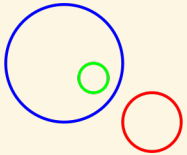

Host-Parasite Coevolution & Microbiome-Mediated Adaptation

TransEvo Core Seminar, June 2024

Bob Week

Postdoctoral Fellow, Bohannan Lab, University of Oregon

bweek@uoregon.edu bobweek.github.io @_bobweek_

Adaptation is Fundamental for Both

Host-Parasite Coevolution

Microbiome-Mediated Adaptation

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Host-Parasite Coevolution

- Coevolution is reciprocal adaptation

Microbiome-Mediated Adaptation

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- Applications:

Microbiome-Mediated Adaptation

Adaptation is Fundamental for Both

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- Applications:
  - Limit pathogen adapation

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- Microbiomes can mediate host adaptation

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- Applications:
  - Increase crop yield

Adaptation is Fundamental for Both

Host-Parasite Coevolution

- Coevolution is reciprocal adaptation
- Applications:
  - Limit pathogen adapation
  - Conserve natural systems

Microbiome-Mediated Adaptation

- Microbiomes can mediate host adaptation
- Applications:
  - Increase crop yield
  - Prevent/treat disease

Adaptation = Selection + Inheritance

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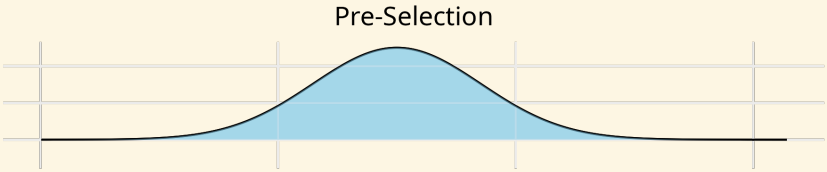
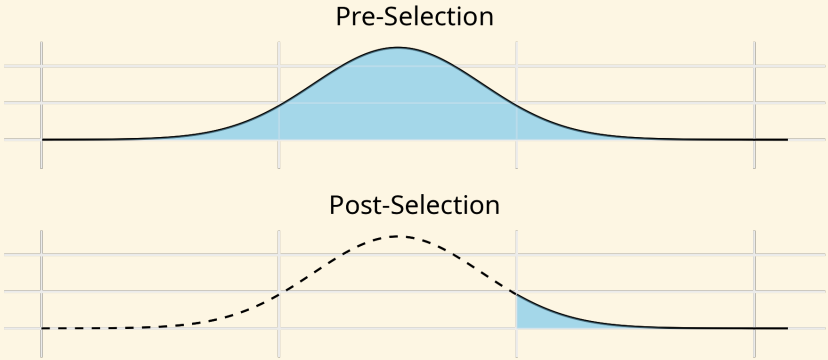
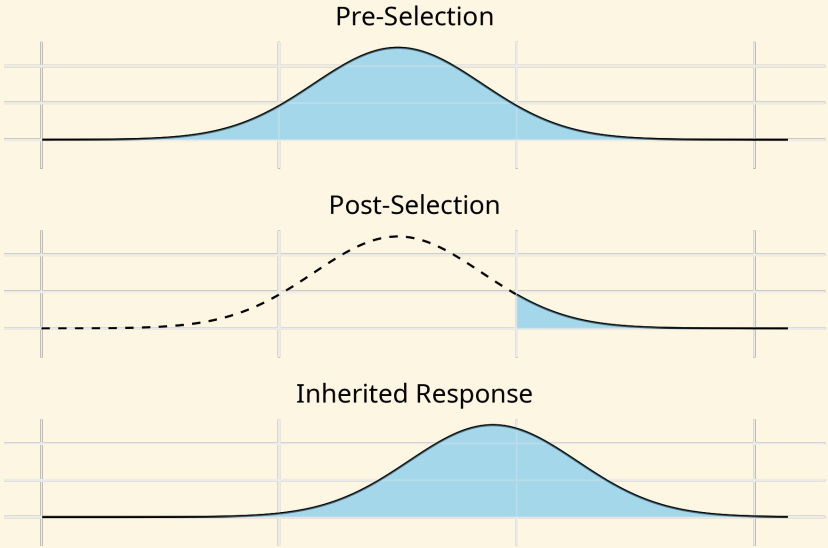


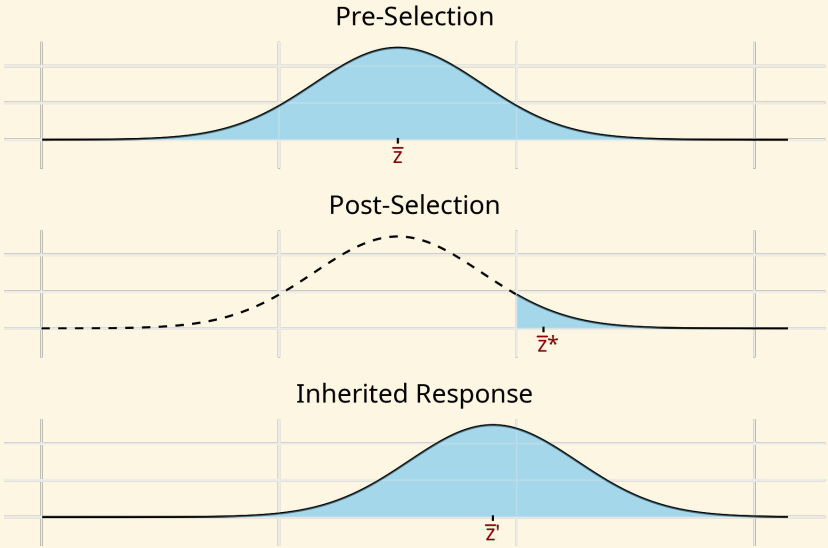
Adaptation = Selection + Inheritance



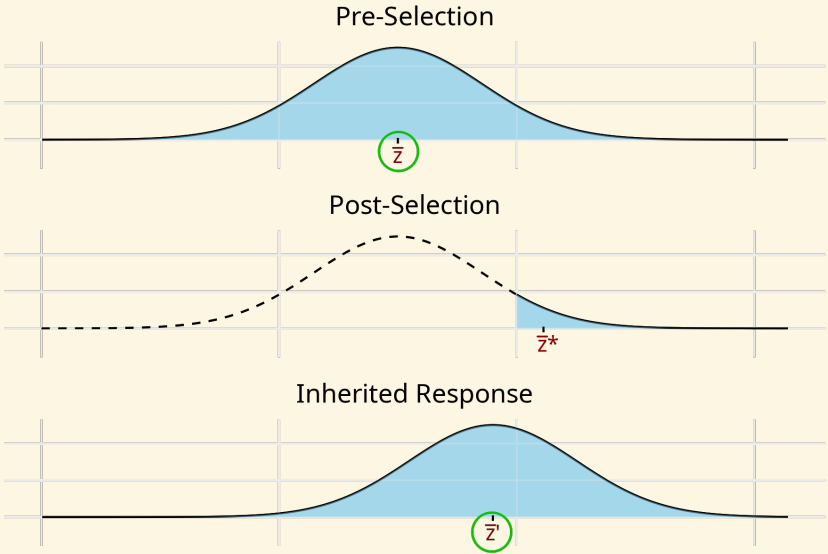
Adaptation = Selection + Inheritance



Focused on Mean Trait Dynamics: $\Delta\bar{z}$

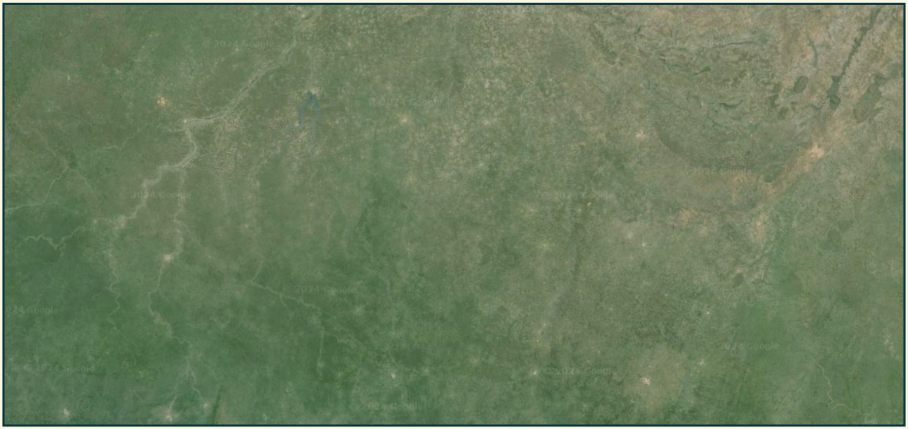


Focused on Mean Trait Dynamics: $\Delta\bar{z} = \bar{z}' - \bar{z}$

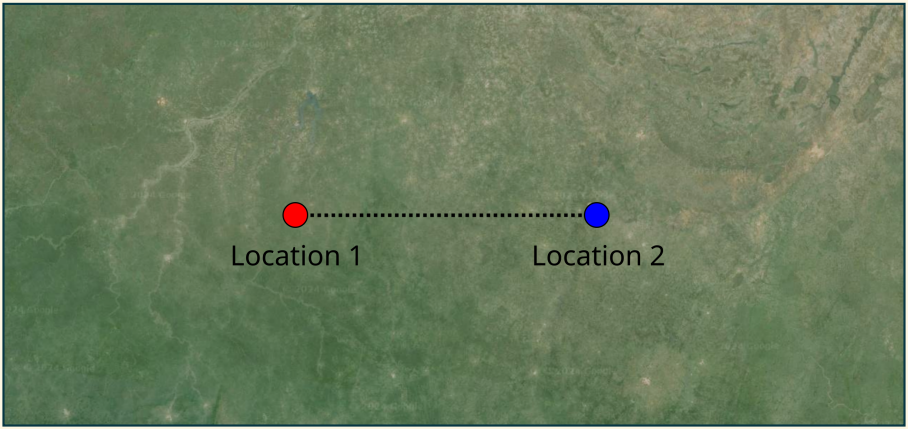


Part 1: Host-Parasite Coevolution in Continuous Space

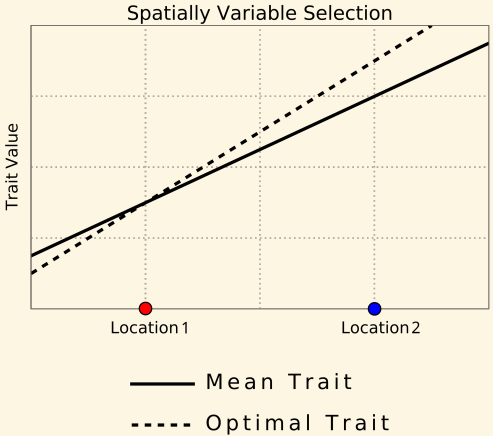
Species are Distributed Continuously in Space



Measure Along a Transect



Spatially Variable Selection Leads to Local Adaptation



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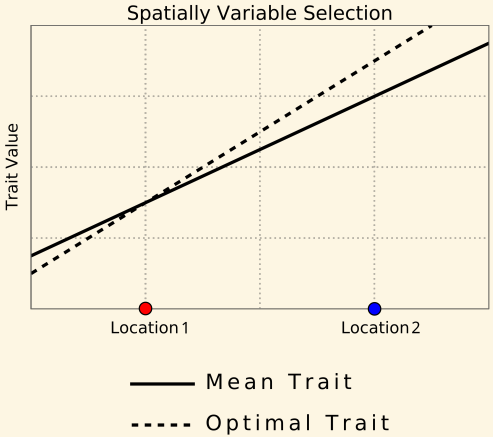
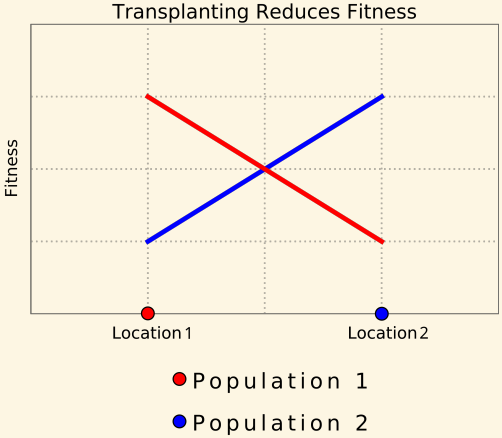
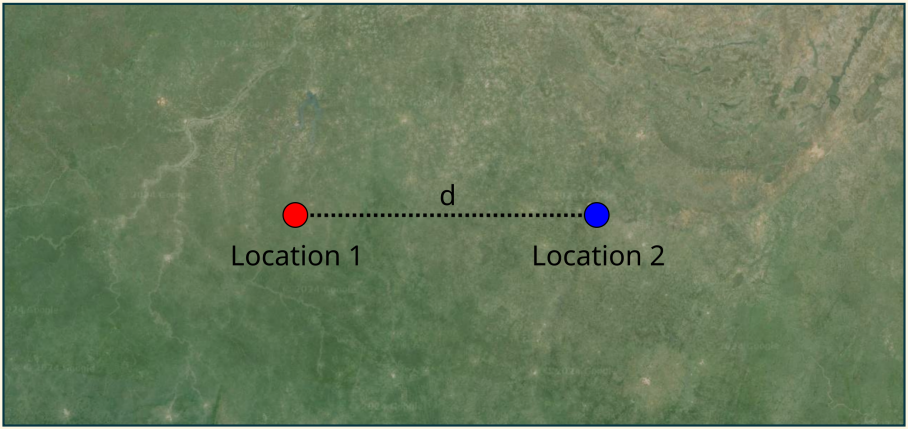




Strength of Local Adaptation Depends on Distance

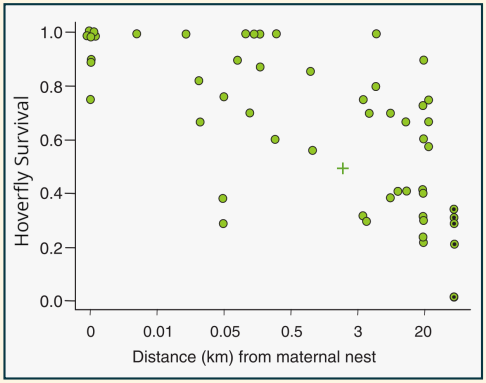


Hoverfly Parasite is Locally Adapted to Ant Host

Courtesy arthropodafotos.de

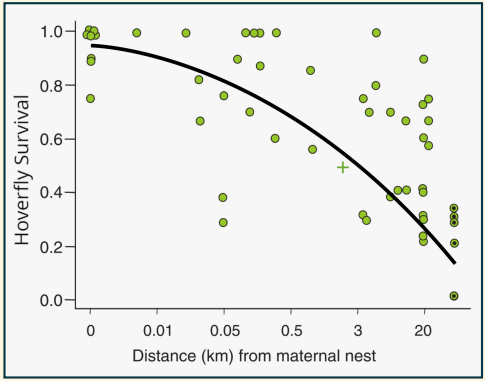
Courtesy linsecterie.com

Parasite Local Adaptation Varies Across Spatial Scales



Courtesy Schönrogge et al. (2006)

Parasite Local Adaptation Varies Across Spatial Scales



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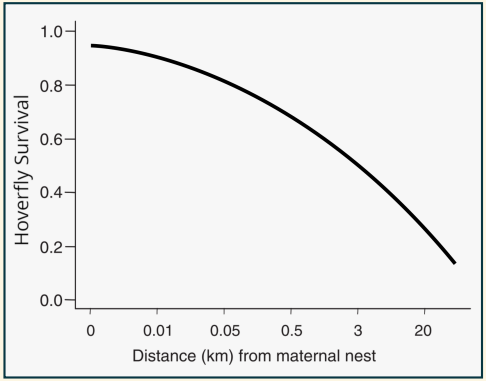

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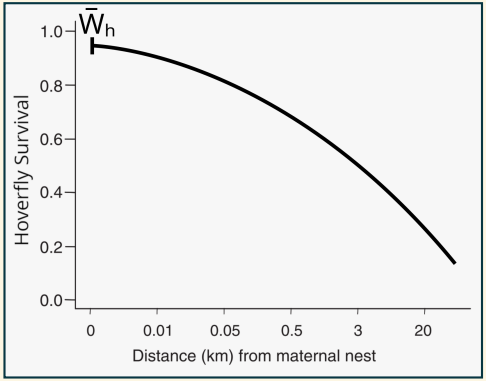

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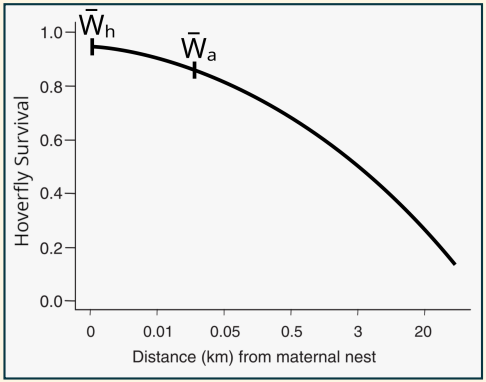

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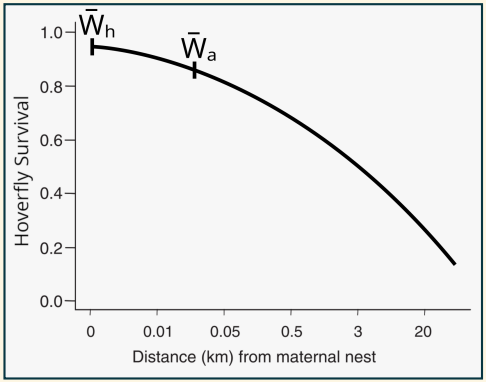
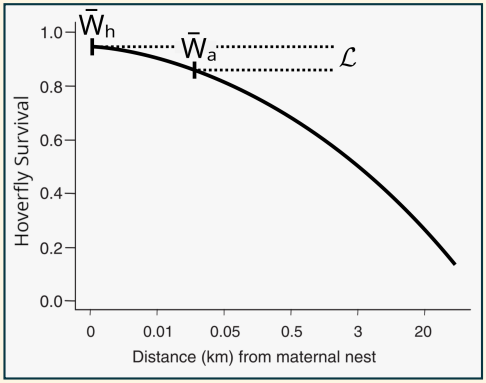


Courtesy Schönrogge et al. (2006)

- $\mathcal{L} = \bar{W}_h - \bar{W}_a$

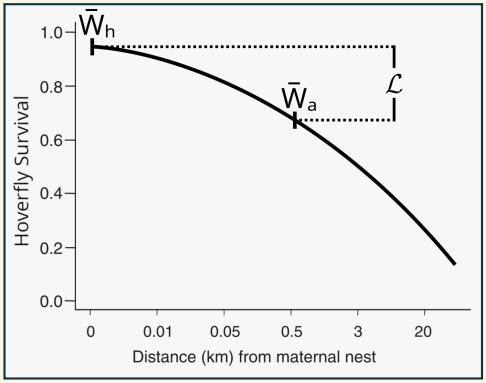
Parasite Local Adaptation Varies Across Spatial Scales



Courtesy Schönrogge et al. (2006)

- $\mathcal{L} = \bar{W}_h - \bar{W}_a$
- Weak at shorter distances

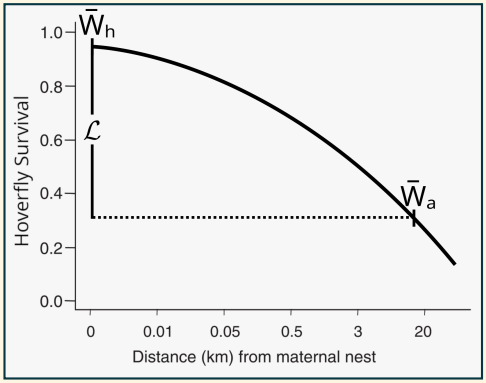
Parasite Local Adaptation Varies Across Spatial Scales



Courtesy Schönrogge et al. (2006)

- $\mathcal{L} = \bar{W}_h - \bar{W}_a$
- Weak at shorter distances
- Moderate at intermediate distances

Parasite Local Adaptation Varies Across Spatial Scales



Courtesy Schönrogge et al. (2006)

- $\mathcal{L} = \bar{W}_h - \bar{W}_a$
- Weak at shorter distances
- Moderate at intermediate distances
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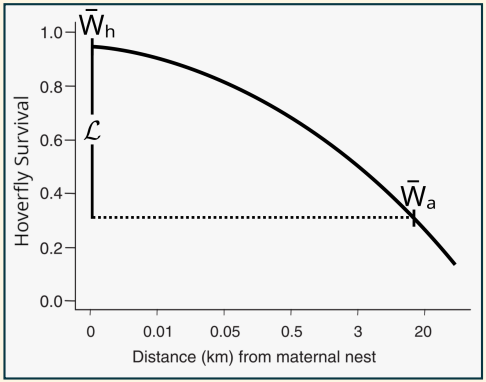
Parasite Local Adaptation Varies Across Spatial Scales

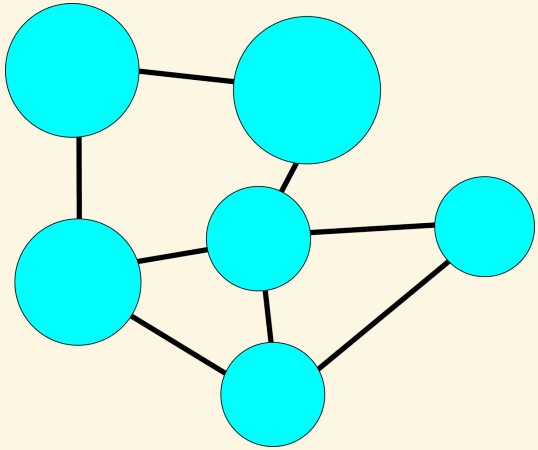


Courtesy Schönrogge et al. (2006)

- $\mathcal{L} = \bar{W}_h - \bar{W}_a$
- Weak at shorter distances
- Moderate at intermediate distances
- Strong at further distances
  - Lacks theoretical explanation

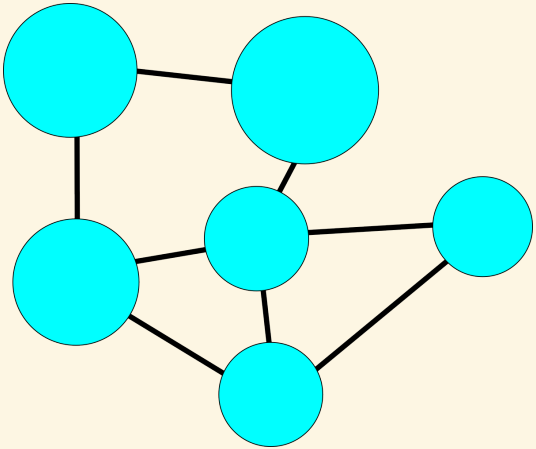
Classical Indices of Local Adaptation Ignore Distance

Classical Indices of Local Adaptation Ignore Distance



A Metapopulation

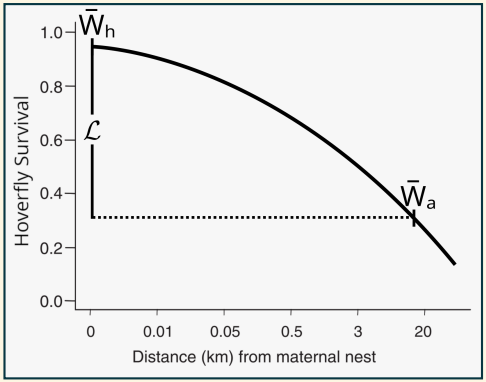
Classical Indices of Local Adaptation Ignore Distance



A Metapopulation

Randomly Picking Marbles

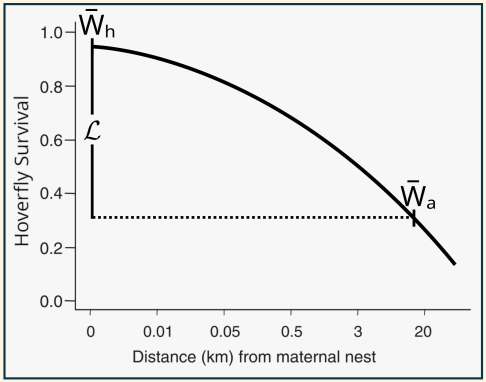
Explaining Cross-Scale Variation in Parasite Local Adaptation



Courtesy Schönrogge et al. (2006)

Need:

Explaining Cross-Scale Variation in Parasite Local Adaptation

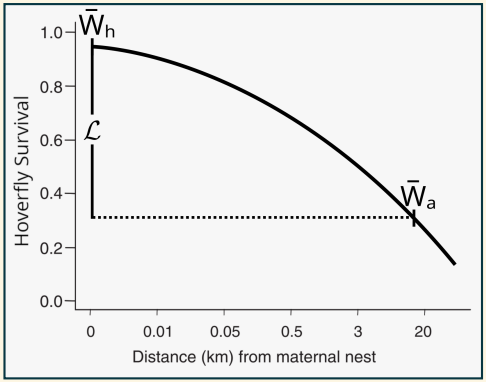


Courtesy Schönrogge et al. (2006)

Need:

1. A continuous space index of local adaptation: $\mathcal{L}$(d)

Explaining Cross-Scale Variation in Parasite Local Adaptation

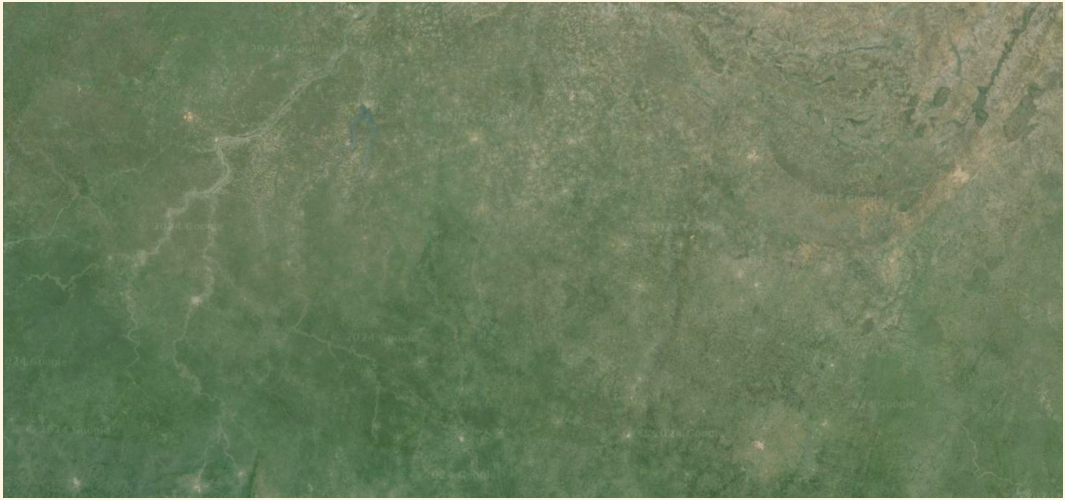


Courtesy Schönrogge et al. (2006)

Need:

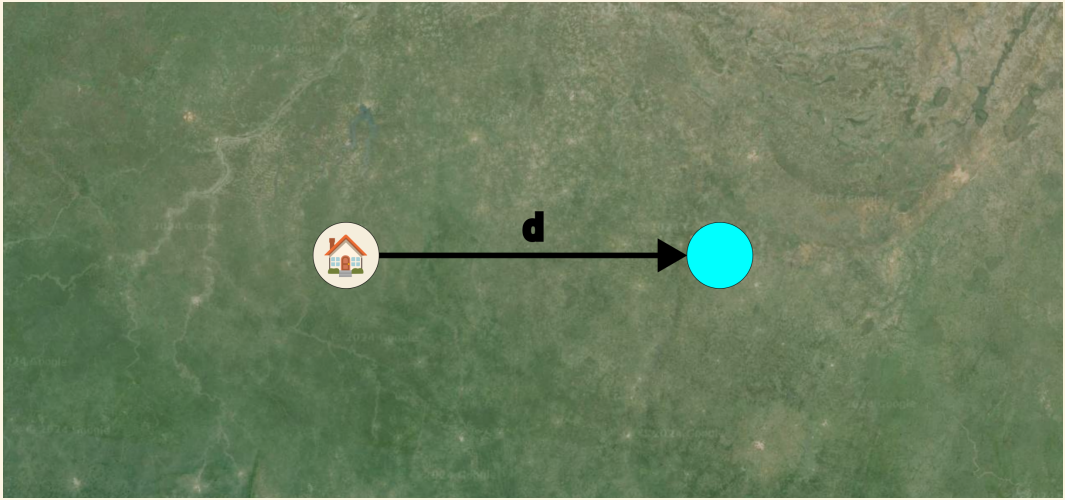
1. A continuous space index of local adaptation: $\mathcal{L}(d)$
2. A model of host-parasite coevolution: 🐜🪰

To Measure Local Adaptation in Continuous Space

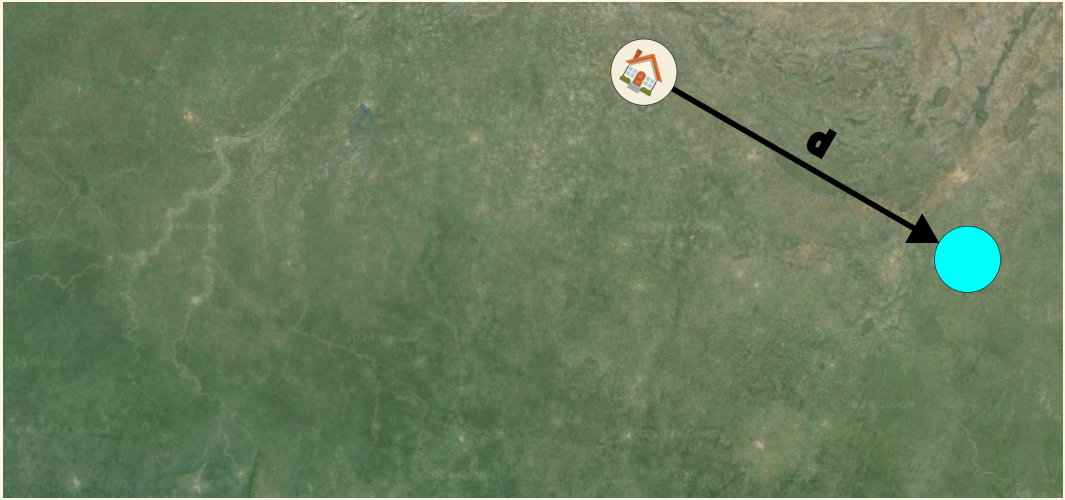


Measure Fitness at Home: $\bar{W}_h$

Measure Fitness Away at Distance d: $\bar{W}_a$



Repeat Across Space While Keeping d Fixed: $\mathbb{E}[\bar{W}_h - \bar{W}_a]$



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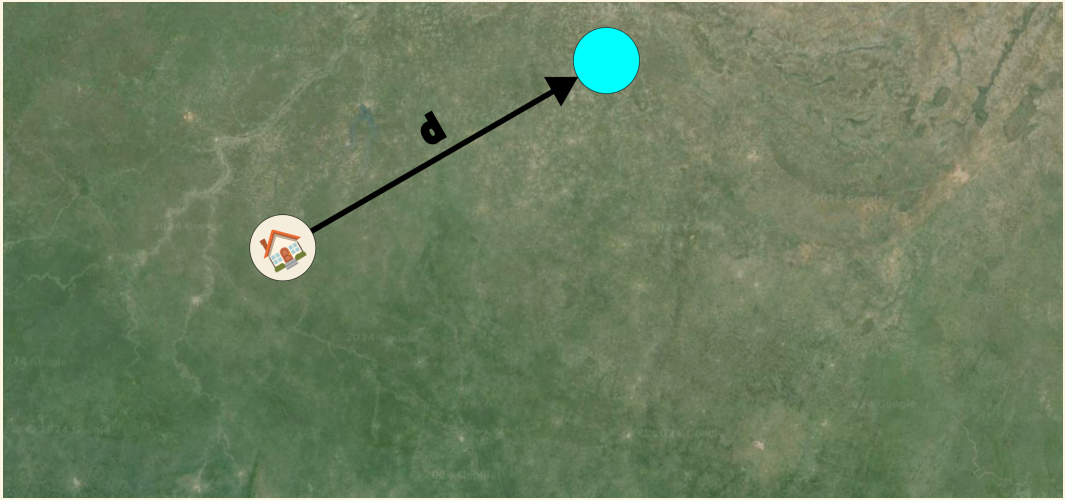

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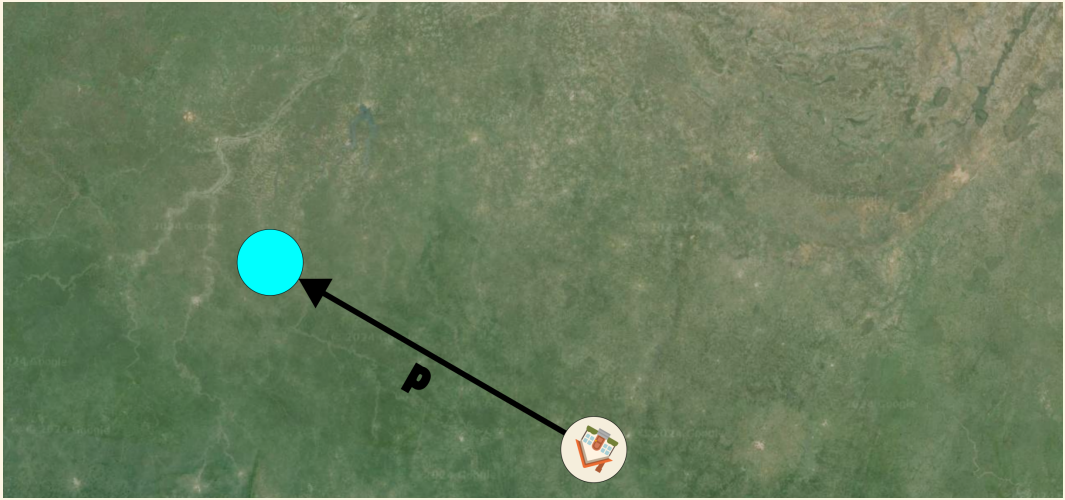

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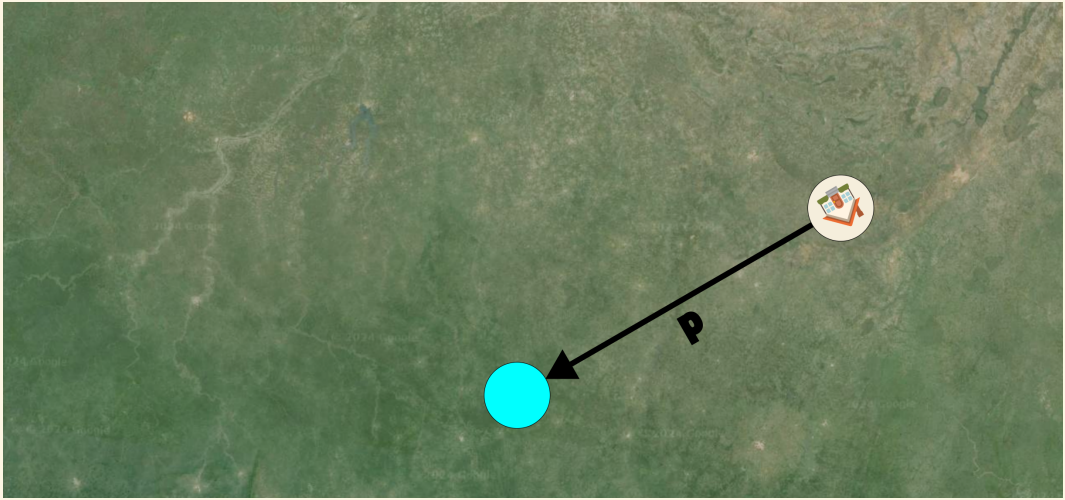
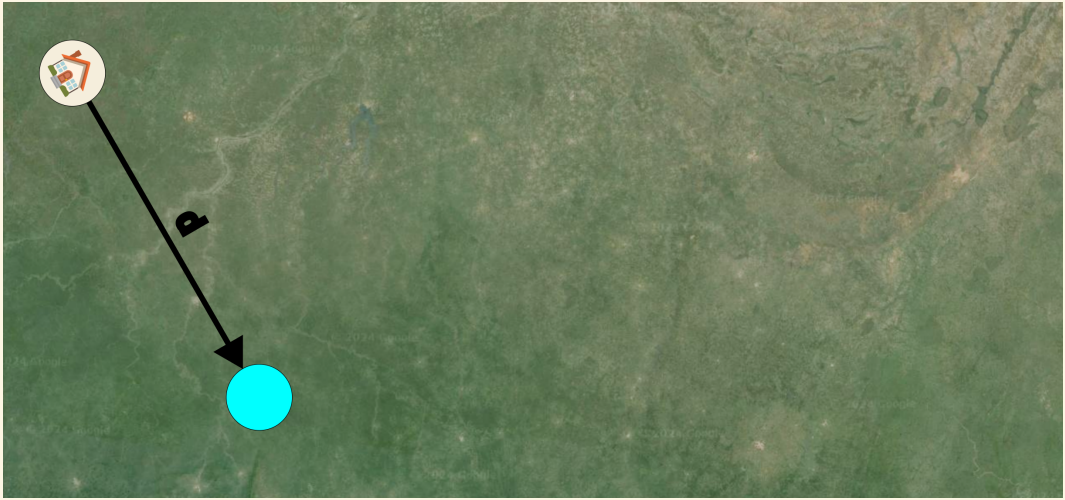
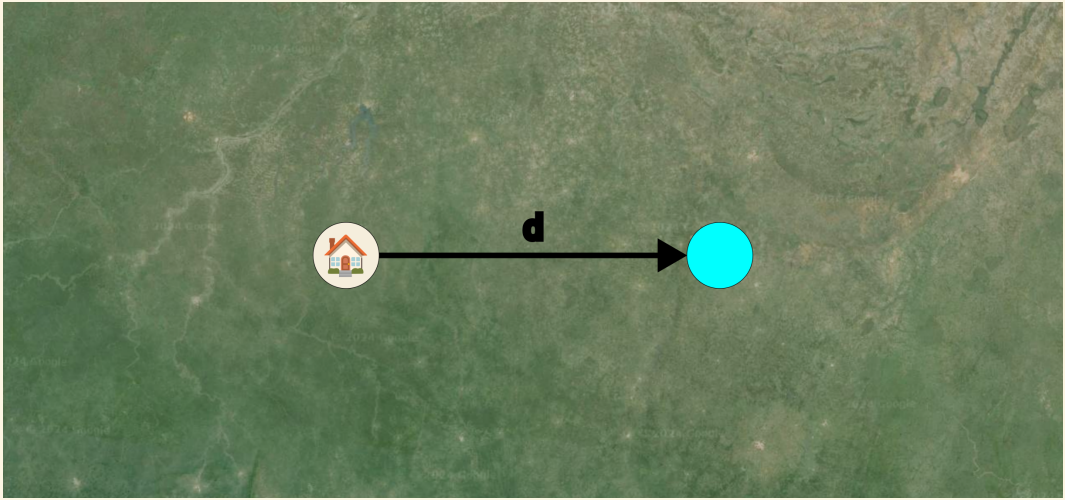


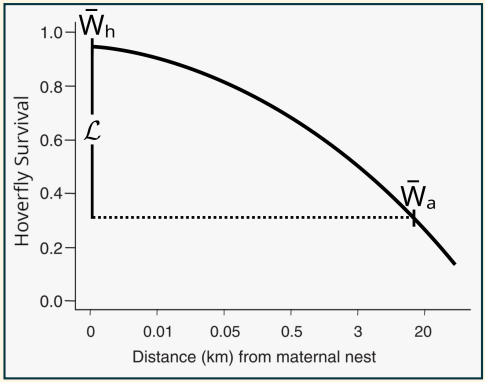
Repeat Across Space While Keeping d Fixed: $\mathbb{E}[\bar{W}_h - \bar{W}_a]$



Local Adaptation as a Function of Distance: $\mathcal{L}(d) = \mathbb{E}[\bar{W}_h - \bar{W}_a]$

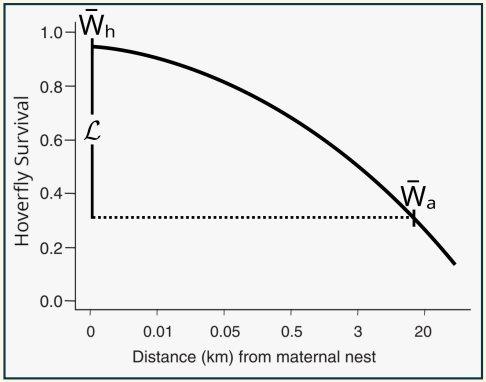


$\mathcal{L}(d)$ Helps Measure Parasite Local Adaptation Variation



Courtesy Schönrogge et al. (2006)

$\mathcal{L}(d)$ Helps Measure Parasite Local Adaptation Variation



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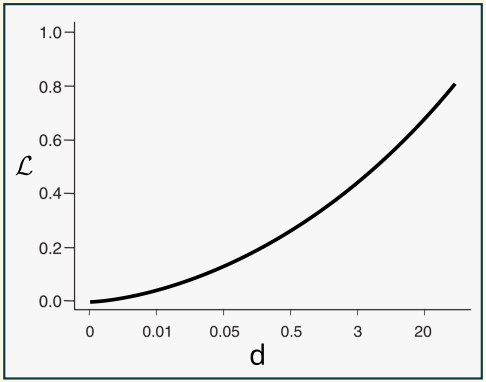
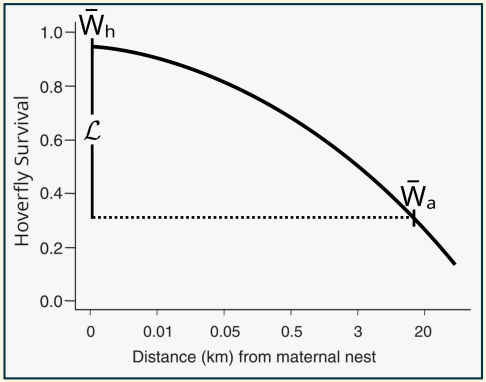


Continuous Space Index of Local Adaptation

An Explanation Requires a Model



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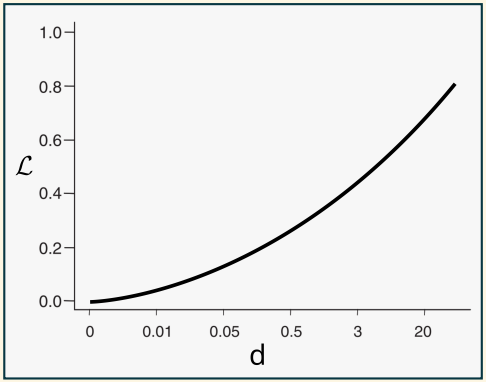


Continuous Space Index of Local Adaptation

A Model of Host-Parasite Coevolution in Continuous Space

Three Main Components:

A Model of Host-Parasite Coevolution in Continuous Space

Three Main Components:

- Random Genetic Drift 🎲

A Model of Host-Parasite Coevolution in Continuous Space

Three Main Components:

- Random Genetic Drift 🎲
- Host-Parasite Interactions 🐜×🪰

A Model of Host-Parasite Coevolution in Continuous Space

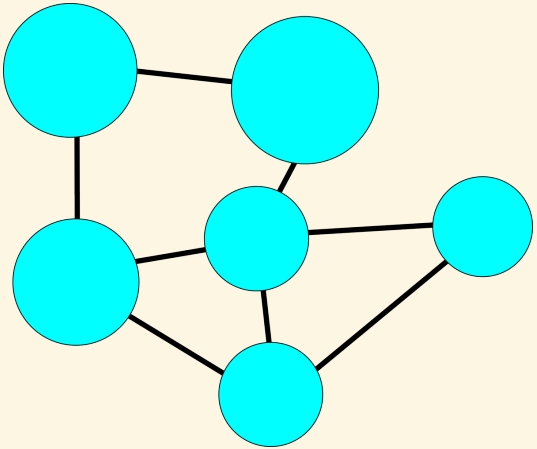
Three Main Components:

- Random Genetic Drift 🎲
- Host-Parasite Interactions 🐜×🪰
- Dispersal ✈️

Random Genetic Drift 🎲

Stochastic evolution resulting from finite population size

Random Genetic Drift Causes Spatial Variation



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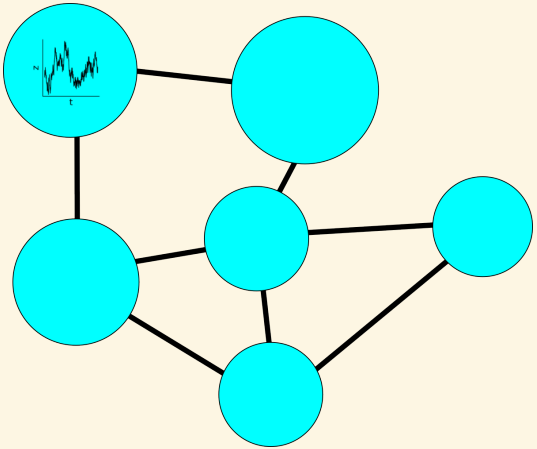

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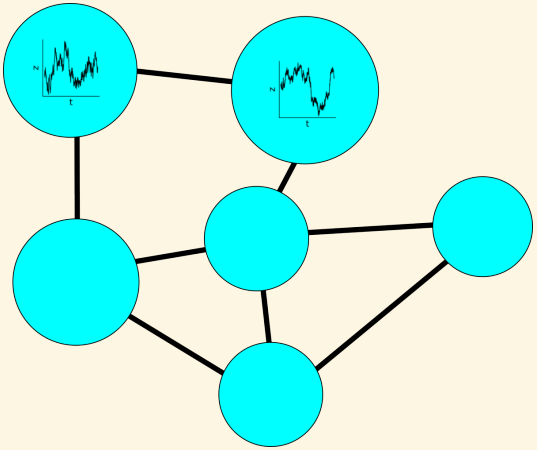

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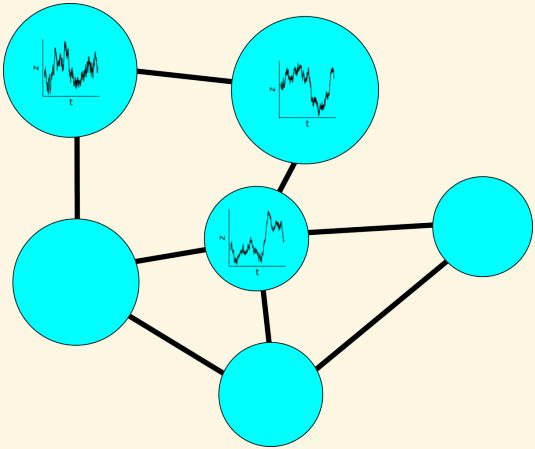

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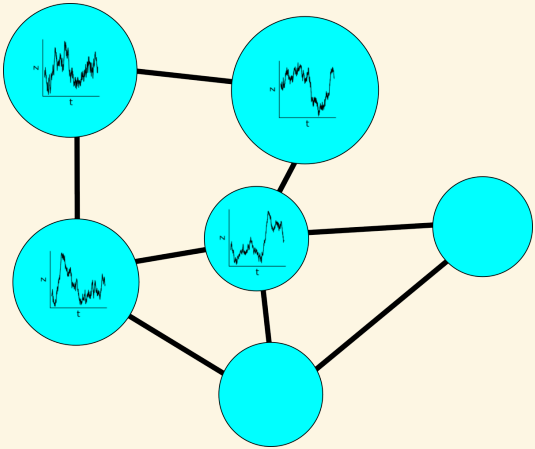

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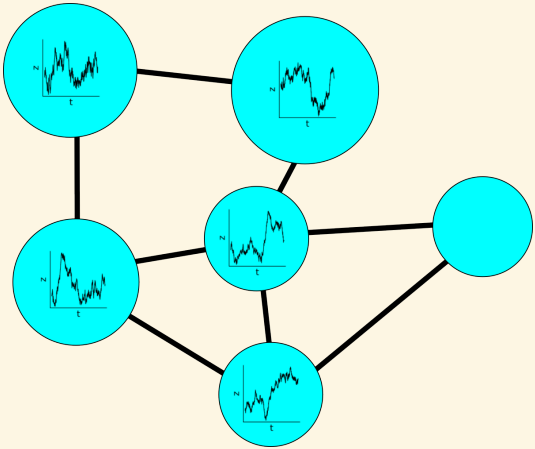

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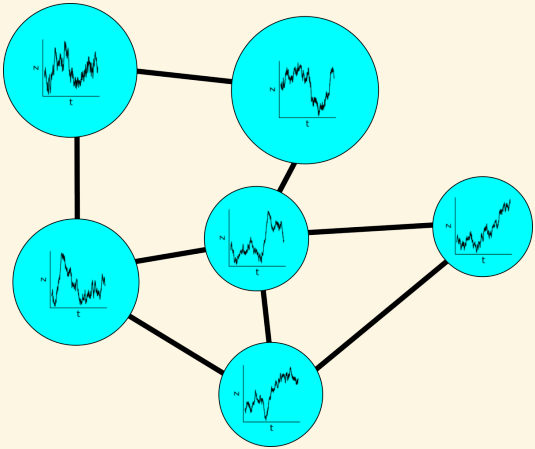
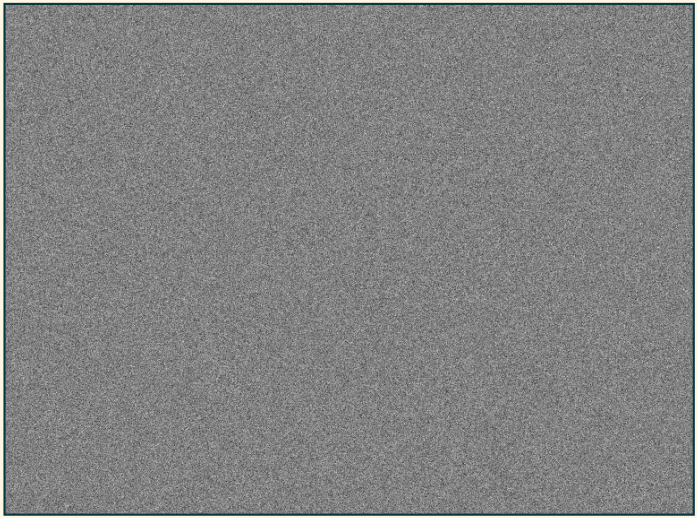


Random Genetic Drift in Continuous Space 🎲

Random Genetic Drift in Continuous Space



White Noise

Coevolution is a Consequence of Interactions

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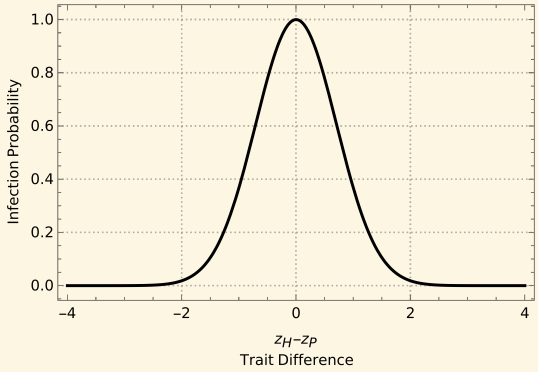
Interaction = Infection of host by parasite

Assumption: Infection Increases with Trait Similarity



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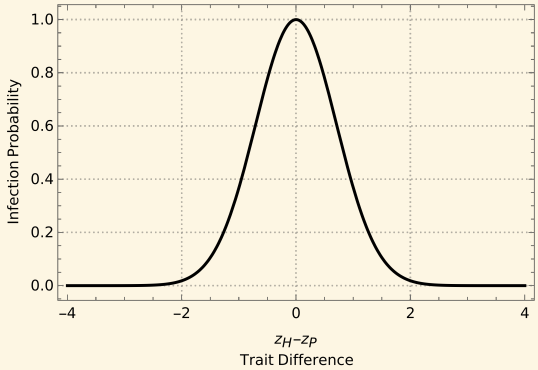

- z_H = Individual host trait

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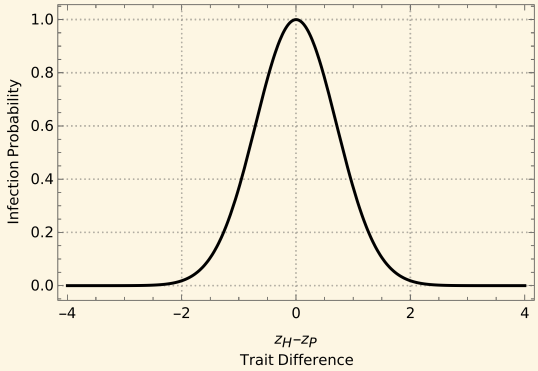
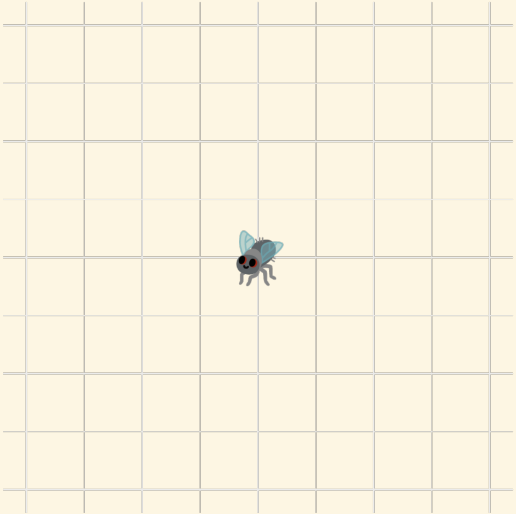


- z_H = Individual host trait
- z_P = Individual parasite trait

Assumption: Offspring Disperse Randomly Around Their Parent



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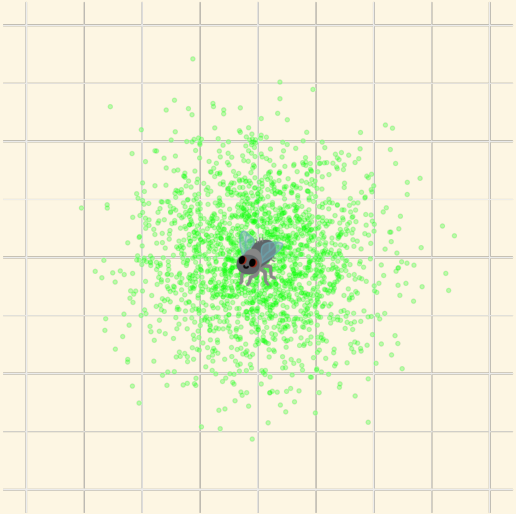

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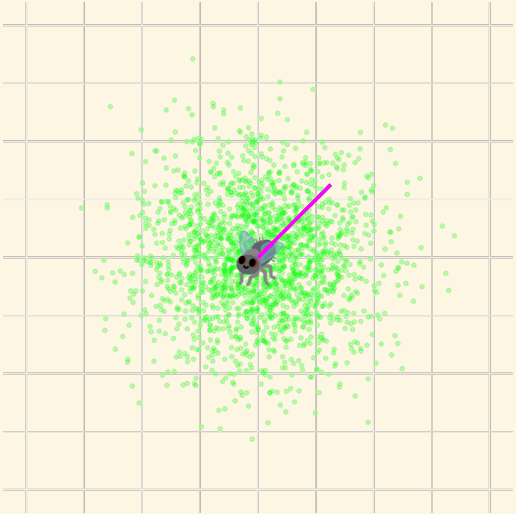

The Resulting Model

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$$\Delta \bar{z}_H$$

The Resulting Model

$$\Delta \bar{z}_H = (\text{🐜} \times \text{🪰})_H$$

The Resulting Model

$$\Delta \bar{z}_H = (\text{🐜} \times \text{🪰})_H + \text{✈️}_H$$

The Resulting Model

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The Resulting Model

$$\Delta\bar{z}_H = (\text{🐜} \times \text{🪰})_H + \text{✈️}_H + \text{🎲}_H$$

$$\Delta\bar{z}_P = (\text{🐜} \times \text{🪰})_P + \text{✈️}_P + \text{🎲}_P$$

The Resulting Model 🔗

$$\Delta\bar{z}_H = (🐜 \times 🪰)_H + ✈️_H + 🎲_H$$

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Host-Parasite Local Adaptation in Continuous Space

$$(\Delta\bar{z}_H, \Delta\bar{z}_P)$$

Host-Parasite Local Adaptation in Continuous Space

$$(\Delta\bar{z}_H, \Delta\bar{z}_P) \; + \; \mathcal{L}(\mathbf{d})$$

Result: Local Adaptation is Proportional to Cross-Covariance

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- d = Geographic distance

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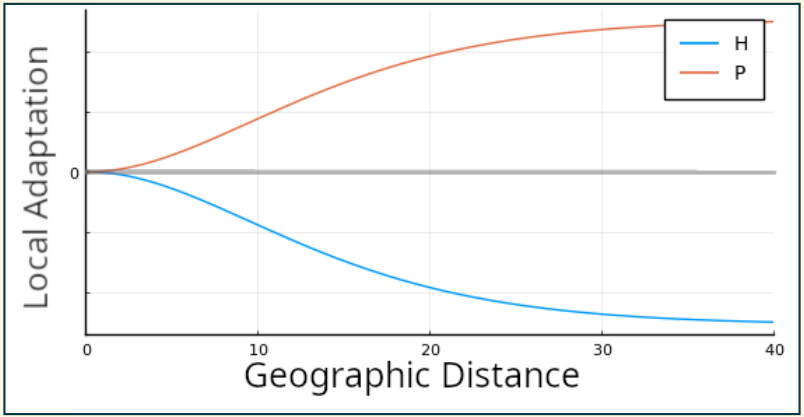
Result: Local Adaptation Depends on Spatial Distance



$$\mathcal{L}_H(d) = S_H(C_{HP}(d) - C_{HP}(0))$$

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Cross-Covariance is Crucial for Local Adaptation

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Cross-Covariance is Crucial for Local Adaptation

But what causes Cross-Covariance?

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Cross-Covariance is Crucial for Local Adaptation

But what causes Cross-Covariance? many things...

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- **Interaction strengths**

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Cross-Covariance is Crucial for Local Adaptation

But what causes Cross-Covariance? many things...

- **Interaction strengths**
- **Disperal distances**

$$\mathcal{L}_H(d) = S_H(C_{HP}(d) - C_{HP}(0))$$
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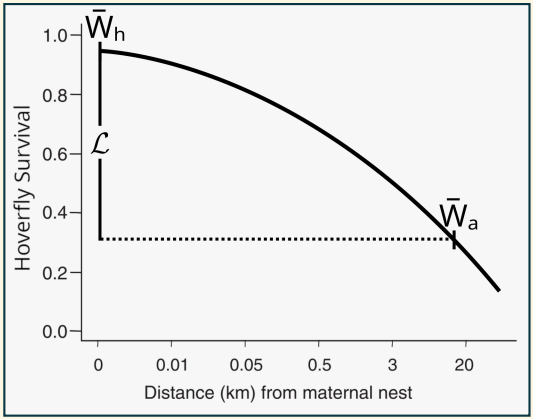
Q: What Causes Spatial Variation of Parasite Local Adaptation?



Courtesy Schönrogge et al. (2006)

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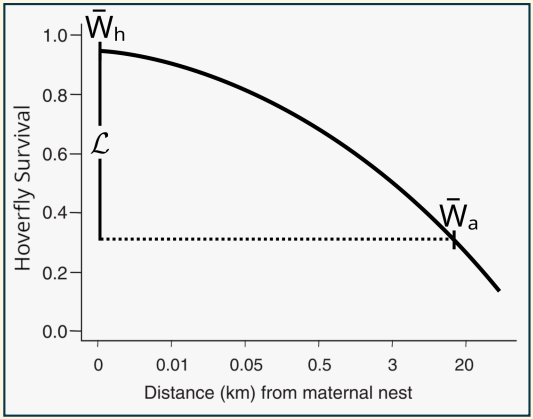
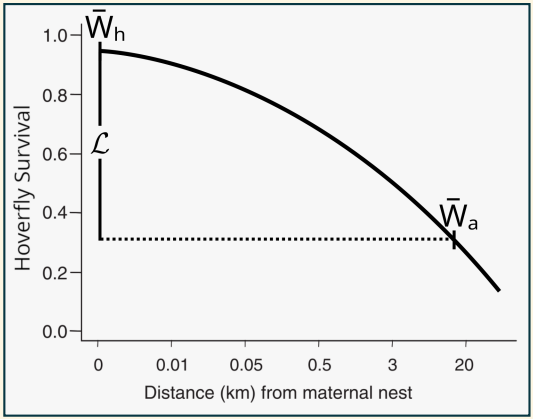


Courtesy Schönrogge et al. (2006)

A: **Cross-Covariance**

Q: What Causes Spatial Variation of Parasite Local Adaptation?



Courtesy Schönrogge et al. (2006)

A: **Dispersal×Selection**

Recap

Recap

- New continuous space index of local adaptation $\mathcal{L}$**(d)**

Recap

- New continuous space index of local adaptation $\mathcal{L}(d)$
- New model of spatial host-parasite coevolution 🐜×🪰

Recap

- New continuous space index of local adaptation $\mathcal{L}(d)$
- New model of spatial host-parasite coevolution 🐜×🪰
- An explanation for spatial variation of parasite local adaptation

See Paper for Full Story

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Host-Parasite Coevolution in Continuous Space Leads to Variation in Local Adaptation across Spatial Scales

Bob Week[1,*] and Gideon Bradburd[2]

Part 2: Microbiome-Mediated Host Adaptation

Examples of Microbiome-Mediated Host Traits

Examples of Microbiome-Mediated Host Traits

Human gut microbiome
aids in nutrient absorption

Examples of Microbiome-Mediated Host Traits

Human gut microbiome
aids in nutrient absorption

Fish skin microbiome
protects against pathogens

Hosts Inherit Microbes Differently from Genes

Inheritance of Genes

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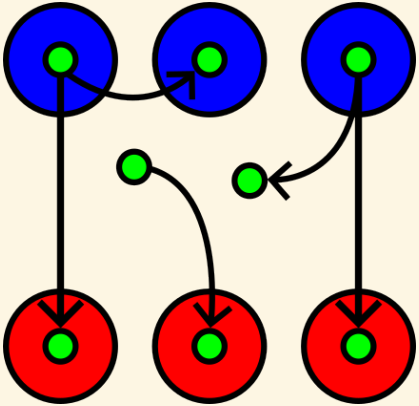
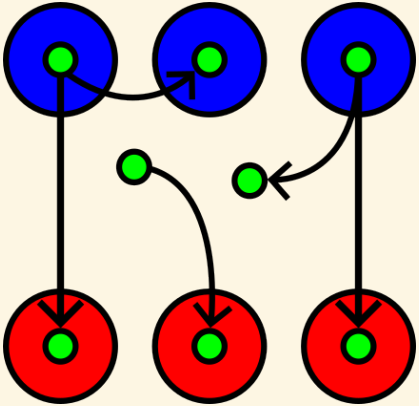
Inheritance of Genes



Inheritance of Microbes

How do Microbiome-Mediated Host Traits Evolve?

Inheritance of Genes



Inheritance of Microbes

A Model of Microbiome-Mediated Trait Evolution

Three Main Components:

A Model of Microbiome-Mediated Trait Evolution

Three Main Components:

- Host Life-Cycle ♻

A Model of Microbiome-Mediated Trait Evolution

Three Main Components:

- Host Life-Cycle ♻️
- Host Trait Architecture 🏗️

A Model of Microbiome-Mediated Trait Evolution

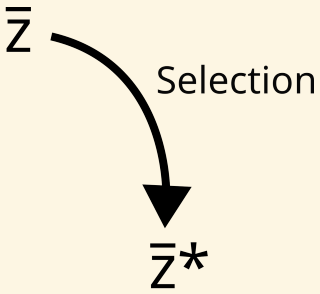
Three Main Components:

- Host Life-Cycle ♻️
- Host Trait Architecture 🏗️
- Microbiome Inheritance 🦠

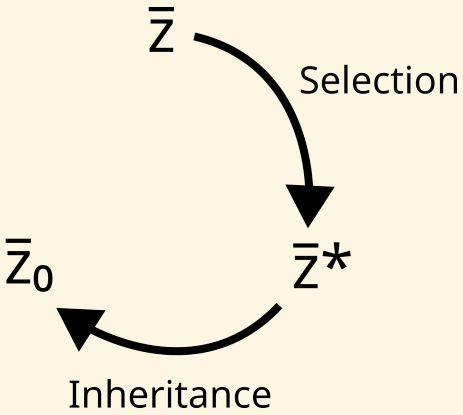
Host Life-Cycle ♻️

$\bar{z}$

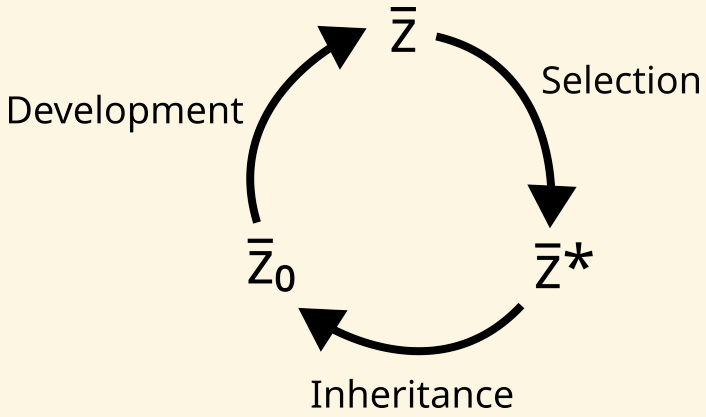
Host Life-Cycle ♻️



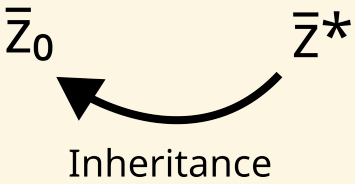
Host Life-Cycle ♻️



Host Life-Cycle ♻️



Host Life-Cycle ♻️



Host Trait Architecture 🏗️

Z =

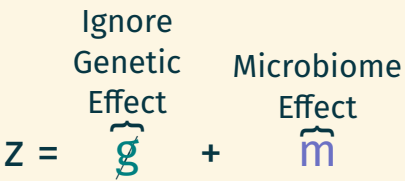
Host Trait Architecture 🏗️

$$z = \overbrace{g}^{\text{Genetic Effect}}$$

Host Trait Architecture 🏗️

$$z = \overbrace{g}^{\text{Genetic Effect}} + \overbrace{m}^{\text{Microbiome Effect}}$$

Host Trait Architecture 🏗️



Focusing on Microbiome Effect

$$z = m$$

Microbiome Inheritance

Three Main Components:

Microbiome Inheritance

Three Main Components:

- Parent-Offspring Transmission

Microbiome Inheritance 🦠

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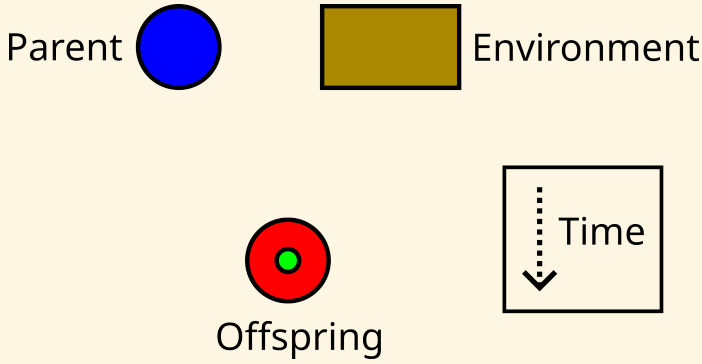
- Parent-Offspring Transmission
- Shedding into Environment

Microbiome Inheritance 🦠

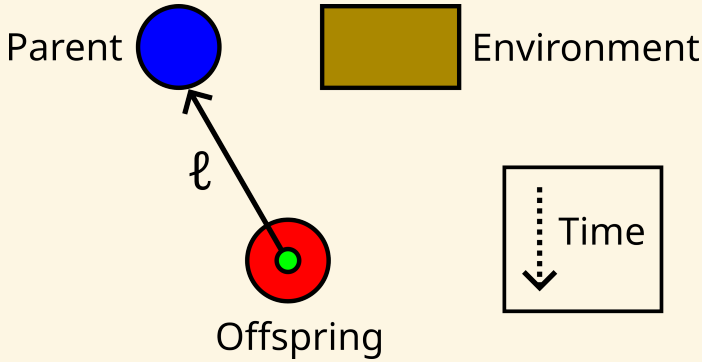
Three Main Components:

- Parent-Offspring Transmission
- Shedding into Environment
- Acquisition from Environment

Microbes Acquired from Parent or Environment



Microbes Acquired from Parent or Environment



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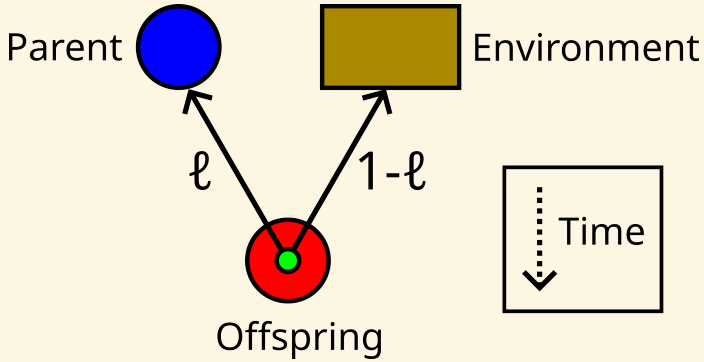
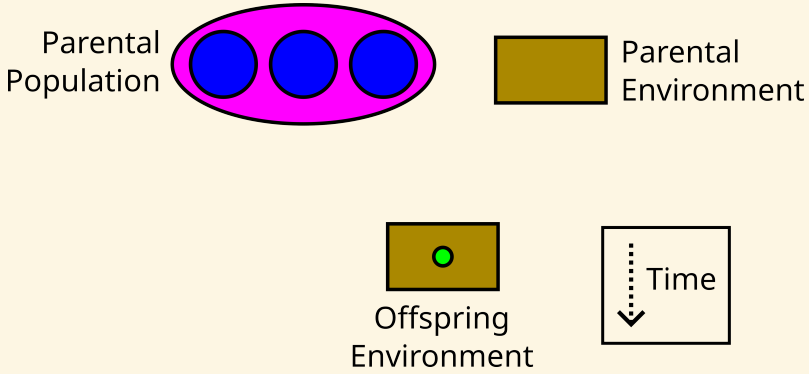


Environmental Microbiome Shaped by Host Shedding



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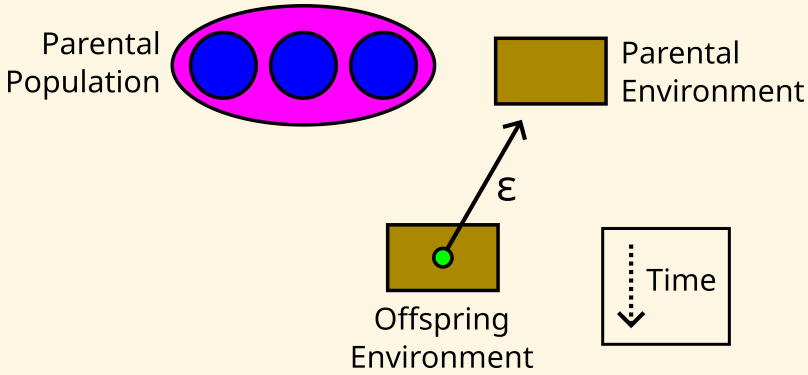

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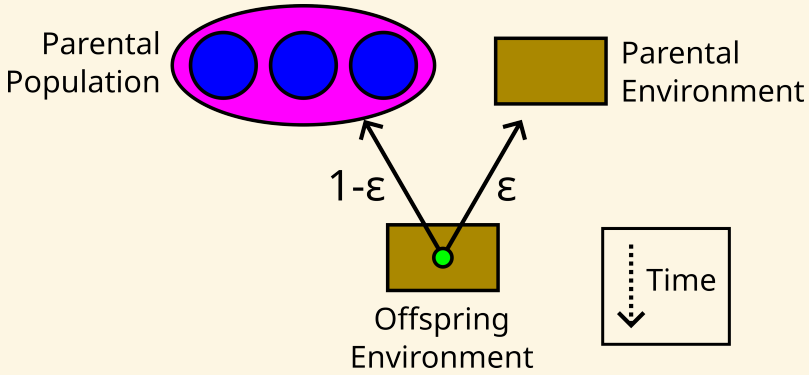
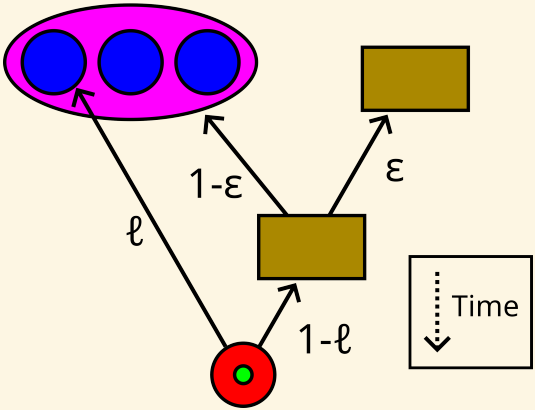


A Model of Microbiome Inheritance



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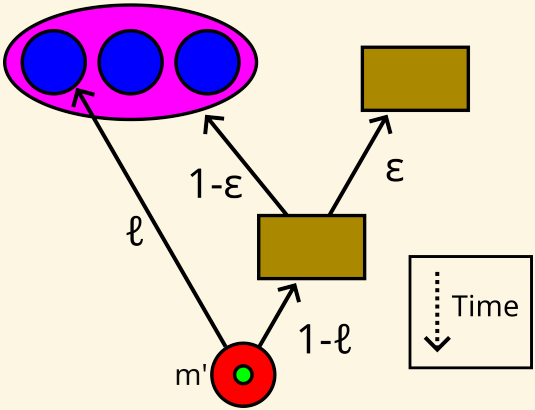

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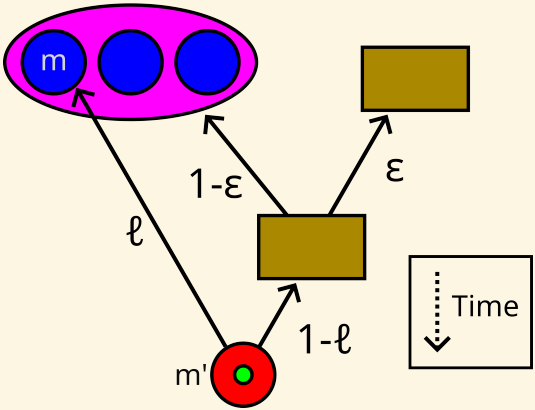

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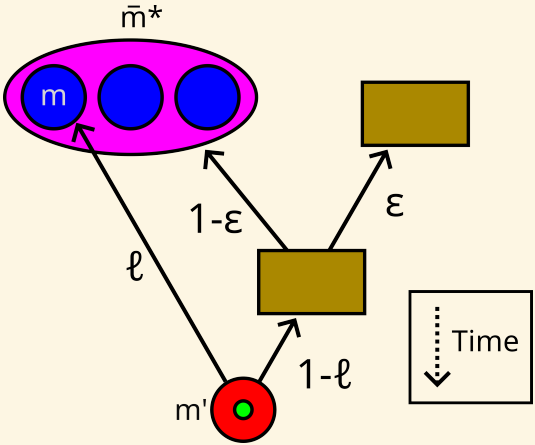

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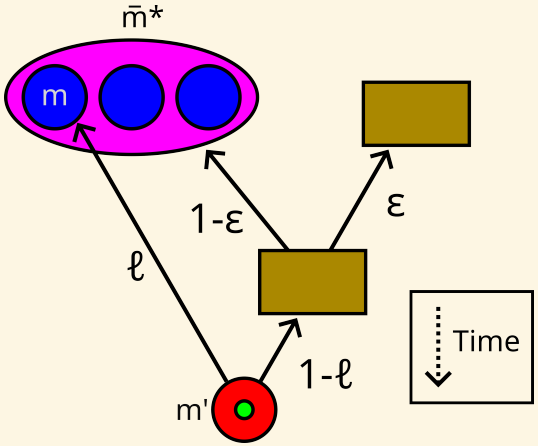
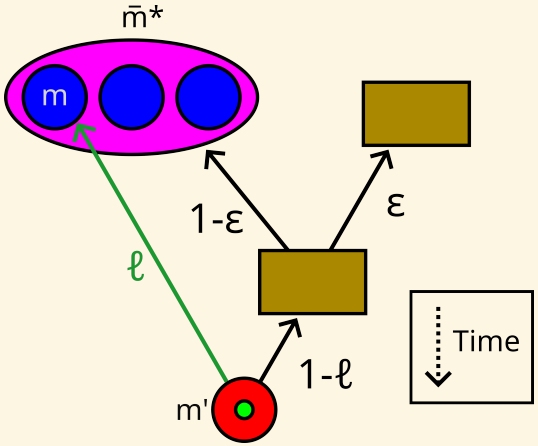


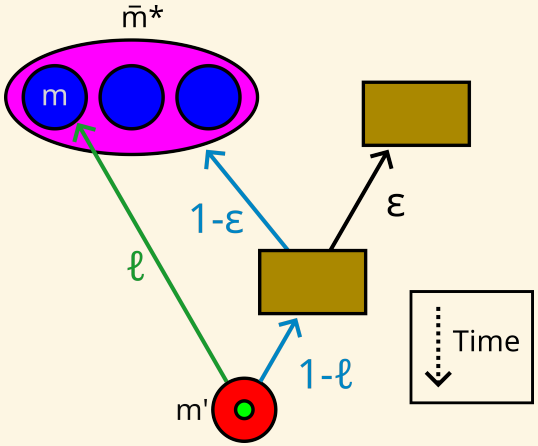
m′ =

A Model of Microbiome Inheritance



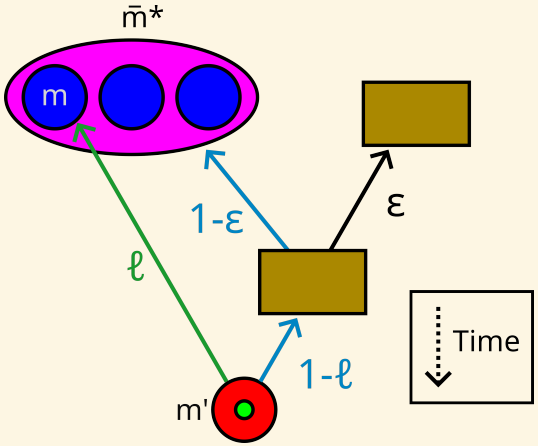
$m' = \ell m$

A Model of Microbiome Inheritance



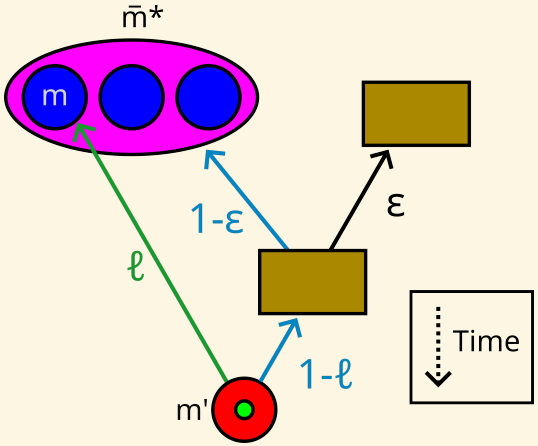
$$m' = \ell m + (1 - \ell)(1 - \varepsilon)\bar{m}^*$$

A Model of Microbiome Inheritance



$$m' = \ell m + (1 - \ell)(1 - \varepsilon)\bar{m}^* + E$$

Microbiome-Mediated Trait Evolution



$$\bar{m}' = \ell\bar{m}^* + (1 - \ell)(1 - \varepsilon)\bar{m}^* + E$$

Result: Adaptation Happens Without Parent-Offspring Transmission

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Result: Adaptation Happens Without Parent-Offspring Transmission

$$\bar{m}' = \ell\bar{m}^* + (1 - \ell)(1 - \varepsilon)\bar{m}^* + E$$

$\ell = 0$

Result: Adaptation Happens Without Parent-Offspring Transmission

$$\bar{m}' = (1 - \varepsilon)\bar{m}^* + E$$

$\ell = 0$

Result: Adaptation Happens Without Parent-Offspring Transmission

$$\bar{m}' = (1 - \varepsilon)\bar{m}^* + E$$

$\ell = 0 \implies$ No parent-offspring resemblance

See Preprint for Full Story

The Evolution of Microbiome-Mediated Traits

Bob Week, Andrew H. Morris, Brendan J. M. Bohannan

Conclusion

Conclusion

Host-Parasite Local Adaptation

$$\mathcal{L}_H(d) = S_H(C_{HP}(d) - C_{HP}(0))$$

$$\mathcal{L}_P(d) = S_P(C_{HP}(0) - C_{HP}(d))$$

Conclusion

Host-Parasite Local Adaptation

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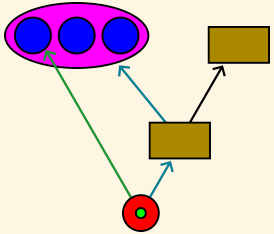
Microbiome-Mediated Evolution



Thanks!

Brendan Bohannan

Karen Adair

Caitlin Smith

Bill Cresko

Peter Ralph

Sophia Lambert

Thanks!Thanks!

Thanks!Thanks!Thanks!

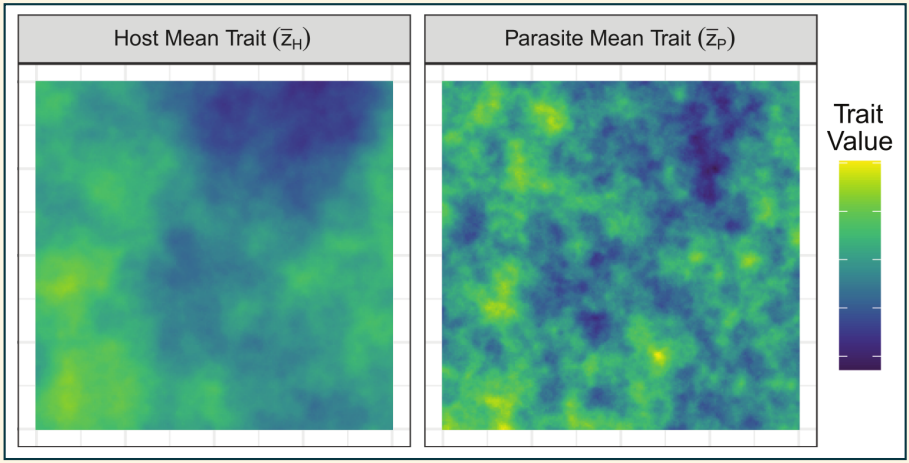
Hinrich Schulenburg

Lingfeng Meng

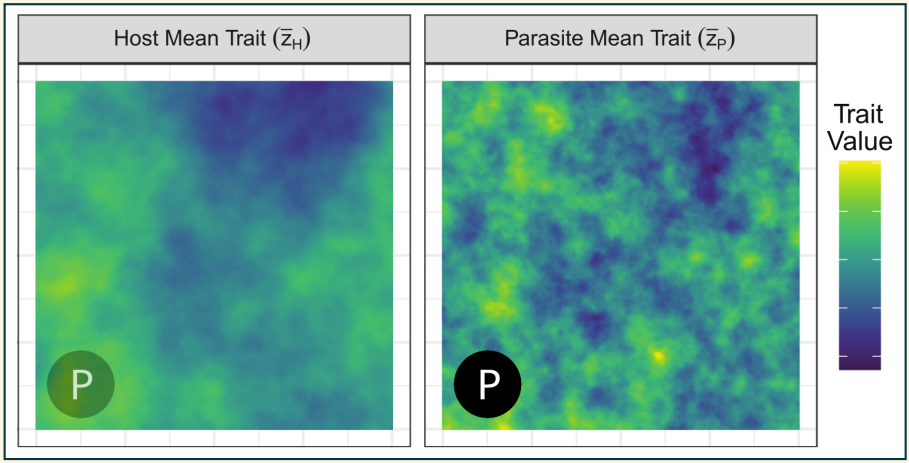
Sabrina Koehler

Questions???

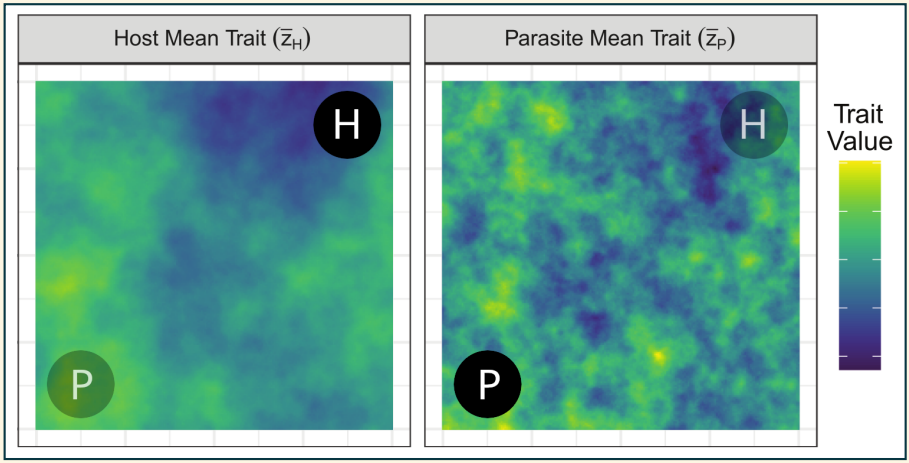
Spatial Cross-Covariance Between Species, $C_{HP}(d)$



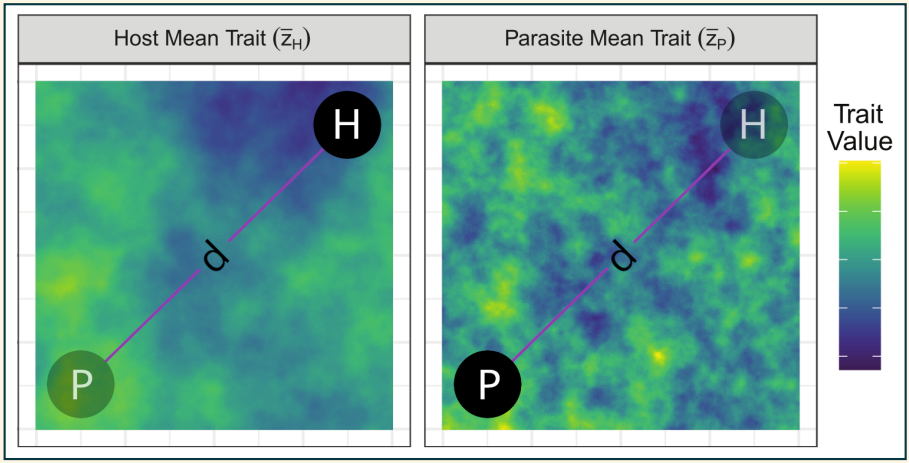
Spatial Cross-Covariance Between Species, $C_{HP}(d)$



Spatial Cross-Covariance Between Species, $C_{HP}(d)$

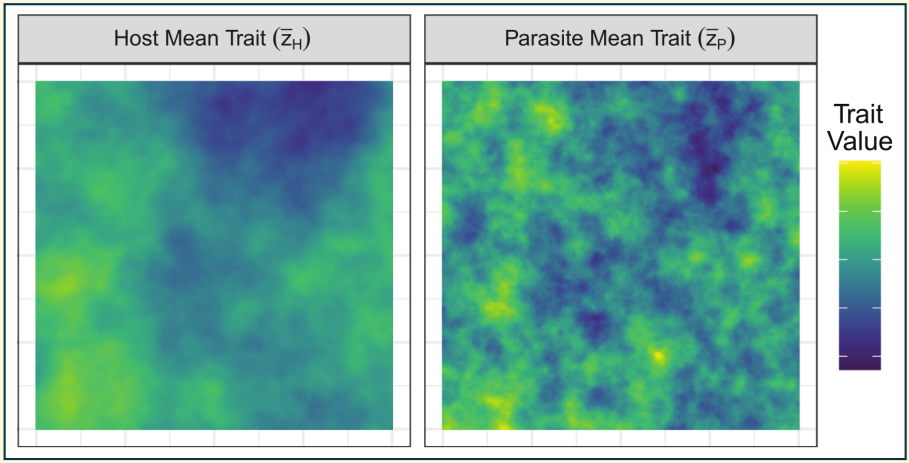


Spatial Cross-Covariance Between Species, $C_{HP}(d)$

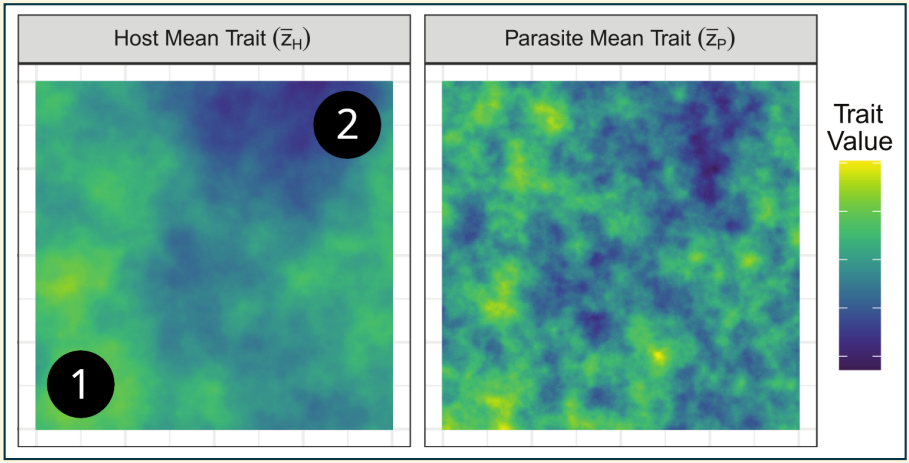


$C_{HP}(d)$ = covariance of ***host*** & ***parasite*** traits separated by distance d

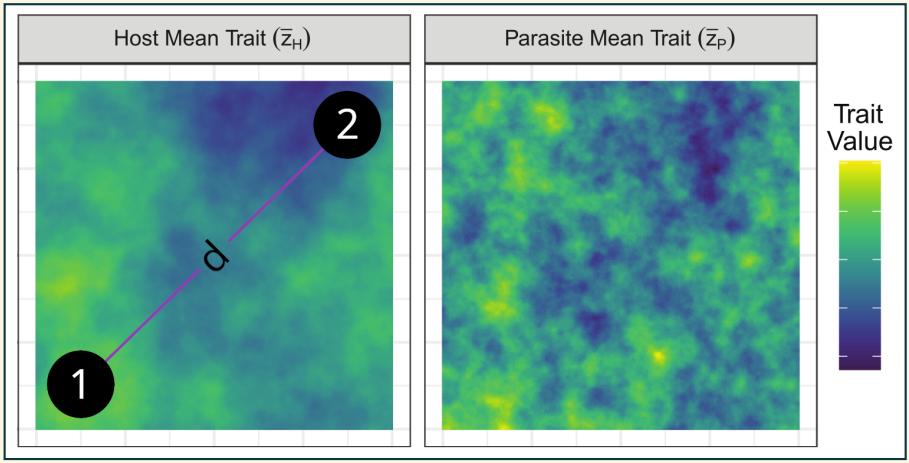
Spatial Auto-Covariance of Host Mean Trait, $C_H(d)$



Spatial Auto-Covariance of Host Mean Trait, $C_H(d)$

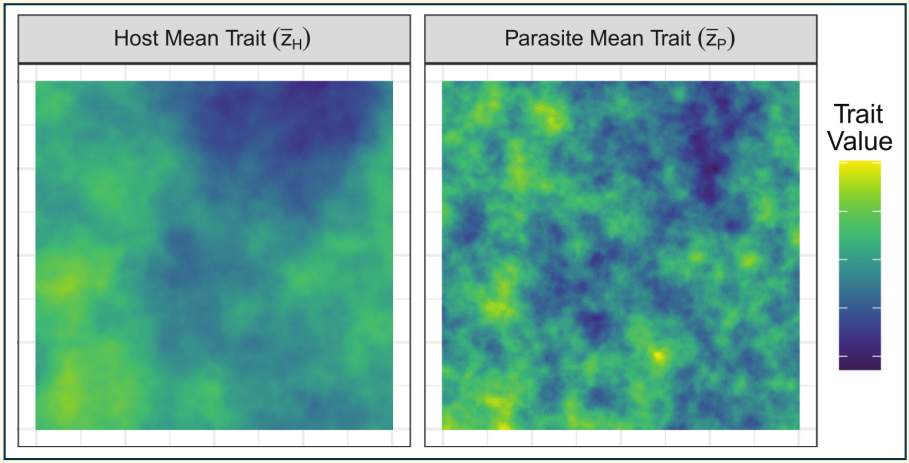


Spatial Auto-Covariance of Host Mean Trait, $C_H(d)$

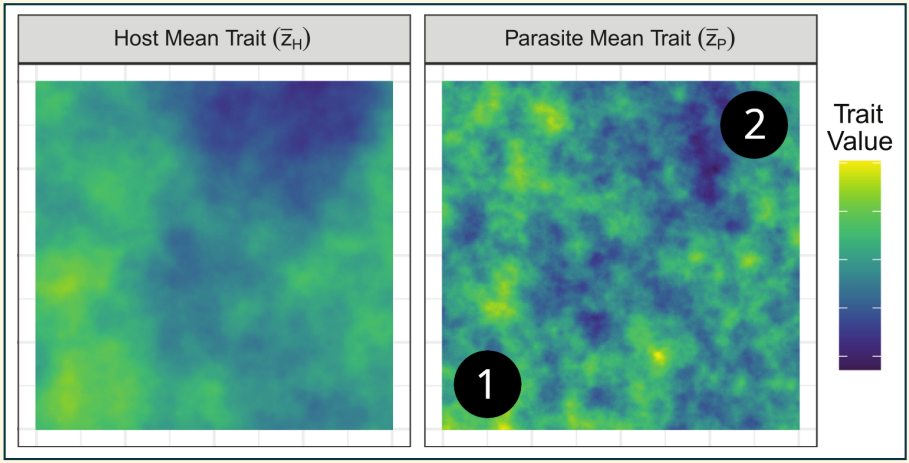


$C_H(d)$ = covariance of ***host*** traits separated by distance d

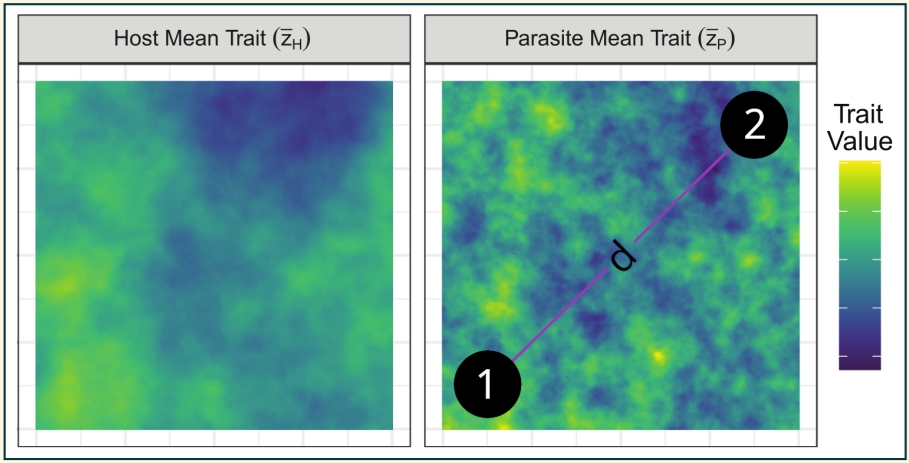
Spatial Auto-Covariance of Parasite Mean Trait, $C_P(d)$



Spatial Auto-Covariance of Parasite Mean Trait, $C_P(d)$

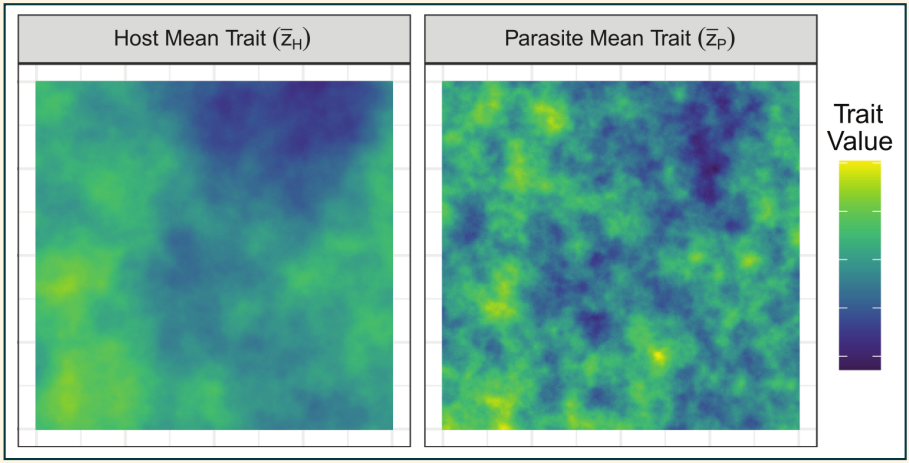


Spatial Auto-Covariance of Parasite Mean Trait, $C_P(d)$

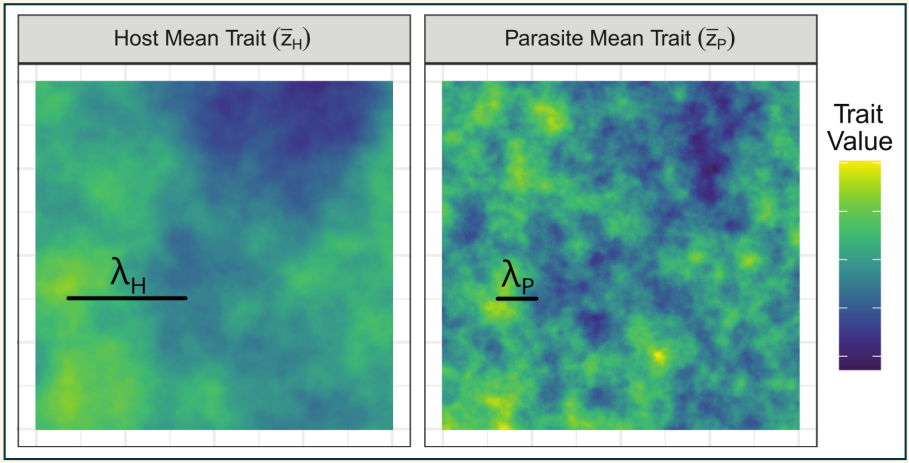


$C_P(d)$ = covariance of ***parasite*** traits separated by distance d

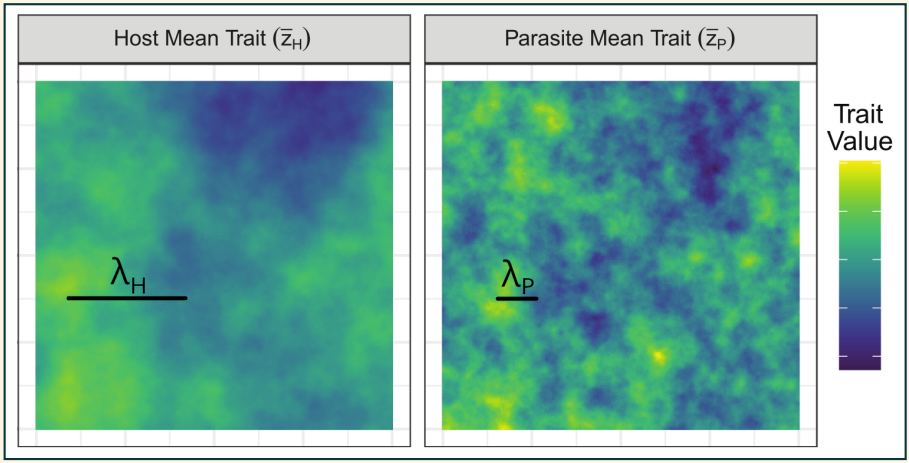
Characteristic Length of Auto-Covariance, λ



Characteristic Length of Auto-Covariance, λ

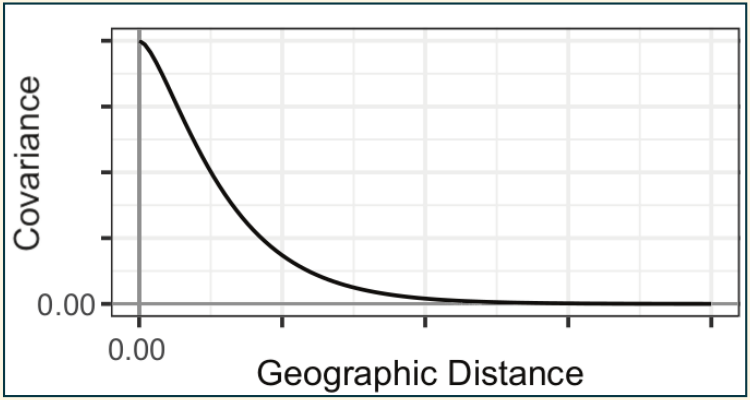


Characteristic Length of Auto-Covariance, λ



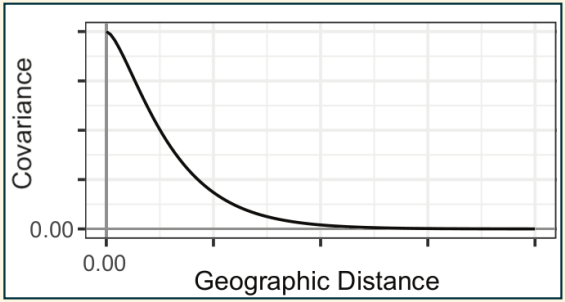
λ = spatial scale at which mean traits vary

Result: Auto-Covariances Described by Matern Functions



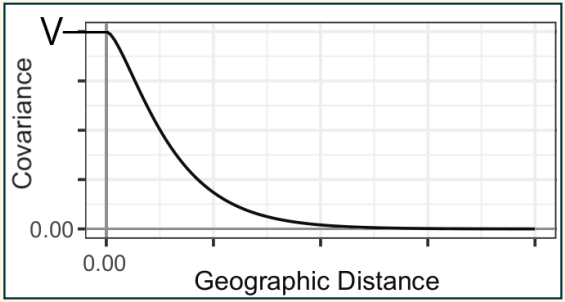
Plot of Matern Covariance Function

Result: Auto-Covariances Described by Matern Functions



Matern paramaterized by

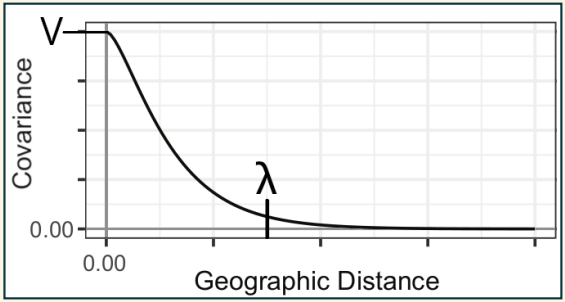
Result: Auto-Covariances Described by Matern Functions



Matern paramaterized by

- V = Colocated trait variance

Result: Auto-Covariances Described by Matern Functions



Matern paramaterized by

- V = Colocated trait variance
- λ = Characteristic length

Characteristic Length Determines Resolution of Spatial Variation