Managing Climate-Driven Zoonotic Risk Interagency Workshop Report

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National Nuclear Security Administration

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ACKNOWLEDGMENTS

This report synthesizes the Managing Climate-driven Zoonotic Risk Interagency Workshop held July 20-21, 2022, in Washington, D.C. We would like to thank the Sandia staff who helped plan the workshop and prepare the report, including Jessica Baxter, Jami Butler, Erica Parilla, Jazmine Price, and Jessica Techel. We are grateful to the federal employees and Sandians interviewed in preparation for the workshop, as well as to the federal employees and DOE lab scientists who attended the workshop, provided briefs, and participated in brainstorming.

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1. INTRODUCTION

In July 2022, Sandia National Laboratories hosted a workshop in Washington, D.C., bringing together representatives from eleven Federal Government agencies, responsible for public health, environmental security, and biodefense, as well as six Department of Energy (DOE) National Laboratories, to discuss how to work together to address climate-driven zoonotic disease risk.

The primary goal of this workshop was to provide a forum for Federal and DOE National Lab attendees to share their missions, programs, and capabilities relevant to zoonotic disease emergence, to discuss how to best leverage these collective resources, identify key gaps, and to determine an effective path forward.

Federal agencies in attendance included:

- **Department of Agriculture (USDA)**
- **Department of Commerce (DOC)**
  - National Oceanographic and Atmospheric Administration (NOAA)
- **Department of Defense (DOD)**
  - Defense Threat Reduction Agency (DTRA)
- **Department of Energy (DOE)**
  - Science and Technology (S&T) Division
- **Department of Health and Human Services (DHHS)**
  - Biological Advanced Research and Development Authority (BARDA)
  - Centers for Disease Control and Prevention (CDC)
  - National Institutes of Health (NIH)
  - National Institute of Allergies and Infectious Diseases (NIAID)
- **Department of Homeland Security (DHS)**
  - S&T Ag Threats
  - US Customs and Border Protection (CBP)
  - Office of Health Security
  - Office of Policy
- **Department of the Interior (DOI)**
  - U.S. Geological Survey (USGS)
- **Department of State (DOS)**
- **Environmental Protection Agency (EPA)**
- **National Aeronautics and Space Administration (NASA)**
- **US Agency for International Development (USAID)**

DOE National Labs in attendance included:

- Sandia National Laboratories (Sandia, workshop lead)
- Lawrence Berkeley National Laboratory (LBNL)
- Lawrence Livermore National Laboratory (LLNL)
- Los Alamos National Laboratory (LANL)
- Oak Ridge National Laboratory (ONL)
- Pacific Northwest National Laboratory (PNNL)

As Federally Funded Research and Development Centers (FFRDCs), the DOE National Laboratories serve as a trusted resource for advice, science, and technology for the government. FFRDCs provide a nexus for interagency collaboration, leveraging their unique relationship with the government to further important research which can be translated into pragmatic policy discourses.

1.1. Framing the Problem

Climate change has both acute and chronic impacts on global ecosystems. Acute impacts might include more frequent and severe storms, whereas chronic impacts might include changing geographies of wildlife and/or human populations, and clean water availability. Both acute and chronic impacts of climate change can increase rates and incidence of zoonotic disease. For example, human, animal, and insect migrations, and associated changes in land use, result in species that were previously geographically isolated to share microbes through physical proximity. These interactions could include human exposures to dangerous pathogens to which they are immunogenically naïve. For more examples, see Figure 1.

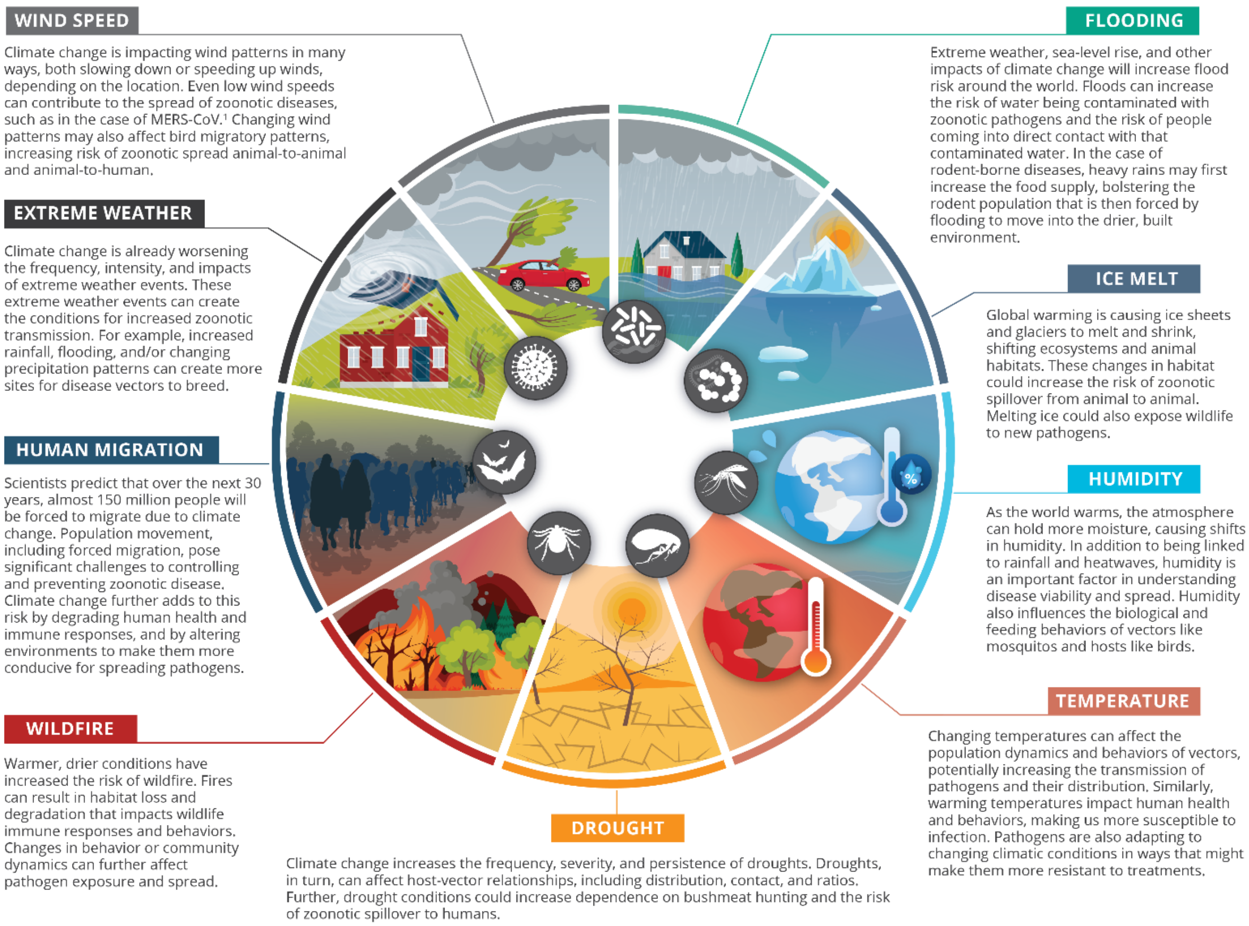

Figure 1. Acute and chronic climate change impacts highlighted in the workshop that influence infectious disease emergence.

Responding to climate-driven zoonotic disease risk will require inter- and transdisciplinary approaches that bring together experts in the climate, environmental, agricultural, wildlife, and epidemiological sciences, with public health policy holders, decisionmakers, and communities. Further, both climate change and zoonoses are inherently global challenges that will require international collaboration. One Health is a transdisciplinary approach working at the global, regional, and local levels that recognizes the interconnectedness between human, animal, and environmental health[2]. We can continue to work to improve interagency communication and collaboration to mitigate resource issues and avoid any duplication of efforts.

Multiple federal agencies have missions, programs, and capabilities relevant to mitigating climate-driven zoonotic risk, with goals of integrating data to generate models and prioritization frameworks that inform preparedness strategies and protect lives. The workshop proved extremely valuable to create a forum where agencies could share with each other their missions, programs, and capabilities, and seed new cross-agency collaborations. Moreover, with the COVID-19 pandemic and monkeypox bringing unprecedented attention to zoonoses, a window of opportunity has opened to improve tools, fill surveillance gaps, increase interagency collaborations to better prepare for emerging and future threats.

1.2. Workshop Structure

The workshop was held over two days, July 20-21, 2022, at the National Press Club in Washington, D.C. The workshop began with a keynote address from Dr. Colin Carlson (Georgetown University), who provided an evidence-based seminar highlighting that climate change has and will continue to increase cross-species viral transmission risk. The two morning sessions of the workshop also included Federal agency and DOE lab briefs, describing missions, programs, and capabilities relevant to zoonotic disease emergence. Afternoon sessions had workshop participants break into small groups to discuss and identify key research questions sparked by the morning briefs, and to discuss critical data and knowledge gaps that would be needed to develop more accurate, predictive models for zoonotic disease emergence. These discussions, moderated by DOE National Lab members, also sought to identify pragmatic next steps to advance new interagency collaborations and sharing of resources.

2. AGENCY BRIEFS

Each agency in attendance at the workshop provided a 15-minute brief on their programming within the scope of the workshop. Table 1 summarizes each agency's mission, capabilities and relevant lines of efforts, and the connections between their work and managing climate-driven zoonotic risk.

Table 1. Summary of Agency briefs

Agency	Mission	Capabilities and Relevant Lines of Effort	Connection to Climate-driven Zoonotic Risk
United States Department of Agriculture (USDA)	The USDA provides leadership on food, agriculture, natural resources, rural development, nutrition, and related issues based on public policy, the best available science, and effective management.	• Climate-smart agriculture, forestry, and clean energy • Advancement of racial justice, equity, and rural prosperity • Food and nutrition security • Creating new market opportunities in agriculture	USDA's efforts in animal and plant health and welfare, such as with the Animal and Plant Health Inspection Service (APHIS), strongly support defense against climate-driven zoonotic risk. Efforts to develop novel biotechnologies, including through the establishment of a National Bio and Agro-Defense facility, provide capabilities for advanced research and countermeasure development. USDA's Agricultural Research Service examines animal and crop safety, assesses natural resources, and maintains test plots for field research to study sustainable agricultural practices for the future amidst climate change.
Department of Commerce – National Oceanic and Atmospheric Administration (NOAA)	NOAA provides key stakeholders in the public health sector with the environmental intelligence needed to mitigate emerging health threats. NOAA supports climate services for health domestically and internationally.	• Environmental observing and sensing of variables, such as temperature, land cover, humidity, and moisture • Operational role in disease prediction through forecasting ecological changes in response to environmental drivers	NOAA's environmental monitoring is of critical importance for understanding climate change and how it drives disease risk. Changes in environmental conditions, such as temperature, humidity, and precipitation, are directly correlated to disease ecology; the many methods NOAA employs to monitor these conditions generate an enormous

Agency	Mission	Capabilities and Relevant Lines of Effort	Connection to Climate-driven Zoonotic Risk
			amount of relevant data which can be integrated into models and forecasts.
Department of Defense – Defense Threat Reduction agency (DTRA)	DTRA's Chemical and Biological Defense Program (CBDP) works to anticipate future threats and deliver capabilities that enable the Joint Force to survive, fight, and win in chemical and biological-contested environments through a coordinated effort designed to neutralize adversarial CB threats. DTRA considers engineered and natural threats in parallel as they develop these capabilities.	• Licensing for medical countermeasures • Development of capabilities to counter current and emerging threats • Development and assessment of wearables • Creation and testing of tools for modeling and responding to disease outbreaks	Potential exposure to biological threats in the battlefield is rapidly becoming a focal point of military preparedness. Ensuring force readiness and deployment of proper protective equipment and medical countermeasures (MCMs) is a key facet of maintaining operational readiness and force superiority around the globe and in any environment.
Department of Health and Human Services – Biomedical Advanced Research and Development Authority (BARDA)	BARDA develops medical countermeasures (vaccines, drugs, therapies, diagnostic tools, etc.) to protect Americans and respond to 21st century health security threats (e.g., emerging infectious diseases) by forming unique public-private partnerships.	• Addressing antimicrobial resistance (AMR) and other biothreats • Clinical indications for approved microbials • Development of first-in-class compounds/novel mechanisms of action • Discovery of significant improvements in drug mechanisms and formulations	As new diseases emerge and re-emerge, the rapid development of medical countermeasures such as vaccines, therapeutics, and diagnostics helps to quickly neutralize infectious disease threats and save lives. Importantly, resistance in pathogens is making existing therapies obsolete, and staying ahead of emerging resistance is key in protecting animal, human, and environmental health against climate change.
Department of Health and Human Services – Centers for Disease Control and Prevention (CDC)	CDC has been charged with addressing climate change-related health risks CDC has an agency-wide Climate and Health Task Force with the mission to detect, investigate, forecast, track, prevent, and respond to the public health threats of climate change, addressing health inequities	• Preparedness, response, prevention, and adaptation activities • Research, implementation, science, and evaluation of surveillance analytics and modeling/forecasting	A state of informed preparedness is essential to mitigating the climate change-driven infectious disease threats and is reliant on community level preparedness and response capabilities being developed. CDC leads these efforts and studies the methods and efficacy

Agency	Mission	Capabilities and Relevant Lines of Effort	Connection to Climate-driven Zoonotic Risk
	and strengthening community resilience.	• Collaboratively identifying infectious disease emergence and issues • Development and implementation of agency-wide strategies to address climate change-driven health impacts • Community preparedness for climate change	around them. From a strategic level, CDC uses modeling, forecasting, and analytics to provide policy recommendations that the public and providers can rely upon to reduce their local risk of disease threats.
Department of Health and Human Services – National Institutes of Health (NIH)/National Institute of Allergy and Infectious Diseases (NIAID)	Conduct and support basic and applied research to better understand, treat, and prevent infectious, immunologic, and allergic diseases. For infectious disease, there is a focus on countermeasure R&D, including genomics, vaccines, therapeutics, novel vector control, diagnostics, clinical studies, and the expansion of research capabilities.	• Climate Change and Health Initiative reduces health threats broadly and builds resilience in individuals, communities, and nations • Identification of disease risks and development of mitigation strategies • Development of necessary research infrastructure (Biocontainment facilities, NIAID Vaccine and Treatment Evaluation Units) and workforce • Establishment of networks (i.e., Centers for Research on Emerging Infectious Diseases) relevant to climate change-related zoonoses	Networks and infrastructure for countering climate driven infectious disease threats are important as they enable capacity development, information sharing, and high-impact research to be done safely and securely. Risk identification and mitigation must be performed rapidly in the event of a biological event, and the work of the NIH and NIAID directly supports bolstering these capacities at all levels.
Department of Homeland Security (DHS)	DHS' strategic goals for climate change are to safeguard the homeland from current and projected climate-	• Lead policy for response to food, animal, and agricultural incidents	Ports of entry (POE) are critical sites for screening. DHS is charged with leading the efforts to

Agency	Mission	Capabilities and Relevant Lines of Effort	Connection to Climate-driven Zoonotic Risk
	driven disasters; foster resilience, adaptation, and recovery efforts; enable a thriving economy; and model sustainable resilience.	• Coordination of screening for incoming domestic products • Facilitate training programs • Engagement in cross-border activities	prepare for and respond to national emergencies, including those correlated with climate change
Department of the Interior – United States Geological Survey (USGS)	USGS provides science on the health of our ecosystems and environment, including the impacts of climate and land-use change.	• Monitor unusual mortality events in wildlife and shifting wildlife distributions • Monitor phenological changes • Consider One Health implications of new policies and initiatives • Lead development of real-time climate adaptation tools for vector control	USGS provides an on-the-ground role for tracking disease in wildlife, fish, throughout ecosystems. From a policy side, USGS advances disease preparedness concepts through the development of climate change adaptation tools and methods for vector control.
Department of State – Bureau of Oceans and International Environmental and Scientific Affairs (OES)	OES provides American leadership, diplomacy, and scientific cooperation to conserve and protect the global environment (including oceans, space) for prosperity, peace, and security of this and future generations.	• Lead foreign affairs aspect of government, diplomacy, and scientific cooperation • Establishment of collaborative research opportunities • Facilitation of on-the-ground information communication and identification of needs for aid and partnerships	As the premier representation for the US government abroad, the State Department serves as the US' eyes and ears internationally and can identify opportunities for the US to assist and collaborate. They play a key role in advancing our partnerships to build health preparedness and response capabilities, particularly in underserved and underdeveloped areas.
Environmental Protection Agency (EPA)	The EPA is responsible for the protection of human and ecosystem health, including impact assessments of climate change and pesticides.	• Supporting role in countering zoonotic disease • Development, registration, and	The EPA plays a major role in shaping environmental policies that directly impact efforts to counter climate change and zoonotic disease. The EPA works

Agency	Mission	Capabilities and Relevant Lines of Effort	Connection to Climate-driven Zoonotic Risk
		regulation of pesticides • Environmental sampling and analysis, biosurveillance, remediation, and carcass disposal • Monitor and model climate, hydrology, and socioeconomic variables • Microbial exposure forecasting in recreational waters	through sampling, analysis, and remediation of hazard incidents, including those of disease and animal mortality. EPA also plays a key role in protecting human freshwater systems by forecasting harmful algal blooms and other toxic growth events of microbes that contaminate water systems.
National Aeronautics and Space Administration (NASA)	NASA advances scientific knowledge and understanding of the Earth, the Solar System, and the Universe. Their applied science program enables decisionmakers to apply insights to benefit the economy, health, quality of life, and environment.	• Lead Earth observations • Support the use of Earth observations in air quality management and public health, particularly regarding infectious disease and environmental health issues • Lead Group on Earth Observations (GEO) Health Community of Practice • Applied Remote Sensing Training Program (ARSET)	NASA delivers technology, expertise, global observations, and applications to better understand Earth systems globally over the long-term and in the short-term. NASA works directly with users to apply this data to questions of ecological forecasting, health and air quality, and climate resilience. NASA also leads a global network of stakeholders interested in using Earth observation data to improve health decision-making.

3. DEPARTMENT OF ENERGY NATIONAL LABORATORIES

As FFRDCs, the national laboratories are well-suited to be centers of interagency collaboration. The cross-domain lines of effort entrusted to the national laboratories by the USG provides a crucial link for fostering research and development which spans multiple mission spaces and topical areas.

The national laboratories in attendance provided detailed overviews of their capabilities, ongoing, and future work pertinent to climate change and zoonotic disease. The major thrust areas described by all six labs are outlined and described below in Table 2, including a brief sampling of relevant projects and lines of effort.

Table 2. Summary of DOE national laboratory briefs

Capabilities	Specific R&D Lines of Effort	Connection to Climate-driven Zoonotic Risk
Sensor Development	• Hyperspectral diagnostics • Multi-omic tools and analyses • Environmental sensing • High-fidelity spatial and temporal sensing	High-throughput sensors for rapid diagnostics and characterization are essential in disease detection. Multi-omics (genomics, proteomics, transcriptomics, etc.) are key in elucidating mechanisms of host-pathogen interactions. Environmental sensing informs modeling for vector/reservoir ecology, disease emergence, and prediction of spillover events.
Medical Countermeasure (MCM) Development	• Advanced gene editing /synthetic biology research • Antibody/peptide/small molecule design • Artificial intelligence (AI) for systems design • AI and machine learning for efficient biomanufacturing • High-throughput drug candidate screening and accurate molecular structure predictions	Advanced biotechnologies, including genomic technologies AI, and machine learning are enabling rapid medical countermeasure development to create therapeutics, vaccines, and other treatments for existing and emerging diseases. As pathogens evolve to resist existing therapies (e.g., antivirals, antibiotics) and evade host defense mechanisms, predictive computing can quickly identify new drug candidates. New manufacturing processes could be discovered as well.
Climate and Ecosystem Modeling	• Disease ecology monitoring and modeling • Spillover event predictive modeling • Multi-variable global change analysis • AI and machine learning for agricultural and food supply systems optimization	As climate change drives ecosystem shifts worldwide, monitoring and modeling of the organisms within them is critical for understanding risks of disease spillover. Development of tools for global monitoring of the ecology of arthropod vectors, migratory birds, and sea mammals provide us with knowledge to predict likely encounters between humans and novel diseases. Agricultural systems and novel plant pathogens are vulnerable to climate change, which can be mitigated by leveraging new computational tools to optimize crop placement, nutrient cycling, and soil microbiology interactions to confer resistance to disease.

Capabilities	Specific R&D Lines of Effort	Connection to Climate-driven Zoonotic Risk
Host-pathogen Interaction Analysis	• Multi-omics analyses of pathogenesis, pathogen attachment and cellular infection • Organ on a chip • High performance computing and predictive genomic modeling for disease and variant emergence	Emergence rates of novel infectious disease and spillover events has increased with climate change. Advanced technologies for rapid and high-throughput pathogen assessment provide data that empowers the development of therapeutics. Understanding how pathogens interact with humans, animals, and plants at the cellular level provides the capability to forecast and predict cellular interactions and defend against them by developing chemical compounds and other therapeutic technologies.
Real-time Environmental Monitoring	• Atmospheric radiation/composition sensing • Arctic climatology and permafrost research • Cross-modality measurements (ground, air, remote sensing) • Data stream integration for impact assessments (wildfires, erosion events, etc.) • Experimental scenario development and simulation	Environmental monitoring is essential for understanding the impacts of climate change on vector, reservoir, and disease ecology. Environmental variables like forest canopy density, atmospheric composition, sea and land temperatures, and land use can be sensed in several ways and translated as proxies to understand how populations respond to climate change. Real-time monitoring for natural disasters, such as wildfires and floods, could play a key role in preventing disease in affected areas. Simulations informed by integrated data streams from multi-sensor monitoring could provide high fidelity predictions to inform preparedness and mitigation efforts.
Vector-borne Disease Surveillance	• Vector surveillance and pathogen identification • Genomics and bioinformatics for pathogen genotyping • Disease vector ecology and migration, assessment of spread to new ecosystems	Vector-borne diseases are among the most sensitive to environmental factors like temperature, humidity, and precipitation. Arthropod and other vector surveillance capabilities are critical for modeling and forecasting disease burden and driving public health programming. Genomics and bioinformatics tools are applied to monitor the pathogens carried by certain vectors, as well as the ranges of these vectors and how they respond to shifts in climate.
Disease Forecasting and Epidemiology	• Situational awareness and anomaly detection • Integrated medical intelligence (news, open-source, wildlife health, pharmaceutical purchases monitoring) • Zoonotic disease risk modeling	Medical intelligence is a critical and growing effort as the impacts of high-consequence infectious disease are recognized. Situational awareness capabilities, open-source medical intelligence, and anomaly detection can drive the ability to forecast and get ahead of outbreaks and novel disease events.

4. WORKSHOP SMALL GROUP DISCUSSION THEMES

This workshop also sought to identify pragmatic next steps to advance collaboration, as well as to encourage continued momentum for work in these areas through new interagency synergies and sharing of resources and knowledge. Towards this, attendees of the workshop participated in focused discussions led by moderators from the national laboratories. These group discussions centered on identifying research questions emerging from the morning briefings, knowledge gaps, and on understanding the role of national laboratories in advancing government efforts through fundamental and applied research, advisory, and technological innovation, and how these laboratories can be leveraged by the USG to drive progress in key research and policy areas.

Figure 2 depicts the overarching themes that emerged from the small group discussions, including needs for data availability, standardization, and integration, which together could enable more accurate and informative predictive disease emergence models, as well as the need for disease and ecology modeling and threat prioritization tools for decision makers, and improved public communication, all to reach a state of informed preparedness.

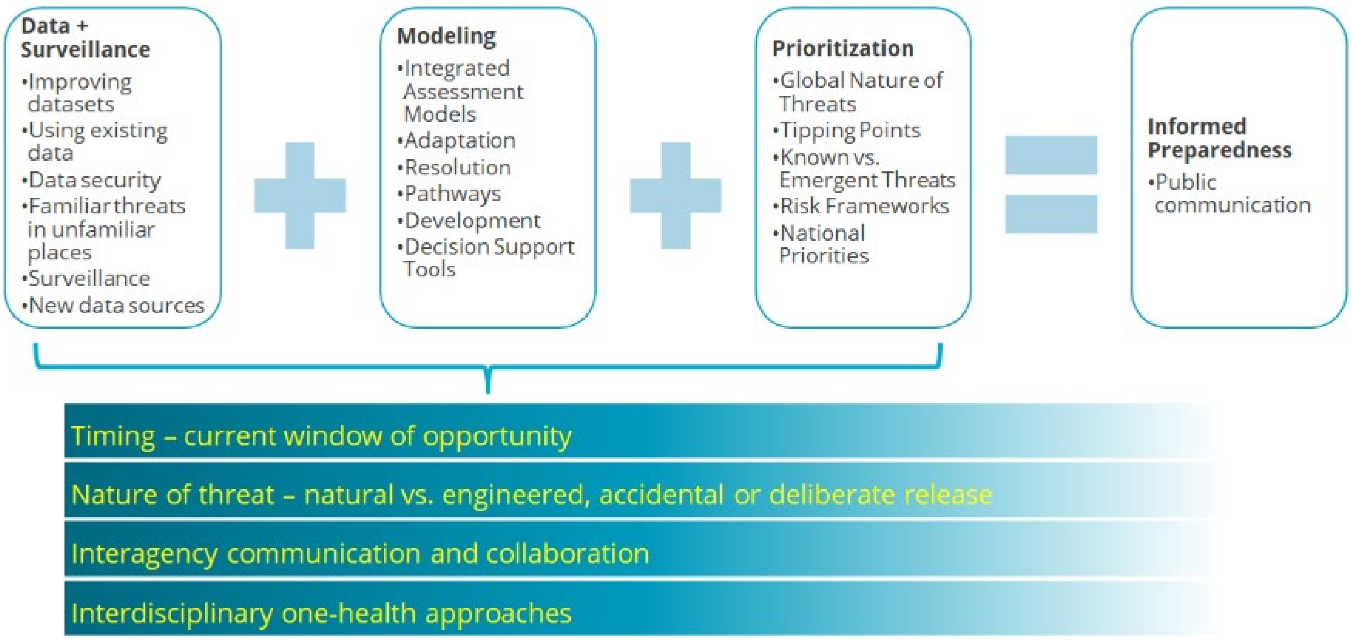

Figure 2. Themes that emerged from the workshop small group discussions

4.1. Data and Surveillance

4.1.1. Existing Data Quality, Accessibility, and Security

An abundance of data, collected through various systems, already exists for measuring and monitoring vector, pathogen, and disease emergence (see Figure 3) but many barriers prevent this data from being accessed and used to its fullest extent. Challenges with using existing data include low visibility outside of specific organizations, lack of standardization, and parsing its sheer volume.

With increased data sharing and accessibility come challenges to data security. Protecting sensitive information (i.e., personally identifiable information) is a top concern as is protecting datasets from adversarial threats, including the potential for disinformation resulting from manipulated data or analyses.

Researchers need to critically examine the quality of existing data and establish safeguards for ensuring data quality and integrity as it is produced and accessed.

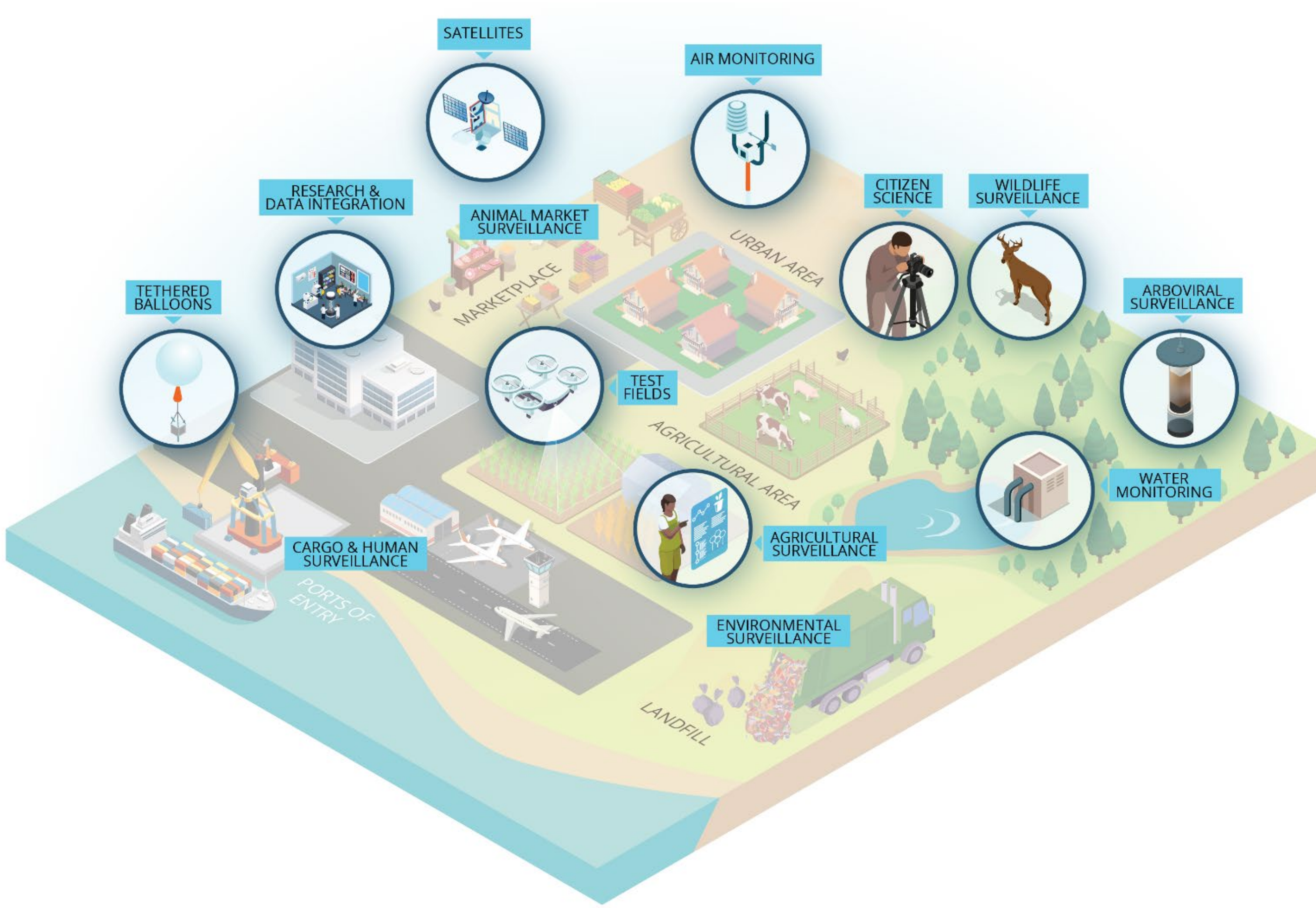

Figure 3. Pathogen and disease surveillance strategies highlighted in the workshop that are currently employed across the USG and DOE National Laboratories.

4.1.2. Data Gaps

Even with data currently available, gaps must be filled to reach the goal of informed preparedness. Most datasets do not reflect the multi-dimensional nature of climate-related zoonotic risk, making it difficult to accurately correlate climate change indicators with individual-level epidemiological information. There also is a clear need for higher spatiotemporal resolution data to allow for the downscaling of models to better assess risk and produce decision-enabling predictions.

Federal agencies interested in this issue could consider standardizing datasets to allow for better integration and the cross-walking of disparate datasets, as well as setting clear expectations for data sharing. Hosting the data on an open-source platform or taking advantage of cloud-computing services could improve visibility and accessibility, as could formal outreach activities by organizations to facilitate use by non-agency users, such as data workshops. Approaches for harnessing big data, including the application of machine learning and artificial intelligence, could also transform our understanding in this space.

While much has been made in the press about the origin of COVID-19, we must better understand in what contexts the nature of these threats matters to identifying appropriate mitigation strategies. There is also the need, especially if climate change exacerbates zoonotic risks, to develop threat-agnostic solutions that can address pathogen groups and zoonoses more generally.

Researchers should be aware of the biases inherent in existing data and data collection methods. For example, rural community health data is often unavailable or limited due to inadequate resources, including both funding and training. This rural data gap restricts our understanding of risk and surveillance capabilities, compounding the threat of climate-related zoonoses on top of the health disparities already facing these communities. We should not only be aware of bias but actively work to address it in this research.

4.1.3. Need for Increased Surveillance

A widespread, integrated surveillance system is needed to detect disease emergence in human and animal populations as early as possible and will require increased agency coordination. An effective system would integrate biological data (e.g., animal-to-animal), environmental data (e.g., air, soil, water, waste), and diverse data collection technologies (e.g., remote sensing). Existing surveillance streams should be leveraged to detect other potential diseases. More field-forward diagnostics could improve early detection, but mechanisms must also be in place for rapidly sharing information with appropriate stakeholders. A comprehensive surveillance system could also incorporate novel data sources, such as citizen science and information collected via camera-based mobile apps.

In his keynote presentation, Dr. Colin Carlson described an impact of climate change as "familiar threats in unfamiliar places," in this case altering disease distribution, abundance, and infection rates. He described specific zoonotic risk factors related to climate change including geographic and seasonal occurrence of disease, animal and human migration, habitat/community/range shifts, invasive species distribution, and host/reservoir/human physiology and susceptibility factors. His presentation was extremely compelling that we need to better understand how changes in these factors alter human-pathogen interactions and transmission routes. As adaptions to climate change will include changing patterns of land use and animal migrations and will create opportunities for viral and bacterial sharing among previously geographically separated species of wildlife, he emphasized that expanded longitudinal wildlife surveillance and geographical tracking, paired with human disease surveillance, is critical for understanding pathogen movement and evolution[3].

4.2. Modeling

To optimize informed preparedness, models must integrate environmental, epidemiological, socio-economic, ecological, agricultural and climate systems at resolutions appropriate for decision-making at multiple levels. These integrated assessment models are needed to understand the pathways by which acute and chronic climate change impacts will exacerbate zoonotic risk and to identify the environmental and ecological determinants of disease incidence and prevalence. Incorporating climate adaptation into risk models will also be critical, especially as we examine whether interventions will be effective against climate-adapted organisms.

In order to be useful, models of climate-driven zoonotic risk should incorporate state-of-the-art science and produce decision-relevant information. Models are needed to support 1) predictive, actionable forecasting; 2) assessment of mitigation strategy effectiveness; and 3) scenario planning. Researchers also need not only to quantify model uncertainty but identify strategies for communicating that uncertainty to decision-makers.

4.3. Prioritization

Risk prioritization will improve informed preparedness by guiding resources to the research, development, and mitigation activities that address the greatest risks. While some organizations have developed risk prioritization frameworks and tools, the question remains whether there is value in having federal administration-level priorities in this area, or if the focus should be even wider considering the global nature of these threats. Many choices must be made in prioritizing this work. Do we focus more on identified threats or unknown potential threats? Should we prioritize threats that will require a whole-of-government approach to address, such as with COVID-19? Are there risks that could coalesce into health 'tipping points' that should be prioritized? Any prioritization framework should consider the associated security risks of climate-driven zoonoses, as well as the intersectional factors (e.g., poverty, gender) that contribute to vulnerability and risk.

4.4. Informed Preparedness

Public communication is a critical element of informed preparedness that has run into challenges in recent years as exemplified by communication patterns observed during the COVID-19 pandemic. We must learn more about what motivates mistrust in the public and develop strategies for building trust around the science of understanding and responding to emergent disease. Federal agencies should be careful to avoid overpromising results. Another lesson from the COVID-19 pandemic is the importance of identifying strategies to quickly counter misinformation and disinformation.

Lastly, as a community, we want to share and apply the lessons we learn from investigating and managing climate-driven zoonotic risk to other important climate and human-health threats.

5. NEXT STEPS

This workshop aimed to increase the federal government's capability to understand and respond to climate-driven zoonotic risk through informed preparedness. More work is needed to map the specific Agency efforts in this space, including priority interests, capabilities, and areas for partnerships. To improve their effectiveness, agencies should consider ways of improving public communication, such as engaging social scientists, and prioritize making data and information available to decision-makers with an emphasis on increasing health equity.

Key insights from the workshop as described in this report included:

Existing Data Quality, Accessibility, and Security

- An abundance of data, collected through various systems, already exists for measuring and monitoring vector, pathogen, and disease emergence but many barriers prevent this data from being accessed and used to its fullest extent. Challenges with using existing data include low visibility outside of specific organizations, lack of standardization, and parsing its sheer volume.
- Researchers should establish safeguards for ensuring data quality and integrity as it is produced and accessed.

Data Gaps

- Most datasets do not reflect the multi-dimensional nature of climate-related zoonotic risk, making it difficult to accurately correlate climate change indicators with individual-level epidemiological information.
- There is a need for higher spatiotemporal resolution data to allow for the downscaling of models to better assess risk and produce decision-enabling predictions.

Need for Increased Surveillance

- A widespread, integrated surveillance system is needed to detect disease emergence in human and animal populations as early as possible and will require increased agency coordination. An effective system would integrate biological data (e.g., animal-to-animal), environmental data (e.g., air, soil, water, waste), and diverse data collection technologies (e.g., remote sensing).

Modeling

- Models should be generated that integrate environmental, epidemiological, socio-economic, ecological, agricultural and climate systems at resolutions appropriate for decision-making at multiple levels. These integrated assessment models are needed to understand the pathways by which acute and chronic climate change impacts will exacerbate zoonotic risk and to identify the environmental and ecological determinants of disease incidence and prevalence. Incorporating climate adaptation into risk models will also be critical, especially as we examine whether interventions will be effective against climate-adapted organisms.

Prioritization

- Risk prioritization will improve informed preparedness by guiding resources to the research, development, and mitigation activities that address the greatest risks.

There is interest in creating a working group to further build community and facilitate cooperation. If you are interested in working with Sandia National Labs or have questions about this report, please contact Catherine Branda (cbranda@sandia.gov), Anthony Falzorano (arfalza@sandia.gov), or Diana Hackenburg (dmhacke@sandia.gov). A series of follow-on workshops are being planned to conduct deep dives on three topics: data sharing and gaps, modeling, and surveillance gaps.

6. AUTHOR'S DISCLOSURE STATEMENT

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525. This paper describes objective technical results and analysis. Any subjective views or opinions that might be expressed in the paper do not necessarily represent the views of the U.S. Department of Energy or the United States Government.

7. FUNDING

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8. REFERENCES

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[3] Carlson, C.J., Albery, G.F., Merow, C. *et al.* Climate change increases cross-species viral transmission risk. Nature 607, 555–562 (2022). https://doi.org/10.1038/s41586-022-04788-w

APPENDIX A. AGENDA

Copies of the briefings are available to attendees via the Sandia Managed File Transfer. Contact Diana Hackenburg, dmhacke@sandia.gov, for access.

Wednesday, July 20

Time (EDT)	**Topic**
7:30 a.m.	Sign-in, Badging, and Breakfast
8:30 a.m.	Welcome, Introductions, and Objectives
9:30 a.m.	Keynote Speaker: Dr. Colin Carlson, Georgetown University, "*Climate change and the next pandemic: The view from the event horizon*"
10:30 a.m.	Break
10:45 a.m.	Agency Briefs: DOS, NASA, CDC, DTRA, EPA
12:45 p.m.	Lunch On Your Own (many local options)
2:00 p.m.	Assigned Small Groups: Brainstorming Topics and Research Questions of Mutual Interest
3:30 p.m.	Break
3:45 p.m.	Small Group Report-outs
4:45 p.m.	Define Day Two Objectives
5:00 p.m.	Adjourn

Thursday, July 21

Time (EDT)	**Topic**
7:30 a.m.	Breakfast
8:30 a.m.	DOE Lab Capabilities Briefs • Dan Jacobson (ONL) – Study and modeling of climate and ecosystem changes • Andy Glen (Sandia) – Real-time environmental monitoring • Jeanne Faire (LANL) – Vector-borne disease surveillance • Dina Weilhammer (LLNL) – Host pathogen interactions • Ben Brown (LBNL) – Rapid sensor and countermeasure development • Lauren Charles (PNNL) – Disease forecasting and epidemiology
9:45 a.m.	Break
10:00 a.m.	Agency Briefs: NOAA, NIAID, BARDA, DHS, USGS, USDA
12:30 p.m.	Lunch On Your Own (many local options)
1:45 p.m.	Assigned Small Groups: Brainstorming Topics and Research Questions of Mutual Interest
3:15 p.m.	Break
3:30 p.m.	Small Group Report-outs
4:30 p.m.	Path Forward/Synopsis (rescheduled to on-line meeting Aug 16, 2022)
5:00 p.m.	Adjourn

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