Lizards and Lyme disease risk

- Diana Erazo
- Luisa Carrillo Rodriguez
- Marilia Palumbo Gaiarsa
- Paula Ribeiro Prist
- Rodrigo Mazzei Carvalho

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- 2. Lyme disease
- 3. Asymmetric mating
- 4. Nurse plants
- 5. Reproductive tactics
- 6. Manipulative parasites
- 7. Esporulation
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Group 2

Lizards and Lyme disease risk

Wiki site of the practical exercise of the III Southern-Summer School on Mathematical Biology.

Here you will find the exercise assignment and the group's products.

If you are a group member login to edit this page, create new pages from it, and upload files.

Group

- Carvalho, Rodrigo Mazzei; *Federal University of Bahia, Biology Institute, Brazil*
- Castro, Danielle; *University of São Paulo, School of Public Health, Brazil*
- Erazo, Diana; *BIOMAC, Universidad de los Andes, Colombia*
- Gaiarsa, Marilia Palumbo; *University of São Paulo, Ecology Department, Brazil*
- Prist, Paula Ribeiro; *University of São Paulo, Ecology Department, Brazil*
- Rodriguez Carrillo, Luisa Fernanda; *National University of Colombia, Mathematics Dept., Colombia*

Assistants

- Bruno Pace
- Renato Coutinho

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Impact of the experimental removal of lizards on Lyme disease risk

Andrea Swei[1,*], Richard S. Ostfeld[2], Robert S. Lane[3] and Cheryl J. Briggs[4]

[1]*Department of Integrative Biology, University of California, 3060 Valley Life Sciences Building, Berkeley, CA 94720-3140, USA*

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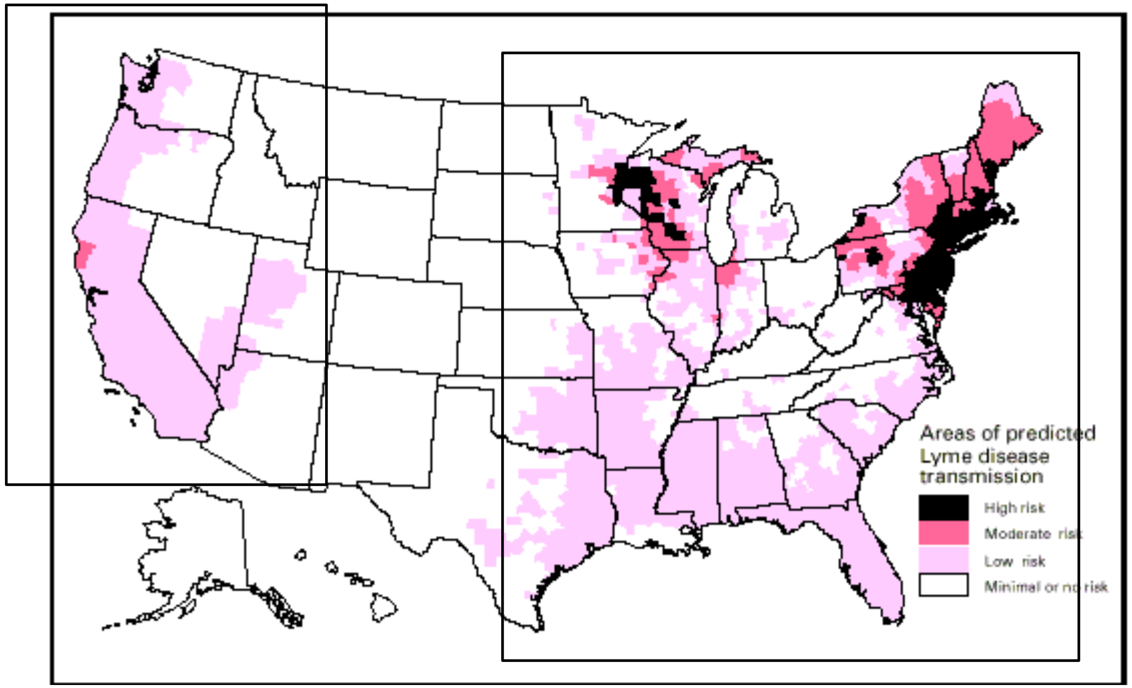
[3]*Department of Environmental Science, Policy and Management, University of California, Berkeley, CA 94720, USA*

[4]*Department of Ecology, Evolution, and Marine Biology, University of California, Santa Barbara, CA 93106-9610, USA*

Introduction

It is an important public health issue in the US, where it is the most common vector-borne disease



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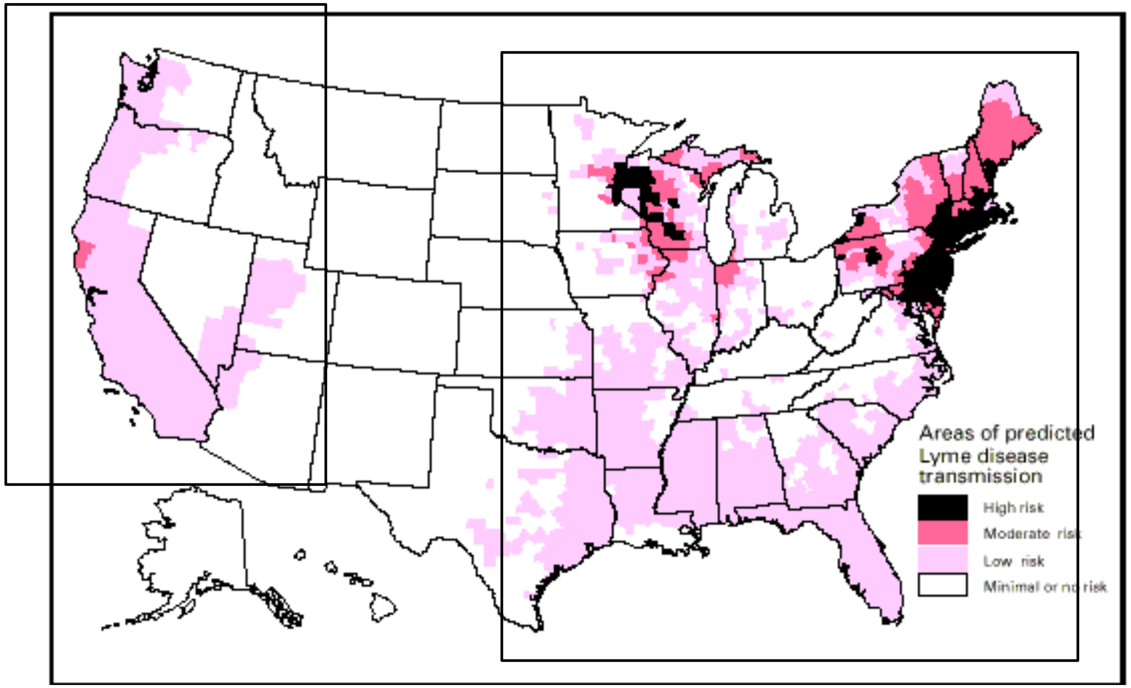

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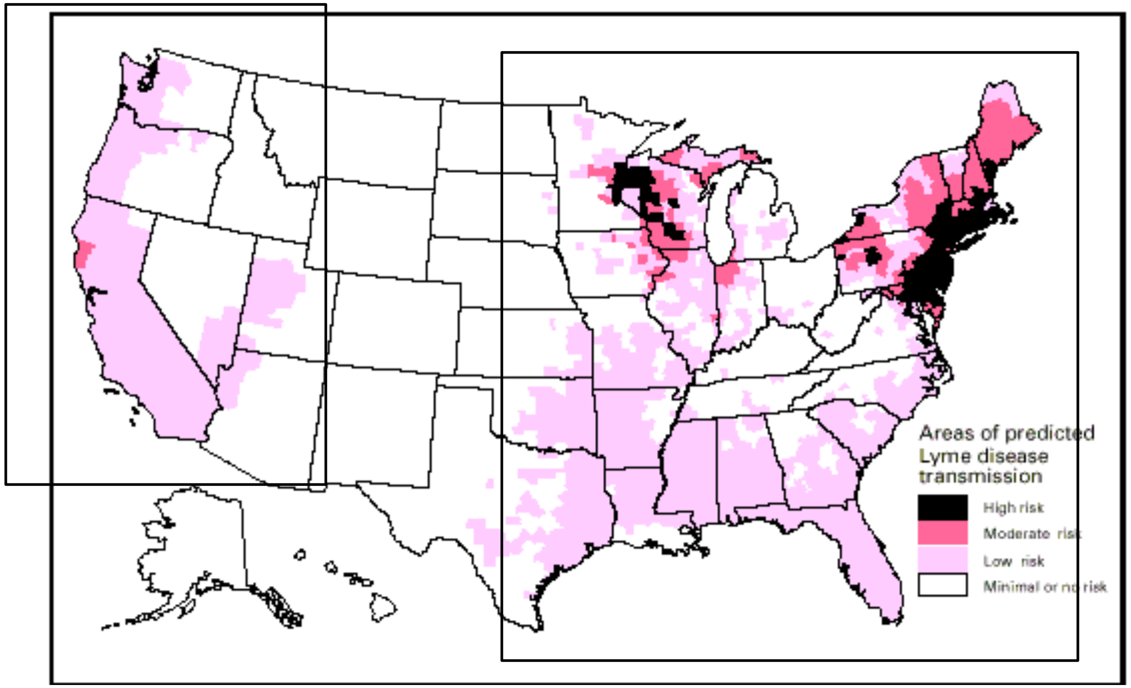

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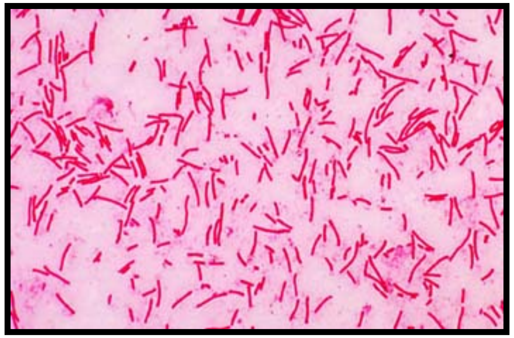
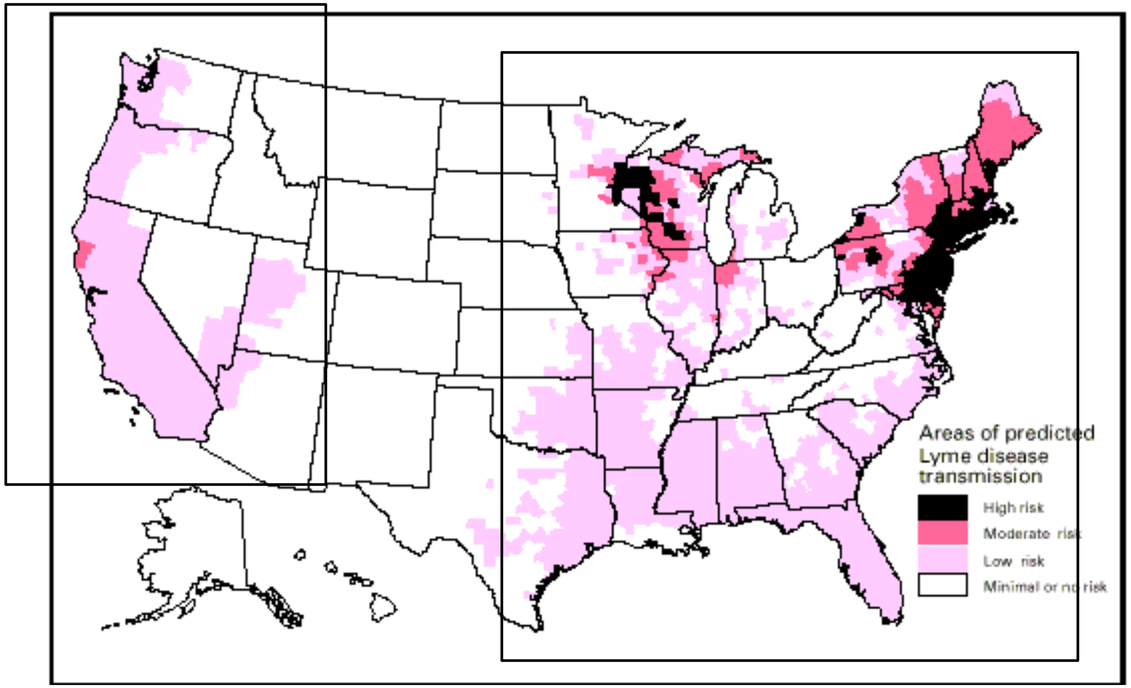


Borrelia burgdorferi



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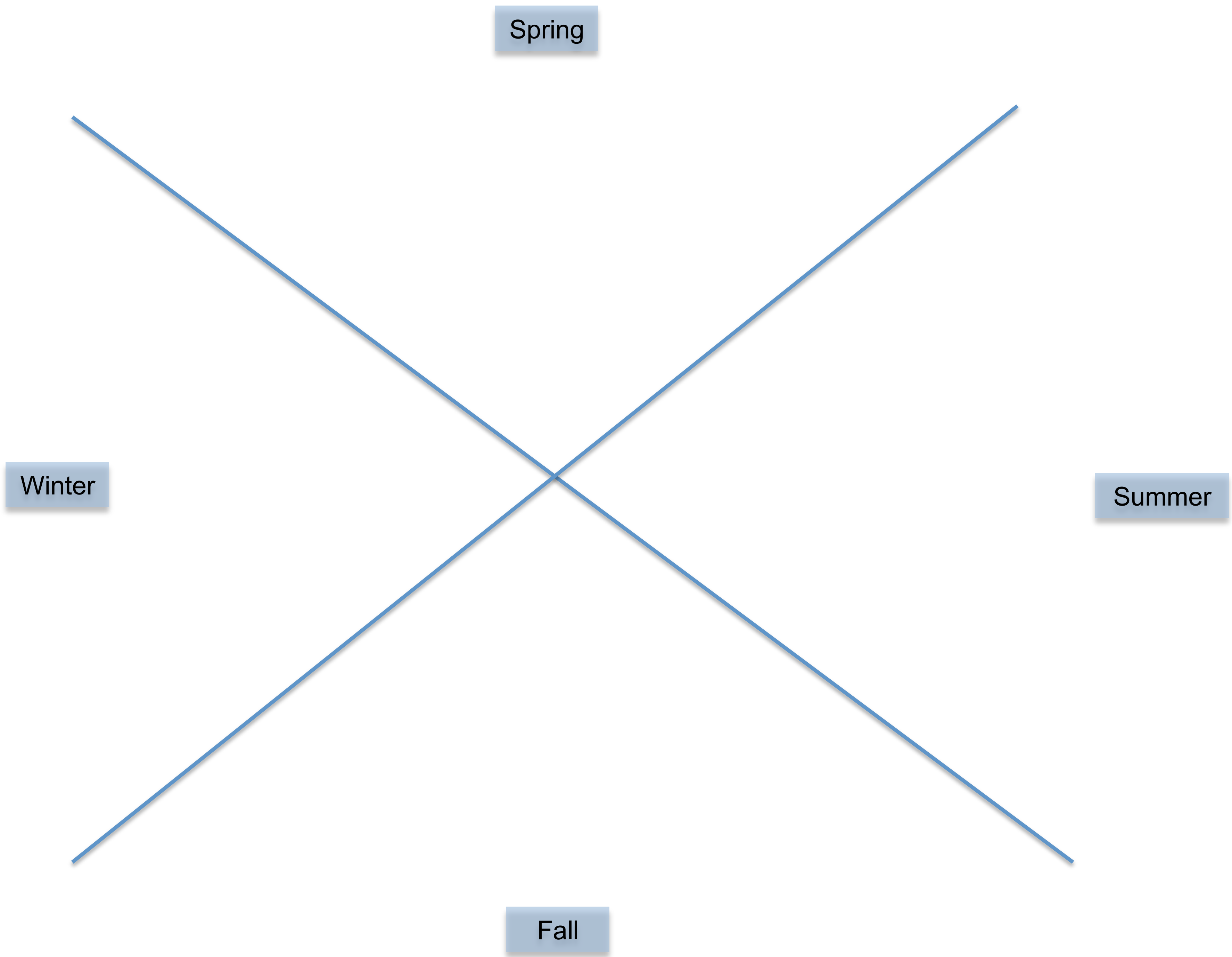
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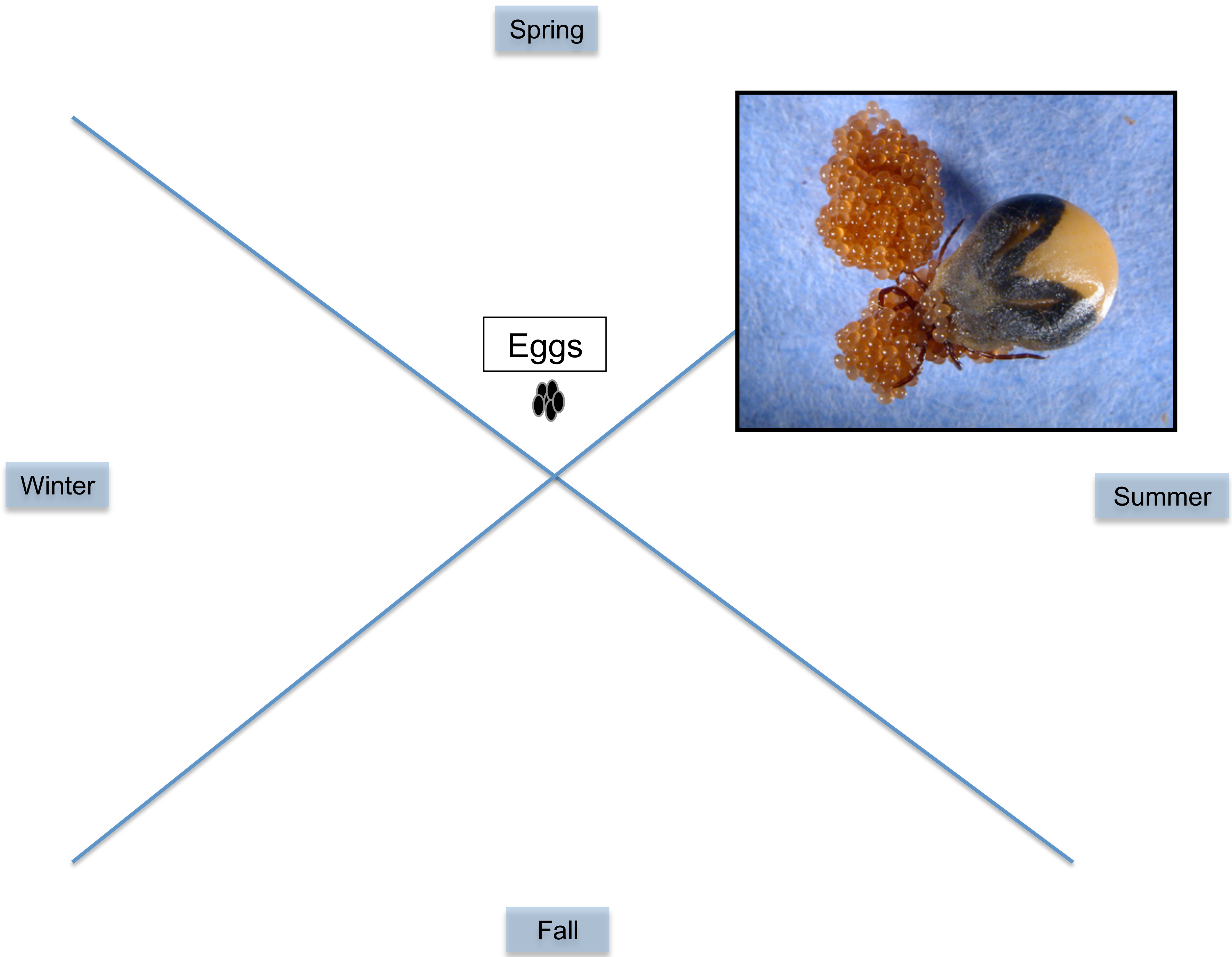
Fall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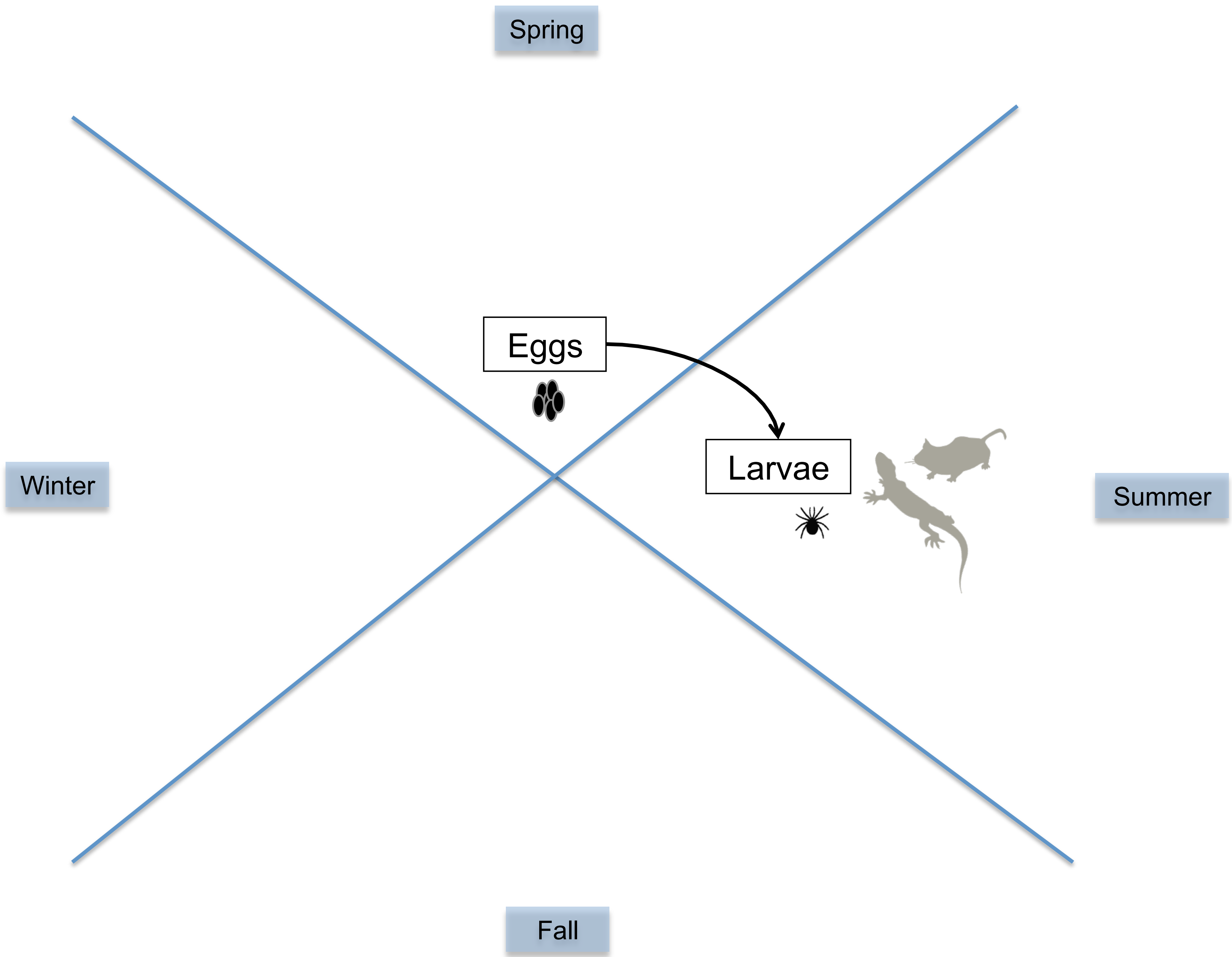
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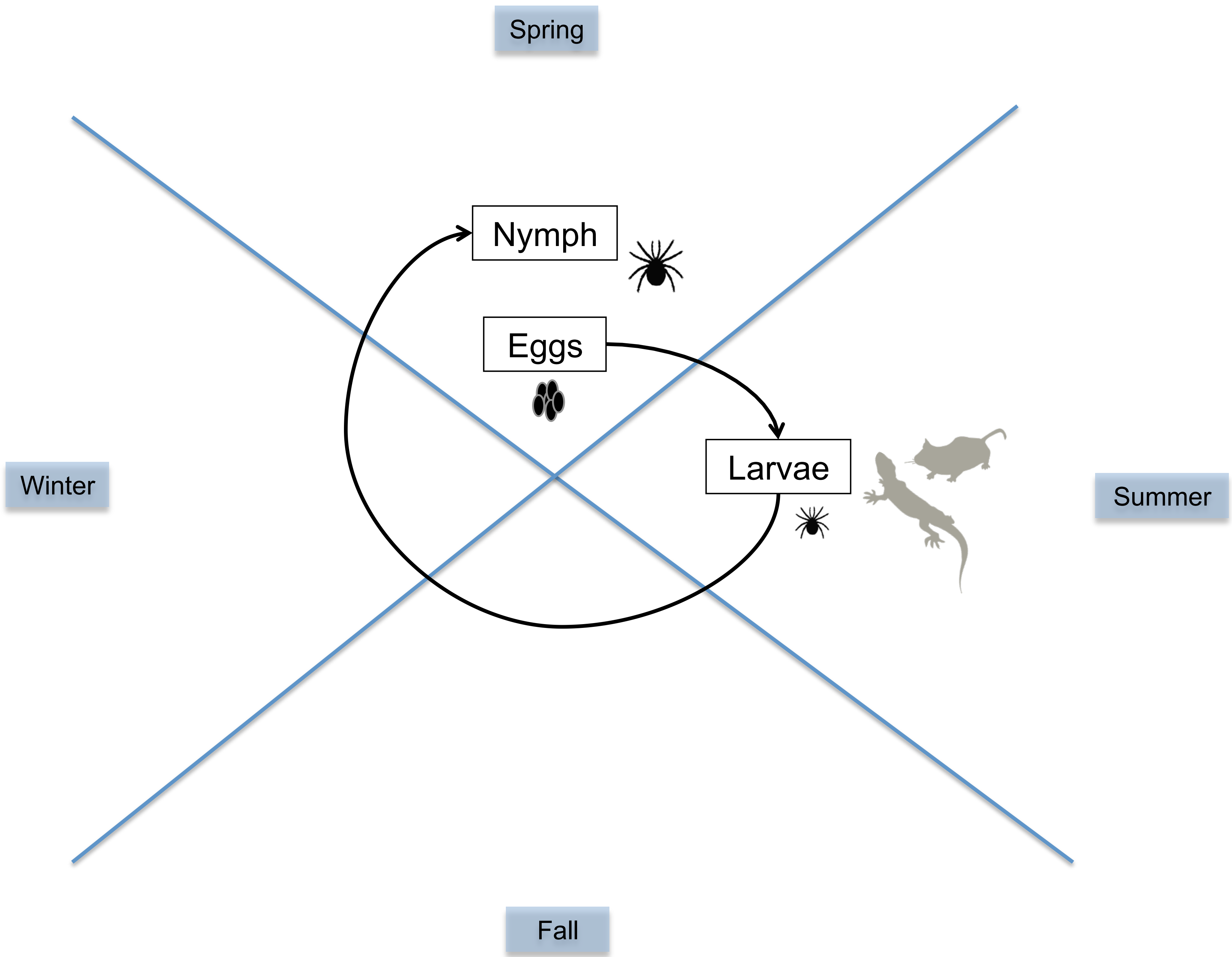

Spring
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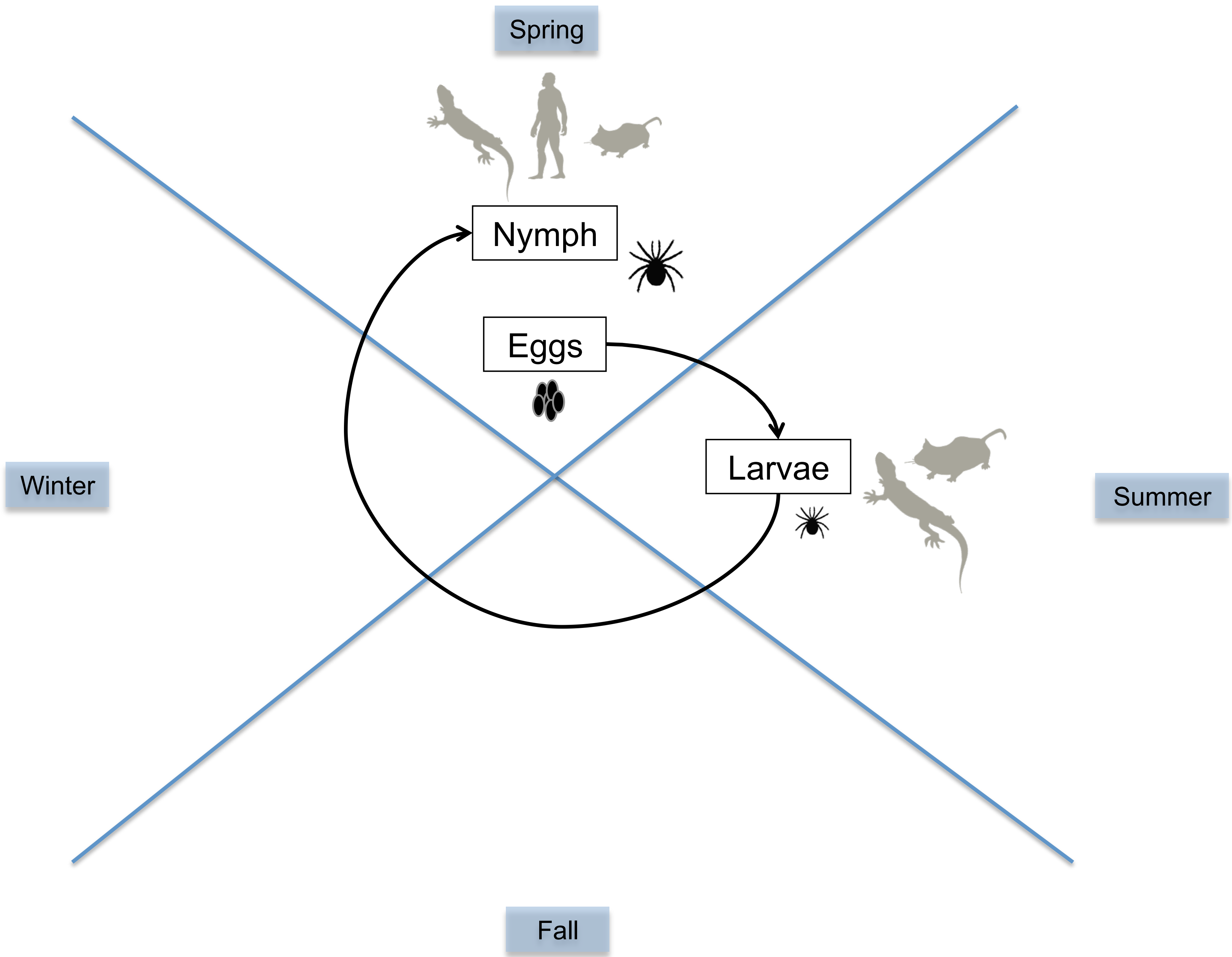
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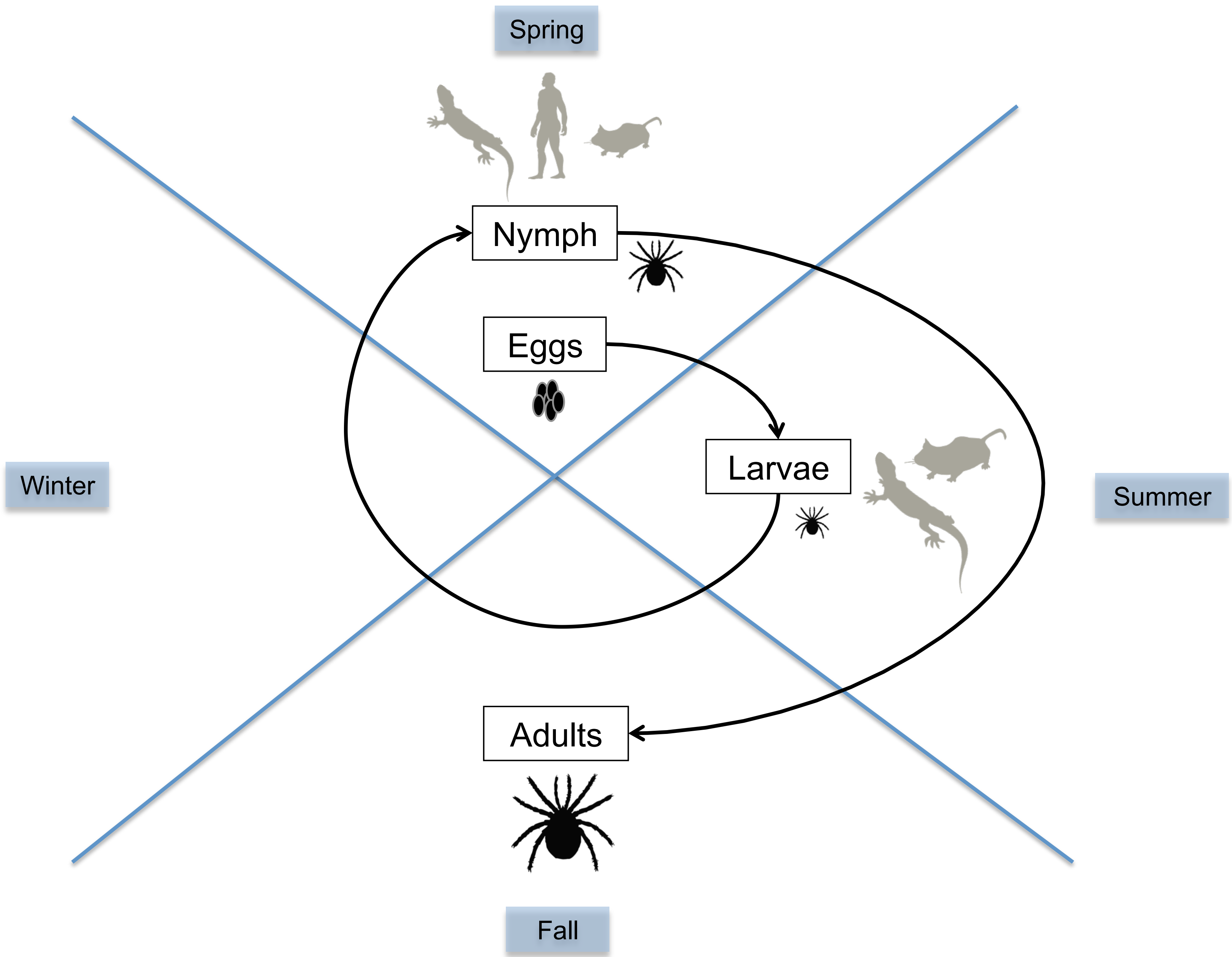
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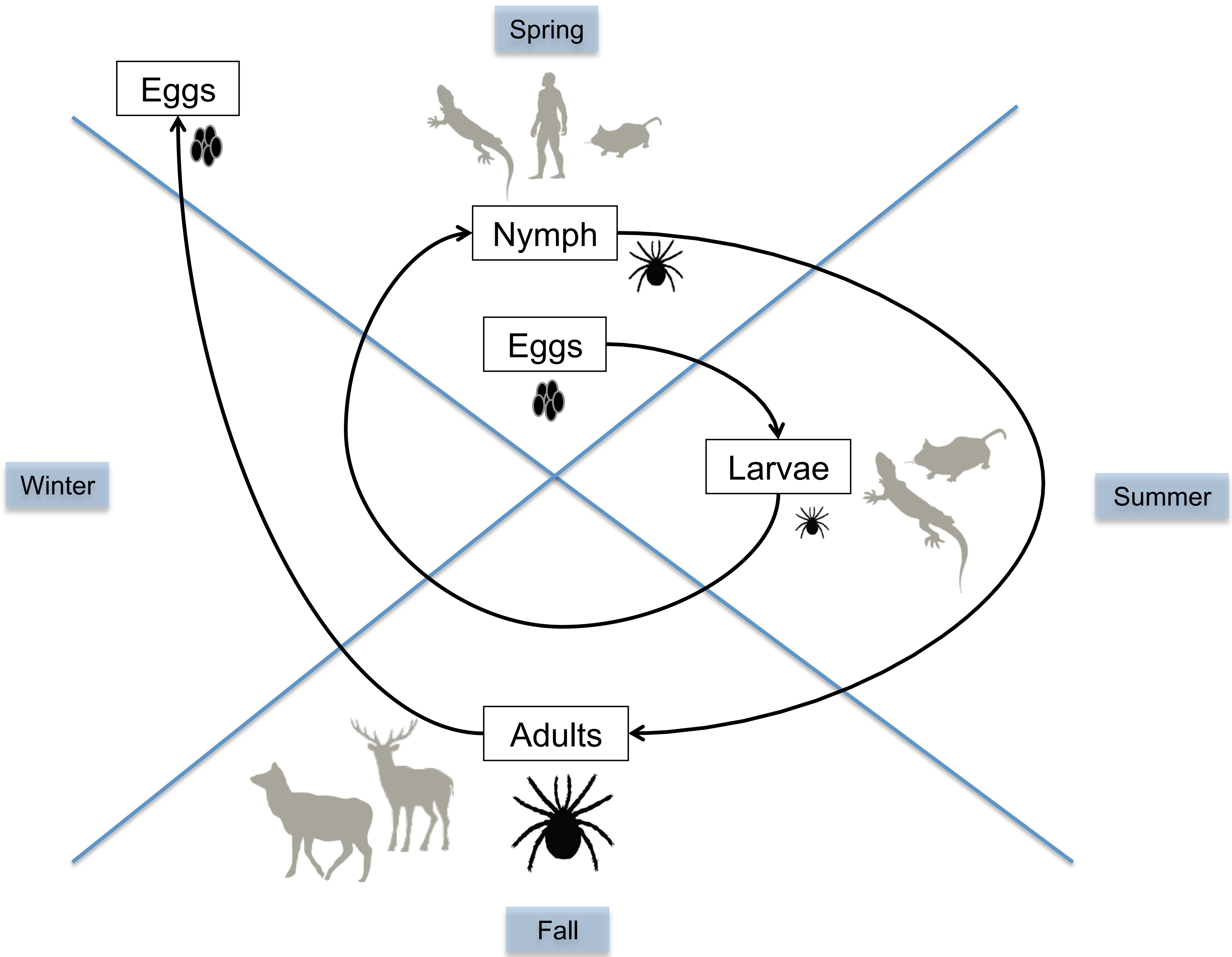

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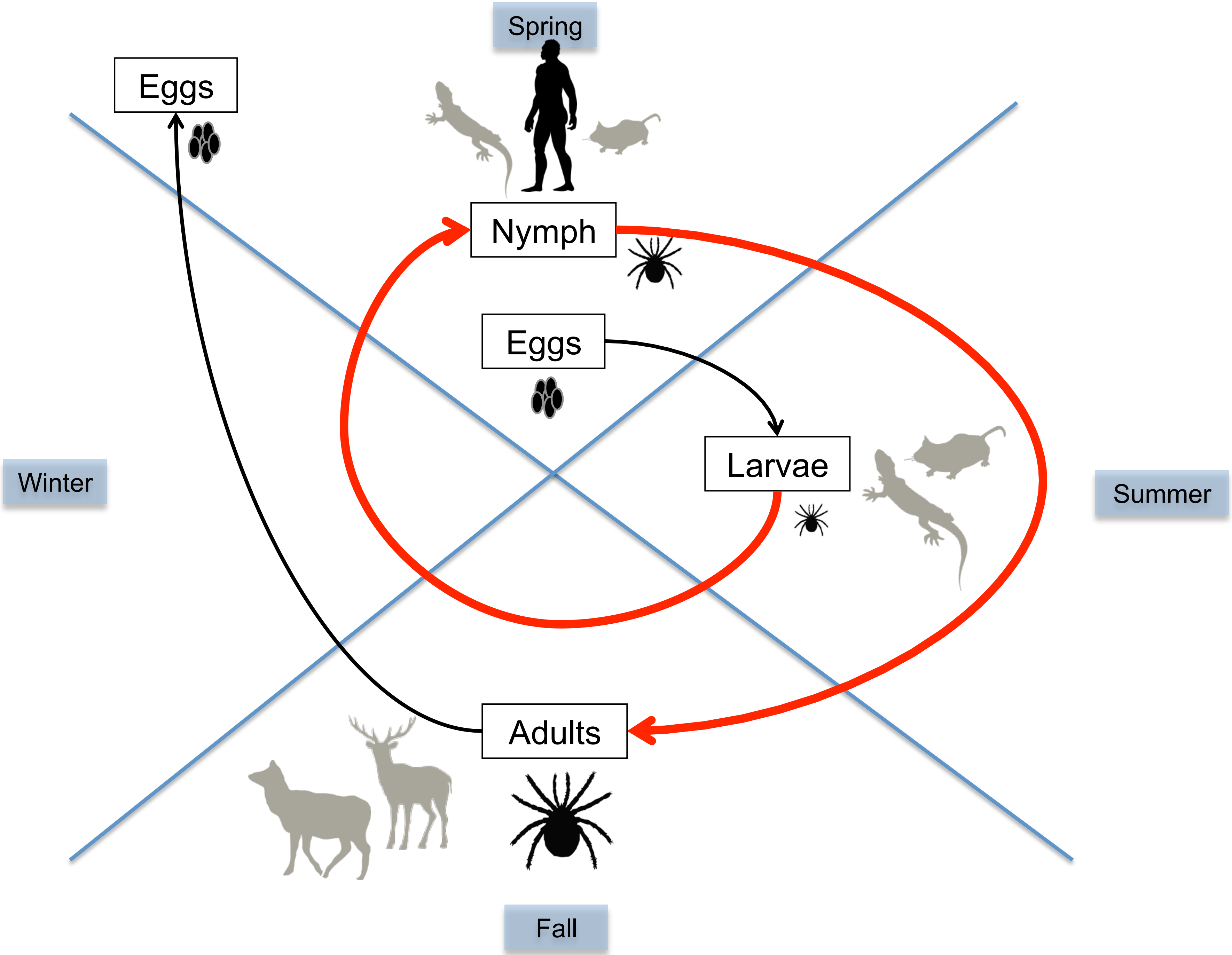
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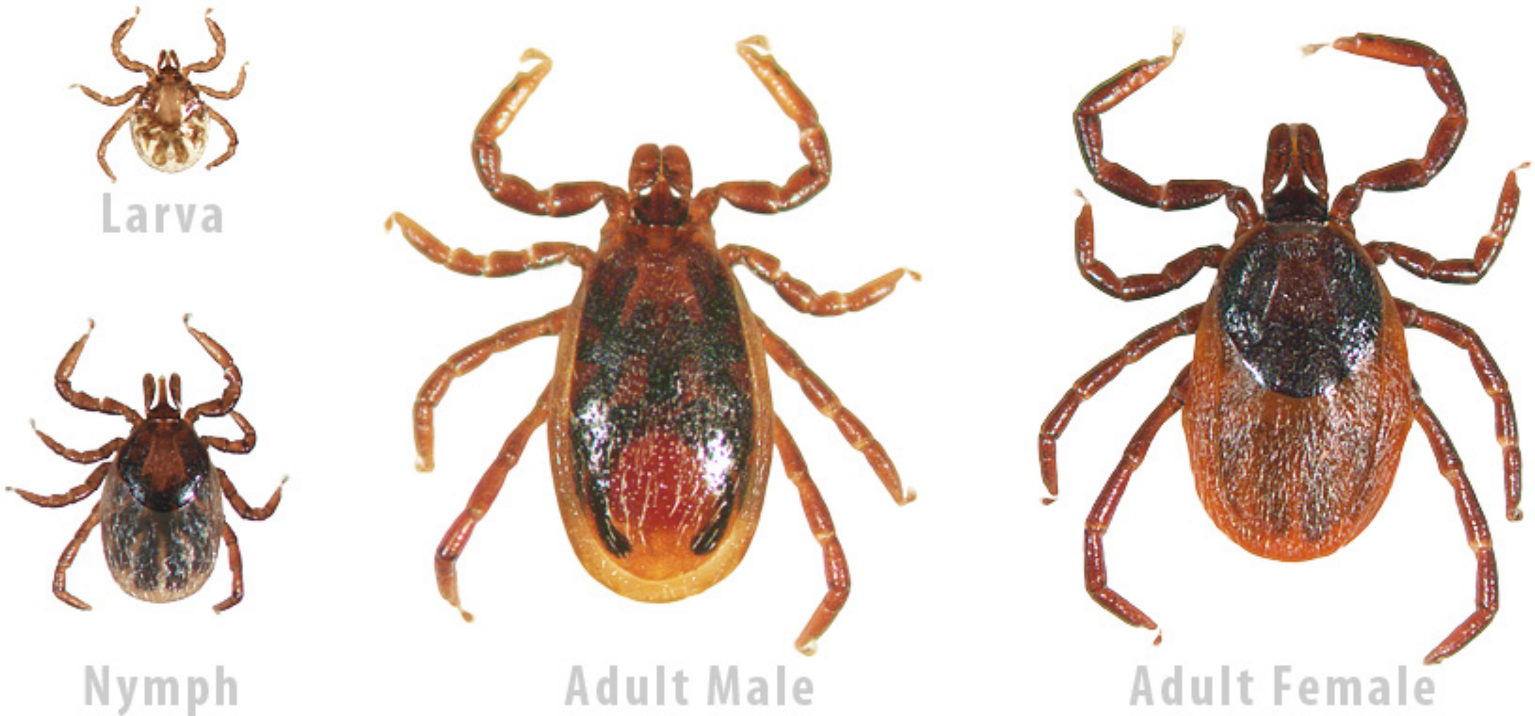
TickEncounter Resource Center

Ixodes pacifcus (Western-Blacklegged Tick)



Hosts

Sceloporus occidentalis

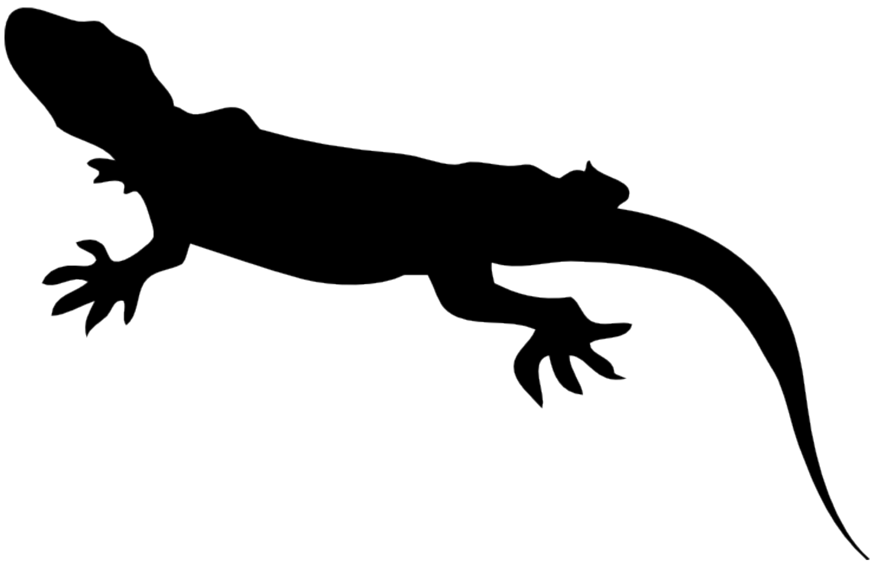
Hosts

Dusky-footed Woodrat
(*Neotoma fuscipes*)

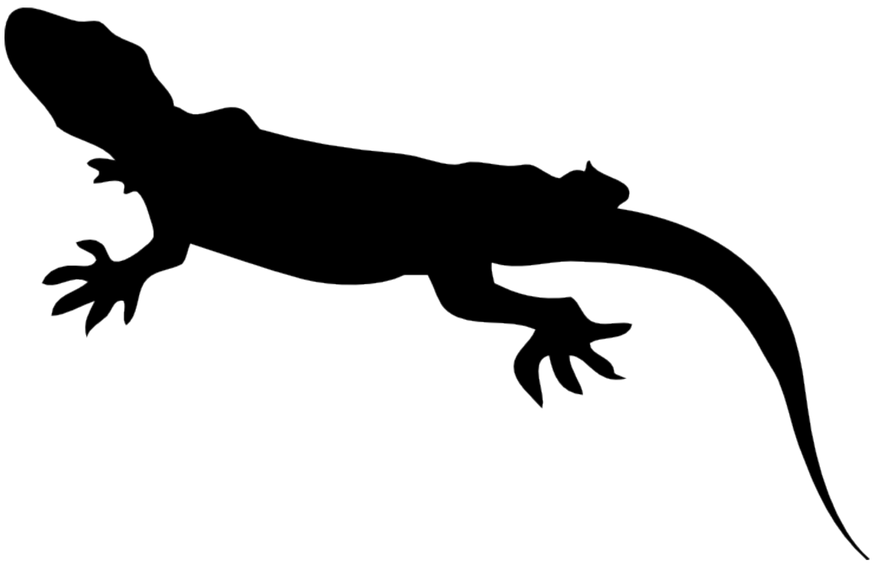
Deer Mouse
(*Peromyscus maniculatus*)

California Kangaroo Rat
(*Dipodomys californicus*)

Western Grey Squirrel
(*Sciurus griseus*)

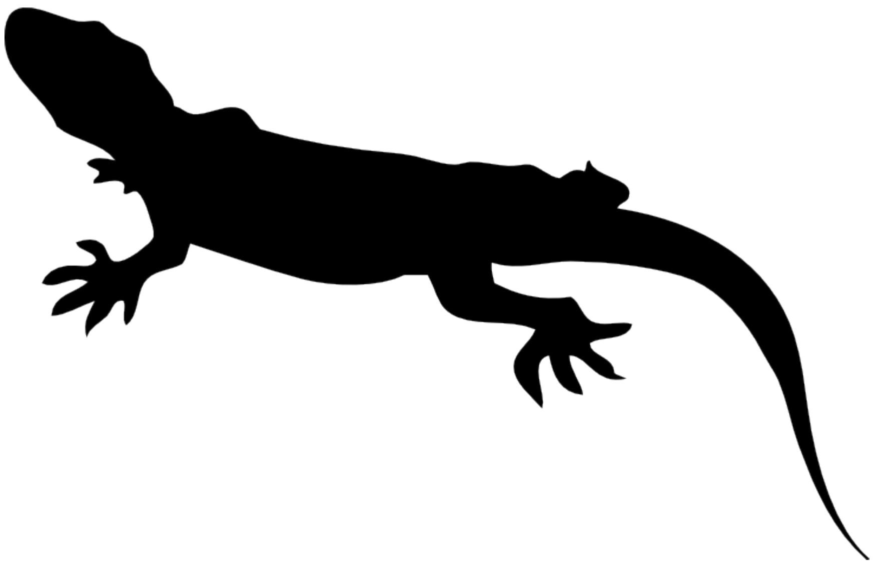



Host competence: ability to sustain the tick population.



Host competence: ability to sustain the tick population.

Reservoir competence: ability of an infected host to infect a tick.



Host competence

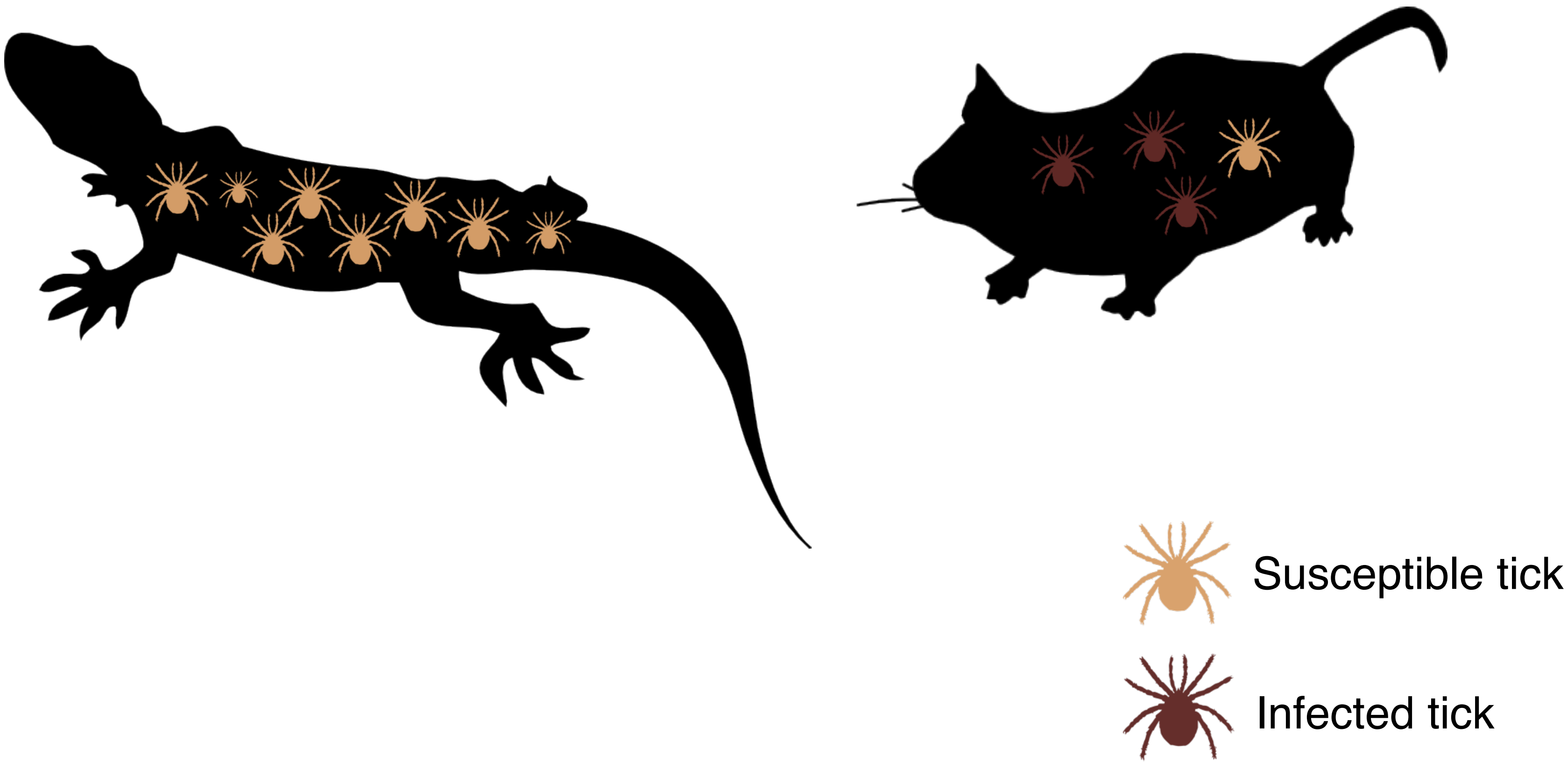
Host competence

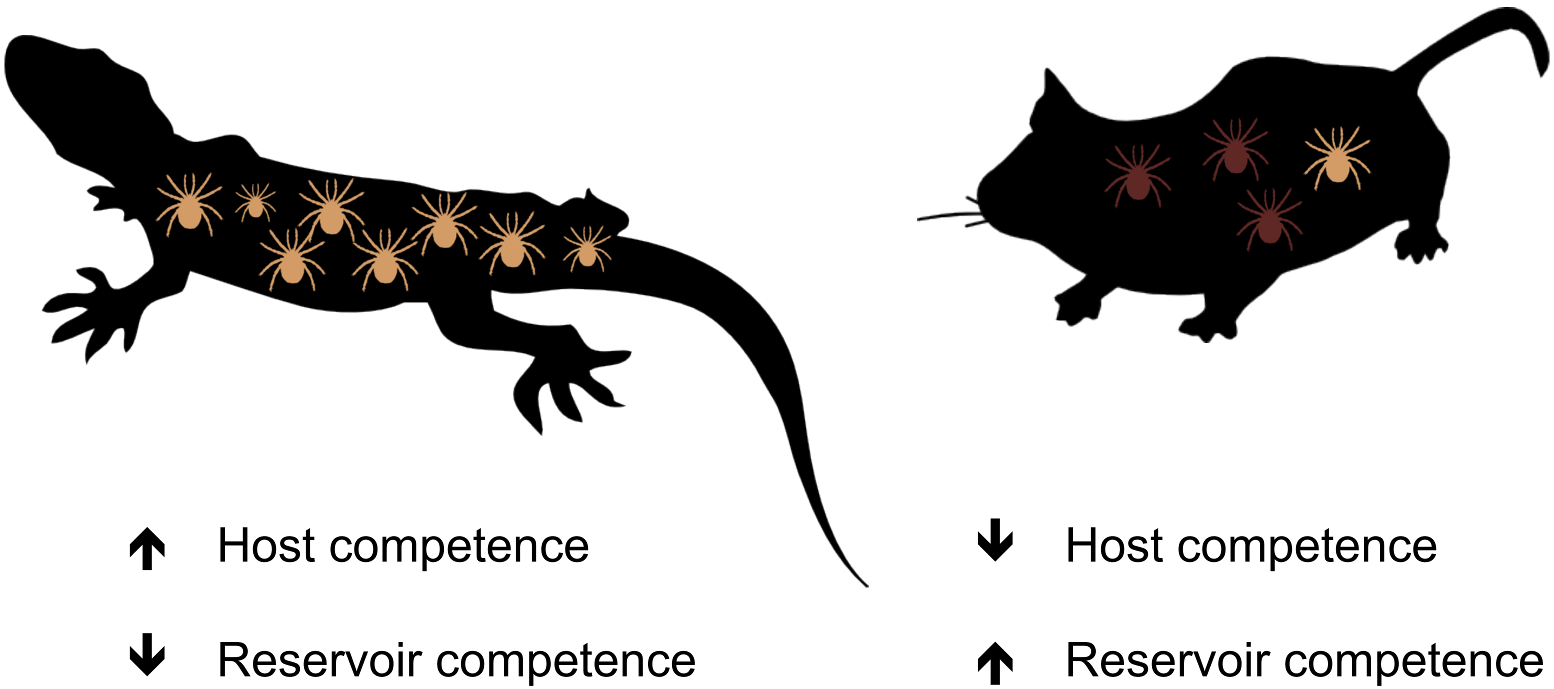
Host competence

Lizards hold up to 90 % of the ticks

Reservoir competence

Reservoir competence





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Objectives

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Objectives

To assess the impacts of experimentally reduced western fence lizard density on abundance and infection prevalence of *Ixodes pacificus* and on tick distributions on the remaining hosts

Sceloporus occidentalis

Ixodes pacificus

✓Abundance
✓Infection prevalence

Other hosts

Hypothesis

The presence of lizards may act as a barrier for the transmission of lyme disease, due to it high host competence and lower reservoir competence

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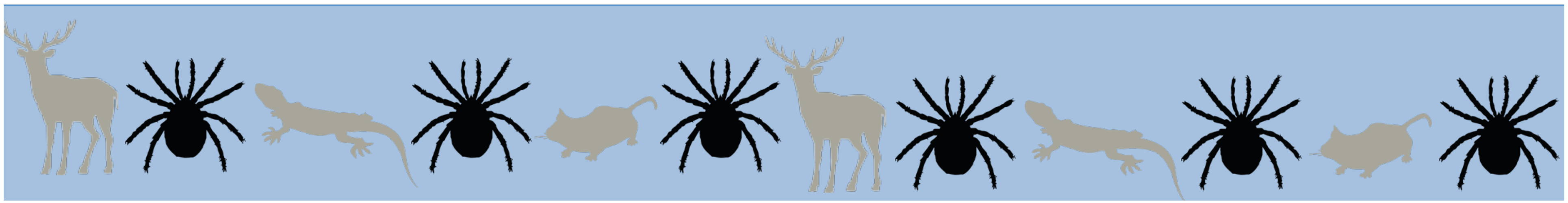
Predictions

1) If ticks switch to other hosts when lizards are scarce, and feed with equal success, then tick abundance might not decline and infection prevalence would increase.



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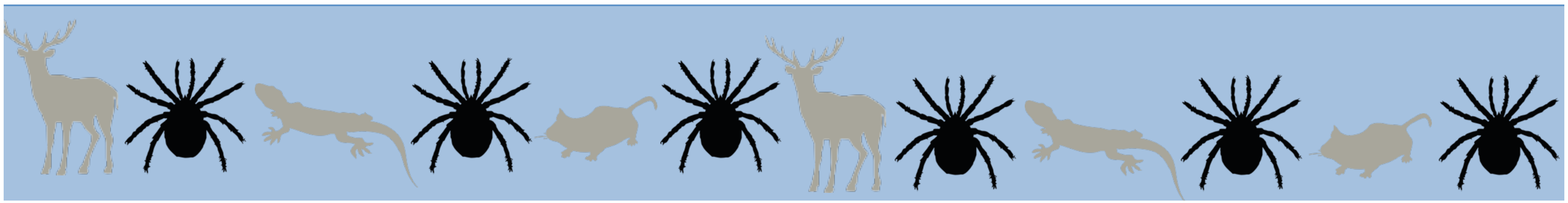

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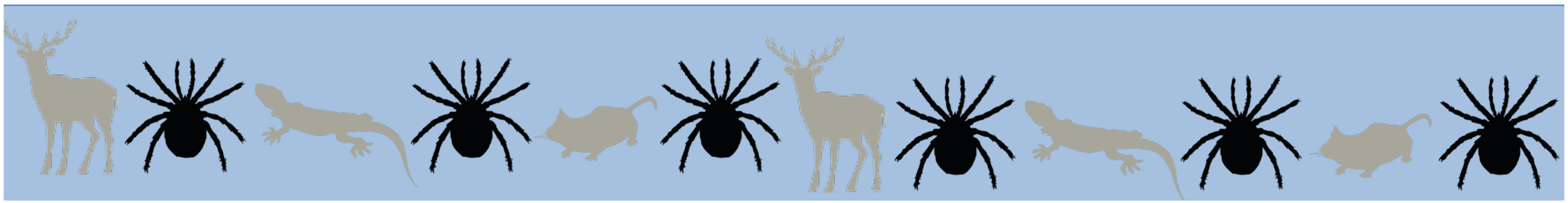
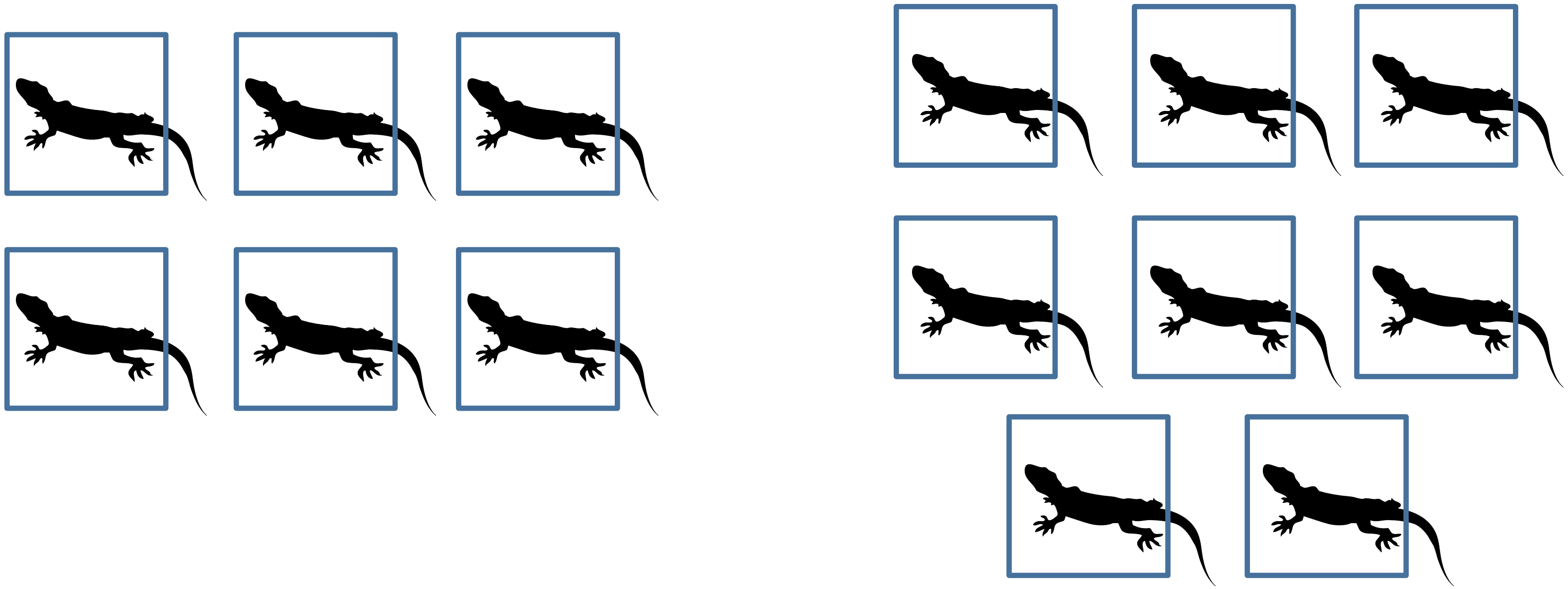
If there is a strong preference for lizards – no switch to an alternate host



Methods

MarinCounty,CA, north of San Francisco

14 long-term 1 ha plots



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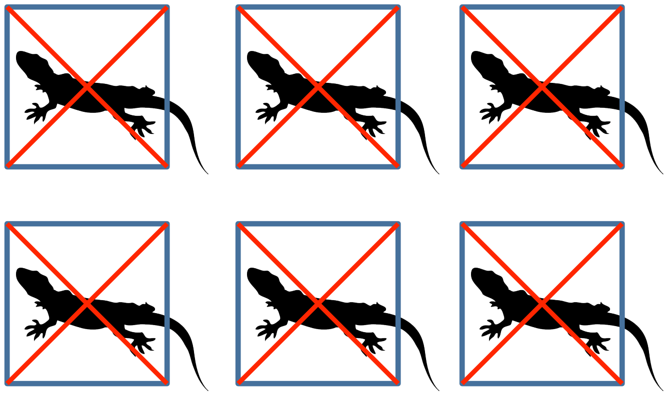
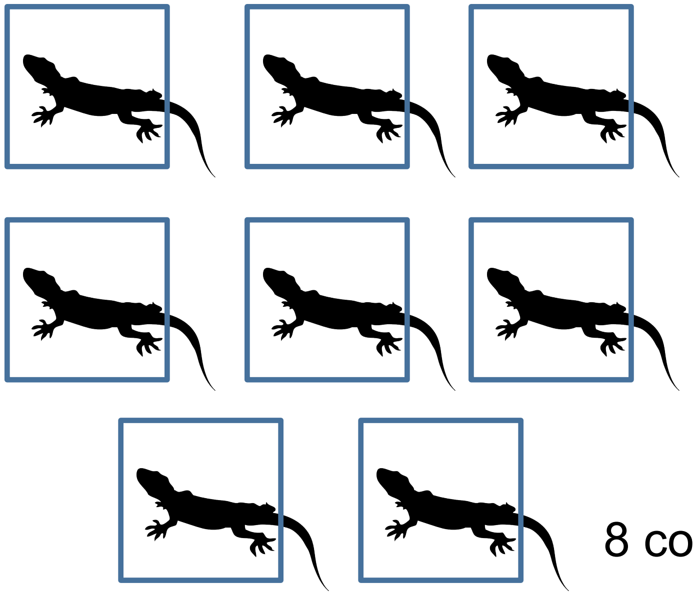


6 experimental removal plots



8 control plots

Results

The effect of lizard removals on the density and infection prevalence of questing ticks was evaluated:

- ✓ Sampling larval ticks in the year of removals (time t)
- ✓ Nymphal ticks the year after the experimental manipulation

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Time t:

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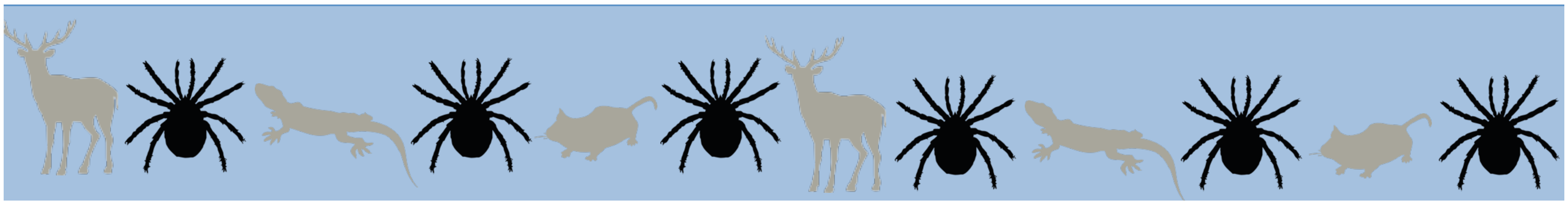
🡅 Larval burdens on female *N. fuscipes* → lizard removal elevated larval tick burden on female woodrats



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The year following lizard removal:

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✓5.19% of larval *I. pacificus* did switch to a competent reservoir host (*N. fuscipes*)

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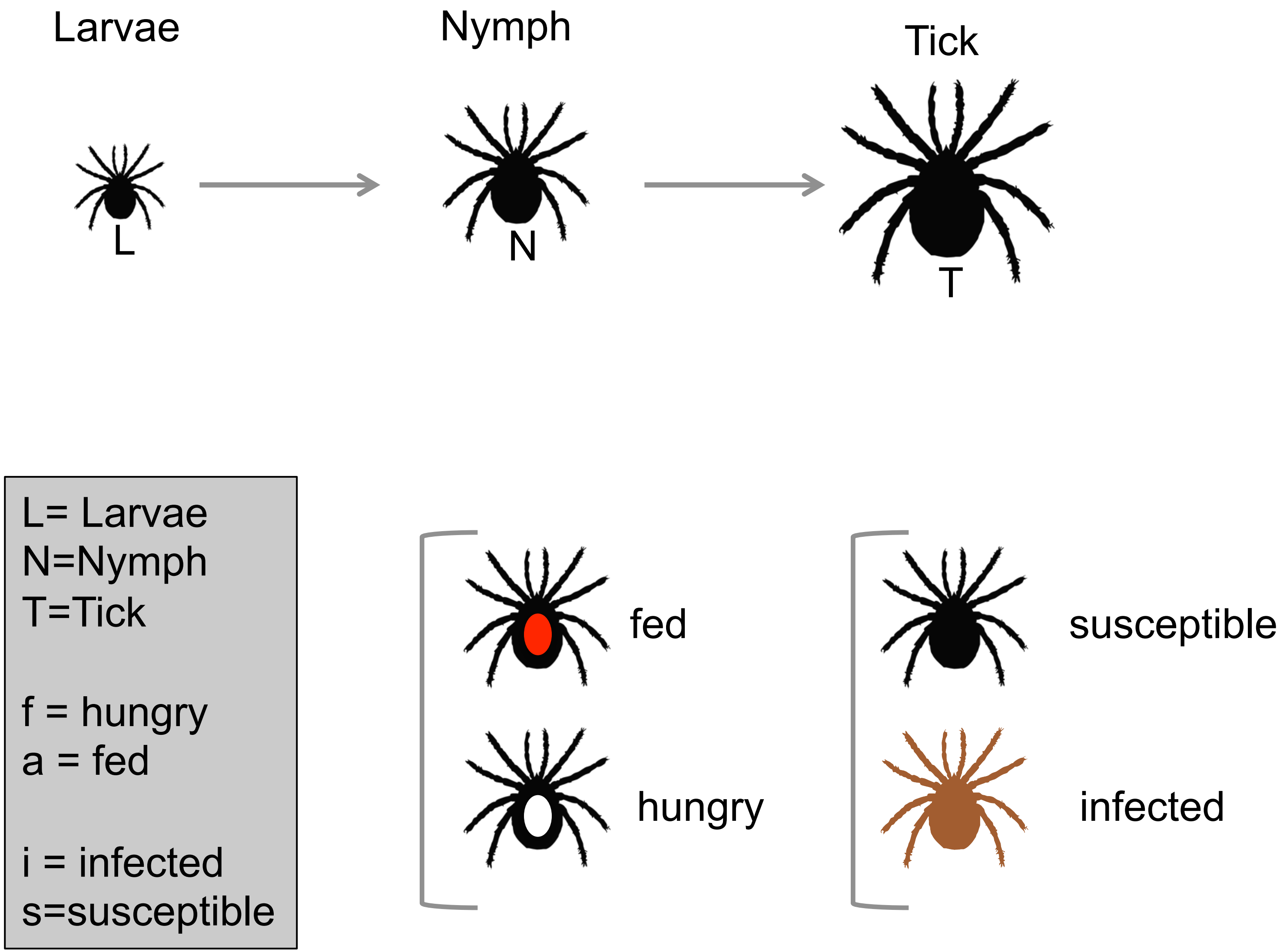
✓The increased larval burden on *N. fuscipes* was not enough to absorb 94.81% of larvae that would have fed on lizards

Results indicate that an incompetent reservoir for a pathogen may, in fact, increase disease risk through the maintenance of higher vector density and therefore, higher density of infected vectors


Larvae
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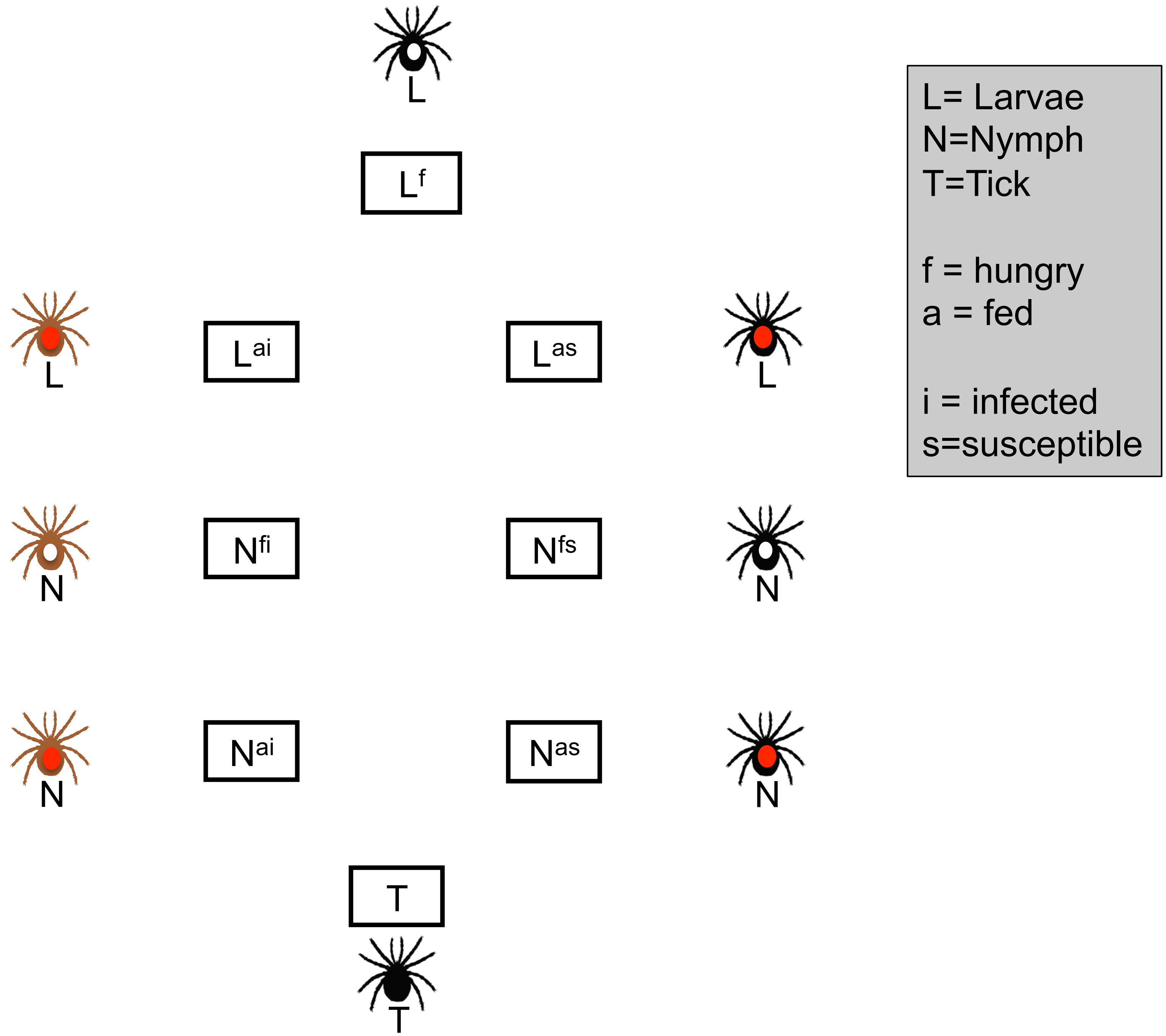
L= Larvae
N=Nymph
T=Tick
f = hungry
a = fed
i = infected
s=susceptible
fed
hungry
susceptible
infected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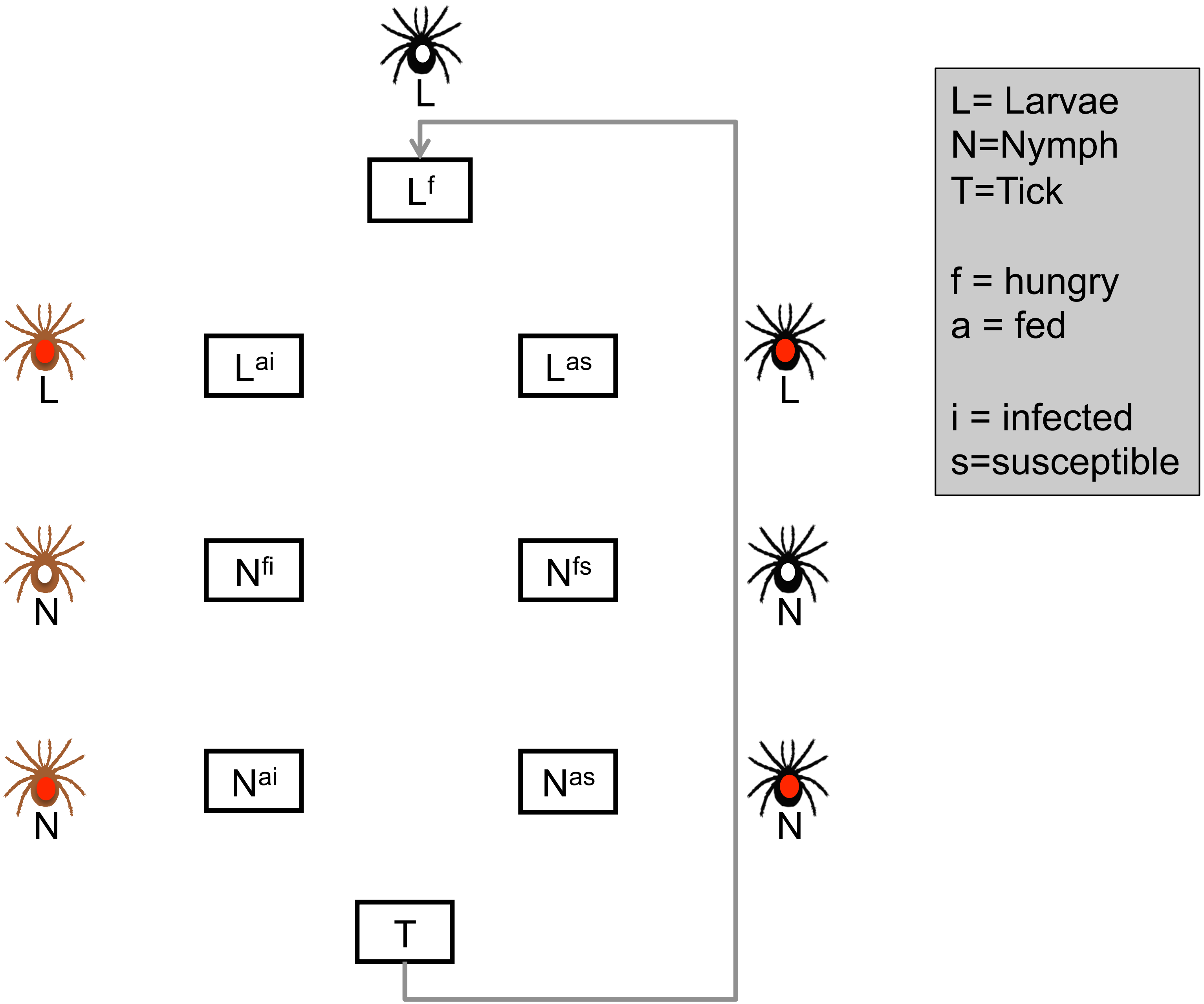
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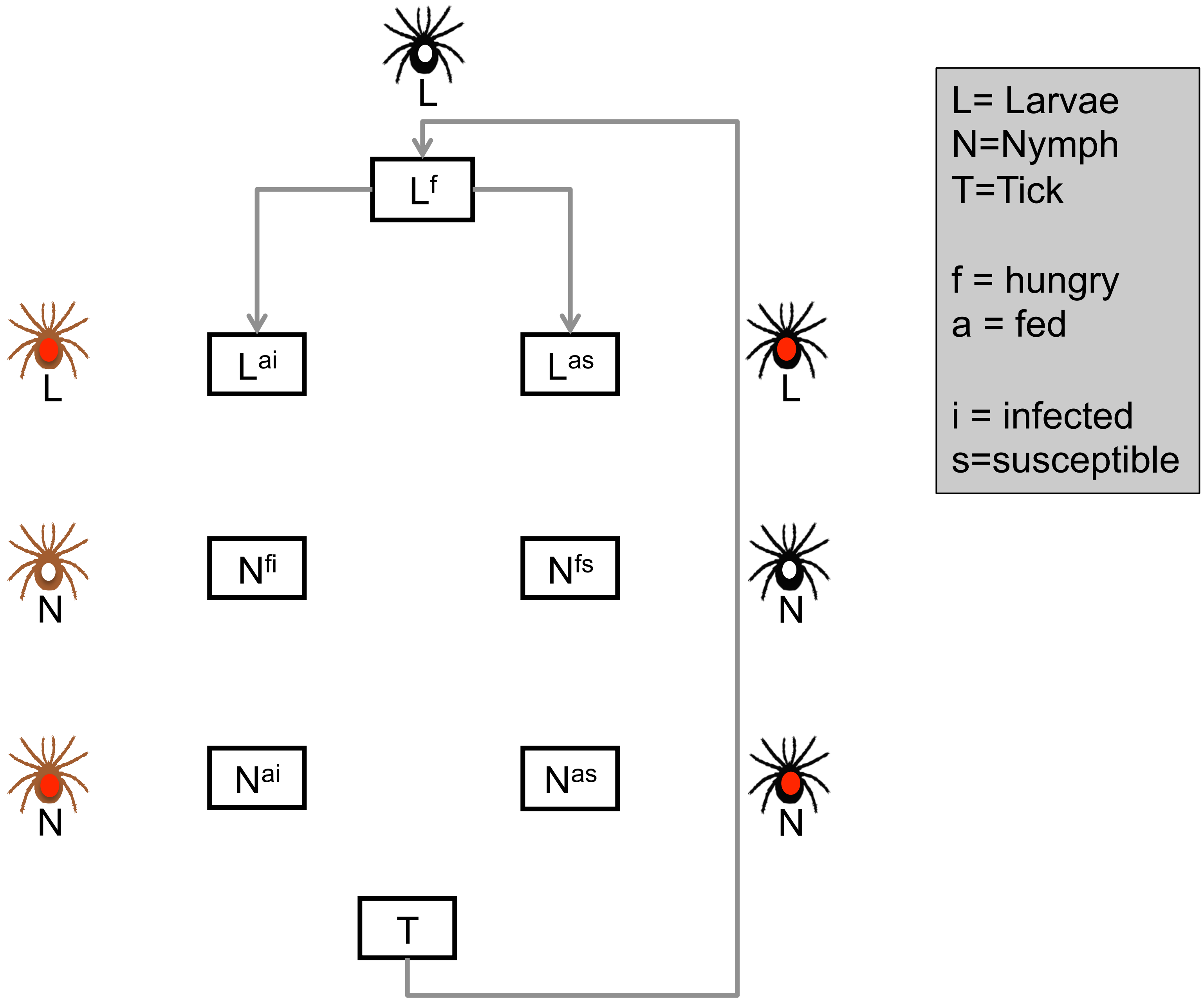
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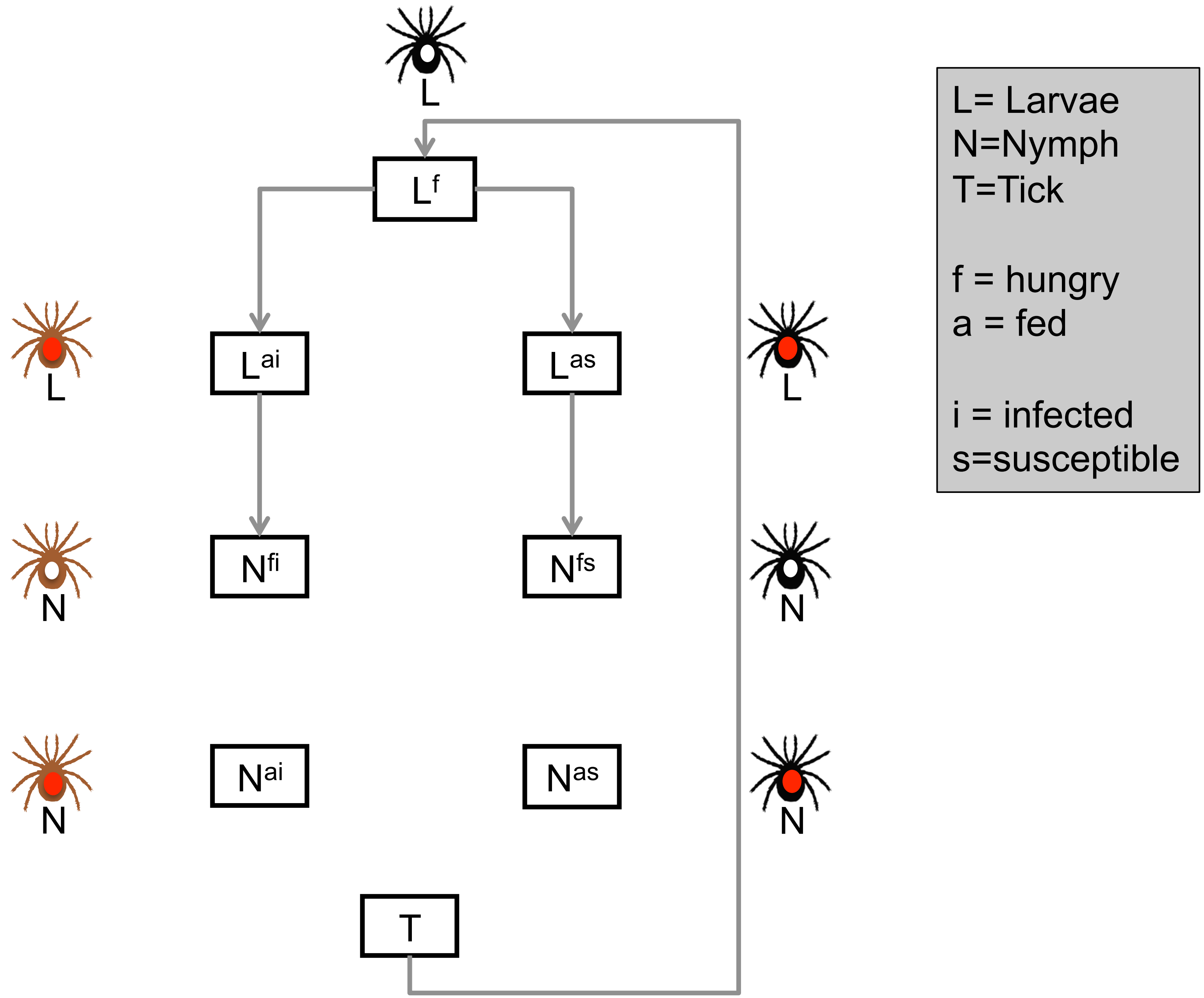

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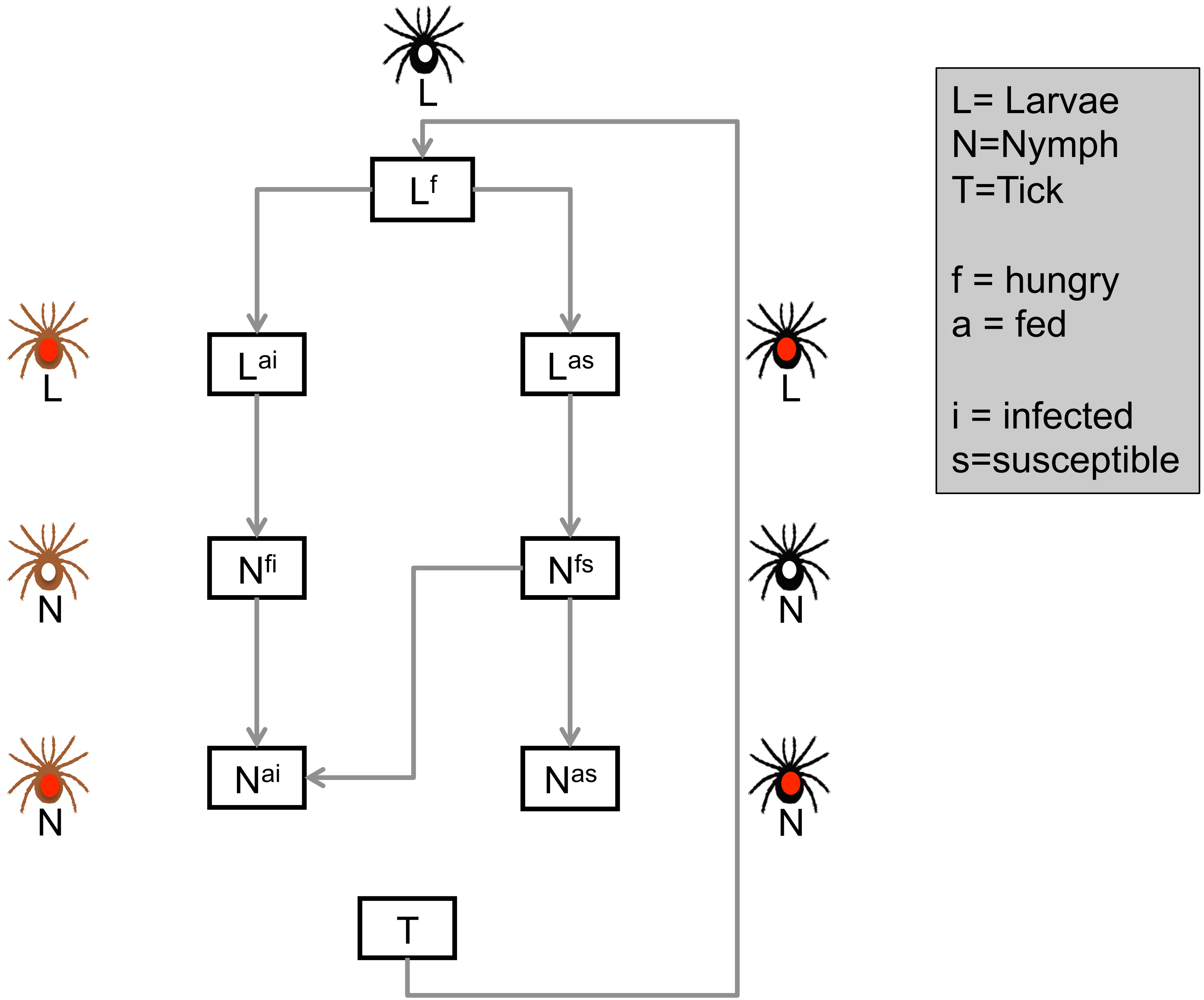
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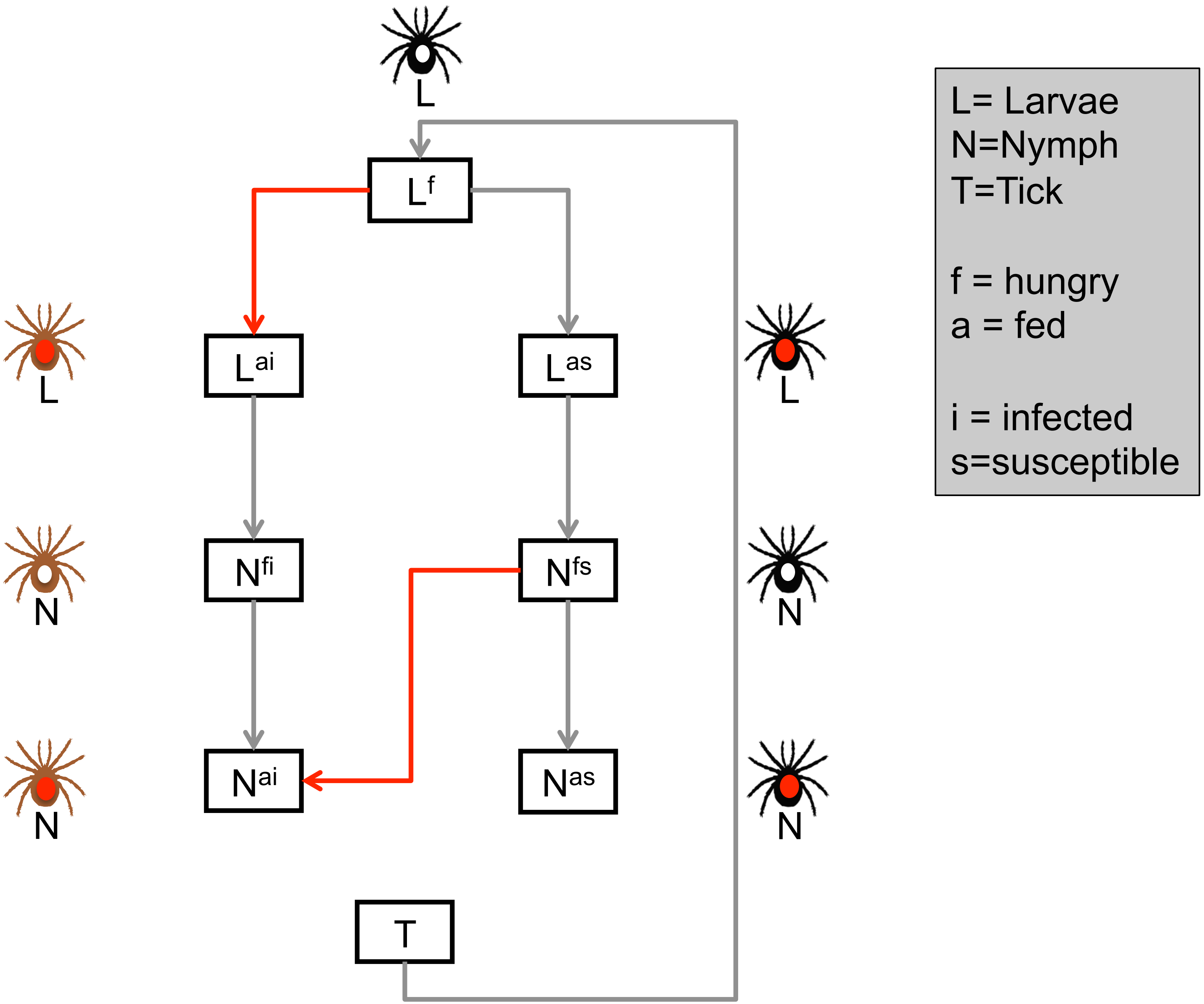

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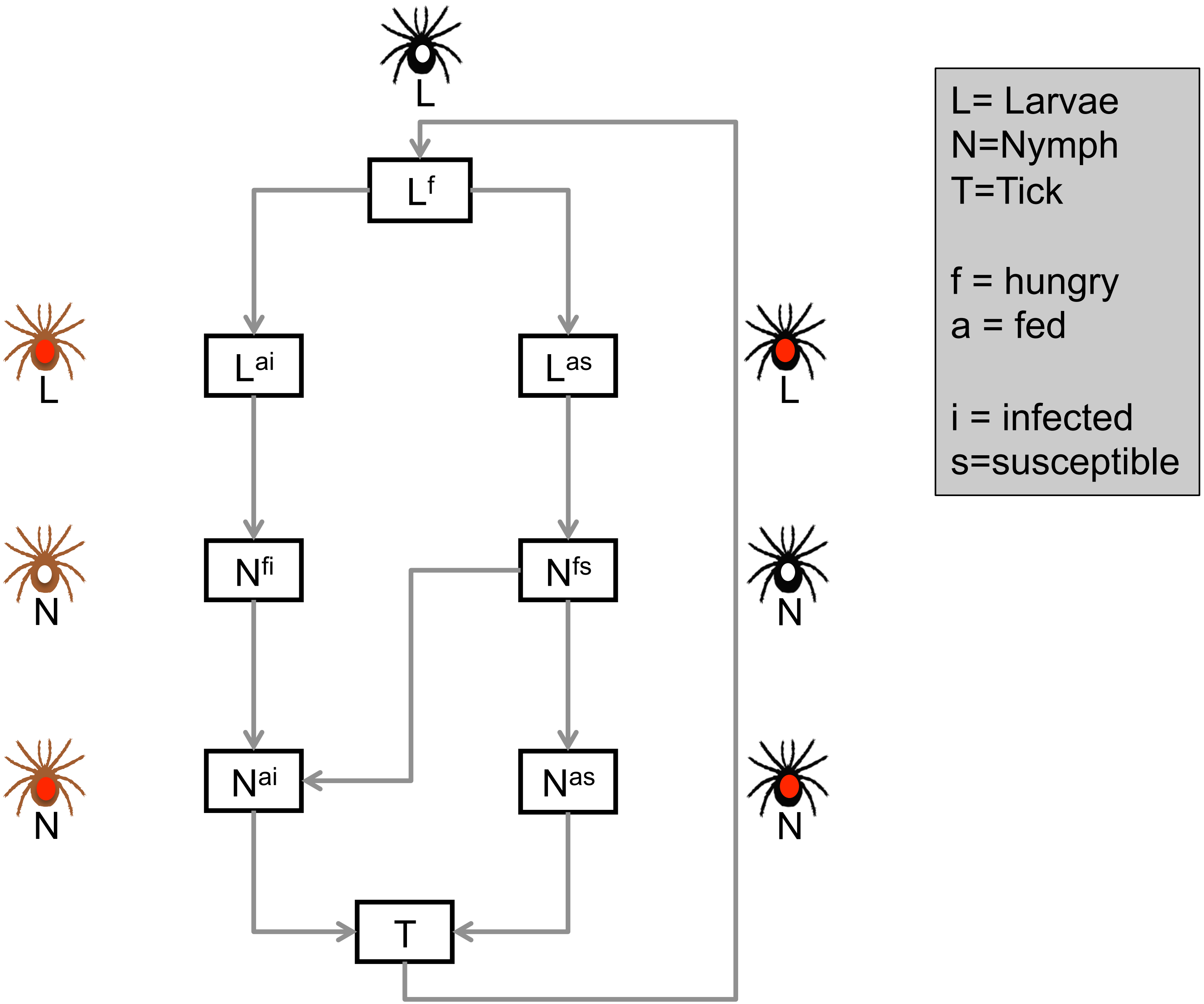

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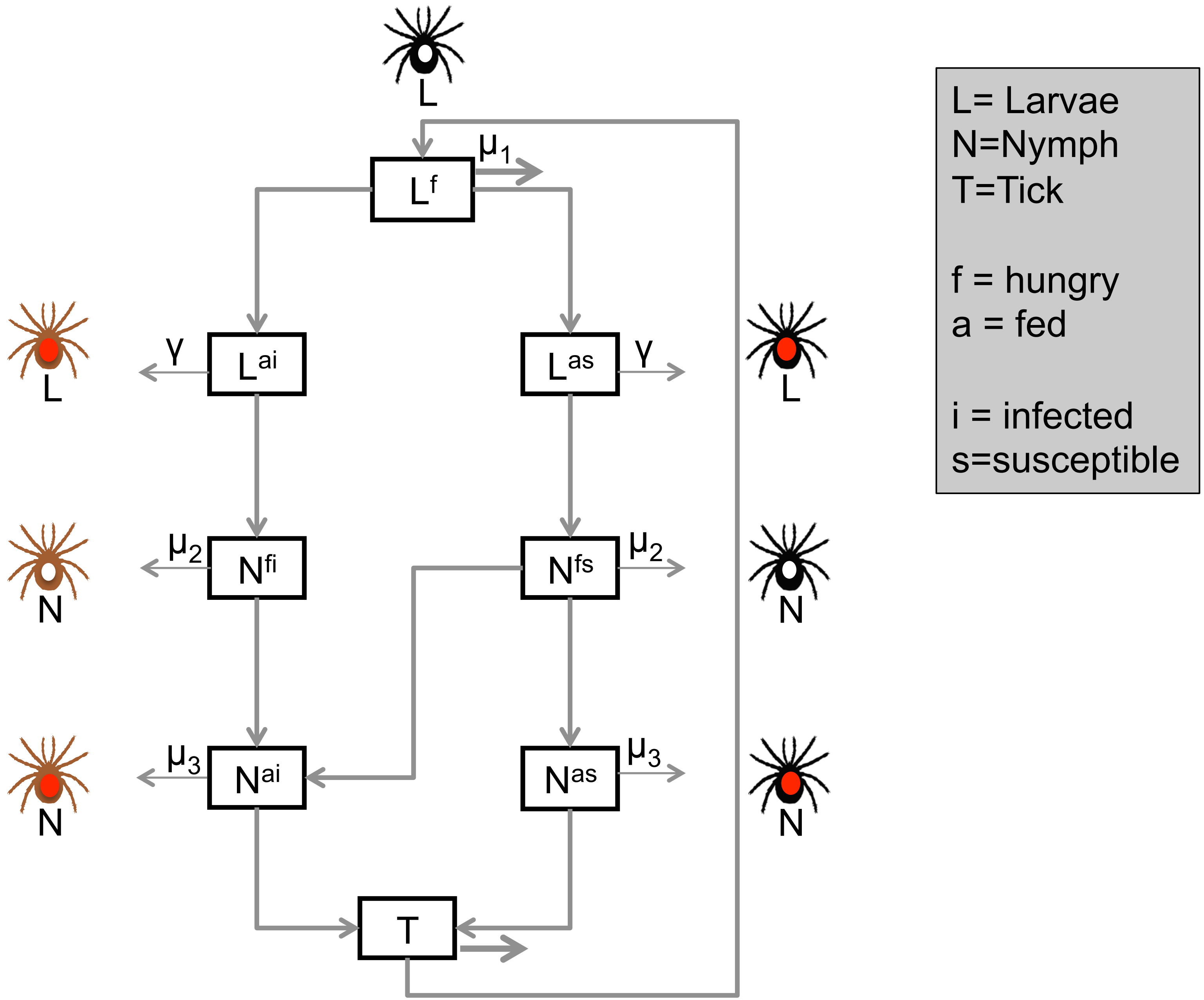
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N^{fi}
μ_2
N^{fs}
μ_2
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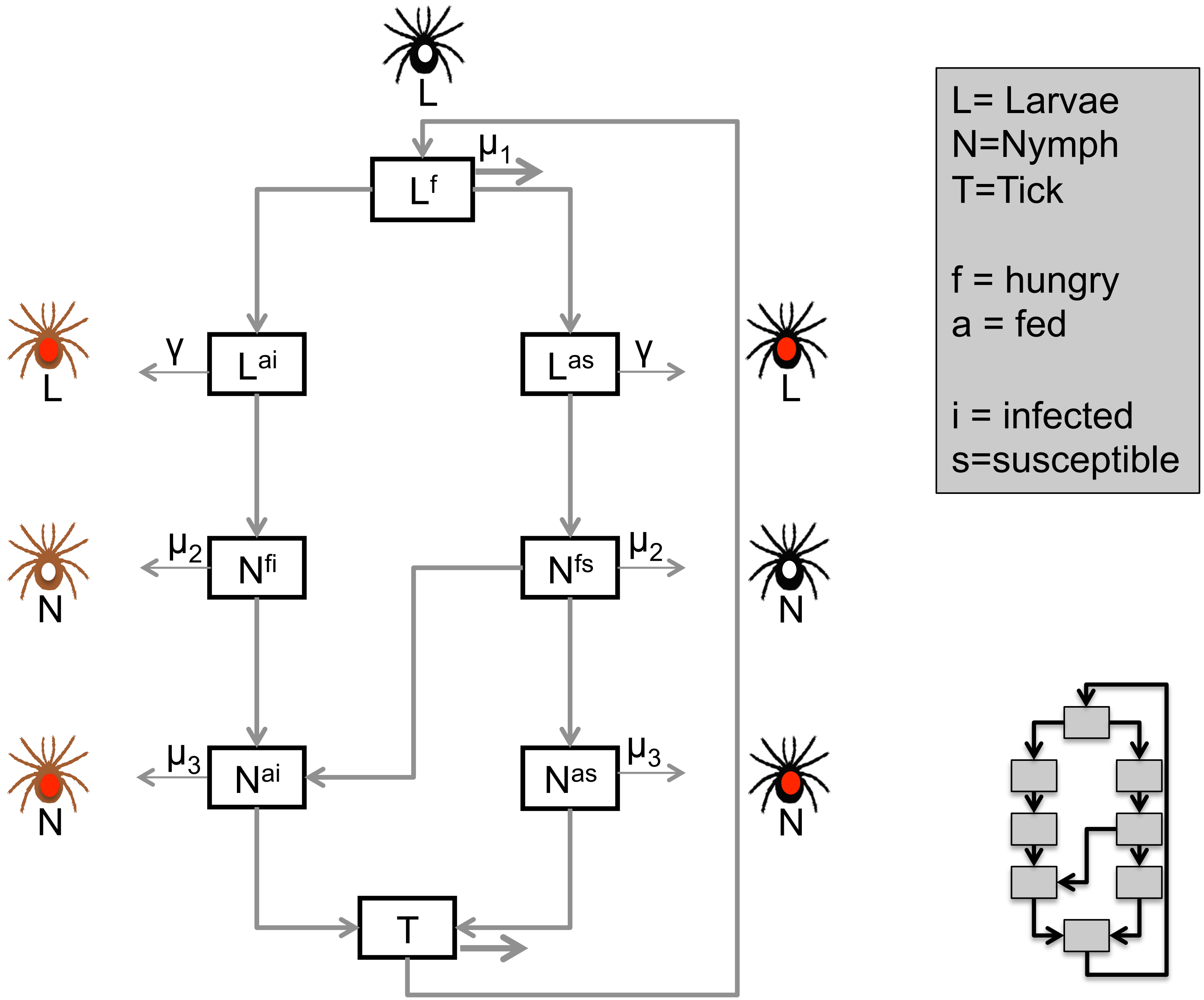
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N^{fs}
μ_2
μ_2
N
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μ_3
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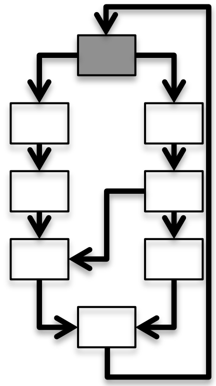
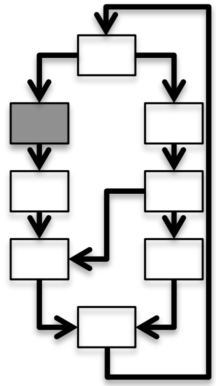
Larvae 

$$L_{t+1}^{f} = eE_t$$ 

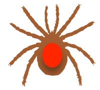


Larvae 

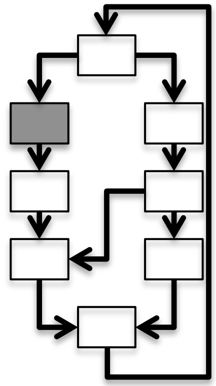


$$L^{f}_{t+1} = eE_t$$

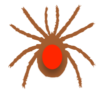
$$L^{ai}_{t+1} = \left(\frac{V_A H_A A^i_t}{(A^i_t + A^s_t) H_A + R H_R + 1}\right) L^f_t (1 - \mu_1)$$



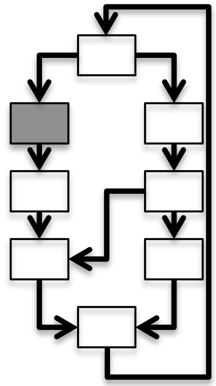
Larvae 



$$L^{f}_{t+1} = eE_t$$ 

$$L^{ai}_{t+1} = \left(\frac{V_A H_A A^i_t}{(A^i_t + A^s_t) H_A + R H_R + 1} \right) L^f_t (1 - \mu_1)$$ 

Larvae 



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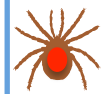
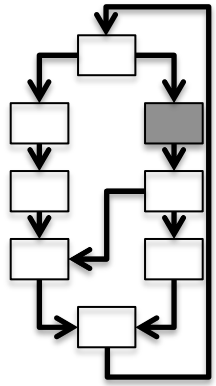
$$L^{ai}_{t+1} = \left(\frac{V_A H_A A^i_t}{(A^i_t + A^s_t)H_A + RH_R + 1}\right) \boxed{L^f_t(1-\mu_1)}$$ 

Larvae 



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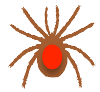
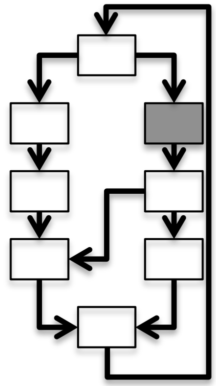
$$L^{ai}_{t+1} = \left(\frac{V_A H_A A^i_t}{(A^i_t+A^s_t)H_A+RH_R+1}\right) L^f_t(1-\mu_1)$$ 

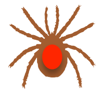
$$L^{as}_{t+1} = \left(\frac{H_A A^s_t+(1-V_A)H_A A^i_t+RH_R+1}{(A^i_t+A^s_t)H_A+RH_R+1}\right) L^f_t(1-\mu_1)$$

Larvae 



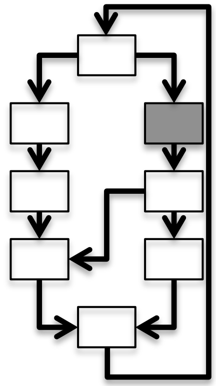
$$L_{t+1}^{f} = eE_t$$

$$L_{t+1}^{ai} = \left(\frac{V_A H_A A_t^i}{(A_t^i + A_t^s)H_A + RH_R + 1}\right) L_t^f (1-\mu_1)$$



$$L_{t+1}^{as} = \left(\frac{H_A A_t^s + (1-V_A) H_A A_t^i + RH_R + 1}{(A_t^i + A_t^s)H_A + RH_R + 1}\right) L_t^f (1-\mu_1)$$

Larvae 



$$L^{f}_{t+1} = eE_t$$

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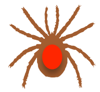

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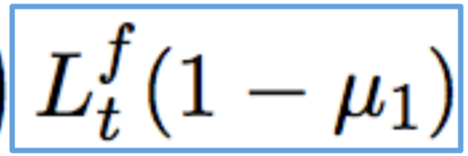
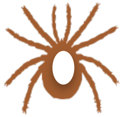
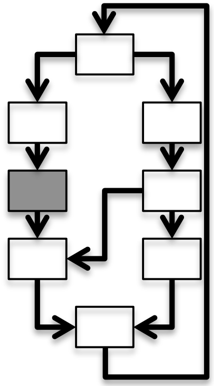


Nymph

$$N_{t+1}^{fi} = (1-\gamma)L_t^{ai}$$





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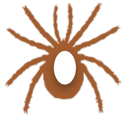

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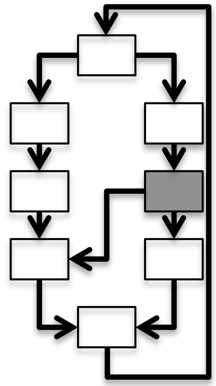

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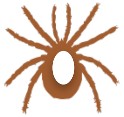
$$N_{t+1}^{fi} = (1-\gamma)L_t^{ai}$$ 

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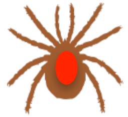
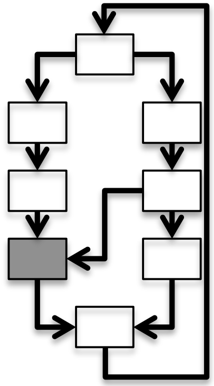
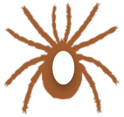
$$N_{t+1}^{ai} = \left(\frac{V_A H_A A_t^i}{(A_t^i + A_t^s)H_A + RH_R + 1}\right) N_t^{fs}(1-\mu_2) + N_t^{fi}(1-\mu_2)$$ 



Nymph 

$$N^{fi}_{t+1} = (1-\gamma)L^{ai}_t$$



$$N^{fs}_{t+1} = (1-\gamma)L^{as}_t$$

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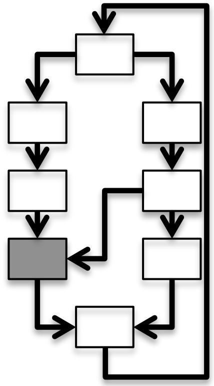

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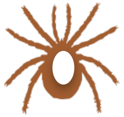

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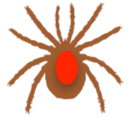
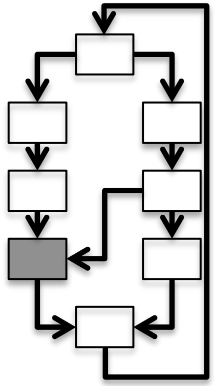
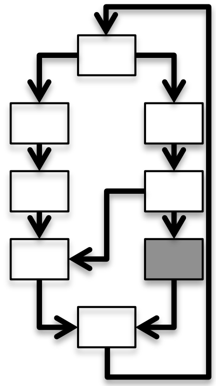




Nymph 



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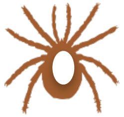

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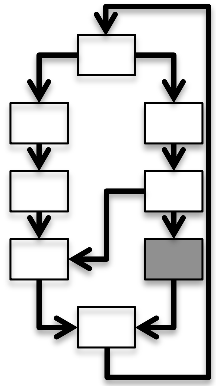

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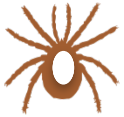

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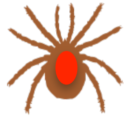

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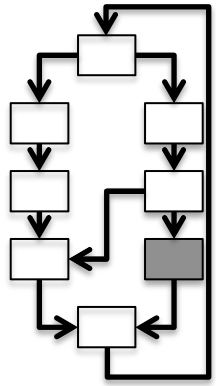

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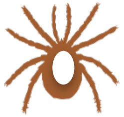

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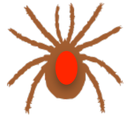

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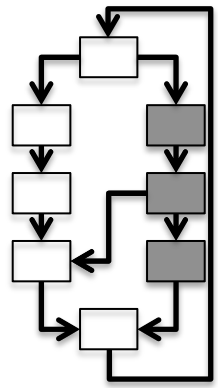
Hosts 



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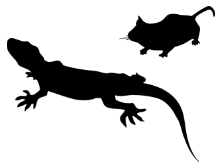
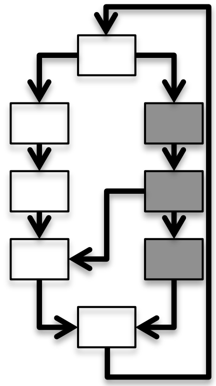


$$+ (1-\gamma_A)A^s_t - \epsilon_A\mu_2\frac{N^{fi}_t}{N^{fi}_t+N^{fs}_t}(1-\gamma_A)A^s_t$$

Hosts 



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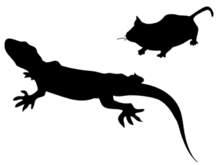

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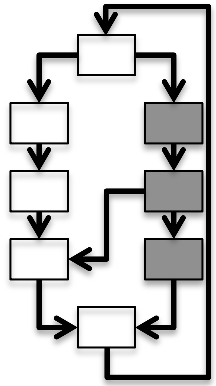

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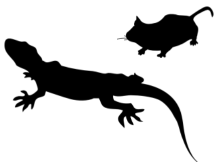

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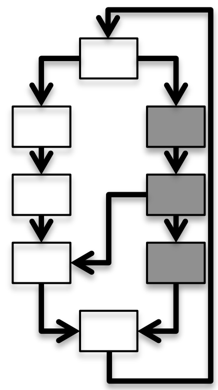

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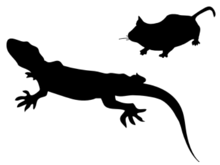

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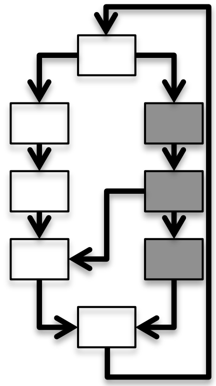

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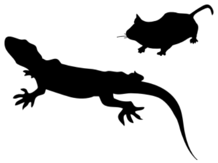

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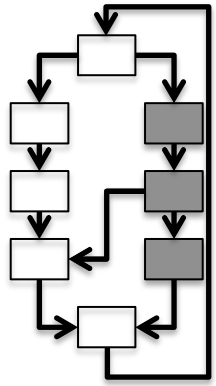

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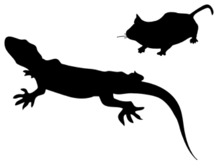

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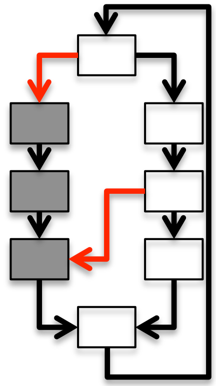

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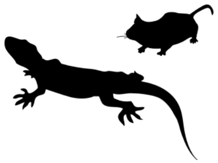

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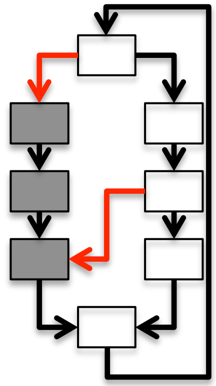
Hosts 



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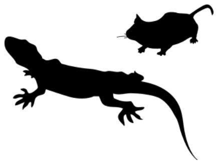

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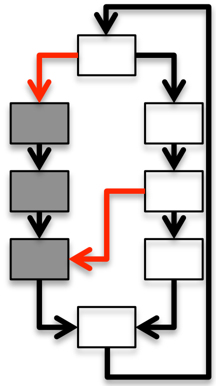

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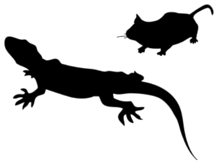

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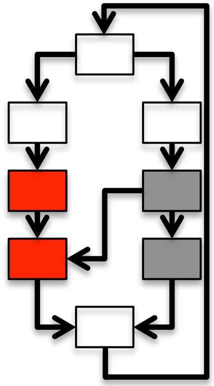
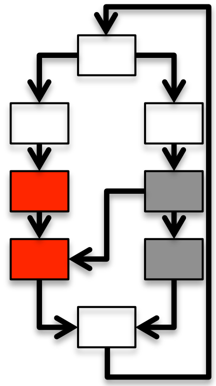
$$A^i_{t+1} = (1-\gamma_A)A^i_t + \epsilon_A(1-\gamma_A)\mu_2\frac{N^{fi}_t}{N^{fi}_t+N^{fs}_t}A^s_t$$

Humans 



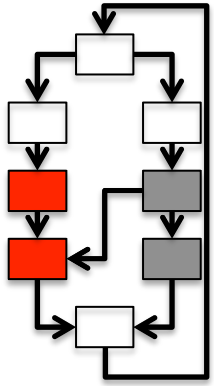
$$H^s_{t+1} = \boxed{\delta H^i_t + H^s_t} - \psi\epsilon\mu \frac{N^{fi}_t}{N^{fi}_t + N^{fs}_t} H^s_t$$

Humans



$$H^s_{t+1} = \delta H^i_t + H^s_t - \psi \epsilon \mu \frac{N^{fi}_t}{N^{fi}_t + N^{fs}_t} H^s_t$$

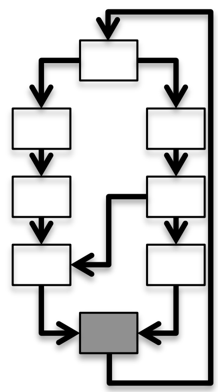
Humans 



$$H_{t+1}^{s} = \delta H_{t}^{i} + H_{t}^{s} - \psi \epsilon \mu \frac{N_{t}^{fi}}{N_{t}^{fi} + N_{t}^{fs}} H_{t}^{s}$$

$$H_{t+1}^{i} = H_{t}^{i} - \delta H_{t}^{i} + \psi \epsilon \mu \frac{N_{t}^{fi}}{N_{t}^{fi} + N_{t}^{fs}} H_{t}^{s}$$

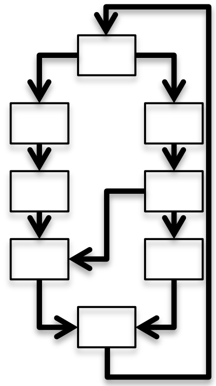
Ticks



$$T_{t+1} = (N_t^{ai} + N_t^{as})(1 - \mu_3)$$

Ticks

$$T_{t+1} = (N_t^{ai} + N_t^{as})(1 - \mu_3)$$



Saturation term

$$\mu = \exp^{-\sigma \frac{AH_A + RH_R}{N_t^{fi} + N_t^{fs}}}$$

Ticks

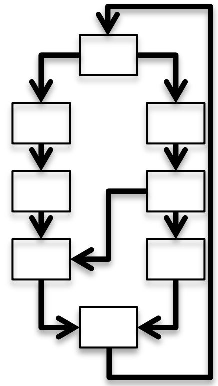
$$T_{t+1} = (N_t^{ai} + N_t^{as})(1 - \mu_3)$$

Saturation term

$$\mu = \exp^{-\sigma \frac{AH_A + RH_R}{N_t^{fi} + N_t^{fs}}}$$

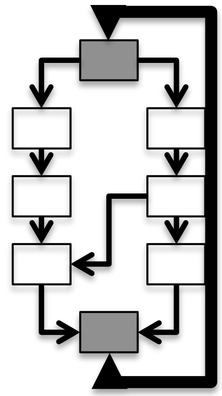
Maintenance term

$$\rho_A = \frac{\gamma_A}{1 - \gamma_A}$$



Ticks

$$T_{t+1} = (N_t^{ai} + N_t^{as})(1 - \mu_3)$$



Saturation term

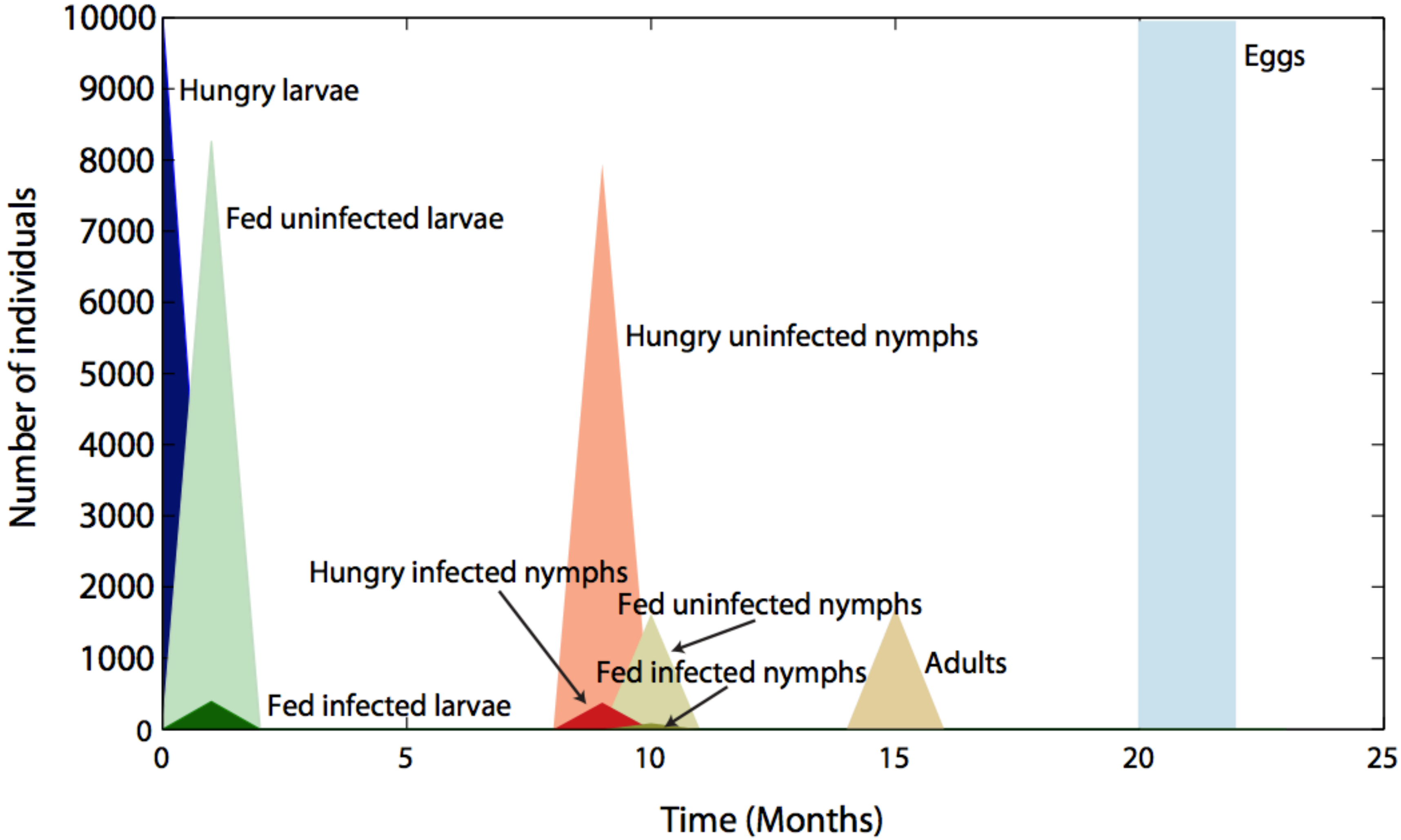
$$\mu = \exp^{-\sigma \frac{AH_A + RH_R}{N_t^{fi} + N_t^{fs}}}$$

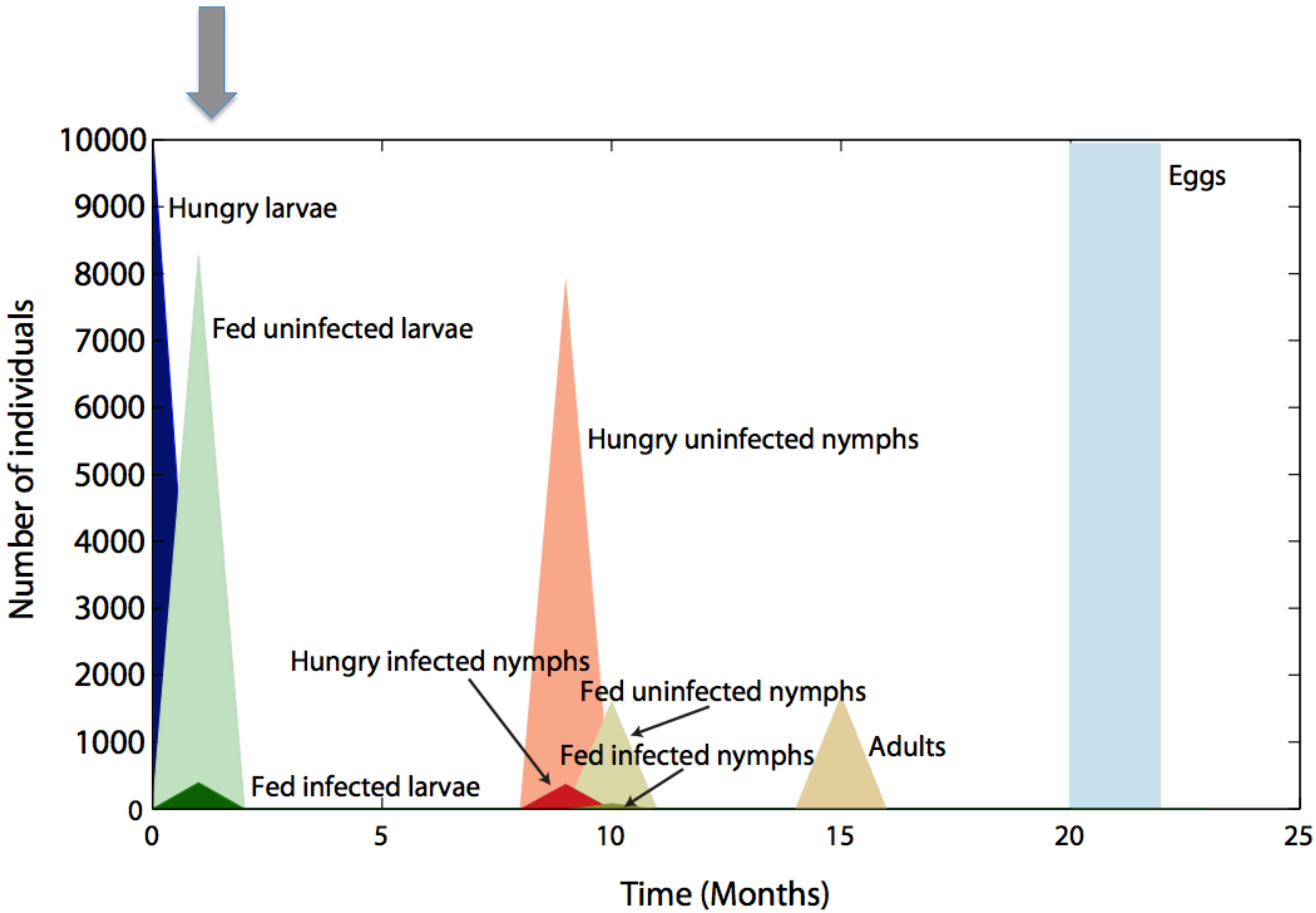
Maintenance term

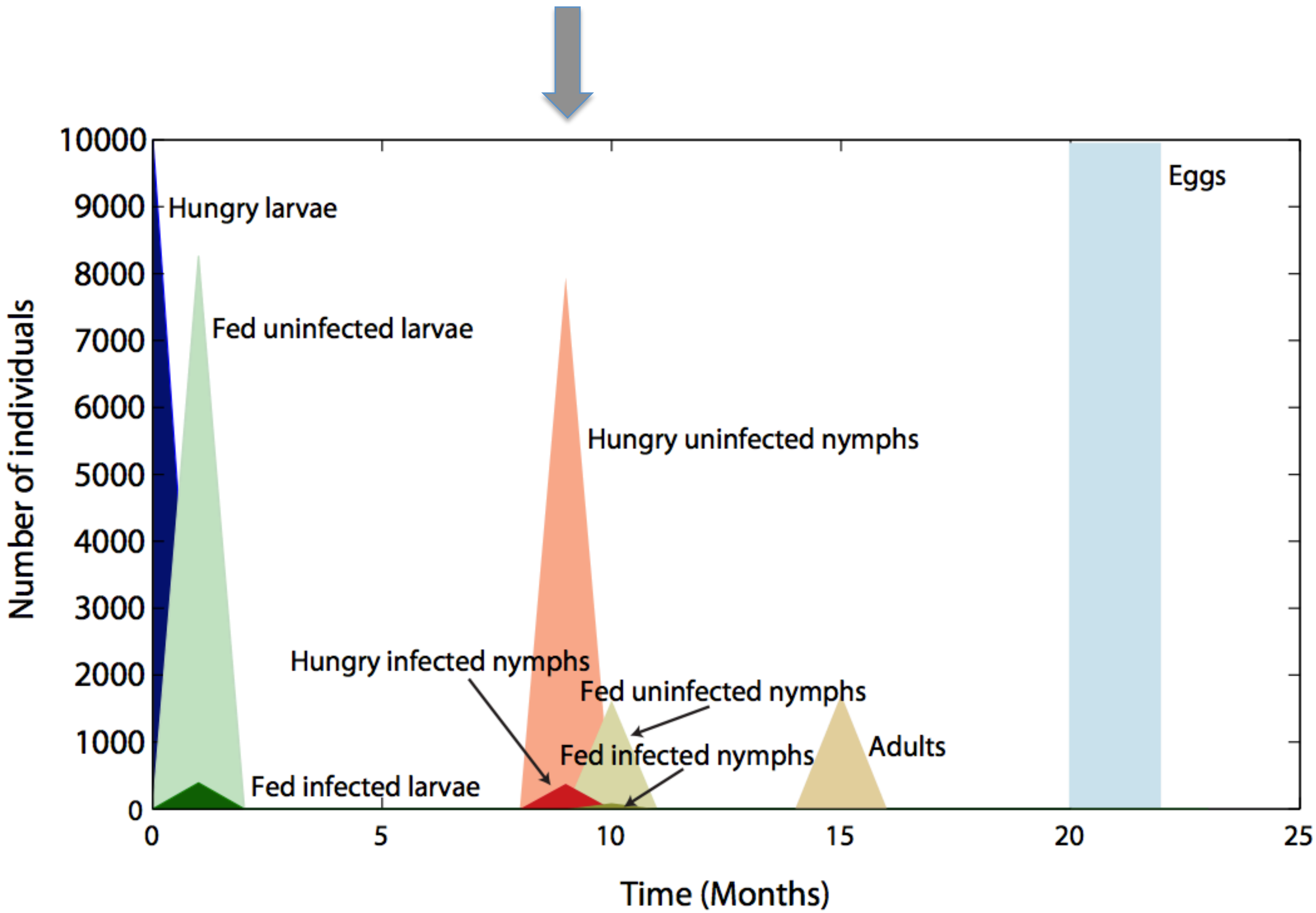
$$\rho_A = \frac{\gamma_A}{1 - \gamma_A}$$

Eggs

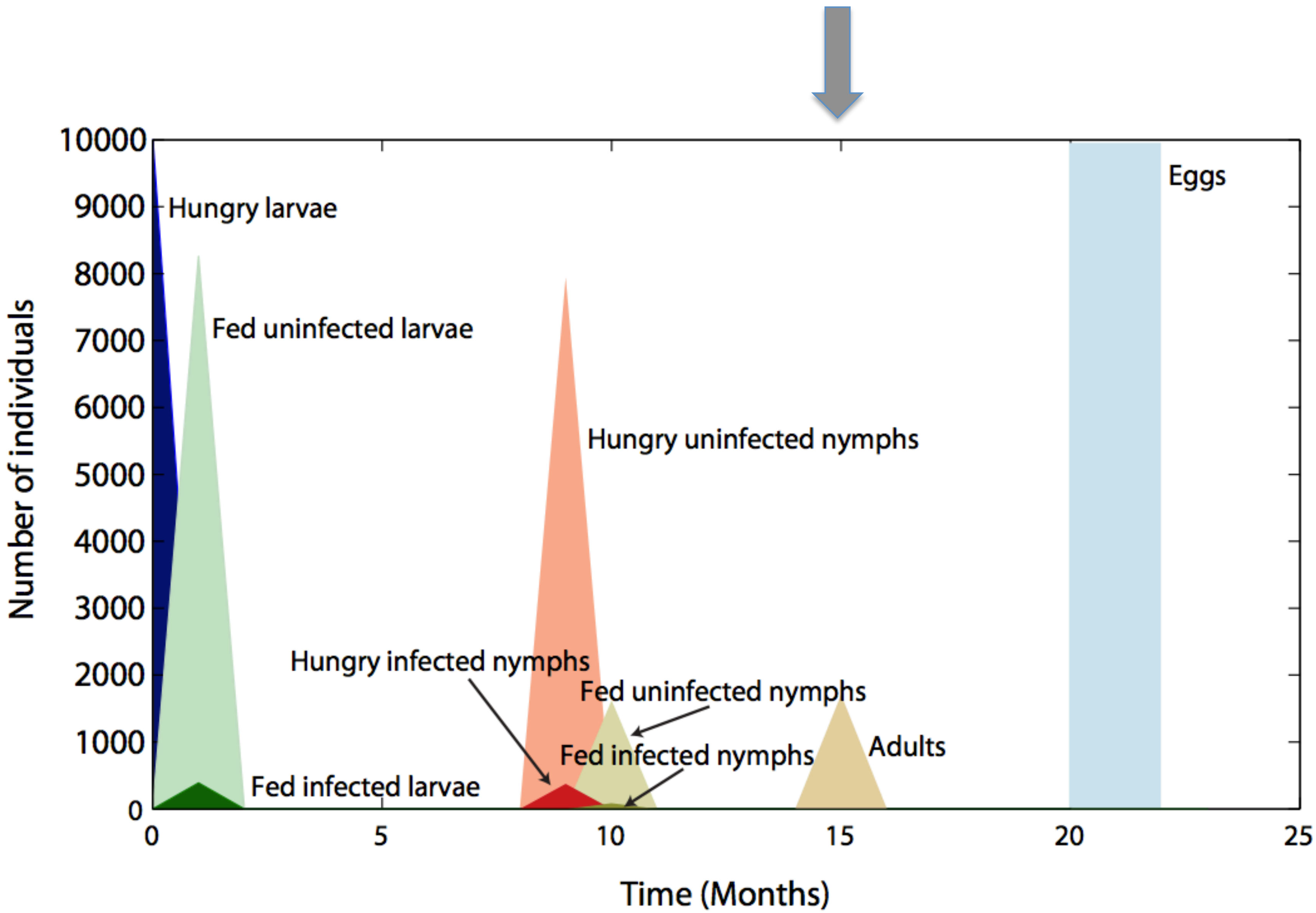
$$E_{t+1} = N_e T_t$$


10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Number of individuals
0
5
10
15
20
25
Time (Months)
Hungry larvae
Fed uninfected larvae
Fed infected larvae
Hungry uninfected nymphs
Hungry infected nymphs
Fed uninfected nymphs
Fed infected nymphs
Adults
Eggs

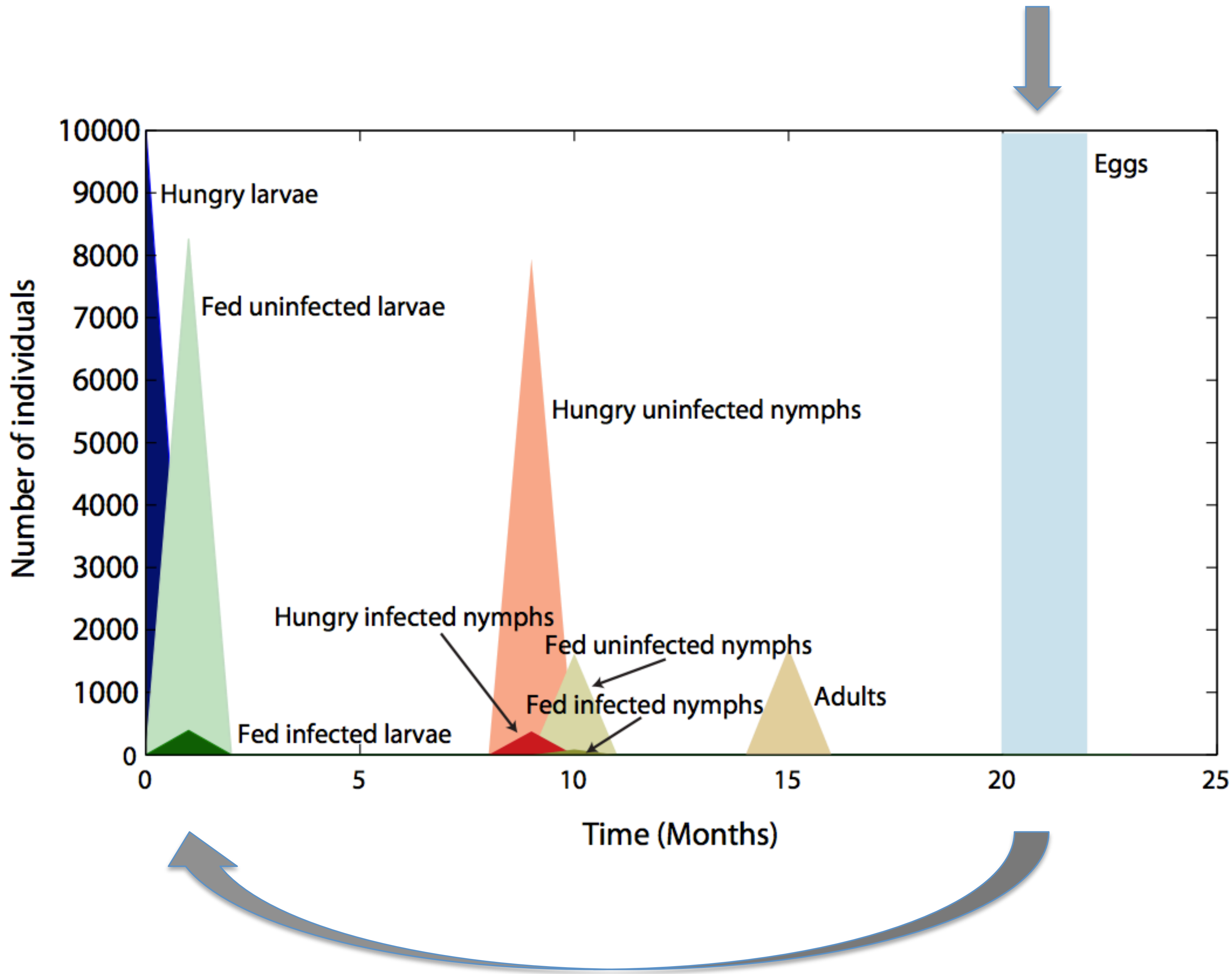

Eggs
Hungry larvae
Fed uninfected larvae
Hungry uninfected nymphs
Hungry infected nymphs
Fed uninfected nymphs
Fed infected nymphs
Adults
Fed infected larvae
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Number of individuals
0
5
10
15
20
25
Time (Months)

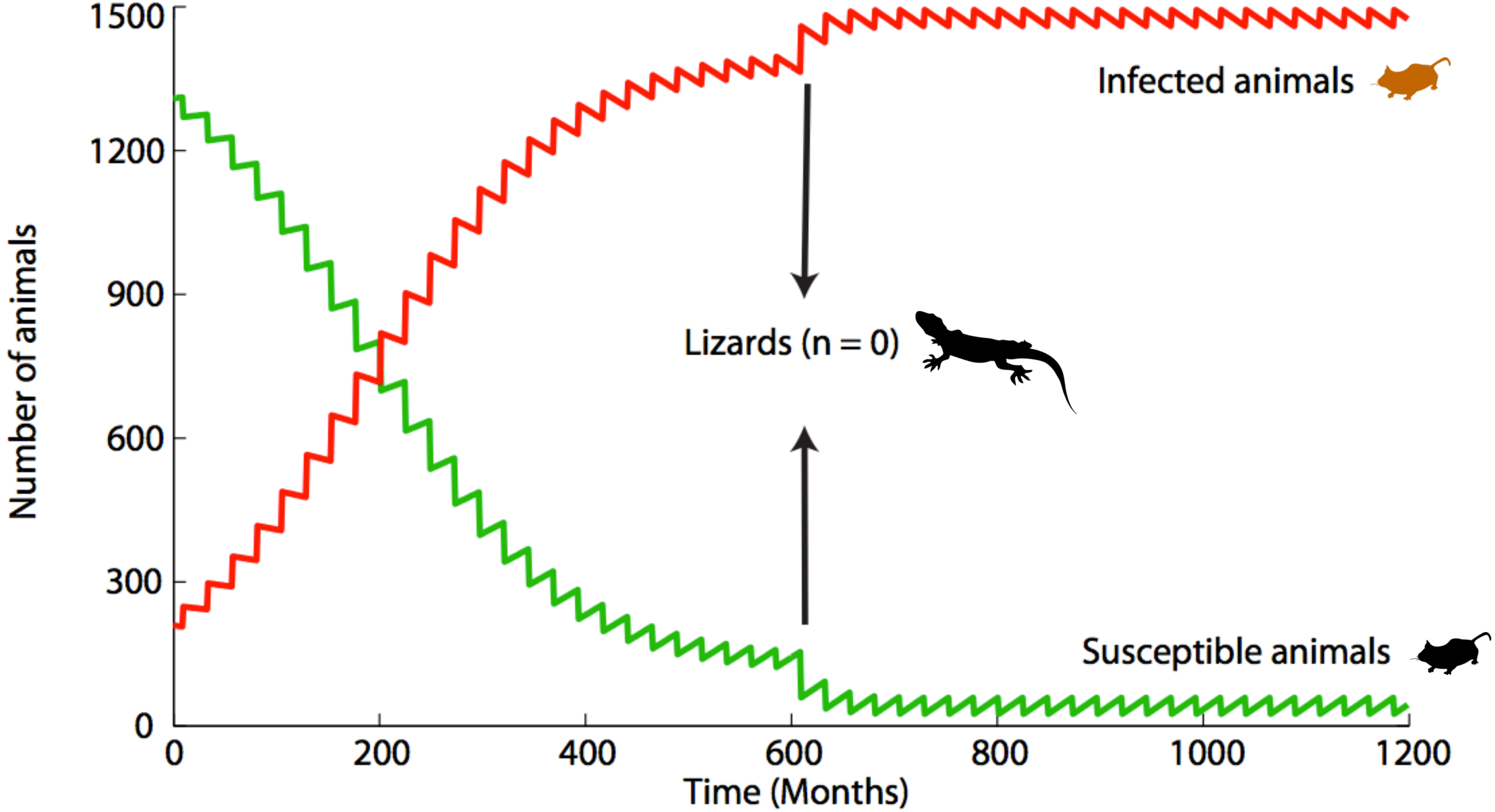


10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Number of individuals
0
5
10
15
20
25
Time (Months)
Hungry larvae
Fed uninfected larvae
Fed infected larvae
Hungry uninfected nymphs
Hungry infected nymphs
Fed uninfected nymphs
Fed infected nymphs
Adults
Eggs

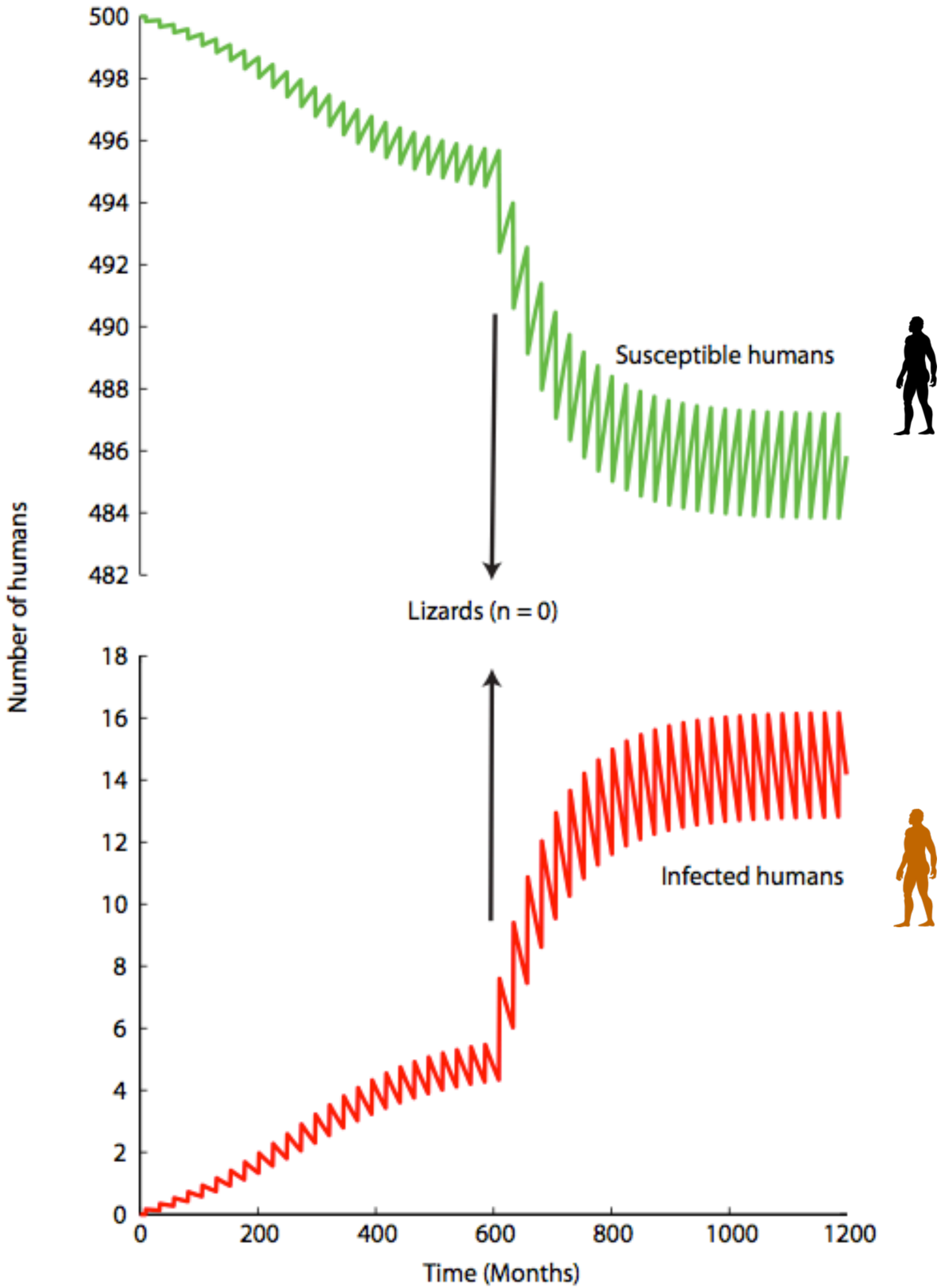


Eggs
Hungry larvae
Fed uninfected larvae
Hungry uninfected nymphs
Hungry infected nymphs
Fed uninfected nymphs
Fed infected nymphs
Adults
Fed infected larvae
Number of individuals
Time (Months)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
0
5
10
15
20
25


Number of individuals
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
5
10
15
20
25
Time (Months)
Hungry larvae
Fed uninfected larvae
Hungry uninfected nymphs
Hungry infected nymphs
Fed uninfected nymphs
Fed infected nymphs
Fed infected larvae
Adults
Eggs



1500
1200
900
600
300
0
Number of animals
0
200
400
600
800
1000
1200
Time (Months)
Infected animals
Lizards (n = 0)
Susceptible animals



Number of humans
500
498
496
494
492
490
488
486
484
482
Susceptible humans
Lizards (n = 0)
18
16
14
12
10
8
6
4
2
0
Infected humans
0
200
400
600
800
1000
1200
Time (Months)

Final Remarks

PROCEEDINGS OF THE ROYAL SOCIETY B

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Impact of the experimental removal of lizards on Lyme disease risk

Andrea Swei[1,*], Richard S. Ostfeld[2], Robert S. Lane[3] and Cheryl J. Briggs[4]

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[2]*Cary Institute of Ecosystem Studies, Millbrook, NY 12545-0129, USA*
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[4]*Department of Ecology, Evolution, and Marine Biology, University of California, Santa Barbara, CA 93106-9610, USA*

- Transient state;
- Lizard = barrier

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Questions

Can a mathematical model for Lyme disease transmission help understand the experimental result described above? What else such a model can predict about:

- infection risk to humans?
- host assemblages and Lyme disease prevalence in humans and reservoirs?
- management of reservoir populations to decrease the risk of infection?

THANKS!!!

- Organizers
- Professors
- T.As

Where

$e =:$ "Number of eggs that hatch"
$V_A =:$ "Reservoir competence on animals"
$H_A =:$ "Host competence of animals"
$R =:$ "Number of lizards"
$H_R =:$ "Host competence of lizards "
$H_H =:$ "Host competence of humans"
$\mu_1 =:$ "Feeding success rate of larva"
$\mu_2 =:$ "Feeding success rate of nymphs"
$\gamma =:$ "Larval death rate"
$\gamma_A =:$ "Animal death rate"
$\gamma_H =:$ "Humans death rate"
$\rho_A =:$ "New animals that born to mantain the equilibrium of the system"
$\epsilon =:$ "Efficiency of the bites on humans"
$\epsilon_A =:$ "Efficiency of the bites on animals"
$\delta =:$ "Human infection recovery rate"
$\lambda =:$ "Encounter rate of infected nymph and human"
$\psi =:$ "Death rate due to the disease"