Ecological & evolutionary determinants of disease distribution in natural populations

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Infectious Disease

- Integral to natural evolutionary and ecological dynamics of populations
- Large impacts on human health, agriculture, wildlife management, and conservation
- Predicting emergence (presence and severity) is useful for anticipating and focusing control strategies
LIMITS to DISEASE DISTRIBUTION in NATURE

Example:
Sylvatic Plague in small mammals limited to west of the 100th Meridian

Antolin et al. 2002; Strapp et al. 2004
What factors affect the distribution of infectious disease?

- Natural History & Population Dynamics
- Geographic Distribution & Evolutionary History
- Host – Pathogen Genetics
- Phenotype & Life-History Traits
- Environmental Variables
- Ecological Interactions
What factors affect the distribution of infectious disease?
What factors affect the distribution of infectious disease?
Predicting disease distribution is necessary for anticipating control strategies

Malaria in the Ethiopian highlands

Pascual & Bouma 2009 *Ecology*

Lafferty 2009 *Ecology*
### The Question

**Predicting disease distribution is necessary for anticipating control strategies**

### Anther Smut Disease Distribution

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</thead>
<tbody>
<tr>
<td>Current % Infected</td>
<td>[\text{Projected}]</td>
<td>[\text{Cumulative population (millions)}]</td>
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### Hypotheses & Results

- Pascual & Bouma 2009 *Ecology*
- Lafferty 2009 *Ecology*

1°C increase in temperature = an extra 2.8 million children affected
Predicting disease distribution is necessary for anticipating control strategies

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Abbate & Antonovics 2014 *Oikos*
What factors affect the distribution of infectious disease?

Natural History & Population Dynamics

Geographic Distribution & Evolutionary History

Host – Pathogen Genetics

Phenotype & Life-History Traits

Environmental Variables

Ecological Interactions

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The pathogen

*Microbotryum* spp. “Anther Smut”

- Obligate species-specific parasitic
- Bacidiomycete
- Pollinator-transmitted (mechanical)
- Sterilizes and alters host behavior
- Model for sexually-transmitted & sterilizing diseases
The host

*Silene vulgaris* “Bladder Campion”

- Perennial Caryophyllaceae
- Gynodioecious
- No (current) agricultural value
The host

*Silene vulgaris* “Bladder Campion”

- Perennial Caryophyllaceae
- Gynodioecious
- No (current) agricultural value
- Morphologically variable
The host

Silene vulgaris “Bladder Campion”

- Perennial Caryophyllaceae
- Gynodioecious
- No (current) agricultural value
- Morphologically variable
- Generalist-pollinated

Kerri Coon (UGA)
Epidemiological Approach
Epidemiological Approach

- Transmission: \( \beta SI \)
- Recovery: \( \gamma I \)

- \( S \): Mortality
- \( I \): Mortality + Virulence
- \( R \): Mortality
Epidemiological Approach

\[ \beta = \text{contact rate (c)} \times \text{probability of infection (}\delta) \]
Epidemiological Approach

\[ I = \beta SI - (\mu + \alpha + \gamma)I \]

\( \beta = \text{contact rate (c)} \times \text{probability of infection (\delta)} \)
Epidemiological Approach

\[ I = \beta SI - (\mu + \alpha + \gamma)I \]

\[ R_o = \frac{\beta SI}{(\mu + \alpha + \gamma)I} \]

\( \beta = \text{contact rate (c) \times probability of infection (\delta)} \)
Epidemiological Approach

\[ I = \beta SI - (\mu + \alpha + \gamma)I \]

\[ R_0 = \frac{\beta SI}{(\mu + \alpha + \gamma)I} \]

Endemic Equilibrium = 1
Epidemic > 1 > Fade-out

\( \beta = \text{contact rate (c) } \times \text{probability of infection (} \delta \text{)} \)
Epidemiological Approach

\[ R_0 < 1? \]
Epidemiological Approach

- Host availability ($S$)
- Pathogen availability ($I$)
- Transmission ($\beta$)
  - Contact
  - Probability of Infection
- Recovery ($\gamma$)
- Virulence (?)
Experiments

- Host population differences across elevation:
  - ecotypic adaptations
  - resistance to disease

- Environmental effects on infection success:
  - disease expression
  - infectivity
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  - disease expression
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The host

*Silene vulgaris* “Bladder Campion”

- Ecological and phenotypic variability
The host

Silene vulgaris “Bladder Campion”

- Ecological and phenotypic variability

Are low-elevation hosts more resistant to the disease?
The host

*Silene vulgaris* “Bladder Campion”

- Ecological and phenotypic variability

Are low-elevation hosts more resistant to the disease?

- Classical AVOIDANCE resistance

- RECOVERY resistance
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Lab-Inoculations

Genetic Effects on Host Resistance?
Genetic Effects on Avoidance Resistance?

- High-elevation host populations have higher rates of avoidance (p<0.05)
• High-elevation hosts appear to carry more resistance

• Not surprising, given anther-smut is known to show patterns of maladaptation to its local host populations (Kaltz et al. 1999)

Local mal-adaptation of *M. violaceum* to *S. latifolia*
Experiments

- Host population differences across elevation:
  - ecotypic adaptations
  - resistance to disease

- Environmental effects on infection success:
  - disease expression
  - infectivity
Temperature Effects on Host Recovery?

Seasonal Change in Ambient Temperature

- **Avg. High**
- **Mean**
- **Avg. Low**

<table>
<thead>
<tr>
<th>Month</th>
<th>Temperature (°C)</th>
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<tbody>
<tr>
<td>May</td>
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<tr>
<td>Jun</td>
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<td>Jul</td>
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<tr>
<td>Apr</td>
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Temperature Effects on Host Recovery?

Temperature-Induced Suppression of Disease
(Flowing at the beginning of Summer)
Temperature Effects on Host Recovery?

Temperature-Induced Suppression of Disease (Flowering at the end of Summer)
Field Recovery

Not yet published
Genetic Effects on Temperature-induced Recovery?

Not yet published
Genetic Effects on Temperature-induced Recovery?

recovery

avoidance

Not yet published
Cost of Host Recovery?

Not yet published
Inducible Defense and Environmental Stress: Costs or Synergy?

Andrea Berardi
(UVA; UC Boulder)

Flavonoids, Local Adaptation, and Inducible Defense
<table>
<thead>
<tr>
<th>The Question</th>
<th>Anther Smut Disease Distribution</th>
<th>Hypotheses &amp; Results</th>
<th>Putting it together</th>
<th>Conclusion</th>
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| Andrea Berardi  
(UVA; UC Boulder) | | | | |
| Flavonoids, Local Adaptation, and Inducible Defense | | | | |
| | | Plant secondary metabolic products: | | |
| | | - Pollinator attraction | | |
| | | - UV sunscreen | | |
| | | - Stress response | | |
| | | - Herbivore and fungal defense | | |
Inducible Defense and Environmental Stress: Costs or Synergy?

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Flavonoids, Local Adaptation, and Inducible Defense

Plant secondary metabolic products:
- Pollinator attraction
- UV sunscreen
- Stress response
- Herbivore and fungal defense

Not yet published
Do high temperatures inhibit infection success?

Mean Daily Maximum Temperatures

- Lautaret (2075m)
- Chamrousse (1785m)
- Vizille (290m)
- St. Martin d'H (220m)
Lab-Inoculations

Do high temperatures inhibit infection success?

![Graph showing the relationship between inoculation temperature and infection success. The graph indicates a decrease in infection success with increasing temperature, with an R² value of 0.98172.]

Abbate 2015 Revised, Resubmitted
Lab-Inoculations

Do high temperatures inhibit infection success?

Abbate 2015 Revised, Resubmitted
Lab-Inoculations

Do high temperatures inhibit infection success?

By Host Elevation

Inoculation Success (D/Total)

Inoculation Temperature (°C)

Abbate 2015 Revised, Resubmitted
Fit it all together: Epidemiological Modeling

\[ R_0 < 1 \]
Fit it all together: Epidemiological Modeling

Not yet published
Fit it all together: Epidemiological Modeling

- Natural History & Population Dynamics
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Fit it all together: Epidemiological Modeling

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Under what conditions is a pathogen likely to invade?
Which parameters play a major role?
Fit it all together: Estimating Ro

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Fit it all together: Estimating Ro

Which parameters play a major role?
Elasticity Analysis

Not yet published
CONCLUSION & PERSPECTIVE

❖ Remember the disease triangle.

❖ An epidemiological approach can help synthesize co-occurrence of important factors.

❖ Temperature seems to be a pretty important factor for anther-smut disease in *S. vulgaris*, but it is not independent of other important factors that change across the climatic gradient (e.g., host recovery).

❖ Might the distribution of *S. vulgaris*-specific anther smut contract as global temperatures rise?
Lab-Inoculations

Do high temperatures inhibit infection success?

![Graph showing the relationship between inoculation temperature and infection success. The graph indicates a decreasing trend in infection success with increasing temperature, with an R² value of 0.98172.]
Can diurnal temperature variations “rescue” pathogen development?

Not yet published
MvSv-MvSm Distribution

Tatiana Giraud
Pierre Gladieux
Alodie Snirc
Michael Hood

Steve Keller
Peter Fields
Andrea Berardi
The pathogen

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Disease Expression and Spore dispersal

Systemic Infection

Germination, Sex, Infection

Giraud et al. 2008 *Eukaryotic Cell*
The pathogen

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Schafer et al. 2010, Botany
Can diurnal temperature variations “rescue” pathogen development?

Not yet published
“tenacitas in adversitas .... ad punctum!”

Serge Aubert, Rolland Douzet, LECA
Janis Antonovics, Michael Hood, Tatiana Giraud, Samuel Alizon
Seb Lion, Sylvain Gandon, Simon Fellous, Nathalie Charbonnel
Andrea Berardi, Peter Fields, Stephen Keller, Pierre Gladieux
Kerri Coon, Christopher Winstead-Derlega