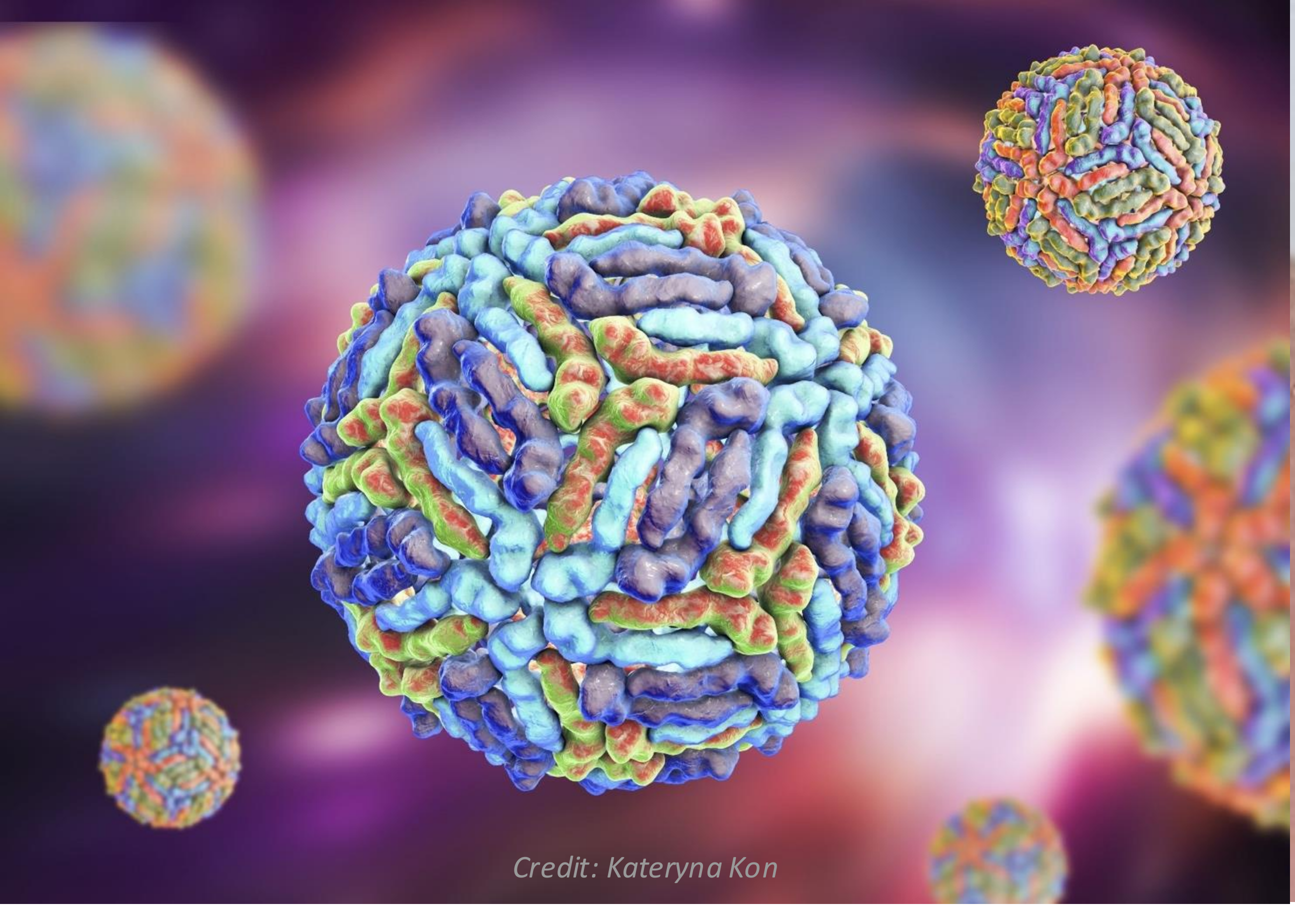


Mosquito Surveillance Standards in the US

We Can Thank West Nile Virus

WNV Introduction to US in 1999

25-year anniversary

WNV is now the leading cause of mosquito-borne disease in the US

WNV changed the game for mosquito management in the US

At the time, the US arboviral surveillance network was limited

WNV initiated a national effort for establishing more robust surveillance and reporting (Federal funding)

Expansion of workload for mosquito control districts

Major impact on US health care system

WNV and US Healthcare

Impact on US health care system- laboratory capacity, patient care, blood bank protocols, surgery, etc.

Initially, it was believed that WNV was only transmitted through infected mosquitoes.

2002- discovered transfusion transmission was possible (21 cases)

2003- first unit of WNV positive blood was intercepted

*80% of WNV infections are asymptomatic

*Nuclear acid amplification testing (NAT) required for testing

2005- FDA first approval of NAT for WNV screening of donor blood, organs, cells, and tissue

Association for the Advancement of Blood & Biotherapies

Methods of Surveillance

Dead bird counts and arbovirus testing

Sentinel chicken flocks

Mosquito collection
- Test for pathogens (Host seeking and Gravid)
- Species density and diversity

Larval and adult mosquitoes
- Habitat mapping and modeling
- Meteorological data tracking
- Record keeping

Sentinel Chicken Program

In 1977 a Saint Louis Encephalitis outbreak in Central Florida prompted Florida Board of Health to began the first arbovirus surveillance initiative.

The Sentinel Chicken Program began in 1978 to detect arboviral antibodies through serological testing. The program now tests for St. Louis Encephalitis (SLE), Eastern Equine Encephalitis (EEE), West Nile Virus (WNV), and Highlands Jay Virus (HJV).

This program is a vital method for early detection of arboviruses and to assist with mosquito management decision making.

WNV Taxonomy

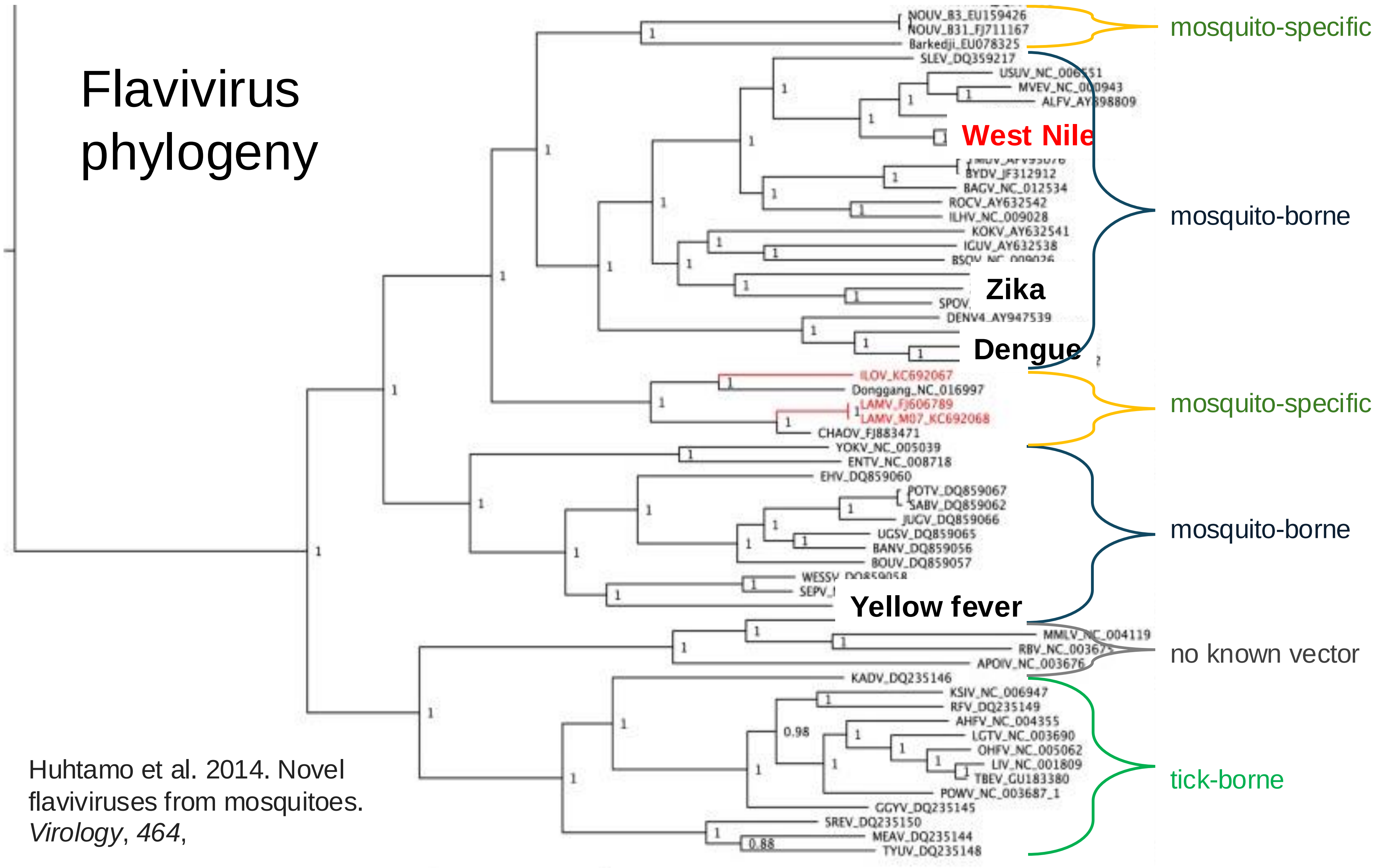
Virus	Virus Family	Virus Genus
Dengue virus	Flaviviridae	Flavivirus
Yellow fever virus	Flaviviridae	Flavivirus
Chikungunya virus	Togaviridae	Alphavirus
Zika virus	Flaviviridae	Flavivirus
West Nile virus	Flaviviridae	Flavivirus
Japanese encephalitis virus	Flaviviridae	Flavivirus
St. Louis encephalitis virus	Flaviviridae	Flavivirus
Murrey Valley encephalitis	Flaviviridae	Flavivirus
Eastern equine encephalitis virus	Togaviridae	Alphavirus

Japanese encephalitis antigenic serocomplex

Courtesy: Dr. Nathan Burkett-Cadena Source: Ecology of Vector-borne Disease

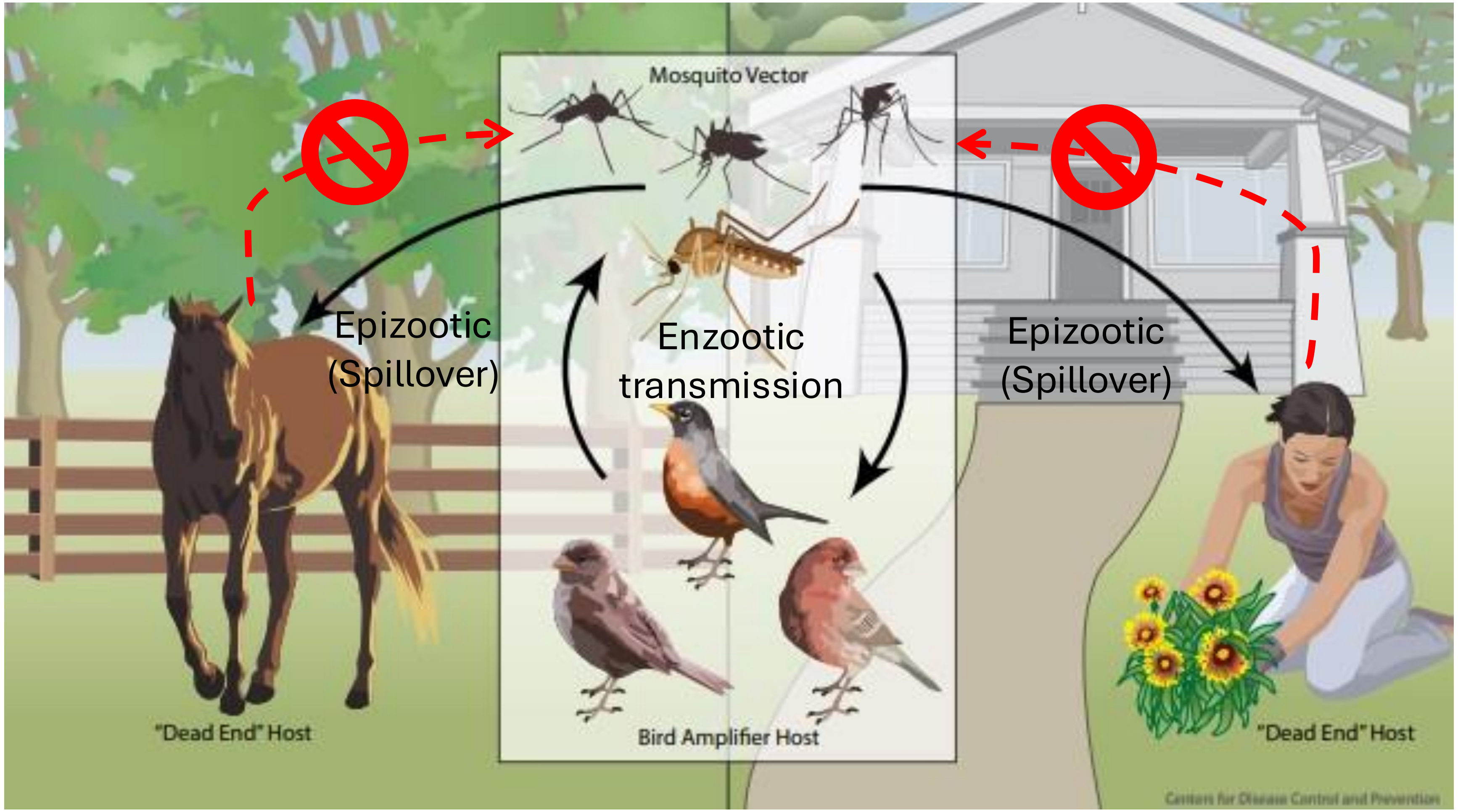
West Nile Virus Classification

Flavivirus phylogeny



Huhtamo et al. 2014. Novel flaviviruses from mosquitoes. *Virology*, *464*,

West Nile Virus Transmission Cycle



West Nile virus is a zoonotic mosquito-borne Flavivirus.

Songbirds are major vertebrate hosts and *Culex* mosquitoes are important vectors of WNV.

WNV Infection

- **West Nile fever**: influenza-like illness, abrupt onset, moderate or high fever for 3-5 days, rash, nausea, abdominal pain, diarrhea, and respiratory distress.
- 80 % WNV infections are asymptomatic. 1 in 5 people develop symptoms
- 1 in 150 develop severe symptoms that can lead to death.
- **West Nile neuroinvasive disease**: acute meningitis, encephalitis, flaccid paralysis, disorder of movement, long recovery period, prolonged depression.
- No vaccine or specific antiviral treatments for West Nile virus infection are available for humans (treat symptoms with over-the-counter medications).
- In severe cases, patients often need to be hospitalized to receive supportive treatment, such as intravenous fluids, pain medication, and nursing care.

Courtesy: Dr. Nathan Burkett-Cadena Source: Ecology of Vector-borne Disease

Diversity of Mosquitoes

<u>Mosquito Diversity (all species)</u>

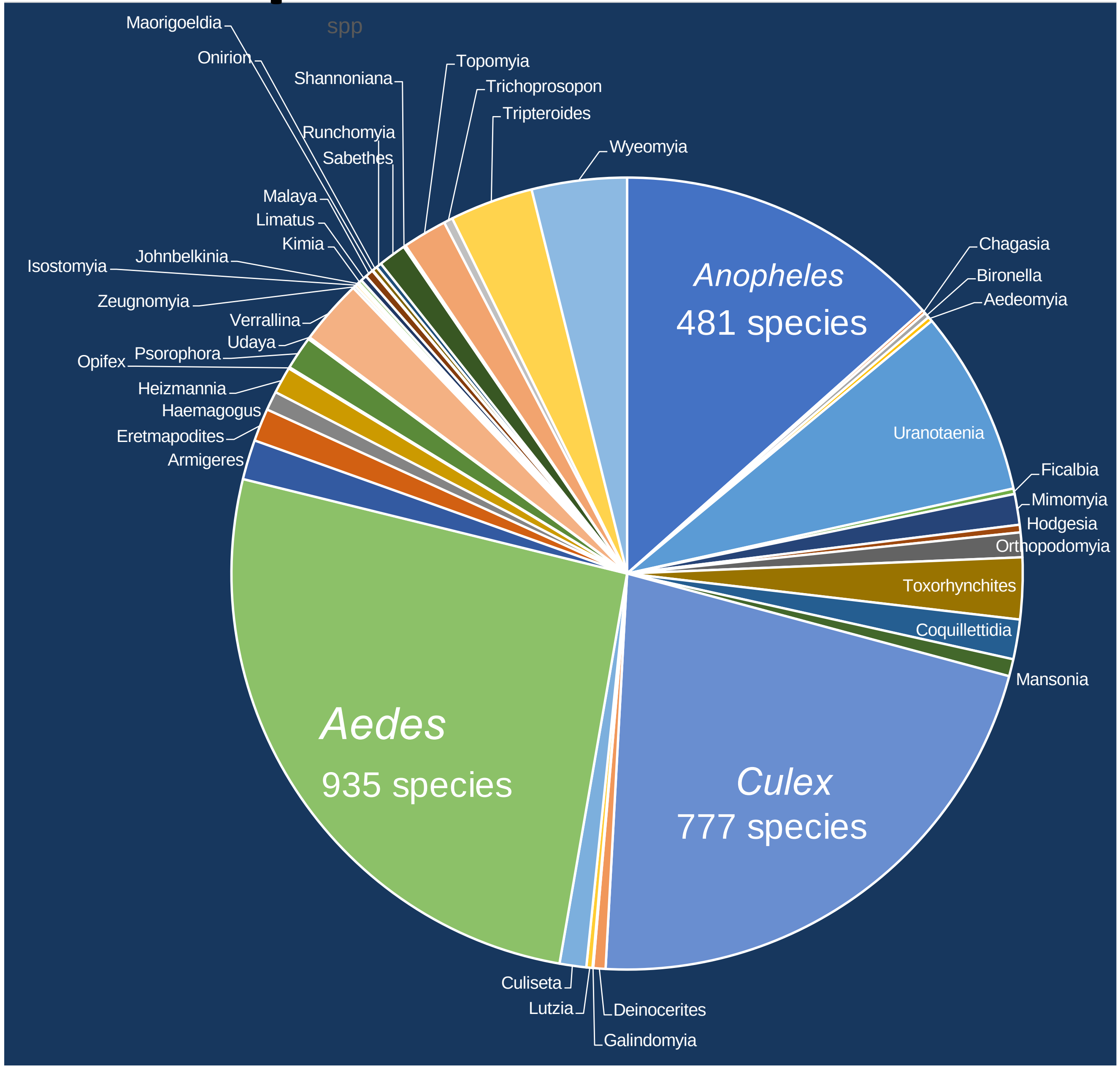
Genera: 41

Species: 3,582

"Big 3"

<u>Genus</u>	<u>species</u>
Aedes	935
Culex	777
Anopheles	<u>481</u>
	2193

Data from *Mosquito Taxonomic Inventory*



Biology of *Culex* mosquitoes

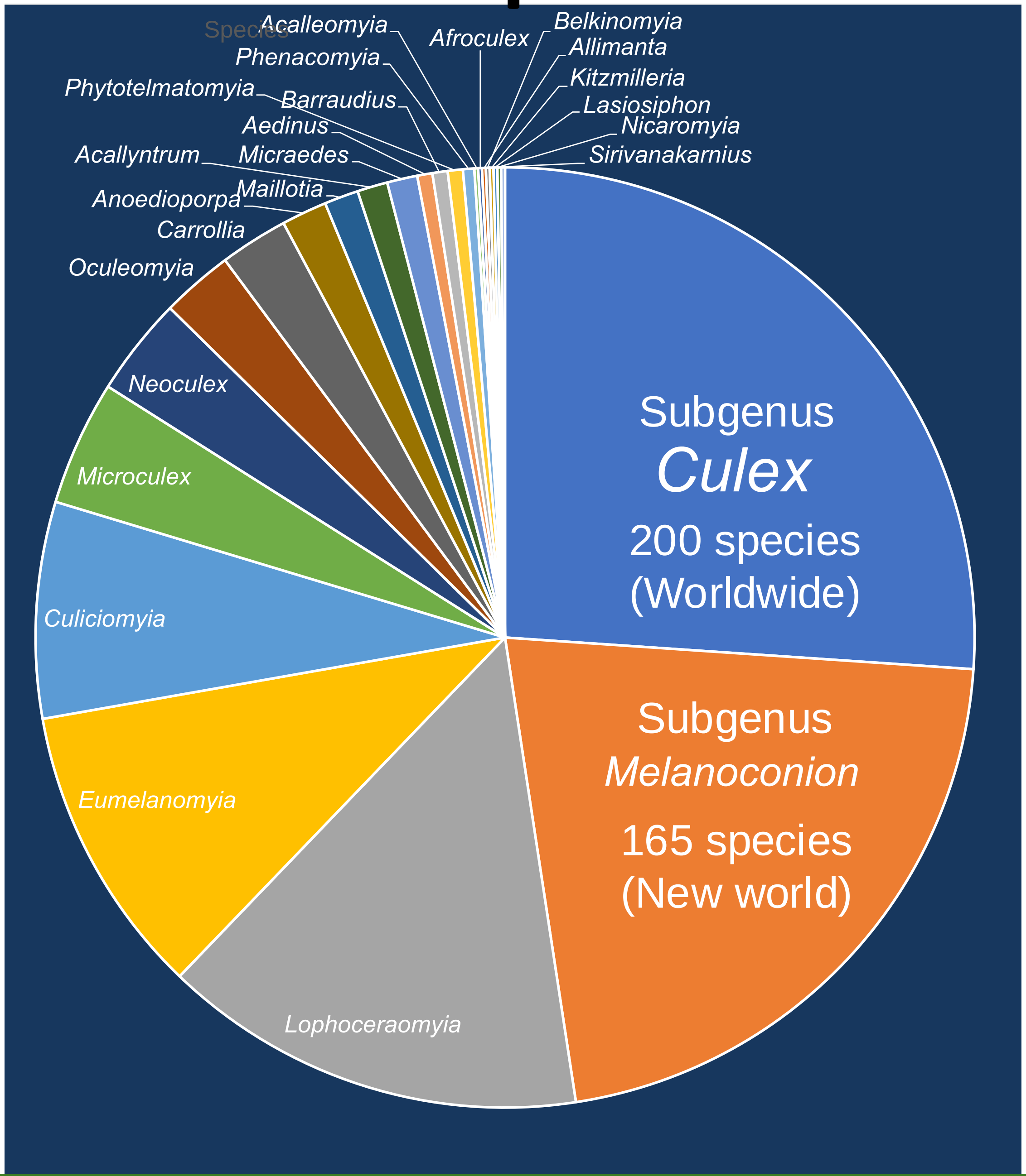
The genus *Culex*

Culex subgenera

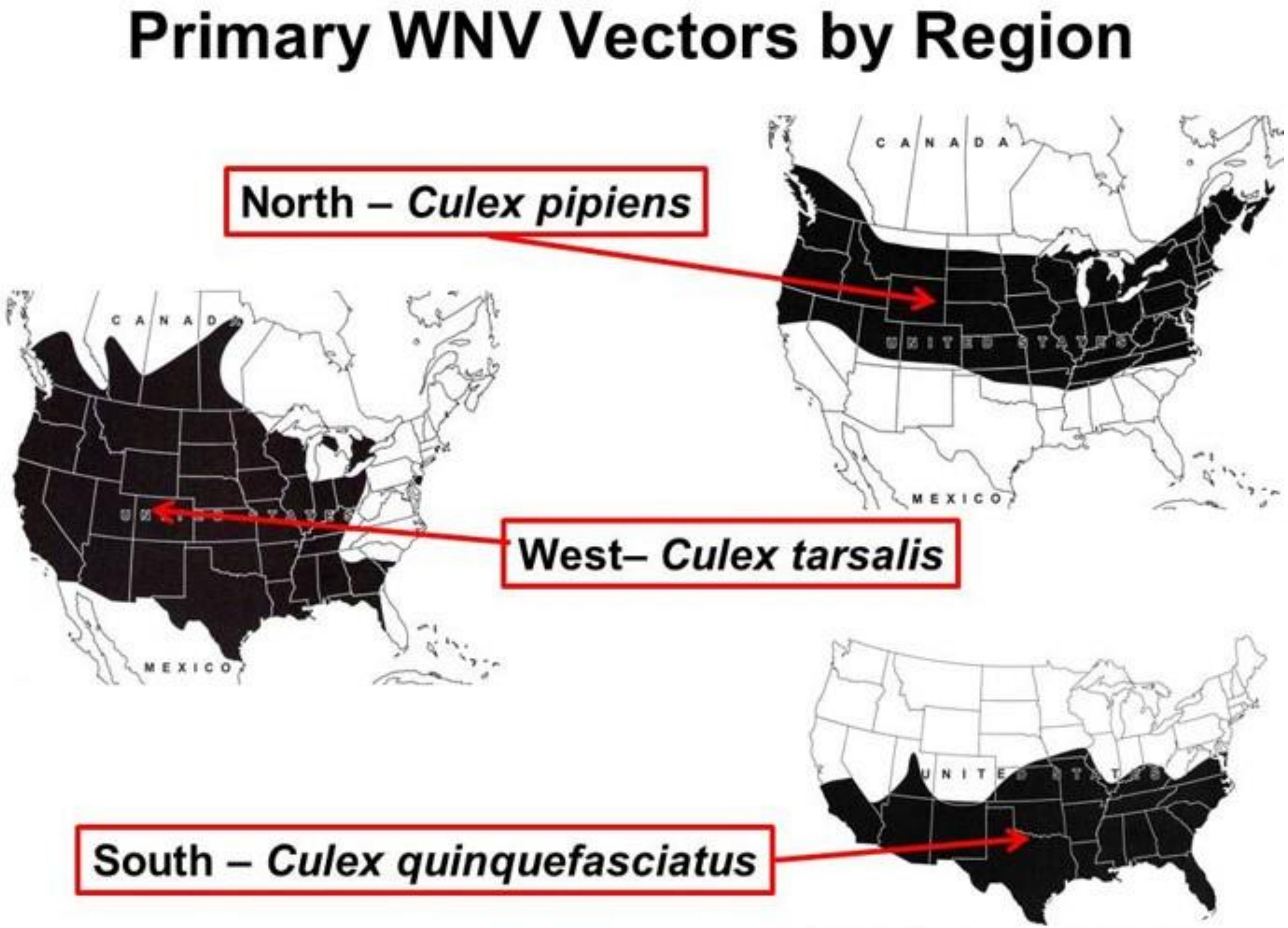
Subgenus	species
Culex	200
Melanoconion	165
	365
	(47.5%)

Subgenus *Culex*: contains most of the vector and pest species of the genus.

Data from *Mosquito Taxonomic Inventory*



West Nile Virus and Culex Mosquitoes



Biology of *Culex* Mosquitoes

floodwater pool

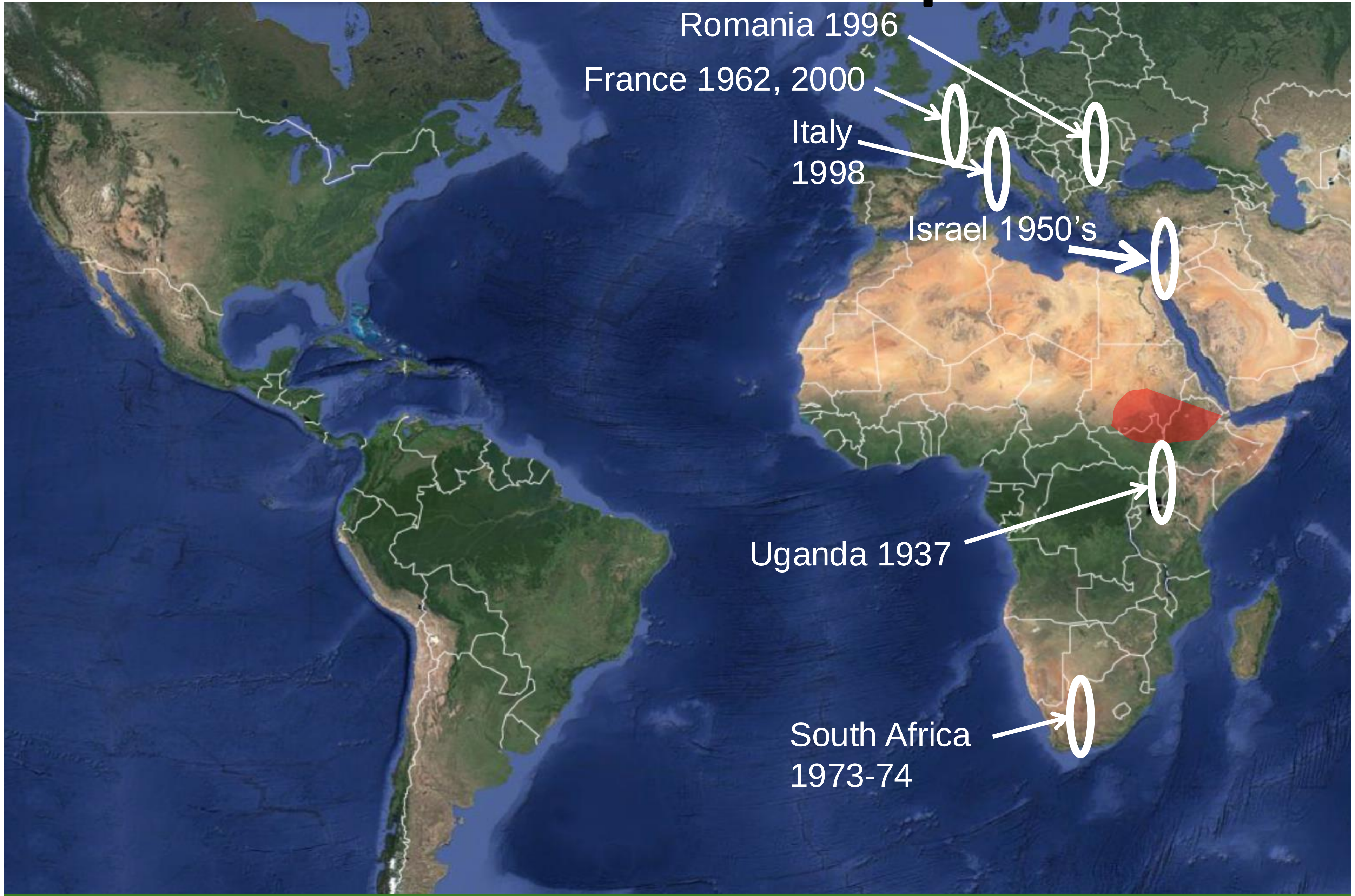
Artificial container

Culex larva habitats

vegetated wetland

Artificial container

West Nile Virus Spread



Mosquitoes are the Likely Candidate

Number of specimens and number of pools of arthropods examined for virus, and number of West Nile virus isolations

	No. of specimens	No. of pools inoculated	W.N. virus isolations
Fleas	3,272	54	
Flies:			
Musca spp	6,351	20	
Phlebotomus sp.	123	6	
Lice	3,648	48	
Mites	6,887	80	
Mosquitoes	51,937	1003	17
Ticks:			
Amblyomma sp.	94	12	
Argas spp.	1,359	92	
Boophilus spp.	431	16	
Dermacentor sp.	133	2	
Haemaphysalis sp.	12	1	
Hyalomma spp.	516	42	
Ornithodoros spp.	1,840	90	
Rhipocephalus spp.	1,422	64	
Unclassified	42	3	

To

A STUDY OF THE ECOLOGY OF WEST NILE VIRUS IN EGYPT[1]

R. M. TAYLOR[2], T. H. WORK, H. S. HURLBUT AND FARAG RIZK

Am J Trop Med Hyg (1956)

West Nile Virus Source

West Nile virus isolations from mosquito pools according to species of mosquito

Mosquito species	Specimens	Pools	Average no. of spec./pools	W.N. virus isolations		
				Number	% of spec.	% of pools
Culex antennatus	34714	485	72	5	0.015	1.03
Culex pipiens	5514	157	35	—	—	—
Culex pipiens &/or *univittatus*	2104	53	40	3	0.14	5.66
Culex univittatus	6332	160	40	9	0.14	5.63
Aedes caspius	2027	84	24	—	—	—
Anopheles pharoensis	1246	64	20	—	—	—
Total	51937	1003	52	17		

A STUDY OF THE ECOLOGY OF WEST NILE VIRUS IN EGYPT[1]

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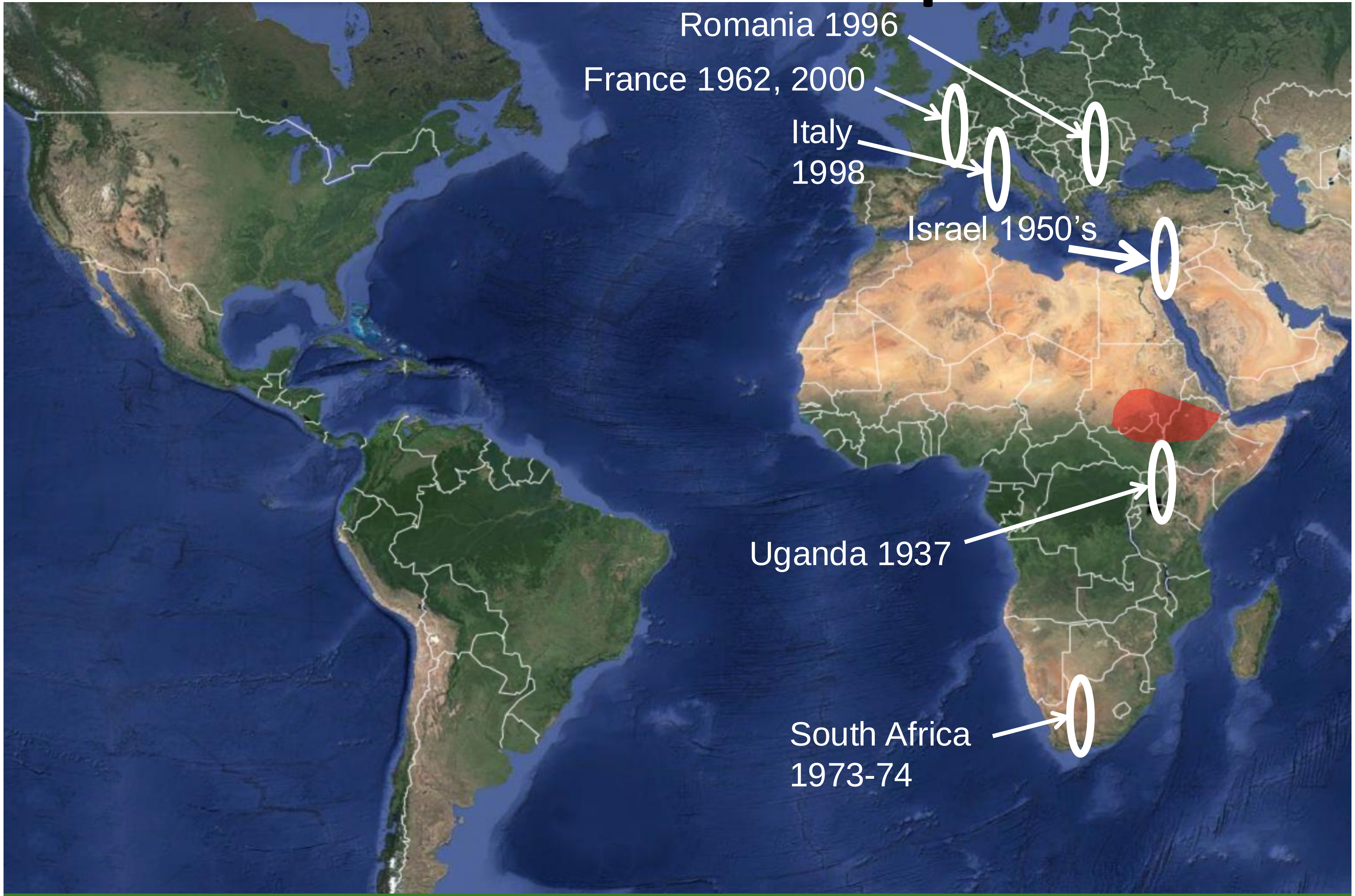
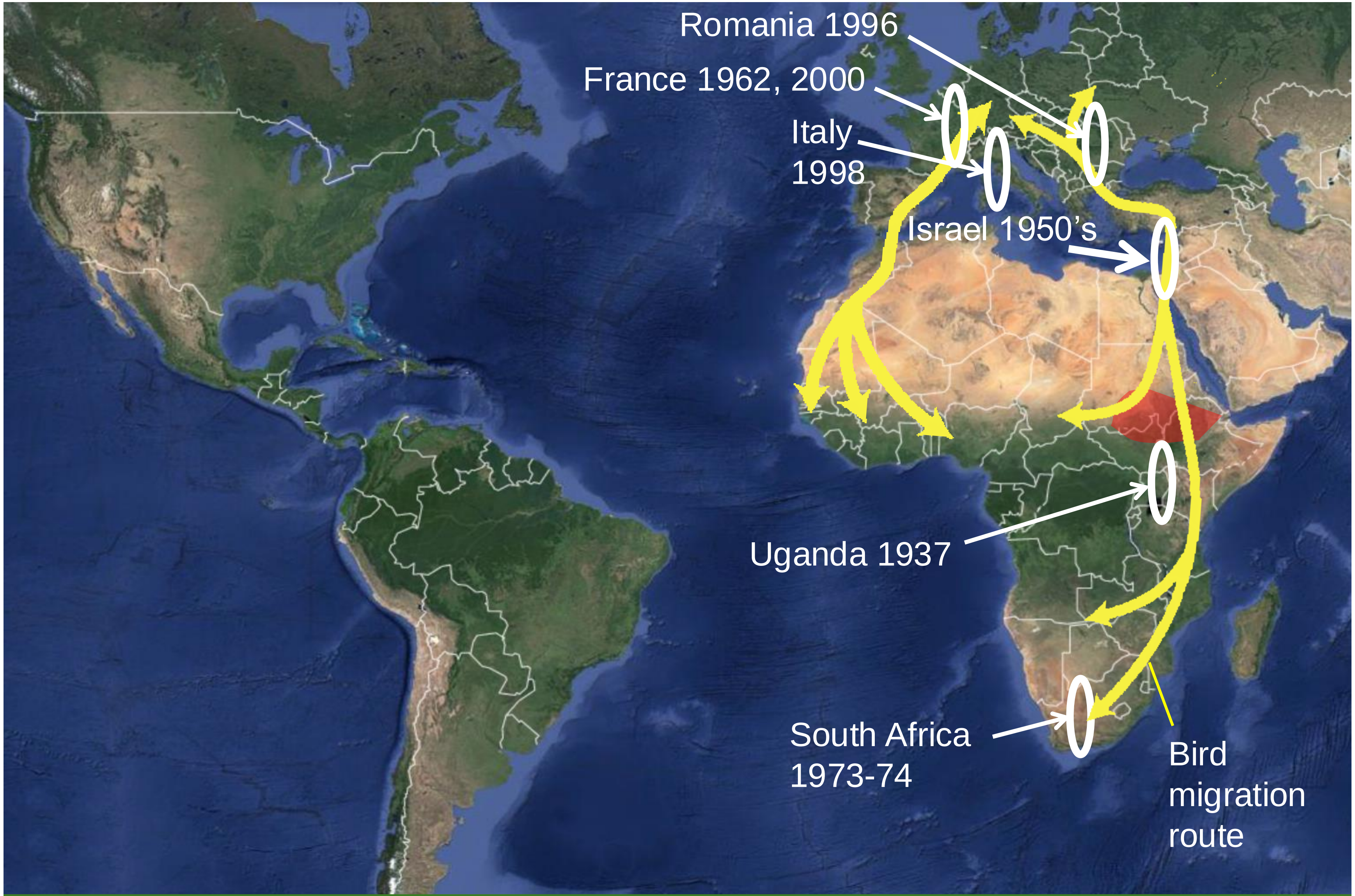
West Nile Virus Spread

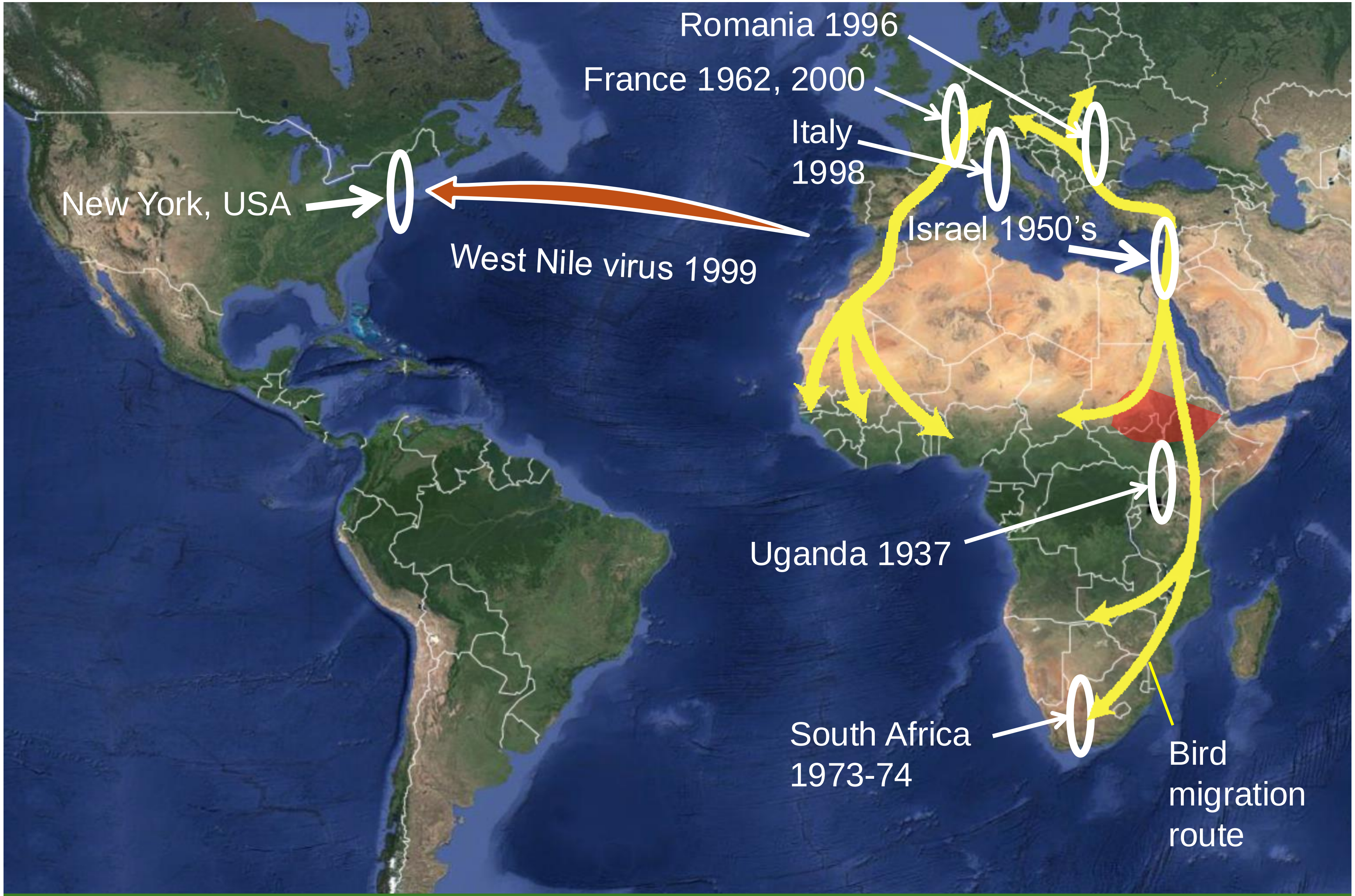


WNV Associated with Avian Flyways

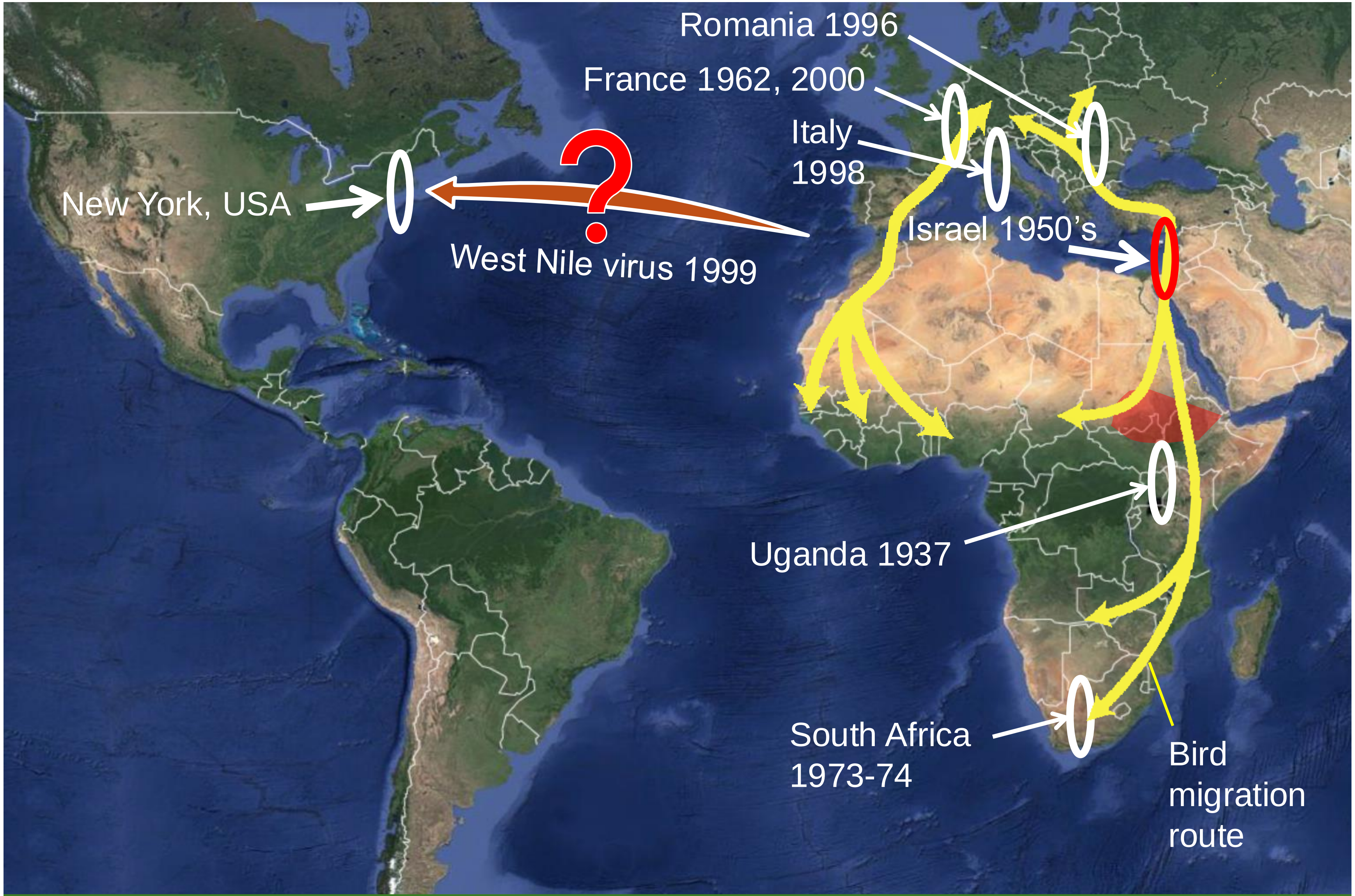


Courtesy: Dr. Nathan Burkett-Cadena

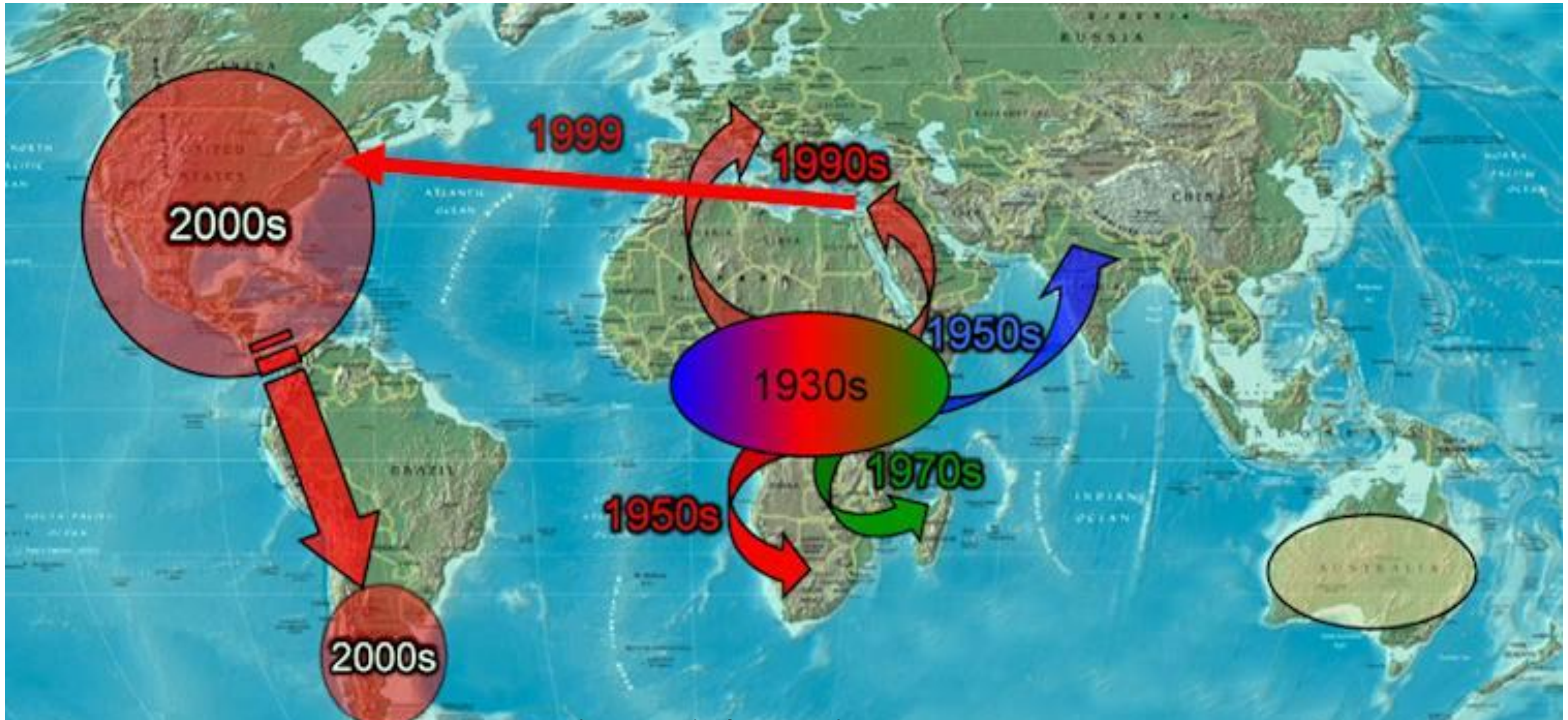
West Nile Virus



West Nile Virus



Timeline of West Nile Virus Expansion



The spread of West Nile virus. AJ Cann

1937	1950-70s	1990s	**1999**	2000-2009	2010-2022
1st case	Israel	Romania	**1st case in**	Argentina	Greece
West Nile District	Egypt	Russia	**Western**	Latin America	Italy
Uganda	France		**Hemisphere**	Canada	India
	South Africa		**New York City**	China	Serbia
				Europe	Hungary

1999 WNV US Introduction- Case History

August of 1999- 2 cases of encephalitis were reported to the New York City Department of Health and Mental Hygiene (NYCDOH) by an infectious disease physician (Dr. Deborah Asnis) in the borough of Queens.

Similar cases were also quickly identified at neighboring hospitals and the Centers for Disease Control and Prevention (CDC) was asked to help identify the cause.

Information from patient interviews pointed toward a mosquito borne disease.

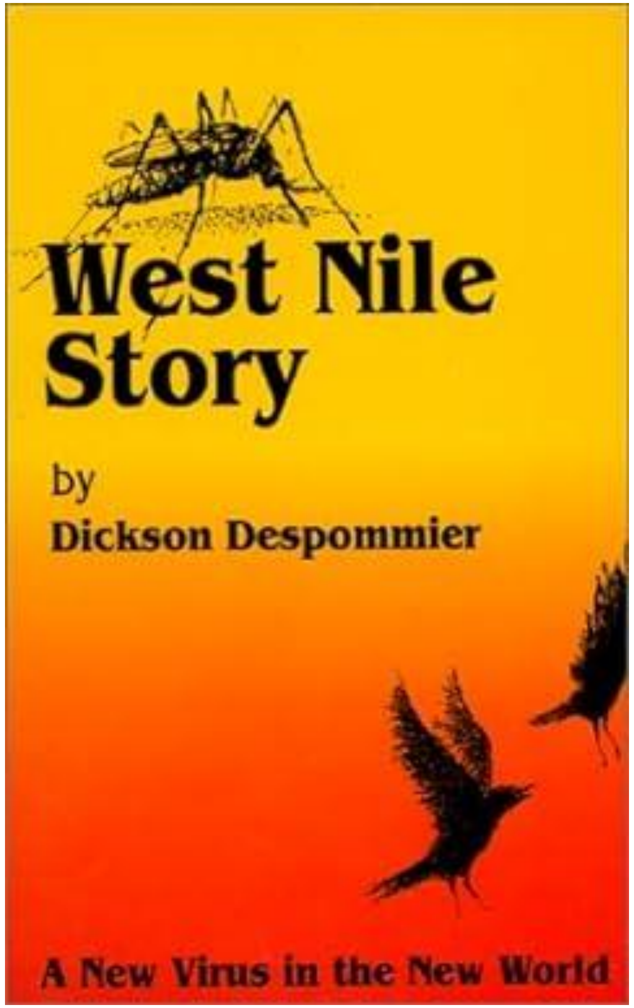
Serum and cerebrospinal fluid (CSF) samples tested positive for **IgM antibodies against St. Louis encephalitis virus (SLEV)** by monoclonal antibody capture-enzyme linked immunosorbent assay (MAC-ELISA) at CDC, leading to swift implementation of mosquito control measures."

1999 WNV US Introduction- Case History

By October 5, the number of laboratory-positive cases had increased to 50 (27 confirmed and 23 probable), including five deaths.

"The increase in cases is mainly a result of completed **retesting with West Nile virus antigen** of specimens previously tested with the related St. Louis encephalitis virus antigen and to intensive retrospective case finding in the ongoing epidemiologic investigations."

Centers for Disease Control and Prevention (CDC). Update: West Nile-like viral encephalitis--New York, 1999. *MMWR Morb Mortal Wkly Rep*. 1999;48(39):890-892.



TWiV
This Week In Virology

TWiV 1: West Nile Virus
September 24, 2008
Podcast

CDC West Nile Virus Guidelines 1999

1) Determine current and future geographic distribution of WNV in the Western Hemisphere
2) Determine if bird migration is a mechanism for WNV dispersal
3) Determine virus, vector, and vertebrate host relationship and range in the W. Hemisphere
4) Determine mechanism of virus persistence
5) Characterize the biology, behavior, **surveillance**, and control approaches for the mosquito vectors of WNV in the Western Hemisphere
6) **Develop and evaluate prevention strategies**
7) Improve laboratory diagnosis
8) Determine the clinical spectrum of disease and long-term prognosis in humans
9) Identify risk factors for human infection
10) Study viral pathogenesis in humans and birds

CDC
CENTERS FOR DISEASE CONTROL AND PREVENTION™

West Nile Virus Notification

ArboNet was developed as a passive electronic reporting surveillance system to monitor WNV spread across the US. CDC funded in collaboration with state health agencies.

Simultaneous gathering of WNV data of infections in humans, mosquitoes, birds, and other animals.

First implemented in states near the New York City epidemic beginning in 2000

Expanded nationwide as the virus moved westward

Human surveillance focused on neuroinvasive disease cases as these are more likely to be diagnosed and reported than West Nile fever cases

WNV neuroinvasive disease nationally notifiable in 2001

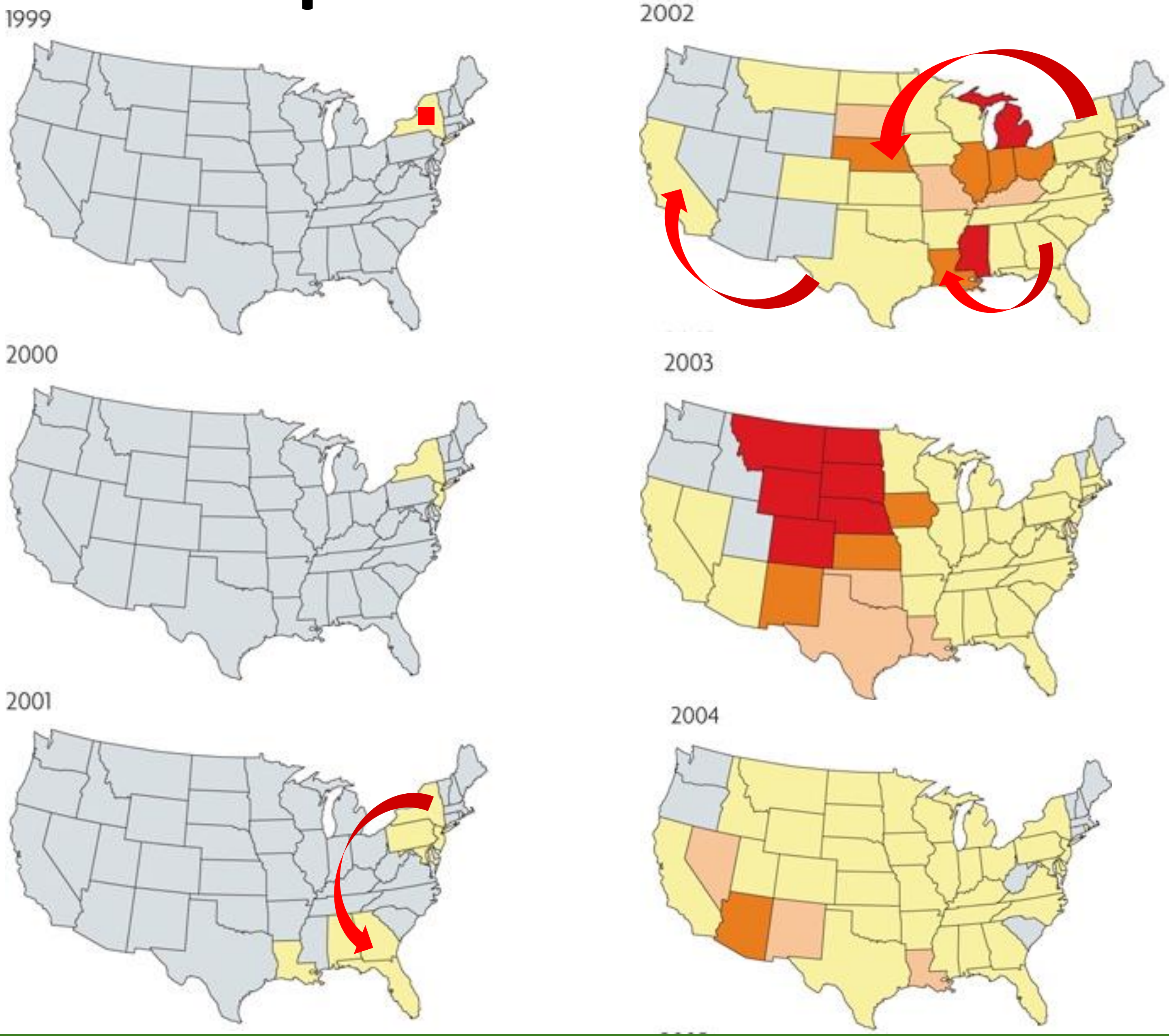
Non-neuroinvasive disease (i.e., West Nile fever) nationally notifiable in 2004

Petersen LR. 2019. Epidemiology of West Nile Virus in the United States: Implications for Arbovirology and Public Health. *J Med Entomol*. ,56:6

ArboNET
National Arbovirus Surveillance System

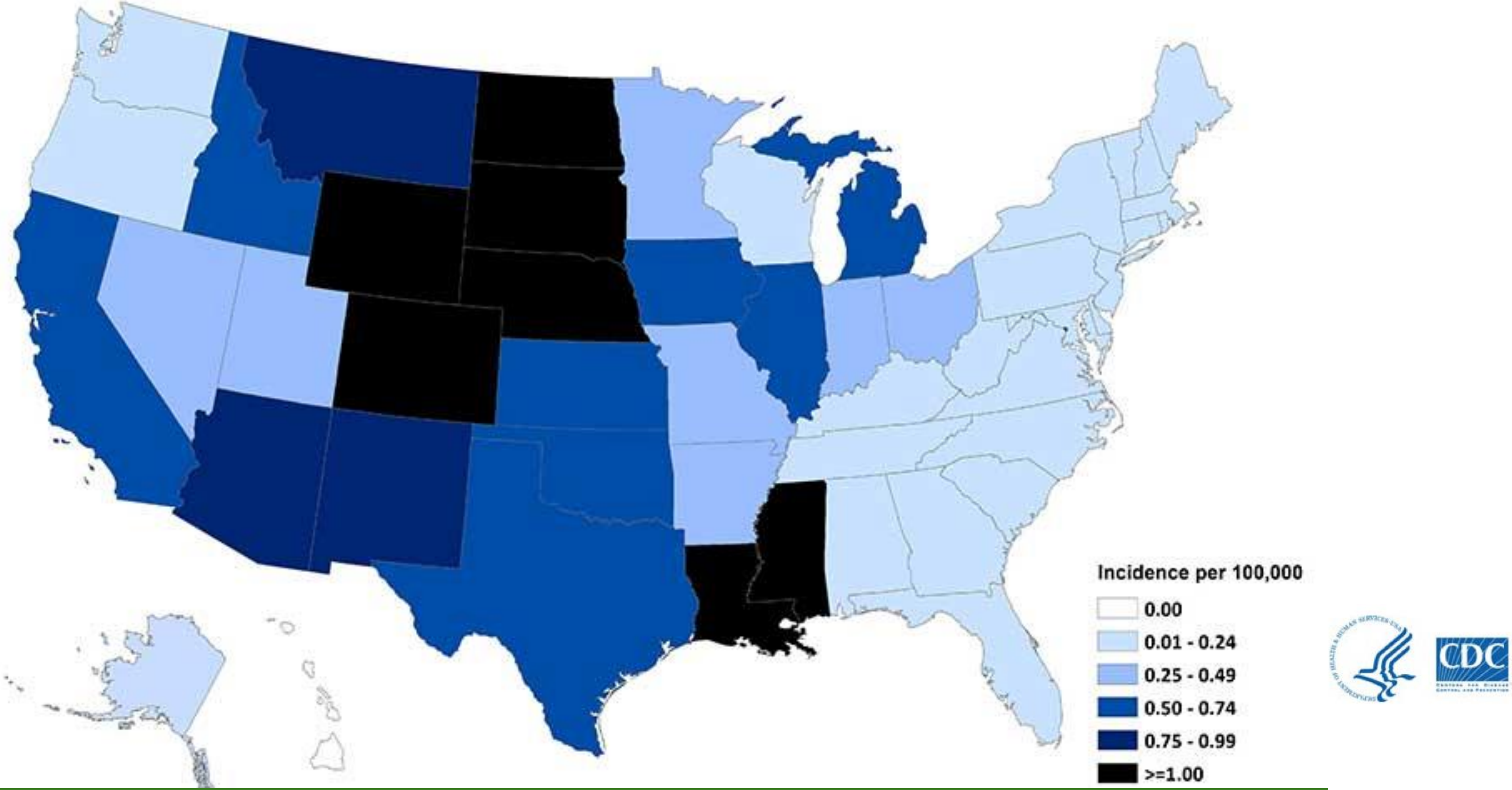
CDC
Centers for Disease Control and Prevention

WNV Expansion in US 1999-2004



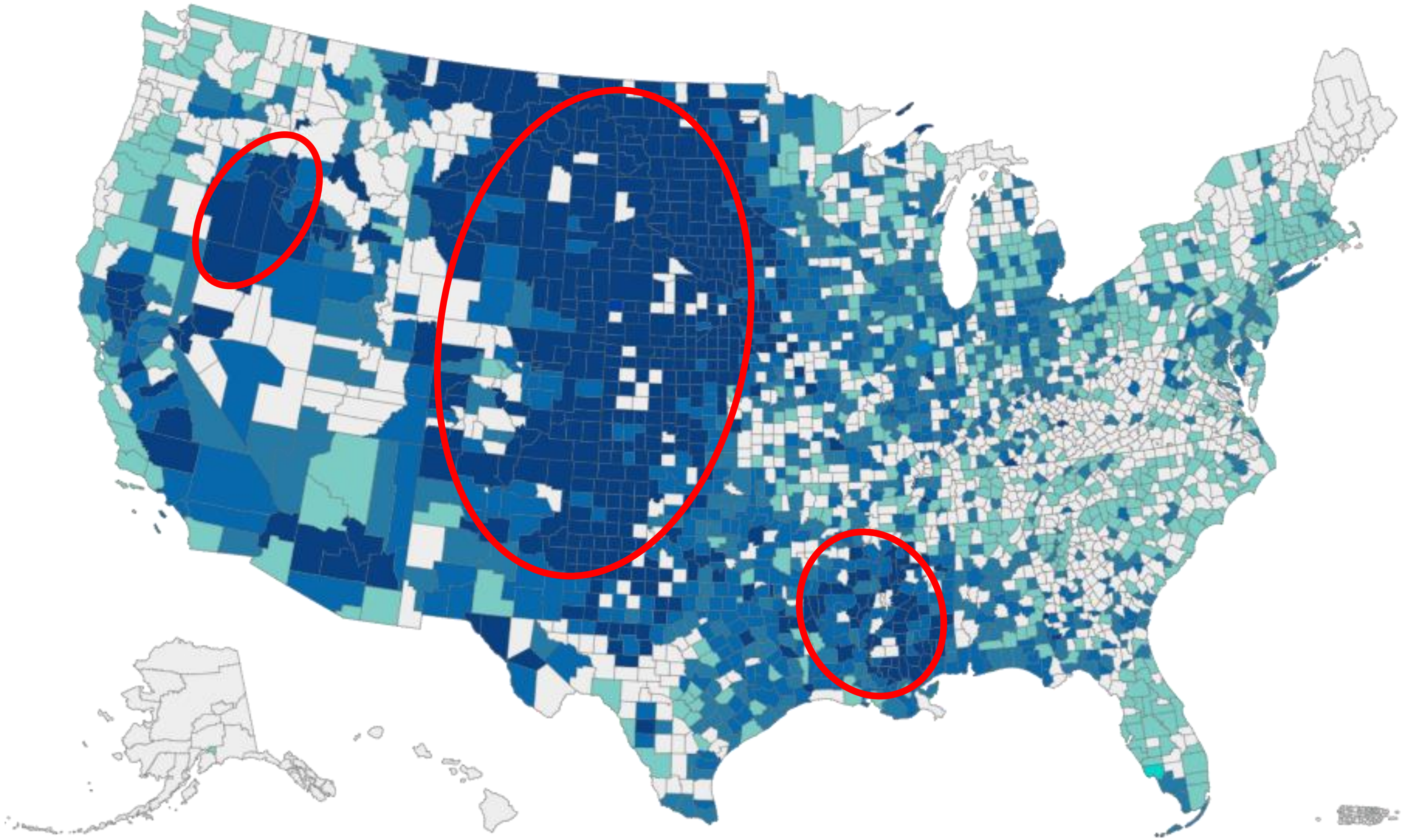
West Nile Virus

Average annual incidence of West Nile virus neuroinvasive disease reported to CDC by state



WNV Symptoms & Statistics

Average annual incidence of WNV neuroinvasive disease reported to CDC by state, 1999-2023



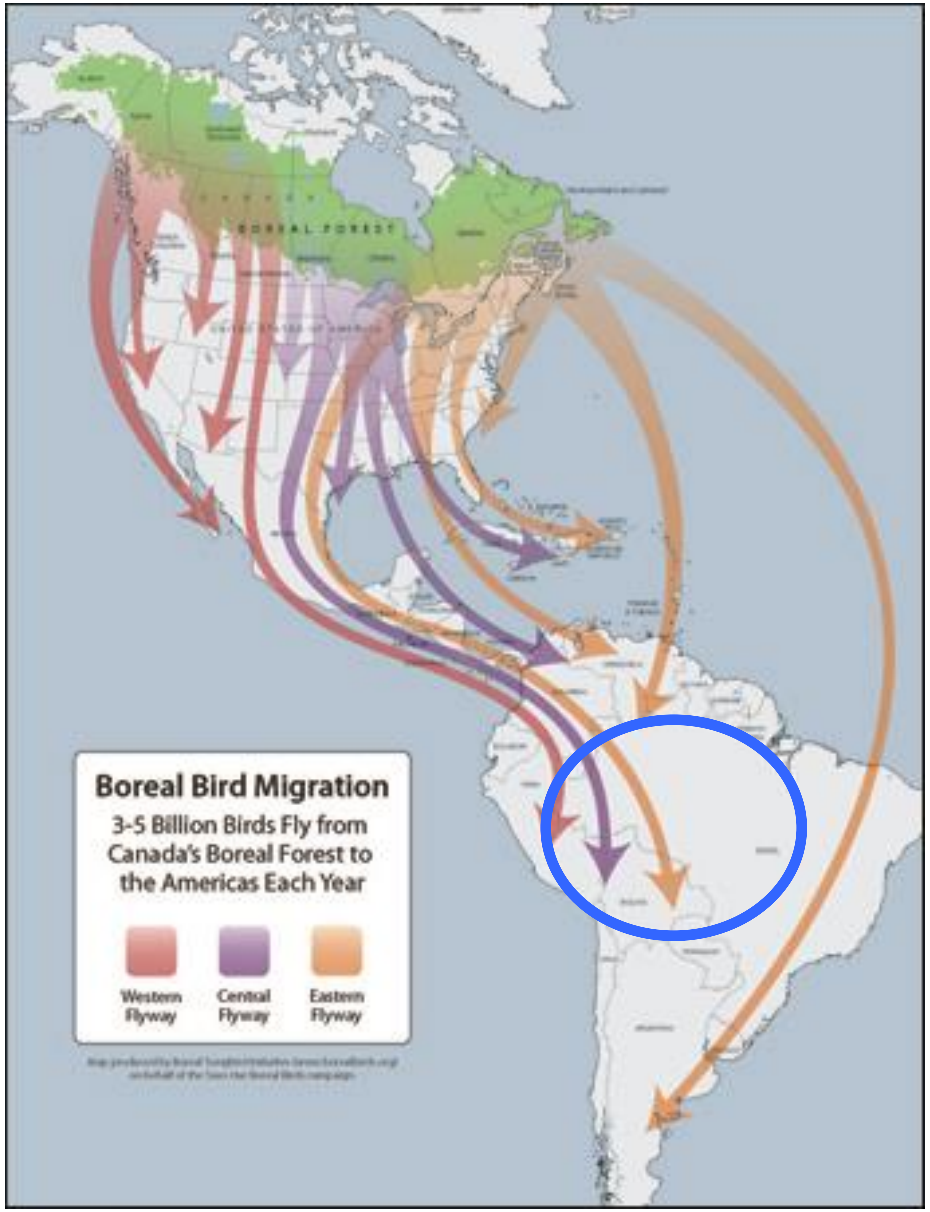
WNV Expansion Due to Avian Migration

Some North American avian populations migrate to South America in the winter months by regional flyways.

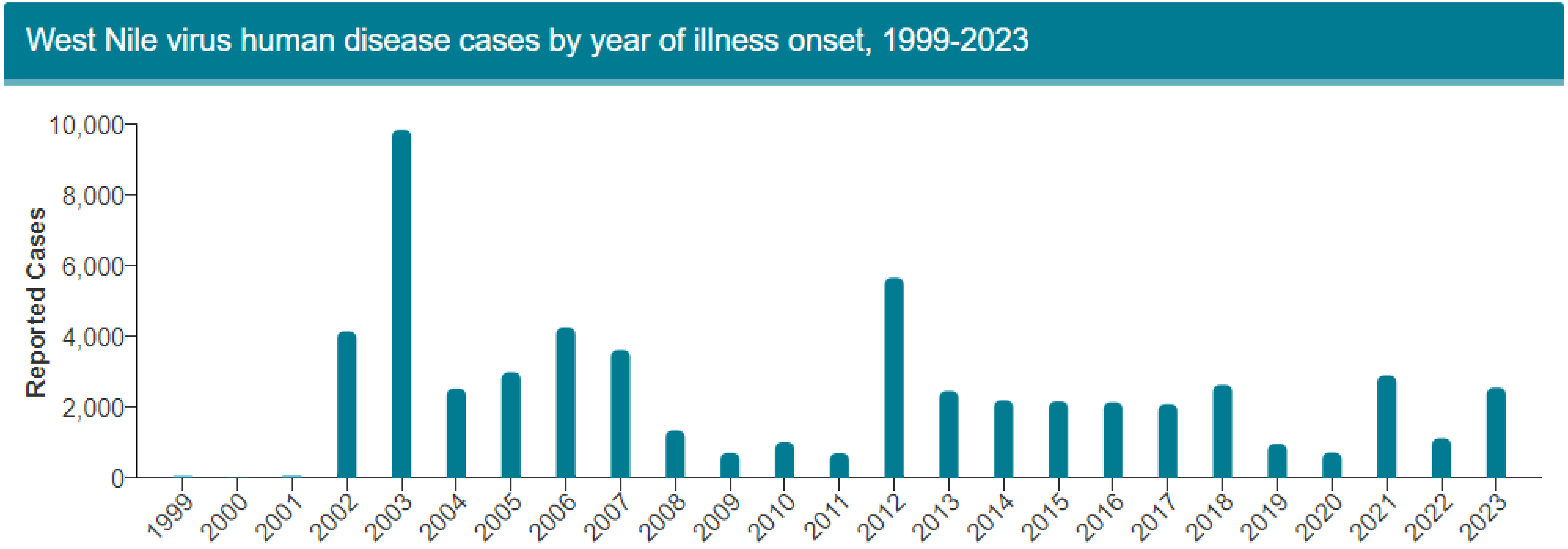
Communal migratory resting grounds allow for interaction between independent avian populations and *Culex* populations.

Possible local transmission of WNV in South American winter range due to *Culex* feeding?

Populations return to northern ranges and disseminate WNV to new regions.



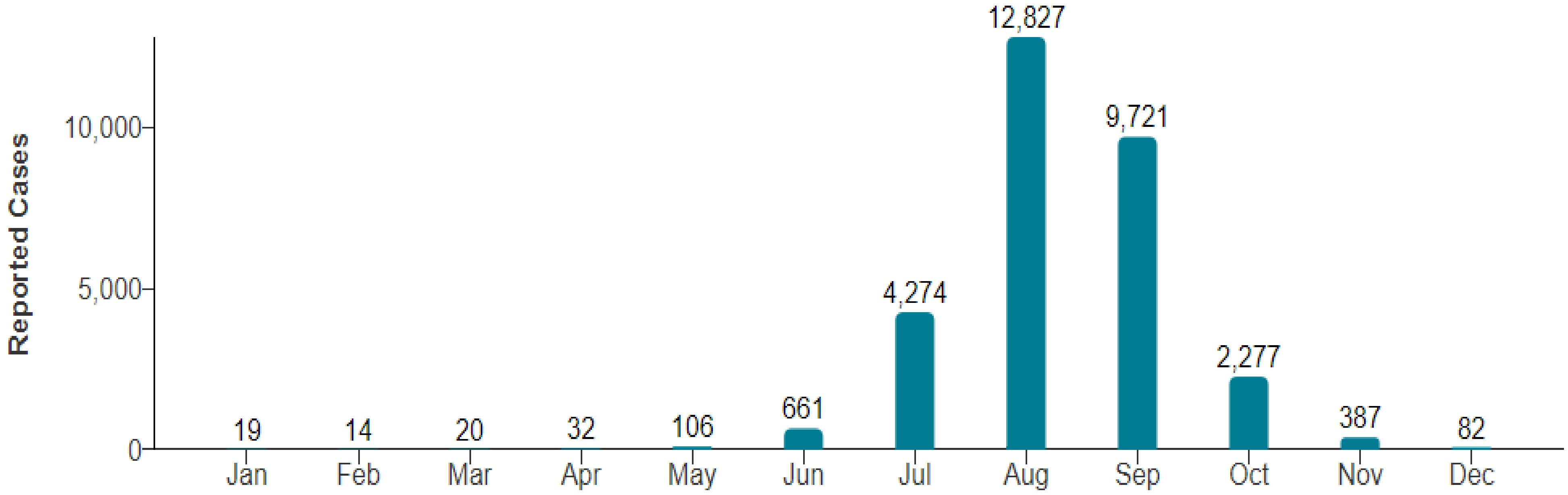
West Nile Virus US Annual Cases 1999-2023



Human Disease Cases	Hospitalizations	Deaths
30,422 *Cases from year(s) and type of case selected above*	**22,564** *Hospitalizations from year(s) and type of case selected above*	**2,820** *Deaths from year(s) and type of case selected above*

West Nile Virus US Annual Cases 1999-2023

Human Disease Cases	Hospitalizations	Deaths
30,422 *Cases from year(s) and type of case selected above*	**22,564** *Hospitalizations from year(s) and type of case selected above*	**2,820** *Deaths from year(s) and type of case selected above*



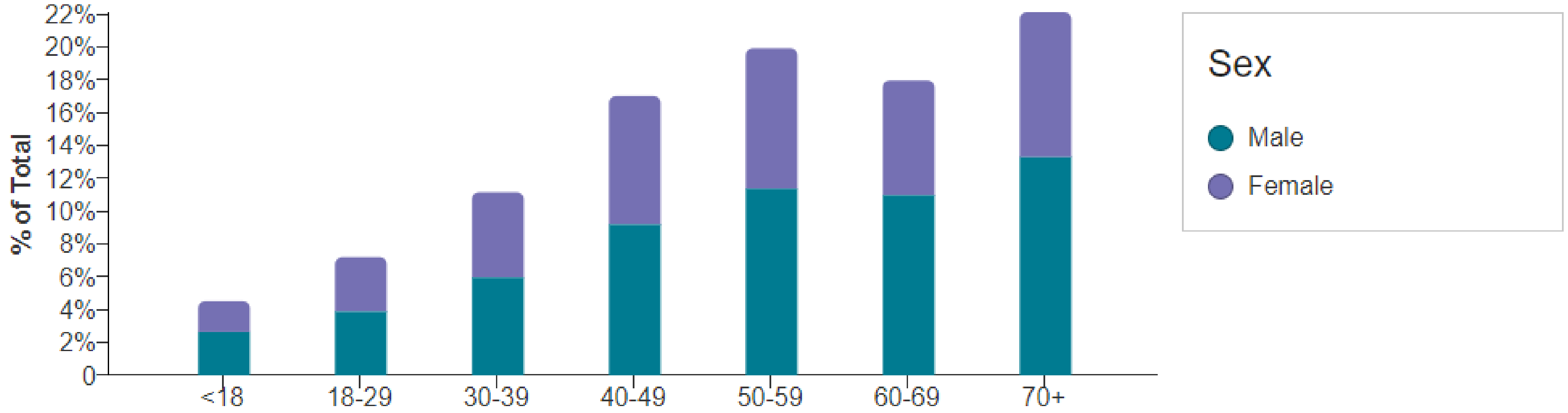
West Nile virus human disease cases reported by month of illness onset, 1999-2023, Neuroinvasive disease cases

WNV by Age

Average annual incidence of West Nile virus neuroinvasive disease by age group (1999 to 2023)

Older people are at much greater risk of neuroinvasive disease.

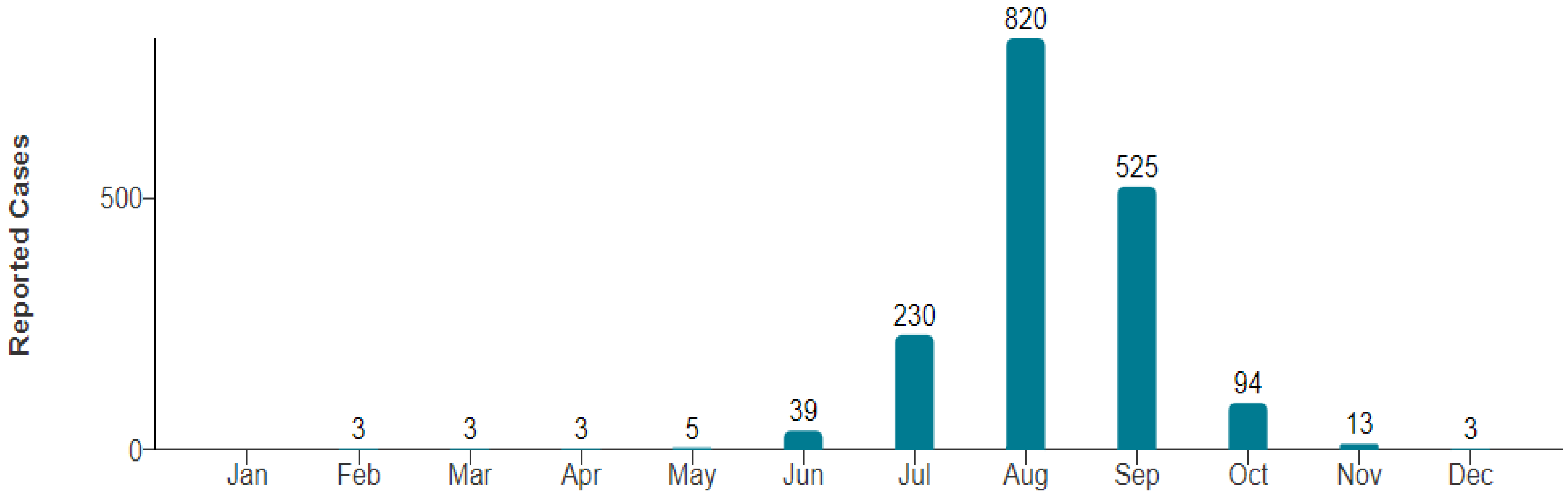
Older males at highest risk



West Nile virus human disease cases by age and sex, 1999-2023

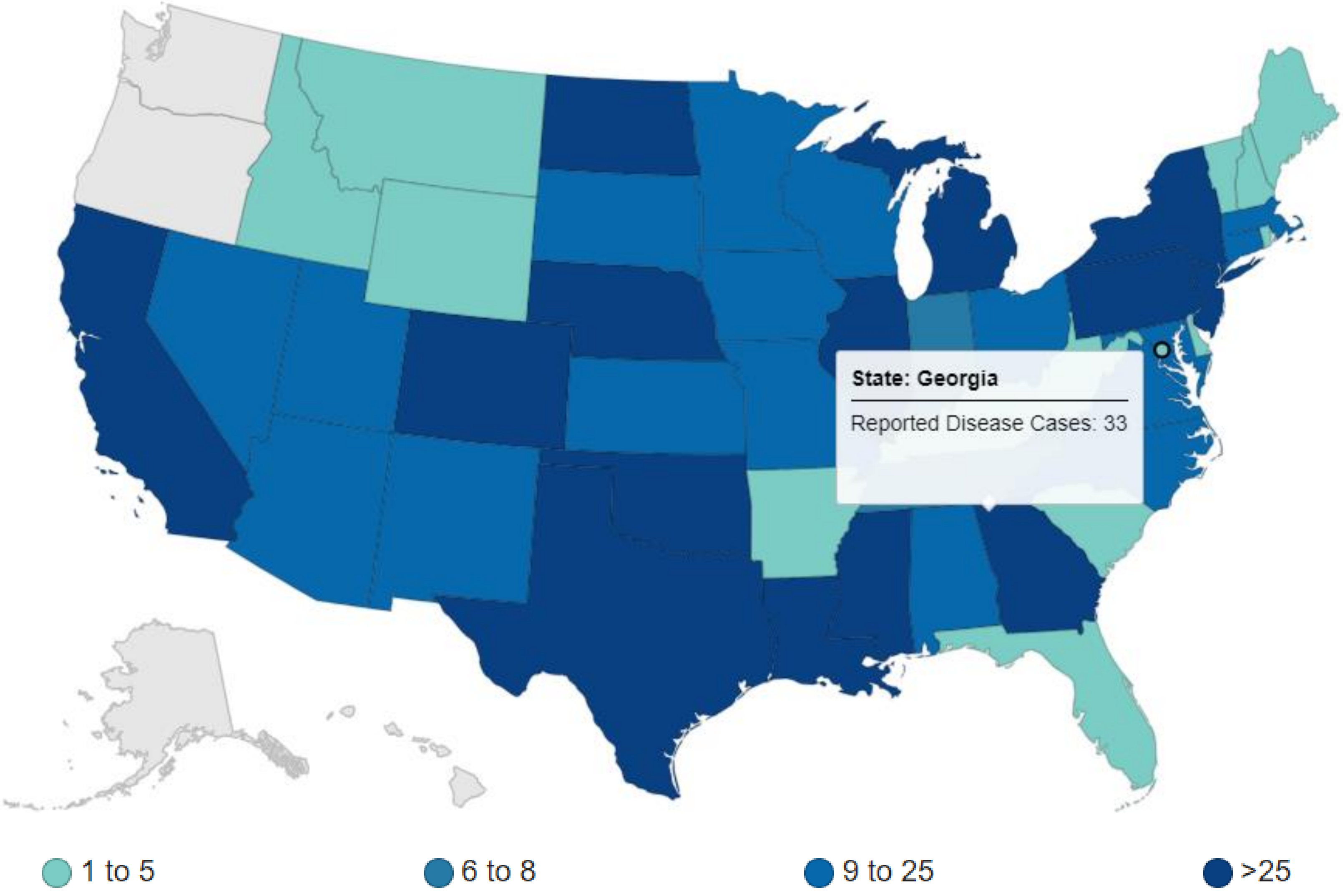
West Nile Virus US Monthly Cases 2023

Human Disease Cases	Hospitalizations	Deaths
1,738 *Cases from year(s) and type of case selected above*	**1,618** *Hospitalizations from year(s) and type of case selected above*	**179** *Deaths from year(s) and type of case selected above*



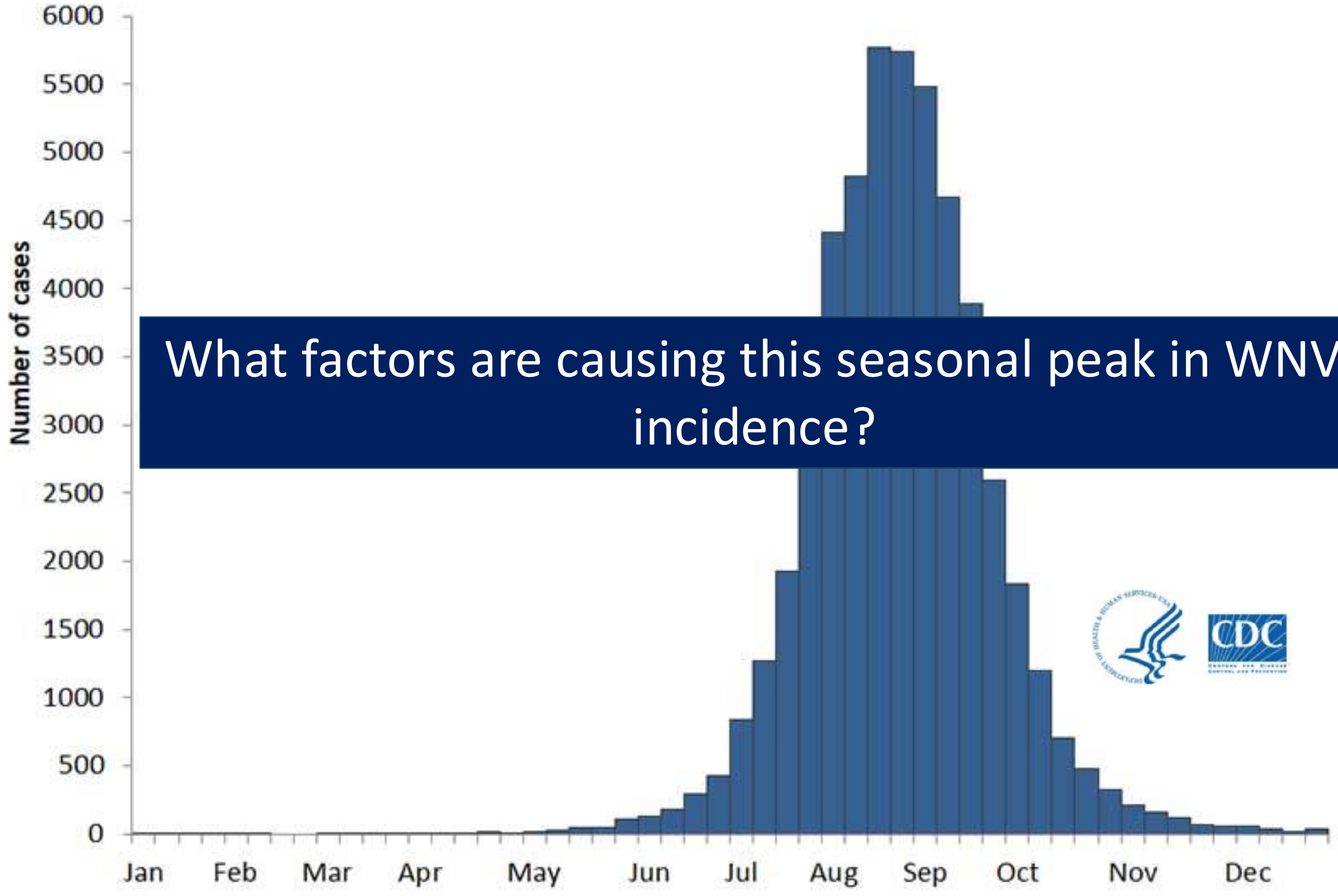
West Nile virus human disease cases reported by month of illness onset, 2023, Neuroinvasive disease cases

Reported WNV Cases- Georgia 2024



WNV Trend of Reported Human Cases

West Nile incidence peaks in the summer and early fall.



What factors are causing this seasonal peak in WNV incidence?

Biology of *Culex* Mosquitoes

J. Med. Ent. Vol. 8, no. 6: 687–695 — 30 December 1971

HOST-FEEDING PATTERNS OF FLORIDA MOSQUITOES
I. *Aedes, Anopheles, Coquillettidia, Mansonia* and *Psorophora*[1]

By John D. Edman[2]

J. Med. Ent. Vol. 9, no. 5: 429-434 — 30 September 1972

HOST-FEEDING PATTERNS OF FLORIDA MOSQUITOES
II. *CULISETA*[1]

By J. D. Edman, L. A. Webber and H. W. Kale II[2]

J. Med. Ent. Vol. 11, no. 1: 95–104 — 28 March 1974

HOST-FEEDING PATTERNS OF FLORIDA MOSQUITOES
III. *Culex* (*Culex*) and *Culex* (*Neoculex*)[1]

By John D. Edman[2]

J. Med. Ent. Vol. 11, no. 1: 105–107 — 28 March 1974

HOST-FEEDING PATTERNS OF FLORIDA MOSQUITOES
IV. *Deinocerites*[1]

By John D. Edman[2]

J. Med. Entomol. Vol. 14, no. 4: 477-479 — 24 December 1977

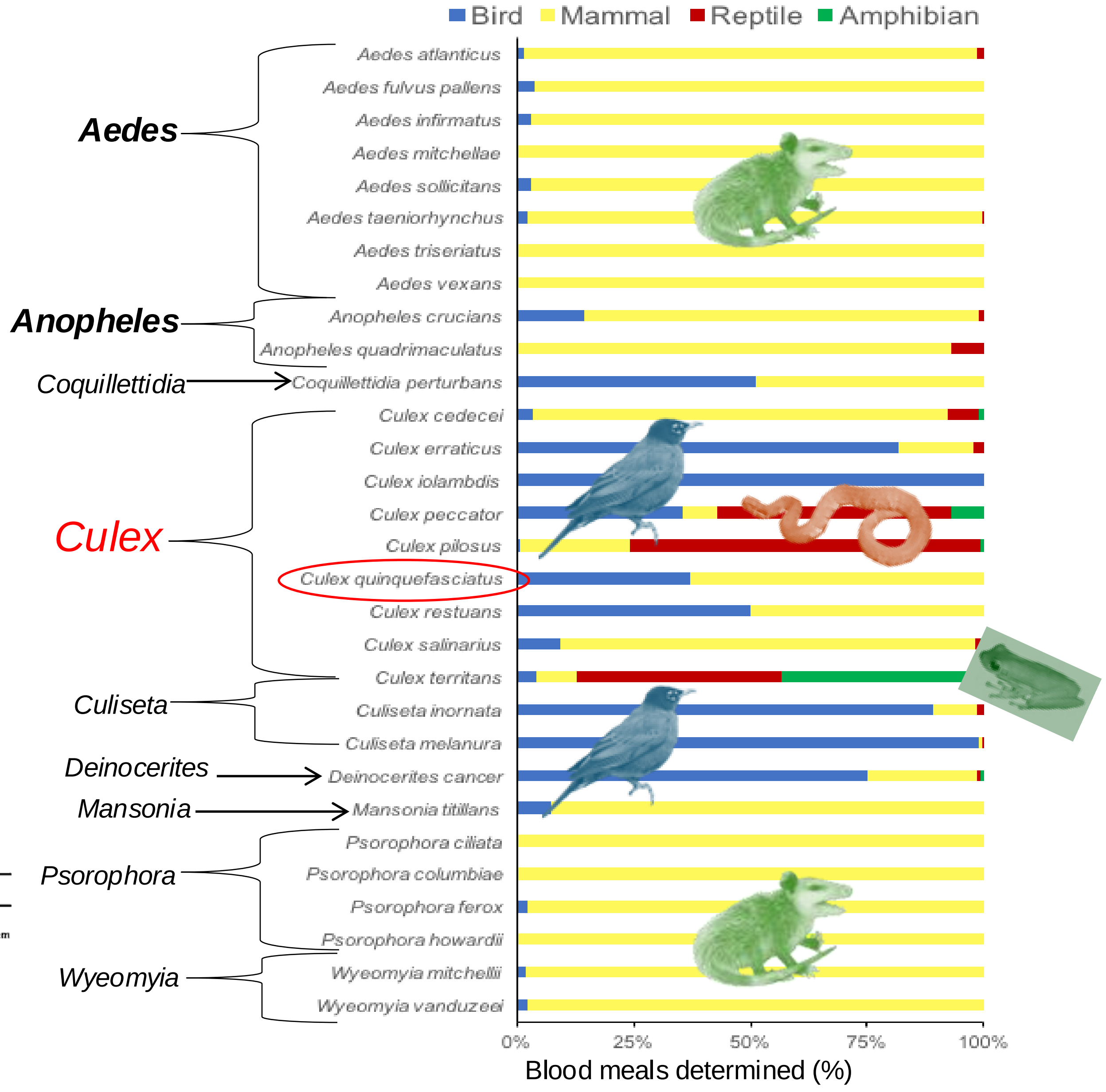
HOST-FEEDING PATTERNS OF FLORIDA MOSQUITOES
V. *Wyeomyia*[1]

J. Med. Entomol. Vol. 15, nos. 5–6: 521–525 — 4 September 1979

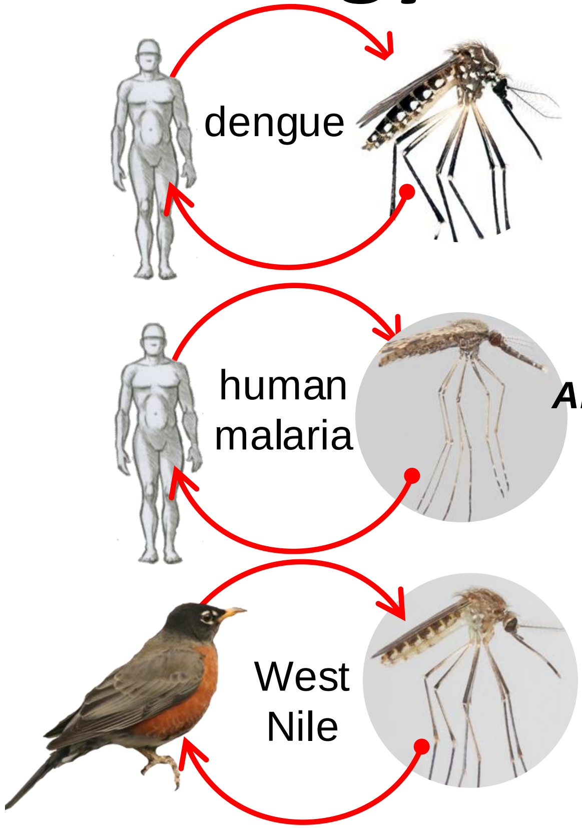
© 1978 by the Bishop Museum

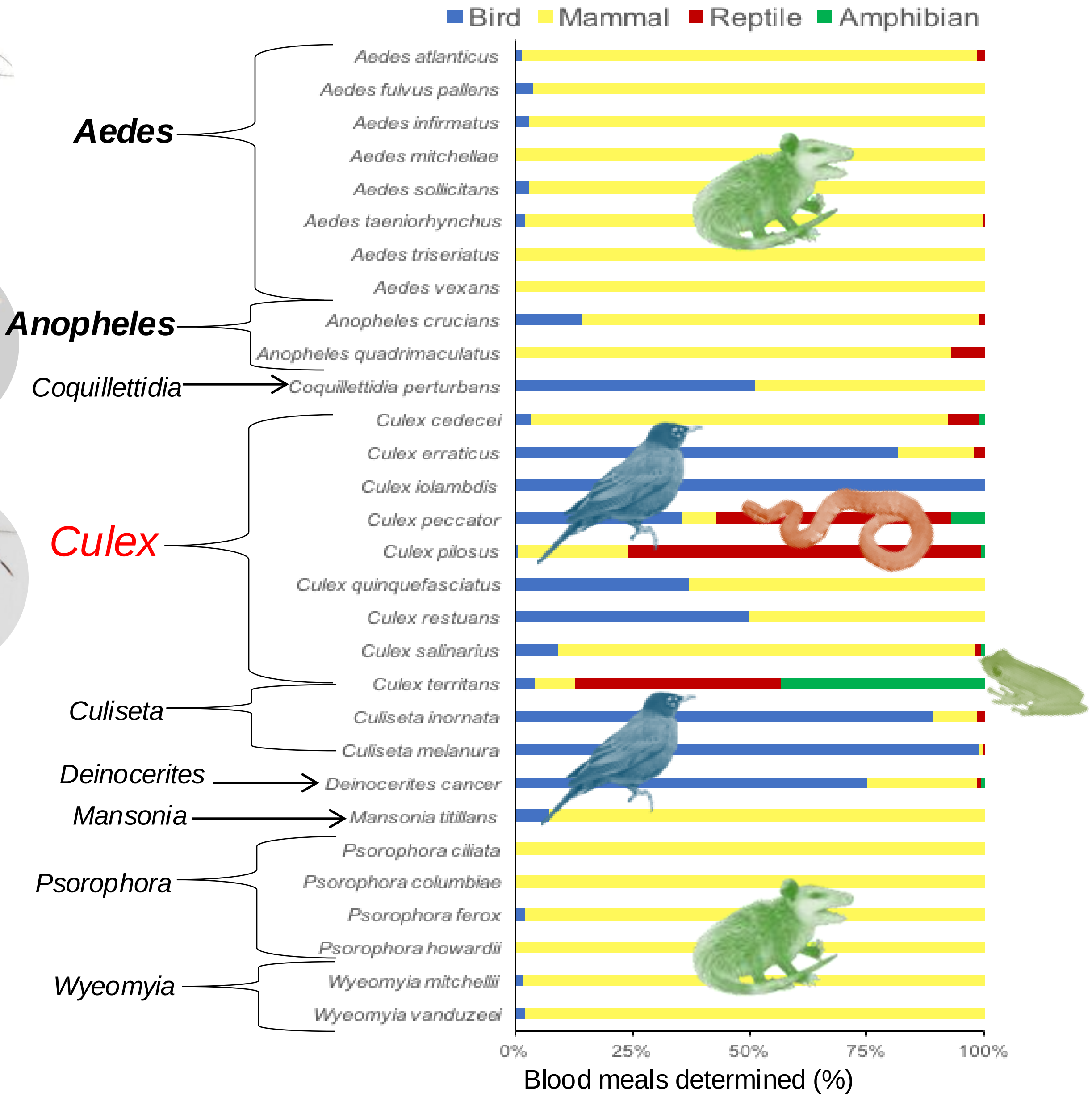
HOST-FEEDING PATTERNS OF FLORIDA MOSQUITOES (DIPTERA: CULICIDAE)
VI. *Culex* (*Melanoconion*)[1]

By John D. Edman[2]



Biology of *Culex* Mosquitoes





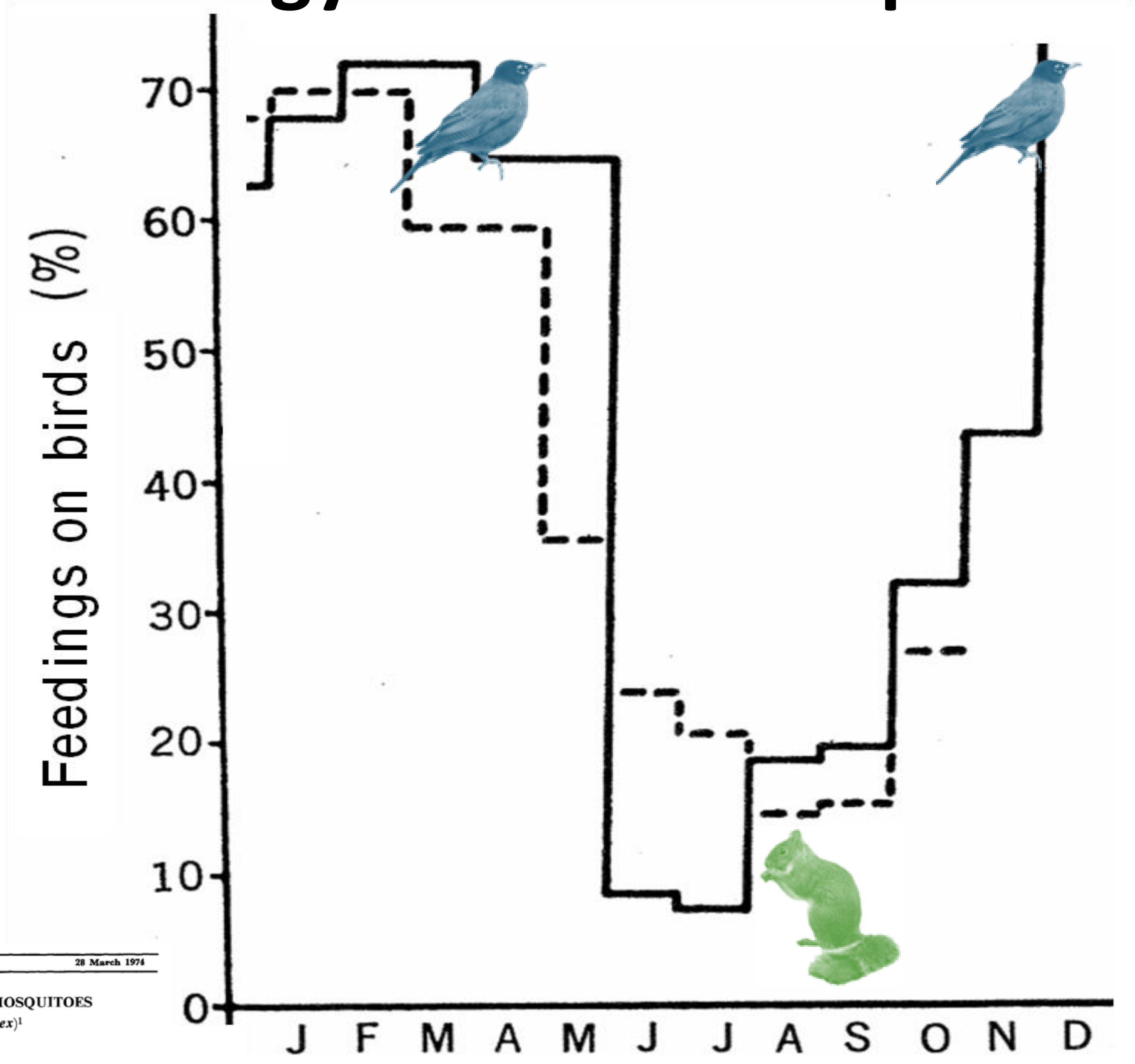
Biology of *Culex* Mosquitoes

Host Species	*Aedes aegypti*				*Culex quinquefasciatus*			
	Key West		Florida Keys		Key West		Florida Keys	
	N	(%)	*N*	(%)	*N*	(%)	*N*	(%)
Human (*Homo sapiens*)	51	(79.7)	57	(69.5)	26	(31.7)	13	(25.5)
Cat (*Felis catus*)	11	(17.2)	14	(17.1)	14	(17.1)	5	(9.8)
Dog (*Canis lupus familiaris*)	2	(3.1)	6	(7.3)	5	(6.1)	2	(3.9)
Brown rat (*Rattus norvegicus*)	0	(0)	5	(6.1)	1	(1.2)	2	(3.9)
Domestic chicken (*Gallus gallus*)	0	(0)	0	(0)	16	(19.5)	5	(9.8)
Green Iguana (*Iguana iguana*)	0	(0)	0	(0)	3	(3.7)	3	(5.9)
Virginia opossum (*Didelphis virginiana*)	0	(0)	0	(0)	2	(2.4)	5	(9.8)
Northern mockingbird (*Mimus polyglottos*)	0	(0)	0	(0)	2	(2.4)	1	(2.0)
African spurred tortoise (*Centrochelys sulcata*)	0	(0)	0	(0)	2	(2.4)	0	(0)
Gray catbird (*Dumetella carolinensis*)	0	(0)	0	(0)	6	(7.3)	0	(0)
Cooper's Hawk (*Accipiter cooperii*)	0	(0)	0	(0)	2	(2.4)	0	(0)
Rock dove (*Columba livia*)	0	(0)	0	(0)	2	(2.4)	0	(0)
Atlantic canary (*Serinus canaria*)	0	(0)	0	(0)	1	(1.2)	0	(0)
Raccoon (*Procyon lotor*)	0	(0)	0	(0)	0	(0)	4	(7.8)
Northern cardinal (*Cardinalis cardinalis*)	0	(0)	0	(0)	0	(0)	2	(3.9)
Common grackle (*Quiscalus quiscula*)	0	(0)	0	(0)	0	(0)	3	(5.9)
EurAsian collared dove (*Streptopelia decaocto*)	0	(0)	0	(0)	0	(0)	3	(5.9)
Common myna (*Sturnus tristis*)	0	(0)	0	(0)	0	(0)	1	(2.0)
Mangrove rail (*Rallus longirostris*)	0	(0)	0	(0)	0	(0)	1	(2.0)
Eastern wood rat (*Neotoma floridana*)	0	(0)	0	(0)	0	(0)	1	(2.0)
Total no. identified	64	(80.0)	82	(85.4)	82	(91.1)	51	(100.0)
Total no. tested	80		96		90		51	

mammals

birds, reptiles

Biology of *Culex* Mosquitoes



J. Med. Ent. Vol. 11, no. 1: 95-104 28 March 1974

HOST-FEEDING PATTERNS OF FLORIDA MOSQUITOES
III. *Culex* (*Culex*) and *Culex* (*Neoculex*)[1]

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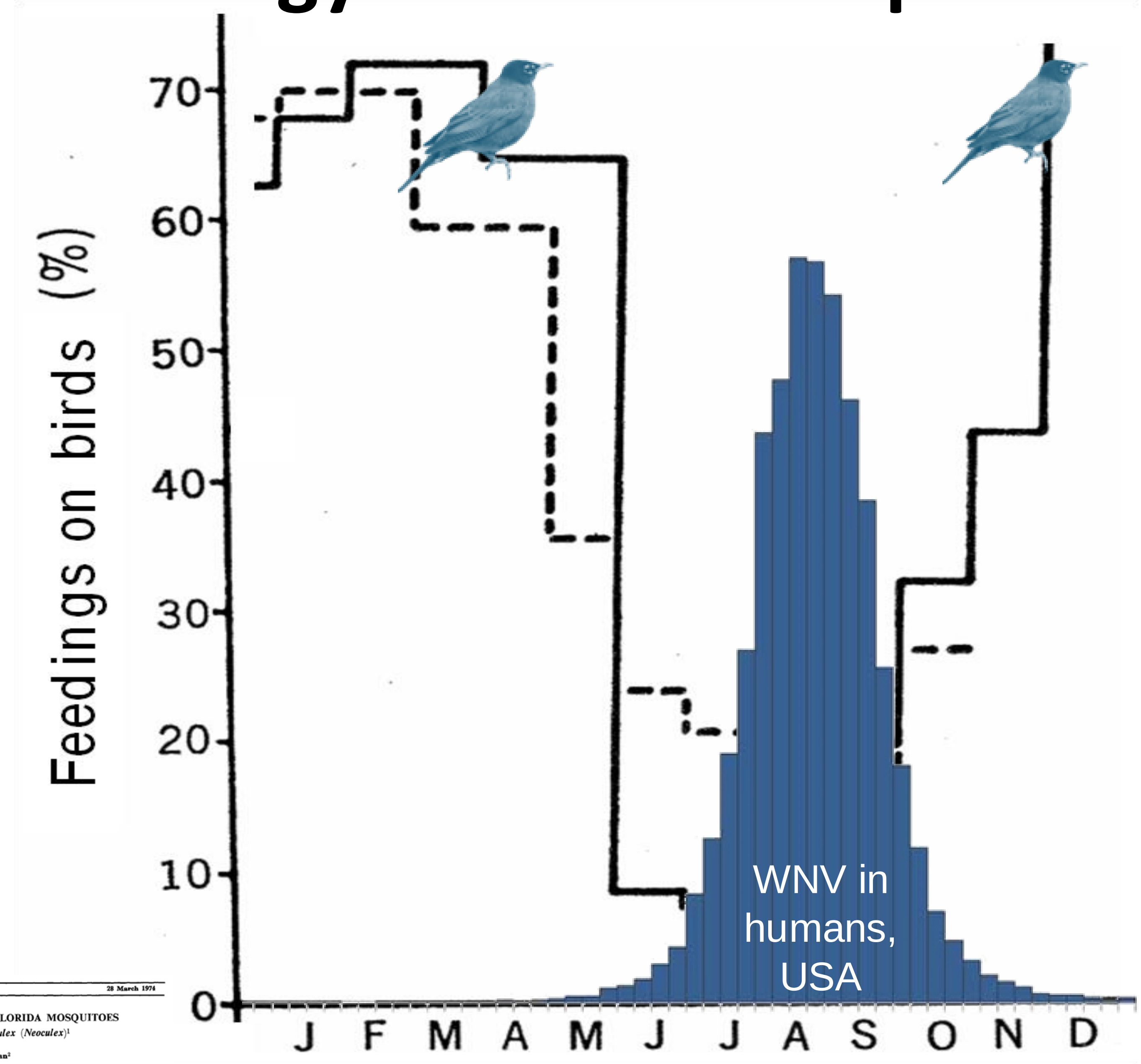
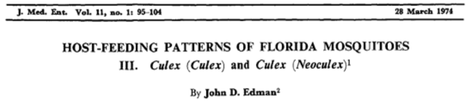
Biology of *Culex* Mosquitoes

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HOST-FEEDING PATTERNS OF FLORIDA MOSQUITOES
III. *Culex* (*Culex*) and *Culex* (*Neoculex*)[1]

By John D. Edman[2]

Biology of *Culex Mosquitoes*

Why do mosquitoes feed on birds more during the breeding season?

Nestling birds
- Lack defensive behaviors
- Lack protective plumage

Mother birds
- Confined to nest
- Have fewer defensive actions

West Nile Virus

Vertebrate reproduction and immunity

Immunity from previous exposure

Winter Spring Summer Fall

West Nile Virus

Vertebrate reproduction and immunity

Immunity from previous exposure

Immunity from previous exposure

Partial immunity from mother

Winter Spring Summer Fall

West Nile Virus

Vertebrate reproduction and immunity

Immunity from previous exposure

Immunity from previous exposure

Immunity from previous exposure

Partial immunity from mother

No immunity

Winter

Spring

Summer

Fall

West Nile Virus

Vertebrate reproduction and immunity

Immunity from previous exposure

Winter

Immunity from previous exposure

Partial immunity from mother

Spring

Immunity from previous exposure

No immunity

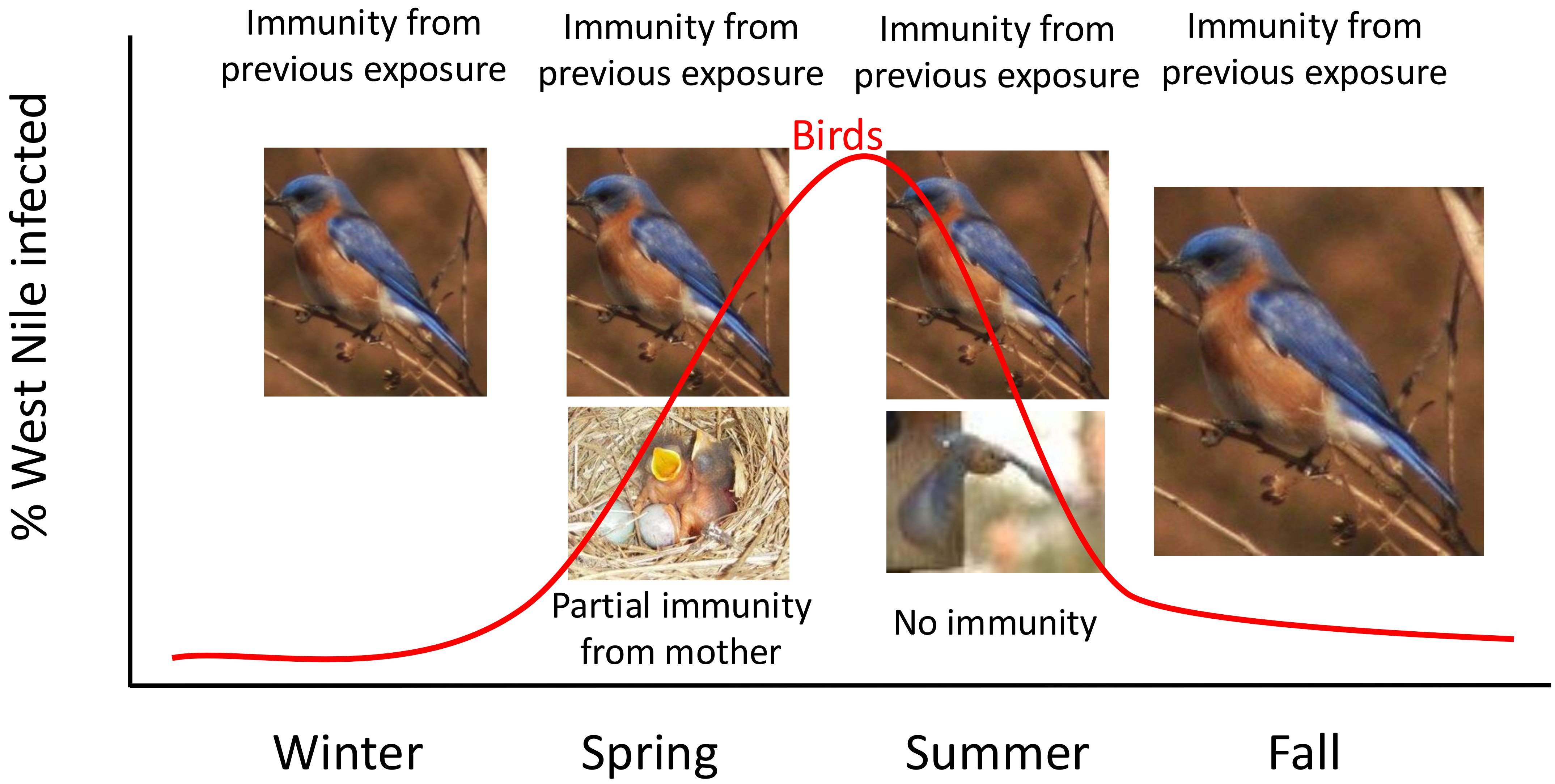
Summer

Immunity from previous exposure

Fall

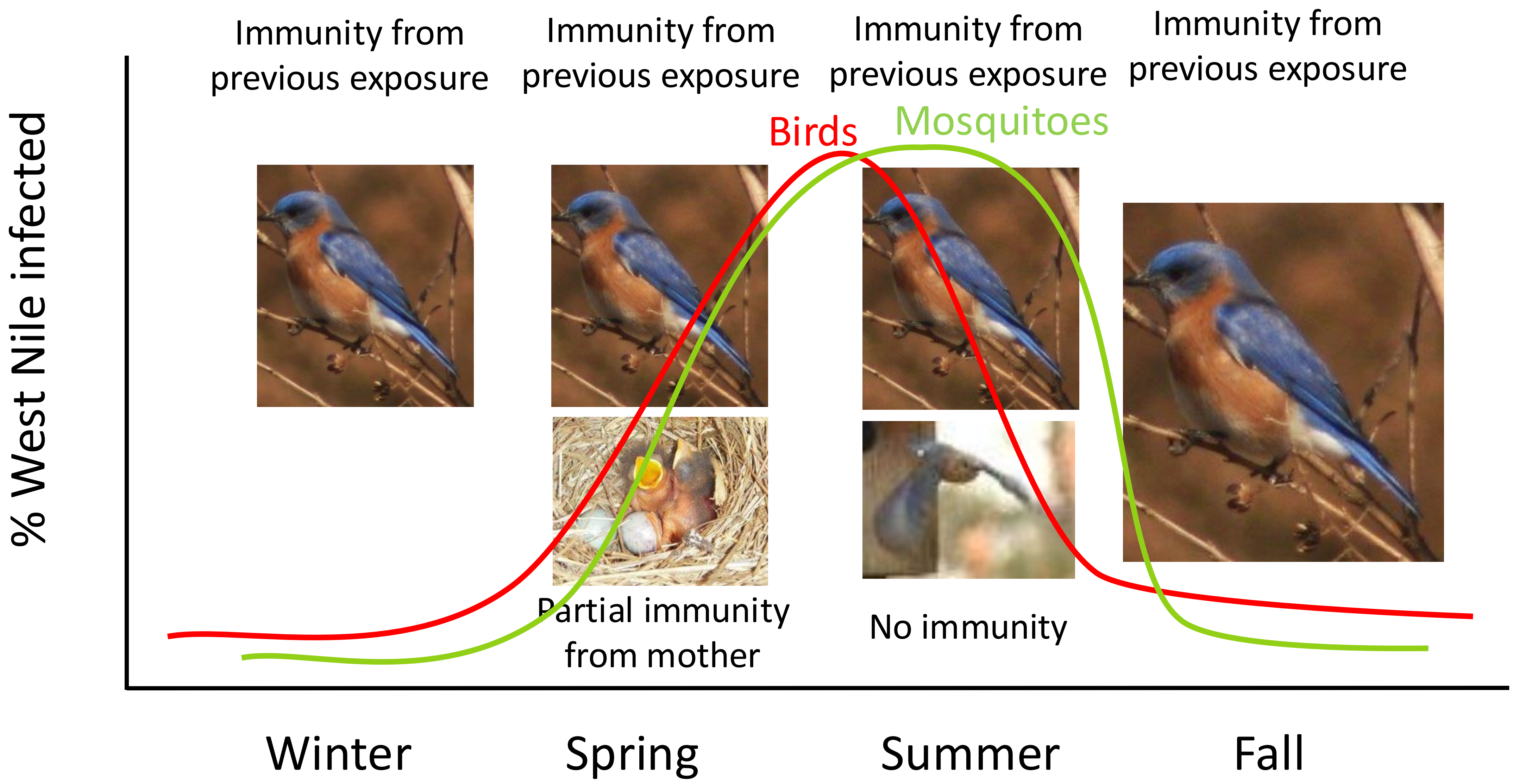
West Nile Virus

Vertebrate reproduction and immunity

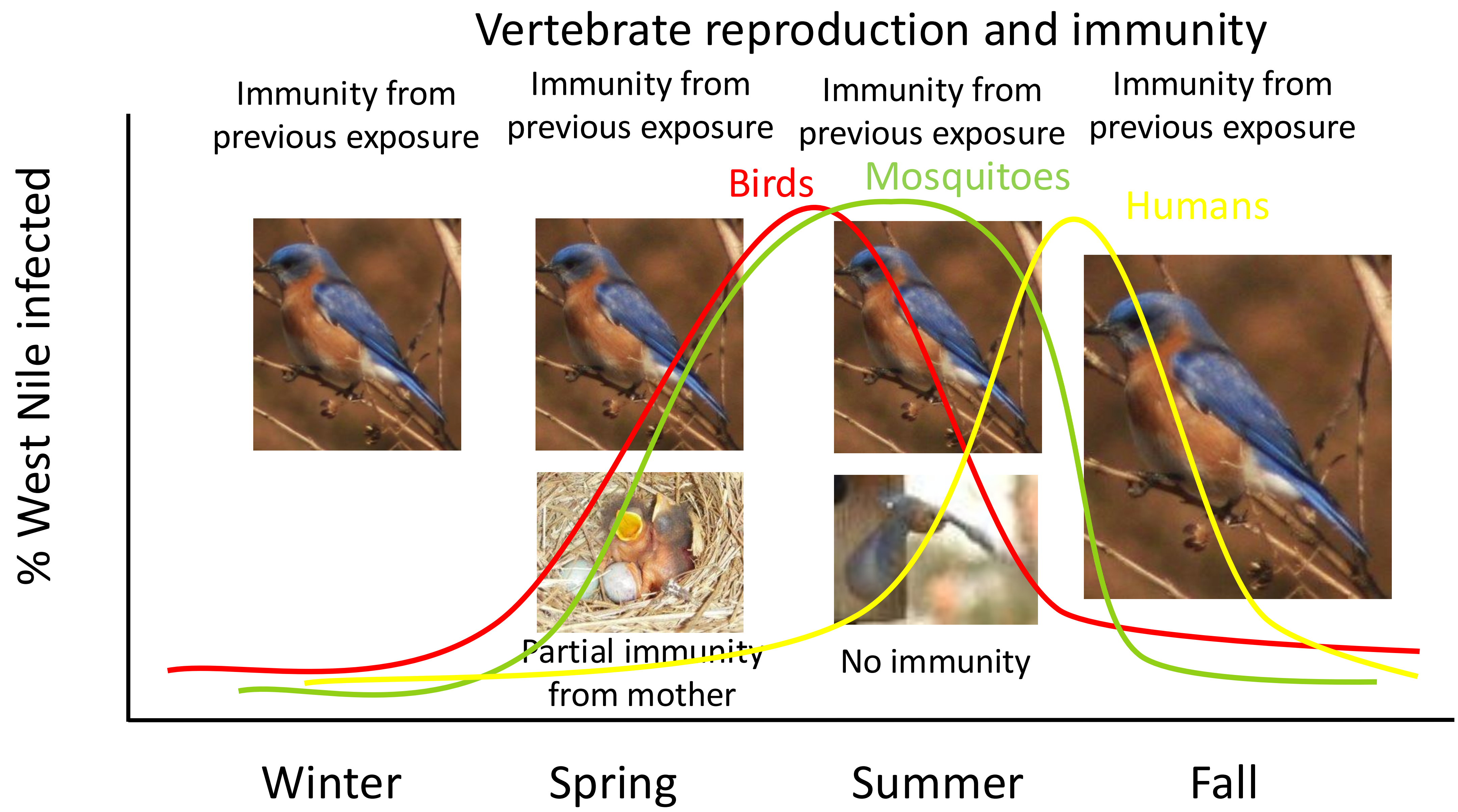


West Nile Virus

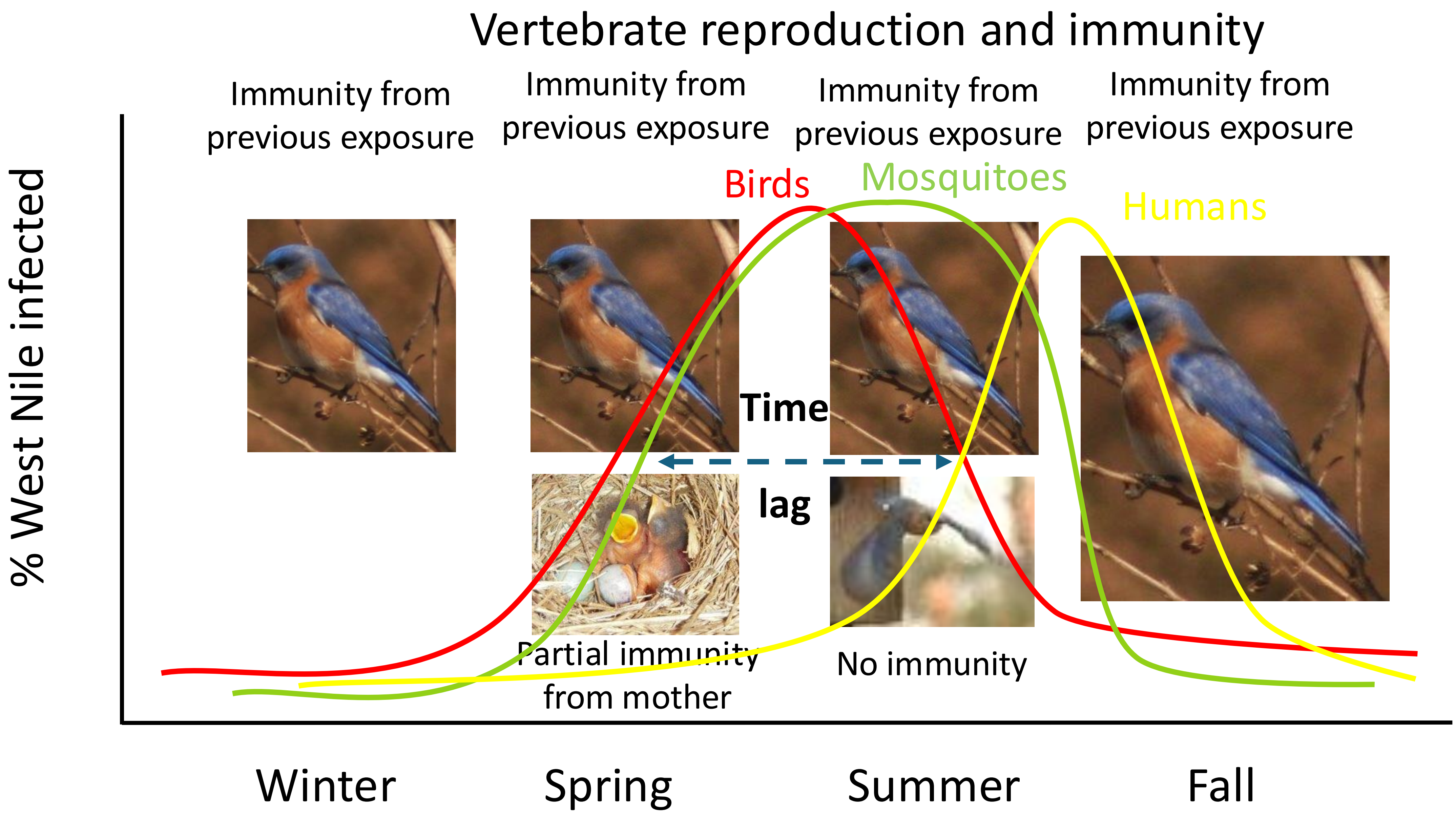
Vertebrate reproduction and immunity



West Nile Virus



West Nile Virus



West Nile Virus

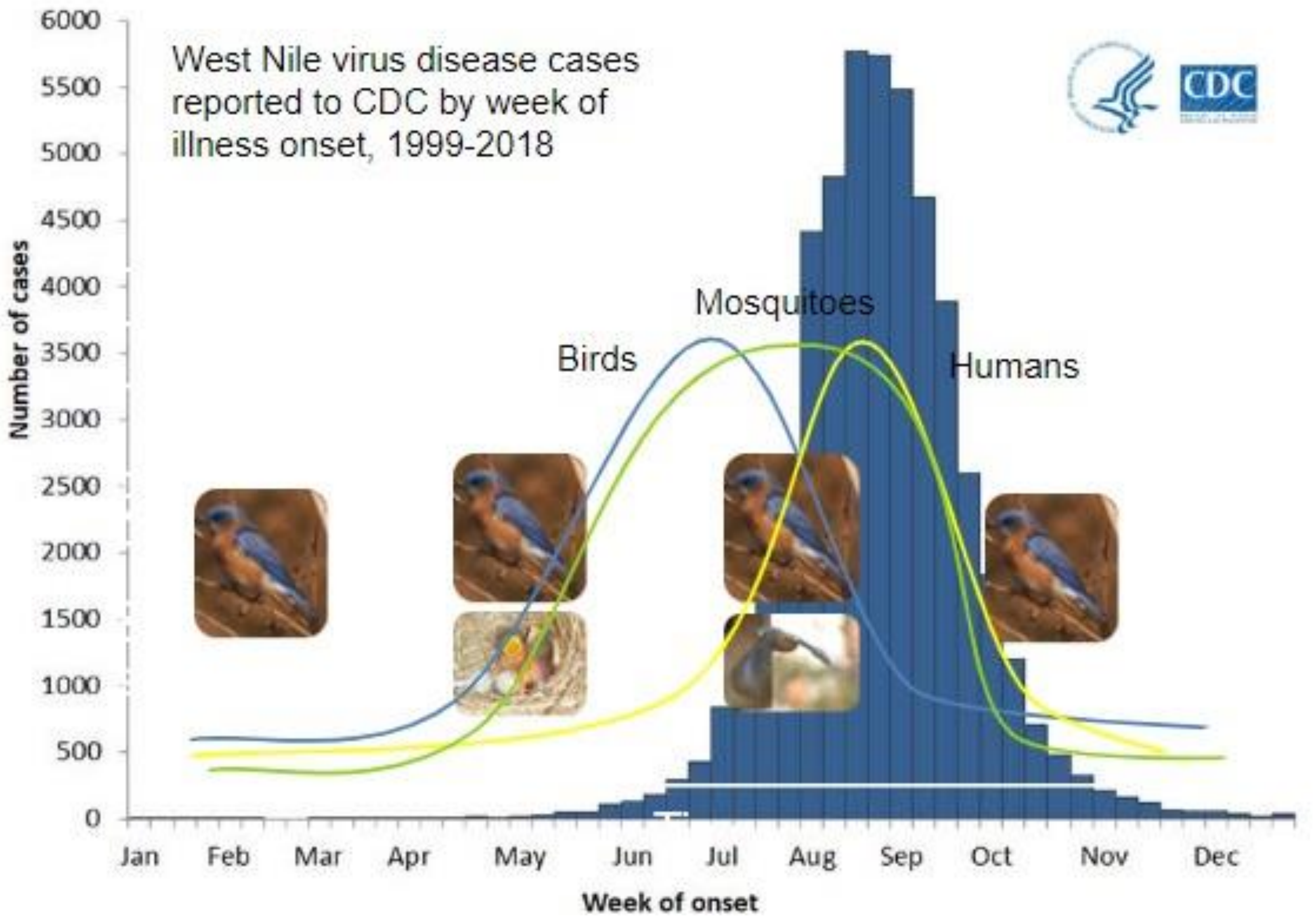
West Nile incidence peaks in late summer/early fall, with most human cases occurring over a short period.

Avian immunity and vectors feeding upon birds in spring drives the amplification of West Nile virus.

Bird migration and defensive behaviors cause vectors to shift from birds to mammals in late summer and fall.

The shift from birds to mammals coincides with the sudden increase in human exposure to West Nile virus.

Spillover (epidemic) of West Nile virus is driven by shifts in mosquito feeding behavior.



Biology of *Culex* mosquitoes

- *Culex* females bite a diverse array of hosts, and many species bite both birds and mammals.
- Many *Culex* species exhibit a seasonal shift in host use, which is driven by the biology of the host animal.
- Seasonal host shifts are thought to drive the spillover of zoonotic *Culex*-transmitted pathogens.
- Limited number of *Culex* species transmit diverse human pathogens.

West Nile virus

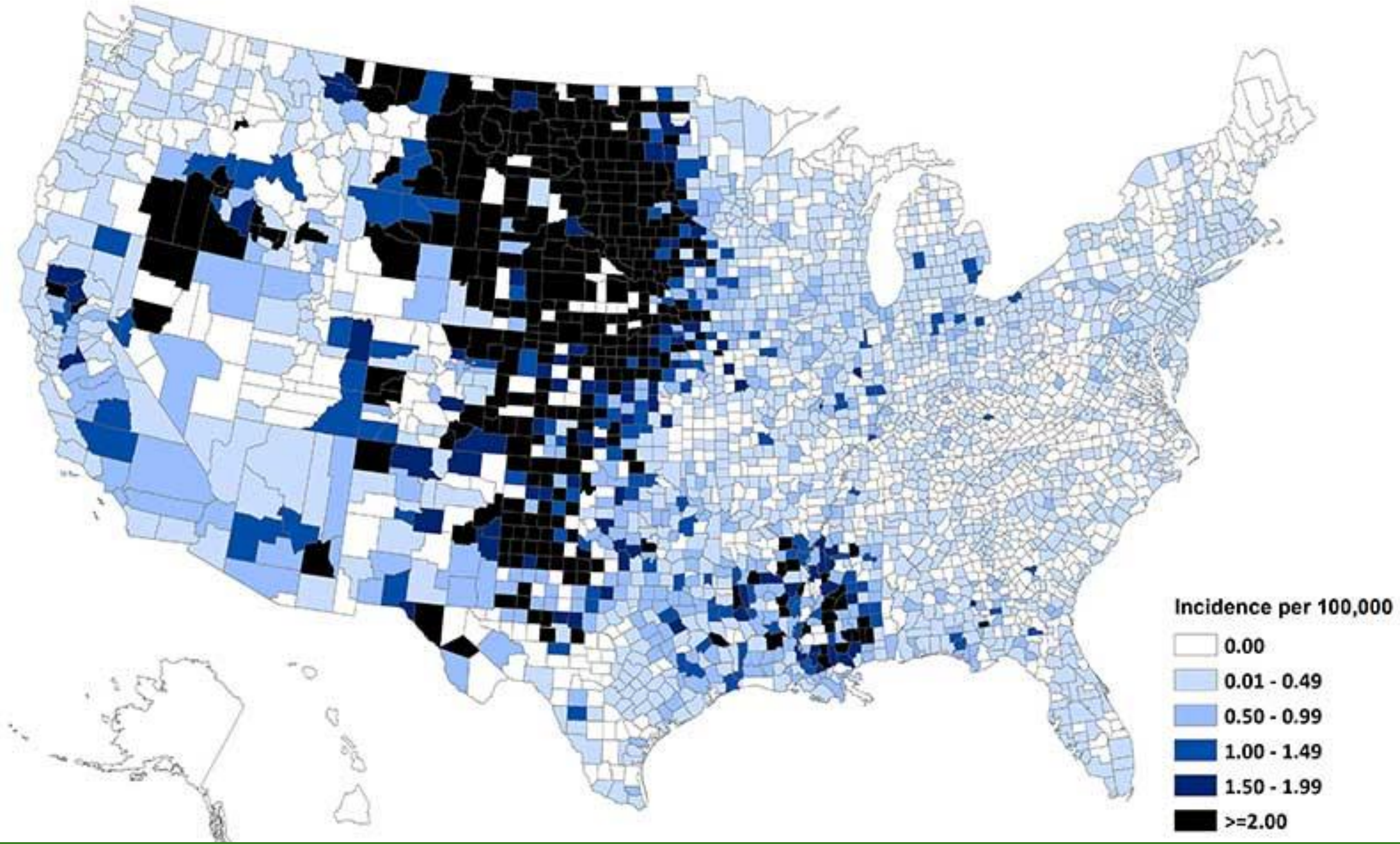
- West Nile virus transmission shows considerable spatial variation on both local and regional scales.
- An episystem is a complex of interacting biological, environmental, economic and social factors affecting emergence and spread of infectious diseases.
- The landscape, climate, vertebrate community, vector community and human population interact in complex ways that determines where transmission is suitable.
- Due to the numerous hosts and vectors of West Nile virus, the drivers of transmission risk vary by location and scale.

UF | IFAS
UNIVERSITY of FLORIDA
Florida Medical Entomology Laboratory

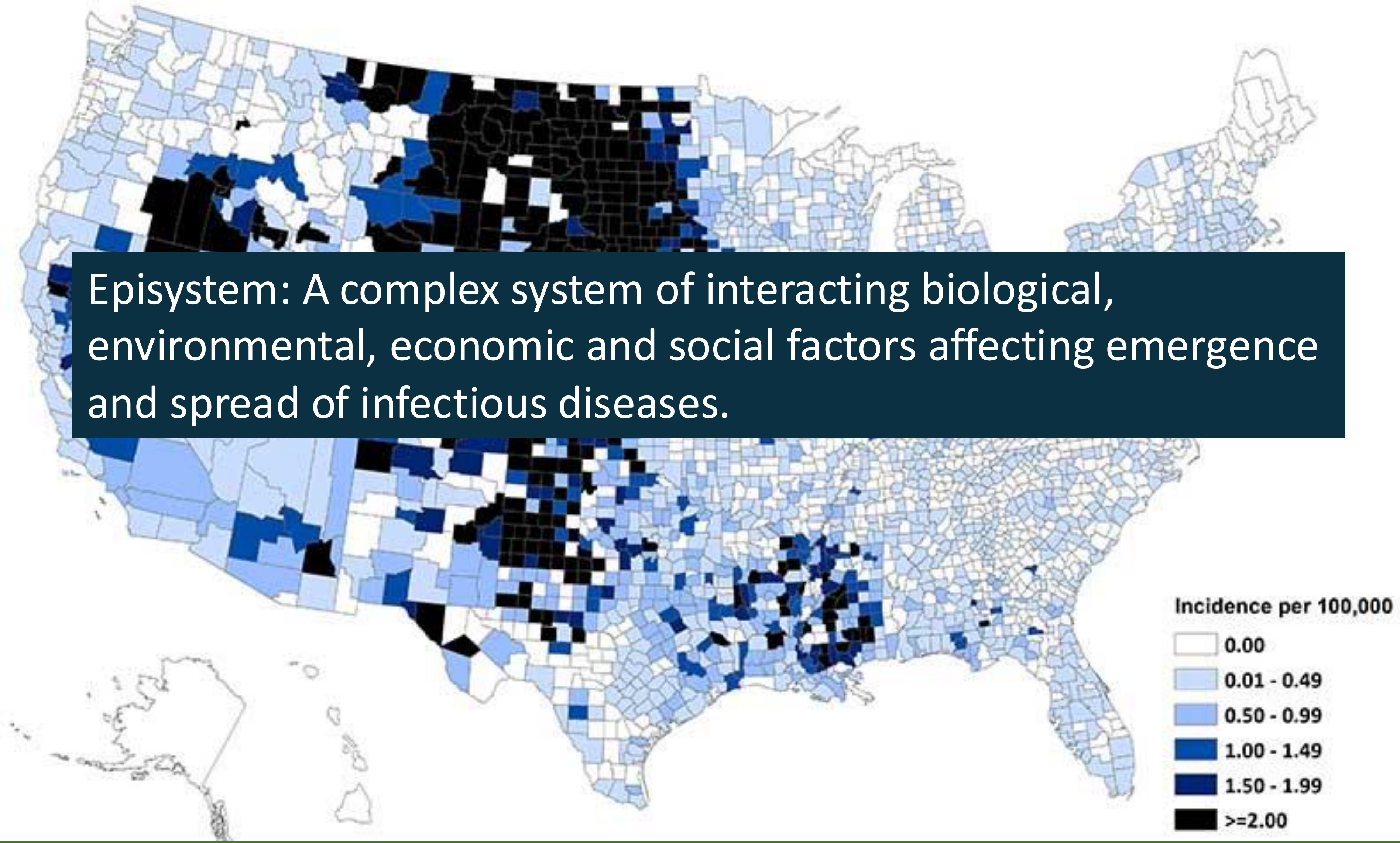
Thank You

Dan Killingsworth   Master's Student
Buckner Lab
Florida Medical Entomology Laboratory

West Nile Virus

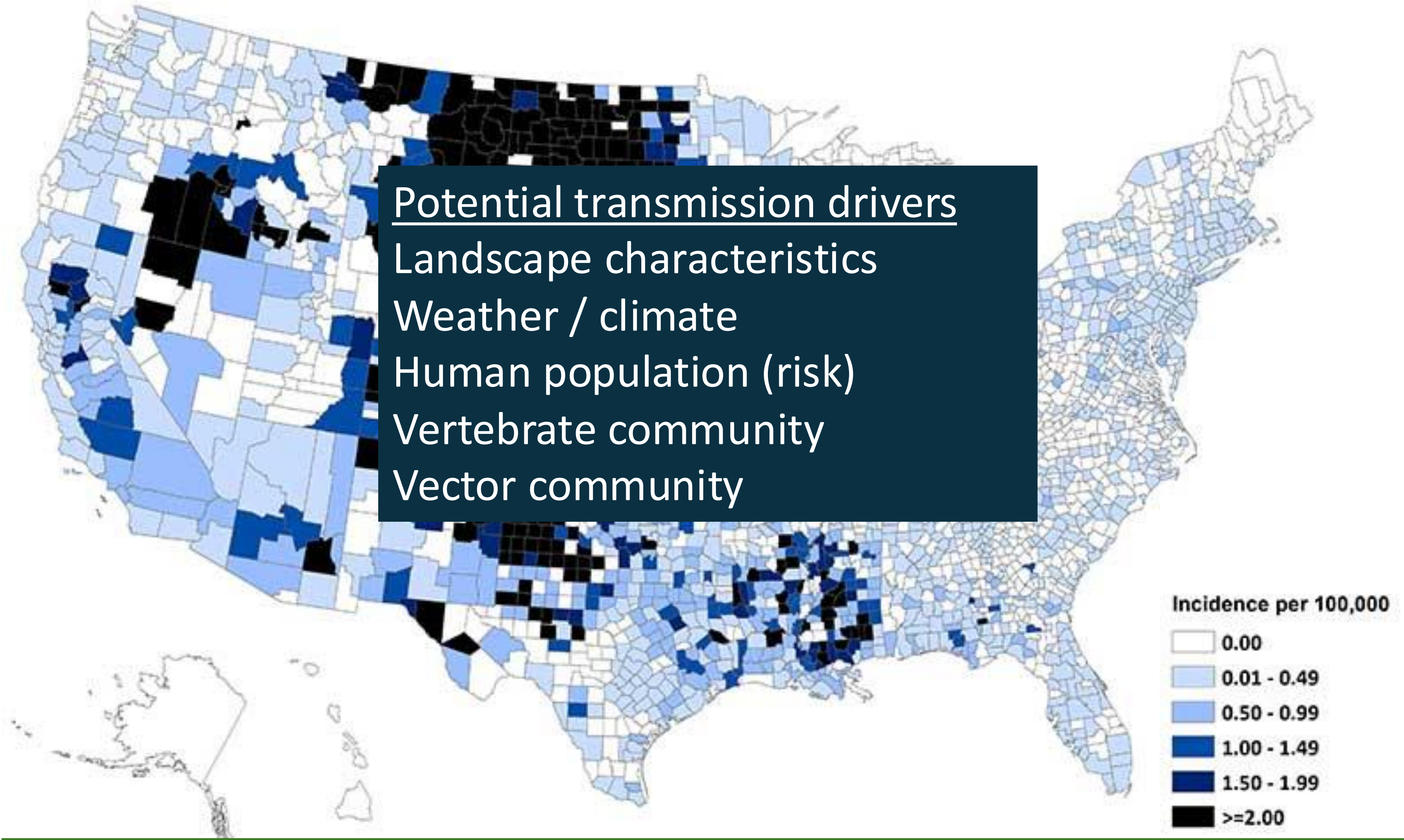


West Nile Virus



Episystem: A complex system of interacting biological, environmental, economic and social factors affecting emergence and spread of infectious diseases.

West Nile Virus

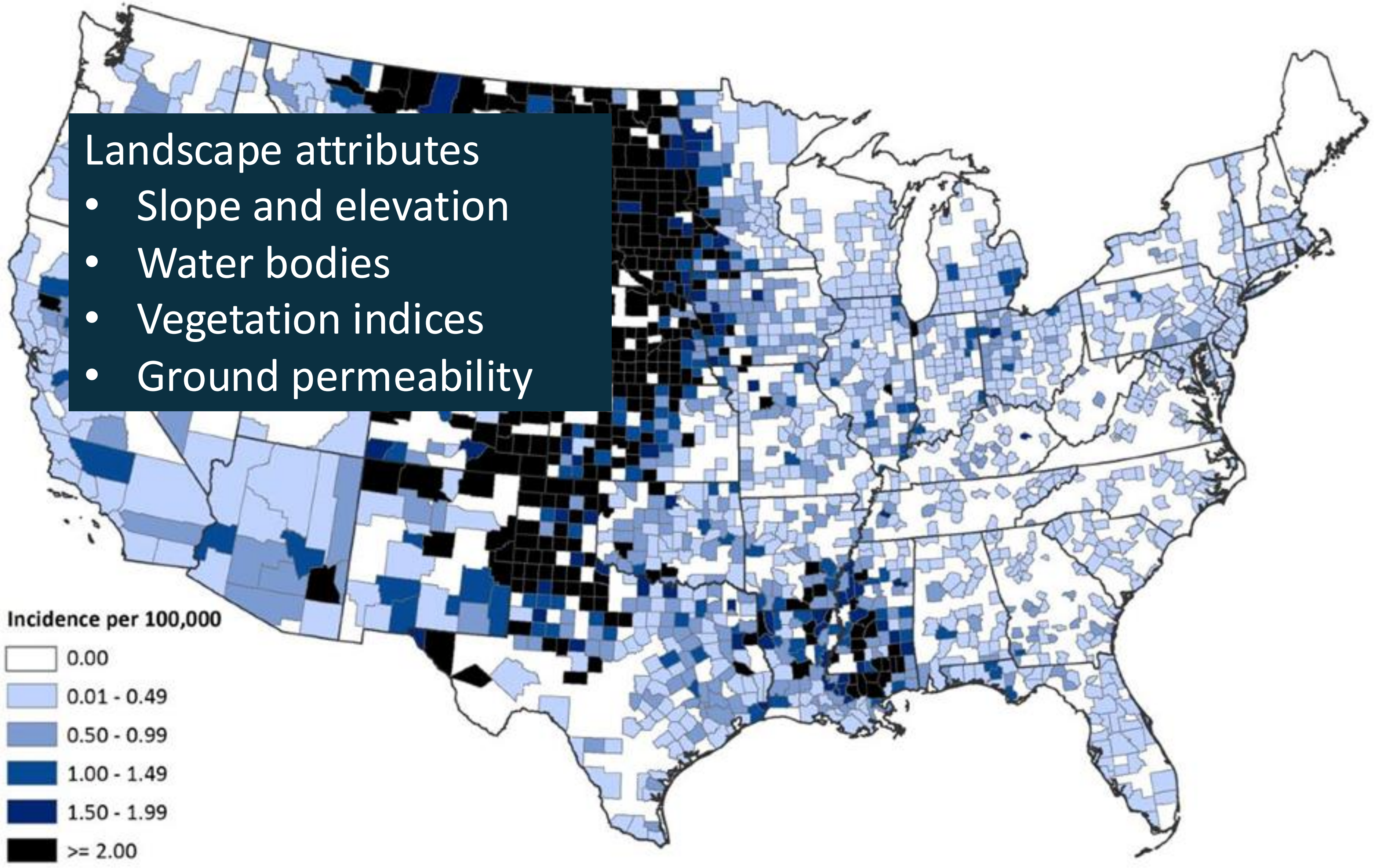


Potential transmission drivers
Landscape characteristics
Weather / climate
Human population (risk)
Vertebrate community
Vector community

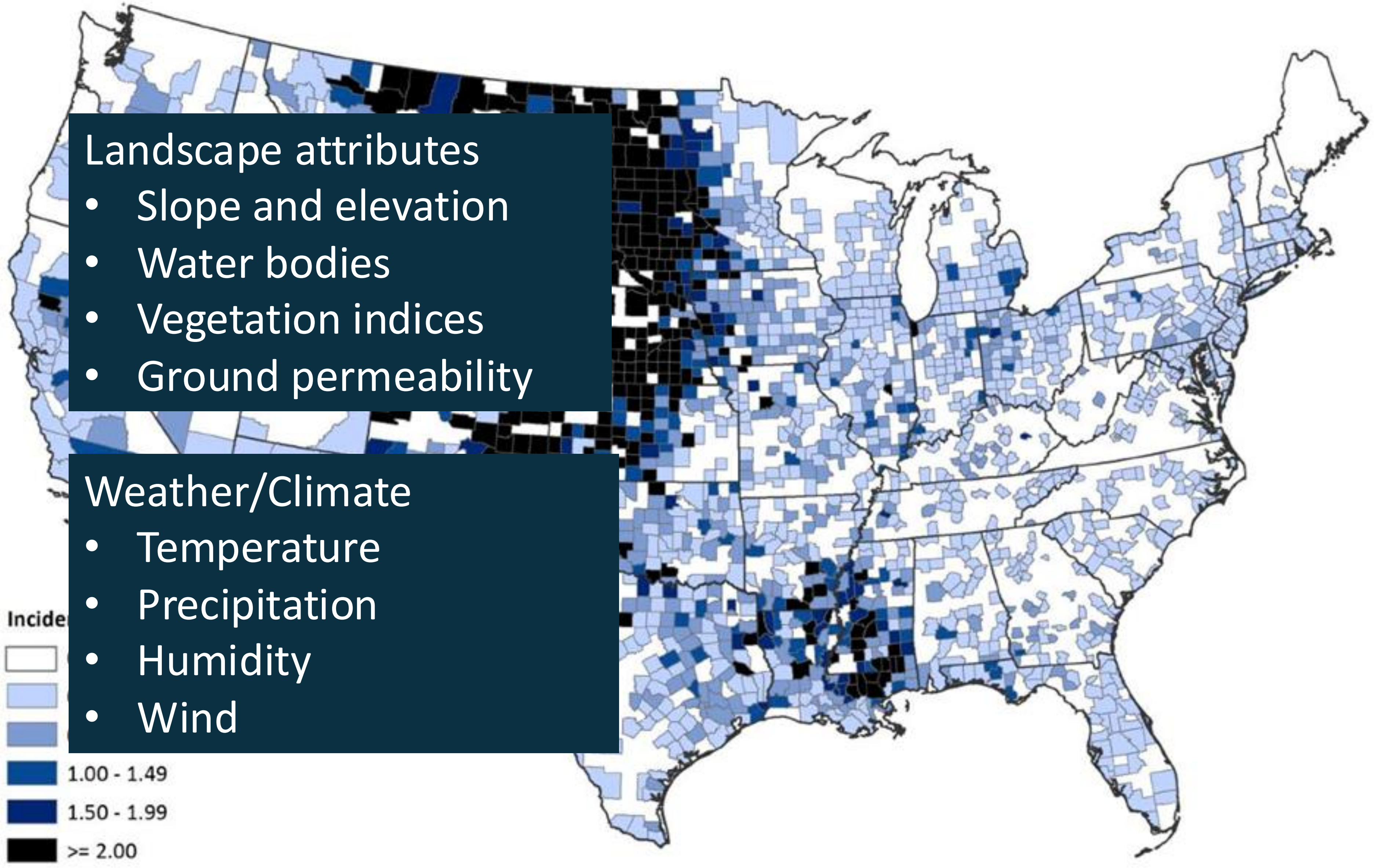
West Nile virus

Landscape attributes

- Slope and elevation
- Water bodies
- Vegetation indices
- Ground permeability



West Nile virus



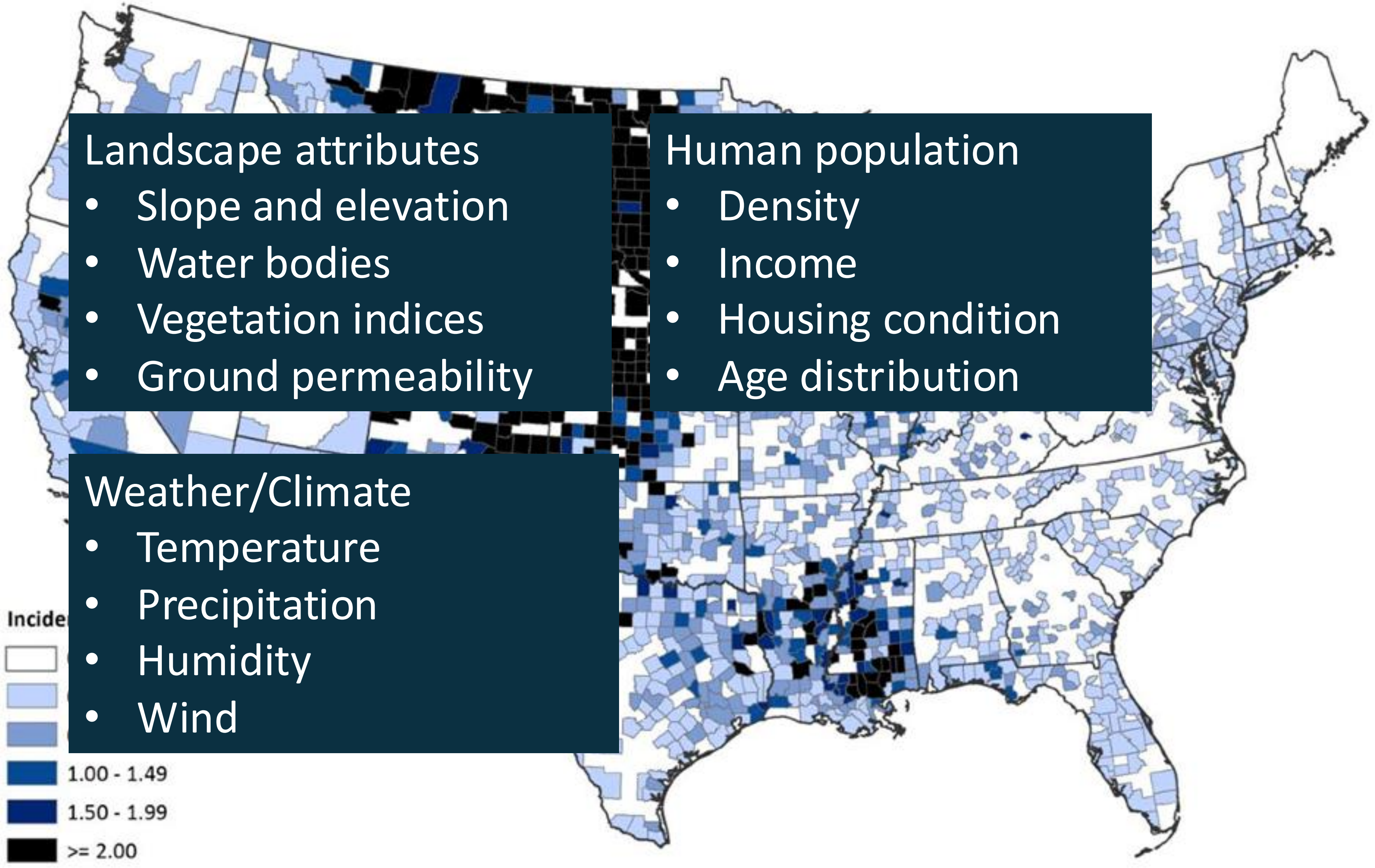
Landscape attributes

- Slope and elevation
- Water bodies
- Vegetation indices
- Ground permeability

Weather/Climate

- Temperature
- Precipitation
- Humidity
- Wind

West Nile virus

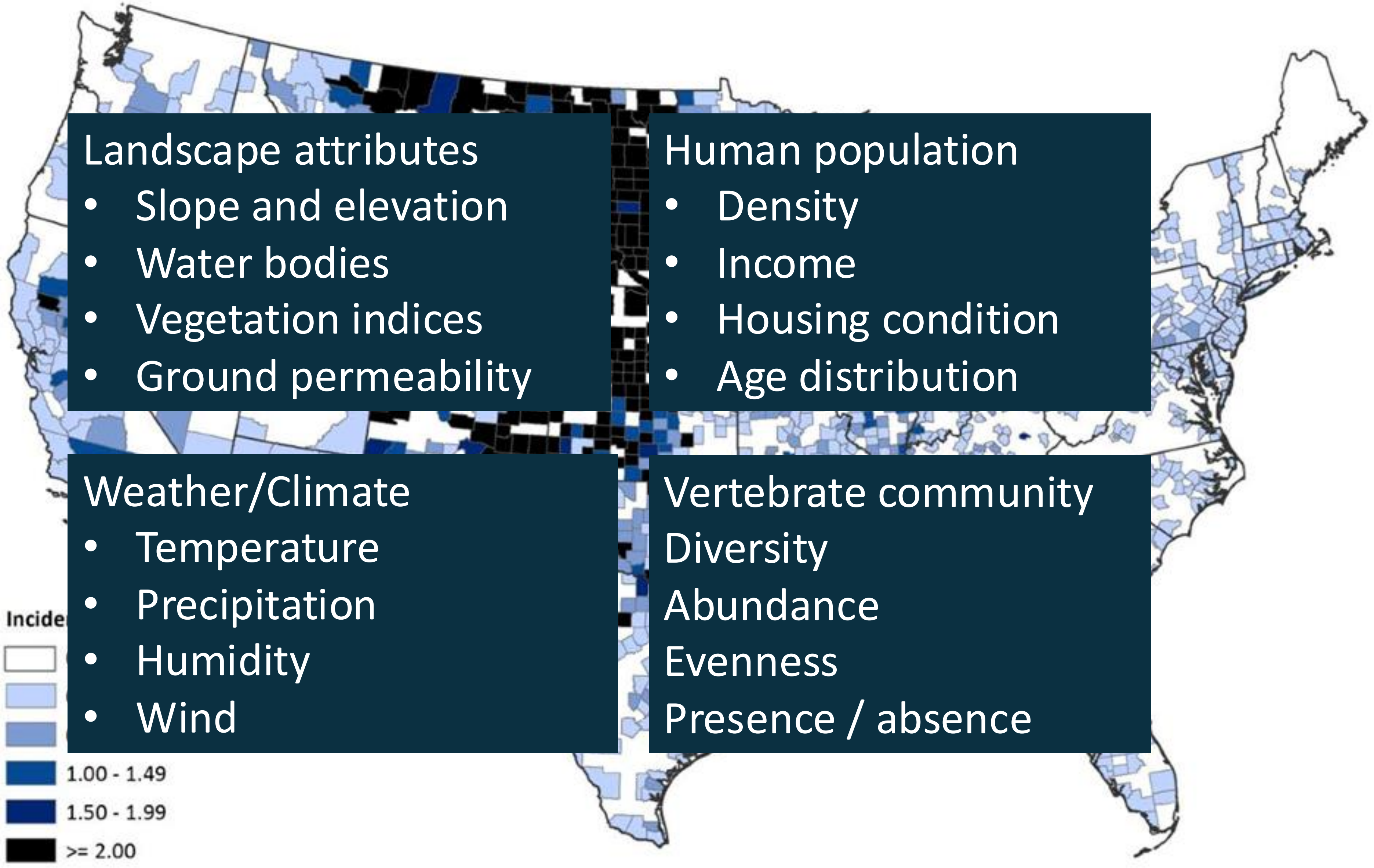


Landscape attributes
- Slope and elevation
- Water bodies
- Vegetation indices
- Ground permeability

Human population
- Density
- Income
- Housing condition
- Age distribution

Weather/Climate
- Temperature
- Precipitation
- Humidity
- Wind

West Nile virus



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Vertebrate community

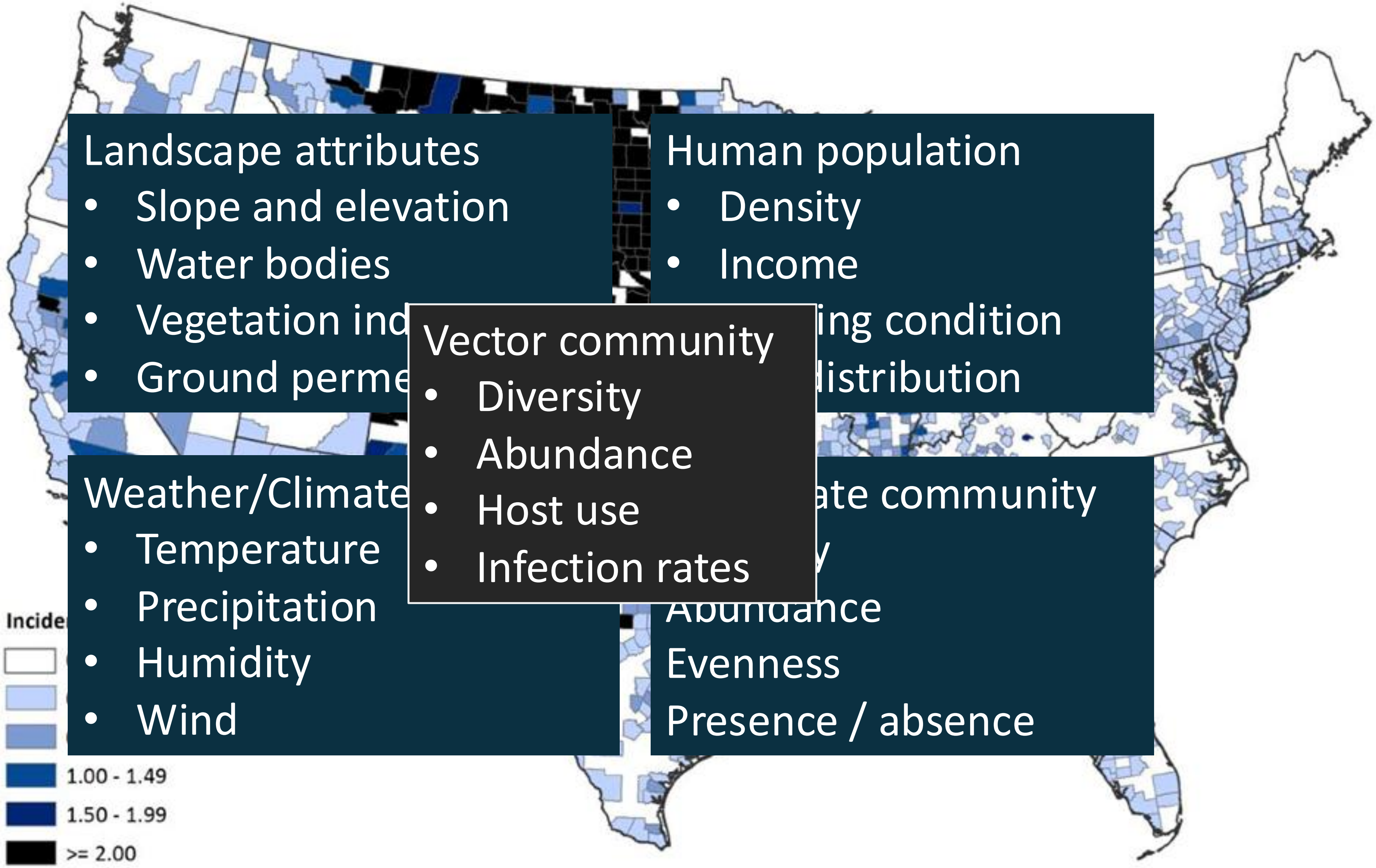
Diversity

Abundance

Evenness

Presence / absence

West Nile Virus



Landscape attributes
- Slope and elevation
- Water bodies
- Vegetation ind
- Ground perme

Human population
- Density
- Income
- ing condition
- distribution

Vector community
- Diversity
- Abundance
- Host use
- Infection rates

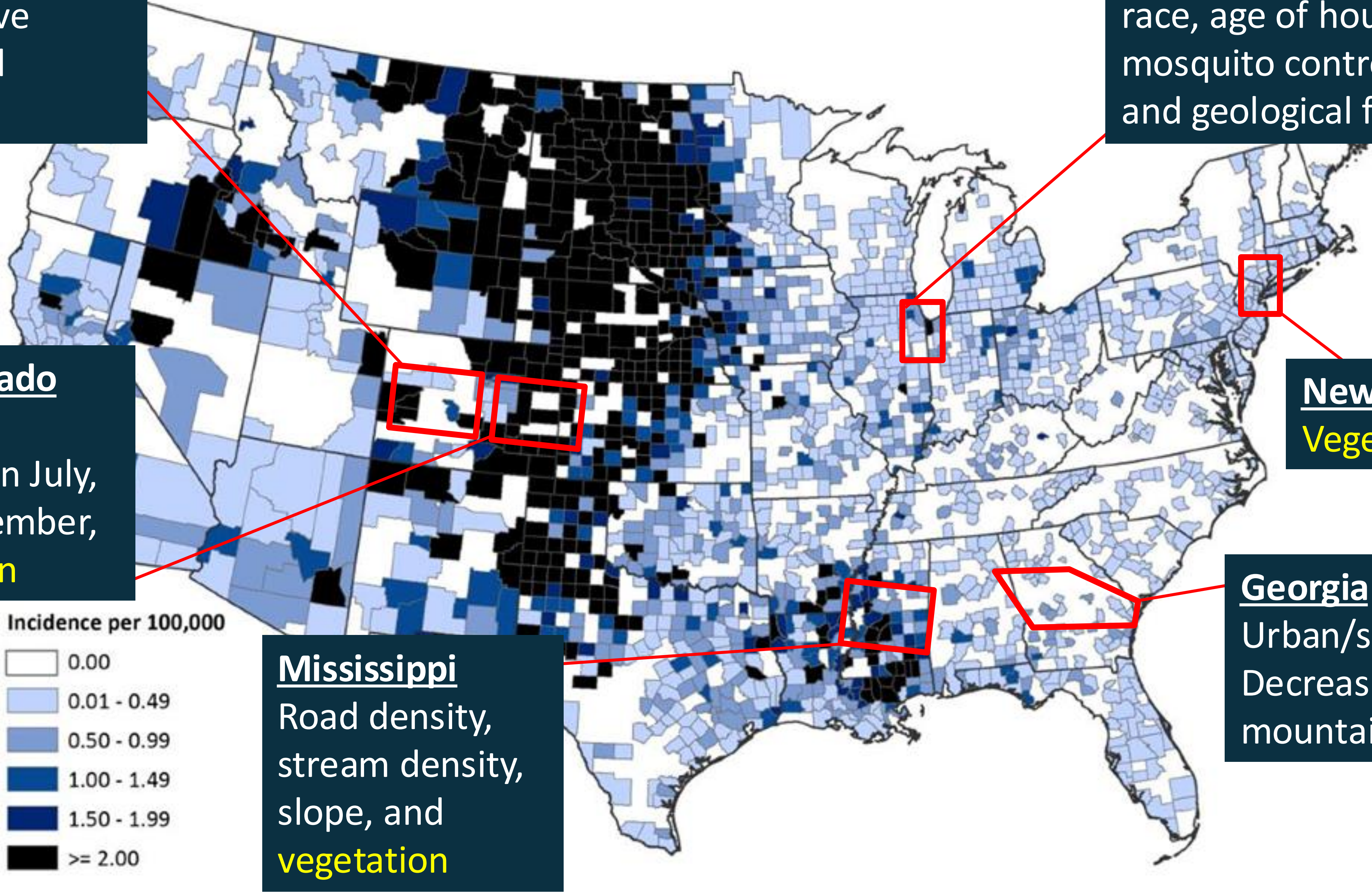
Weather/Climate
- Temperature
- Precipitation
- Humidity
- Wind

ate community
y
Abundance
Evenness
Presence / absence

West Nile Virus

Western Colorado
Temperature in March, relative humidity, and vegetation

Chicago
Vegetation, age, income, race, age of housing, mosquito control activities, and geological factors



Eastern Colorado
Elevation, Precipitation in July, Snow in September, and vegetation

New York City
Vegetation

Georgia
Urban/suburban, Decrease in mountainous region

Mississippi
Road density, stream density, slope, and vegetation