UNIVERSITY OF LIVERPOOL

INSTITUT PASTEUR DE MADAGASCAR

The effects of climate on the epidemiology of plague in Madagascar

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LUCINDA

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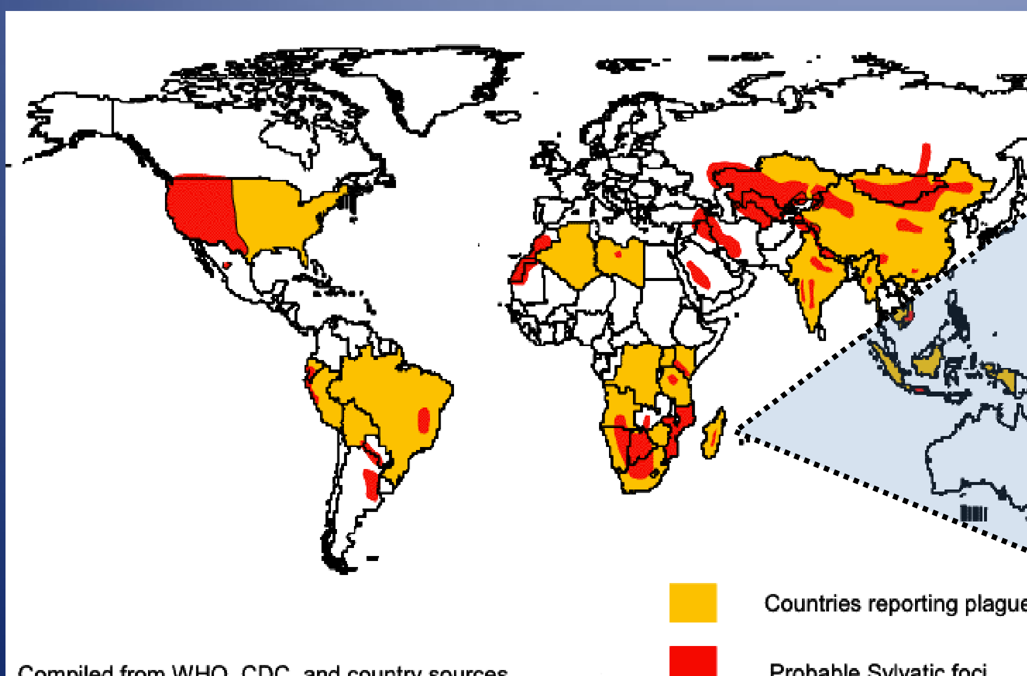
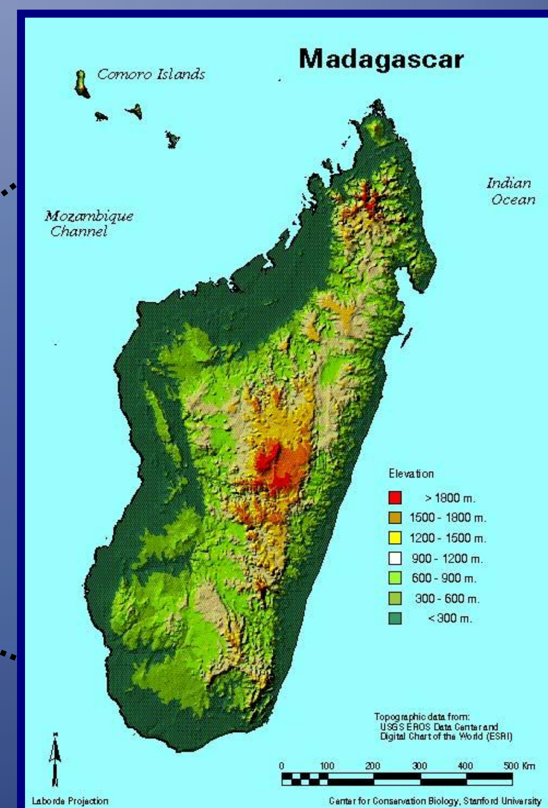
Human Plague

Presently 38 countries in Asia, Africa and America report human plague cases

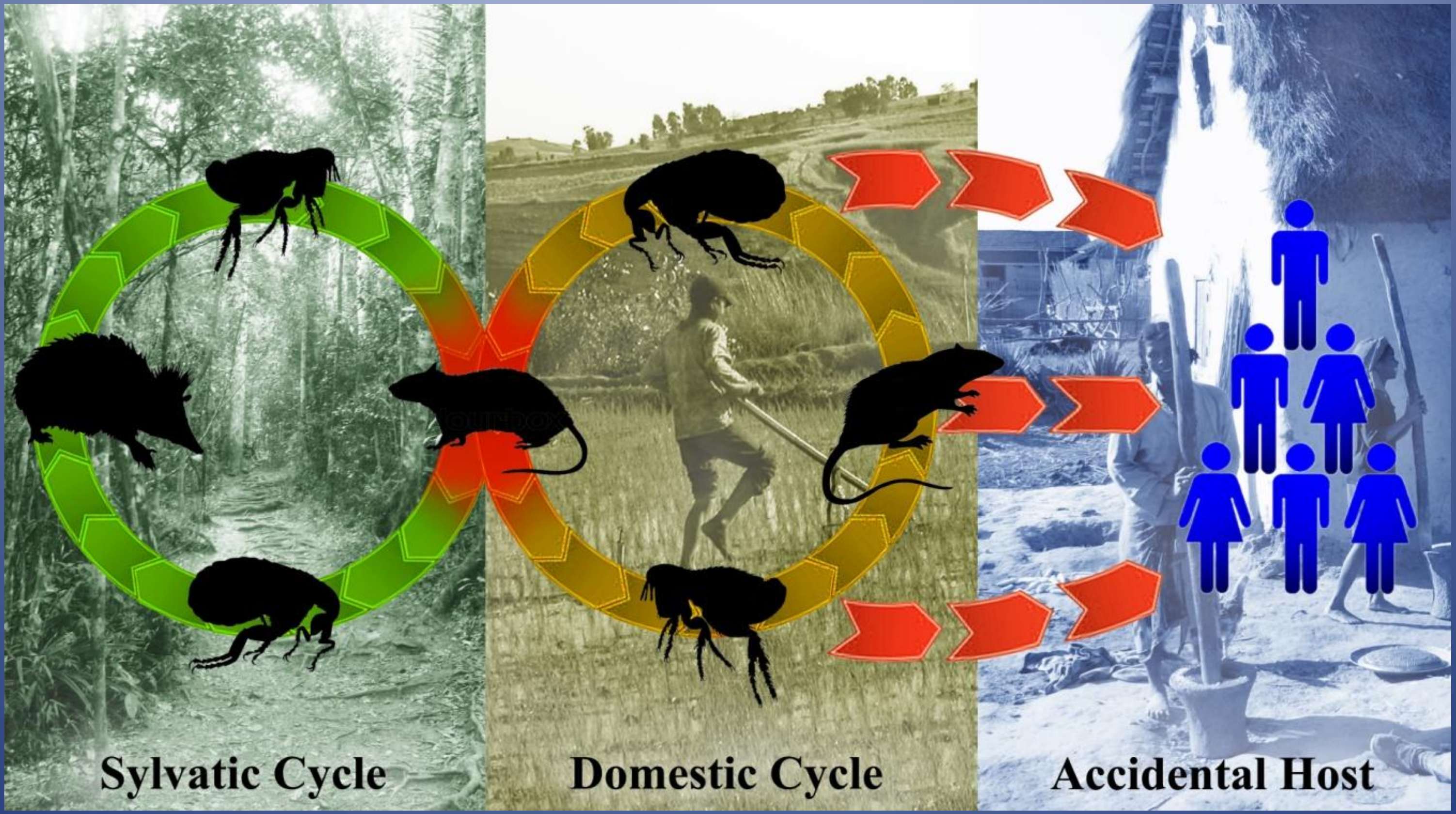
Most cases annually reported from the African continent

Within the African countries 60% of all cases reported from Madagascar and Tanzania

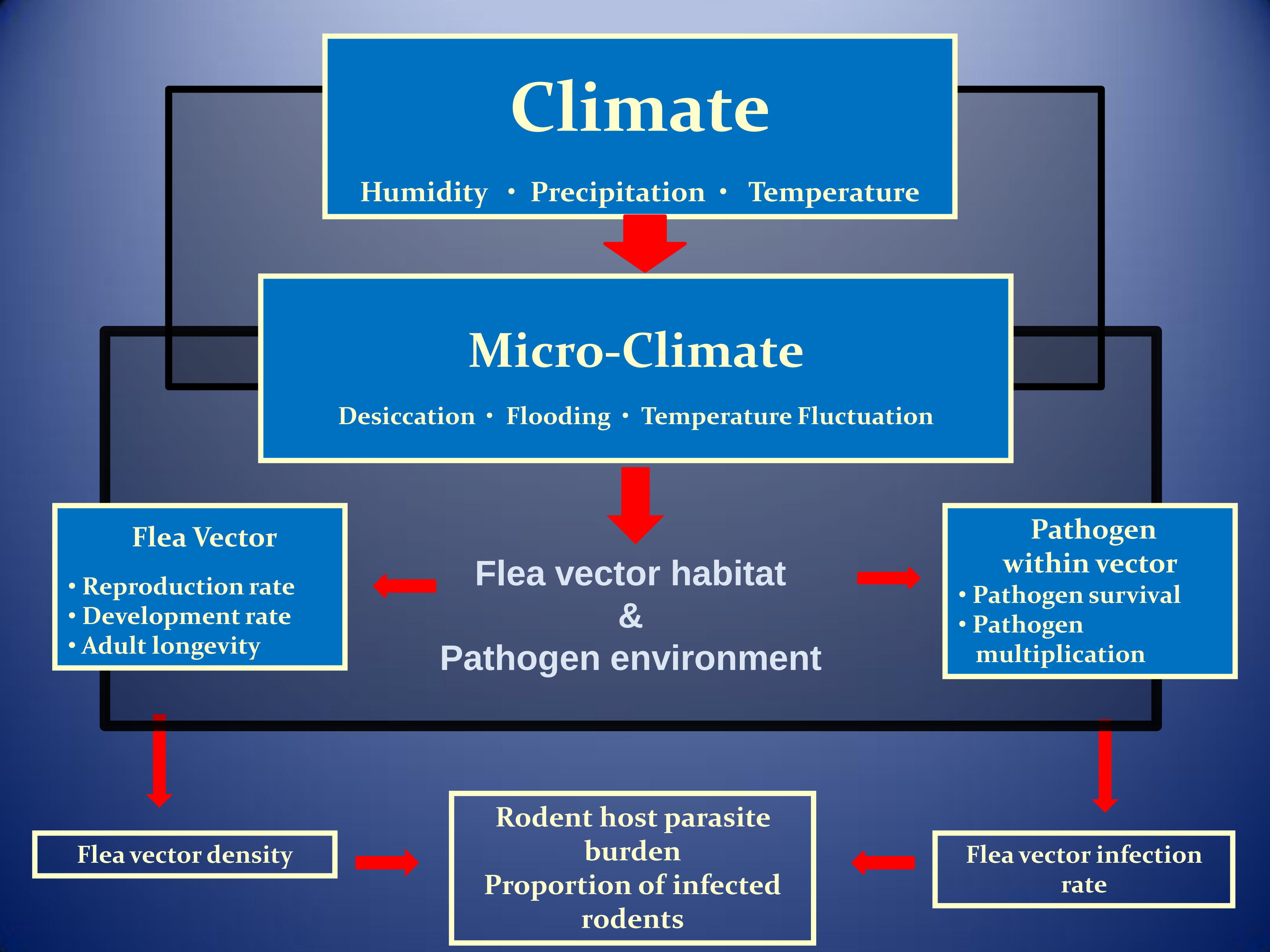




Epidemiology of plague...

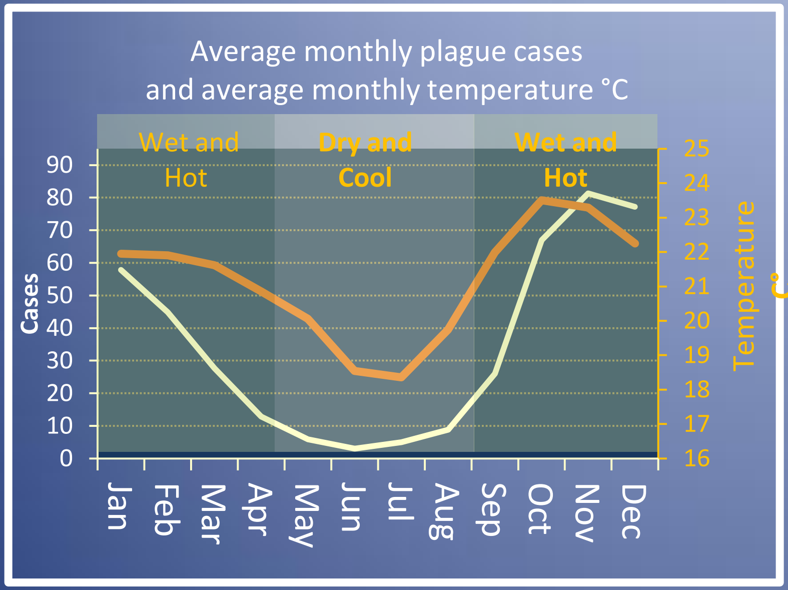


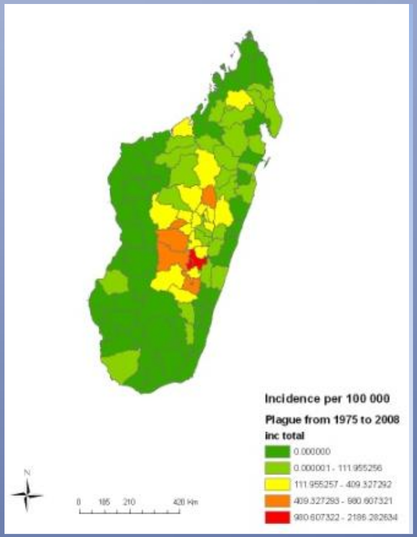
... in Madagascar

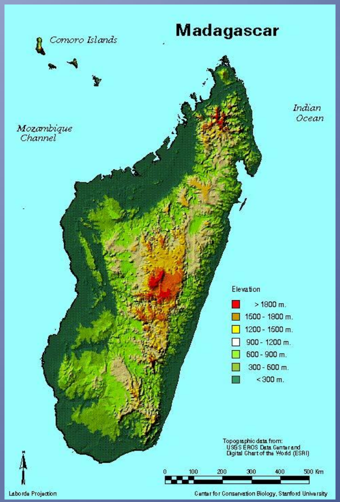

Climate
Humidity • Precipitation • Temperature
Micro-Climate
Desiccation • Flooding • Temperature Fluctuation
Flea Vector
• Reproduction rate
• Development rate
• Adult longevity
Flea vector habitat
&
Pathogen environment
Pathogen within vector
• Pathogen survival
• Pathogen multiplication
Flea vector density
Rodent host parasite burden
Proportion of infected rodents
Flea vector infection rate

Climate and plague

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







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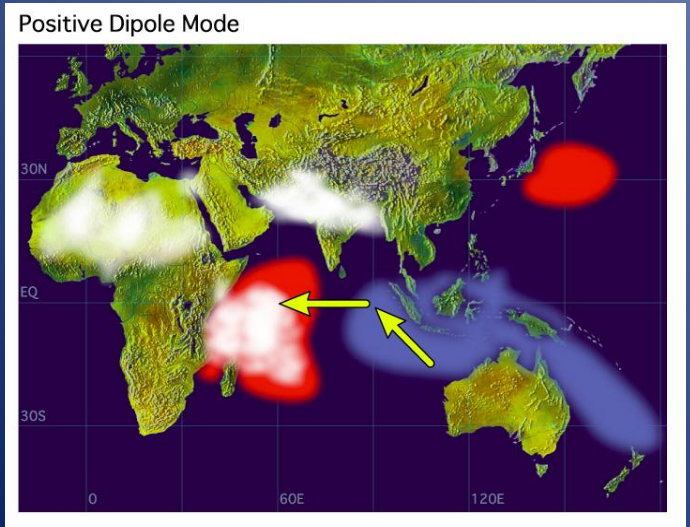
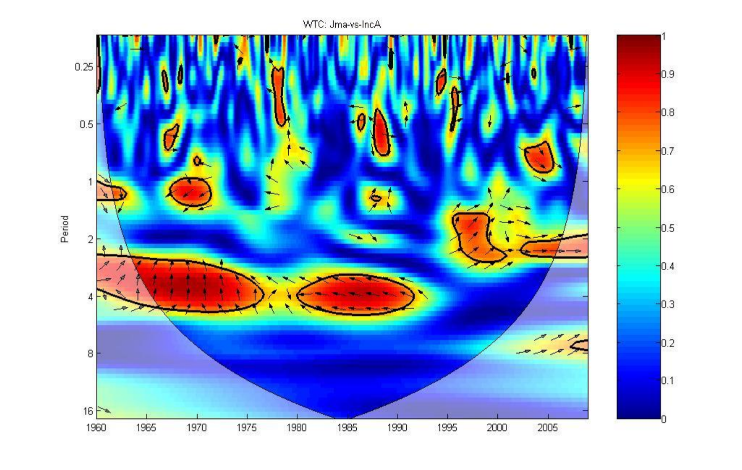


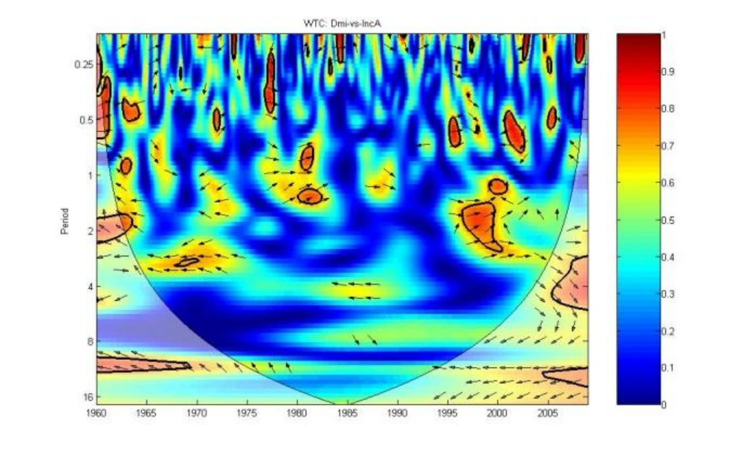
Madagascar is affected by:
- El Niño Southern Oscillation (ENSO)
- Indian Ocean Dipole (IOD)
- Frequent cyclones

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

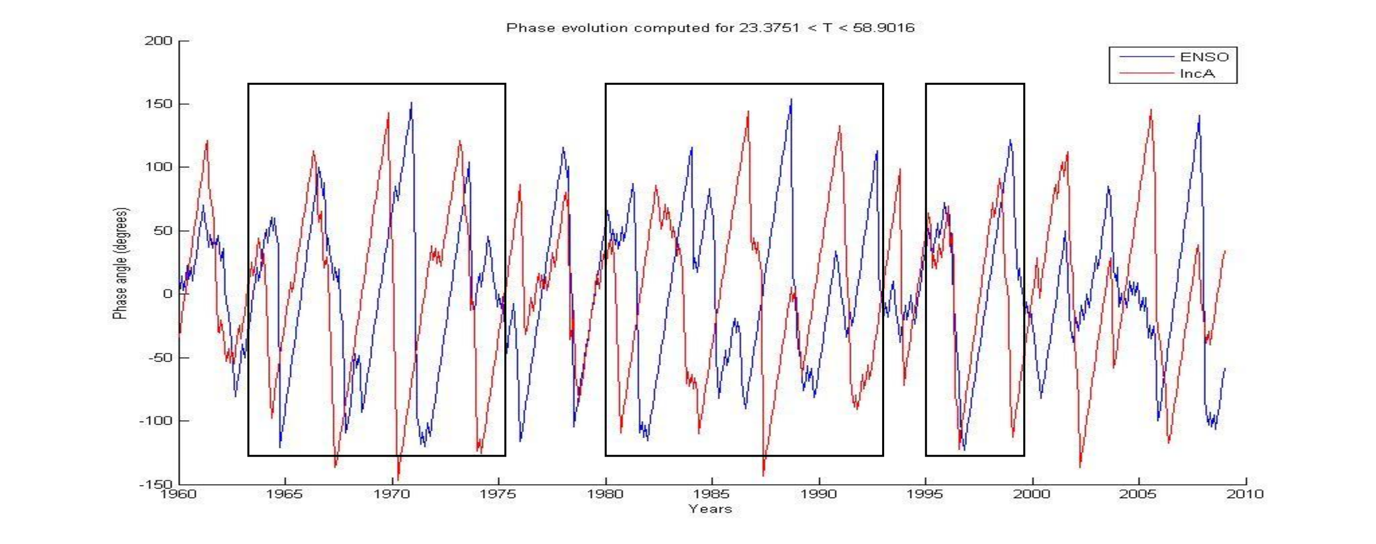


Figure: Phase angle evolution of JMA and incidence anomalies with 2-5 year periodicity. The red line represents incidence anomalies, the blue line the ENSO index. The *x*-axis is the wavelet location in time. The *y*-axis denotes the phase angles.

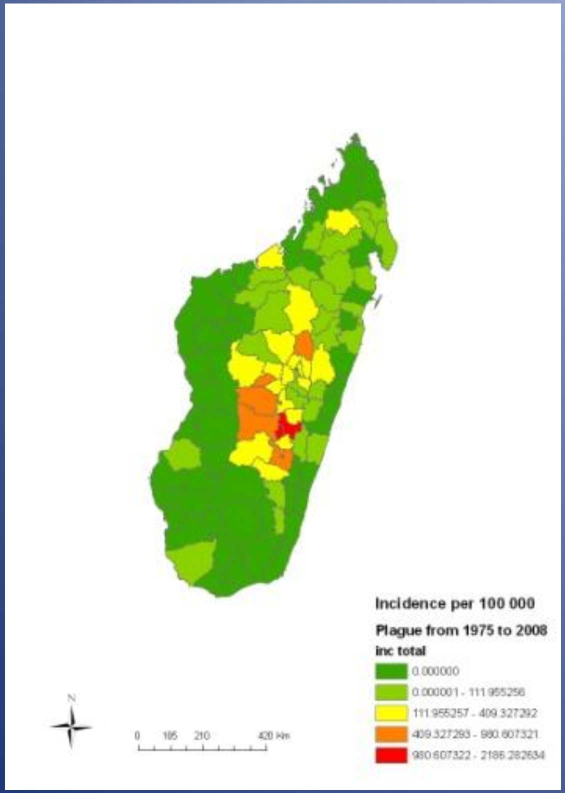
Summary of climate analysis

Global climate:

- El Niño Southern Oscillation affects human plague in Madagscar
- 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



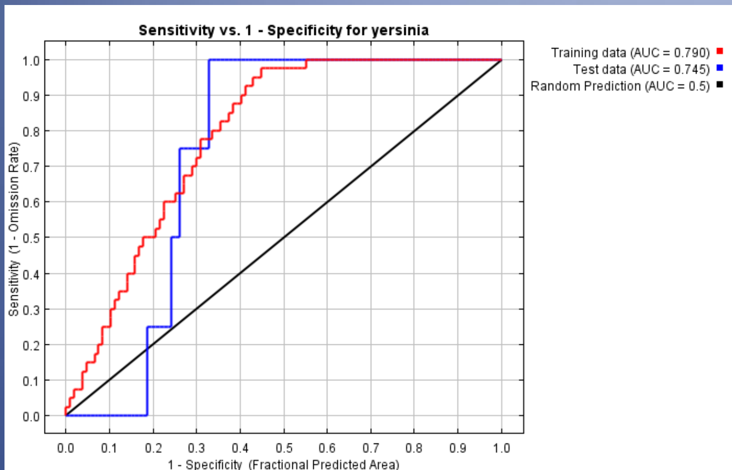
Districts reporting plague from 1975 to 2008

1. **Absence – Presence**
   Maximum Entropy model

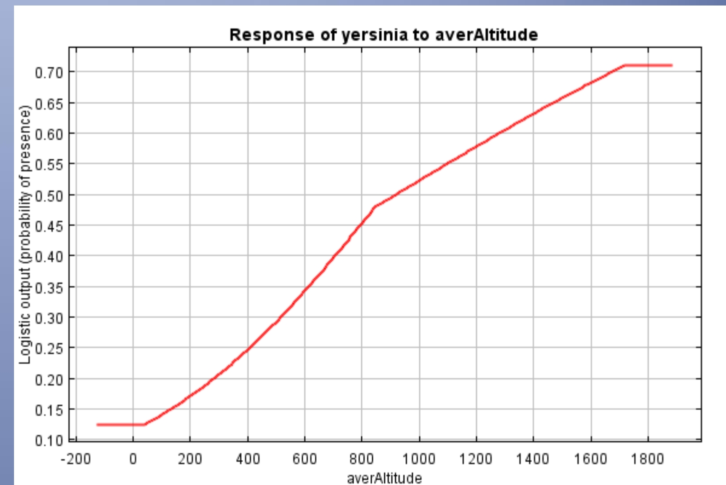
2. **Magnitude of incidence**
   Linear regression model

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

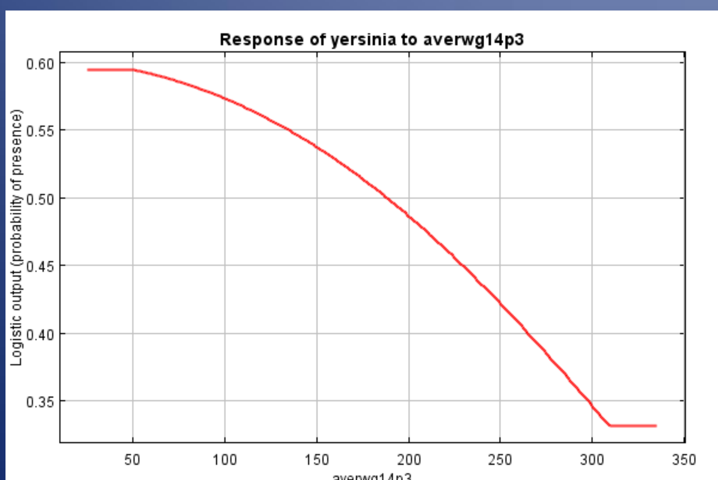
Maximum Entropy



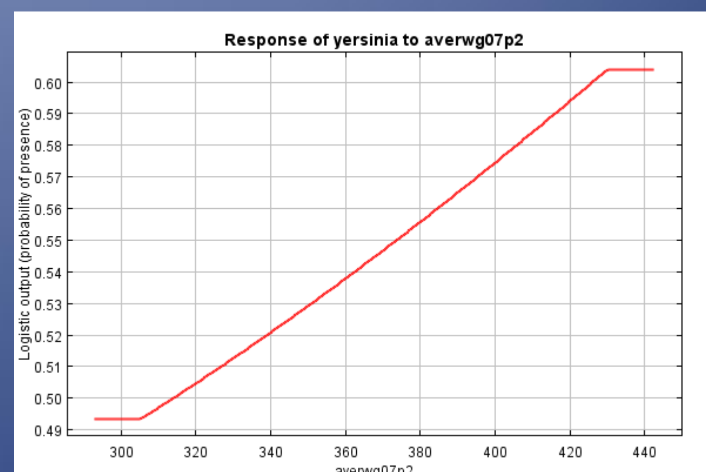
Model performance



Response curve of altitude to plague presence



Response curve of the NDVI to plague presence



Response curve of dLST to plague presence

Spatial analysis of plague incidence and environmental variables

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

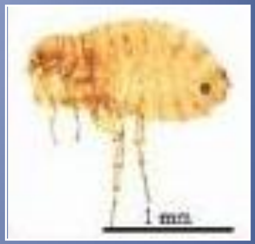
nLST is negatively correlated

dLST is negatively correlated

EVI is positively correlated

MIR (amplitude) is positively correlated

Effects on....



Pathogen

- Temperature

Vector

- mortality
- survival
- development

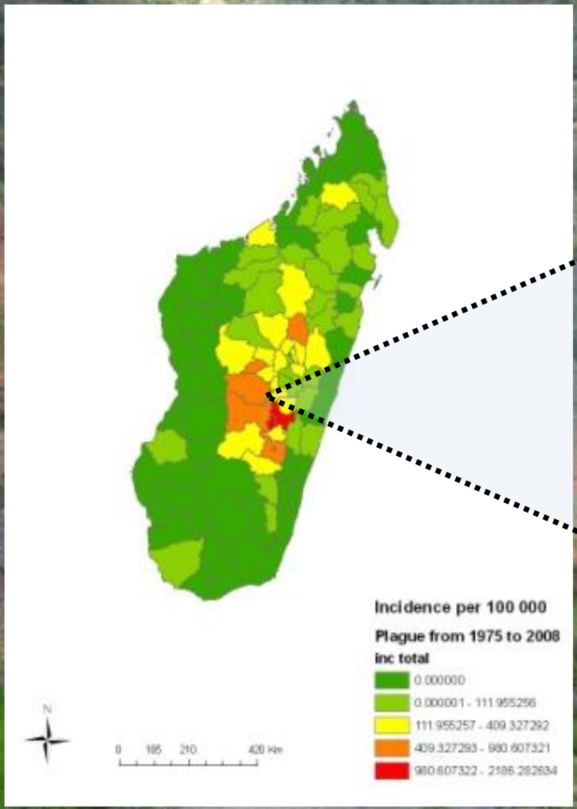
Rodent Host

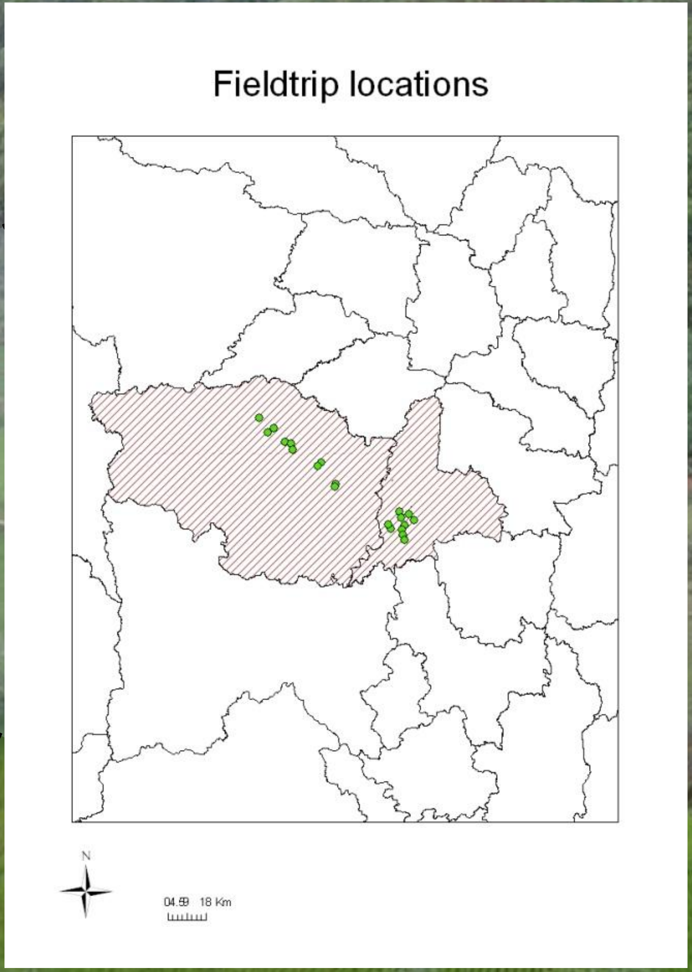
- Mortality
- survival
- Habitat

Human host

- migration
- poverty
- crop choice
- housing conditions

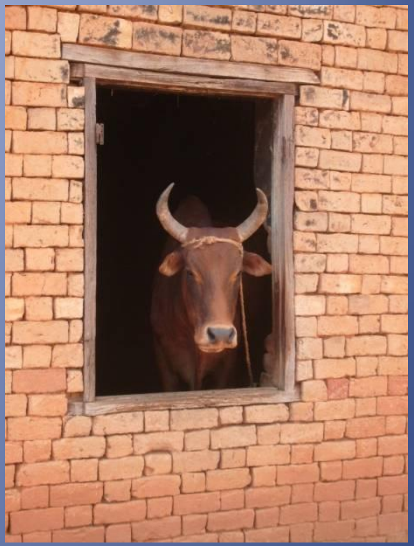
Study location

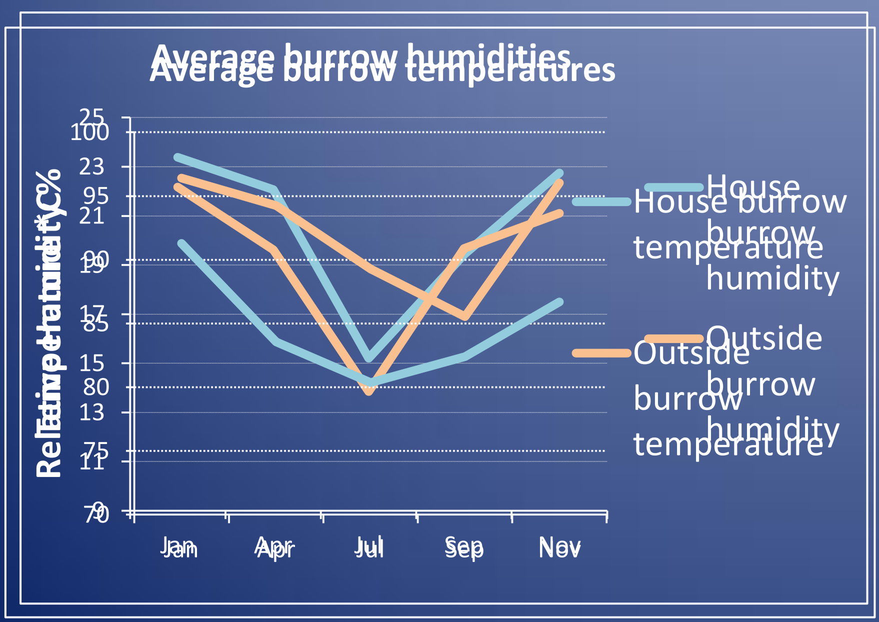




Micro-climate

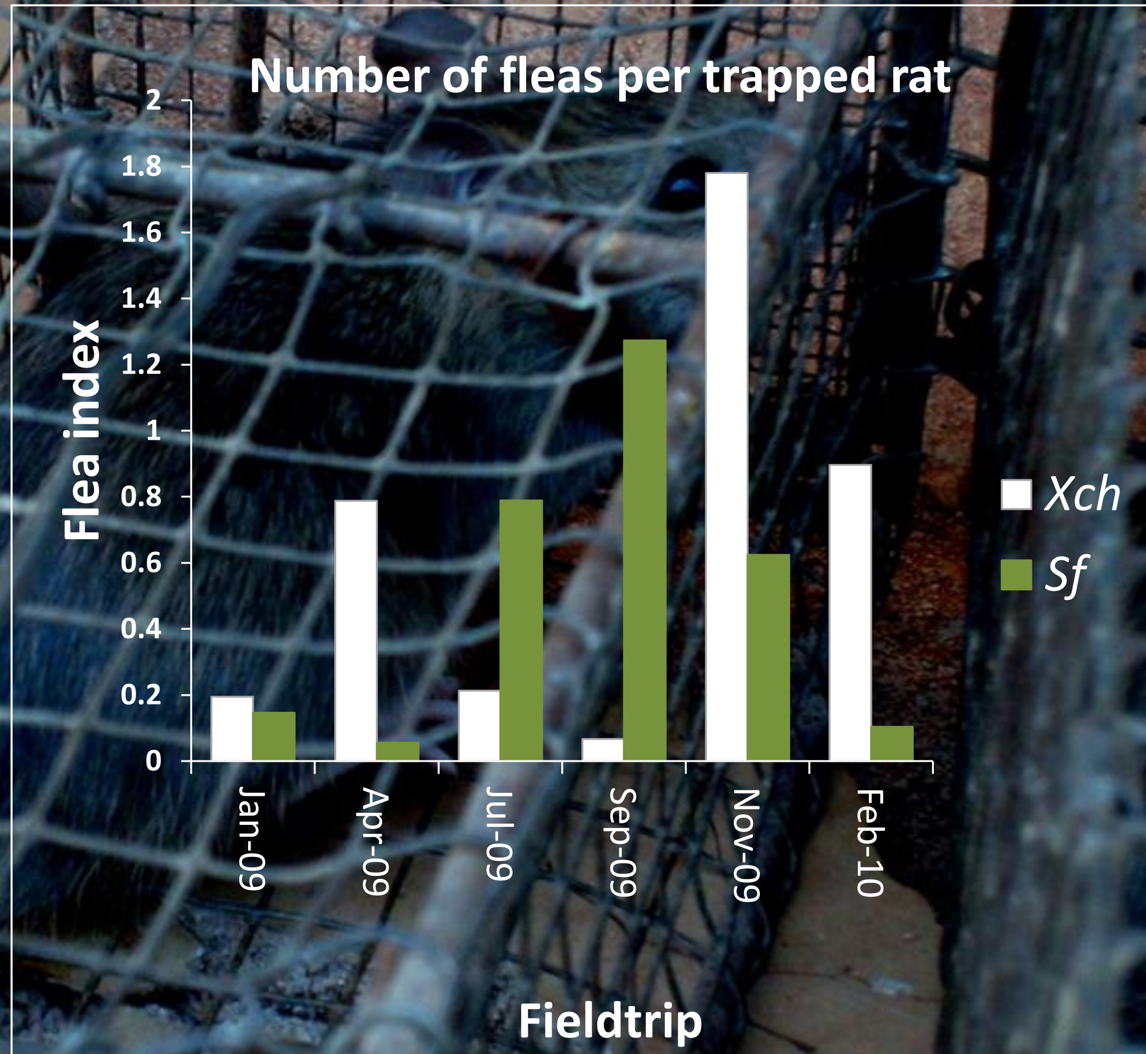
- It is warmer and less humid indoors
- Temperature values are very similar between house burrows and outside burrows
- Humidity values show large differences





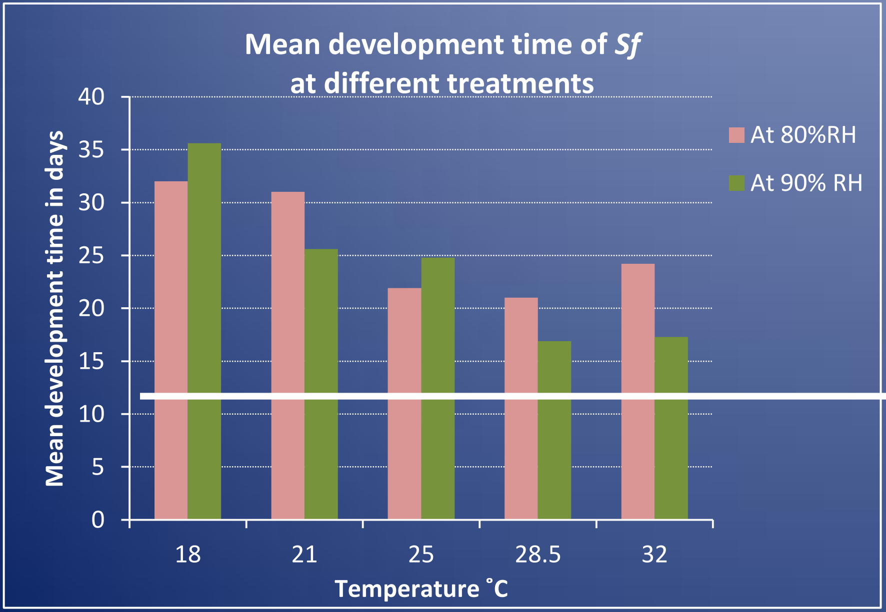
Fleas

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?

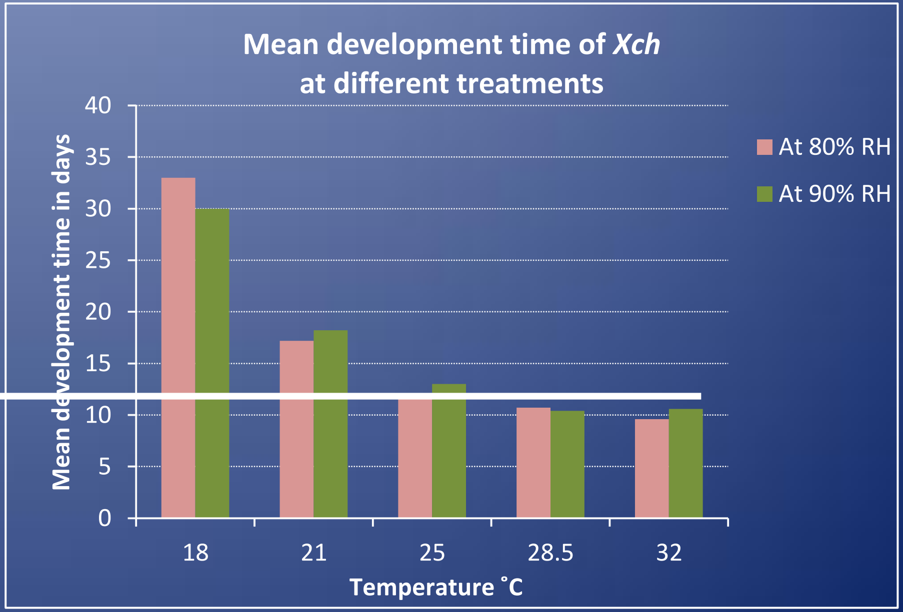


Laboratory data

- 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



Endemic *Sf*

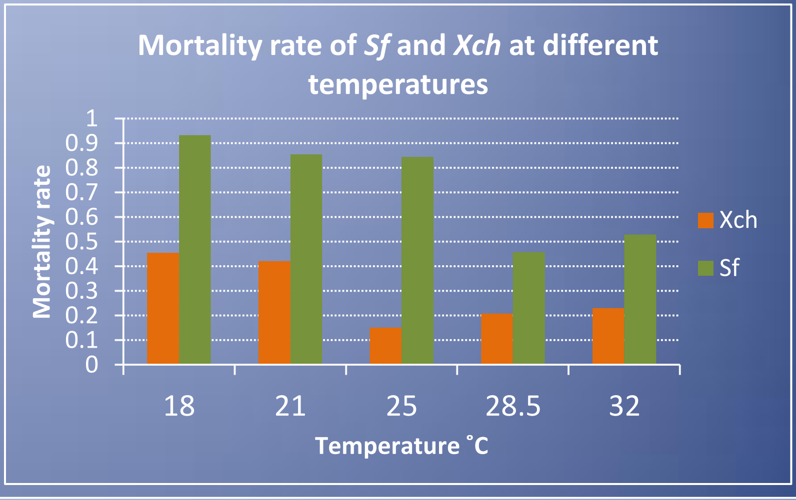


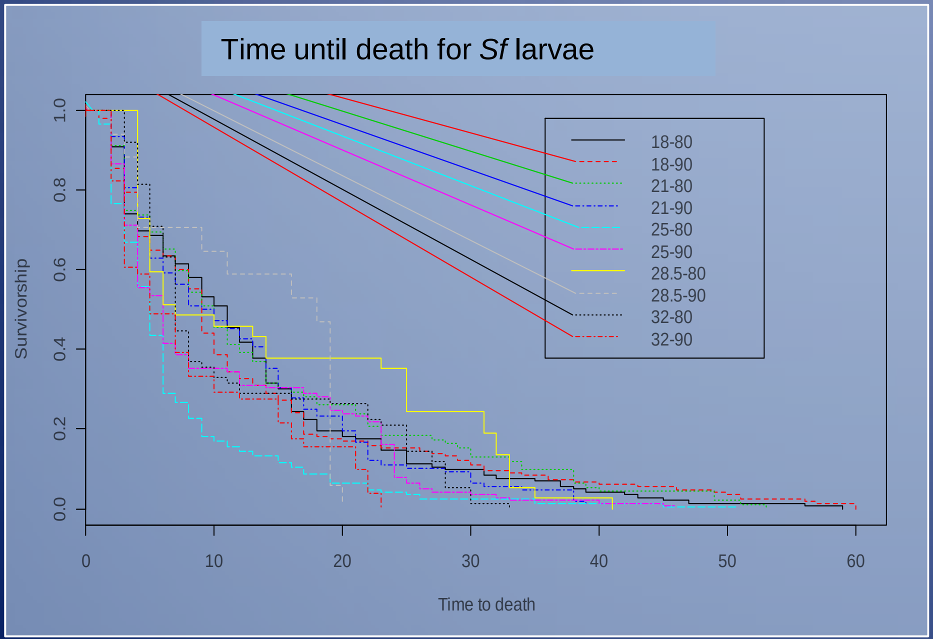
Ubiquitous *Xch*

Laboratory data

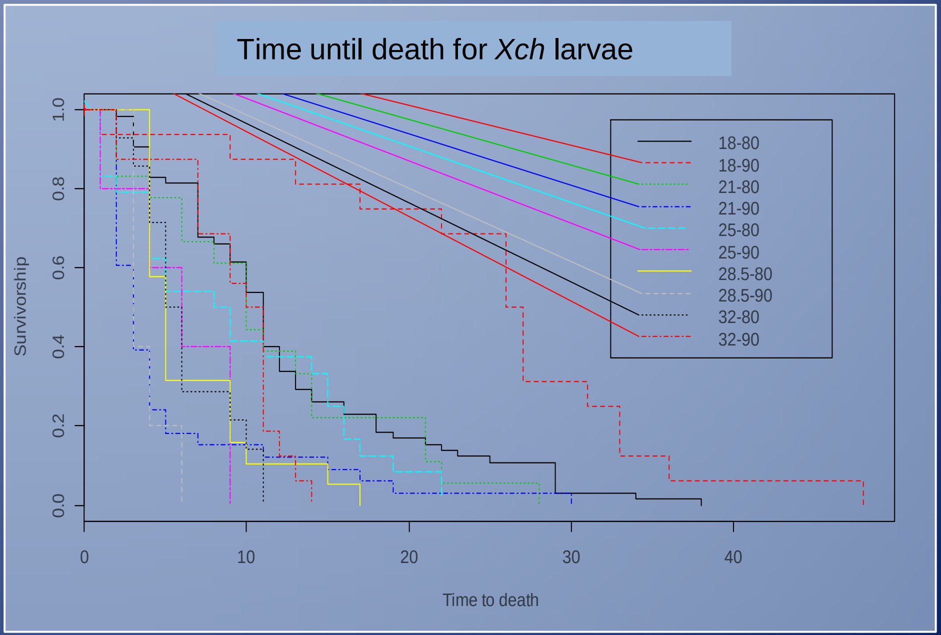
Sf larvae have a 43% higher mortality rate than *Xch*

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





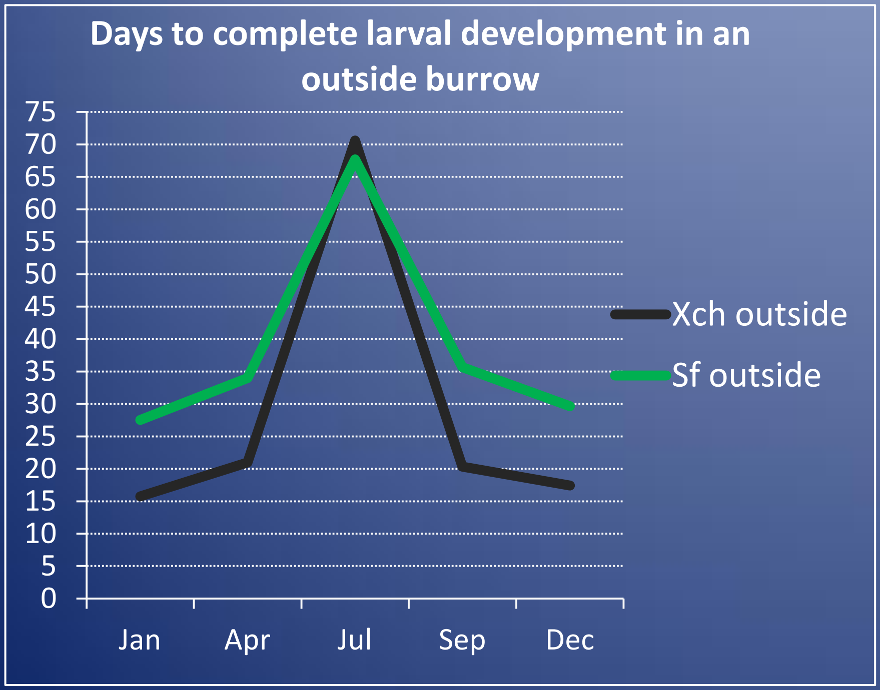
Endemic ***Sf***

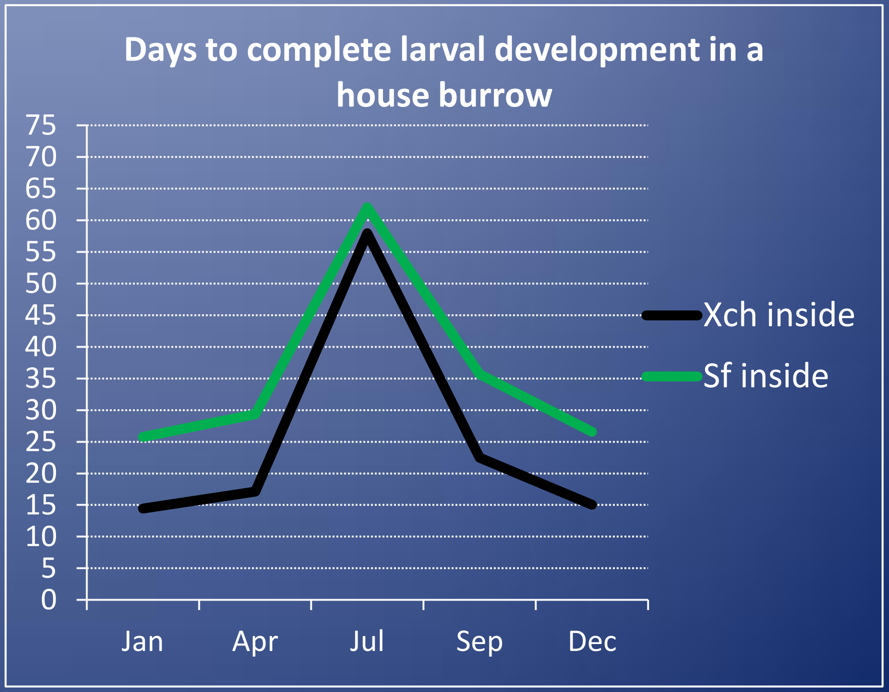


Ubiquitous ***Xch***

Combining field and laboratory data

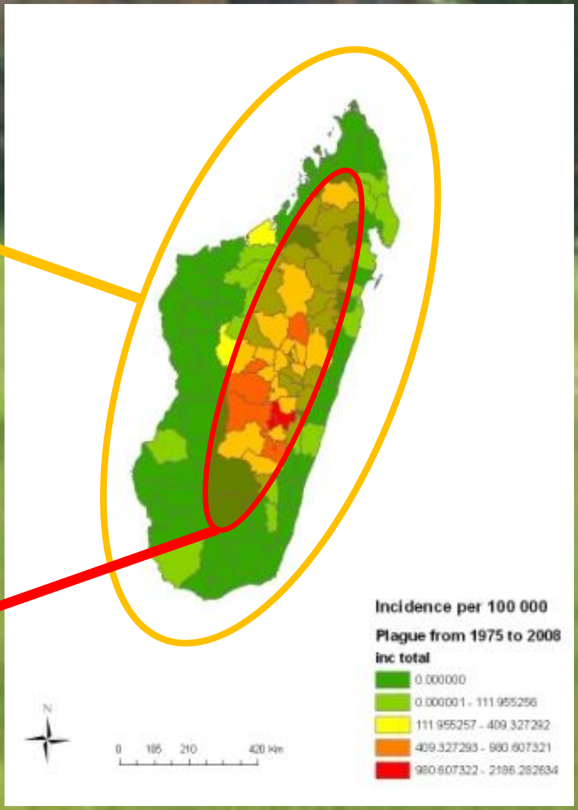
The larvae of *Sf* take longer to develop than *Xch* except in an outside burrow during July

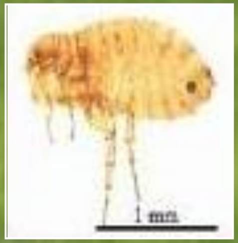




Summary of vector study

Xenopsylla cheopis (ubiquitous)





Synopsyllus fonquerniei (endemic)

Vector presence all year round

Vectors link the exterior focus with houses – human infection

***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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Many thanks to the technicians Corinne and Tojo for their help with the lab experiment and the technicians of the plague unit for their hard work during each field trip.

Questions?

Environmental variables

Variable	Feature	Coefficient
Average altitude	quadratic hinge	9.016 -0.319
Average NDVI peak timing of triannual cycle	quadratic	-1.082
Average dLST peak timing of biannual cycle	linear	0.668
Average dLSTd2	quadratic	0.937
Average nLSTp2	quadratic	0.875

Magnitude of plague

Variable	Feature	Coefficient	Std Error	t	P>|t|	95% Conf. Interval
Average MIR a2	linear	-.0717949	.0194965	-3.68	0.001	-.1114164 -.0321733
Average MIR a2	quadratic	.0001889	.0000496	3.81	0.001	.0000881 .0002896
Average MIR d2	linear	.3156656	.121508	2.60	0.014	.0687316 .5625995
Average dLST d2	linear	.3680068	.086814	4.24	0.000	.1915796 .544434
Average dLST d2	quadratic	-.0074938	.0019328	-3.88	0.000	-.0114217 -.0035658
Average nLST d1	linear	.1554398	.0291623	5.33	0.000	.0961749 .2147047
Average nLST d1	quadratic	-.001523	.0003071	-4.96	0.000	-.0021472 -.0008989
Average EVI d3	linear	-1.919053	.5244084	-3.66	0.001	-2.984779 -.8533271
Average EVI d3	quadratic	.7311711	.2387242	3.06	0.004	.2460252 1.216317
Constant		-3.123993	.9695764	-3.22	0.003	-5.094409 -1.153577