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Ecology and geography of human monkeypox case occurrences across Africa.

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Institutions: Animal and Plant Health Inspection Service, Centers for Disease Control and Prevention, University of Kansas, University of Kinshasa ...+1 more institutions

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Topics: Environmental niche modelling and Environmental data

Ecology and Geography of Human Monkeypox Case Occurrences Across Africa

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- Monkeypox
- Ecological Niche Modeling
- My Project

Introduction to Monkeypox

Monkeypox – Virus

- *Orthopoxvirus, Poxviridae, Chordopoxvirinae*
  - cowpox, vaccinia, variola
- Central genome tightly conserved
  - Key functions:
    - transcription, virus assembly
- Genes at termini are more variable
  - Associated with virus-host interactions

www.ci.vbi.vt.edu/pathinfo/pathogens/Monkeypox_virus_Info.shtml

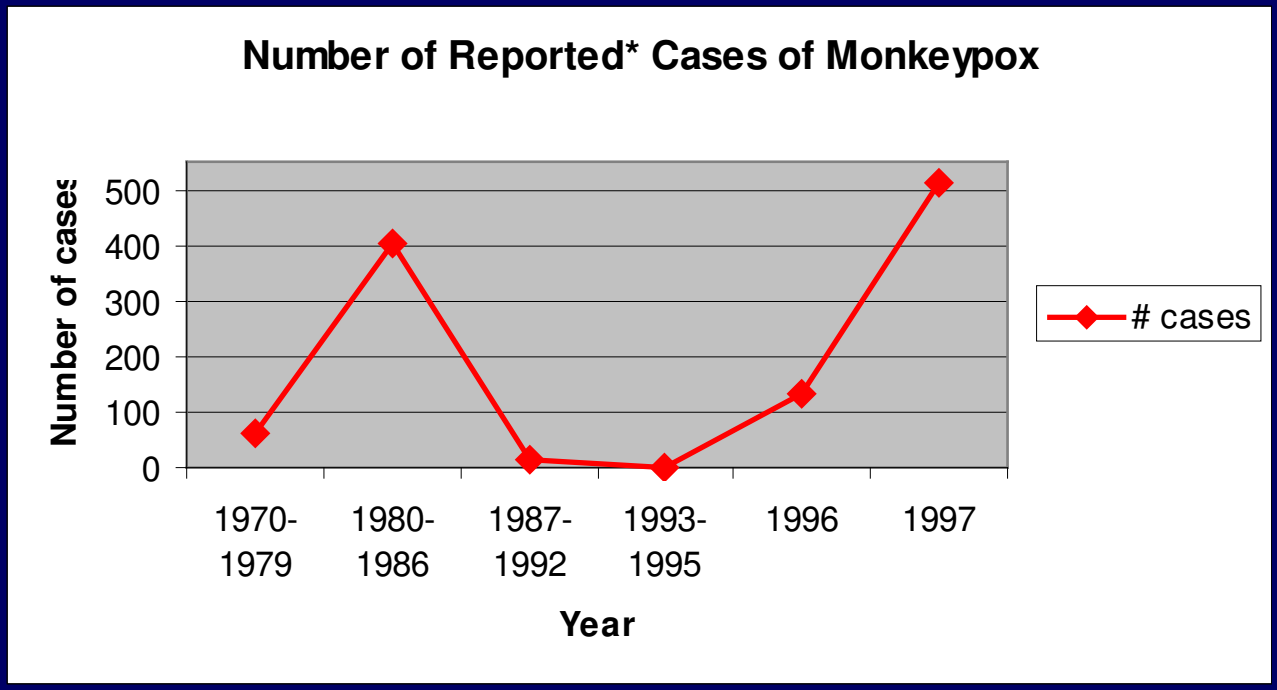
Monkeypox – Virus

- 2 geographically distinct clades
  - Congo Basin clade
  - West African clade
- 99% identical
  - Diversity is located in the terminal regions
- West African clade
  - Less virulent
  - Less transmissible

www.rst.gsfc.nasa.gov/Sect6/Sect6

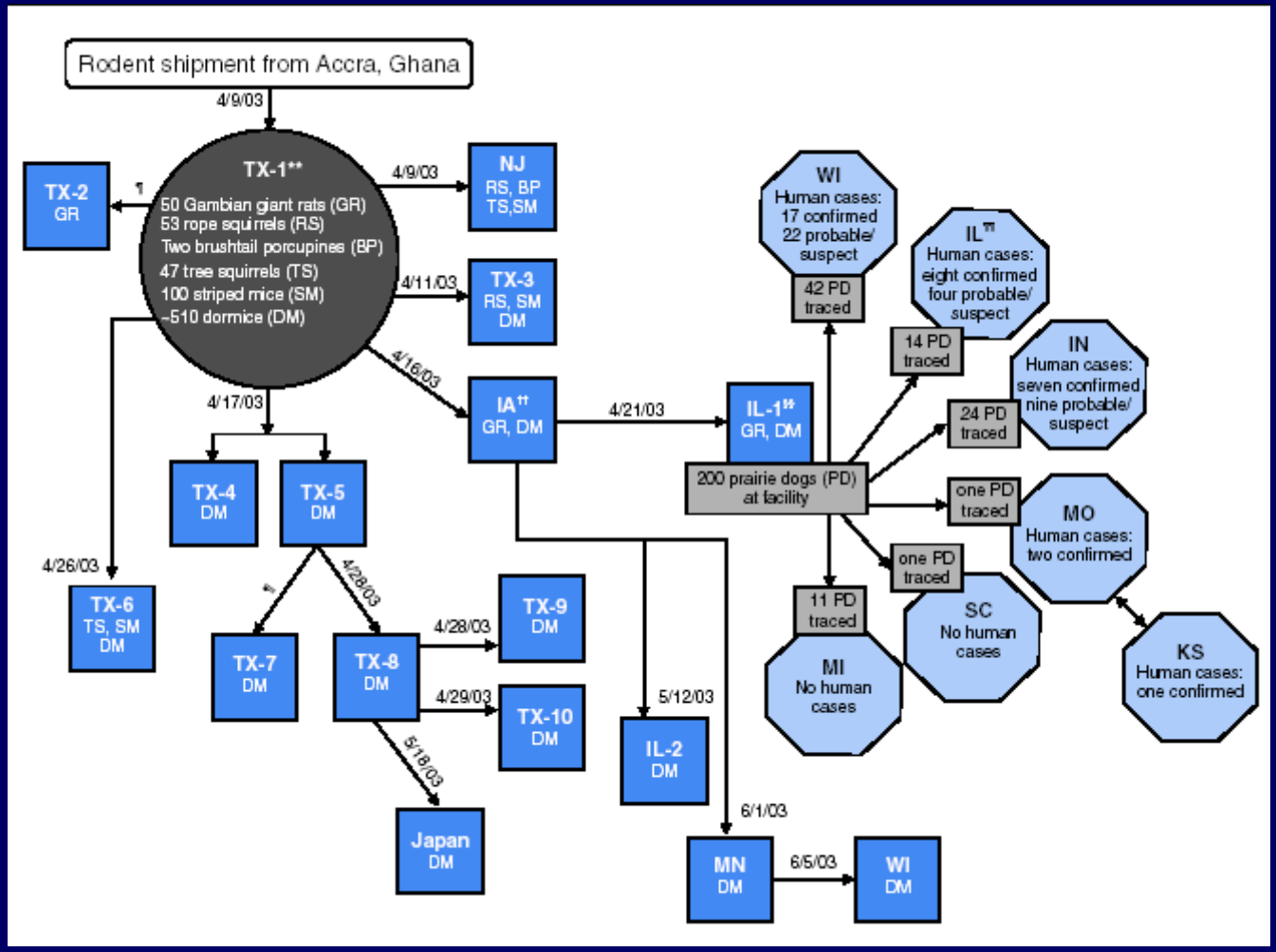
Monkeypox – Human Disease

- "Emerged" in 1970-1971
  - After successful eradication of smallpox
    - West and Central Africa
      - rural, tropical rainforest areas



Monkeypox – Human Disease

- 2003: United States 72 cases: 37 confirmed



Monkeypox – Human Disease

Source of virus

Source of human infection

www.nps.gov
photos.igougo.com
www.pets-classifieds.co.uk
www.everwonder.com/david/bullwinkle

Monkeypox – Clinical Presentation

- 10-14 day incubation
- 1-3 day prodrome
  - Fever, malaise, lymphadenopathy, URT illness
- 2-4 weeks: febrile rash illness:
  - Begins on the trunk, spreads centrifugally
  - Macular, papular, vesicular, pustular stages
- Complications
  - DIC, ocular lesions, CNS disease, multi-organ failure
  - Death
    - Case fatality 10% (range: 1.7 – 17%)
      - Children < 10 years

www.ci.vbi.vt.edu/pathinfo/pathogens/Monkeypox_virus_Info.shtml

Monkeypox - Epidemiology

- Endemic to West and Central Africa
  - Tropical rainforest regions
- Epidemiologic range not definitively identified
- Human cases occur sporadically in clusters
  - 80% in the DRC (Congo Basin)

Monkeypox - Epidemiology

- Transmission:
  - Direct contact
    - infected animals
  - Human-to-Human (~ 9%)
    - direct contact
    - respiratory aerosol
    - body fluids

www.bushmeat.org.za/mission.htm

Monkeypox - Epidemiology

- Zoonotic Reservoir Host(s) – unknown
- WHO and CDC ecological surveys
  - 13 rodents
  - 10 primates
  - 3 other mammals
  - 2 birds
- Virus isolated twice
  - 1985
  - 2003

www.pbase.com
www.britannica.com
www.mammalwatching.com

Monkeypox – Why Is It Important?

- WHO: “the most significant orthopoxvirus infection of man with regards to surveillance and research”
- Possible bioterrorism agent
- Clinically similar to smallpox
- Preventable but not eradicable

Monkeypox – Why Is It Important?

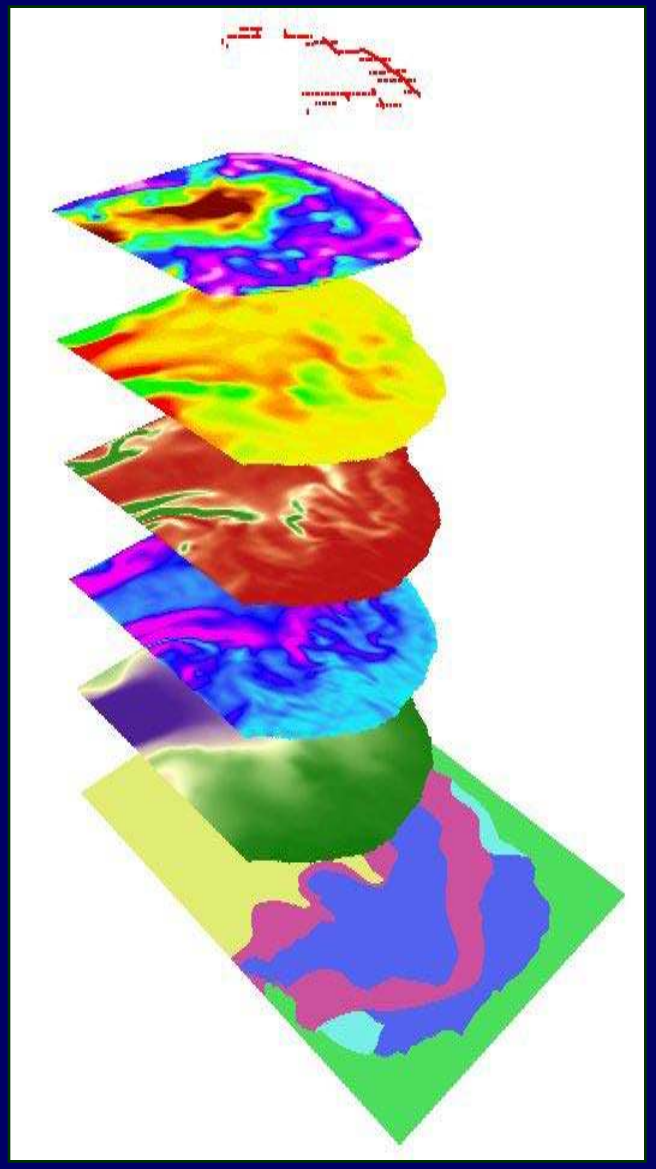
- Broad host range:
  - Large number of potential hosts
  - Endemic and novel landscapes
- Increasing incidence?
  - Encroachment
  - Ecosystem degradation
  - Susceptible individuals
  - Concomitant disease
  - Socioeconomic factors
  - Better surveillance?

www.mongabay.com

Introduction to Niche Modeling

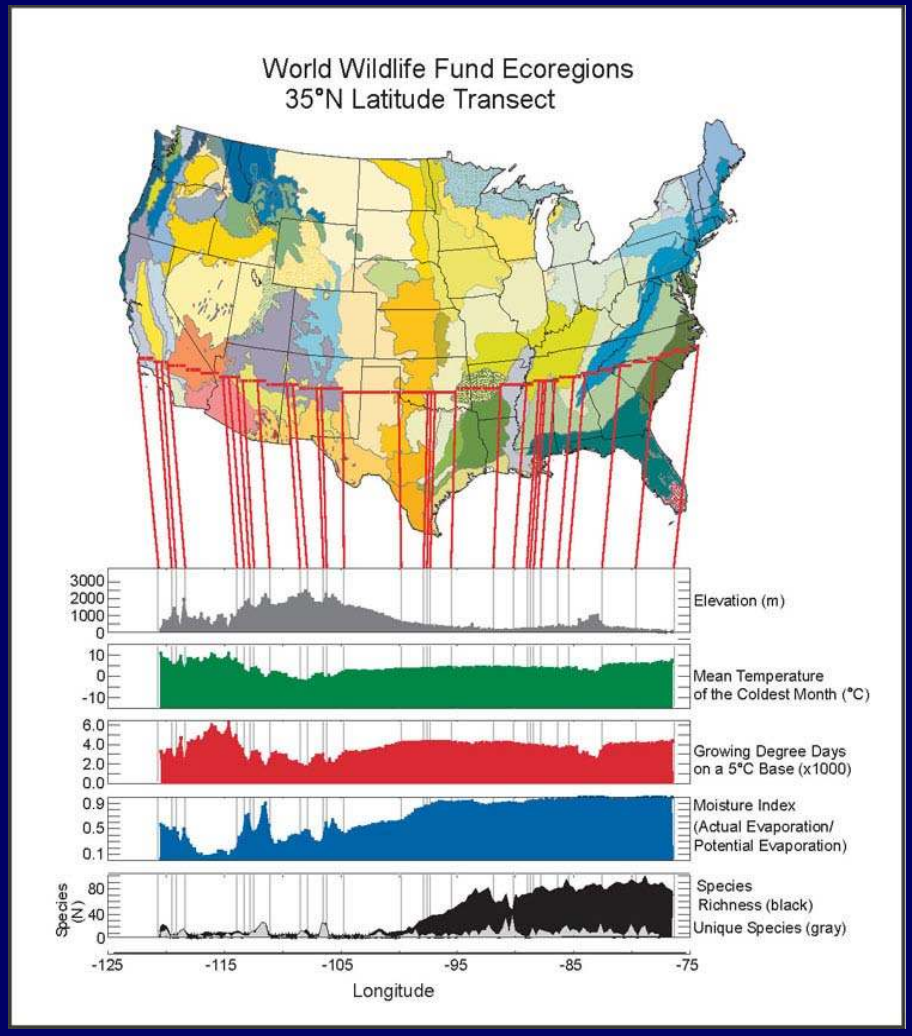
Ecological Niche Modeling

- Ecological niche
  - Set of environmental conditions capable of maintaining a population without immigration
- Ecological niche model
  - A set of environmental conditions classified as suitable (*versus* unsuitable) for the species, based on
    - localities of known occurrence
    - environmental variables
  - Integrated into a GIS system



www.oceanecology.ca/species_modelling

Ecological Niche Modeling - Uses



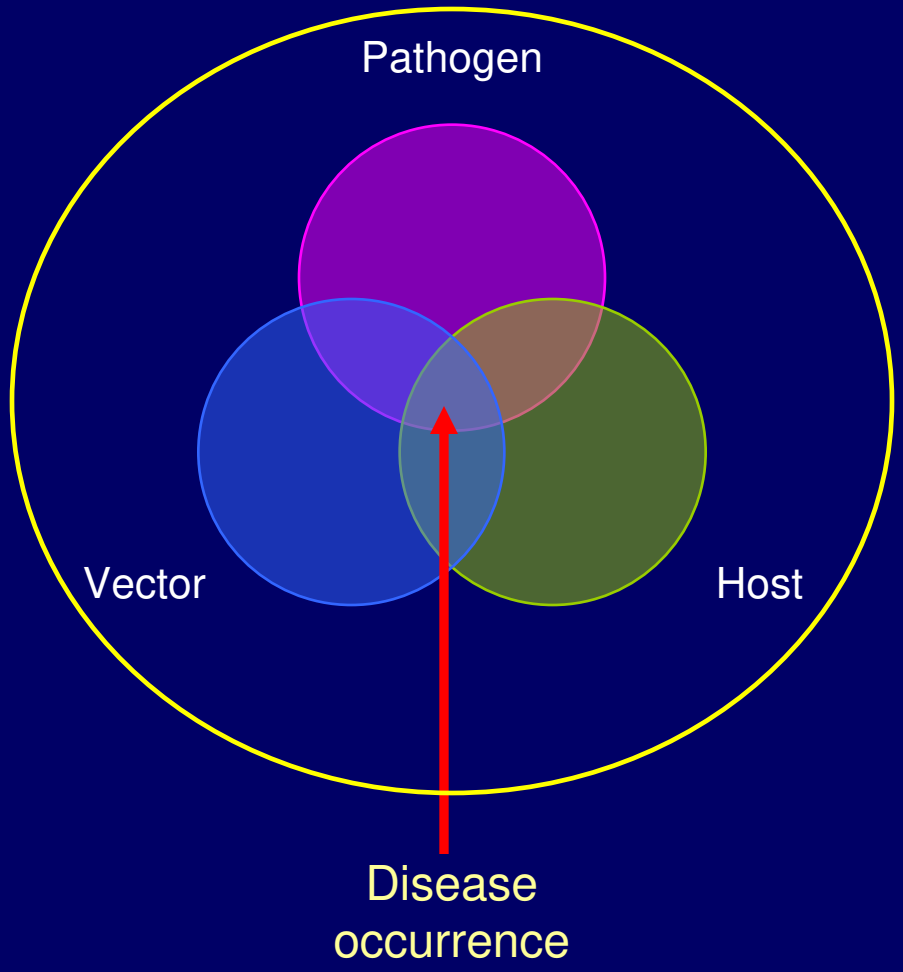
- Biogeographic research
- Conservation biology
- Ecology
- Paleoecology
- Wildlife conservation
- Spatial epidemiology

www.geography.usgs.gov/gcw

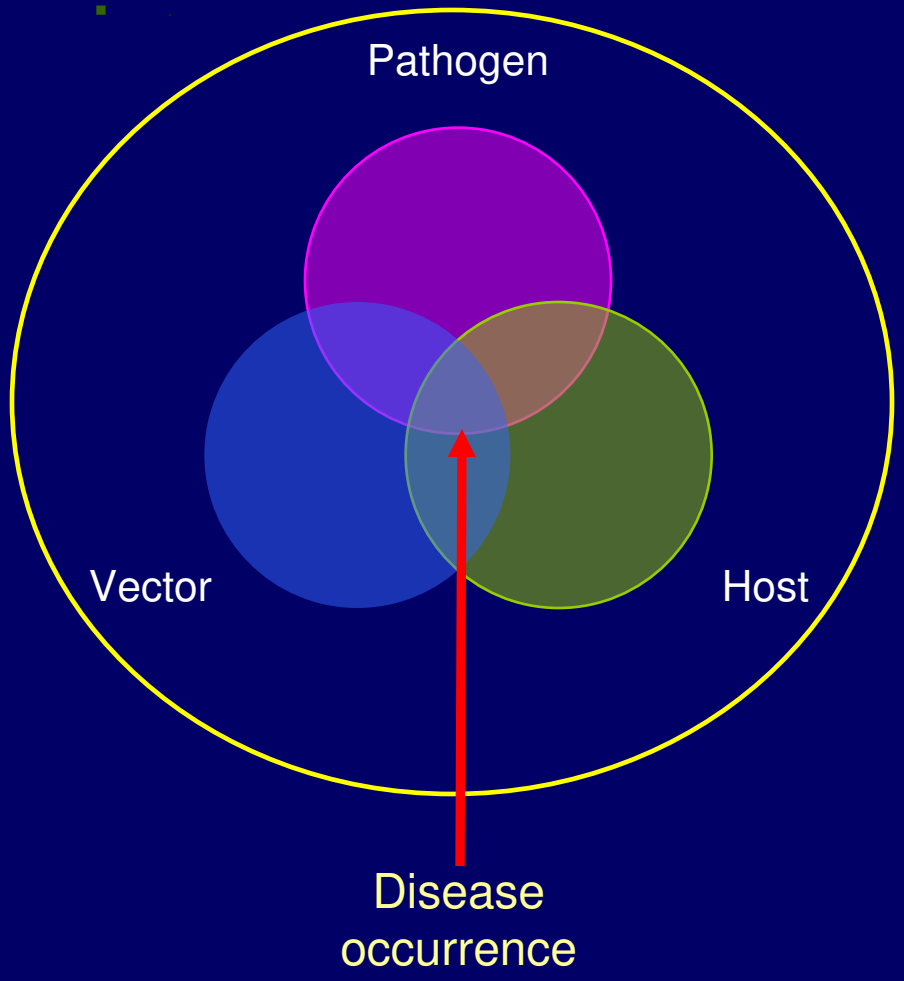
Ecological Niche Modeling
Spatial Epidemiology

- The geographic distribution of disease is an epidemiological event

  occurring at the convergence of each participating population's ecological niche



Ecological Niche Modeling
Spatial Epidemiology



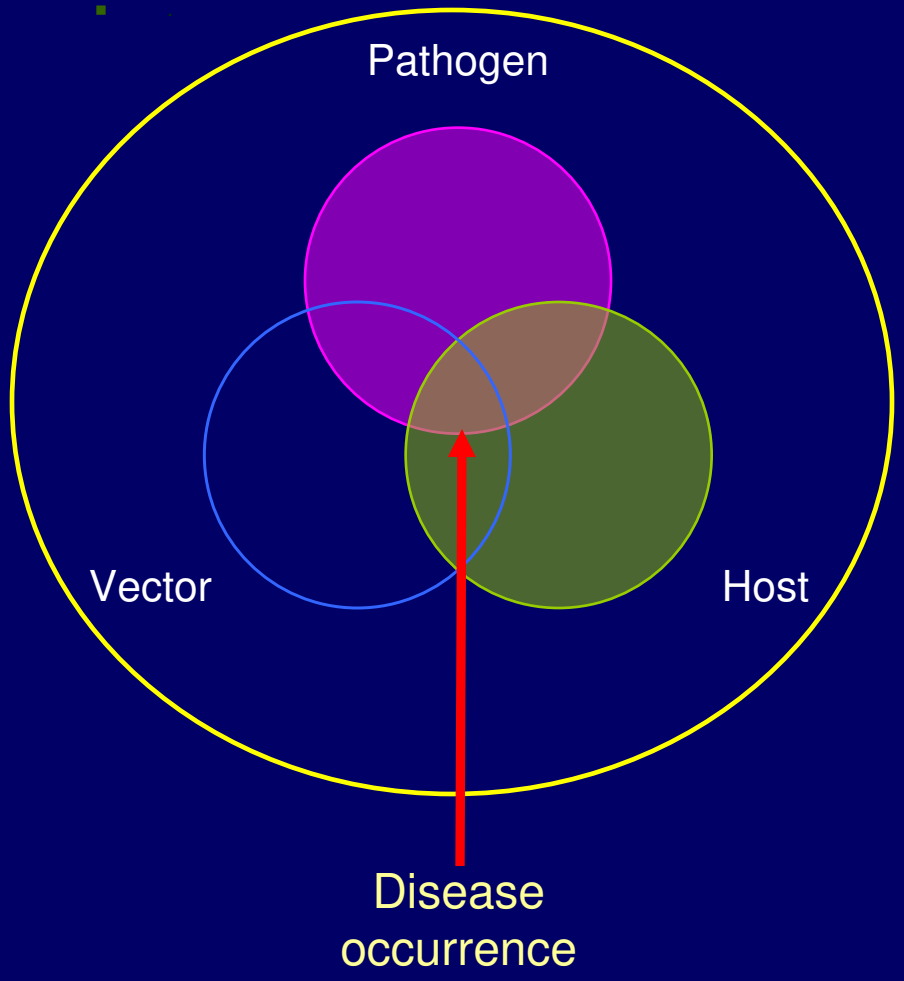
ENMs can:

Clarify environmental variables associated with disease transmission

Identify unknown components of transmission cycle

Anticipate unknown foci of disease occurrence

Ecological Niche Modeling
Spatial Epidemiology



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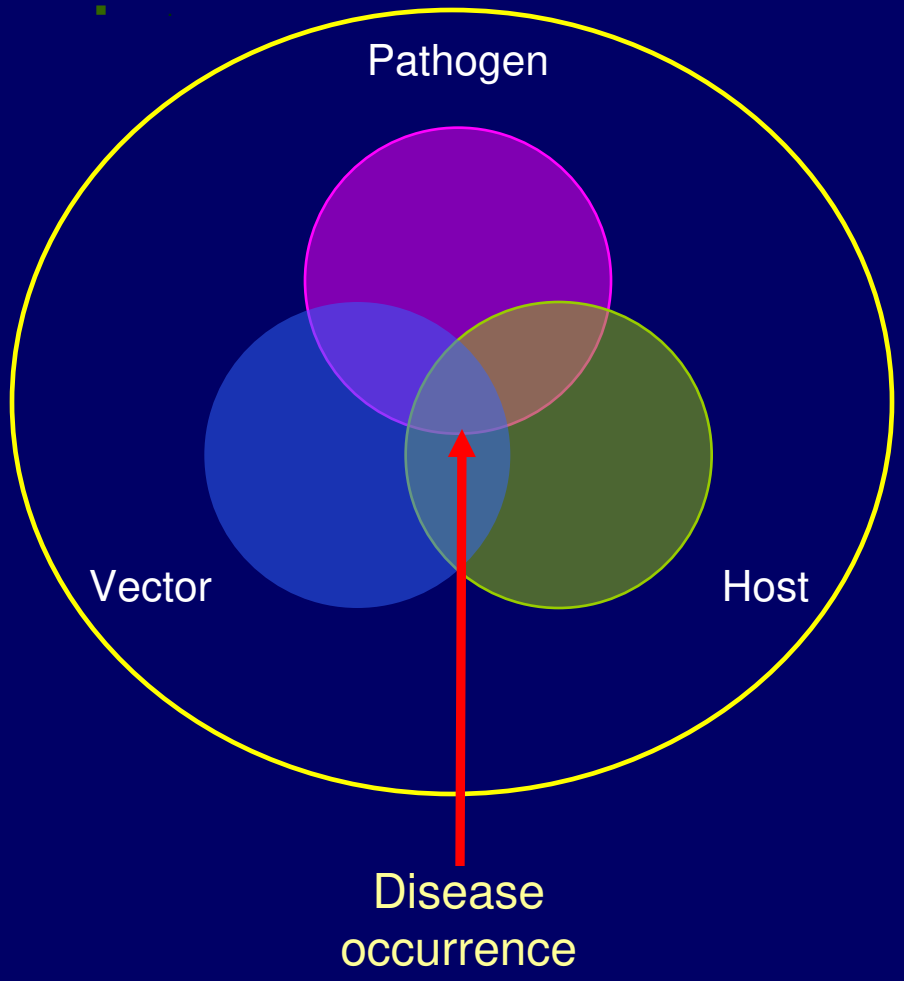


ENMs can:

Clarify environmental variables associated with disease transmission

Identify unknown components of transmission cycle

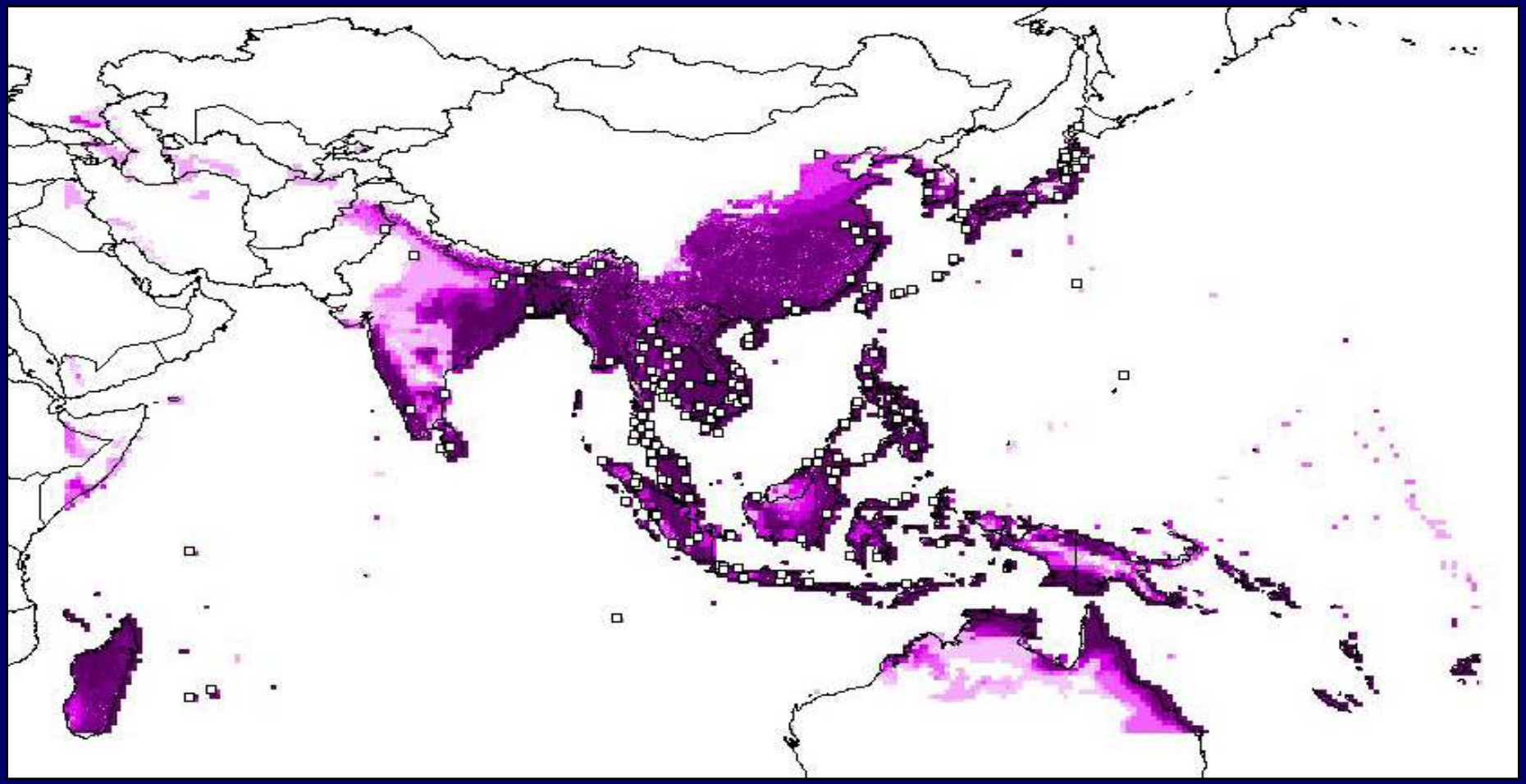
Anticipate unknown foci of disease occurrence

ENM Example:
Invasion of the USA by *Aedes albopictus*

Mark Q. Benedict et al
Vector-Borne and Zoonotic Diseases. March 1, 2007, 7(1): 76-85.
doi:10.1089/vbz.2006.0562.

- Invader
  - Fastest spreading mosquito in the world
- Aggressive
  - Daytime biter
- Transmits
  - Dengue, WNV
  - Encephalitis viruses
    - (LCE, SLE, EEE)
  - Ross River fever
  - Rift Valley fever

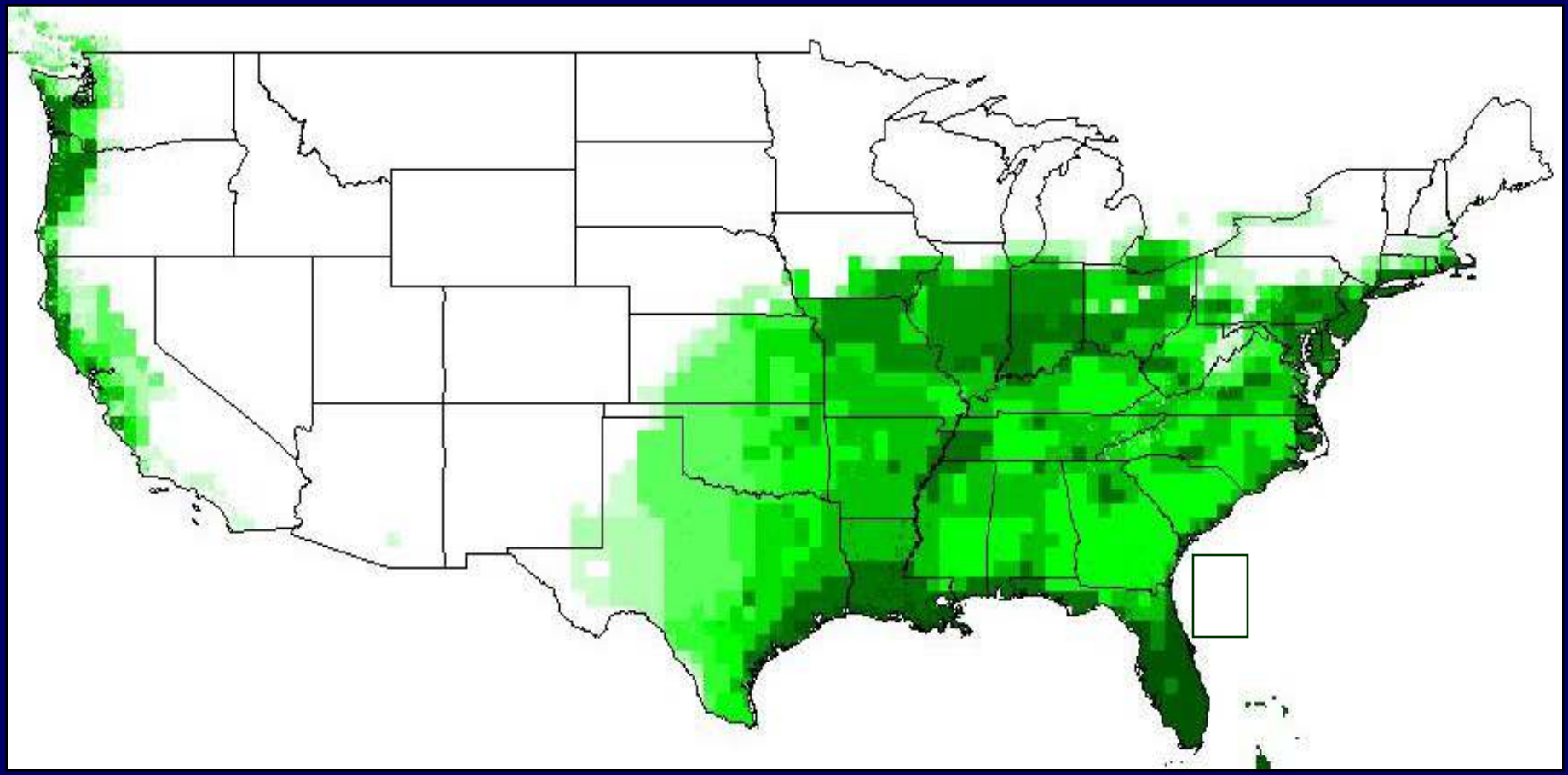
Aedes albopictus: Native Range



Present predicted distribution, native range in Asia

Mark Q. Benedict et al

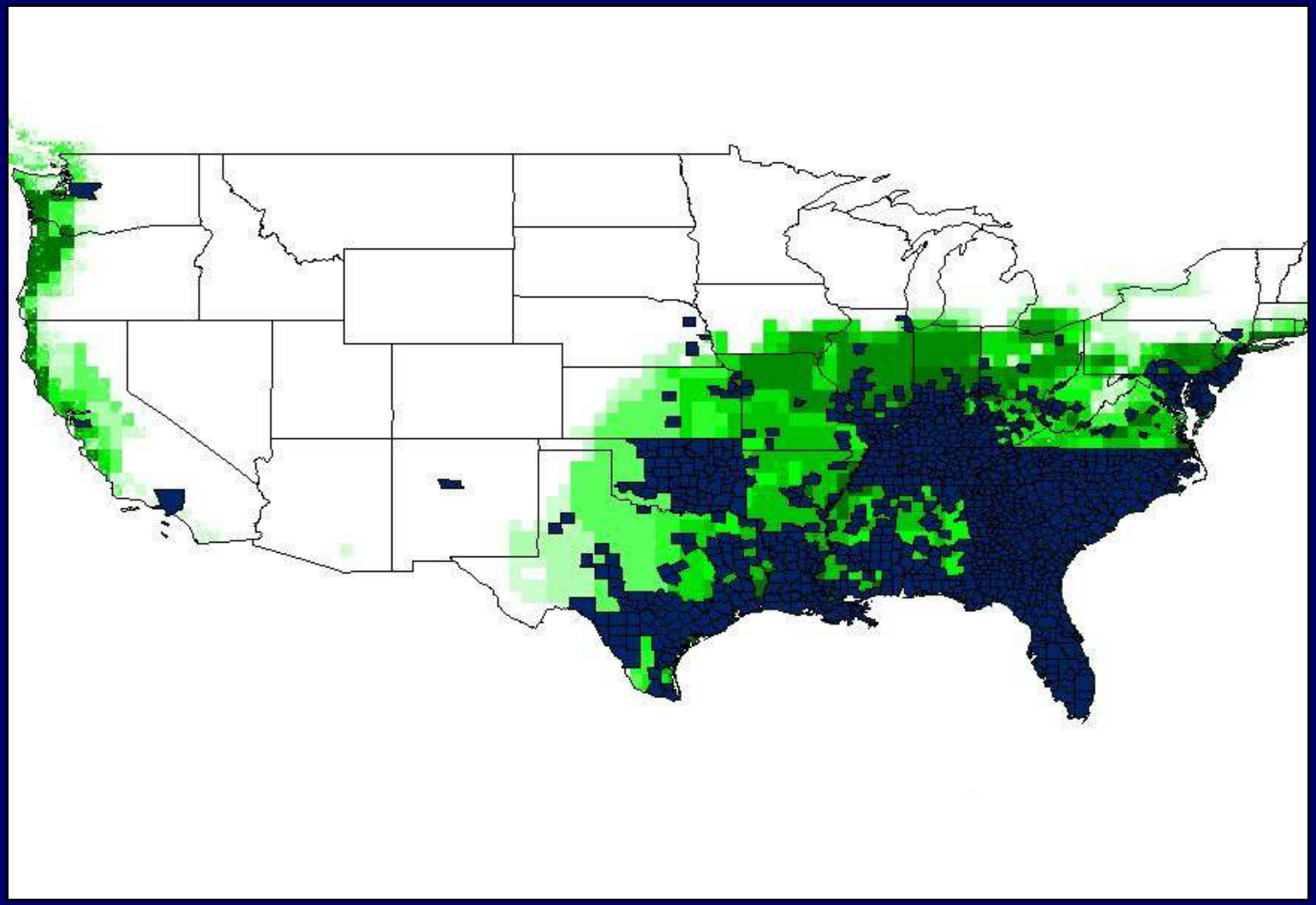
Aedes albopictus: USA invasion



Projected Asian niche into USA to create an invasion risk-map.

Mark Q. Benedict et al

Aedes albopictus: USA invasion



Mark Q. Benedict et al

My Project

Ecology and Geography of Human Monkeypox Case Occurrences Across Africa

- Goal:

1) Identify ecological factors relevant to the geographic distribution of monkeypox in Africa

2) Use this knowledge to understand better the geography of monkeypox across Africa

3) Perform a comparative assessment of ENM methodology

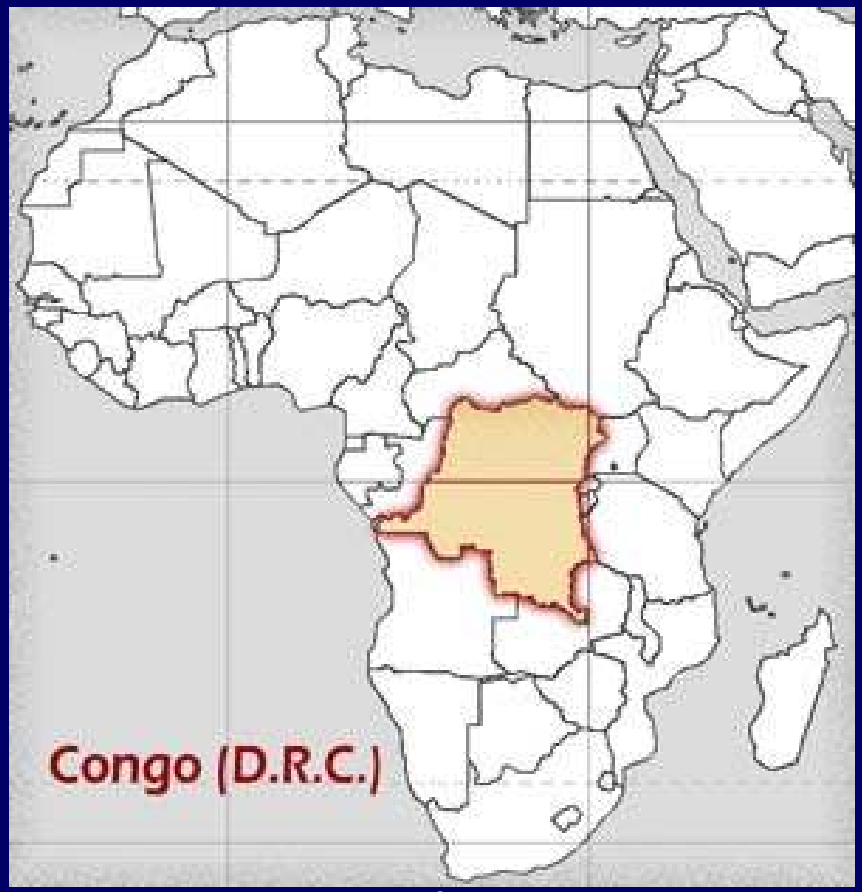
Occurrence Data

- Occurrence Data:
  - CDC and WHO
    - outbreak investigation and surveillance data
- Case Definition:
  - Laboratory confirmed
    - Published reported case
    - Non-redundant unpublished case

Occurrence Data

- Georeferencing Case Occurrence
  - Country
  - Region
  - District / Zone
  - Municipality
  - Specific locality

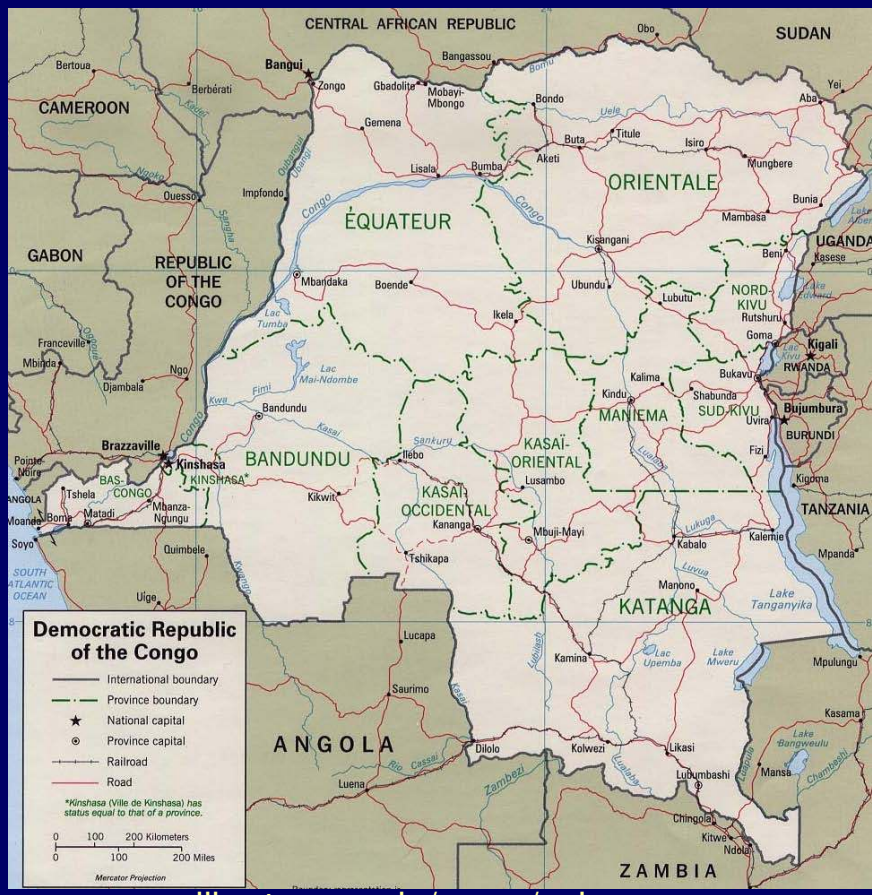
Democratic Republic of the Congo



Occurrence Data

- Georeferencing Case Occurrence
  - Country
  - Region
  - District / Zone
  - Municipality
  - Specific locality

Democratic Republic of the Congo -- Equateur

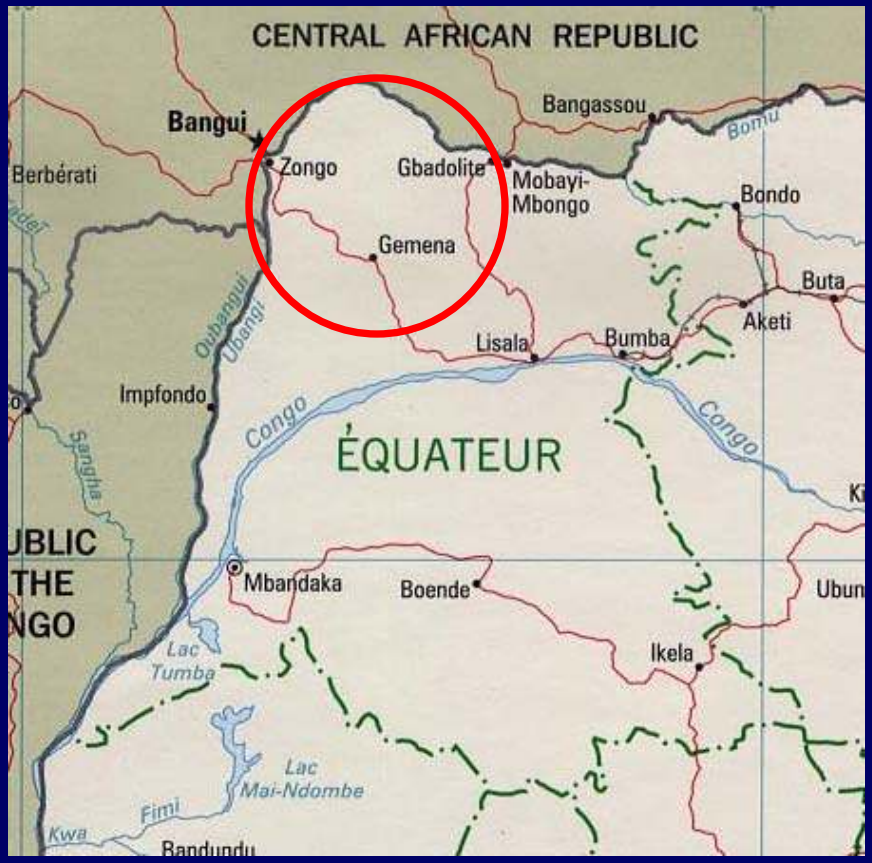


www.lib.utexas.edu/maps/zaire

Occurrence Data

Democratic Republic of the Congo – Equateur – Bumba

- Georeferencing Case Occurrence
  - Country
  - Region
  - District / Zone
  - Municipality
  - Specific locality

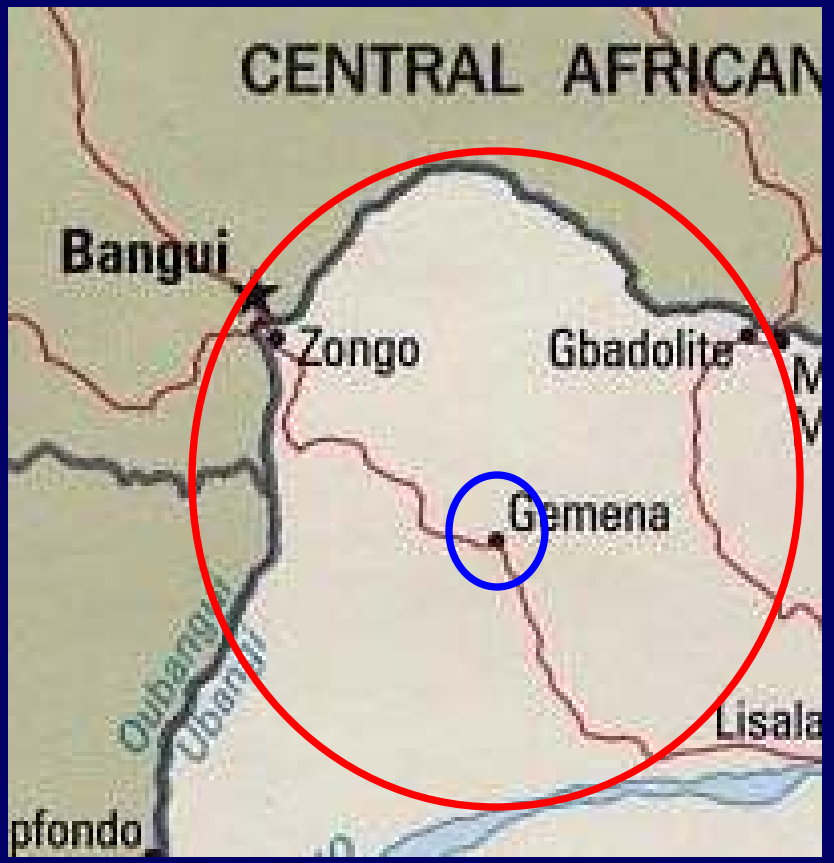


www.lib.utexas.edu/maps/zaire

Occurrence Data

Democratic Republic of the Congo – Equateur – Bumba – Gemena

- Georeferencing Case Occurrence
  - Country
  - Region
  - District / Zone
  - Municipality
  - Specific locality

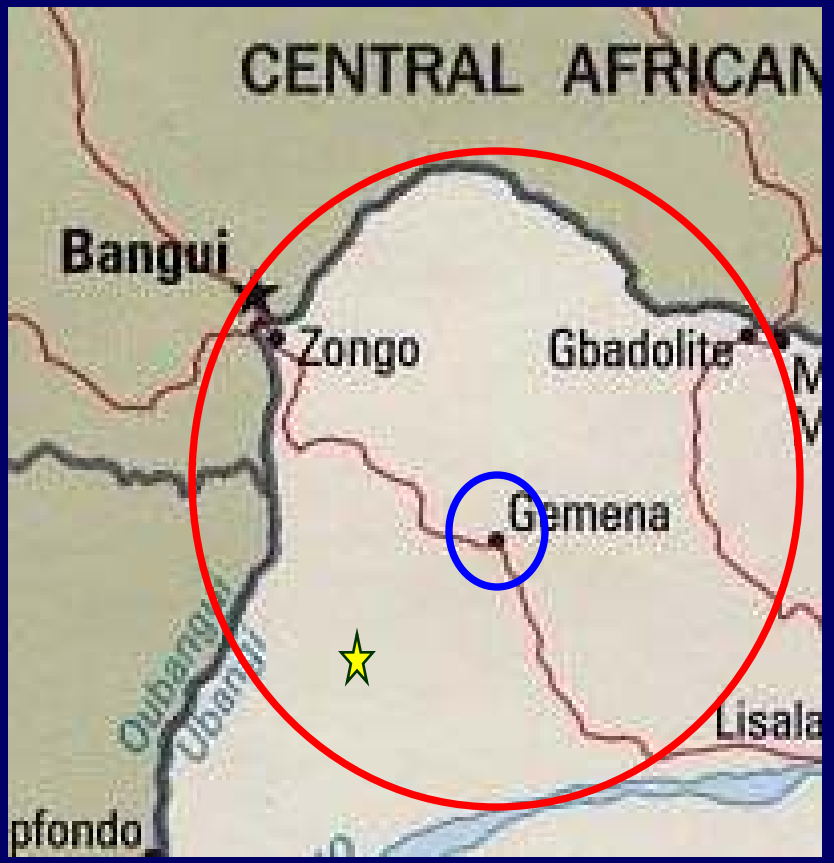


www.lib.utexas.edu/maps/zaire

Occurrence Data

Democratic Republic of the Congo – Equateur – Bumba – Gemena – Ebata

- Georeferencing Case Occurrence
  - Country
  - Region
  - District / Zone
  - Municipality
  - Specific locality



www.lib.utexas.edu/maps/zaire

Occurrence Data

- Started with: 404 cases
- Georeferenced: 216 localities

- But, you can't just georeference the occurrence and call it good…

- Must account for …..

Occurrence Data

- Error….
- Spatial uncertainty
  - Extent of named places
  - Imprecise locality descriptions
  - Incomplete locality descriptions
  - Datum error
    - 10 cm – 1000 meters

www.manisnet.org

"*"georeferencing" or "geocoding," can be rather complicated*."

- Georeferencing Manual
  - Contains information about assigning
    - Geographic coordinates to locality descriptions
    - Extent to those coordinates

- Georeferencing Calculator
    - Corrected GPS coordinates
    - Assigns an error extent

    - Result: greater spatial precision

Occurrence Data

Point-radius method:

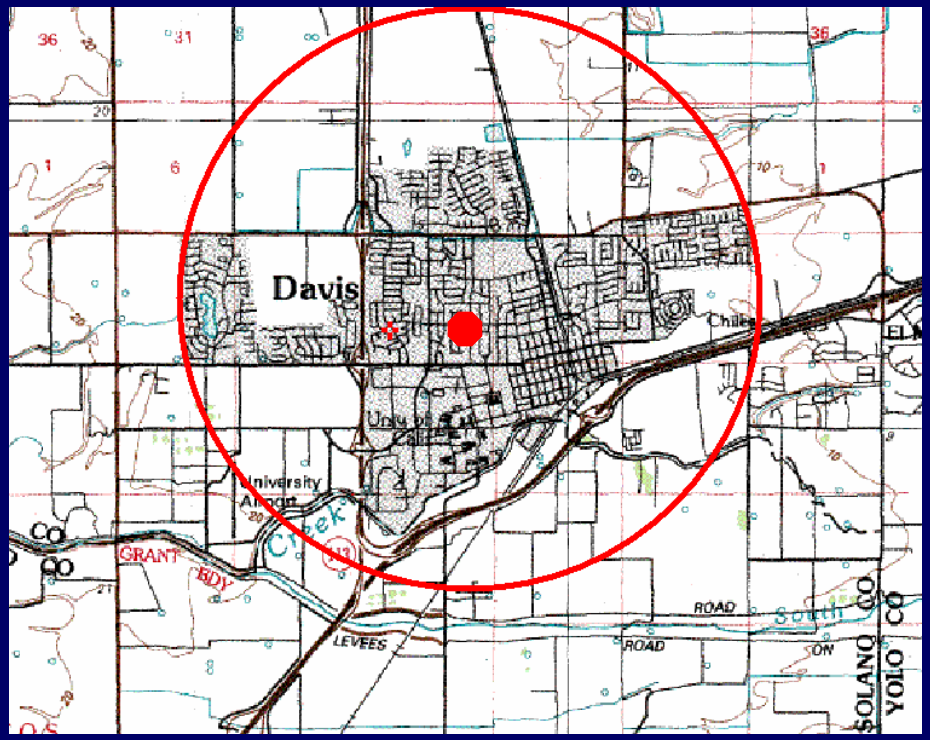
A locality is a geographic point surrounded by an error extent

Summarizes effects of error-related factors

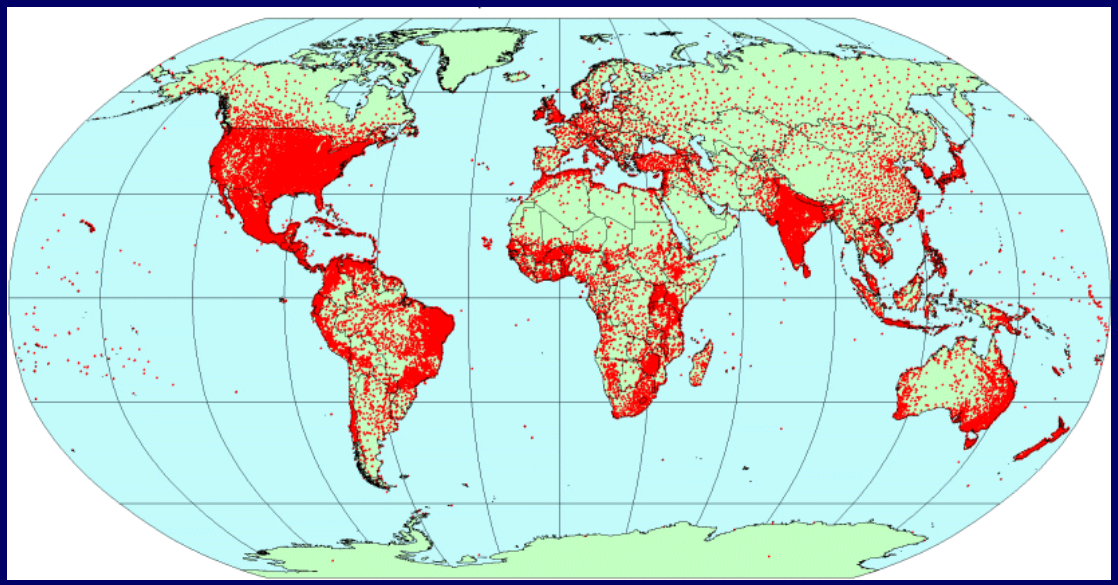
All MPX occurrences were assigned an error radius

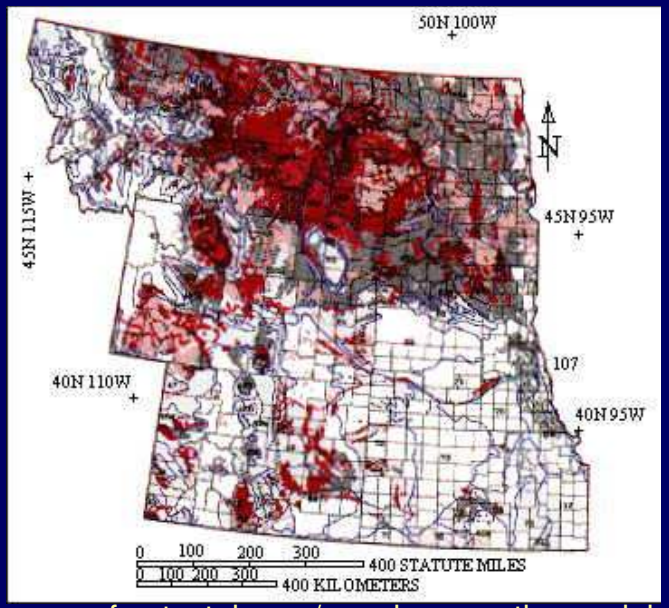
Restricted analysis to sites with a precision = 10 km^2

139 occurrences for final analysis



Environmental Data (raster GIS data layers)

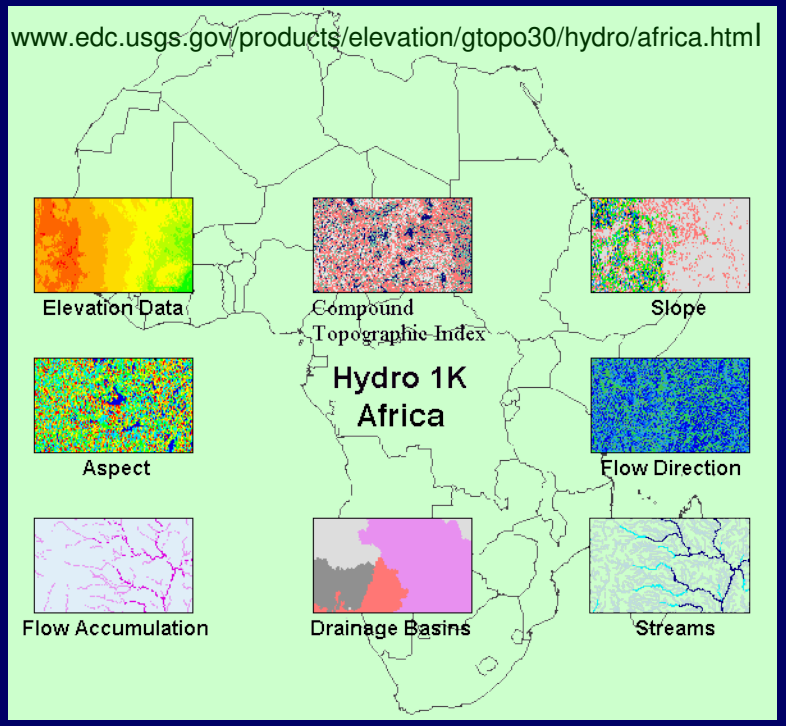


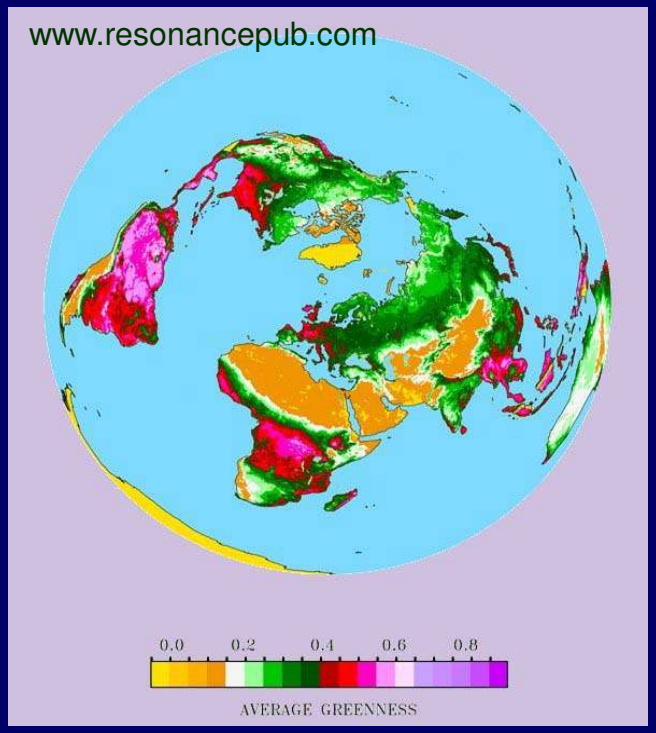


www.mnforstustain.org/americas_northern_plains

- Climate
  - Weather station data
  - Long temporal applicablity
- WorldClim
  - www.worldclim.com
- Soil characteristics
- Vegetation data
- UNEP GeoData Portal
  - www.geodata.grid.unep.ch/data

Environmental Data (raster GIS data layers)





- Topography
- USGS Hydro-1K DEM
  - www.edc.usgs.gov
- Normalized Difference Vegetation Index (NDVI)
- University of Maryland
  - AVHRR satellite
  - www.glcf.umiacs.umd.edu

Environmental Data

- Environmental Data – 30 total layers
  - Climate - 19 variables
  - Topography - 4 variables
  - Soil & Vegetation - 5 variables
  - Surface reflectance (monthly NDVI composites) - 12 variables
- Must determine
  - How much data is enough….
  - Which variables are best suited for model construction….

Ecological Niche Modeling: Maxent

www.es.princeton.edu~schapire/maxent

- General purpose maximum entropy-based machine learning method
- Origins:
  - Statistical mechanics
  - Bayesian statistics
- Entropy:
  - A measure of the disorder or randomness in a closed system
  - The tendency for all matter and energy to evolve toward a state of disorder

Ecological Niche Modeling: Maxent

www.es.princeton.edu~schapire/maxent

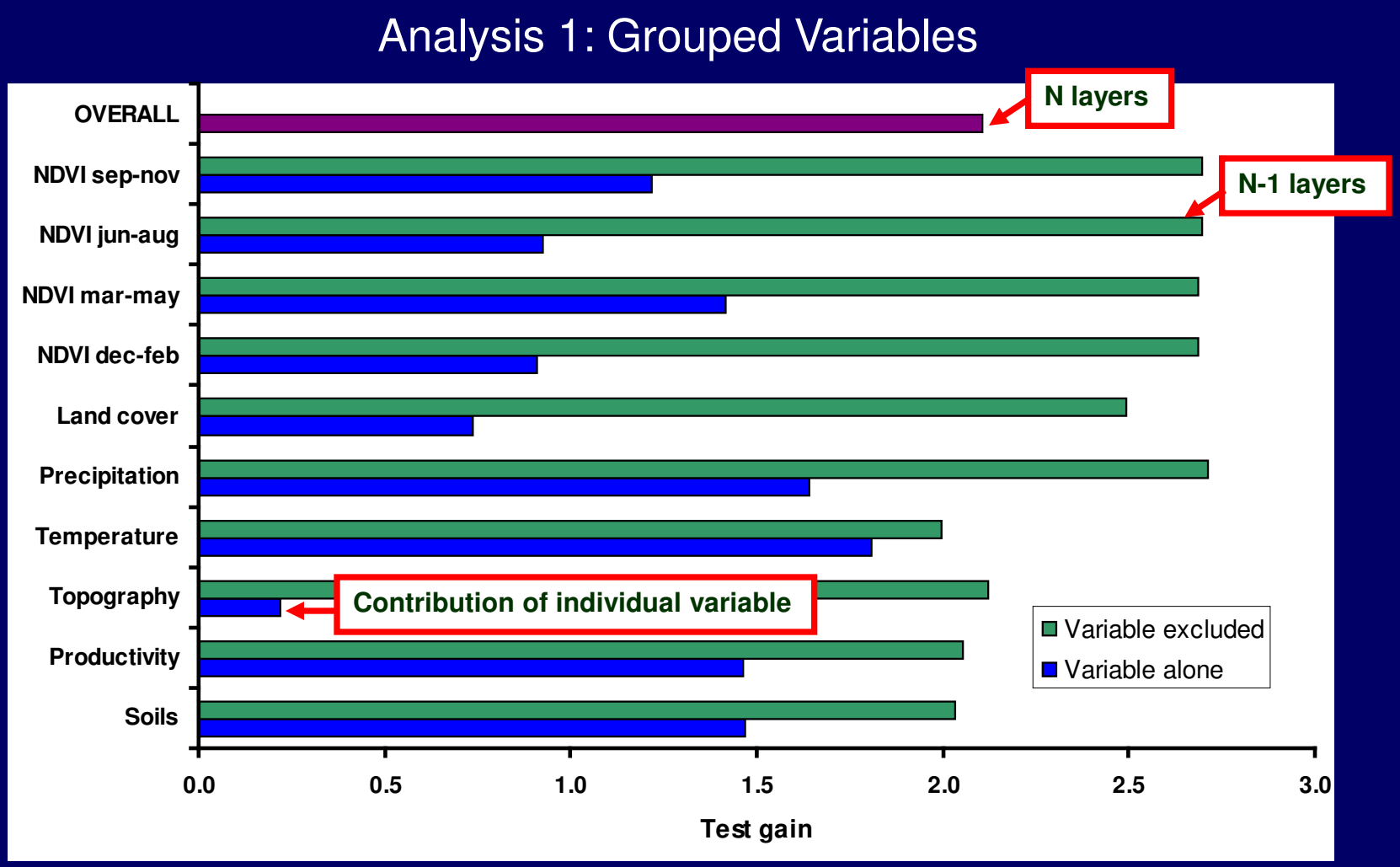
- Estimates the EN as a probability distribution
  - Closest to maximum entropy

    subject to the constraint that higher probabilities will occur under conditions associated with observed presence
- Performs statistical analysis
  - Environmental variable suitability
- Niche model construction:
  - Presence-only occurrence data
  - 10,000 random background points representing non-occurrence
  - Environmental data

Analysis of Ecological Factors

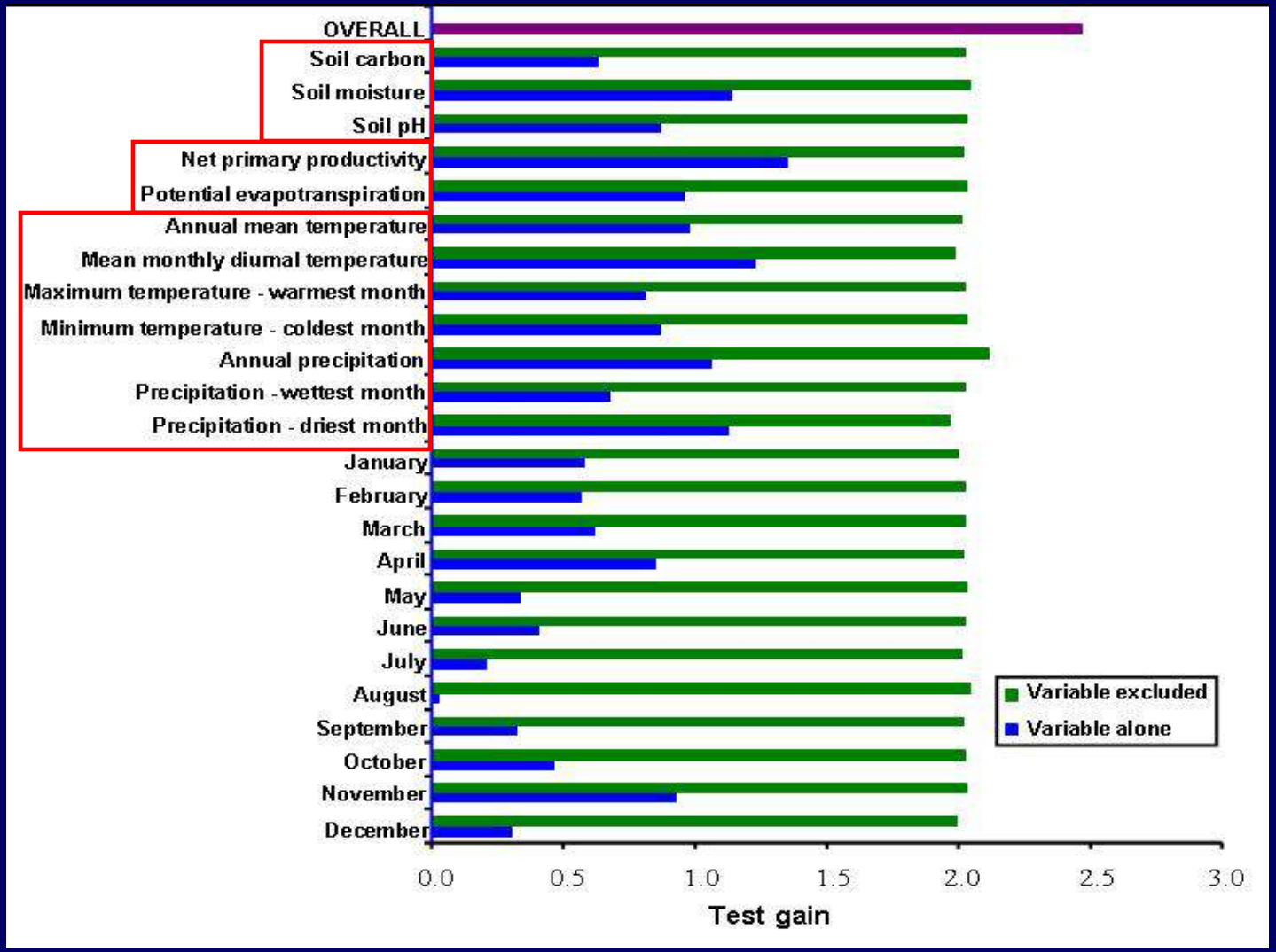
- Jackknife Analysis
  - N layers (N = 30 total # layers used)
  - N-1 layers
    - omitted each variable sequentially
    - assess importance of variables by examining effects of their omission
  - 2 analyses
    - Suites of environmental variables
    - Individual variables

Environmental Data

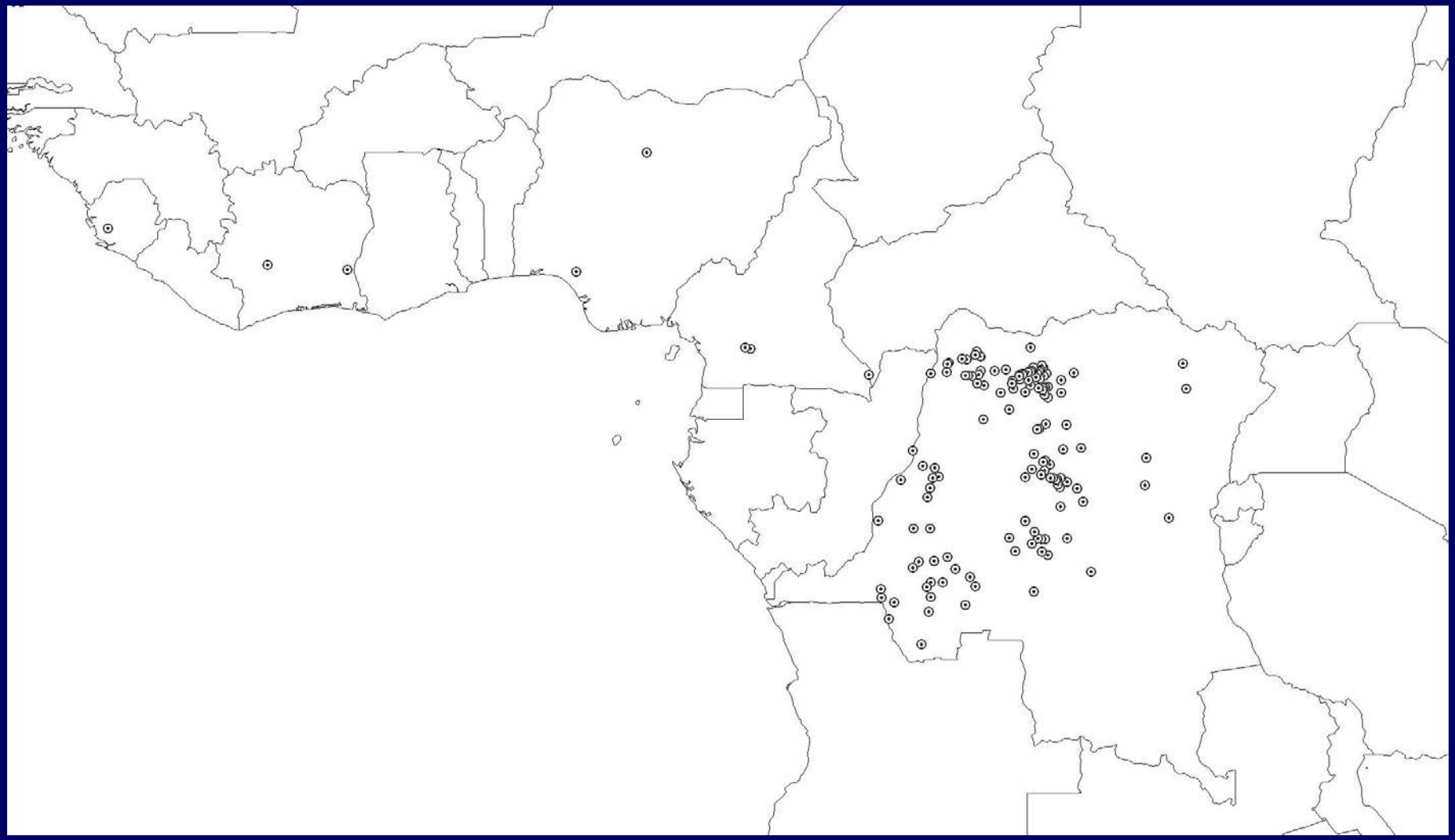


Environmental Data

Analysis 2: Individual variables



Monkeypox Ecology and Geography



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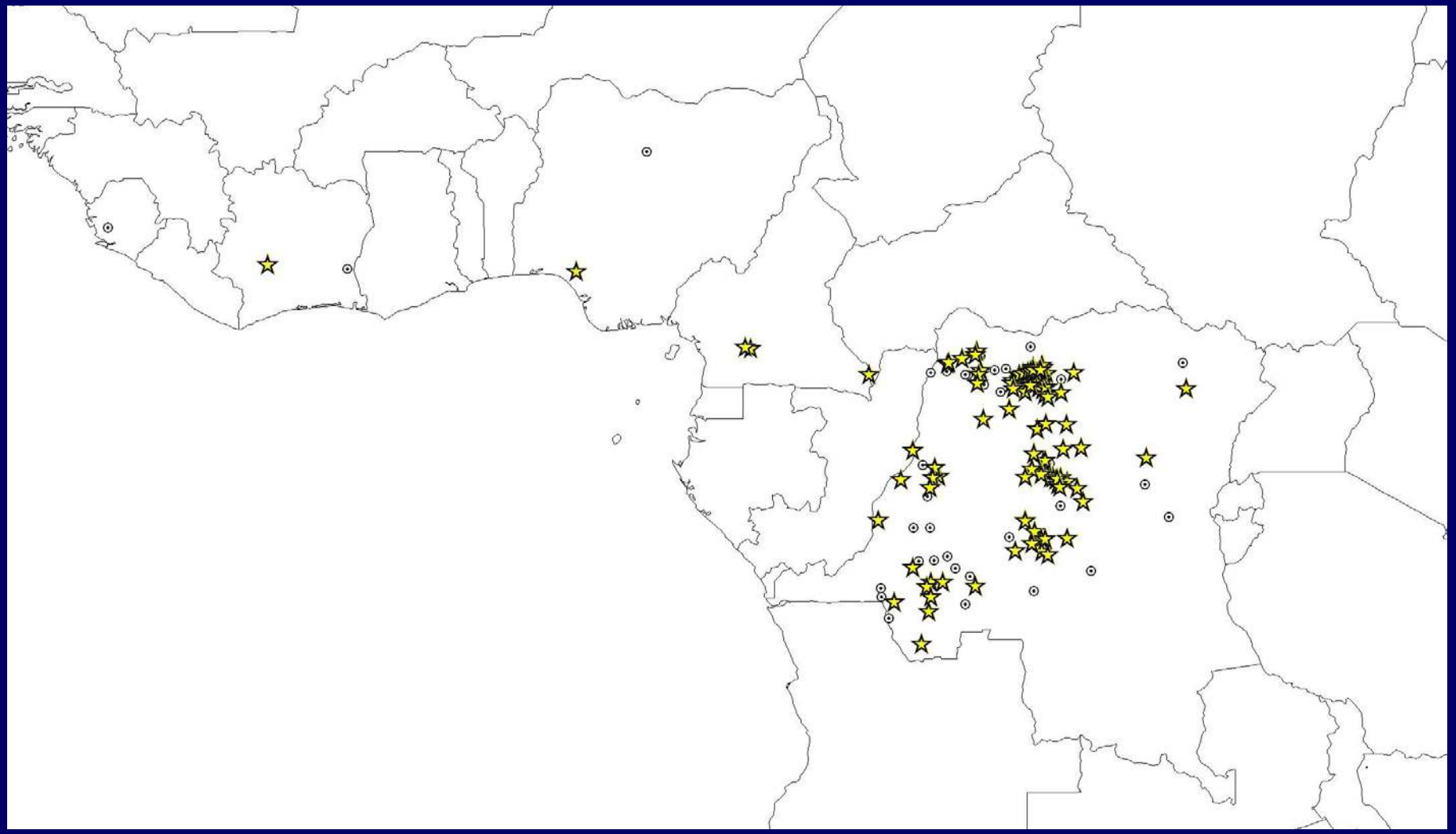

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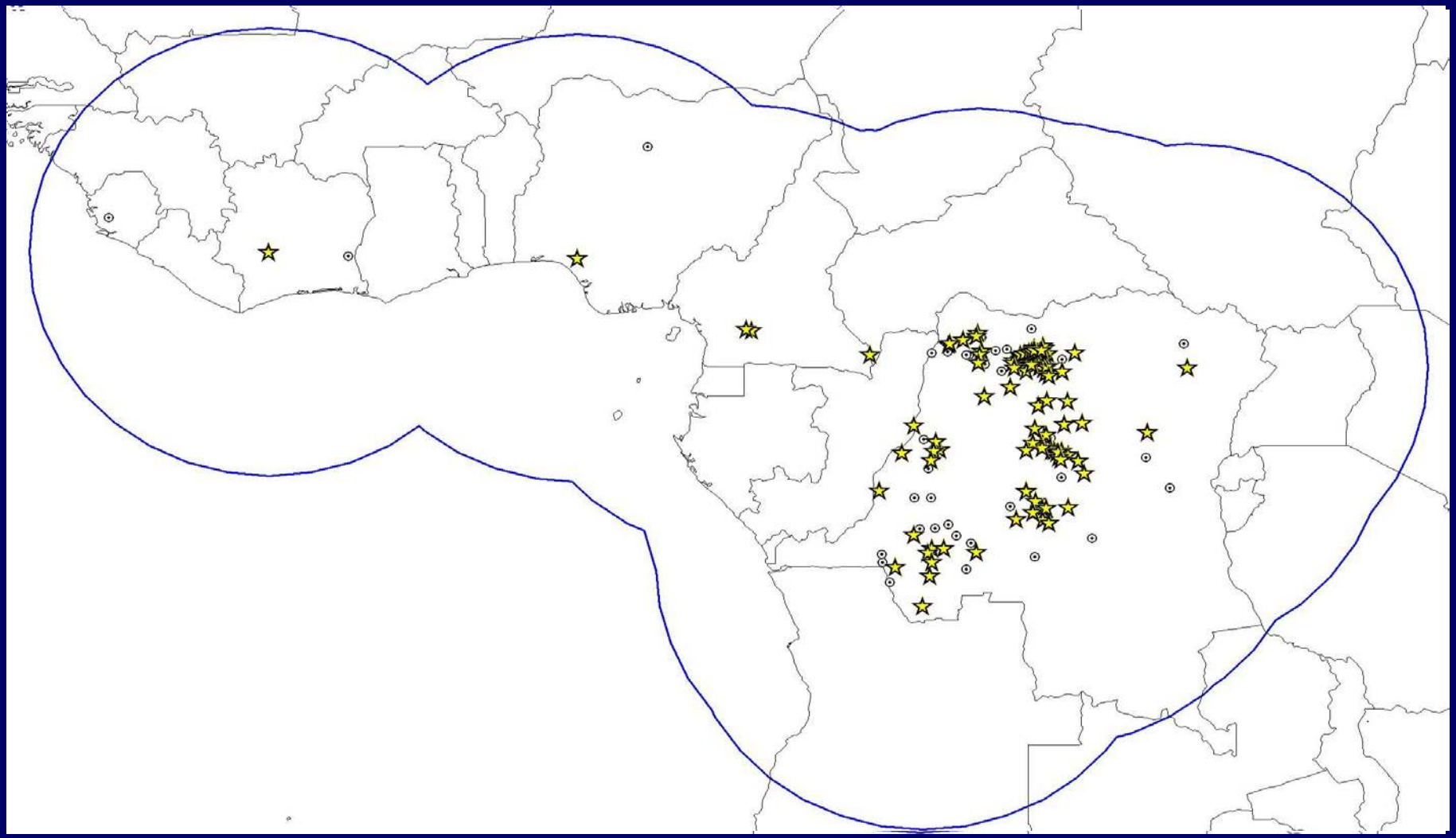

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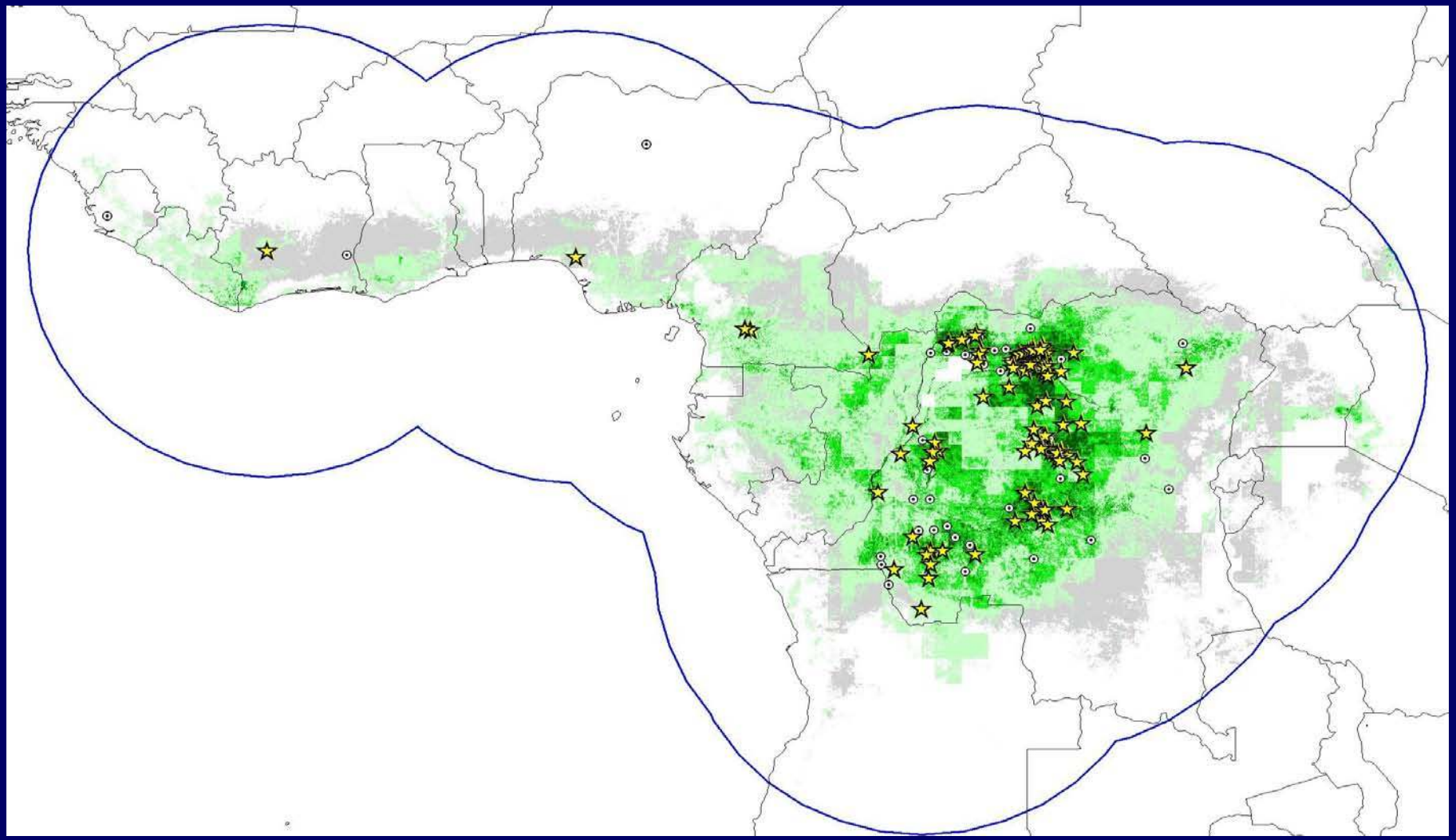
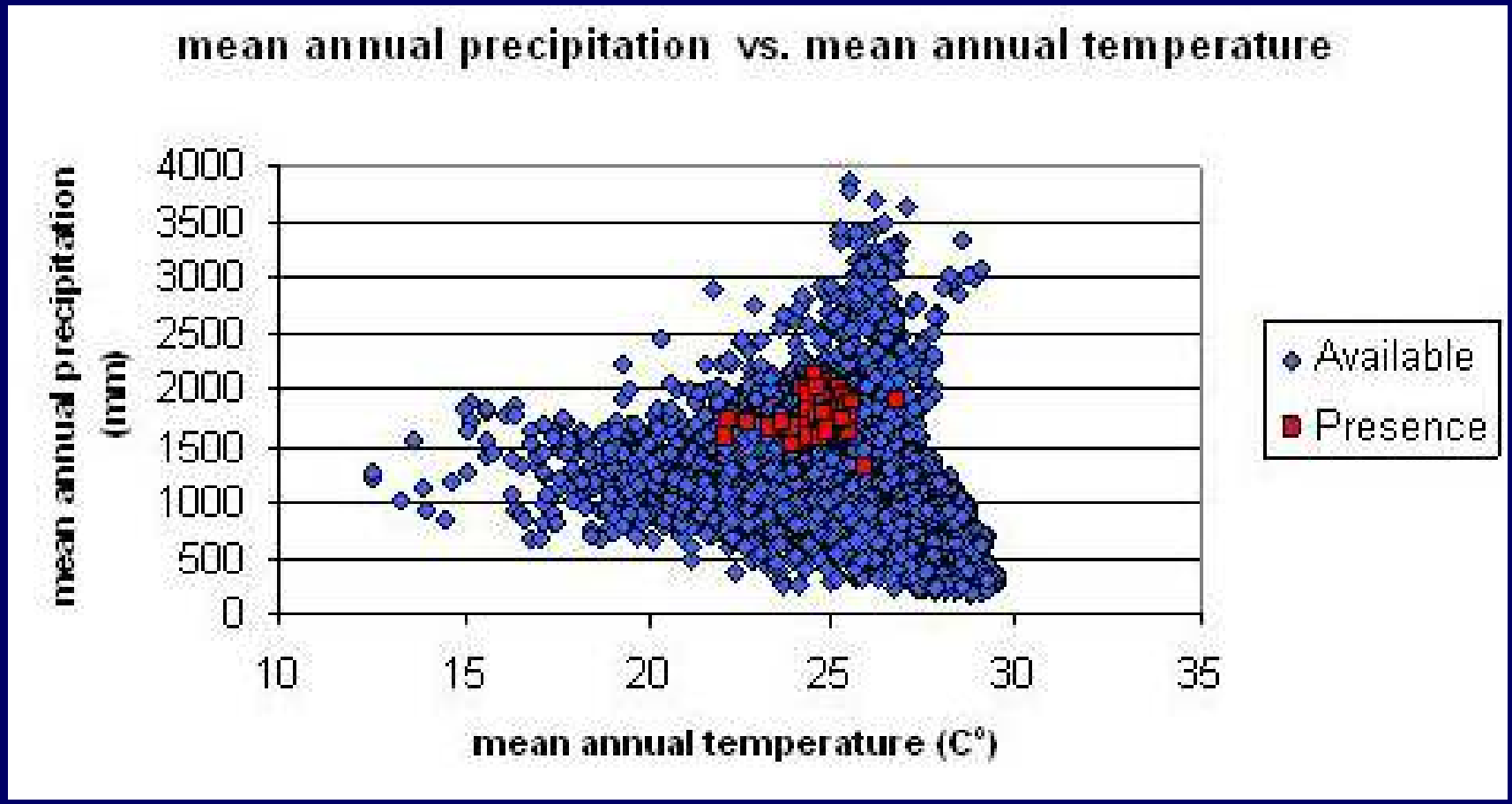
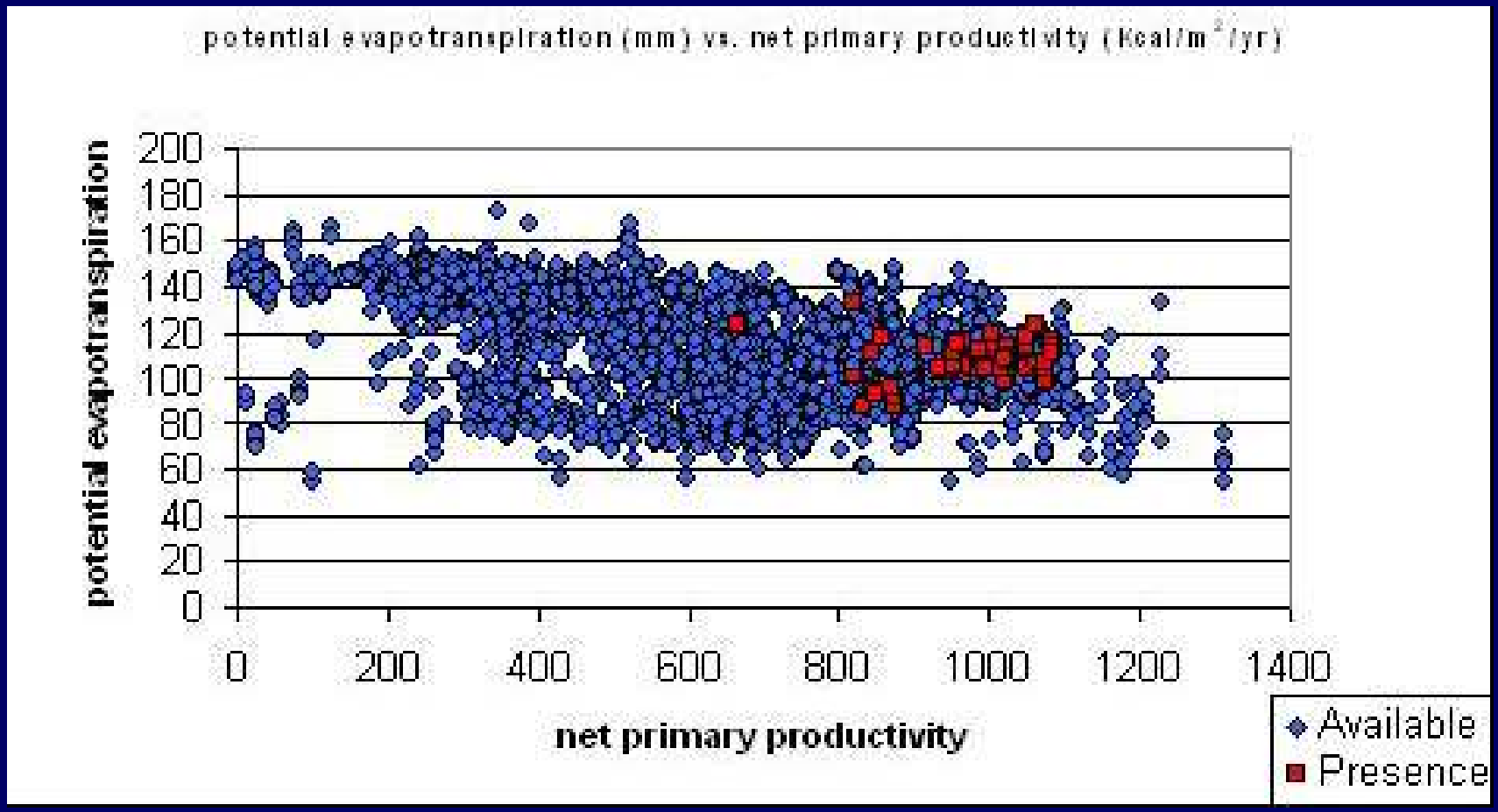


Monkeypox Ecological Niche



Monkeypox Ecological Niche

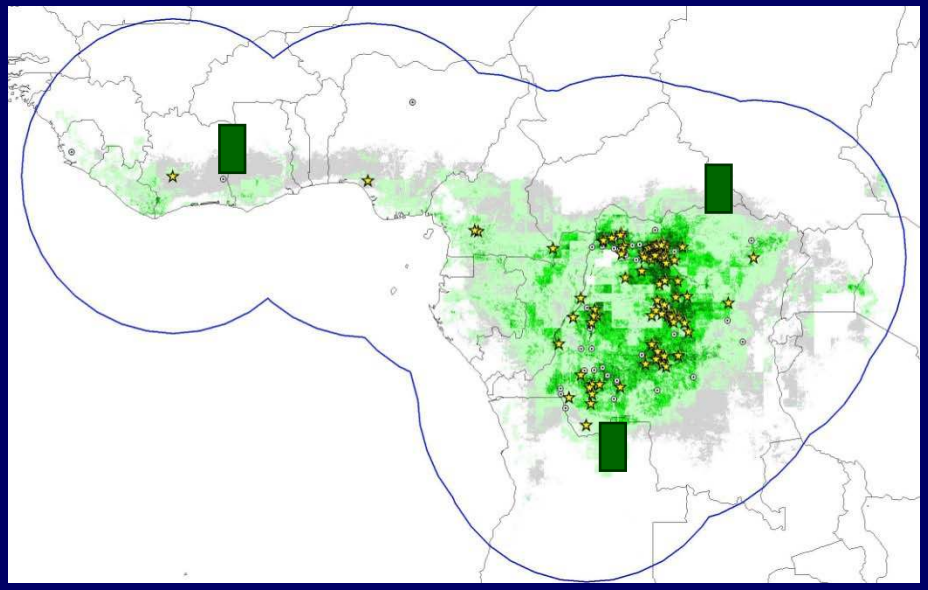


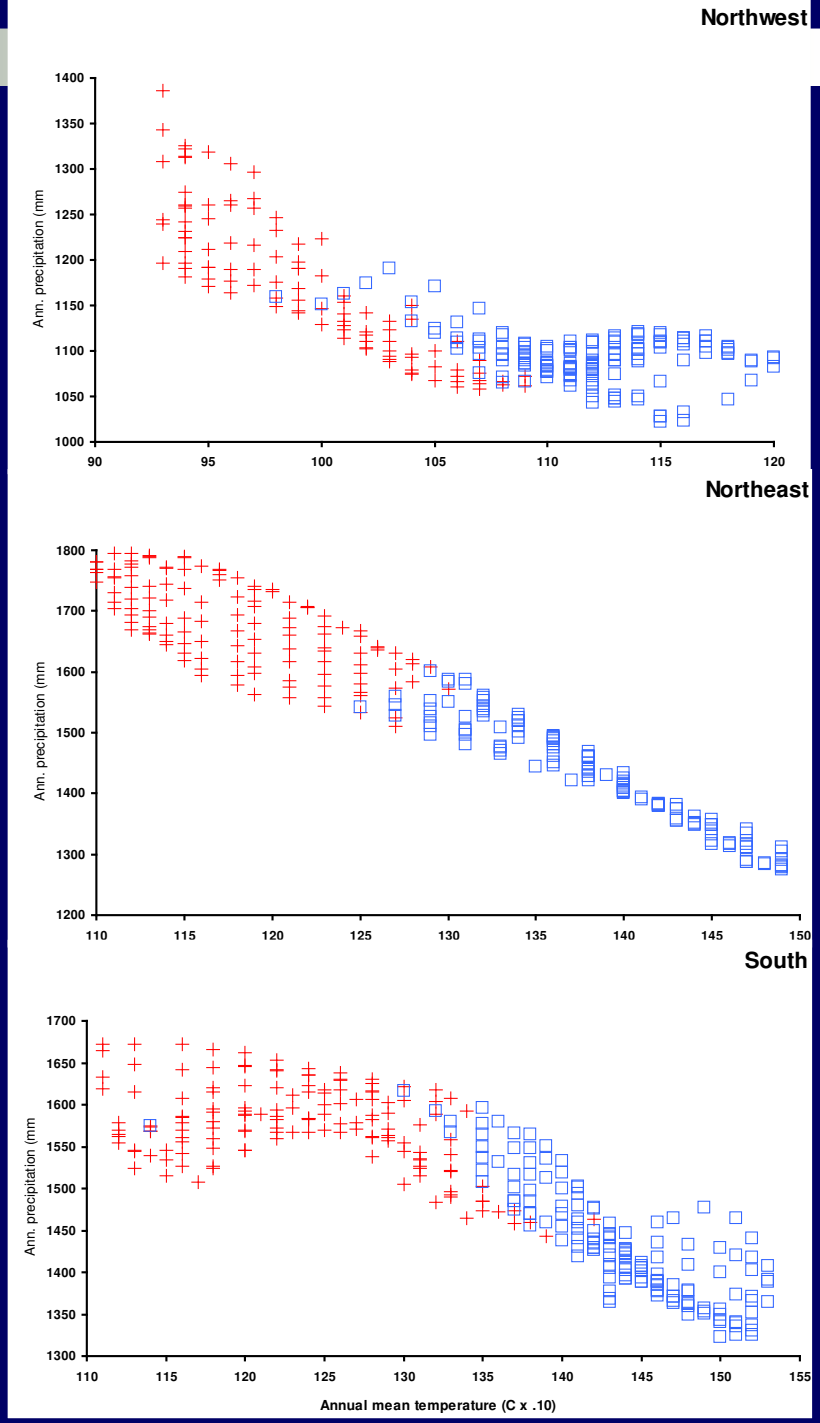
Ecological Niche Variable Ranges

	Areas of Known Occurrence	Areas of Predicted Favorable Environment
Mean annual precipitation	1500 – 2100 mm	500 – 3500 mm
Precipitation of wettest month	2000 – 2500	600 – 4500 mm
Mean annual temperature	21 – 26 ^{o}C	15 – 30 ^{o}C
Maximum temperature warmest month	30 – 34 ^{o}C	25 – 42 ^{o}C
Potential evaoptranspiration	80 - 120 mm	60 – 160 mm
Net primary productivity	800 – 1100 Kcal/ m^2/ year	100 – 1200 Kcal/ m^2/ year
Soil pH	5 – 6	5 – 7.5
Soil carbon	4 – 10 %	1 – 11 %

Characterizing Distributional Limits

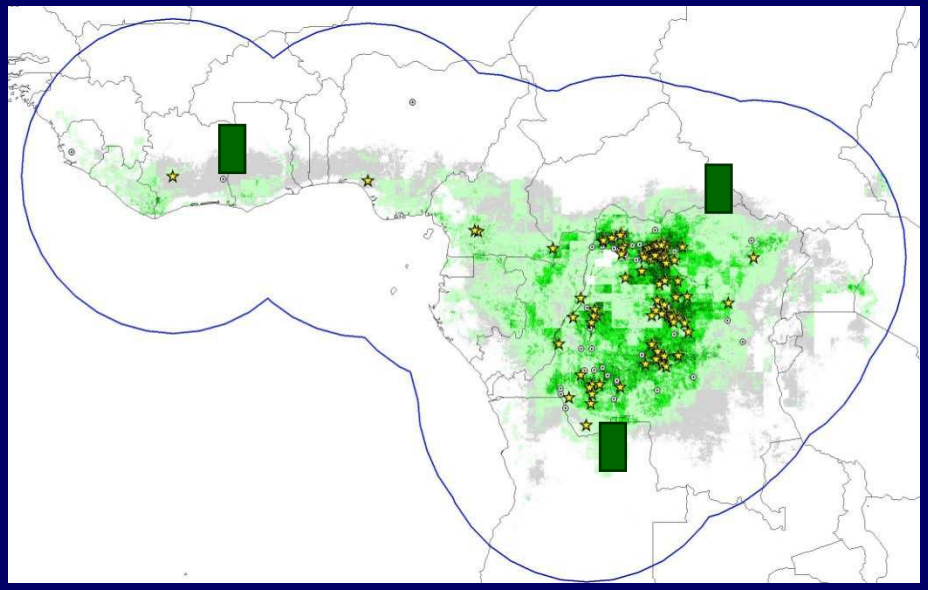
mean annual precipitation (mm)
vs.
mean annual temperature (ºC)

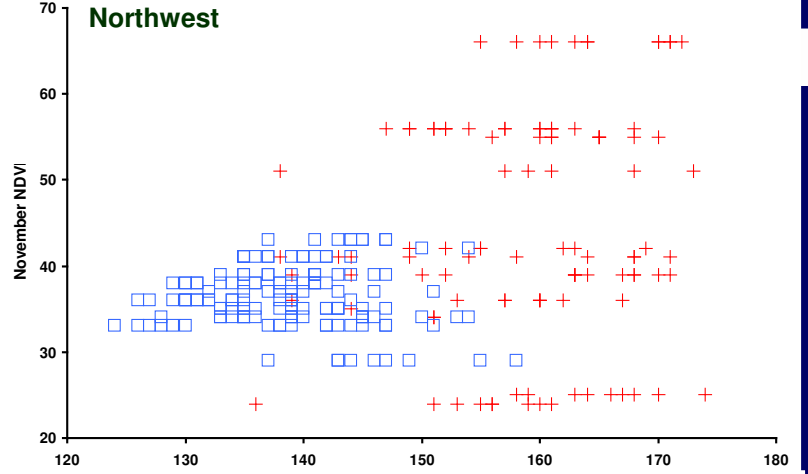


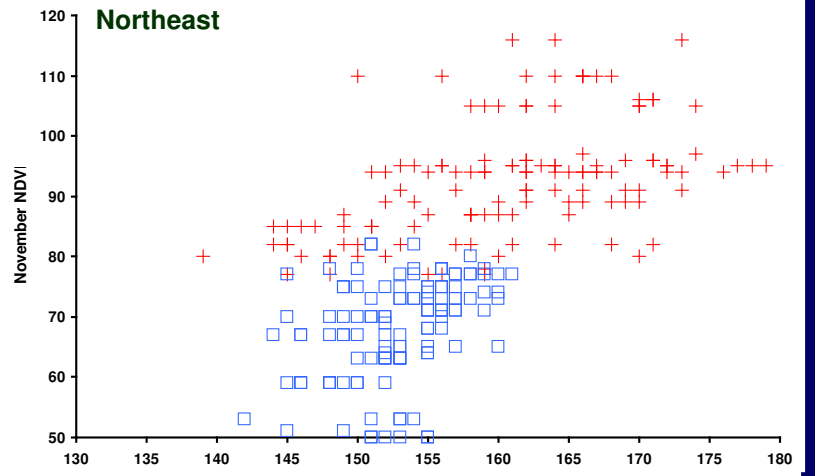


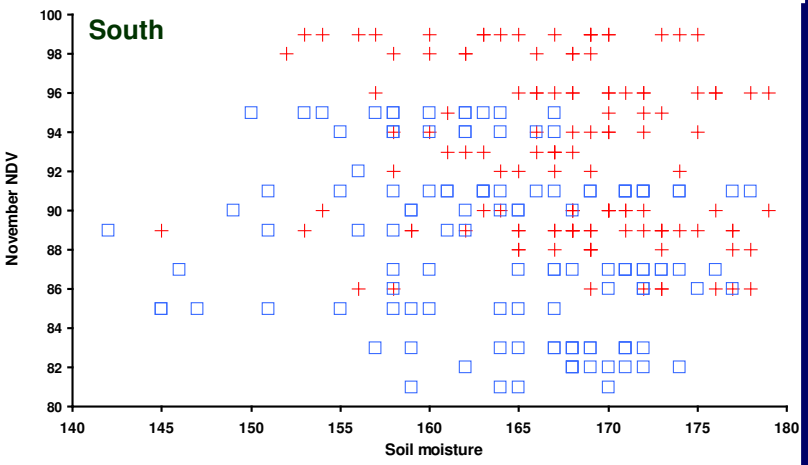
Characterizing Distributional Limits

November NDVI
vs.
soil moisture (mm)

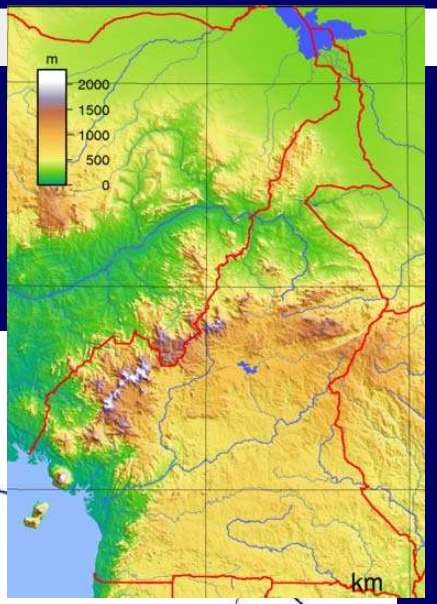








Monkeypox Ecology and Geography



- Restricted to humid lowland evergreen tropical forest
- Geographic break in eastern Nigeria – western Cameroon
- Geographic break separates 2 clades

Comparison with Previous Study

OPEN ACCESS Freely available online

PLoS one

Ecological Niche and Geographic Distribution of Human Monkeypox in Africa

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Monkeypox virus, a zoonotic member of the genus *Orthopoxviridae*, can cause a severe, smallpox-like illness in humans. Monkeypox virus is thought to be endemic to forested areas of western and Central Africa. Considerably more is known about human monkeypox disease occurrence than about natural sylvatic cycles of this virus in non-human animal hosts. We use human monkeypox case data from Africa for 1970–2003 in an ecological niche modeling framework to construct predictive models of the ecological requirements and geographic distribution of monkeypox virus across West and Central Africa. Tests of internal predictive ability using different subsets of input data show the model to be highly robust and suggest that the distinct phylogenetic lineages of monkeypox in West Africa and Central Africa occupy similar ecological niches. High mean annual precipitation and low elevations were shown to be highly correlated with human monkeypox disease occurrence. The synthetic picture of the potential geographic distribution of human monkeypox in Africa resulting from this study should support ongoing epidemiologic and ecological studies, as well as help to guide public health intervention strategies to areas at highest risk for human monkeypox.

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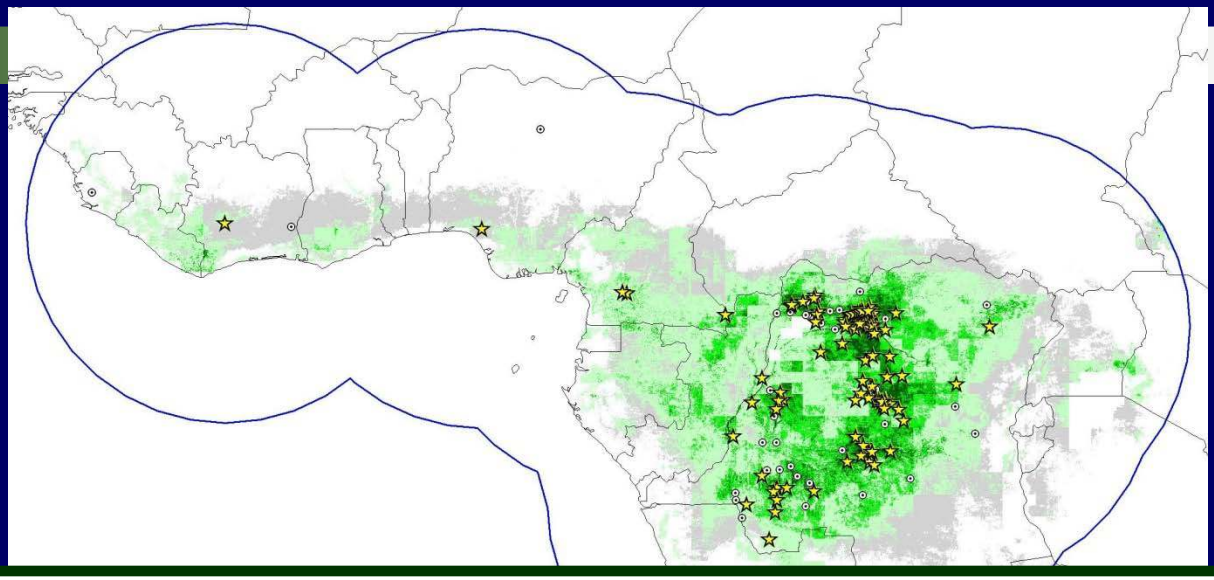
This study

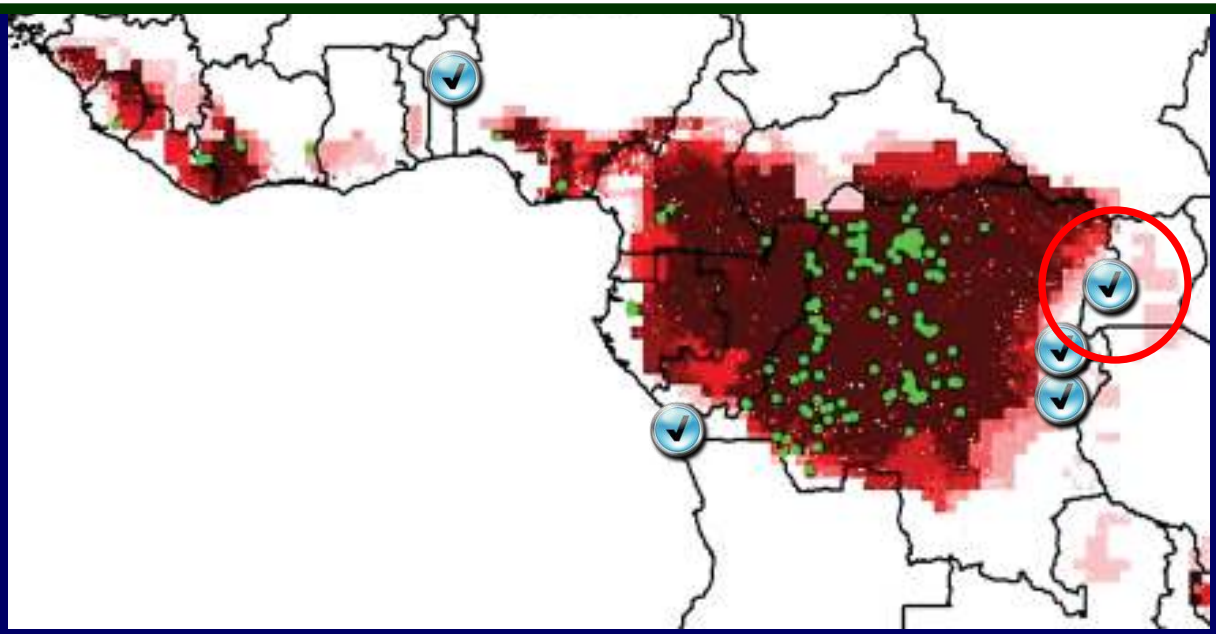


Serologic Evidence for Novel Poxvirus in Endangered Red Colobus Monkeys, Western Uganda

Goldberg TL et al

Emerging Infectious Diseases, May 2008, 14(5): 801-803

Levine et al.



Comparison with Previous Study

- Levine et al.
- Climate, topography, landcover
- 156 occurrences, no error "filter"
- Assessment of variable importance
  - Student's t-test
  - Kappa statistic

- This study
- Climate, soil, vegetation, NDVI
- 139 occurrences, used an error "filter"
- Assessment of variable importance
  - Jackknife

Summary

- Niche models are useful in identifying ecological parameters associated with disease occurrence

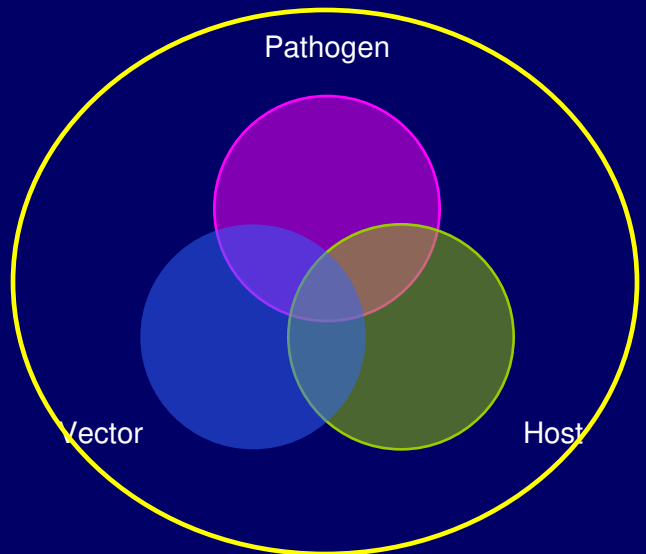
	Areas of Known Occurrence	Areas of Predicted Favorable Environment
Mean annual precipitation	1500 – 2100 mm	500 – 3500 mm
Precipitation of wettest month	2000 – 2500	600 – 4500 mm
Mean annual temperature	21 – 26 ^{o}C	15 – 30 ^{o}C
Maximum temperature warmest month	30 – 34 ^{o}C	25 – 42 ^{o}C
Potential evaoptranspiration	80 - 120 mm	60 – 160 mm
Net primary productivity	800 – 1100 Kcal/ m^2/ year	100 – 1200 Kcal/ m^2/ year
Soil pH	5 – 6	5 – 7.5
Soil carbon	4 – 10 %	1 – 11 %

Summary

- Niche model quality is affected by
  - Georeferencing methodology
    - Use of spatial precision filters
      - MaNIS point radius method
  - Quality and types of environmental data
    - Data sources
    - Statistical analysis

Summary

- Niche models have applicable and versatile uses in spatial epidemiology
  - Identify environmental characteristics associated with disease occurrence
  - Identifying Identify components of transmission cycle
  - Identify foci of disease occurrence



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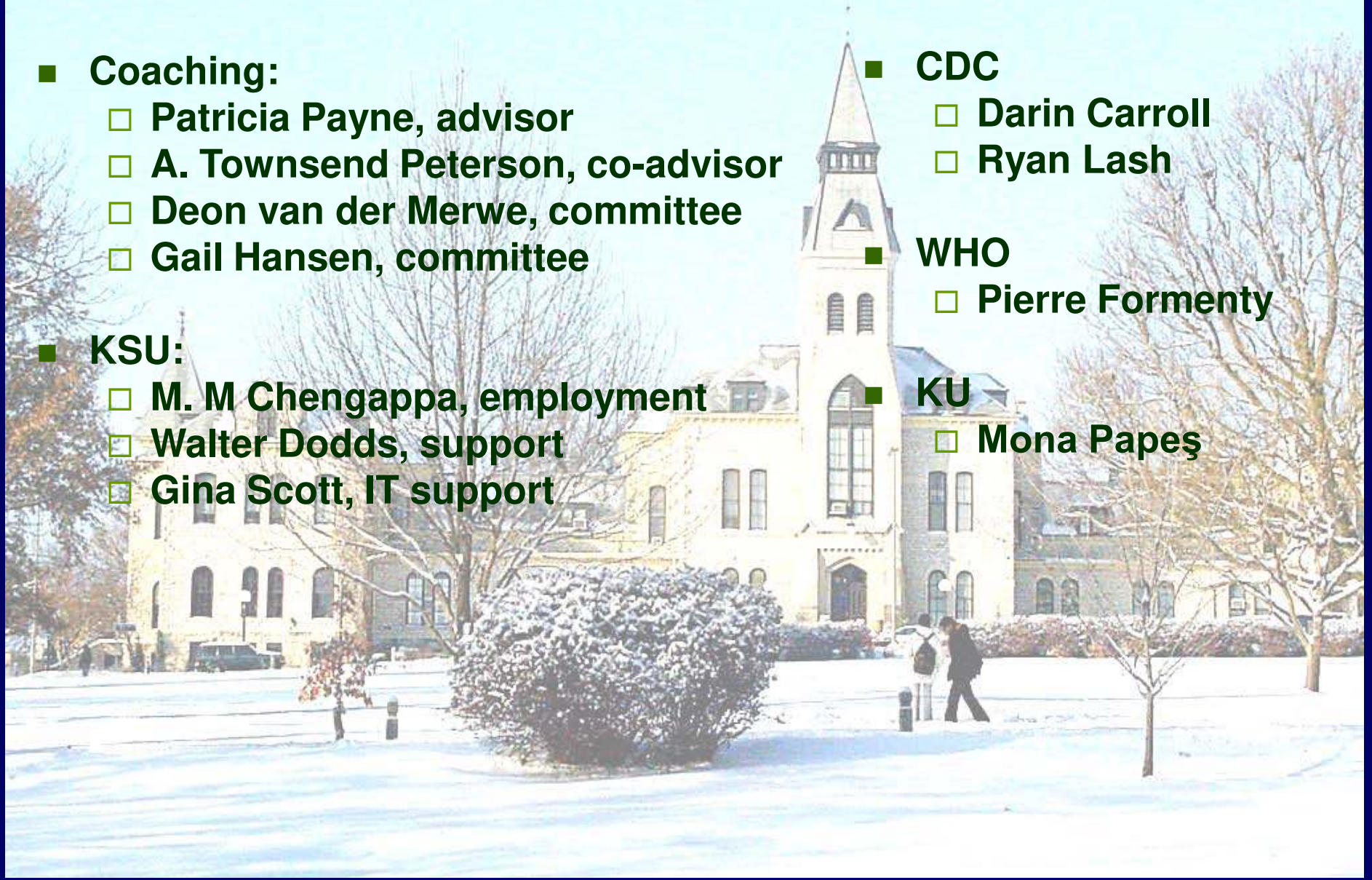

Questions?