safety of livestock employees. To date, research has emphasized animal health and production, with minimal attention to workers, their working environment, and their animal interactions. A OH research framework could facilitate an understanding of worker-animal and worker-environmental factors that may increase the risk of adverse health outcomes among livestock workers and potentially catastrophic events/pandemics.

A healthy and present workforce is crucial to US dairy production [39]. The anticipation and identification of worker health needs and occupational exposures is paramount [40]. The Texas Panhandle and South Plains are rural, isolated agricultural centers with low-skill, low-wage jobs in dairy, farming, animal husbandry, and meatpacking [41].

Important health hazards on dairies include the bacteria within the *Mycobacterium tuberculosis* complex (MTBC) and *Brucella* spp. (e.g. *Brucella abortus*). Researchers from TAMU and UT Health School of Public health are using a OH model to work with these pathogens and describe the "shared risk" among humans, animals, and the environment [42,43]. Understanding zoonotic diseases at multiple intervention levels is critically important for eradication efforts and can help bridge surveillance data gaps and can *impact* the creation, delivery, and evaluation of disease control and prevention programs and policies [43,44]. As an example of innovative OH collaboration, Texas-based academic professionals are partnering with the dairy industry to study MTBC and brucellosis threats to workers and livestock. These unique collaborations benefit both public health and industry.

3.5. Employing the OH approach in influencing national and Texas policy

Many of Texas's OH capabilities, capacities, and expertise were facilitated by evolving state and national policies and appropriations after the 2001 anthrax letter attacks and the 2003 SARS outbreak. Although we are better prepared today, continued advocacy and education for political leaders in Congress and the executive branch are essential to galvanize public support and political will. TAMU's College of Veterinary Medicine and Bush School of Government Service are working to muster support through policy research that has influenced the National Biodefense Strategy and contributed to the Bipartisan Commission for Biodefense's recent reports, including, 1) The Apollo Program for Biodefense – Winning the Race Against Biological Threats; 3) The Athena Agenda: Advancing the Apollo Program for Biodefense; and 4) Boots on the Ground: Land-Grant Universities in the Fight Against Threats to Food and Agriculture.

A *national and state* biodefense and pandemic preparedness enterprise that applies a OH approach to drive multi-sector coordination, collaboration, communication, and innovation will be essential for success.

3.6. Future needs in employing OH to counter catastrophes

The connection of many catastrophes to largescale agriculture requires engaging producers in OH training, research, and response to detect threats before they cause large clusters of human or animal illness. Furthermore, education and communication will help producers view public-health efforts in a less-threatening light [45,46]. In turn, public-health officials could incentivize participation by providing new technologies that enhance producers' biosecurity and business goals, such as improved novel pathogen detection techniques [47–49] that can head-off the economic hardship of diseased livestock. A pilot at a North Carolina swine farm employed bioaerosol sampling and detected an incursion of circovirus in pigherds approximately one week before the circovirus reached a level to alert the farmer [47]. Another pilot employed next-generation sequencing in nine swine fecal-slurry samples and assembled 1792 viral genomes, 30% newly identified [47]. Active participation of agricultural industry will greatly enhance the value of the OH collaborations in Texas (Fig. 4).

4. Conclusion

In recent years, Texas has experienced numerous catastrophic events with profound nationwide effects. In the setting of epidemiologic transitions, globalization, climate change, and confluent pandemics, such events can be expected to increase. This paper presents a sampling of the ongoing initiatives in Texas supporting state preparedness for current and future catastrophic events by way of OH-oriented research, training, policy, and practice. These programs have potential global applicability. Moving forward, academic, state, non-profit, and private institutions in Texas would benefit from working together to develop more training and research opportunities that stimulate interprofessional and transdisciplinary OH collaborations.

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Conflict of interest statement

Authors declare there is no known conflict of interest.

CRediT authorship contribution statement

Matthew M. Dacso: Writing – review & editing, Conceptualization, Visualization. **Dennis A. Bente:** Investigation, Writing – review & editing. **Scott C. Weaver:** Investigation, Writing – review & editing, Funding acquisition. **Gary P. Kobinger:** Investigation, Writing – review & editing. **Peter C. Melby:** Investigation, Writing – review & editing. **Susan L.F. McLellan:** Investigation, Writing – review & editing. **Philip H. Keiser:** Investigation, Writing – review & editing, Methodology. **Sarah A. Hamer:** Investigation, Writing – review & editing. **Gabriel L. Hamer:** Writing – review & editing. **Gerald W. Parker:** Conceptualization, Writing – original draft, Writing – review & editing. **David I. Douphrate:** Writing – review & editing. **Anabel Rodriguez:** Conceptualization, Writing – original draft, Writing – review & editing. **Michael L. Goodman:** Data curation, Investigation, Methodology, Visualization, Writing – review & editing. **Ara XIII:** Data curation, Writing – review & editing, Investigation. **Gregory C. Gray:** Conceptualization, Investigation, Writing – original draft, Supervision.

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References

[1] L.C. Ivers, E.T. Ryan, Infectious diseases of severe weather-related and flood-related natural disasters, Curr. Opin. Infect. Dis. 19 (5) (2006) 408–414, https://doi.org/10.1097/01.qco.0000244044.85393.9e (PubMed PMID: 16940862).

[2] M. Ijaz, M.K. Yar, I.H. Badar, S. Ali, M.S. Islam, M.H. Jaspal, et al., Meat production and supply chain under COVID-19 scenario: current trends and future prospects, Front. Vet. Sci. 8 (2021), https://doi.org/10.3389/fvets.2021.660736, 660736. Epub 20210507. PubMed PMID: 34026895; PubMed Central PMCID: PMCPMC8137951.

[3] J.W. Dyal, M.P. Grant, K. Broadwater, A. Bjork, M.A. Waltenburg, J.D. Gibbins, et al., COVID-19 among workers in meat and poultry processing facilities - 19 States, April 2020, MMWR Morb. Mortal. Wkly Rep. 69 (18) (2020), https://doi.org/10.15585/mmwr.mm6918e3. Epub 20200508. PubMed PMID: 32379731.

[4] USDA, Confirmed Cases of SARS-CoV-2 in Animals in the United States [cited 2022 July 3, 2022]. Available from, https://www.aphis.usda.gov/aphis/dashboards/tableau/sars-dashboard, 2022.

[5] P.M. Palermo, J. Orbegozo, D.M. Watts, J.C. Morrill, SARS-CoV-2 neutralizing antibodies in white-tailed deer from Texas, Vector Borne Zoonotic Dis. 22 (1) (2022) 62–64. Epub 20211210, https://doi.org/10.1089/vbz.2021.0094. PubMed PMID: 34890284; PubMed Central PMCID: PMCPMC8787703.

[6] C.M. Roundy, C.M. Nunez, L.F. Thomas, L.D. Auckland, W. Tang, J.J. Richison 3rd, et al., High seroprevalence of SARS-CoV-2 in white-tailed deer (*Odocoileus virginianus*) at one of three captive cervid facilities in Texas, Microbiol. Spectr. 10 (2) (2022), https://doi.org/10.1128/spectrum.00576-22 e0057622. Epub 20220323. PubMed PMID: 35319276; PubMed Central PMCID: PMCPMC9045306.

[7] F.Z.X. Lean, A. Nunez, S. Spiro, S.L. Priestnall, S. Vreman, D. Bailey, et al., Differential susceptibility of SARS-CoV-2 in animals: evidence of ACE2 host receptor distribution in companion animals, livestock and wildlife by immunohistochemical characterisation, Transbound. Emerg. Dis. (2021), https://doi.org/10.1111/tbed.14232. Epub 20210710. PubMed PMID: 34245662; PubMed Central PMCID: PMCPMC8447087.

[8] I.B. Rwego, O.O. Babalobi, P. Musotsi, S. Nzietchueng, C.K. Tiambo, J.D. Kabasa, et al., One health capacity building in sub-Saharan Africa, Infect. Ecol. Epidemiol. 6 (2016), https://doi.org/10.3402/iee.v6.34032, 34032. Epub 2016/12/03. PubMed PMID: 27906125; PubMed Central PMCID: PMCPMC5131459.

[9] J. Wu, L. Liu, G. Wang, J. Lu, One health in China, Infect. Ecol. Epidemiol. 6 (2016) 33843. Epub 2016/12/03, https://doi.org/10.3402/iee.v6.33843. PubMed PMID: 27906124; PubMed Central PMCID: PMCPMC5131455.

[10] J.S. McKenzie, R. Dahal, M. Kakkar, N. Debnath, M. Rahman, S. Dorjee, et al., One Health research and training and government support for One Health in South Asia, Infect. Ecol. Epidemiol. 6 (2016) 33842. Epub 2016/12/03, https://doi.org/10.3402/iee.v6.33842. PubMed PMID: 27906123; PubMed Central PMCID: PMCPMC5131453.

[11] S.A. Reid, J. McKenzie, S.M. Woldeyohannes, One Health research and training in Australia and New Zealand, Infect. Ecol. Epidemiol. 6 (2016) 33799. Epub 2016/12/03, https://doi.org/10.3402/iee.v6.33799. PubMed PMID: 27906122; PubMed Central PMCID: PMCPMC5131460.

[12] R. Sikkema, M. Koopmans, One Health training and research activities in Western Europe, Infect. Ecol. Epidemiol. 6 (2016) 33703. Epub 2016/12/03, https://doi.org/10.3402/iee.v6.33703. PubMed PMID: 27906121; PubMed Central PMCID: PMCPMC5131506.

[13] C. Stroud, B. Kaplan, J.E. Logan, G.C. Gray, One Health training, research, and outreach in North America, Infect. Ecol. Epidemiol. 6 (2016) 33680. Epub 2016/12/03, https://doi.org/10.3402/iee.v6.33680. PubMed PMID: 27906120; PubMed Central PMCID: PMCPMC5131458.

[14] J.R. Sinclair, Importance of a One Health approach in advancing global health security and the sustainable development goals, Rev. Sci. Tech. 38 (1) (2019) 145–154. Epub 2019/10/01, 10.20506/rst.38.1.2949. PubMed PMID: 31564744.

[15] M.K. O'Brien, A.M. Perez, K.M. Errecaborde, Transforming the One Health workforce: lessons learned from initiatives in Africa, Asia and Latin America, Rev. Sci. Tech. 38 (1) (2019) 239–250. Epub 2019/10/01, 10.20506/rst.38.1.2956. PubMed PMID: 31564727.

[16] S.J. Bright-Ponte, B.K. Walters, H. Tate, L.M. Durso, J.M. Whichard, K.E. Bjork, et al., One Health and antimicrobial resistance, a United States perspective, Rev. Sci. Tech. 38 (1) (2019) 173–184. Epub 2019/10/01, 10.20506/rst.38.1.2951. PubMed PMID: 31564732.

[17] B.H. Bird, J.A.K. Mazet, Detection of emerging zoonotic pathogens: an integrated one health approach, Annu. Rev. Anim. Biosci. 6 (2018) 121–139. Epub 2017/11/17, https://doi.org/10.1146/annurev-animal-030117-014628. PubMed PMID: 29144769.

[18] C. Degeling, J. Johnson, I. Kerridge, A. Wilson, M. Ward, C. Stewart, et al., Implementing a One Health approach to emerging infectious disease: reflections on the socio-political, ethical and legal dimensions, BMC Public Health 15 (2015) 1307. Epub 2015/12/31, https://doi.org/10.1186/s12889-015-2617-1. PubMed PMID: 26715066; PubMed Central PMCID: PMCPMC4696140.

[19] P.J. Hotez, The rise of neglected tropical diseases in the "new Texas", PLoS Negl. Trop. Dis. 12 (1) (2018) https://doi.org/10.1371/journal.pntd.0005581 e0005581. Epub 20180118. PubMed PMID: 29346369; PubMed Central PMCID: PMCPMC5773009.

[20] R. Curtis-Robles, I.B. Zecca, V. Roman-Cruz, E.S. Carbajal, L.D. Auckland, I. Flores, et al., Trypanosoma cruzi (Agent of Chagas Disease) in sympatric human and dog populations in "Colonias" of the Lower Rio Grande Valley of Texas, Am. J. Trop. Med. Hyg. 96 (4) (2017) 805–814. Epub 20170206, https://doi.org/10.4269/ajtmh.16-0789. PubMed PMID: 28167589; PubMed Central PMCID: PMCPMC5392625.

[21] B. Šafářová, C.H. Giusti, M.P. Perez, I.B. Zecca, E.S. Carbajal, G.L. Hamer, et al., Habitat and environmental risks of Chagas disease in low-income colonias and peri-urban subdivisions in South Texas, Habit. Int. 118 (2021), 102460.

[22] K.S. Chen, L. Monrouxe, Y.H. Lu, C.C. Jenq, Y.J. Chang, Y.C. Chang, et al., Academic outcomes of flipped classroom learning: a meta-analysis, Med. Educ. (2018), https://doi.org/10.1111/medu.13616. Epub 20180625. PubMed PMID: 29943399; PubMed Central PMCID: PMCPMC6120558.

[23] K.F. Hew, C.K. Lo, Flipped classroom improves student learning in health professions education: a meta-analysis, BMC Med. Educ. 18 (1) (2018) 38. Epub 20180315, https://doi.org/10.1186/s12909-018-1144-z. PubMed PMID: 29544495; PubMed Central PMCID: PMCPMC5855972.

[24] A.J. Greenberg-Worisek, K.A. Campbell, E.W. Klee, N.P. Staff, L.A. Schimmenti, K. M. Weavers, et al., Case-based learning in translational biomedical research education: providing realistic and adaptive skills for early-career scientists, Acad. Med. 94 (2) (2019) 213–216, https://doi.org/10.1097/ACM.0000000000002470. PubMed PMID: 30256254; PubMed Central PMCID: PMCPMC6351155.

[25] A. Burgess, J. Bleasel, I. Haq, C. Roberts, R. Garsia, T. Robertson, et al., Team-based learning (TBL) in the medical curriculum: better than PBL? BMC Med. Educ. 17 (1) (2017) 243. Epub 20171208, https://doi.org/10.1186/s12909-017-1068-z. PubMed PMID: 29221459; PubMed Central PMCID: PMCPMC5723088.

[26] C. Moro, Z. Stromberga, Enhancing variety through gamified, interactive learning experiences, Med. Educ. 54 (12) (2020) 1180–1181. Epub 20200705, https://doi.org/10.1111/medu.14251. PubMed PMID: 32438478.

[27] C. Moro, C. Phelps, Z. Stromberga, Utilizing serious games for physiology and anatomy learning and revision, Adv. Physiol. Educ. 44 (3) (2020) 505–507, https://doi.org/10.1152/advan.00074.2020 (PubMed PMID: 32795126).

[28] A.G. Fitzmaurice, M. Mahar, L.F. Moriarty, M. Bartee, M. Hirai, W. Li, et al., Contributions of the US centers for disease control and prevention in implementing the global health security agenda in 17 partner countries, Emerg. Infect. Dis. 23 (13) (2017), https://doi.org/10.3201/eid2313.170898. PubMed PMID: 29155676; PubMed Central PMCID: PMCPMC5711326.

[29] V. Jain, A. Duse, D.G. Bausch, Planning for large epidemics and pandemics: challenges from a policy perspective, Curr. Opin. Infect. Dis. 31 (4) (2018) 316–324, https://doi.org/10.1097/QCO.0000000000000462 (PubMed PMID: 29846209).

[30] J.W. Buehler, Centers for Disease C, Prevention., CDC's vision for public health surveillance in the 21st century. Introduction, MMWR Suppl. 61 (3) (2012) 1–2. PubMed PMID: 22832989.
[31] Health NIo, National Institutes of Health Physician-Scientist Workforce Working Group Report, National Institutes of Health, Washington, DC, 2014 June, 2014. Report No.
[32] A.M. Andre, A. Lopez, S. Perkins, S. Lambert, L. Chace, N. Noudeke, et al., Frontline field epidemiology training programs as a strategy to improve disease surveillance and response, Emerg. Infect. Dis. 23 (13) (2017), https://doi.org/10.3201/eid2313.170803. PubMed PMID: 29155657; PubMed Central PMCID: PMCPMC5711307.
[33] L. Rosenstock, G.B. Silver, K. Helsing, C. Evashwick, R. Katz, M. Klag, et al., Confronting the public health workforce crisis: ASPH statement on the public health workforce, Public Health Rep. 123 (3) (2008) 395–398, https://doi.org/10.1177/003335490812300322. PubMed PMID: 19006982; PubMed Central PMCID: PMCPMC2289968.
[34] Rising Stress and Burnout in Public Health, Results of a National Survey of the Public Health Workforce [cited 2022 July 3 2022]. Available from, https://debeaumont.org/wp-content/uploads/dlm_uploads/2022/03/Stress-and-Burnout-Brief_final.pdf.
[35] E.M. Bunge, B. Hoet, L. Chen, F. Lienert, H. Weidenthaler, L.R. Baer, et al., The changing epidemiology of human monkeypox-A potential threat? A systematic review, PLoS Negl. Trop. Dis. 16 (2) (2022), https://doi.org/10.1371/journal.pntd.0010141 e0010141. Epub 20220211. PubMed PMID: 35148313; PubMed Central PMCID: PMCPMC8870502.
[36] K.M. Lillibridge, R. Parsons, Y. Randle, A.P. Travassos da Rosa, H. Guzman, M. Siirin, et al., The 2002 introduction of West Nile virus into Harris County, Texas, an area historically endemic for St. Louis encephalitis, Am. J. Trop. Med. Hyg. 70 (6) (2004) 676–681. PubMed PMID: 15211013.
[37] G. Molaei, T.G. Andreadis, P.M. Armstrong, R. Bueno Jr., J.A. Dennett, S.V. Real, et al., Host feeding pattern of Culex quinquefasciatus (Diptera: Culicidae) and its role in transmission of West Nile virus in Harris County, Texas, Am. J. Trop. Med. Hyg. 77 (1) (2007) 73–81. PubMed PMID: 17620633.
[38] H.J. Lee, M. Longnecker, T.L. Calkins, A.D. Renfro, C.L. Fredregill, M. Debboun, et al., Detection of the Nav channel kdr-like mutation and modeling of factors affecting survivorship of *Culex quinquefasciatus* mosquitoes from six areas of Harris County (Houston), Texas, after permethrin field-cage tests, PLoS Negl. Trop. Dis. 14 (11) (2020), https://doi.org/10.1371/journal.pntd.0008860 e0008860. Epub 20201119. PubMed PMID: 33211688; PubMed Central PMCID: PMCPMC7714350.
[39] S. Lerman, E. Eskin, D. Flower, E. George, B. Gerson, N. Hartenbaum, et al., Fatigue risk management in the workplace, J. Occup. Environ. Med. 54 (2) (2012) 231–258.
[40] D. Baker, D. Chappelle, Health status and needs of Latino dairy farmworkers in Vermont, J. Agromed. 17 (3) (2012) 277–287.
[41] A. Ramos, A. Lowe, J. Herstein, S. Schwedhelm, K.L. Dineen, JJ., Invisible no more: the impact of COVID-19 on essential food production workers, J. Agromed. 25 (4) (2020) 378–382, https://doi.org/10.1080/1059924X.2020.1814925.
[42] F. Olea-Popelka, A. Muwonge, A. Perera, A. Dean, E. Mumford, E. Erlacher-Vindel, et al., Zoonotic tuberculosis in human beings caused by Mycobacterium bovis—a call for action, Lancet 17 (1) (2016). E21-E5.
[43] C. Thoen, J. Steele, J. Kaneene, Zoonotic Tuberculosis: Mycobacterium bovis and Other Pathogenic Mycobacteria, Third edition, Blackwell Publishing, 2014, 432 p.
[44] WHO, The challenges of preventing bovine tuberculosis, Bull. World Health Organ. 96 (2018) 82–83, https://doi.org/10.2471/BLT.18.020218.
[45] G.C. Gray, J.A. Merchant, Pigs, pathogens, and public health, Lancet Infect. Dis. 18 (4) (2018) 372–373. Epub 2018/03/28, https://doi.org/10.1016/S1473-3099(18)30158-0. PubMed PMID: 29582757.
[46] G.C. Gray, W.S. Baker, Editorial commentary: the problem with pigs: it's not about bacon, Clin. Infect. Dis. 52 (1) (2011) 19–22. Epub 2010/12/15, https://doi.org/10.1093/cid/ciq051. PubMed PMID: 21148515.
[47] B.D. Anderson, M. Yondon, E.S. Bailey, E.K. Duman, R.A. Simmons, A.G. Greer, et al., Environmental bioaerosol surveillance as an early warning system for pathogen detection in North Carolina swine farms: a pilot study, Transbound. Emerg. Dis. 68 (2) (2021) 361–367. Epub 2020/06/15, https://doi.org/10.1111/tbed.13683. PubMed PMID: 32535997.
[48] B.D. Anderson, M. Ma, Y. Xia, T. Wang, B. Shu, J.A. Lednicky, et al., Bioaerosol sampling in modern agriculture: a novel approach for emerging pathogen surveillance? J. Infect. Dis. 214 (4) (2016) 537–545, https://doi.org/10.1093/infdis/jiw180. PubMed PMID: 27190187; PubMed Central PMCID: PMC4957437.
[49] A. Ramesh, E.S. Bailey, V.L.C. Ahyong, M. Phelps, N. Neff, R. Sit, et al., Microbial diversity in a North American swine farm operation, Sci. Rep. Sci Rep. 11 (2021) 16994.
[50] S. Evans, Hurricane Nicholas Insured Loss Estimated up to $2.2bn by RMS, 2021 September 24, 2021. Report No.
[51] Texas State Overview [Internet] [cited July 27, 2022]. Available from, https://coronavirus.jhu.edu/region/us/Texas, 2022.
[52] D.S. Peel, R. Blach, D. Close, J. Maples, G. Tonsor, D. Aherin, et al., Economic Damages to the U.S. Beef Cattle Industry Due to COVID-19. CR-630, Oklahoma State University, 2020.
[53] United States National Hurricane Center, Costliest U.S. Tropical Cyclones Tables Update, 2018.