The effects of climate on the epidemiology of plague in Madagascar

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Presently 38 countries in Asia, Africa and America report human plague cases. Most cases annually reported from the African continent. Within the African countries, 60% of all cases reported from Madagascar and Tanzania.
Epidemiology of plague...

... in Madagascar
Climate
- Humidity
- Precipitation
- Temperature

Micro-Climate
- Desiccation
- Flooding
- Temperature Fluctuation

Flea Vector
- Reproduction rate
- Development rate
- Adult longevity

Flea vector habitat & Pathogen environment

Rodent host parasite burden
Proportion of infected rodents

Flea vector density

Pathogen within vector
- Pathogen survival
- Pathogen multiplication

Flea vector infection rate
Climate and plague

Climate effects on plague are not obvious and direct as with malaria

Madagascar is affected by:
- El Niño Southern Oscillation (ENSO)
- Indian Ocean Dipole (IOD)
- Frequent cyclones
Climate analysis

El Niño event => drier and warmer conditions than usual 12 months later (the hot season gets hotter)

Positive IOD => warmer conditions than usual 1-2 months later (the cold season gets warmer)

Significant correlations in time frequency space
- ENSO and plague
- IOD and plague

El Nino => decreased plague incidence 9-12 months later

Positive IOD => increased plague incidence 1-2 months later

Interplay can result in plague epidemics
ENSO and plague incidence

Figure: Phase angle evolution of JMA and incidence anomalies with 2-5 year periodicity. The red line represents incidence anomalies, the blue line the ENSO index. The x-axis is the wavelet location in time. The y-axis denotes the phase angles.
Summary of climate analysis

Global climate:

- El Niño Southern Oscillation affects human plague in Madagascar
- The Indian Ocean Dipole affects plague incidence from the 1990s
- There is a non-stationarity in the relationship
Spatial analysis of plague incidence and environmental variables

1. Absence – Presence
   Maximum Entropy model

2. Magnitude of incidence
   Linear regression model

MODIS variables:
- NDVI
- EVI
- MIR
- dLST
- nLST
- Altitude

Districts reporting plague from 1975 to 2008
Maximum Entropy

Model performance

Response curve of the NDVI to plague presence

Response curve of altitude to plague presence

Response curve of dLST to plague presence
Absence – Presence

Altitude is positively correlated with plague presence in districts

NDVI is negatively correlated (peak timing of triannual cycle)

dLST is positively correlated (peak timing of biannual cycle and variation)

nLST is positively correlated (peak timing of biannual cycle)

Magnitude of incidence

nLST is negatively correlated

dLST is negatively correlated

EVI is positively correlated

MIR (amplitude) is positively correlated

Spatial analysis of plague incidence and environmental variables
### Effects on...

<table>
<thead>
<tr>
<th>Pathogen</th>
<th>Vector</th>
<th>Rodent Host</th>
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</thead>
<tbody>
<tr>
<td>- Temperature</td>
<td>- mortality</td>
<td>- Mortality</td>
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<tr>
<td>- survival</td>
<td>- survival</td>
<td>- Habitat</td>
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<tr>
<td>- development</td>
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</table>

**Human host**
- migration
- poverty
- crop choice
- housing conditions
Study location
Micro-climate

• It is warmer and less humid indoors
• Temperature values are very similar between house burrows and outside burrows
• Humidity values show large differences
*Sf* is more abundant in the cold months July and September, while *Xch* is most abundant in November... is the endemic *Sf* adapted to the colder highlands?
Laboratory data

- Larvae of the endemic *Sf* pupate on average 8.5 days later
- At individual temperatures humidity affects development
- No consistent effect of humidity across the range of temperatures
- Humidity seems to affect *Sf* more
Laboratory data

*Sf* larvae have a 43% higher mortality rate than *Xch*

*Sf* larvae which do not pupate live longer than *Xch* larvae which do not pupate

**Endemic Sf**

**Ubiquitous Xch**
Combining field and laboratory data

The larvae of *Sf* take longer to develop than *Xch* except in an outside burrow during July.
Summary of vector study

Vector presence all year round

Vectors link the exterior focus with houses – human infection

*Synopsyllus fonquerniei* (endemic)

*Sf* have a slight advantage in summer
Conclusion

- Temperature and humidity affect the vectors Plague season onset
- All year round vector cover and transmission cycle is only in the highlands Altitudinal threshold
- Host burrow climate differs between indoor and outdoor Different habitats favoured at different times of the year
Overall conclusions

- Climate does affect human plague incidence in Madagascar. Global climate drivers such as El Niño and the Indian Ocean Dipole influence the epidemiology of plague.
- Spatial analysis identified altitude and environmental variables such as vegetation cover and temperature as predictors of presence and absence of plague and magnitude of incidence.
- Evidence suggests that temperature and humidity have a significant effect on both flea vectors.
- This implies that climate and environmental variables have an impact and could be used as warning and forecasting tools in a country with very limited resources.
Acknowledgements

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Questions?
## Environmental variables

<table>
<thead>
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<th>Variable</th>
<th>Feature</th>
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<tbody>
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