Disentangling the ecological conditions favoring West Nile virus hazard in the Old World

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Introduction: WNV Biological Cycle

“By far, the most widely distributed arbovirus, isolated in all Continents apart from Antarctica”

“Emergence and spread of new lineages, and increased pathogenicity, is the cause of escalating public health concern”

< 1% Neurological disease
~ 20% West Nile Fever
~ 80% Asymptomatic

“No human vaccines available”

“Prevention currently depends on organized, sustained vector control campaigns and risk communication”
2,248 WNF human cases in Europe and neighbourhood countries from 2010 to 2012 reported by ECDC from 146 areas defined at the NUTS3/GAUL1 level.
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Introduction: Aims

Modelling WNF incidence in the Old World to identify the *environmental* conditions associated with occurrence in *humans*.

By identifying *key environmental drivers* of WNF, we aim to *lay the foundations* for the development of statistical models able to *predict* WNF risk at a *continental* scale.
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Methods: Workflow

Data preparation and screening

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Model selection and Multimodel Inference

Candidate models:

Null model  →  Full model

Variables varying in time (T,R,NDVI, NDWI)

Temporal windows for average and anomalies

Log-transformation of the response variable (Incidence)

AICc to select the best temporal window

AICc to select the best variables in each group

Full Linear Model using variables arising from pre selection

Full IC-based approach with some constraints (GLMULITI)

Computation of the relative evidence weight of each model term (AICc ≤ 4)

BEST PREDICTORS IDENTIFICATION
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Methods: Data preparation and pre-selection of predictor variables

Response variable:
- WNF Annual incidence (Number of cases / Population) * 100,000; NUTS3

Predictor variables:
- Temperature (multitemporal windows)
- Precipitation (multitemporal windows)
- Vegetation Index (multitemporal windows)
- Water Index (multitemporal windows)
- Land use (Glob Cover)
- Human footprint (Anthromes)
- Human population (VIIRS)
- Bird abundance (GBIF)
- Protected areas (UNEP)
- Water Body (OpenStreetMap)
- Landscape evenness index

Variables varying in time (T, R, NDVI, NDWI)

Fixed variables (land use, bird records, landscape fragmentation and heterogeneity, urbanization)

Correlation analysis

Log-transformation of the response variable (Incidence)

AICc to select the best temporal window

AICc to select the best variables in each group

Multi-temporal windows

4-months

WNF Annual incidence (NUTS3) ~ Temporal window

\[ n = \text{AICc value} \]
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Methods: Model selection and Multimodel Inference

- **Linear Mixed-effect Model** (LMM) to consider the clustering of incidence in districts and years.
- Running LMMs with all possible combinations of predictors.
- **Ranking** LMMs using AICc (**Multi model selection**).
- Selection of all LMMs in $\Delta$AICc < 4 (Statistically very similar; model-selection uncertainty).
- **Classify** the predictors using the “Relative Importance Weight”.
- **Averaged predictor coefficients** and confidence intervals using all the models in the best set (**Multi model inference**).

Model selection and Multimodel Inference
(Burnham and Anderson 2002)
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**Results: Best Model, Best models set, Best predictors set**

\[
\text{Imer}(\log(\text{Incidence}) \sim \text{Anomaly Precipitation 2-5} + \text{Average NDWI 4-7} + \text{Pielou} + \% \text{Populated forest} + \% \text{Cropland} + (1|\text{YEAR}) + (1|\text{REGION}))
\]

| Model | Params | AICc  | \( \Delta_i \) | \( L(g_i|x) \) | \( w_i \) | ER  |
|-------|--------|-------|----------------|----------------|----------|-----|
| 1     | 9      | 617.42| 0.00           | 1.00           | 0.22     | 1.8 |
| 2     | 10     | 618.60| 1.16           | 0.56           | 0.12     |     |
| 3     | 10     | 618.86| 1.44           | 0.49           | 0.11     |     |
| 13    | ...    | ...   | 4              | ...            | ...      |     |

- \(~ 100\) initial potential predictors.
- \(14\) predictors in the LMM.
- Relatively little evidence for the best model.
- \(13\) models in the best model set.
- \(9\) predictors in the best models set:
  1. \% cover of irrigated croplands +
  2. Precipitation in late winter/early spring +
  3. \% cover of populated forests +
  4. Landscape evenness index -
  5. Summer average water index -
  6. \% cover of protected areas +
  7. Summer average temperature +
  8. \% cover of water bodies -
  9. \% cover of mixed natural vegetation -

- Predicted vs. Observed \( R^2 = 0.32 \)
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Discussion

- **General discussion**
- **High importance** of both climate and land use variables.
- Other variables less relevant (e.g. bird abundance, NDVI, human population density).

- **Climatic conditions**
  - **Late winter-early spring precipitation anomalies.** Suitable ecological niches (accumulation of high amount of ground water).
  - **Summertime temperature.** High temperature speeds up mosquito population dynamics and virus replication.
  - **Summer NDWI.** Summer drought condition may create localized habitats (small remnant ponds?) where mosquitoes and birds may gather together.

- **Land use and landscape structure**
  - **Populated forests.** Environmental gradients might enhance virus spill over from sylvatic cycle (exposure to infected mosquitoes).
  - **Irrigated croplands and water bodies** may favour the concomitant presence of mosquitoes, birds and humans in the same place.
  - Pielou index – Landscape Evenness has a negative effect. The more even is the landscape the lower WNV incidence (i.e., populated forest low even).
Conclusions and Future Research

➢ **First attempt** to model WNF incidence at continental scale in Europe.

➢ **Both climate** and **land use** should be considered as predictors for WNV hazard at **large spatial scale**.

➢ Land uses that allow the **co-occurrence of vector and hosts** are key for the virus circulation.

➢ Large-scale study can be better understood if **fine-scale data** are available and the same hypotheses tested on them.

➢ Inclusion of other variables such as **birds migration routes** and **socio-economical indicators**.

➢ **Bayesian Inference** could improve the model performance allowing the inclusion of prior knowledge.
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Overview

- Landscape Ecology
- Remote Sensing
- Modelling
- Epidemiology

Public Health
Thanks!

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Questions? Suggestions? Comments?