RESEARCH ON TAP

Climate Change and Infectious Diseases

Wednesday, March 27, 2024

bu.edu/research/events

BOSTON UNIVERSITY

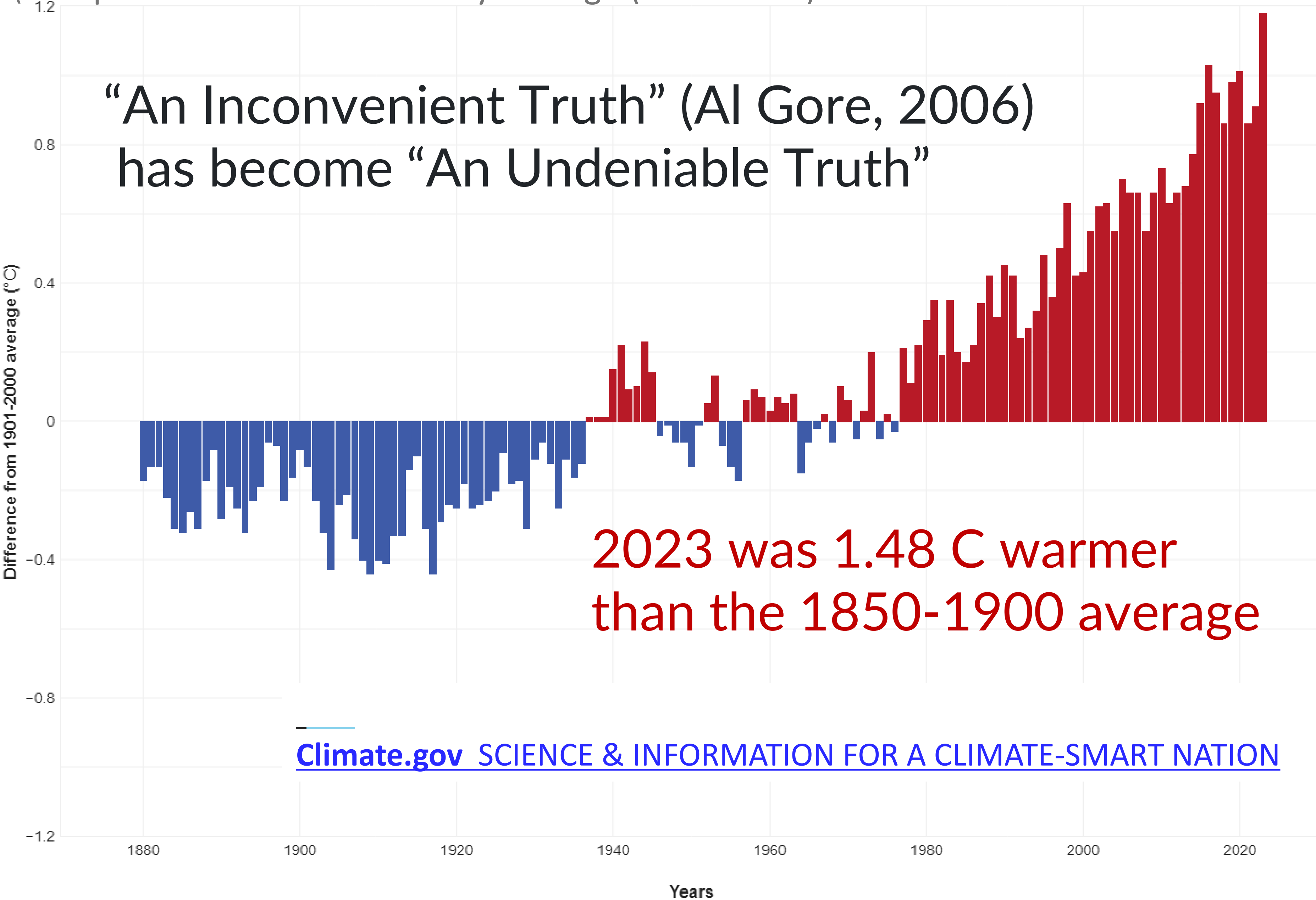
Boston University Office of Research

Agenda

- Welcome Remarks
- Presentations
  - Bruce T. Anderson
  - Ethan Deyle
  - Adam Hume
  - Meg A. Younger
  - Fabiana Feitosa-Suntheimer
  - Jessica Leibler
  - Michael Dietze
  - Kayoko Shioda
  - Les Kaufman
- Panel
  - David Hamer
  - Greg Wellenius
  - Nahid Bhadelia
  - Carly Ching
  - Rebecca Pearl-Martinez
  - Yannis Paschalidis
- Q&A
- Closing Remarks

GLOBAL AVERAGE SURFACE TEMPERATURE

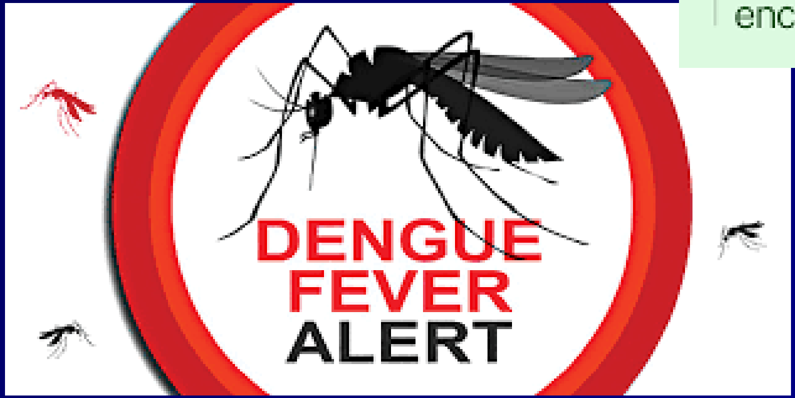
(Compared to the 20th-century average (1901-2000)



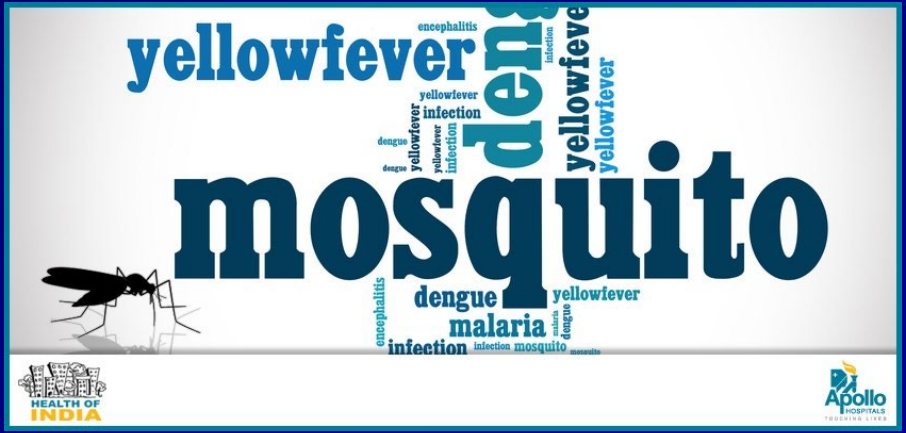

Eastern Equine Encephalitis
is spreading rapidly across the US. Learn how to naturally protect yourself from the EEE Virus with these facts & prevention tips!

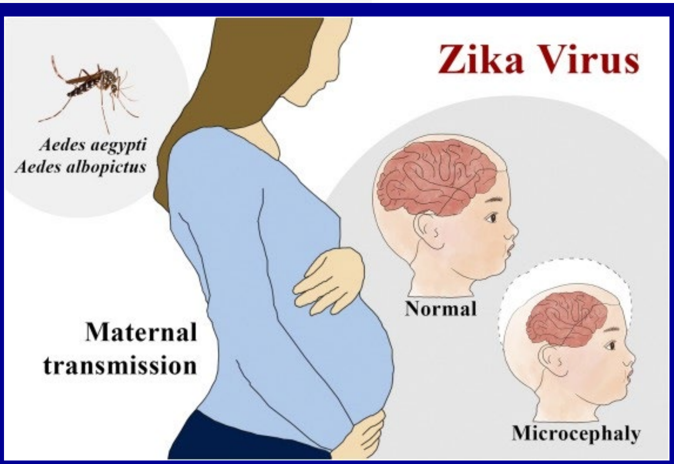

Health alert
Japanese encephalitis virus
NSW


WEST NILE VIRUS
How do you get it?
Mosquitoes bite infected birds, then bite humans.
What if you think you have it?
Only about 20% of people have any symptoms at all. Those are most often mild, flu-like complaints.
Symptoms usually show up 3 -14 days after being bitten by an infected mosquito.
Fewer than 1% of people get a serious illness that can be deadly.
If you develop severe headaches or confusion, see a health care provider right away.
How do you fight it?
Remember the 4 D's
Use an insect repellant such as DEET, picaridin or IR3535.
Drain standing water around your house routinely. Remember to drain tires, cans, flowerpots, clogged gutters, rain barrels, toys and puddles.
Mosquitoes are most active at dawn and dusk. Stay inside, or take precautions to prevent mosquito bites during these times.
Dress in long sleeves and pants in areas where mosquitoes are active.


DENGUE
FEVER
ALERT


Chikungunya
Outbreak
Alert


yellowfever
encephalitis
yellowfever
infection
dengue
yellowfever
mosquito
dengue
malaria
infection
HEALTH OF INDIA
Apollo HOSPITALS


Zika Virus
Aedes aegypti
Aedes albopictus
Normal
Maternal transmission
Microcephaly

Climate Change Impact on Human Health

Climate effects:
Temperature
Wild fires
Precipitation
Sea level rise
Flooding

Food insecurity, crop failures → Malnutrition, mass migration
Immune dysfunction

Extreme weather events → Infectious disease exposure,
Environmental damage,
Economic impacts

Thermal extremes → Altered immune function at cold and hot extreme temps

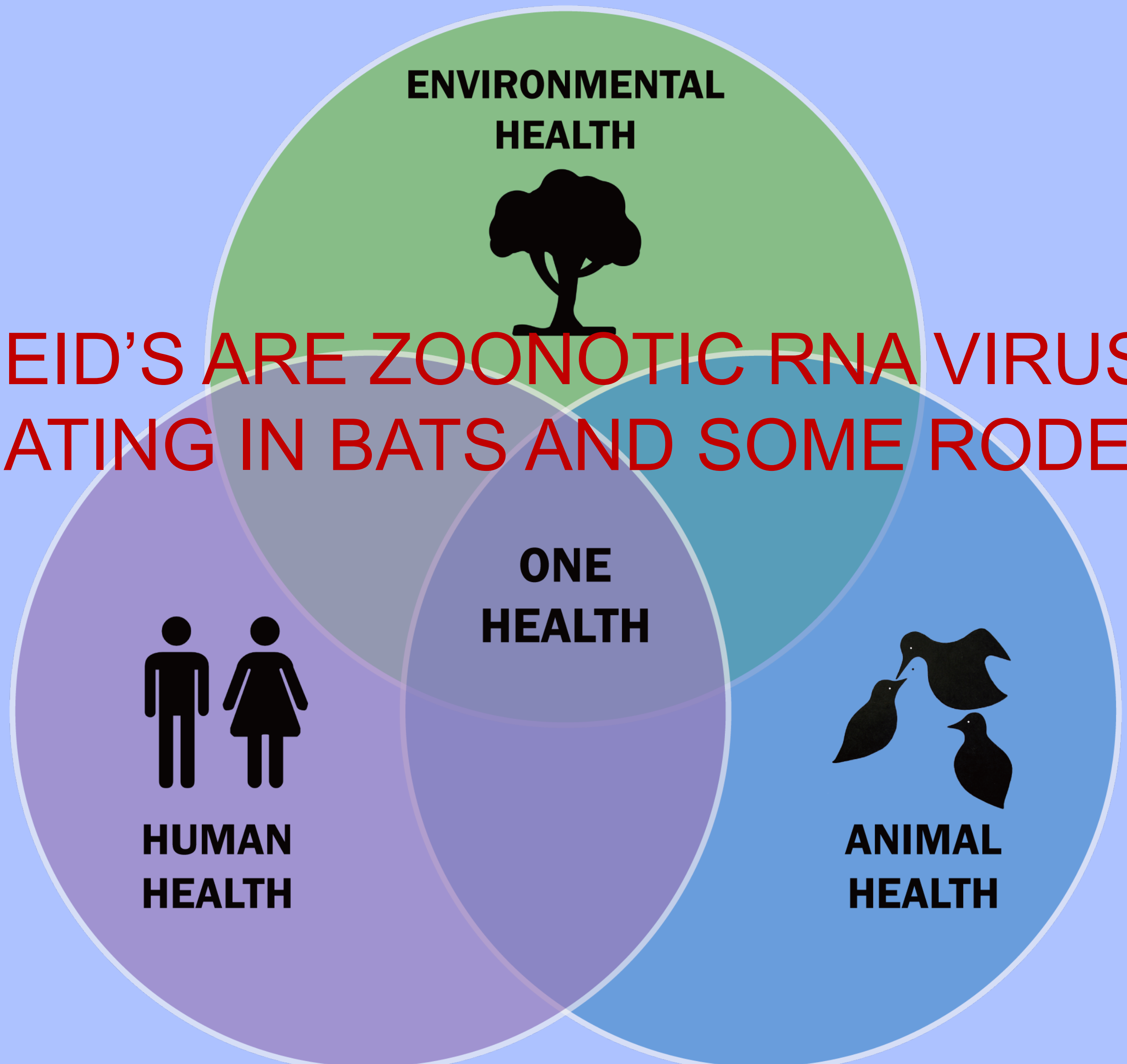
Air pollution → Respiratory diseases acute and chronic

Increases in vectors, and pathogens → Infectious diseases

Thawing permafrost may free novel and known bacterial, viral, parasitic and fungal pathogens, and new AMR. PMC10326340

THE "ONE HEALTH" PARADIGM: INTERACTIONS AT THE INTERFACES

MOST EID'S ARE ZOONOTIC RNA VIRUSES ORIGINATING IN BATS AND SOME RODENTS

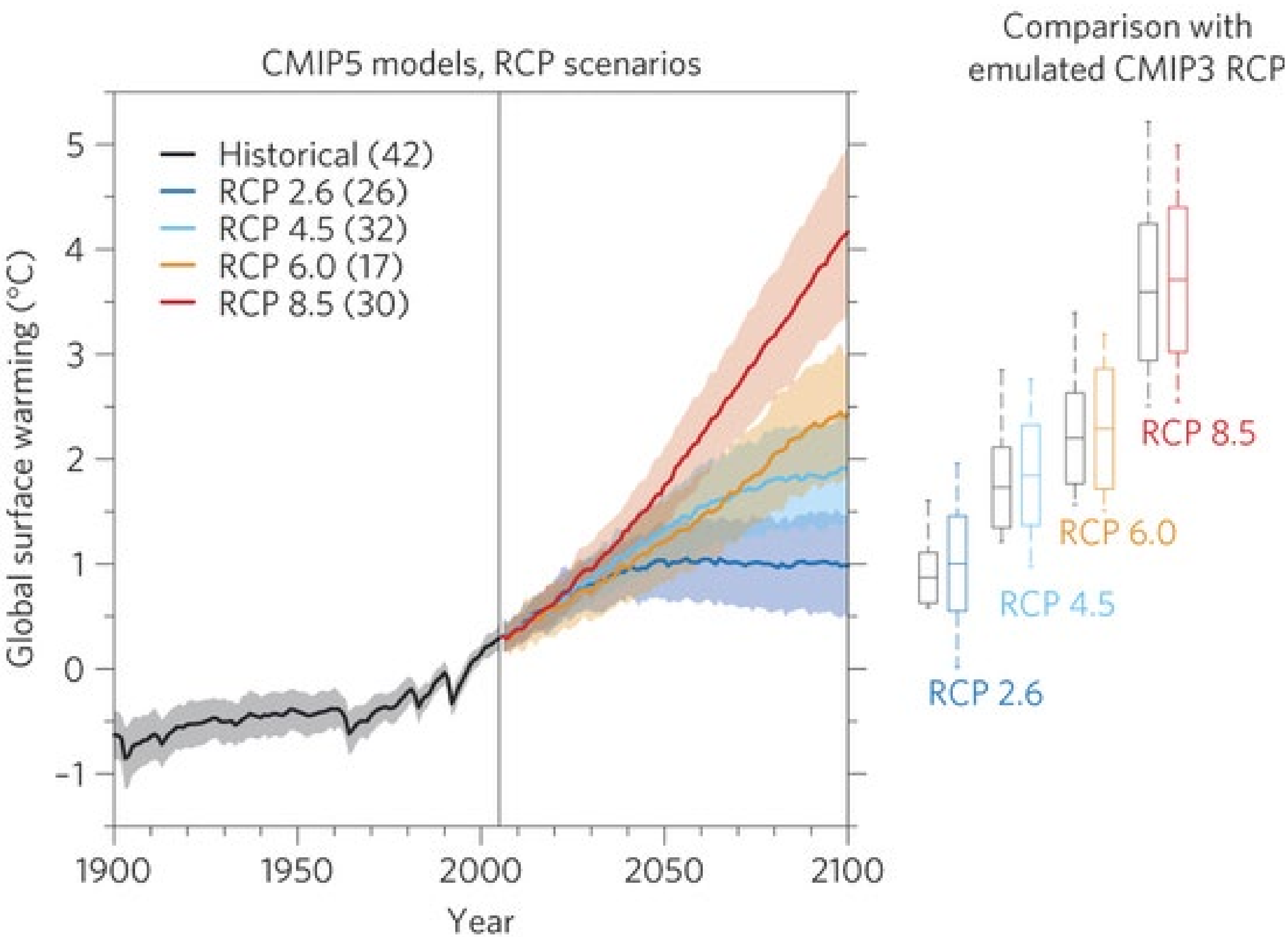


Regional Changes in Exposure to Extreme Heat

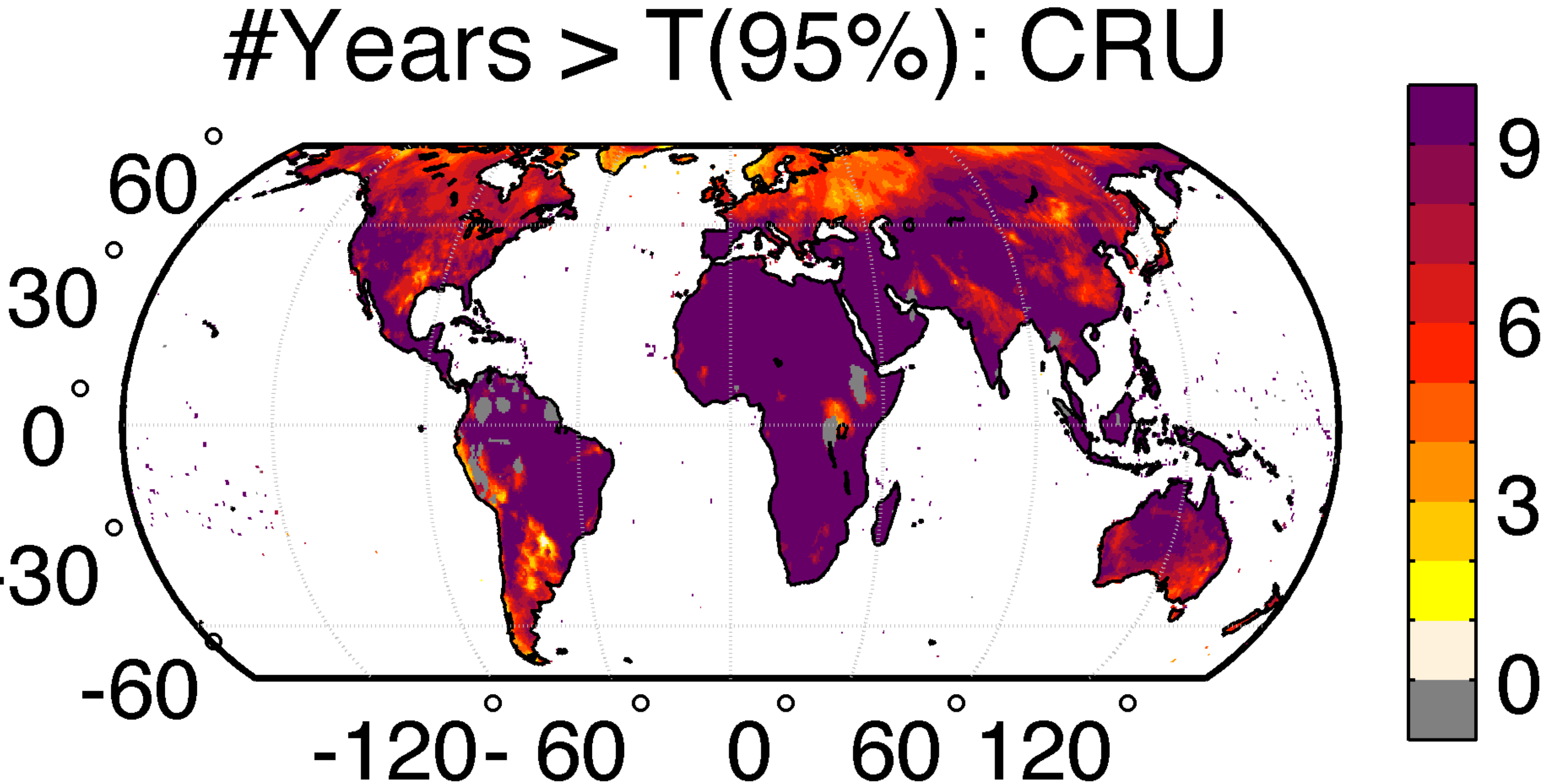
Bruce T. Anderson

Professor and Associate Chair
Earth & Environment, CAS

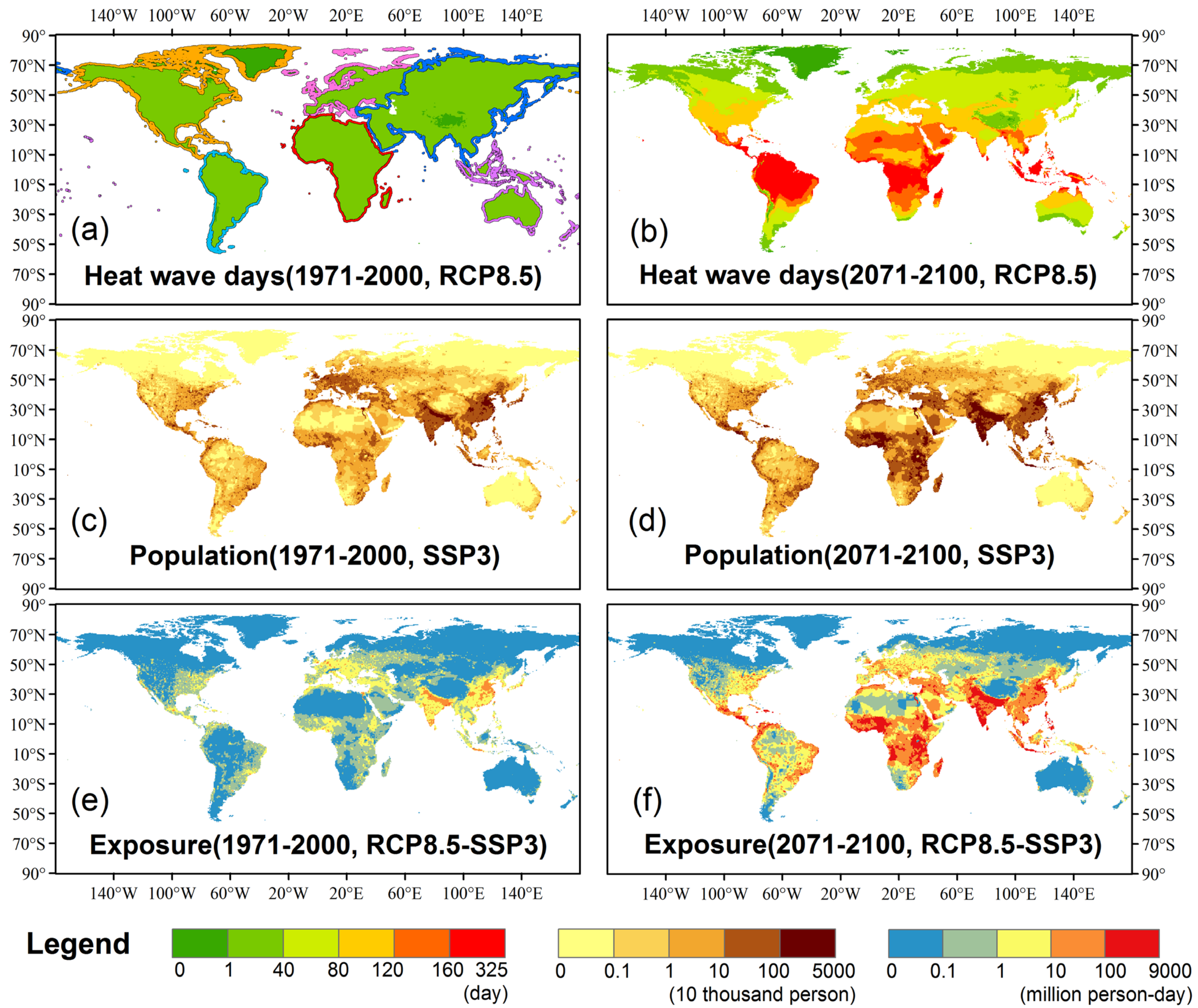
Future Warming of the Globe



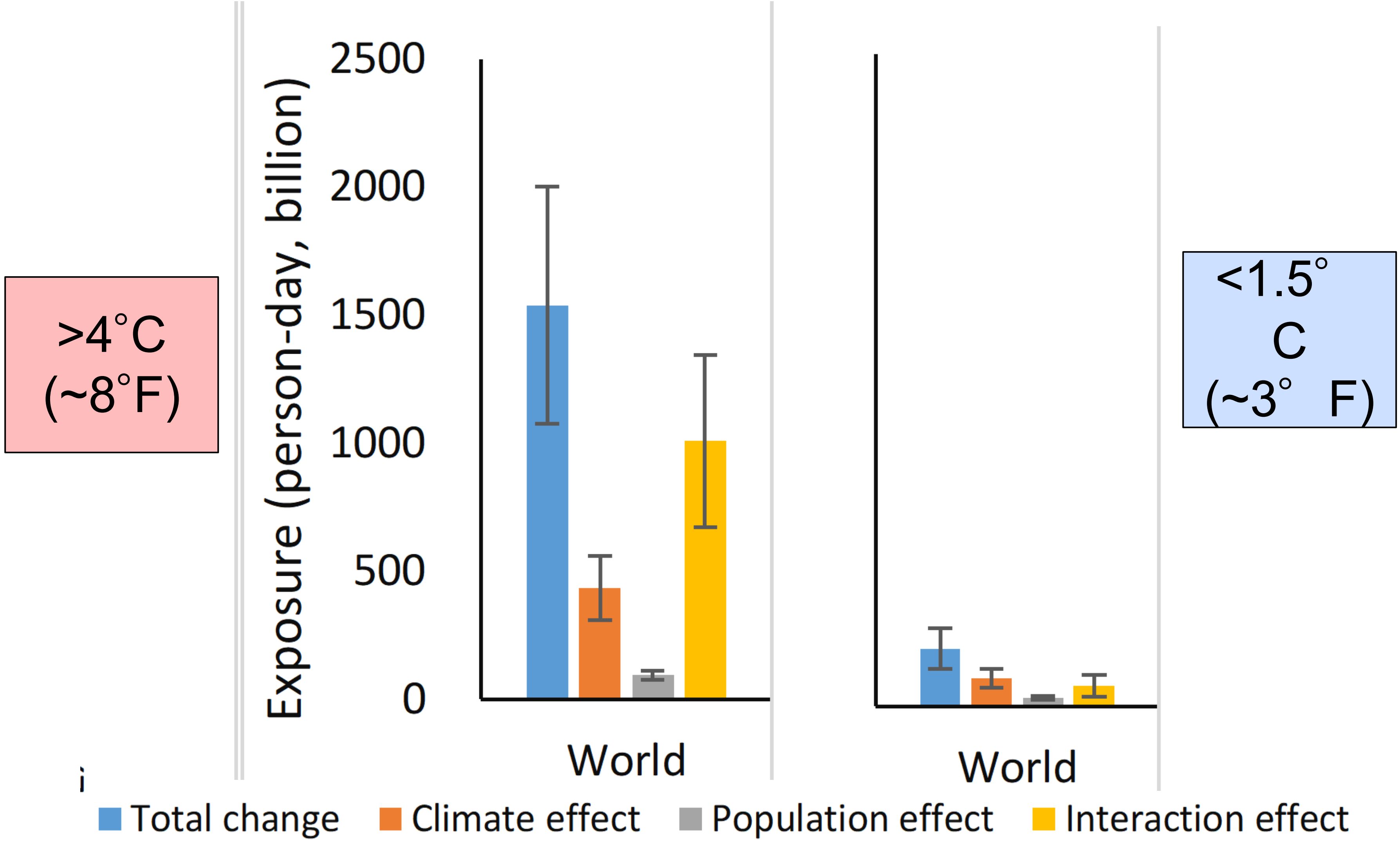
Frequency of Extreme Hot Seasons

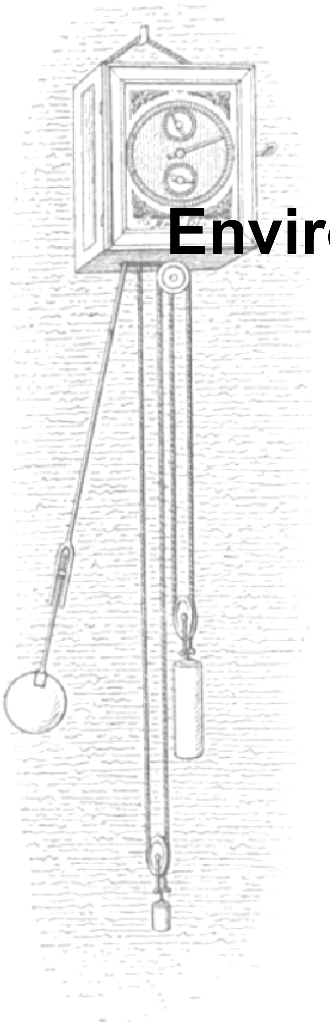


Exposure to Extreme Heat

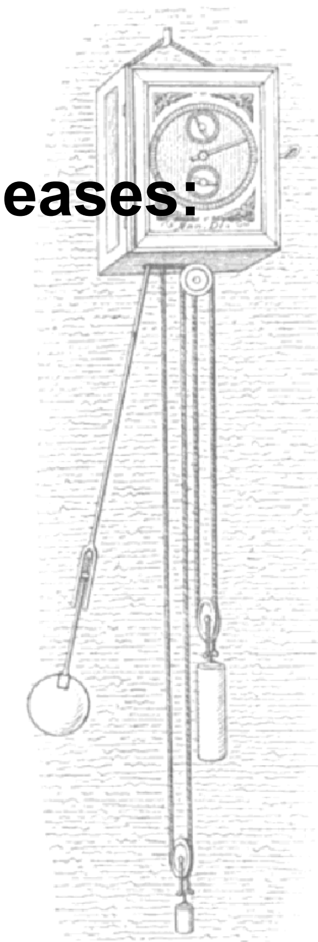


Exposure to Extreme Heat





Environmental Drivers of Infectious Diseases: Interactions vs. Correlations



Christiaan Huygens 1658

Ethan Deyle

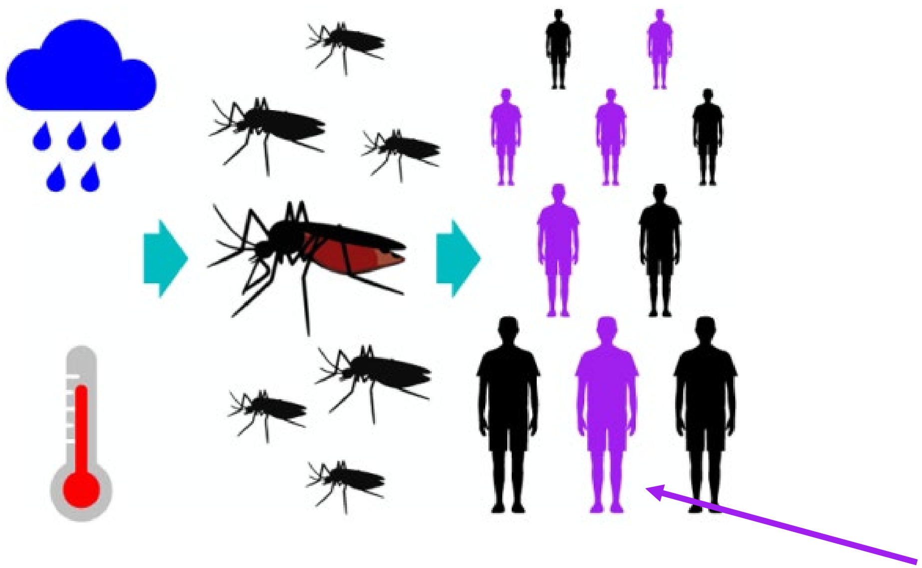
Research Assistant Professor

Boston University Marine Program &
Department of Biology

College of Arts and Sciences

Dengue fever regarded as seasonal with incidence during or after rainy seasons.
Relationship between human cases and climate drivers mediated by multiple possible (and lab measurable) mechanisms…

…**<u>But they don't act independently!</u>**



Mosquito

Pathogen

ч (Human, Mosquito)

…

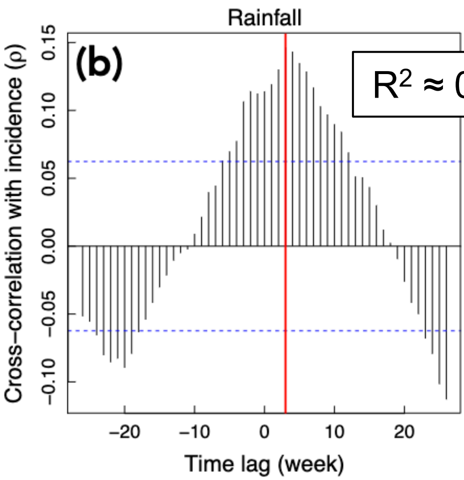
Human susceptibility necessary for cases in any environment.

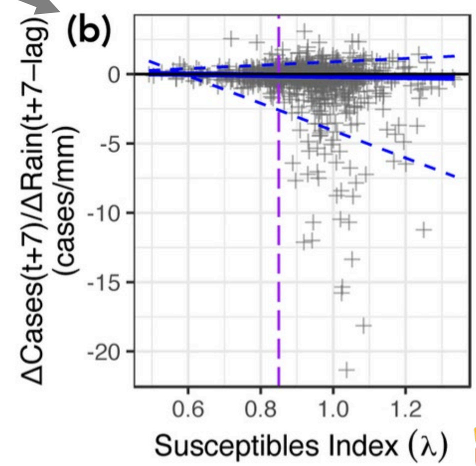
Mordecai et al. 2017
doi.org/10.1371/journal.pntd.0005568

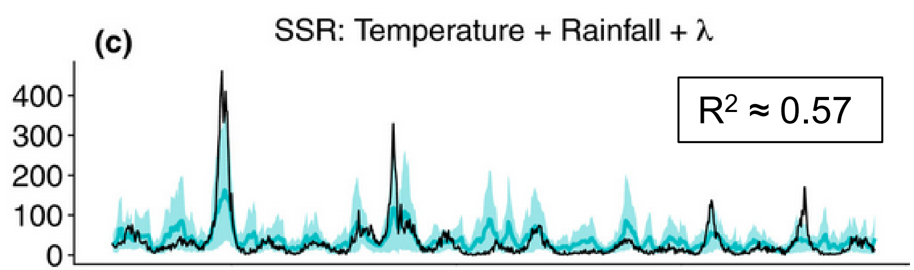
In systems with non-additive causal relationships, **lack of correlation ≠ lack of causation**.

Level of response matches *level* of driver

Level of driver affects *change-over-time* of response





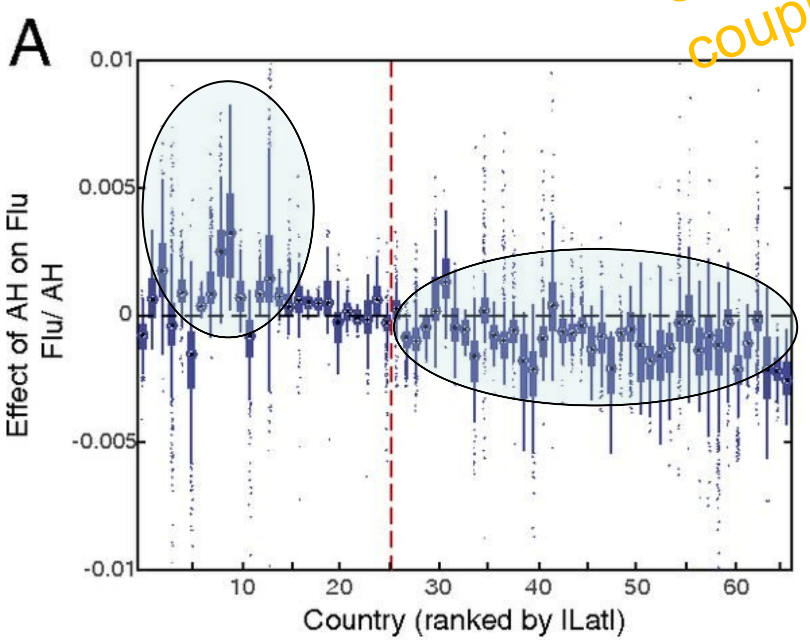


Nova et al. 2021
doi.org/10.1111/ele.13652

Influenza in Tropics: **lack of correlation ≠ lack of causation**. Influenza in Temperate: Strong correlations with weak forcing through “seasonal resonance” and synchrony.

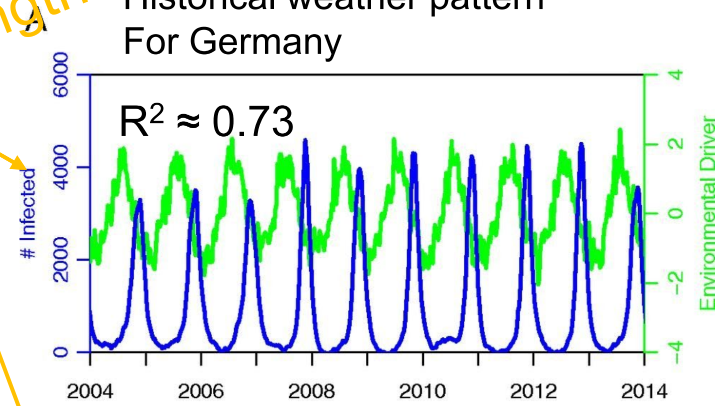
Deyle et al. 2016
doi.org/10.1073/pnas.1607747113

Same model & coupling strength

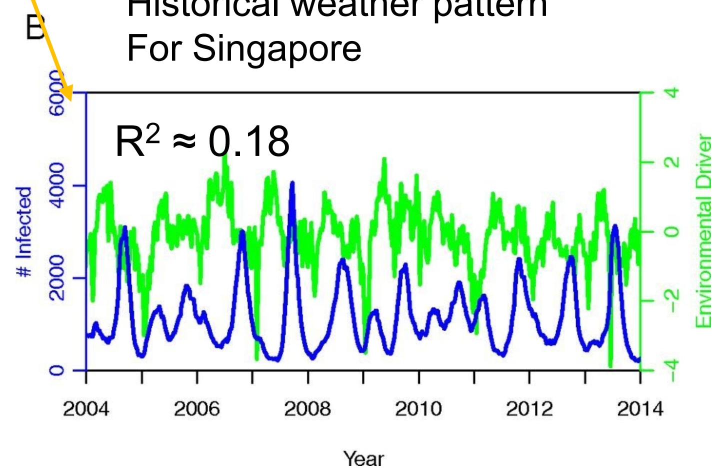


Distance from equator

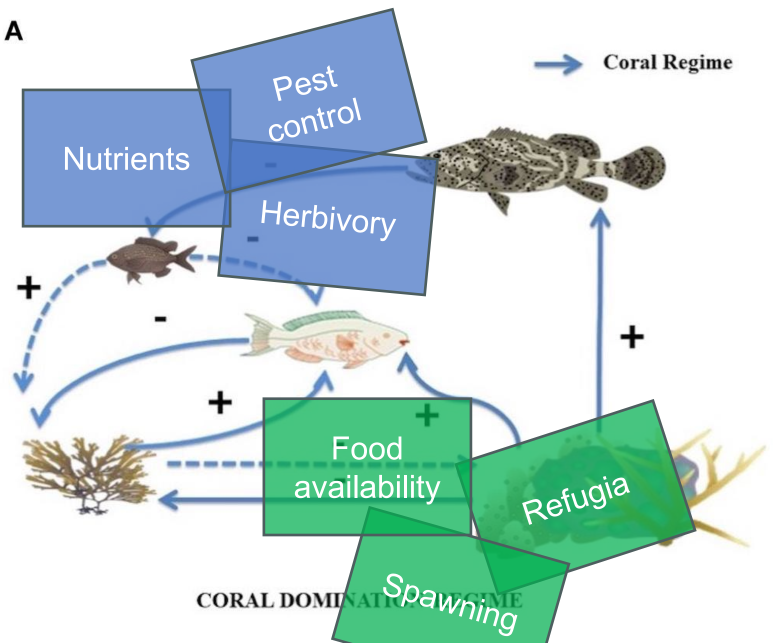
Historical weather pattern For Germany



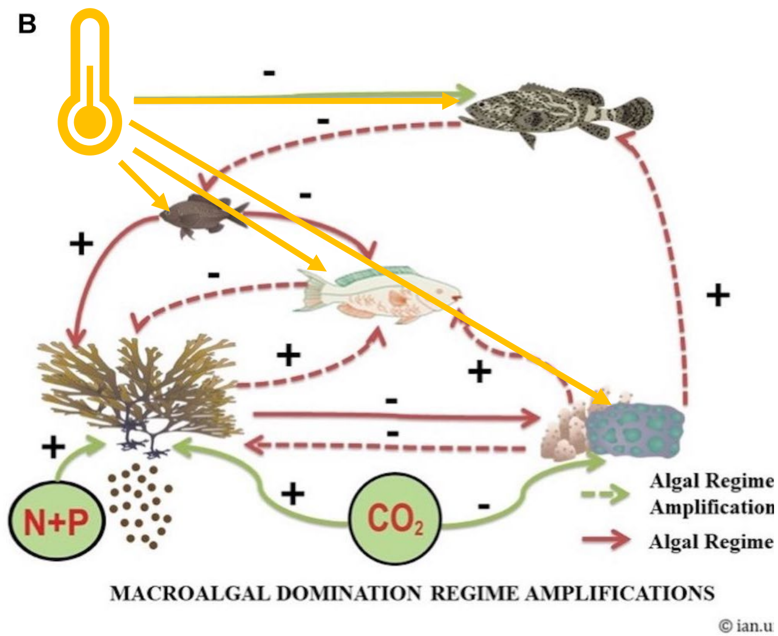
Historical weather pattern For Singapore



Addressing ecosystem based management and public health alike…
…even **well studied mechanisms** like temperature tolerance can lead to **emergence** of **complex patterns** in real systems.



Many coupling mechanisms



Complex, system-level responses to drivers

Eisemann et al. 2019
doi.org/10.3389/fmars.2019.00414

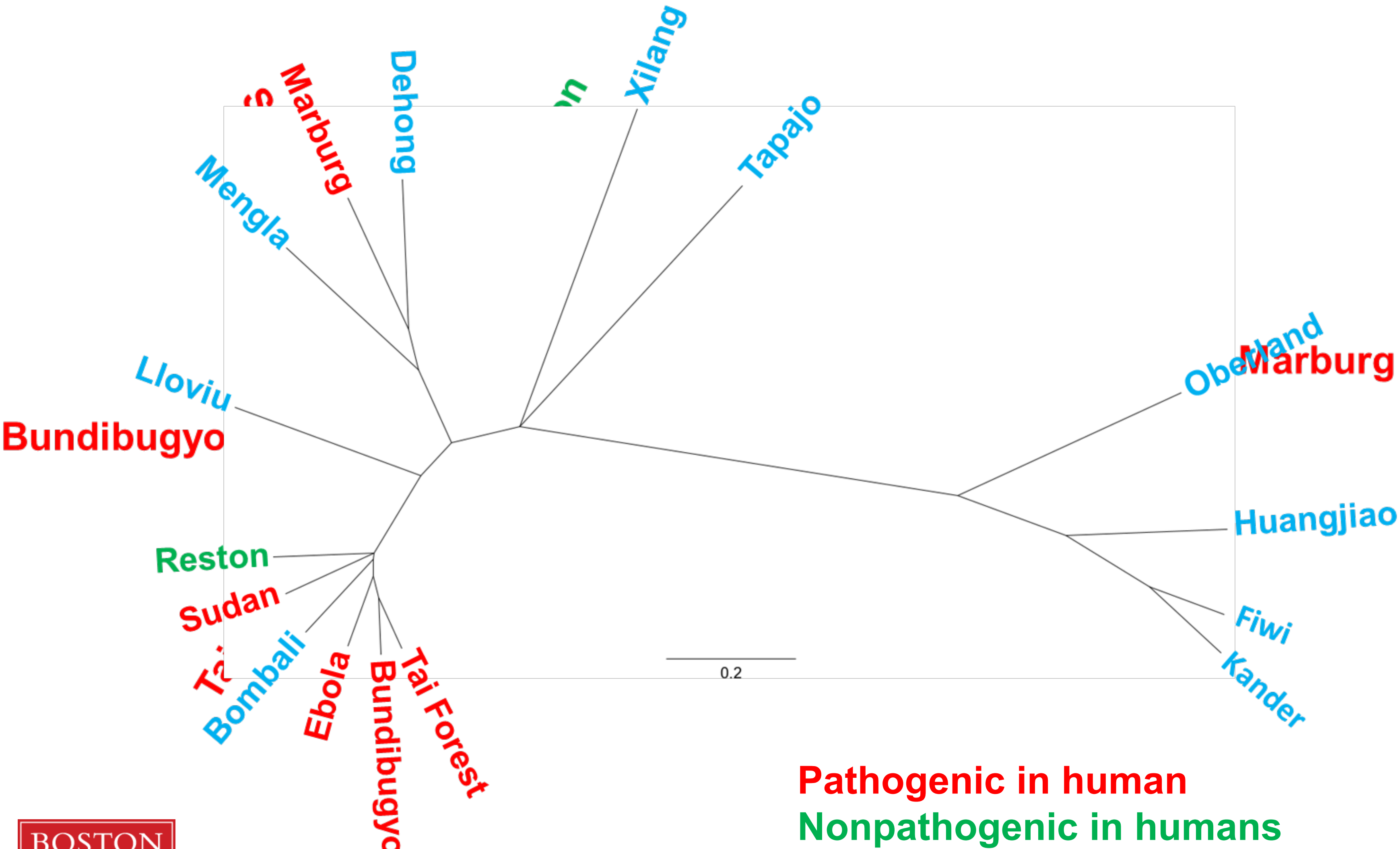
The Next Big Thing: Emerging Virus or Reemerging Virus in a New Place?

Adam Hume

Research Assistant Professor
Department of Virology, Immunology & Microbiology
Chobanian & Avedisian School of Medicine
National Emerging Infectious Diseases Laboratories

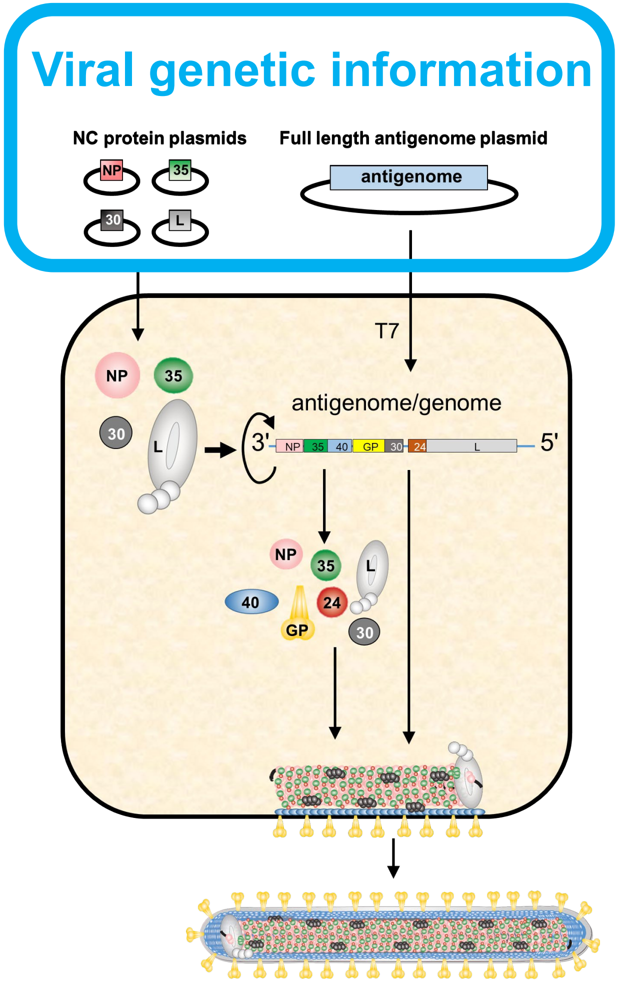
Filoviruses 15 years ago

Filoviruses today

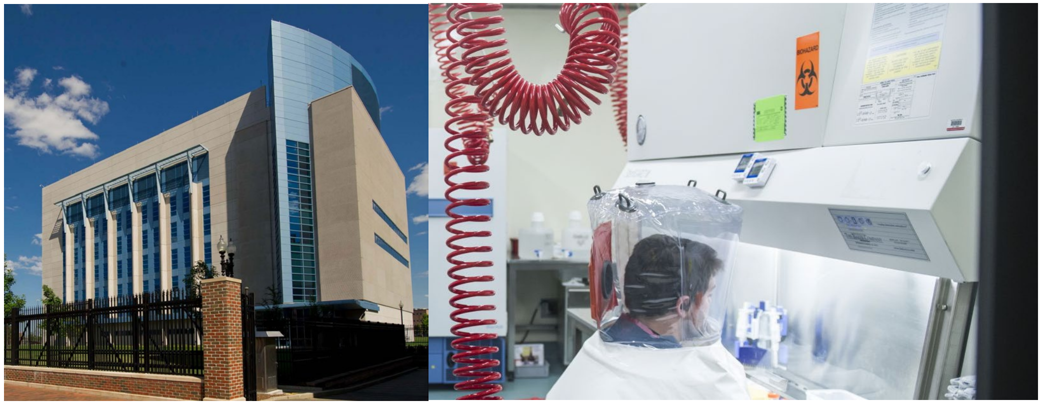


Pathogenic in human
Nonpathogenic in humans
Unknown pathogenicity in humans

New viruses: are they a pathogenic threat?

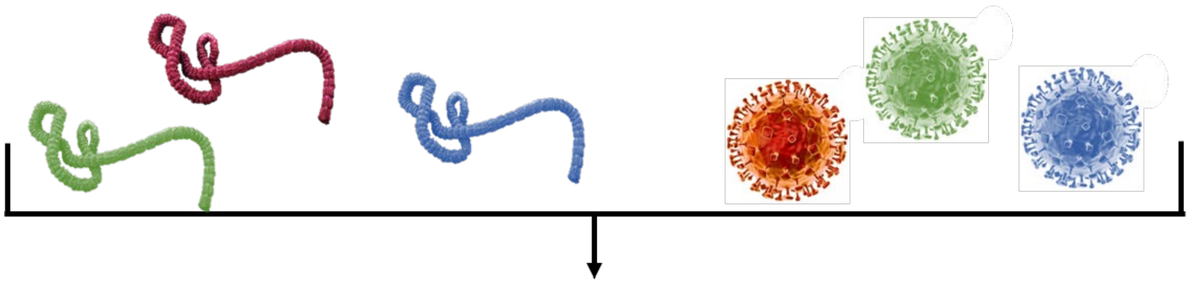


Biosafety level 4 (BSL-4) at the NEIDL



Filoviruses: Ebola, Marburg viruses
Henipaviruses: Nipah, Hendra, Langya viruses
Arenaviruses: Lassa, Junin viruses
Nairoviruses: Crimean-Congo hemmorhagic fever virus

New viruses: are they a pathogenic threat?

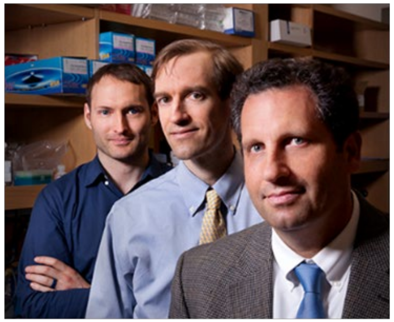


human iPSC-derived cells
and organoids

- Can the human cells be infected?
- How do they respond to infection?
- Identify druggable targets

BU CReM collaborators

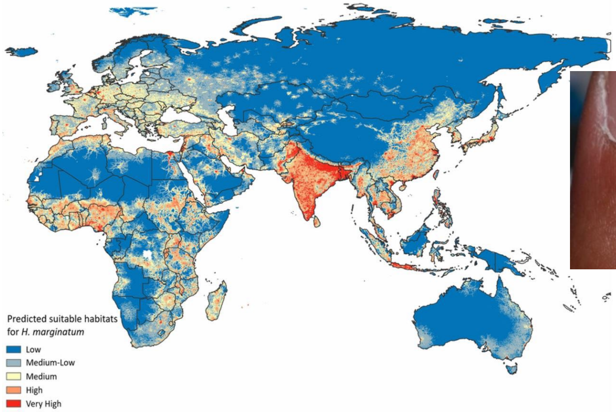
Gustavo Mostoslavsky



Darell Kotton
Andrew Wilson
Finn Hawkins

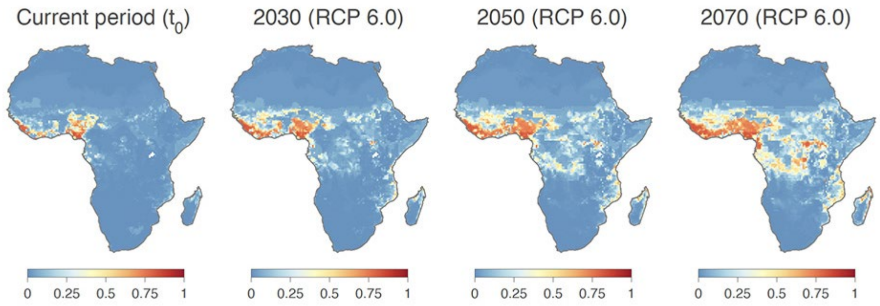
The next big thing:
Emerging virus or Reemerging virus?
Emerging virus in a new place?


Lloviu virus: new filovirus in a new place



CCHFV: increased vector range


Langya virus: new pathogenic henipavirus



Lassa virus: expanding host range



nature communications

Article

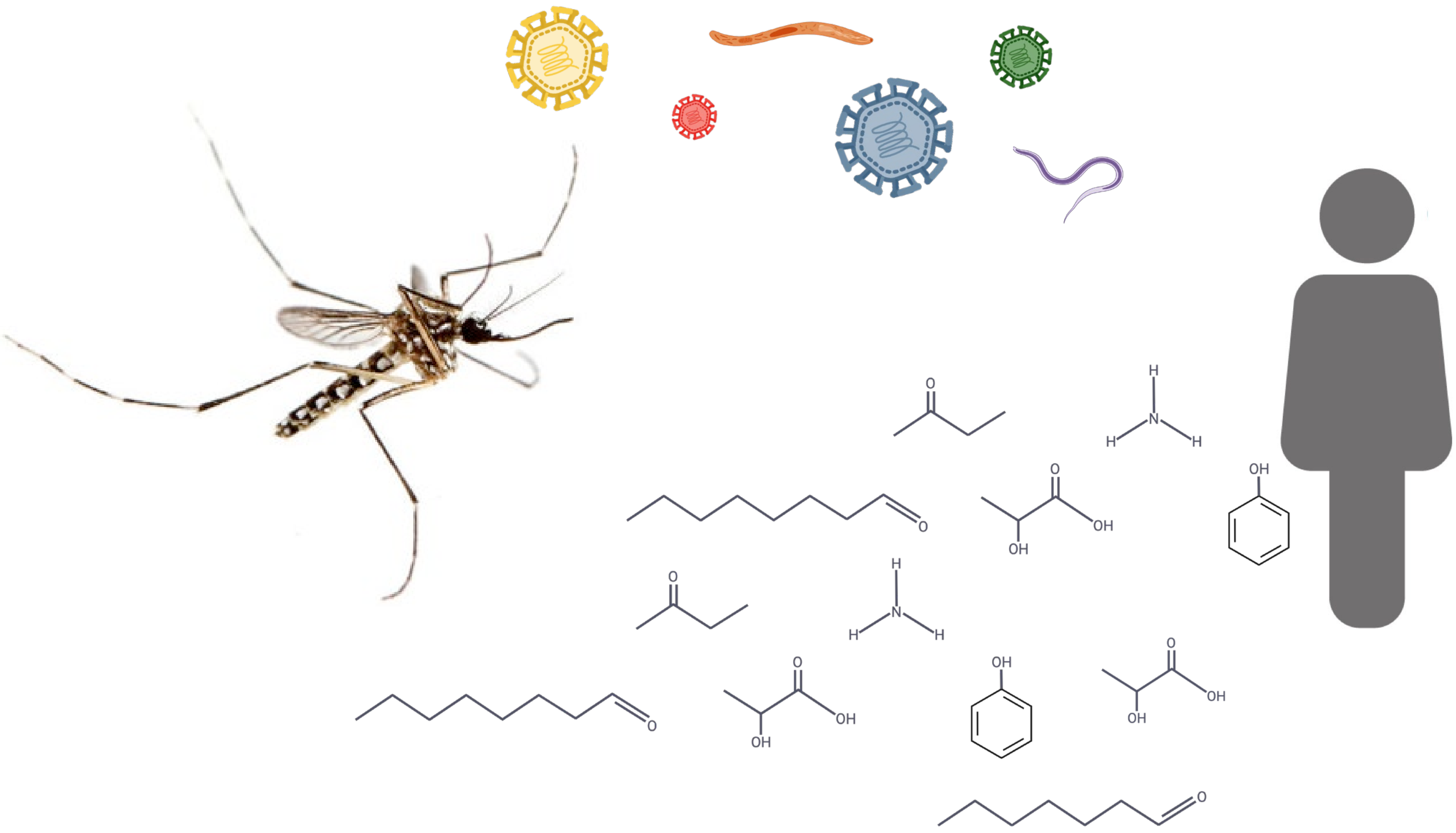
Predicting the evolution of the Lassa virus endemic area and population at risk over the next decades

Non-Canonical Olfaction in Disease-Vector Mosquitoes

Meg A. Younger, PhD

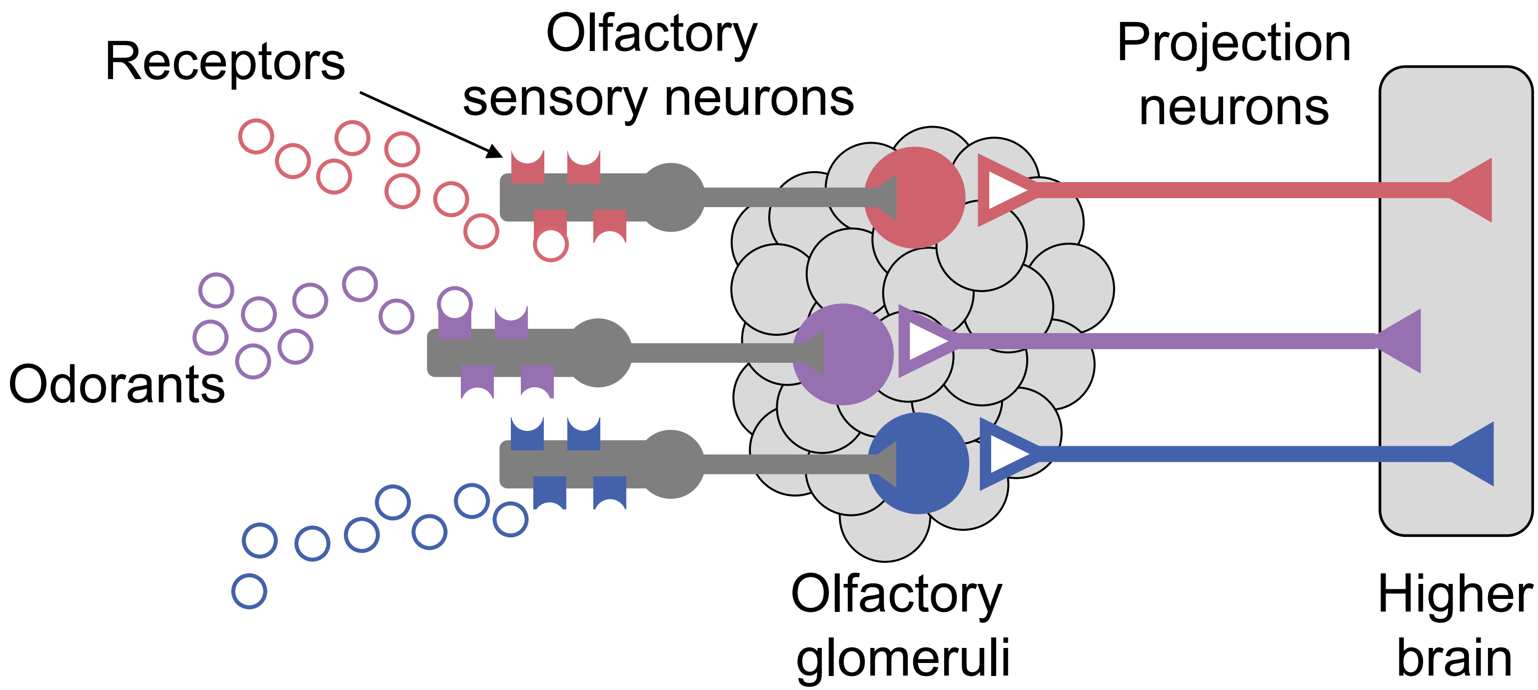
Assistant Professor
Department of Biology

Mosquitoes kill ~700,000 people every year.



Mosquitoes rely heavily on olfaction to detect humans.

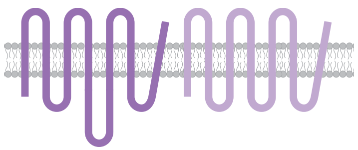
Canonical organization:
"One-receptor-to-one-neuron-to-one-glomerulus"

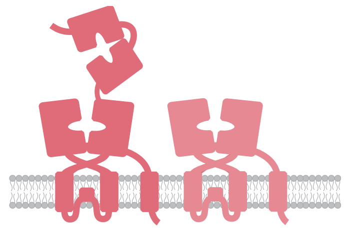


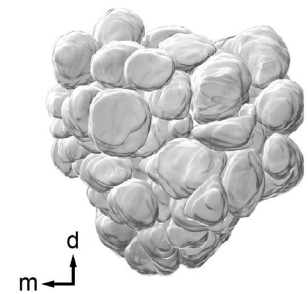
Mosquitoes break these rules

There are more receptors than glomeruli in *Aedes aegypti*.

117 ORs + 135 IRs >> ~65 glomeruli

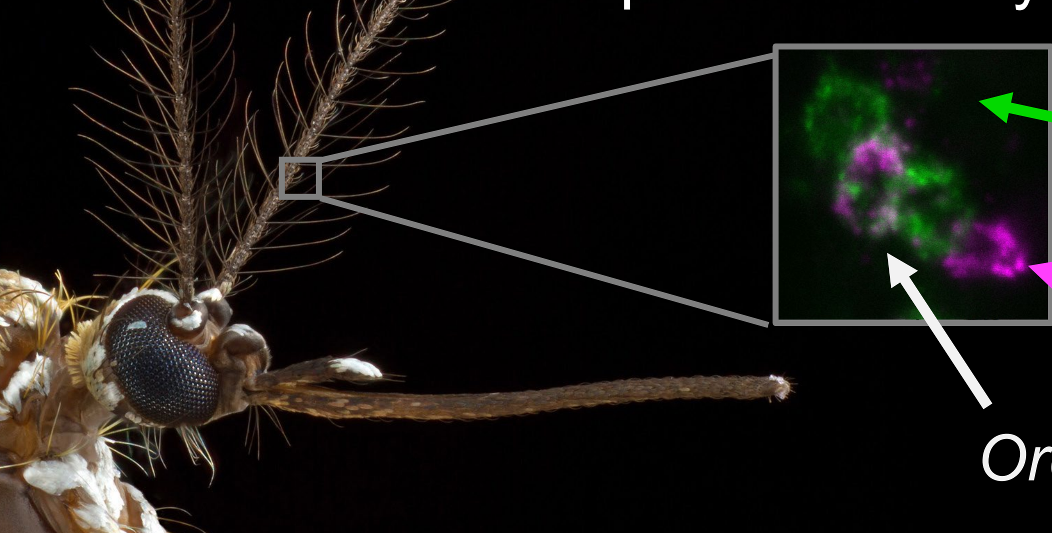




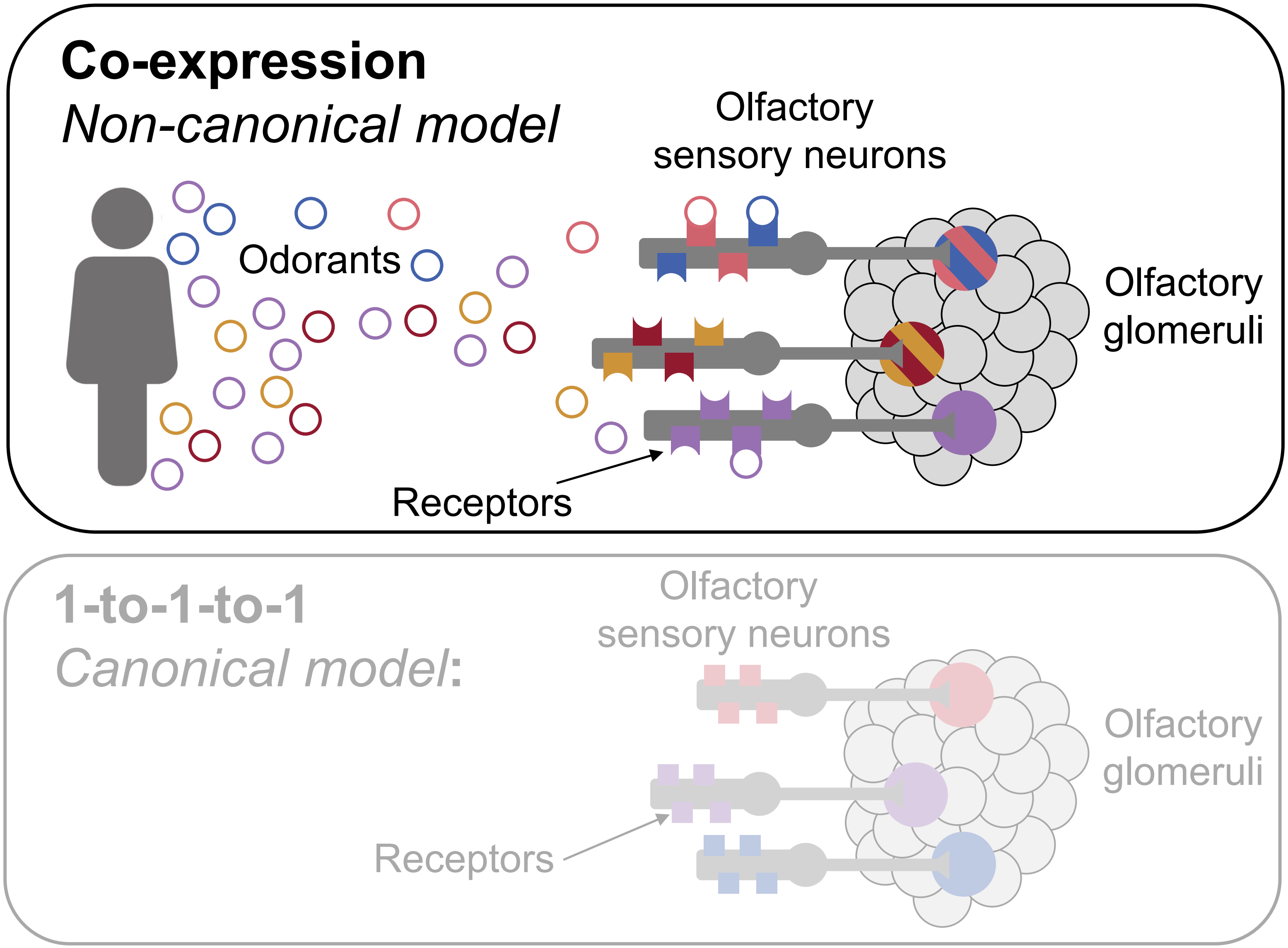


Chemoreceptor genes

There is widespread olfactory receptor co-expression



What role does co-expression play in olfaction?



Herre et al., 2022

Emergence and Expansion of Arboviruses in the USA due to Climate Change

Fabiana Feitosa-Suntheimer, PhD

Director Arthropod Containment Level-3 (ACL-3)

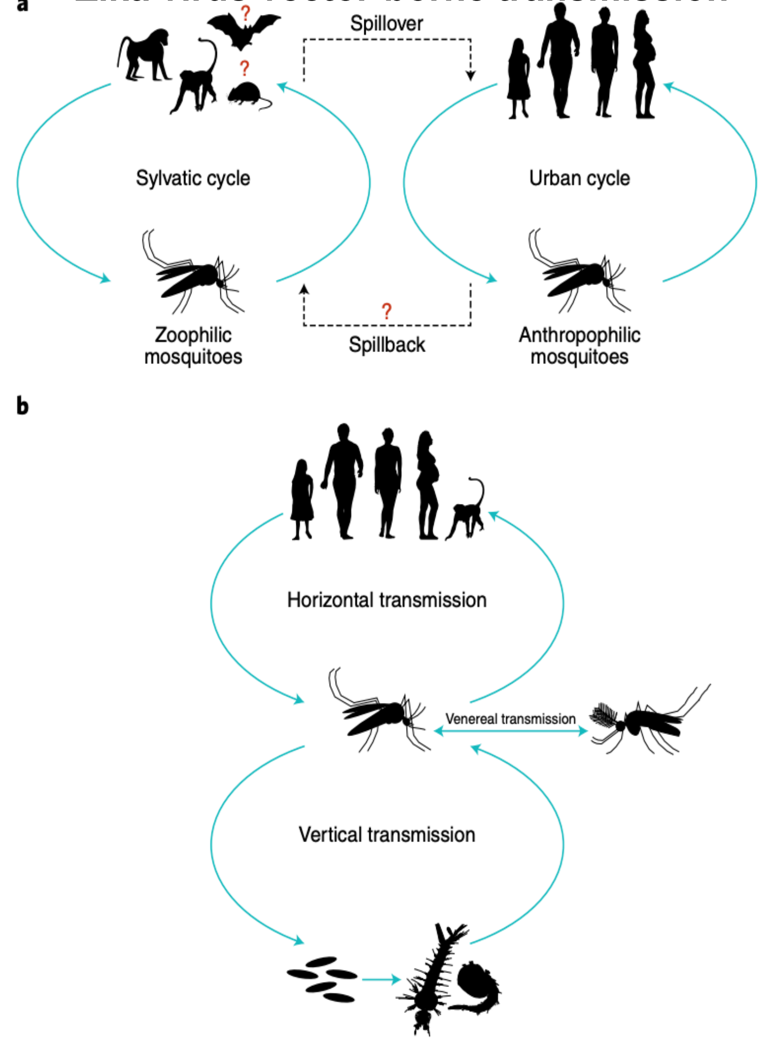
National Emergence Infectious Diseases Laboratories (NEIDL)

Arboviruses is a Public Heath Concern

Arthropod-Borne (Arbo) Viruses: viruses transmitted by arthropod vectors

Mosquitoe	Ticks	Triatomine bugs	Sand flies
			

Zika virus vector-borne transmission



Gutiérrez-Bugallo *et al*. Nature ecology and Evol. 2019

Cases

477

Dengue cases in 2023 for travel status selected above

Jurisdictions

32

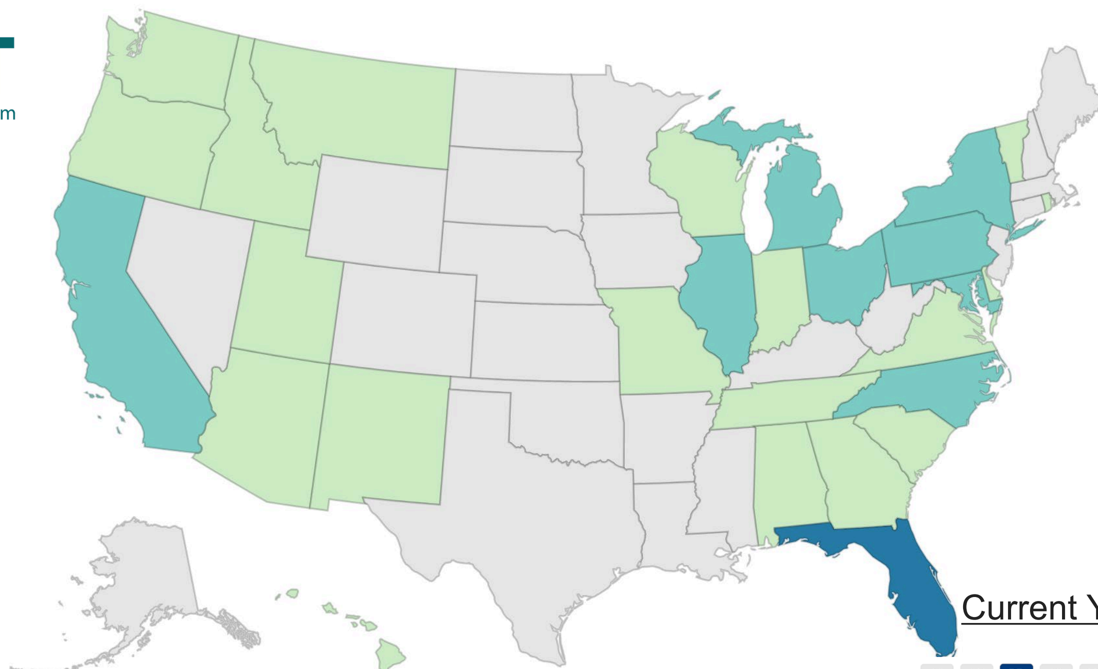
Jurisdicitons reporting cases in 2023 for travel status selected above

Centers for Disease Control and Prevention
CDC 24/7: Saving Lives, Protecting People™

Dengue

All dengue cases by jurisdiction of residence in US states and territories, 2024

ArboNET
National Arbovirus Surveillance System



Current Year Data (2024)

Territories and freely associated states AS GU PR VI MP FM PW MH

Legend

- No reported cases
- 1 to 4
- 5 to 49
- 50 to 249
- 250+

Prediction of Mosquito Expansion in the North America

Rising concern with urbanization of mosquito vectors and climate change

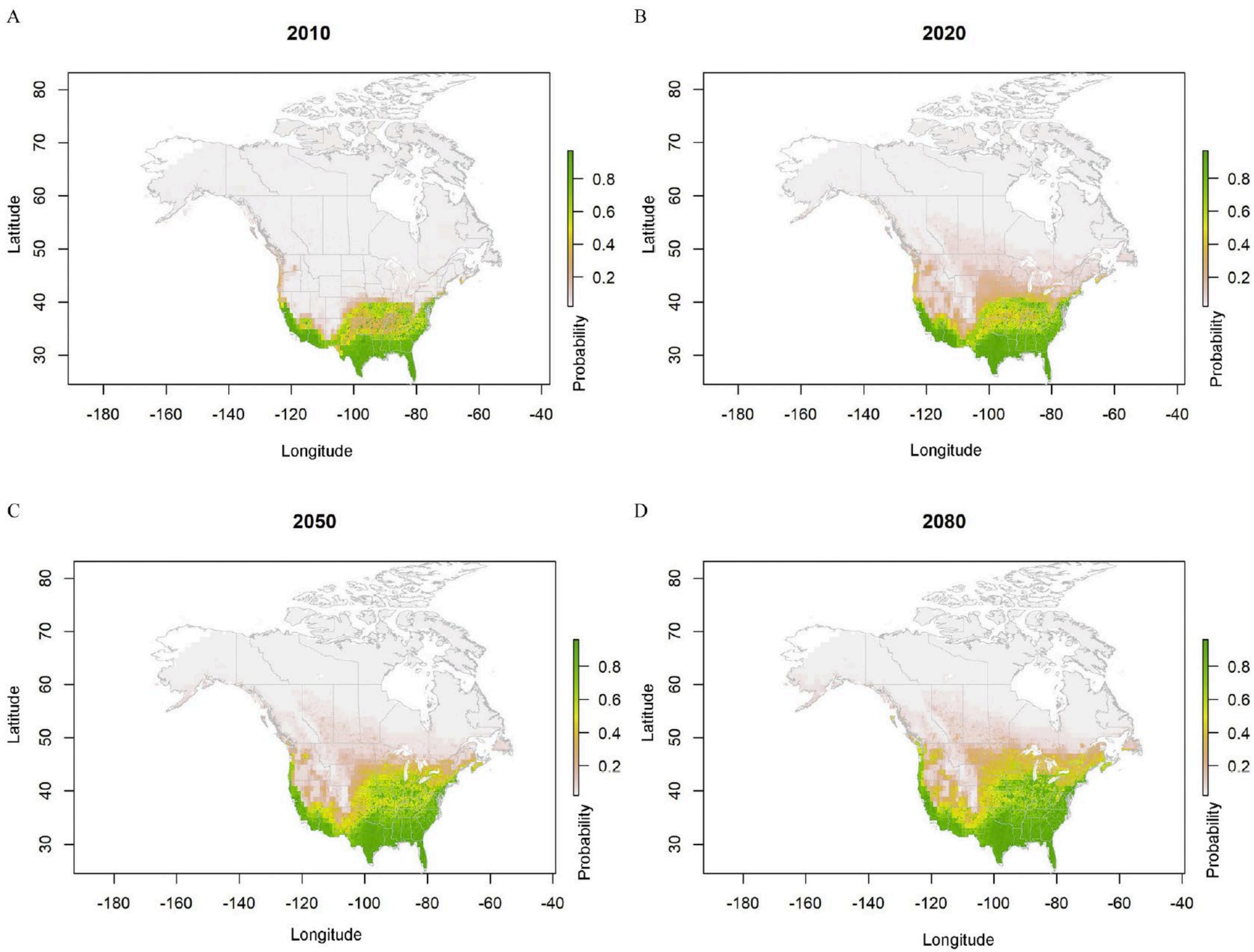


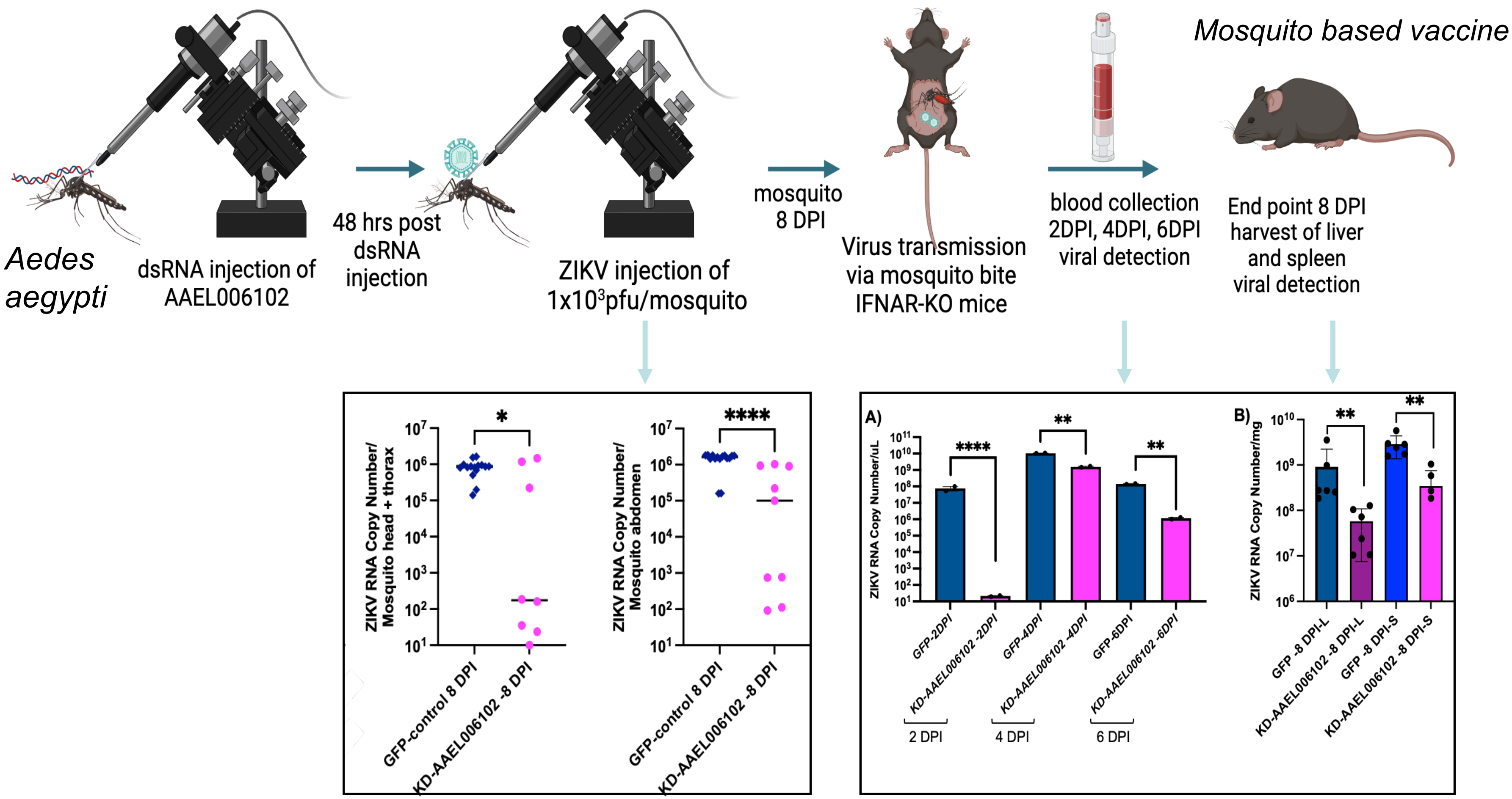
Figure 2. Predicted probabilities for *Aedes aegypti* ecological niche areas based on ensemble model simulations using four regional climate model data sets (CanRCM4-CanESM2, CRCM5-CanESM2, CRCM5-MPI-ESM-LR, and HIRHAM5-EC-EARTH), under representative concentration pathway (RCP) 4.5 from the year 2006 to 2100. Estimated probabilities shown for (A) 2010, (B) 2020, (C) 2050, and (D) 2080 are climatological conditions averaged over the 2006–2016, 2011–2040, 2041–2070, and 2071–2100 periods, respectively.

Khan, *et al*. Environmental Health Perspectives, 2020

Dengue outbreak in Brazil

- Brazil has broken the historical mark of dengue cases reported, totaling 1,889,206 in the first 11 weeks of the year.
- The maximum cases reported was1,688,688 in 2015.
- It also has recorded its hottest temperature ever (44.8^{o}C/ 112.6^{o}F).

How Can We Help?



FFS-Confidential-Unpublished data

Wild Rodents, Human Health, and Climate Change

Jessica Leibler, DrPH

Associate Professor

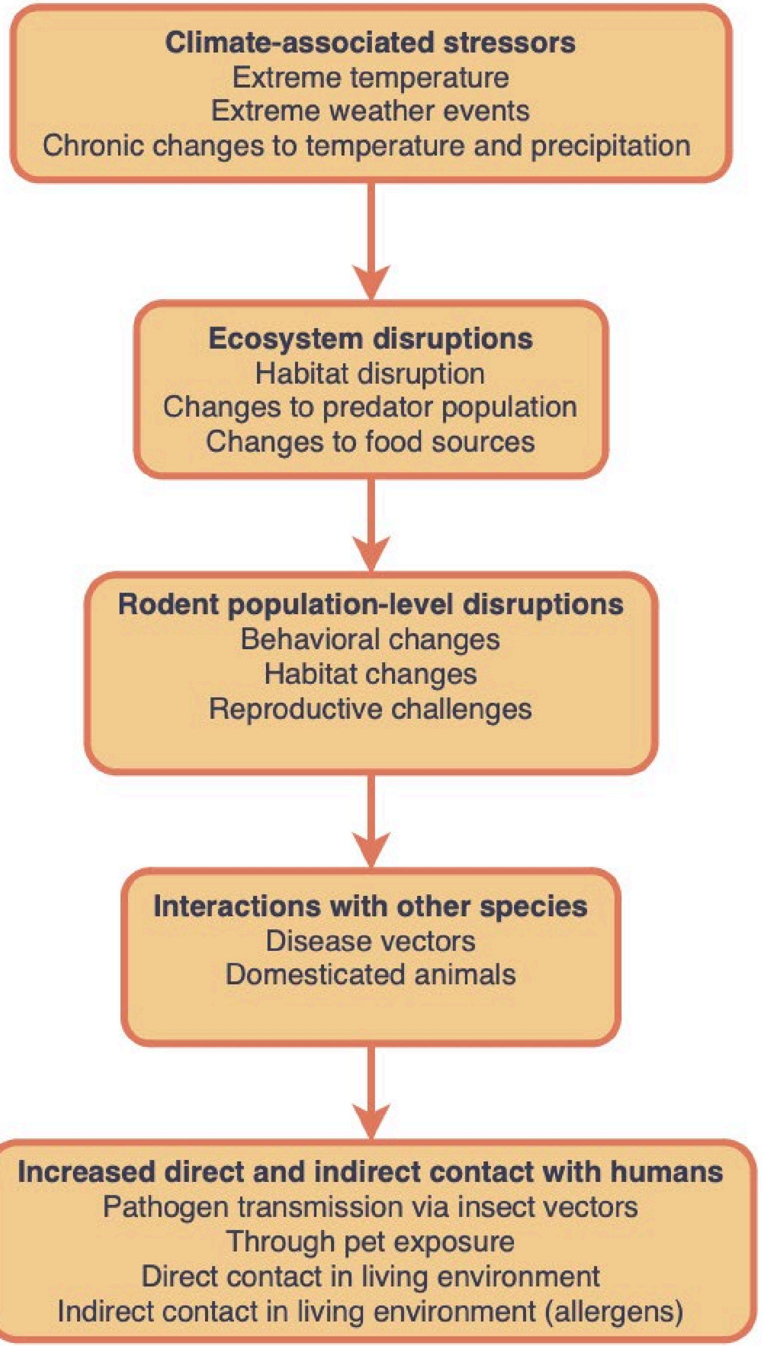
Department of Environmental Health

Boston University School of Public Health

jleibler@bu.edu

Wild rodents as health-relevant sentinels of climate change

- Research on wild animals can provide critical insight into complex interactions between climate change, ecosystem health, and human health
- Wild rodents (*rattus rattus*) have adapted exceedingly well (too well?!?) to co-habitation with humans in urbanized areas
- Rodents carry pathogens of relevance to human disease
- <u>Unsheltered or inadequately sheltered people are most vulnerable to exposure</u>


Climate-associated stressors
Extreme temperature
Extreme weather events
Chronic changes to temperature and precipitation
Ecosystem disruptions
Habitat disruption
Changes to predator population
Changes to food sources
Rodent population-level disruptions
Behavioral changes
Habitat changes
Reproductive challenges
Interactions with other species
Disease vectors
Domesticated animals
Increased direct and indirect contact with humans
Pathogen transmission via insect vectors
Through pet exposure
Direct contact in living environment
Indirect contact in living environment (allergens)

Rodents as vectors, hosts, irritants, allergens

- Rodent-borne disease with insect vector
  - *Bartonella spp*, *Yersenia pestis,* hantavirus, *Rickettsia*
- Reservoirs of pathogens of clinical concern
  - *Leptospira spp,* Lymphocytic choriomeningitis virus (LCMV)
  - *S. aureus*, antibiotic resistance genes
  - Novel and emerging viruses
- Respiratory irritant and allergen
  - Asthma, allergies, other respiratory disease

- **Mental health** component of rodent visibility in the home

Interested in collaborations!

- Integrated modeling focused on climate projections + rodent ecology + pathogen transmission + human exposure scenarios
- Focused research on unsheltered people in US urban areas and contact with rodents, exposure to rodent-borne disease
- Policies and strategies to reduce human:rodent exposure in urban areas

Jessica Leibler, jleibler@bu.edu

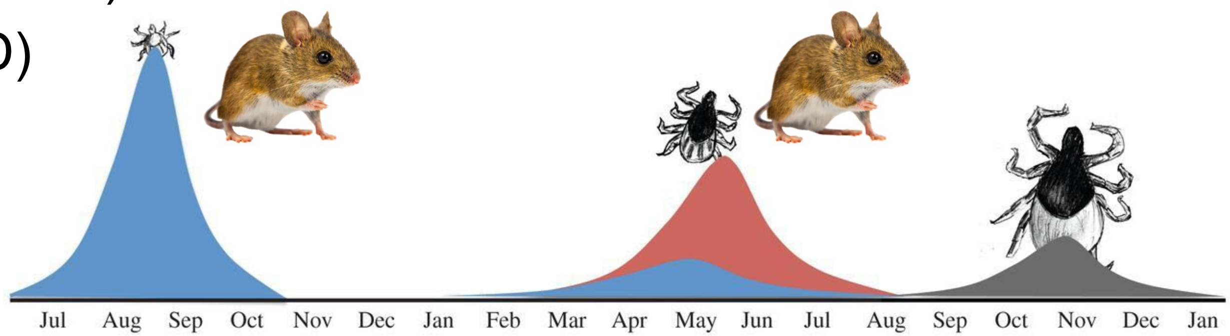
Forecasting tick populations across the eastern United States

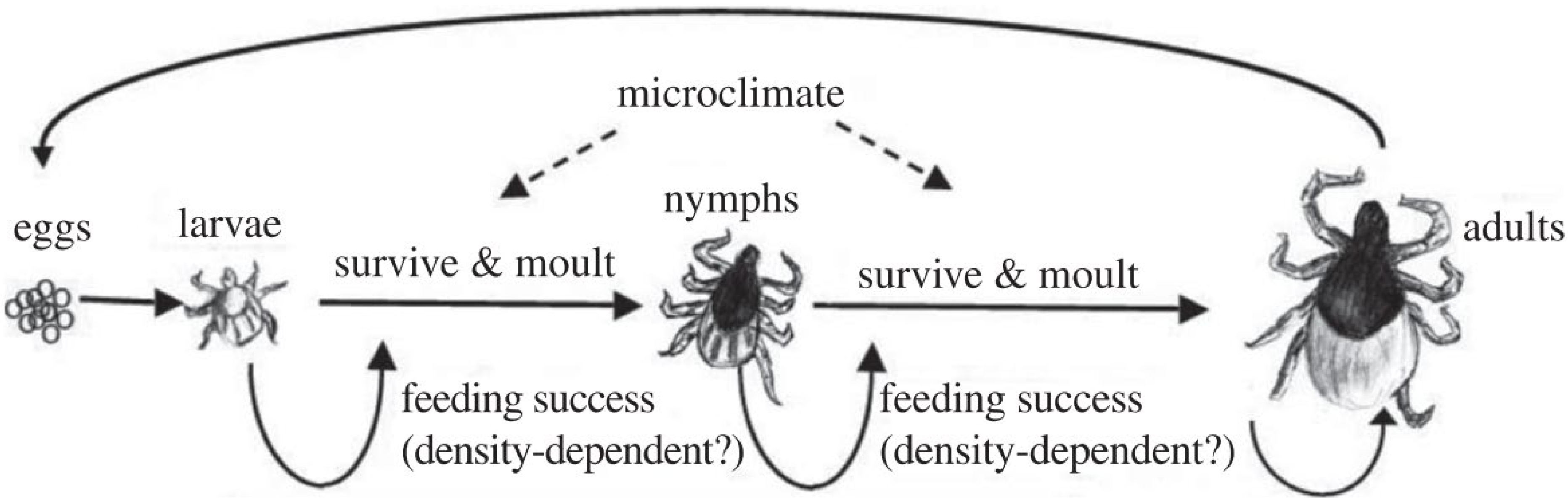
Michael Dietze

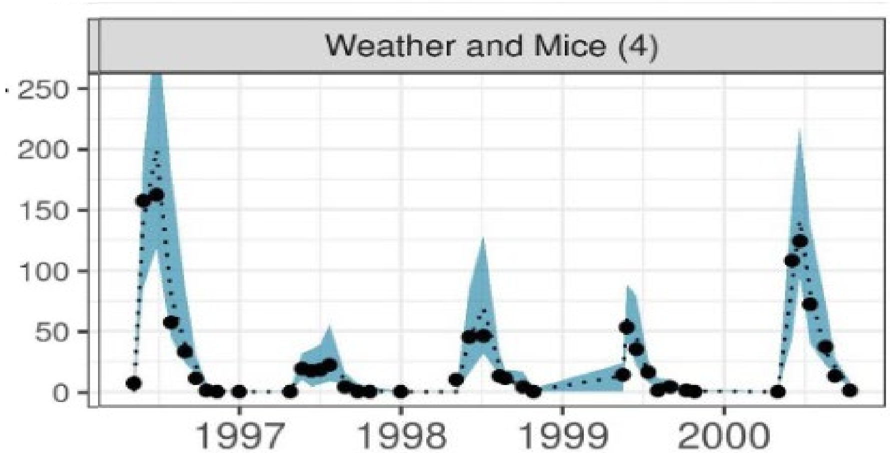
Professor
Department of Earth & Environment, CAS

Ticks, Mice, & Lyme

- Priors from tick survival exp.
- Calib to ~monthly field counts
- Survival = f(daily T, ppt, VPD)
- Transition = f(mice, GDD)
- Fecund = f(GDD)
- Mice surv = f(T,ppt)
- Capture = f(T)





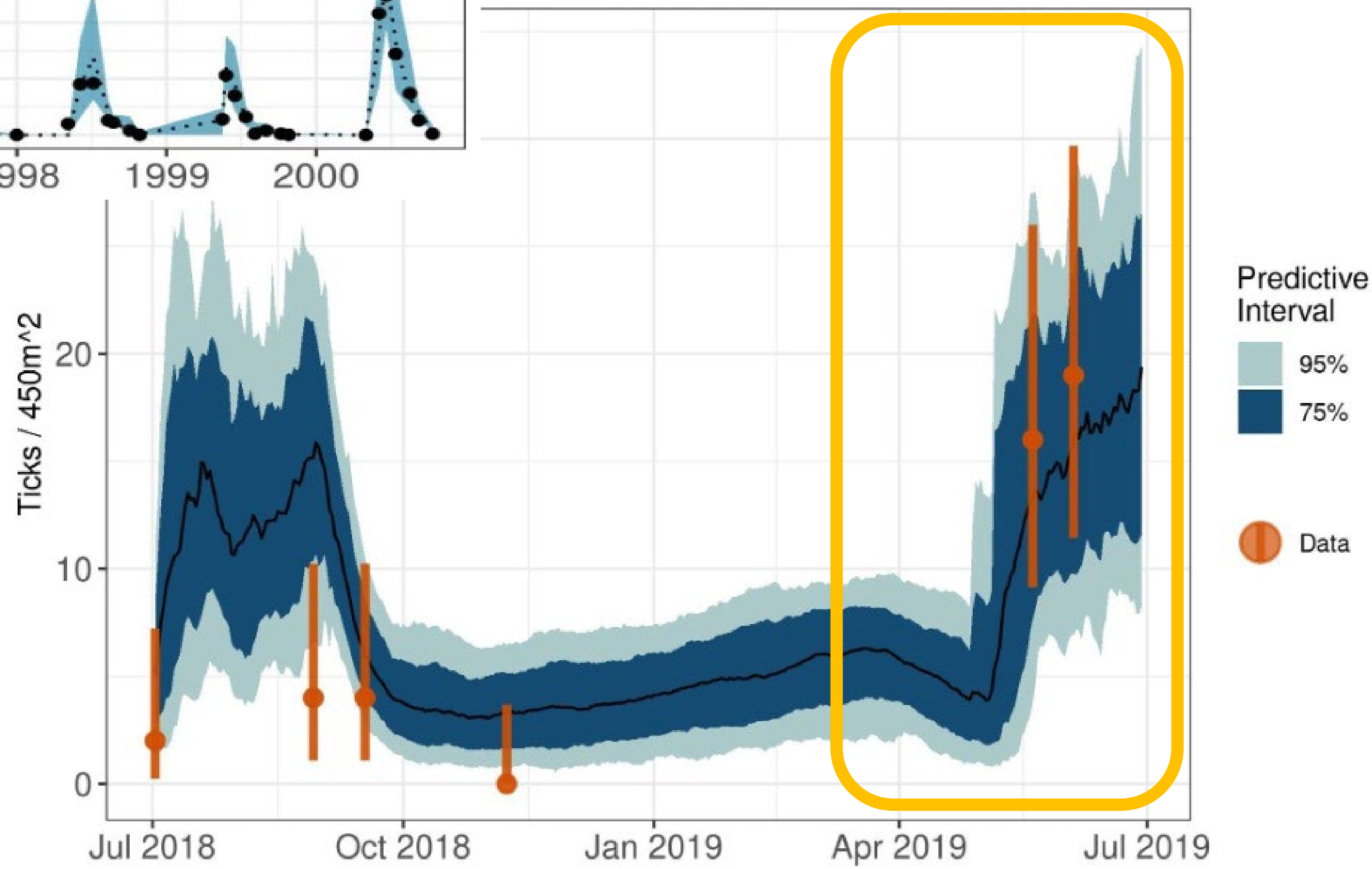


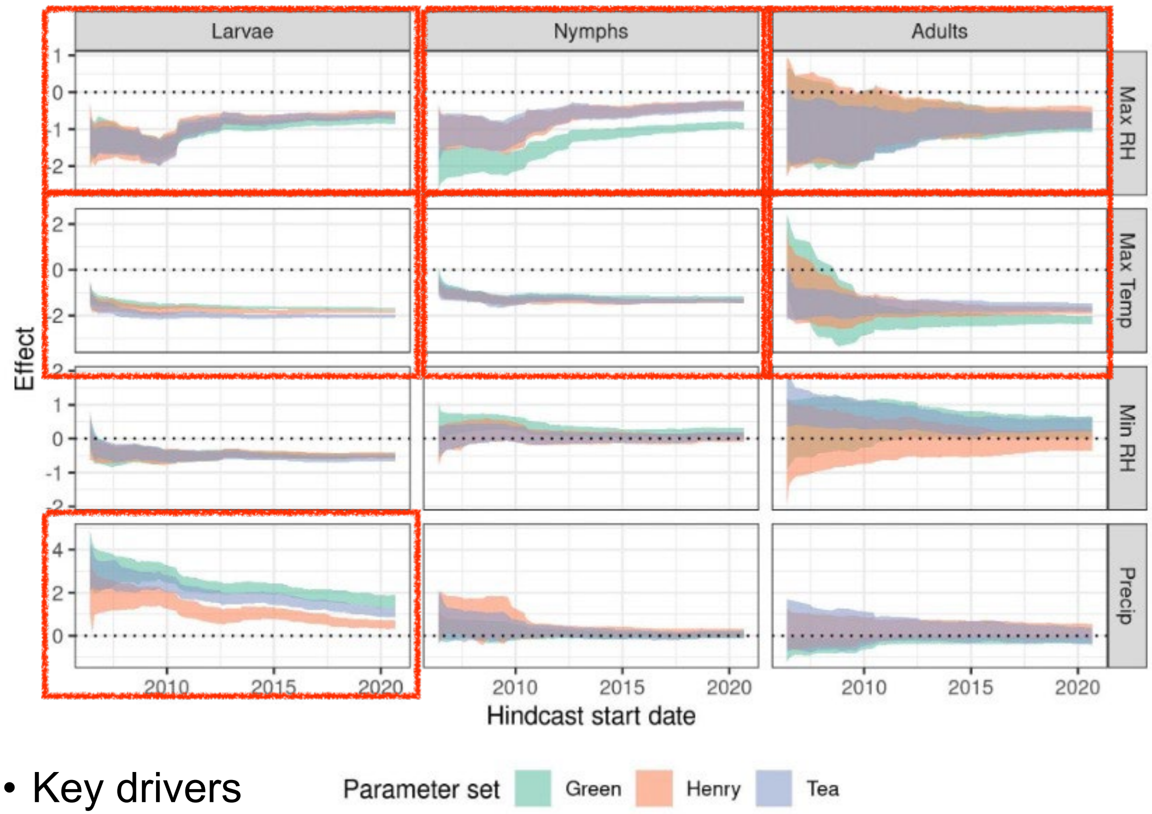
Calibration

Iterative Forecast

Nymphs

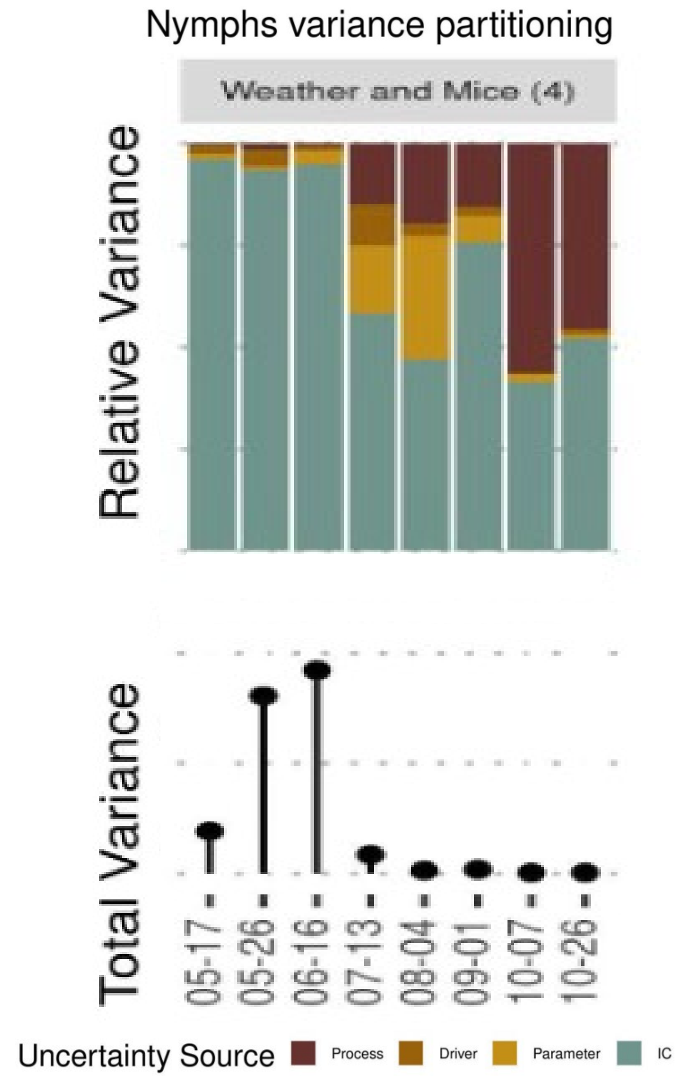
Start date: 2018-07-02

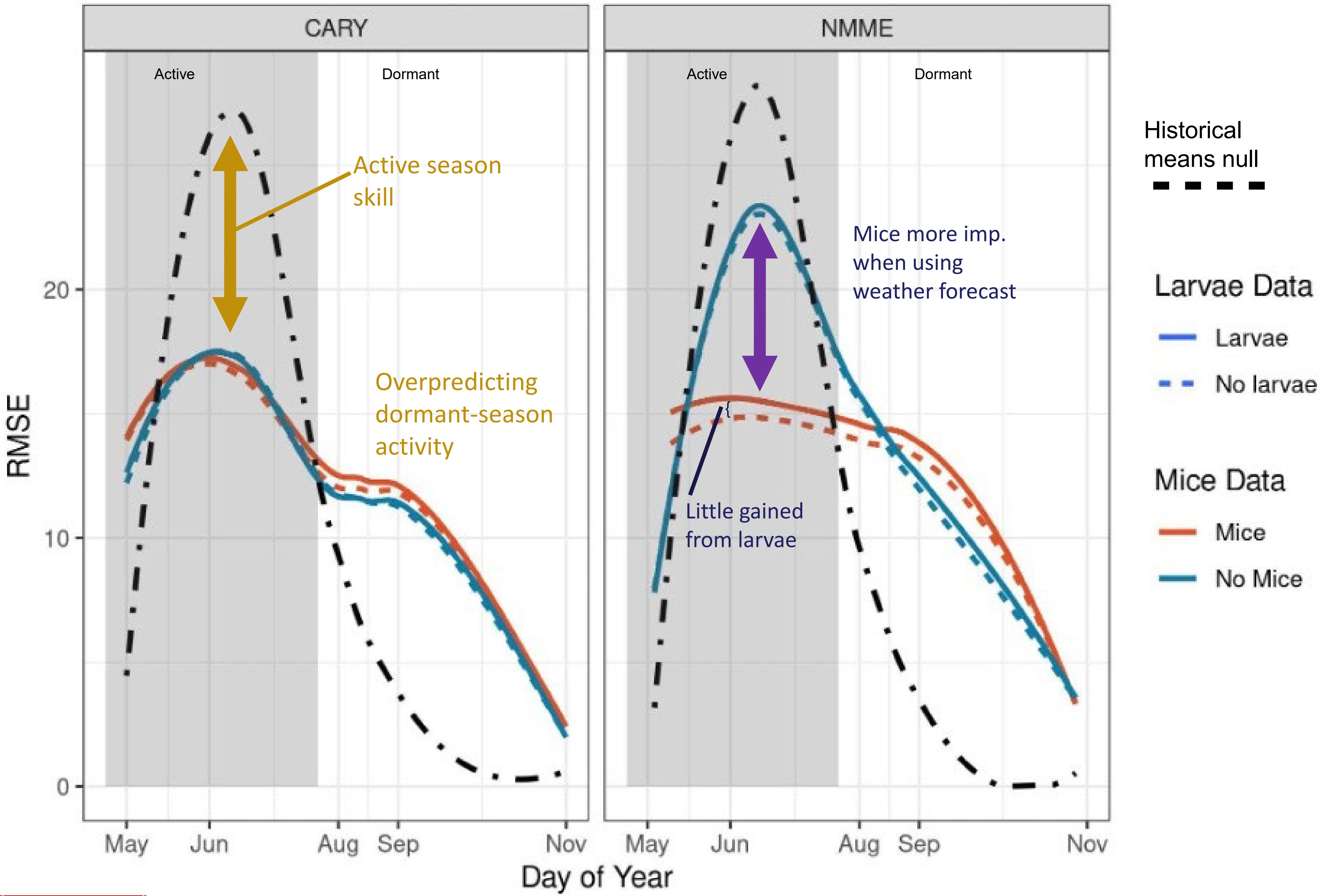




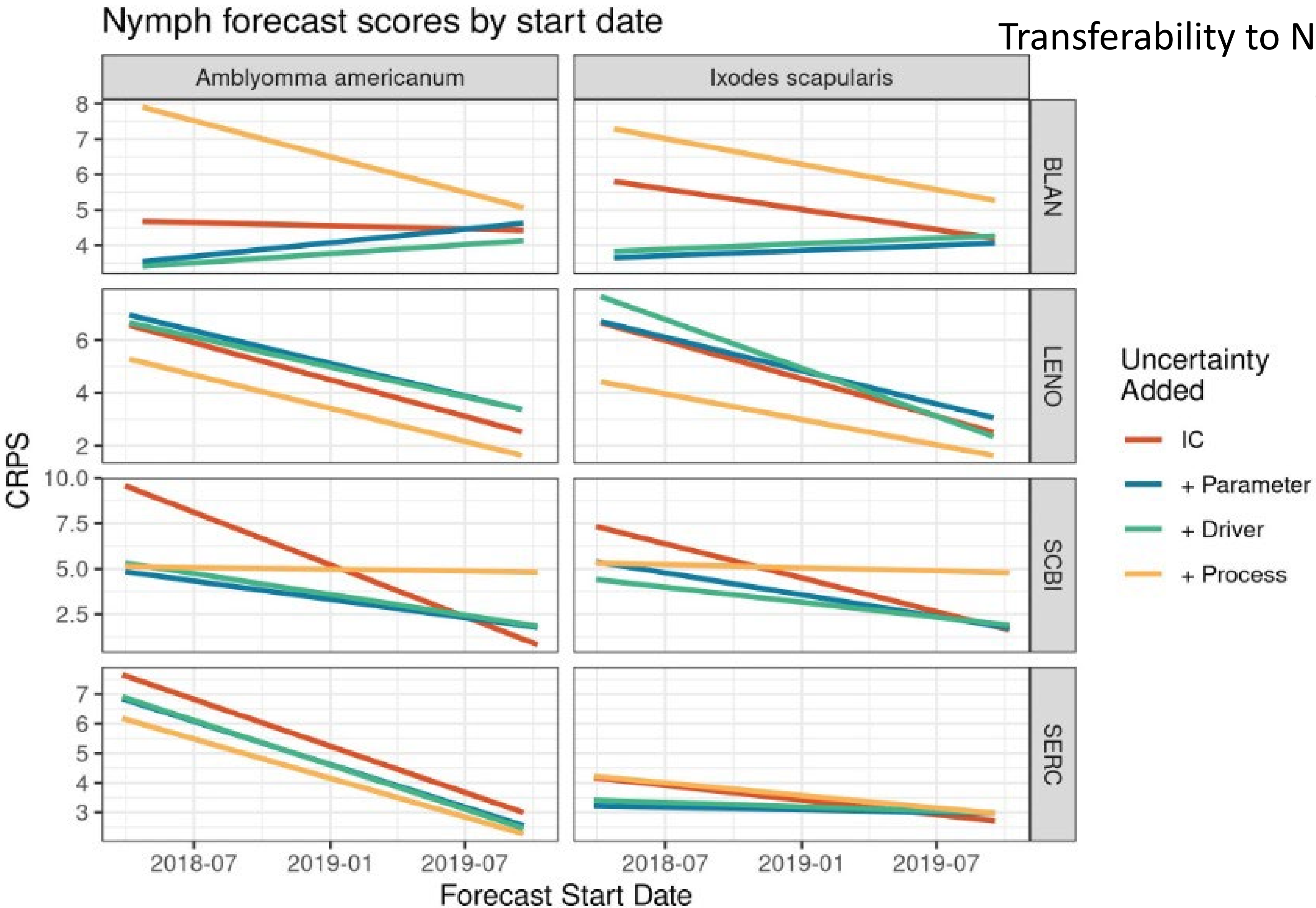
- Key drivers
- Consistent across sites
- Iterative Learning

Methods: Iterative state and parameter updating
Bayesian MCMC in NIMBLE




CARY
NMME
Active
Dormant
Active
Dormant
Active season skill
Overpredicting dormant-season activity
Mice more imp. when using weather forecast
Little gained from larvae
RMSE
20
10
0
May
Jun
Aug
Sep
Nov
May
Jun
Aug
Sep
Nov
Day of Year
Historical means null
Larvae Data
Larvae
No larvae
Mice Data
Mice
No Mice

Transferability to NEON sites



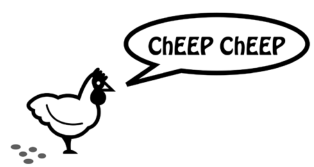
One Health with Climate Change

Kayoko Shioda

Assistant Professor
Global Health, School of Public Health

Kayoko Shioda, PhD, DVM, MPH kshioda@bu.edu

Understanding the risk of zoonotic enteropathogen infections along food systems in Mozambique

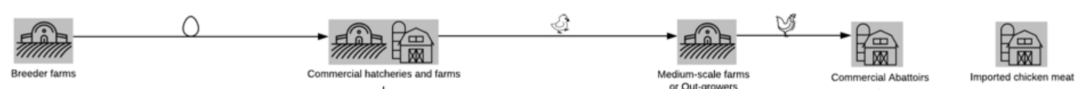
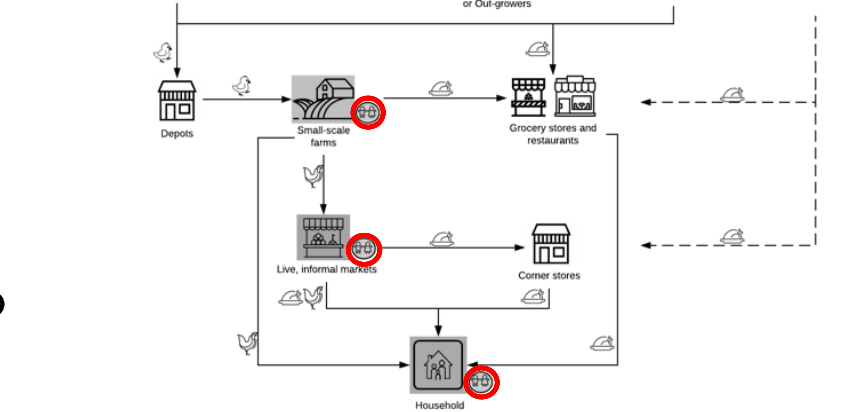


Matt Freeman (Emory)

Karen Levy (UW)

Hermógenes Mucache (UEM)

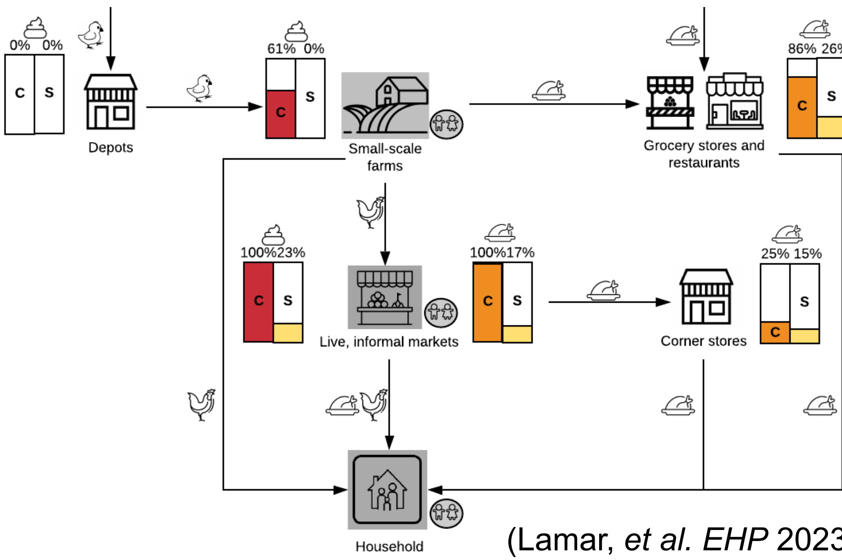
Kayoko Shioda (BU)

(Lamar, *et al. EHP* 2023)

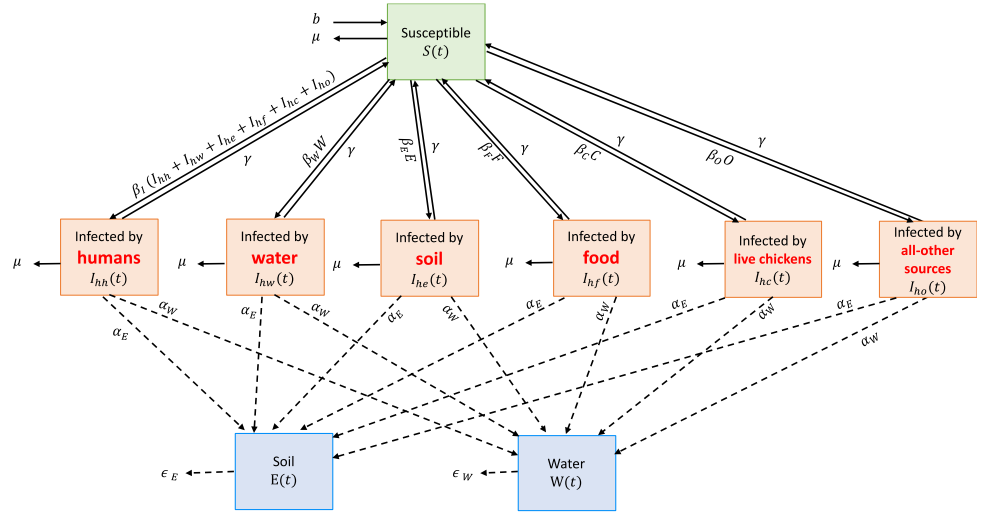
Kayoko Shioda, PhD, DVM, MPH kshioda@bu.edu

Campylobacter and *Salmonella* in chicken feces and carcasses



(Lamar, *et al. EHP* 2023)

Transmission dynamic modeling



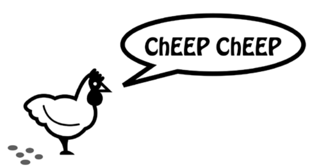
(Shioda, *et al. EHP* 2023)

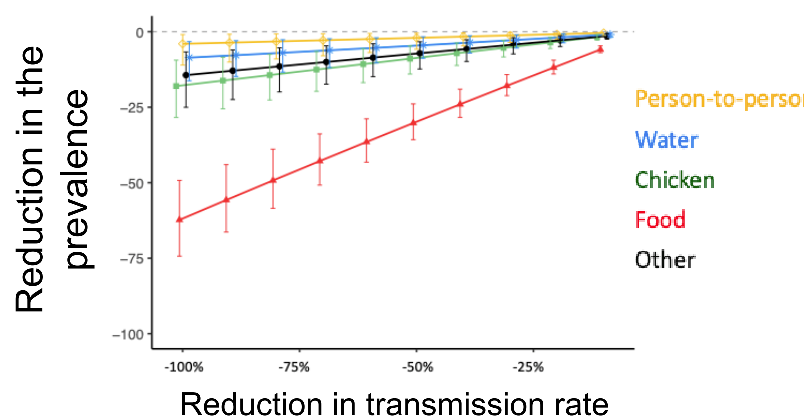
Findings from the field study:

Contamination increased as chickens progressed along the value chain

Findings from simulation analysis:

50% reduction in **foodborne** pathway would decrease *Campylobacter* infection by **30%**





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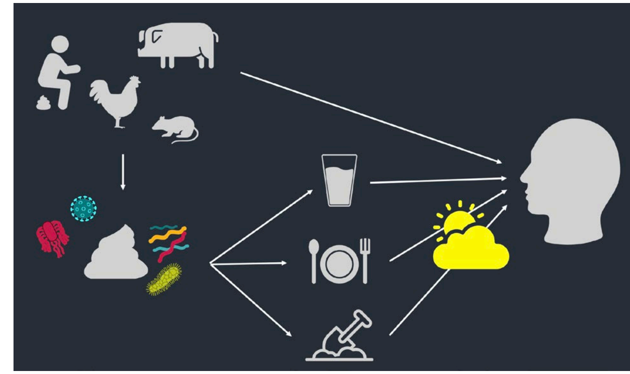
How many zoonotic infections are coming from each of different pathways?

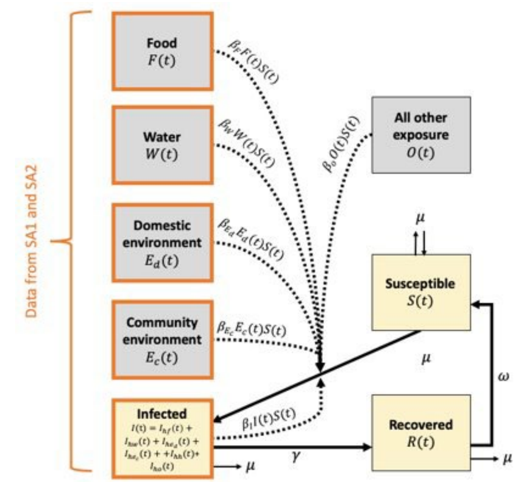
How does it change by weather, season, and climate?



Child infections + **Exposure sources** + **Seasonal drivers** + **Modeling**

Exposure sources:
- Food
- Drinking Water
- Community Environment
- Domestic Environment

Seasonal drivers:
- Meteorological Conditions
- Human-environment contact patterns



Objective: Identify **climate-resilient** control measures, tailored to this local context

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What are the impact of extreme weather events and natural disasters on diseases and medicine use?

Warren Kaplan

David Hamer

Kayoko Shioda

Flood

Wildfire

Landslide

Respiratory illness

Gastroenteritis

Vector-borne diseases

Medicine use

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ceid

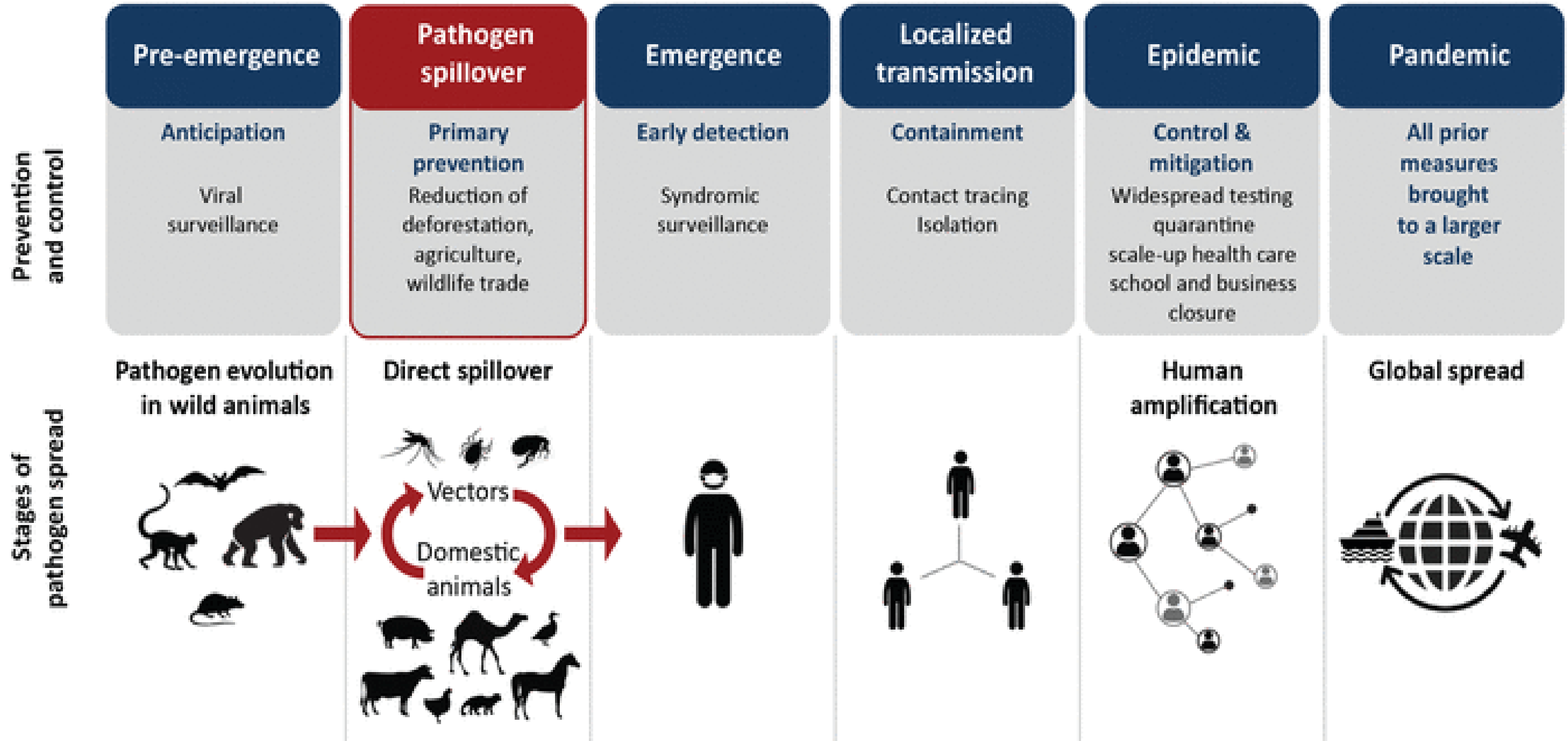
Pandemic Prevention and Arresting Mass Extinction:

A Huge Potential Win-Win on a Future-Facing Gameboard Where Few Choose to Play

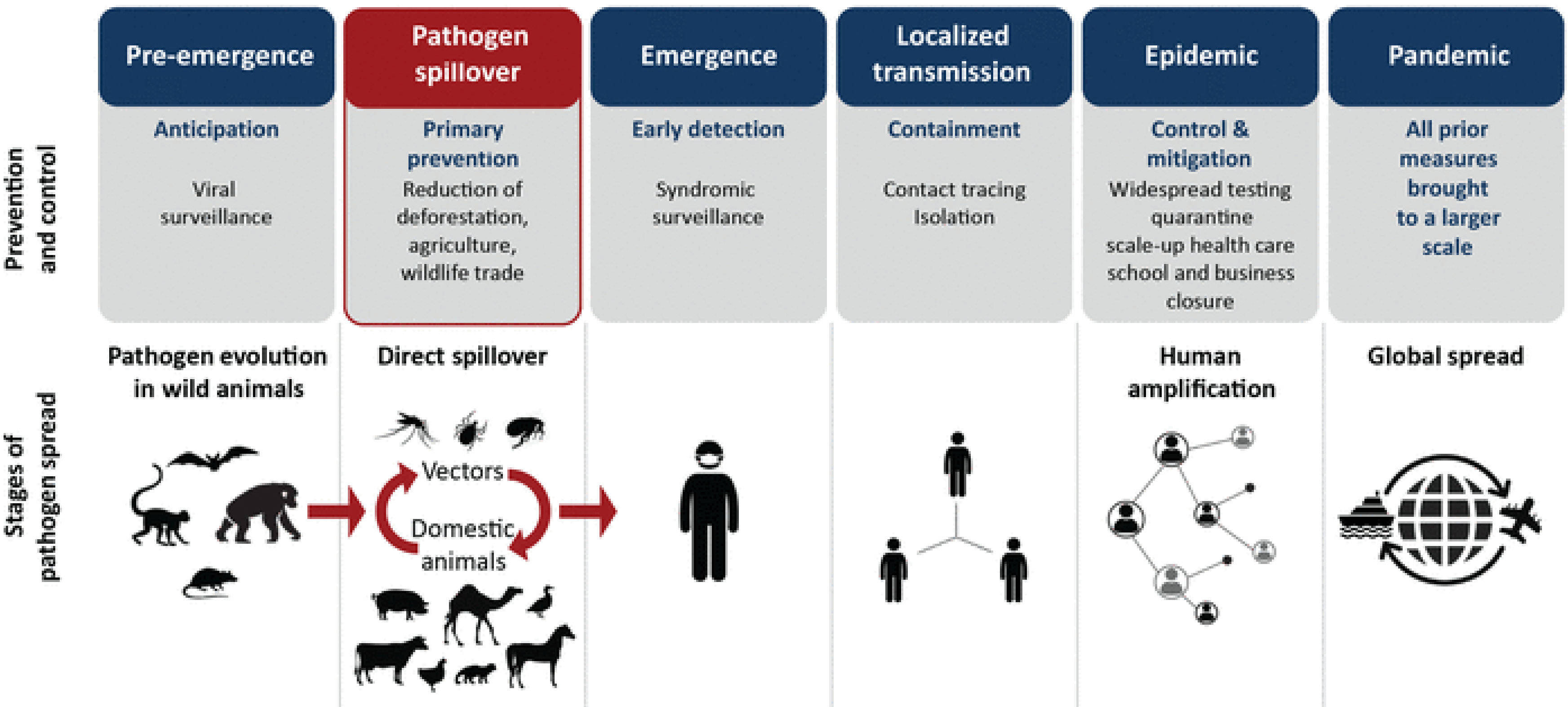
Les Kaufman

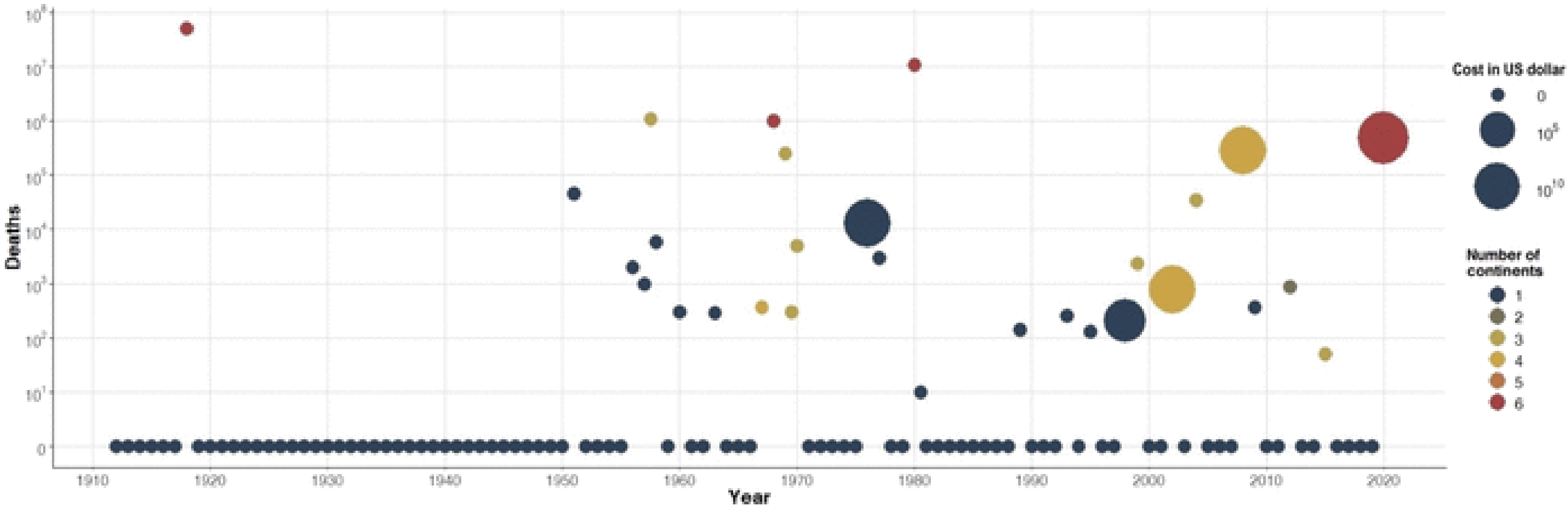
Professor of Biology

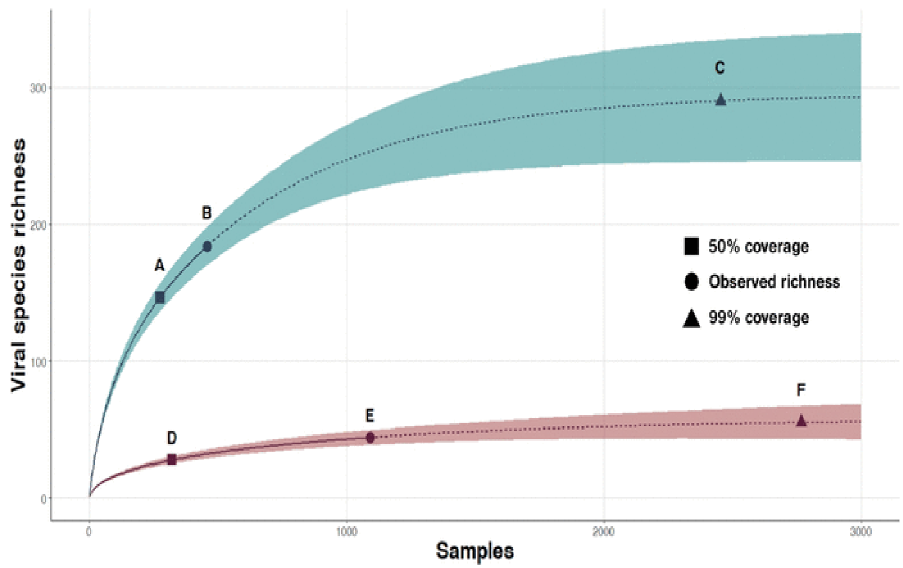
Biology, CAS


Prevention and control
Stages of pathogen spread
Pre-emergence
Anticipation
Viral surveillance
Pathogen spillover
Primary prevention
Reduction of deforestation, agriculture, wildlife trade
Emergence
Early detection
Syndromic surveillance
Localized transmission
Containment
Contact tracing
Isolation
Epidemic
Control & mitigation
Widespread testing
quarantine
scale-up health care
school and business closure
Pandemic
All prior measures brought to a larger scale
Pathogen evolution in wild animals
Direct spillover
Vectors
Domestic animals
Human amplification
Global spread

Deforestation and Encroachment: Major drivers both of extinction and viral spillover




Deaths
Year
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
Cost in US dollar
0
10^5
10^10
Number of continents
1
2
3
4
5
6


Viral species richness
Samples
0
100
200
300
1000
2000
3000
A
B
C
D
E
F
50% coverage
Observed richness
99% coverage

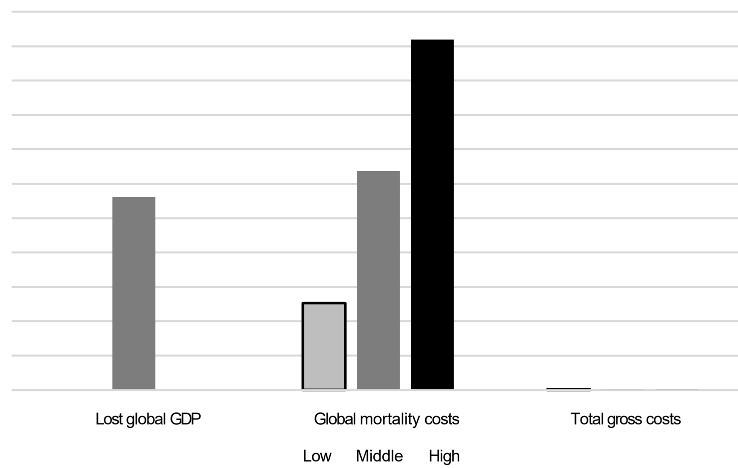
Summary of prevention costs, benefits, and break-even probability change

ITEM	VALUES (2020 $)
Expenditures on preventive measures	
Annual funding for monitoring wildlife trade (CITES+)	\$250–\$750 M
Annual cost of programs to reduce spillovers	\$120–\$340 M
Annual cost of programs for early detection and control	\$217–\$279 M
Annual cost of programs to reduce spillover via livestock	\$476–\$852 M
Annual cost of reducing deforestation by half	\$1.53–\$9.59 B
Annual cost of ending wild meat trade in China	\$19.4 B
TOTAL GROSS PREVENTION COSTS (*C*)	**\$22.0–\$31.2 B**
Ancillary benefit of prevention	
Social cost of carbon	\$36.5/tonne
Annual CO_2 emissions reduced from 50% less deforestation	118 Mt
Ancillary benefits from reduction in CO_2 emissions	\$4.31 B
TOTAL PREVENTION COSTS NET OF CARBON BENEFITS (*C*)	**\$17.7–\$26.9 B**
Damages from COVID-19	
Lost GDP in world from COVID-19	\$5.6 T
Value of a statistical life (*V*) adjusted for COVID-19 mortality structure	\$5.34 M or \$10.0 M
Total COVID-19 world mortality (Q_D) forecast by 28 July 2020, 50th percentile with 95% error bounds	590,643 [473,209, 1,019,078]
Value of deaths in world from COVID-19 = $Q_D \times V$	
Lowest (\$5.34 M × 2.5th percentile mortality forecast)	\$2.5 T
Middle (\$10 M × 50th percentile mortality forecast)	\$5.9 T
Highest (\$10 M × 97.5th percentile mortality forecast)	\$10.2 T
TOTAL DISEASE DAMAGES (*D*):	
Lowest (\$5.34 M × 2.5th percentile mortality forecast)	**\$8.1 T**
Middle (\$10 M × 50th percentile mortality forecast)	**\$11.5 T**
Highest (\$10 M × 97.5th percentile mortality forecast)	**\$15.8 T**

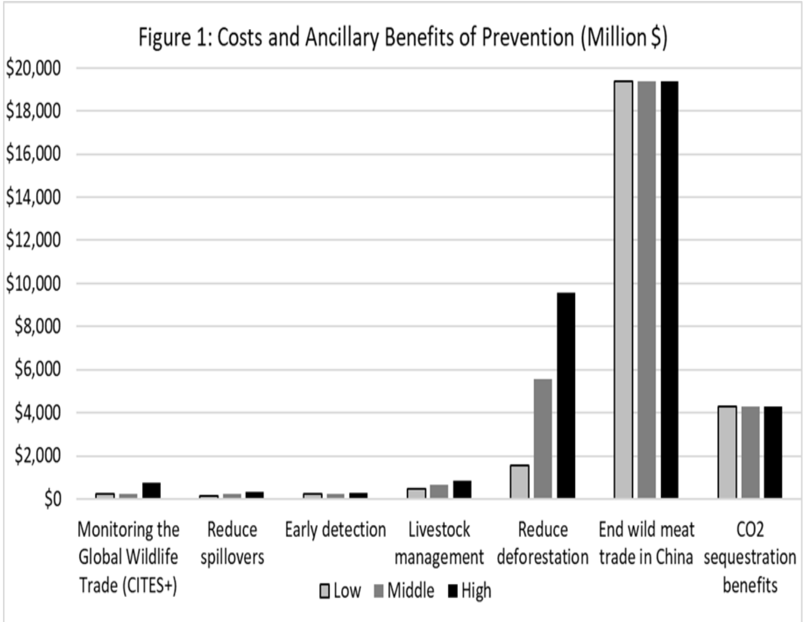
The break-even change in annual probability of pandemic satisfies $C = \Delta P \times D$, where P_0 = benchmark probability of pandemic; P_1 = probability of pandemic with prevention efforts in place; $\Delta P = P_0 - P_1$; and $\%\Delta P = (\Delta P / P_0) \times 100$.

If $P_0 = 0.01$, C = \$30.7 B, and D = \$11.5 T (most likely scenario, ignoring ancillary benefits of CO_2 reductions), prevention results in net benefits if it decreases P by 26.7% to $P_1 = 0.00733$. Using other values of C, D, and P results in $\%\Delta P$ ranging from 11.8% to 75.7%; only one scenario has a $\%\Delta P$ exceeding 50%. See supplementary materials.

COVID-19 Damages and Total Gross Prevention Costs (million \$)



Costs and ancillary benefits of zoonotic prevention efforts



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Template slide

So…what came of all this?

1. We got to Fauci…but attention on current pandemic, not preventing future ones.
2. Our proposal was in a bill for funding…then removed to help the bill pass
3. Major win for EcoHealth Alliance…then Trump punishes them for causing the pandemic
4. At least…the ties between tropical forest health and human health, and the validity of the OneHealth philosophy, made clear for pathogen spillover.

THANK YOU!

UPCOMING EVENTS

Learn more & RSVP: bu.edu/research/events
Topic ideas & feedback: bu.edu/research/topic-ideas

RESEARCH ON TAP

BU and Africa: Culture, Development, Health, Environment, and Governance
Monday, 4/8 | 4-6pm

RESEARCH HOW-TO

Amplify Your Expertise: How to Elevate Your Research with *The Conversation*
Thursday, 4/11 | 3-4pm

The Innovator's Journey
Tuesday, 5/7 | 3-4pm