National Center for Emerging and Zoonotic Infectious Diseases

Mapping Monkeypox risk in the Congo basin using Remote Sensing and Ecological Niche Models

Yoshinori Nakazawa, Andrea McCollum, Christine Hughes, Benjamin Monroe, Whitni Davidson, Kimberly Wilkins, Joelle Kabamba, Okitolonda Wemakoy, Beatrice Nguete, Jean-Jacques Muyembe Tamfum, Victoria Olson, Mary Reynolds

International Meeting on Emerging Diseases and Surveillance
November 2018

Monkeypox

- Described in 1958

  In humans in 1970
- *Poxviridae, Orthopoxvirus*
- Smallpox-like illness
  - Easily confused with varicella
- No treatment or cure
- Mortality rate ~10%
- Attack rate of ~5 per 10,000 population, although it has been reported to be as high as 14 per 10,000.

Damon, Roth, & Chowdhary 2006. NEJM 355(9):962-963
Rimoin *et al.* 2010. PNAS 107(7):16262-16267

Monkeypox

- Two recognized clades
  - Central African
  - Western African
- More pronounced morbidity, mortality, human-to-human transmission and viremia in Congo Basin clade.

Journal of General Virology (2005), 86, 2661–2672 DOI 10.1099/vir.0.81215-0

A tale of two clades: monkeypox viruses

Anna M. Likos,[1]† Scott A. Sammons,[1]† Victoria A. Olson,[1] A. Michael Frace,[1] Yu Li,[1] Melissa Olsen-Rasmussen,[1] Whitni Davidson,[1] Renee Galloway,[1] Marina L. Khristova,[1] Mary G. Reynolds,[1] Hui Zhao,[1] Darin S. Carroll,[1] Aaron Curns,[1] Pierre Formenty,[2] Joseph J. Esposito,[1] Russell L. Regnery[1] and Inger K. Damon[1]

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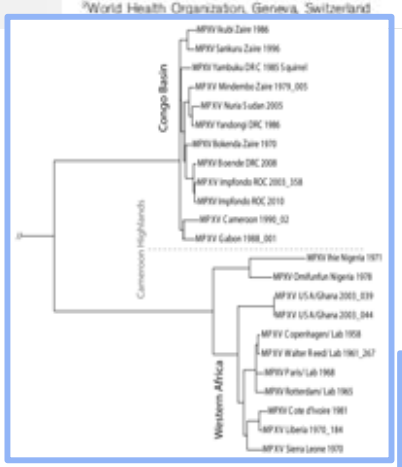
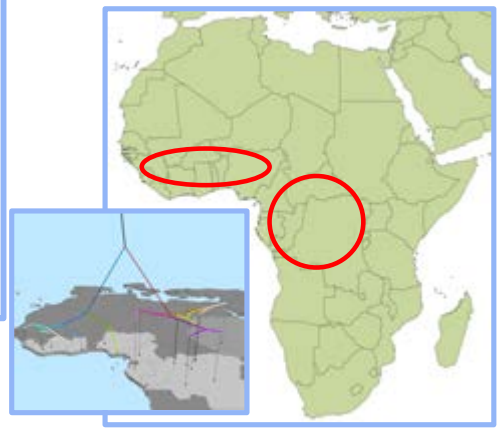




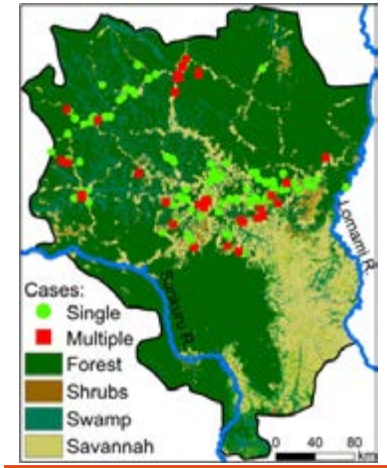
Bull. Org. mond. Santé
Bull. Wld Hlth Org.
1972, **46**, 569–576

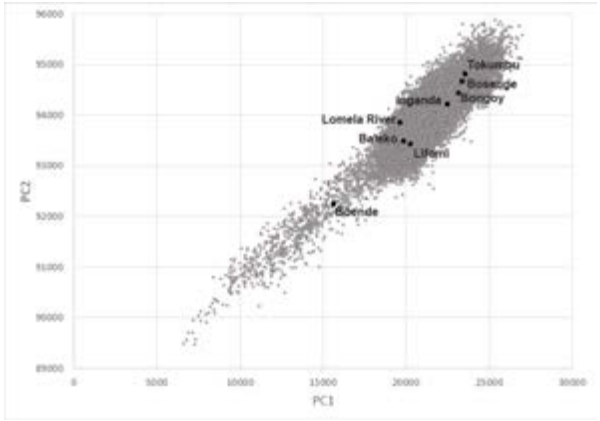
Human monkeypox *

STANLEY O. FOSTER,[1] EDWARD W. BRINK,[2] DEANE L. HUTCHINS,[3] JOHN M. PIFER,[4] BERNARD LOURIE,[5] CLAUDE R. MOSER,[6] EVELYN C. CUMMINGS,[7] O.E.K. KUTEYI,[8] REGINALD E. A. EKE,[9] J. B. TITUS,[10] E. ADEMOLA SMITH,[11] JAMES W. HICKS,[12] & WILLIAM H. FOEGE[13]

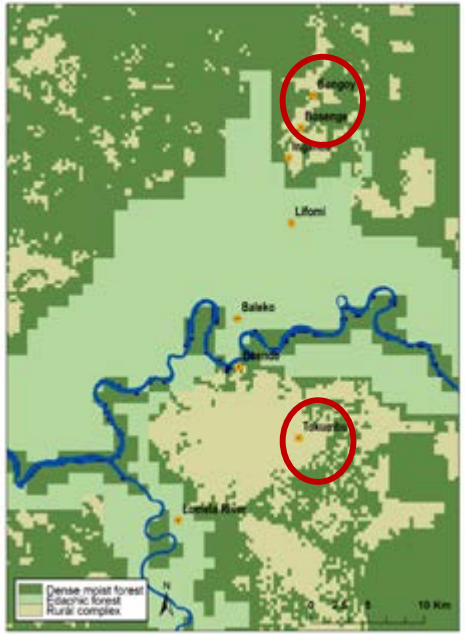
Monkeypox

- Associated with densely forested areas of central and west Africa
  - Potential difference between dense and seasonally or permanently flooded forest





Fuller *et al.* 2011. EcoHealth 8(1):14-25.



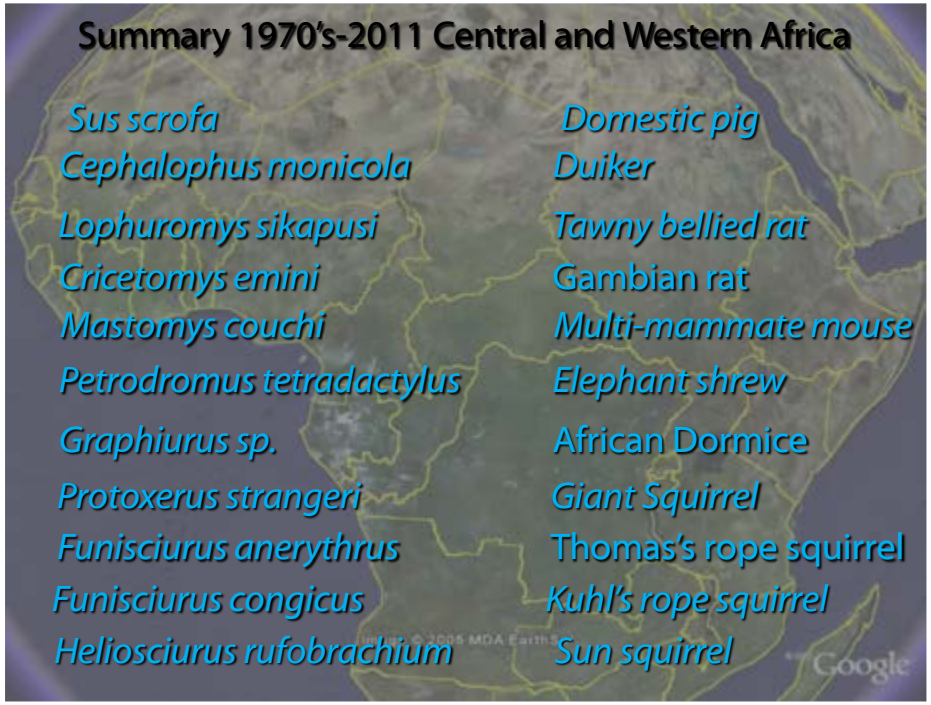
Doty *et al.* 2017. Viruses 9(10):283; doi:10.3390/v9100283.

Monkeypox

Dwarf dormice
Graphiurus murinus

Gambian giant pouched rats
Cricetomys gambianus

Rope squirrels
Funisciurus sp.



Sun squirrels
Heliosciurus sp.

Striped mice
Hybomys trivirgatus

Brush-tail porcupine
Atherurus africanus

Monkeypox

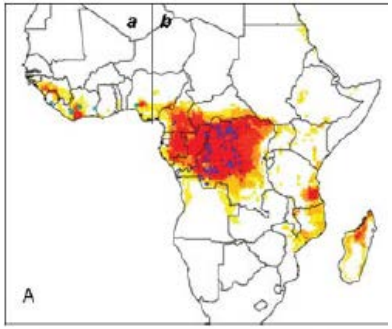
Phylogenetic and Ecologic Perspectives of a Monkeypox Outbreak, Southern Sudan, 2005

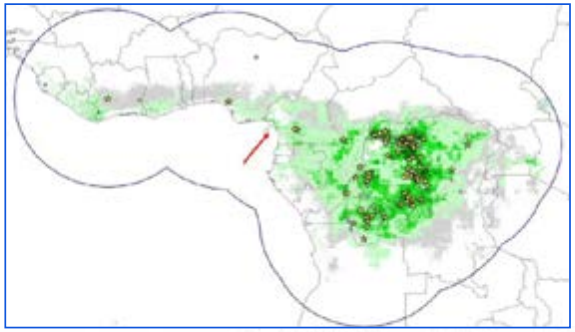
Yoshinori Nakazawa, Ginny L. Emerson, Darin S. Carroll, Hui Zhao, Yu Li, Mary G. Reynolds, Kevin L. Karem, Victoria A. Olson, R. Ryan Lash, Whitni B. Davidson, Scott K. Smith, Rebecca S. Levine, Russell L. Regnery, Scott A. Sammons, Michael A. Frace, Elmangory M. Mutasim, Mubarak E. M. Karsani, Mohammed O. Muntasir, Alimagboul A. Babiker, Langova Opoka, Vipul Chowdhary, and Inger K. Damon

OPEN ACCESS Freely available online PLoS one

Ecological Niche and Geographic Distribution of Human Monkeypox in Africa

Rebecca S. Levine[1], A. Townsend Peterson[2], Krista L. Yorita[3], Darin Carroll[1], Inger K. Damon[1], Mary G. Reynolds[1]*

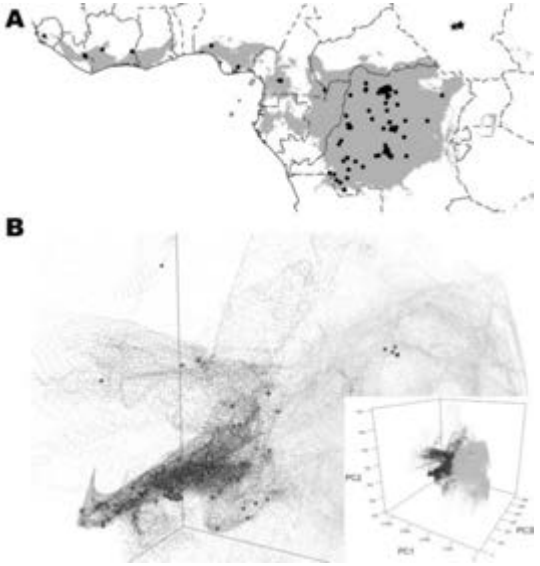




Journal of Wildlife Diseases, 48(2), 2012, pp. 335–347

ECOLOGY AND GEOGRAPHY OF HUMAN MONKEYPOX CASE OCCURRENCES ACROSS AFRICA

Christine K. Ellis,[1] Darin S. Carroll,[2] Ryan R. Lash,[2] A. Townsend Peterson,[3,6] Inger K. Damon,[2] Jean Malekani,[4] and Pierre Formenty[5]



Monkeypox

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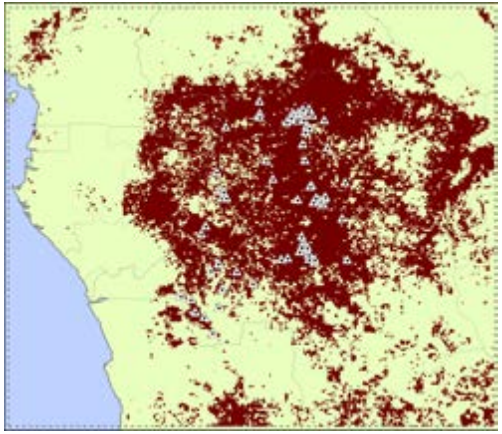
PLOS ONE

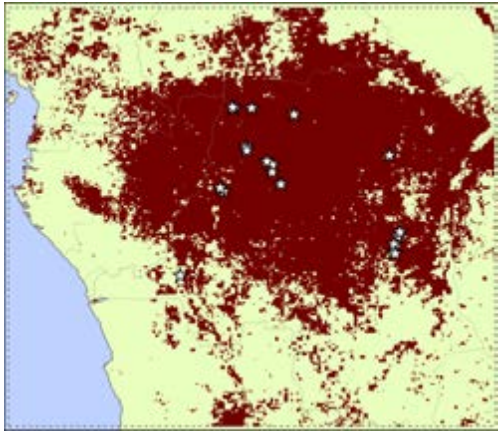
Mapping Monkeypox Transmission Risk through Time and Space in the Congo Basin

Yoshinori Nakazawa[1,2]*, R. Ryan Lash[1], Darin S. Carroll[1], Inger K. Damon[1], Kevin L. Karem[1], Mary G. Reynolds[1], Jorge E. Osorio[3], Tonie E. Rocke[4], Jean M. Malekani[5], Jean-Jacques Muyembe[6], Pierre Formenty[7], A. Townsend Peterson[8]

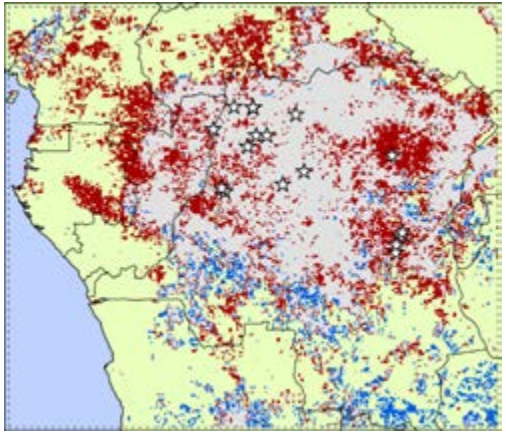
1982-1986



2002-2006



Difference



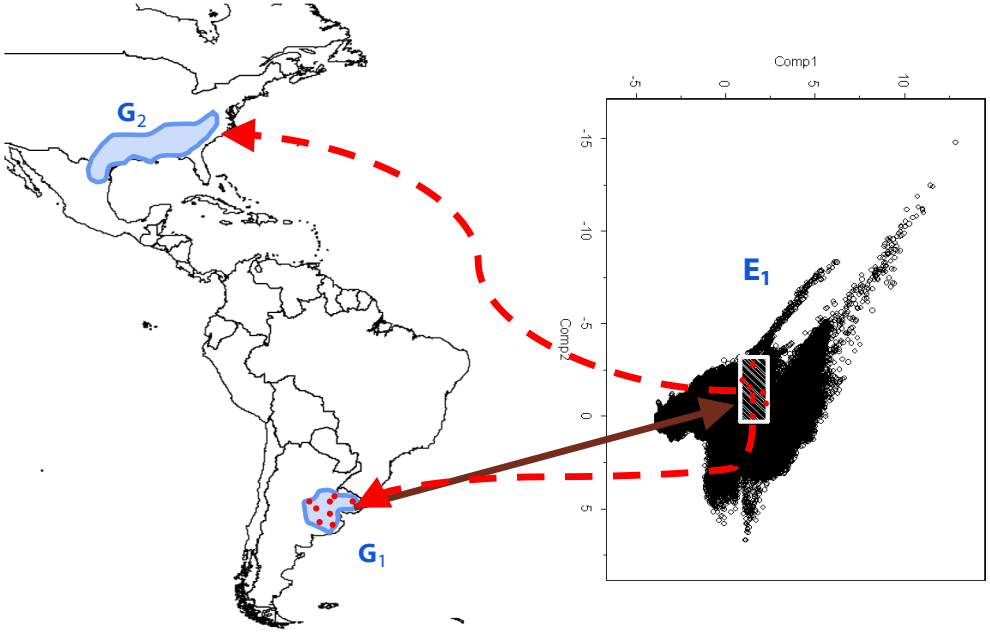
Built a model based on human cases and environmental conditions during the 80's and project it into environmental conditions during 2000's.

- Northward shift
- Possible expansion

Objectives

- Create models using recent disease reports and contemporary high (spatial/temporal) resolution environmental layers (RSIF and EVI).
- Create/update disease transmission risk maps for central Africa.
- Evaluate predictability of models based on two environmental datasets.

Ecological Niche Models



G-space

E-space

BIOCLIM (Envelope Model)
BRT (Boosted Decision Trees)
BRUTO (Regression)
GARP (Genetic Algorithm)
DOMAIN (Multivariate Distance)
GAM (Generalized Additive Model)
GDM (Generalized Dissimilarity Modelling)
GLIM (Generalized Linear Model)
LIVES (Multivariate Distance)
MARS (Multivariate Adaptive Regression Splines)
MAXENT (Maximum Entropy)

Peterson et al. 2006 J Mammal. 87(3):427-432

Disease data

- Monkeypox surveillance in Tshuapa District
- Case localities are reported and geocoded to the village
  - Gazetteers, maps and geographic data collected in the field
- Unique localities were extracted
- Test for predictivity using diagonals
- Random subsets to reduce effects of spatial autocorrelation

P1	17	**P7**	14
P2	18	**P8**	13
P3	35	**P9**	25
P4	25	**P10**	12
P5	28	**P11**	13
P6	15	**P12**	6

Environmental data

- Reconstructed Solar-Induced Fluorescence (RSIF)
  - 2002-2016 – 8-day composites
  - 4-week summary statistics (maximum, minimum, mean, range)
  - Spatial resolution ~5km

- Enhanced Vegetation Index (EVI) – MODIS
  - 2011-2014 – monthly maximum value composites
  - Summary statistics calculated (max, min, mean, range)
  - Spatial resolution ~1km

Maxent

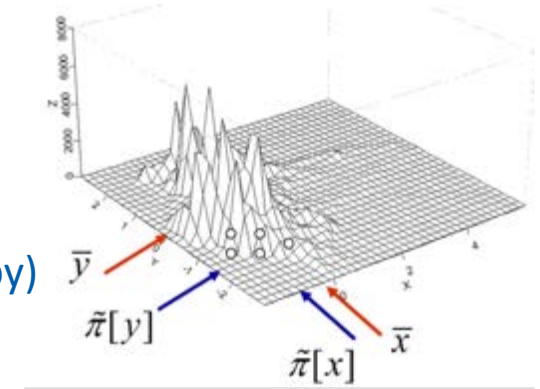
Available online at www.sciencedirect.com
SCIENCE DIRECT
Ecological Modelling 190 (2006) 231–259
ECOLOGICAL MODELLING
www.elsevier.com/locate/ecolmodel

Maximum entropy modeling of species geographic distributions

Steven J. Phillips[a,*], Robert P. Anderson[b,c], Robert E. Schapire[d]

- Presence-only algorithm
  - Pseudo-absences selected from background.
- Uses the maximum entropy concept to estimate probabilities based on environmental conditions at the occurrence localities

- The core of idea of maxent is:
- Find the probability distribution that:
  - 1) Have the same means of features as the observed means
  - 2) It is as flat as possible (maximizes entropy)



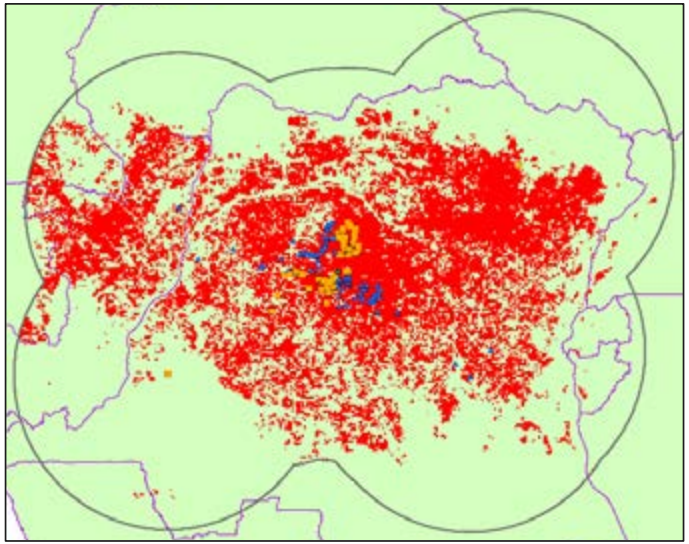
ENMs

- Occurrence data
  - Diagonals ON (training) and OFF (testing); using median latitude and median longitude
  - Unique occurrences → 25 subsets based on 10Km radius
- Environmental data
  - Clipped using a 500km buffer from the localities
  - A combination of maximum, median minimum and range values if RSIF and EVI
- Threshold: 5% omission allowed
- 25 maps aggregated into final map

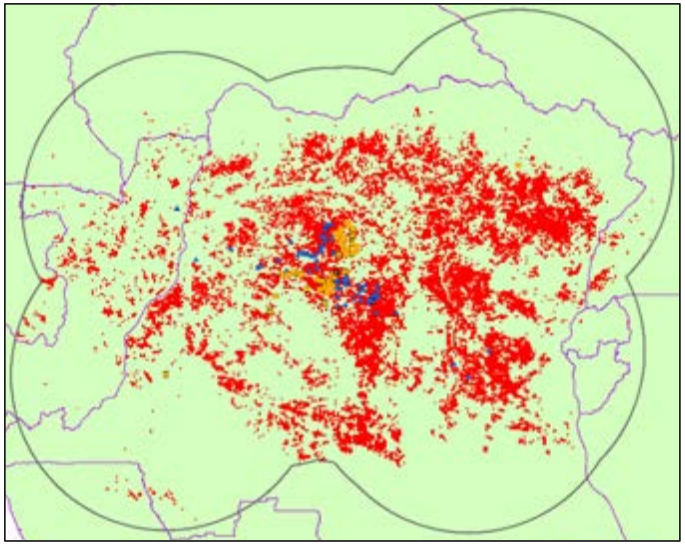
Results

ON Diagonal = Training (blue triangles)
Environmental data = mean, min, max, range in the entire year

ENM RSIF
ON AUC = 0.884388
ON AUC test = 0.857688



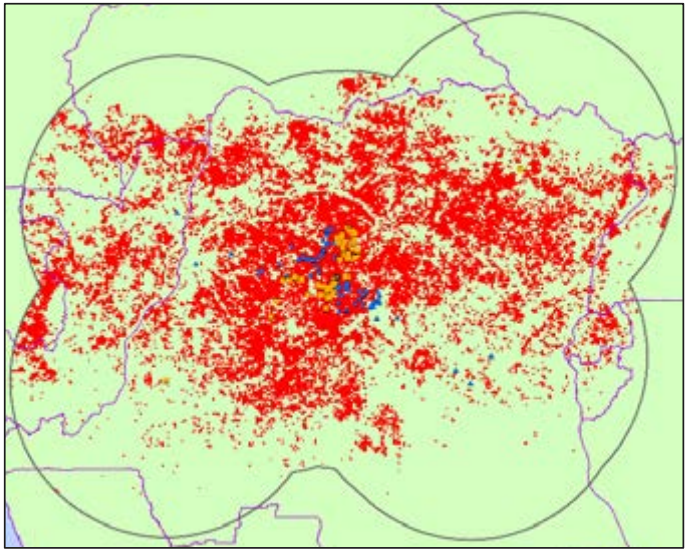
ENM EVI
ON AUC = 0.95572
ON AUC test = 0.92248



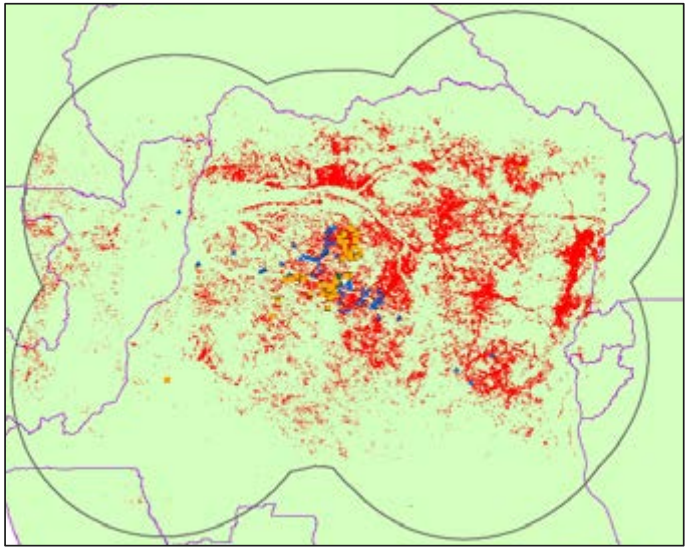
Results

ON Diagonal = Training (blue triangles)
Environmental data = maximum values of 4week periods

ENM RSIF (max)
ON AUC = 0.943276
ON AUC test = 0.784952



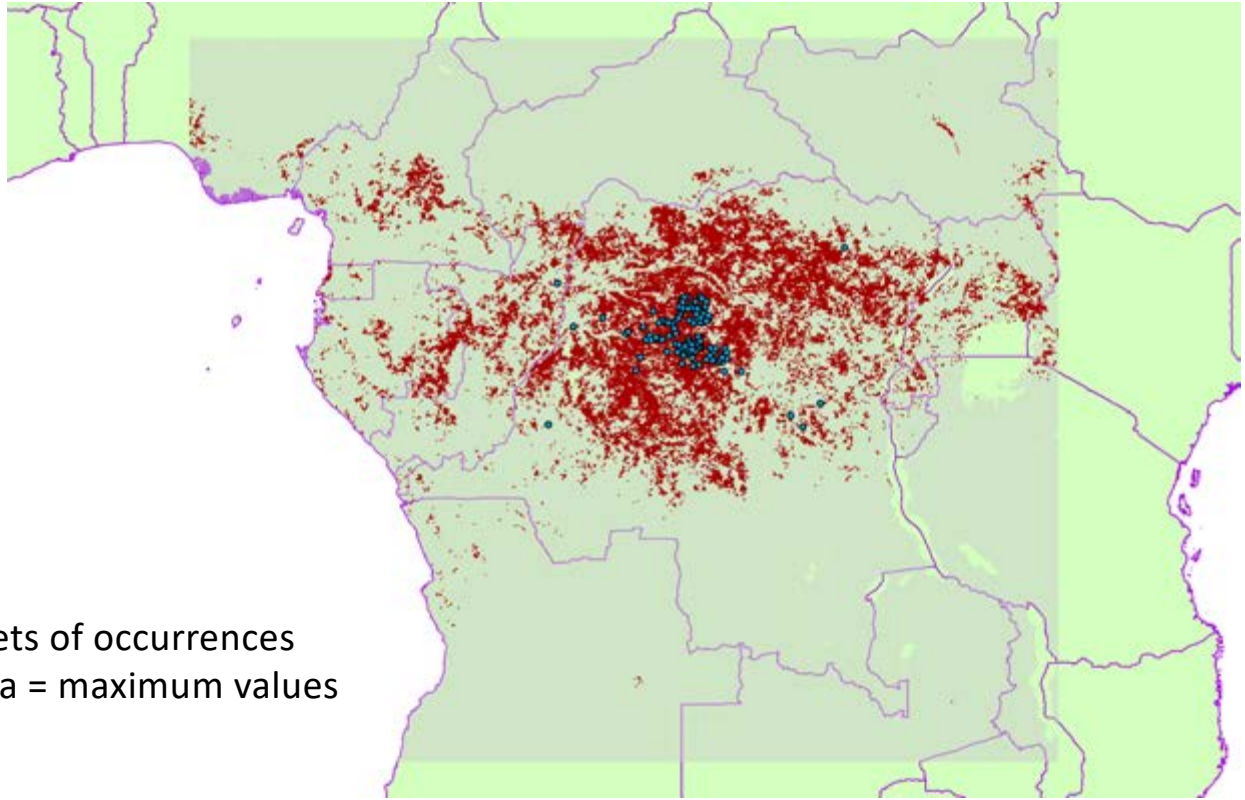
ENM EVI (max)
ON AUC = 0.931164
ON AUC test = 0.891428



Results

ENM_RSIF (max)

- Period 7
- Period 1
- Period 12
- Period 8
- Period 11



Training – 25 subsets of occurrences
Environmental data = maximum values of 4week periods

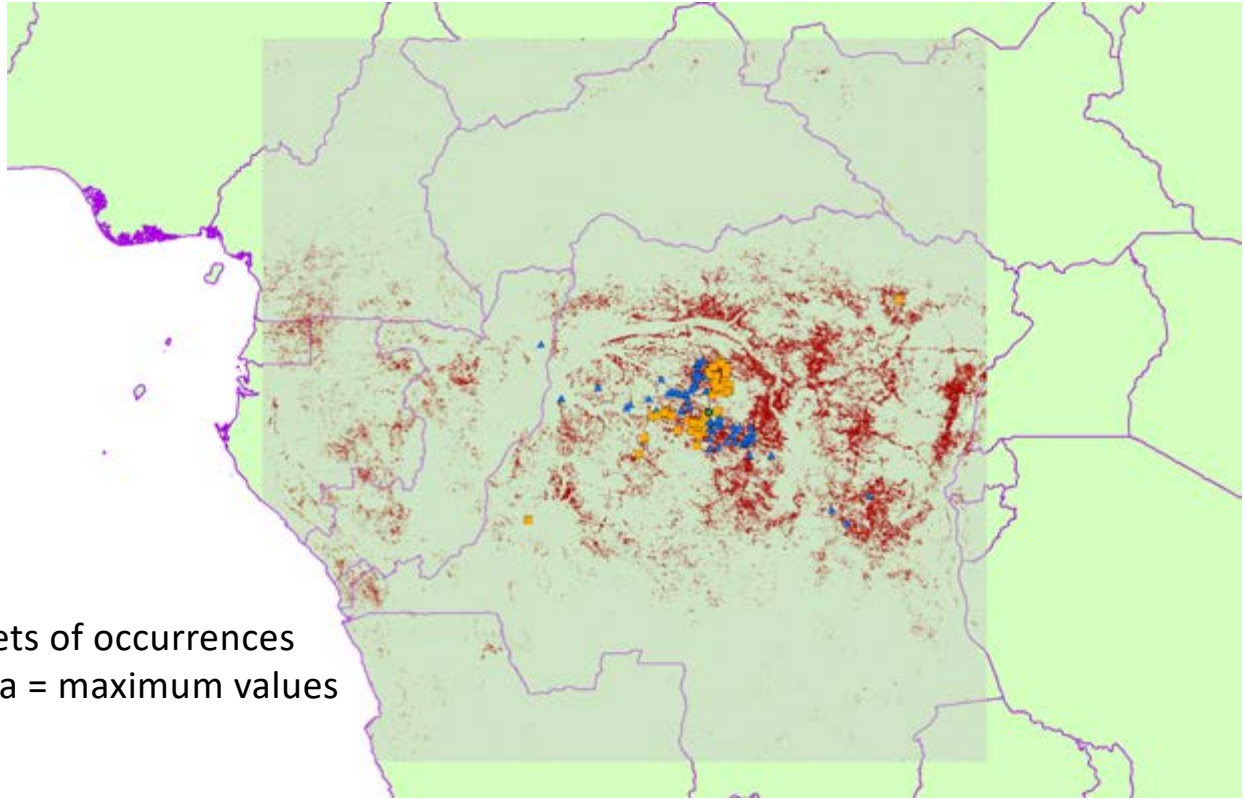
Results

ENM_EVI (max)

- December
- October
- May

- July
- March

Training – 25 subsets of occurrences
Environmental data = maximum values of 4week periods



Conclusions and Future Work

- Better predictive ability for cases outside of Tshuapa when using RSIF; possibly related to spatial resolution
- Possible associations with environmental conditions at specific time periods
- Explore temporal/seasonal associations between MPX cases and climatic/environmental variables.

Thank you!

For more information, contact CDC
1-800-CDC-INFO (232-4636)
TTY: 1-888-232-6348 www.cdc.gov