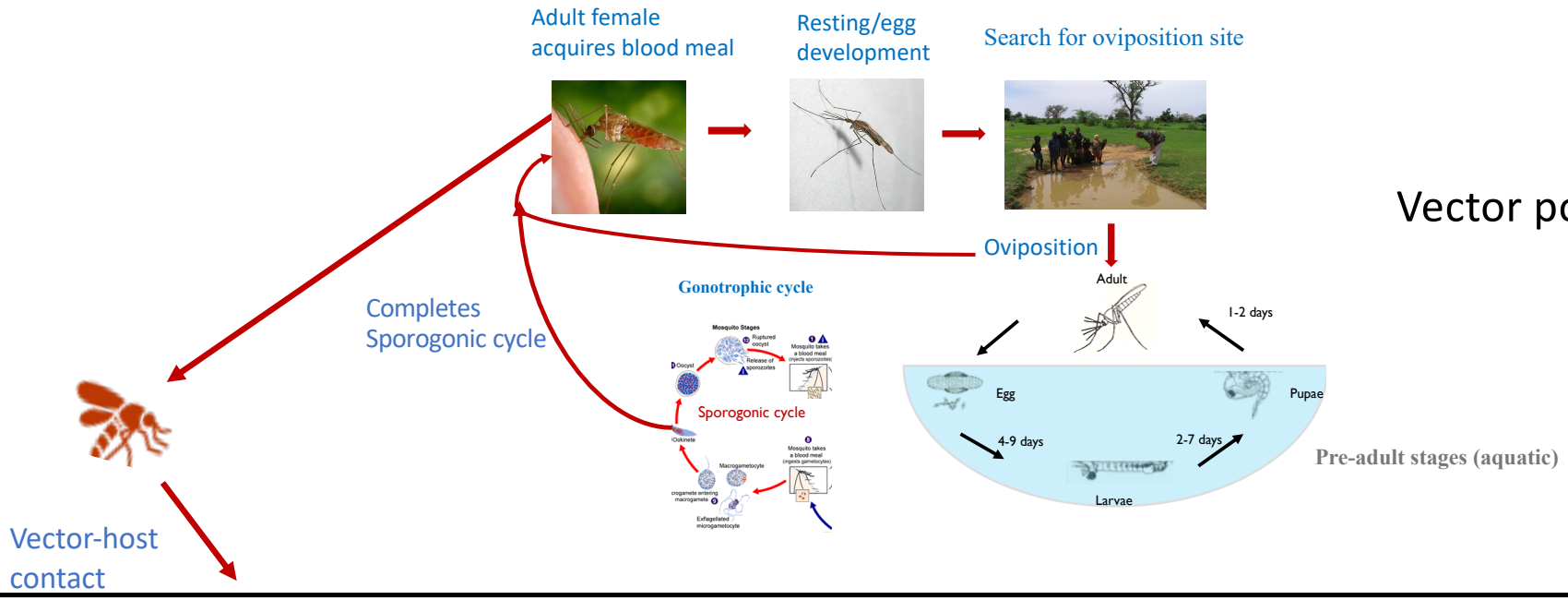
Previous session

- Climate affects life: biomes and climate variation
- Lifecycle:
  - Oviposition
  - Aquatic development and survival: Egg, larvae, and pupae
- Adult survival & host-seeking
- Climate & disease ecology: parasite lifecycle

Today's session

- Overview malaria transmission vector+host
- Aspects of transmission for climate modification
  - From ecology to model entomology
- Class exercise

Review of malaria transmission



Vector population

Human population

Adult female acquires blood meal

Resting/egg development

Search for oviposition site

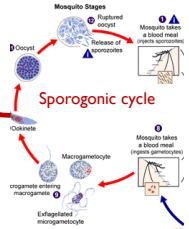
Oviposition

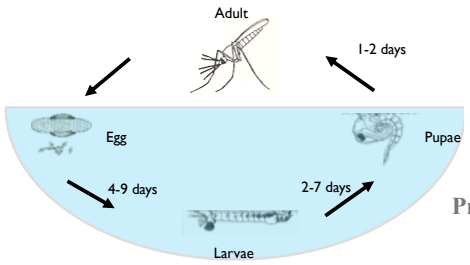
Completes Sporogonic cycle

Vector-host contact

Vector population

Gonotrophic cycle





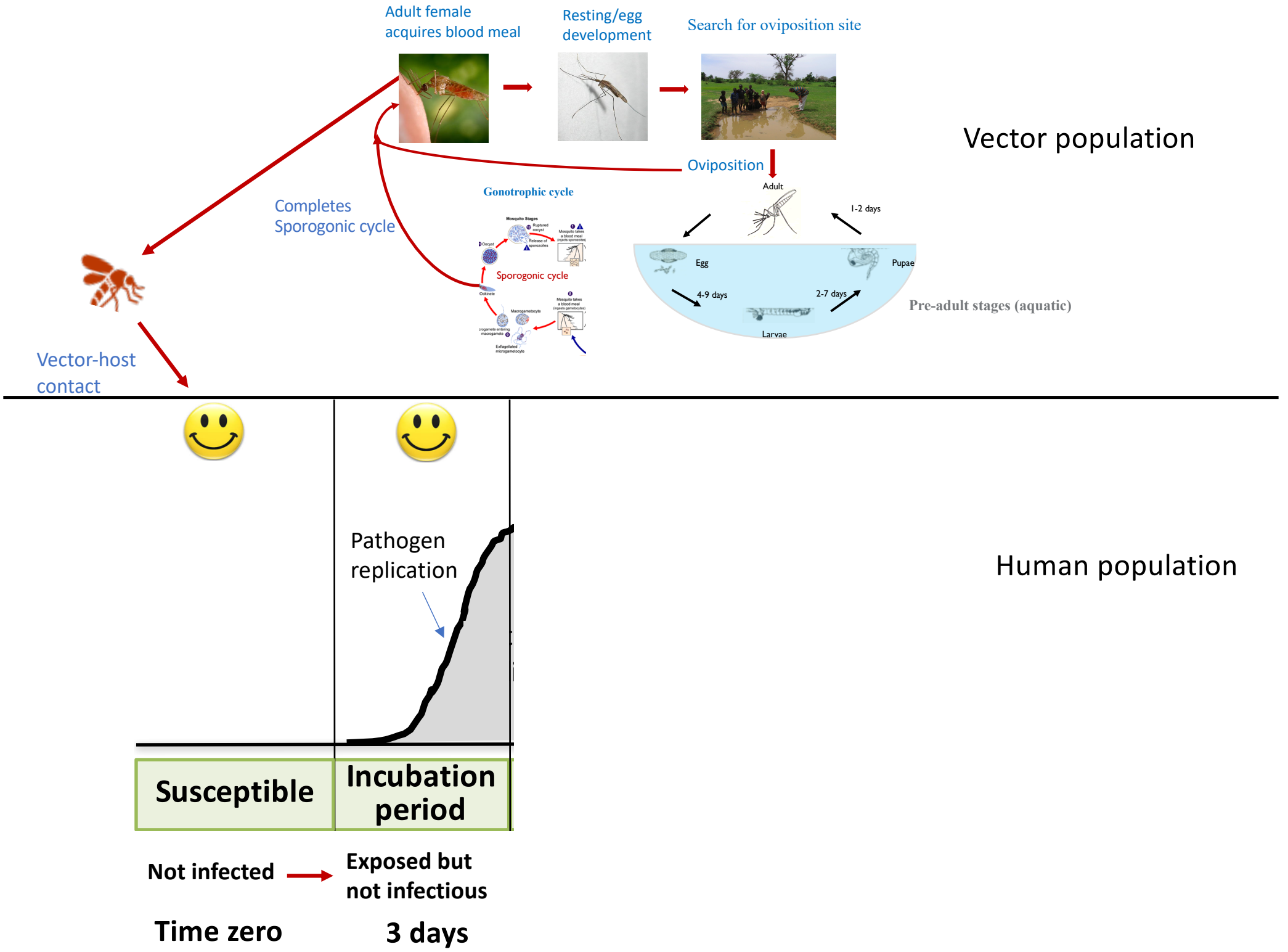
Pre-adult stages (aquatic)

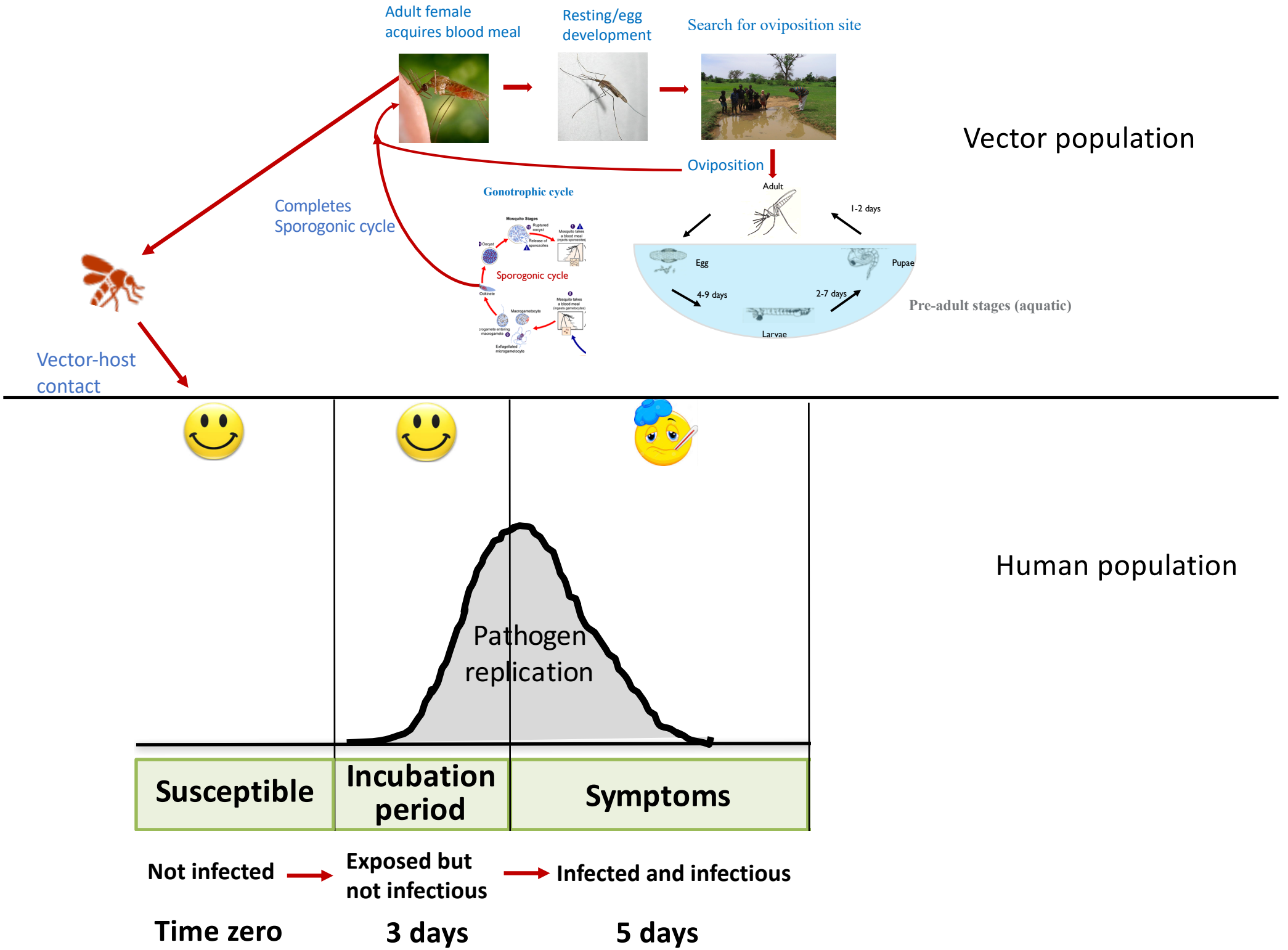
Human population

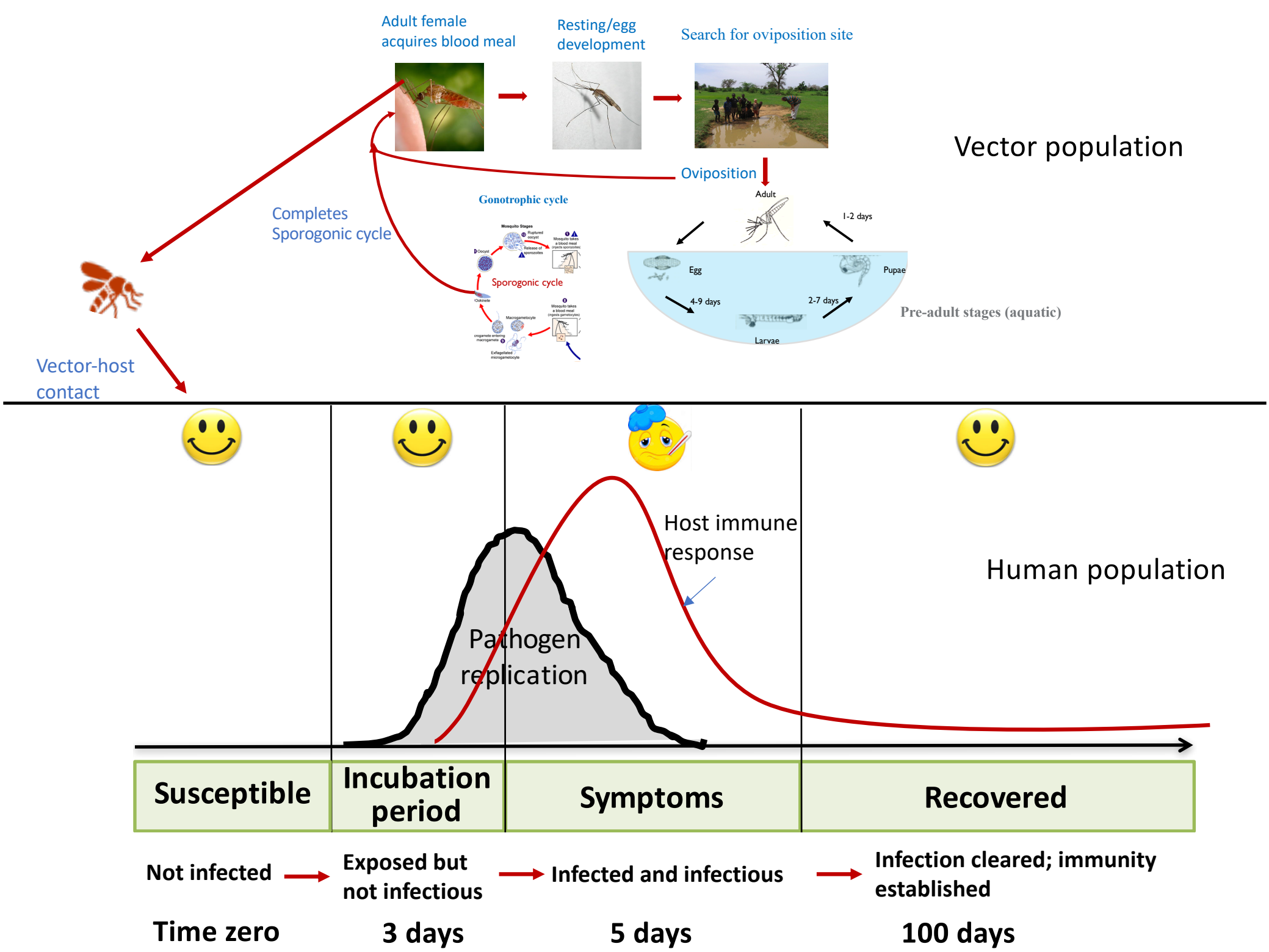
Susceptible

Not infected

Time zero


Adult female
acquires blood meal
Resting/egg
development
Search for oviposition site
Vector population
Oviposition
Gonotrophic cycle
Adult
1-2 days
Completes
Sporogonic cycle
Sporogonic cycle
Egg
Pupae
4-9 days
2-7 days
Larvae
Pre-adult stages (aquatic)
Vector-host
contact
Pathogen
replication
Human population
Susceptible
Incubation
period
Not infected
Exposed but
not infectious
Time zero
3 days


Adult female acquires blood meal
Resting/egg development
Search for oviposition site
Oviposition
Completes Sporogonic cycle
Gonotrophic cycle
Sporogonic cycle
Adult
1-2 days
Egg
Pupae
4-9 days
2-7 days
Larvae
Pre-adult stages (aquatic)
Vector population
Vector-host contact
Pathogen replication
Susceptible
Incubation period
Symptoms
Human population
Not infected
Exposed but not infectious
Infected and infectious
Time zero
3 days
5 days

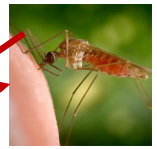

Adult female acquires blood meal
Resting/egg development
Search for oviposition site
Vector population
Oviposition
Gonotrophic cycle
Adult
1-2 days
Completes Sporogonic cycle
Sporogonic cycle
Egg
Pupae
4-9 days
2-7 days
Larvae
Pre-adult stages (aquatic)
Vector-host contact
Host immune response
Human population
Pathogen replication
Susceptible
Incubation period
Symptoms
Recovered
Not infected
Exposed but not infectious
Infected and infectious
Infection cleared; immunity established
Time zero
3 days
5 days
100 days

Avenues for climate interaction

What are the avenues of climate modulation?

Vector population

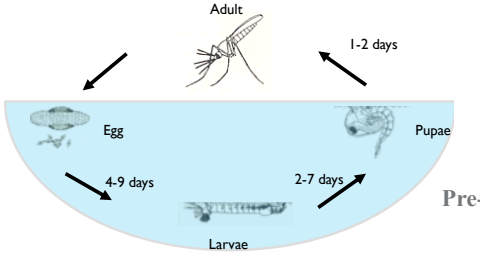
Adult female acquires blood meal



Resting/egg development

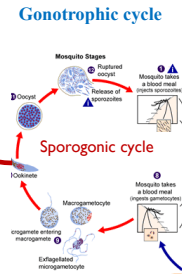
Search for oviposition site

Oviposition



Pre-adult stages (aquatic)

Completes Sporogonic cycle

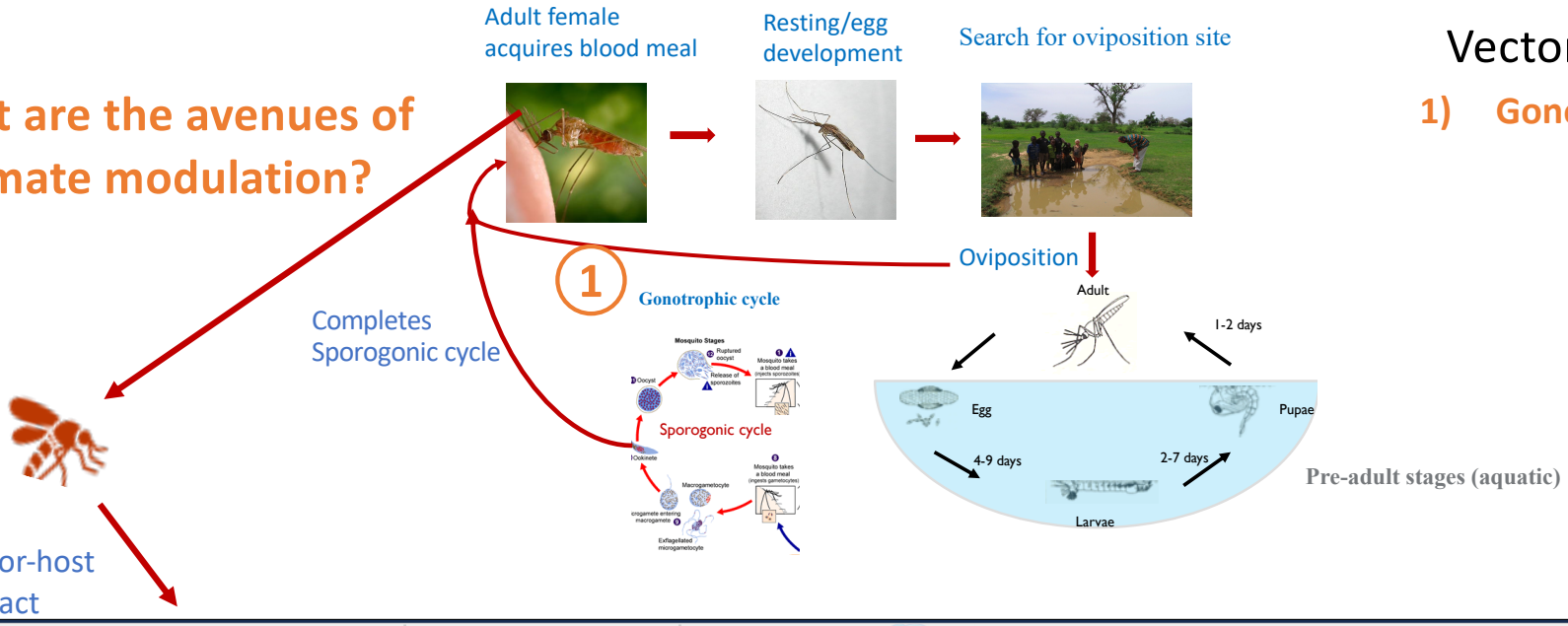


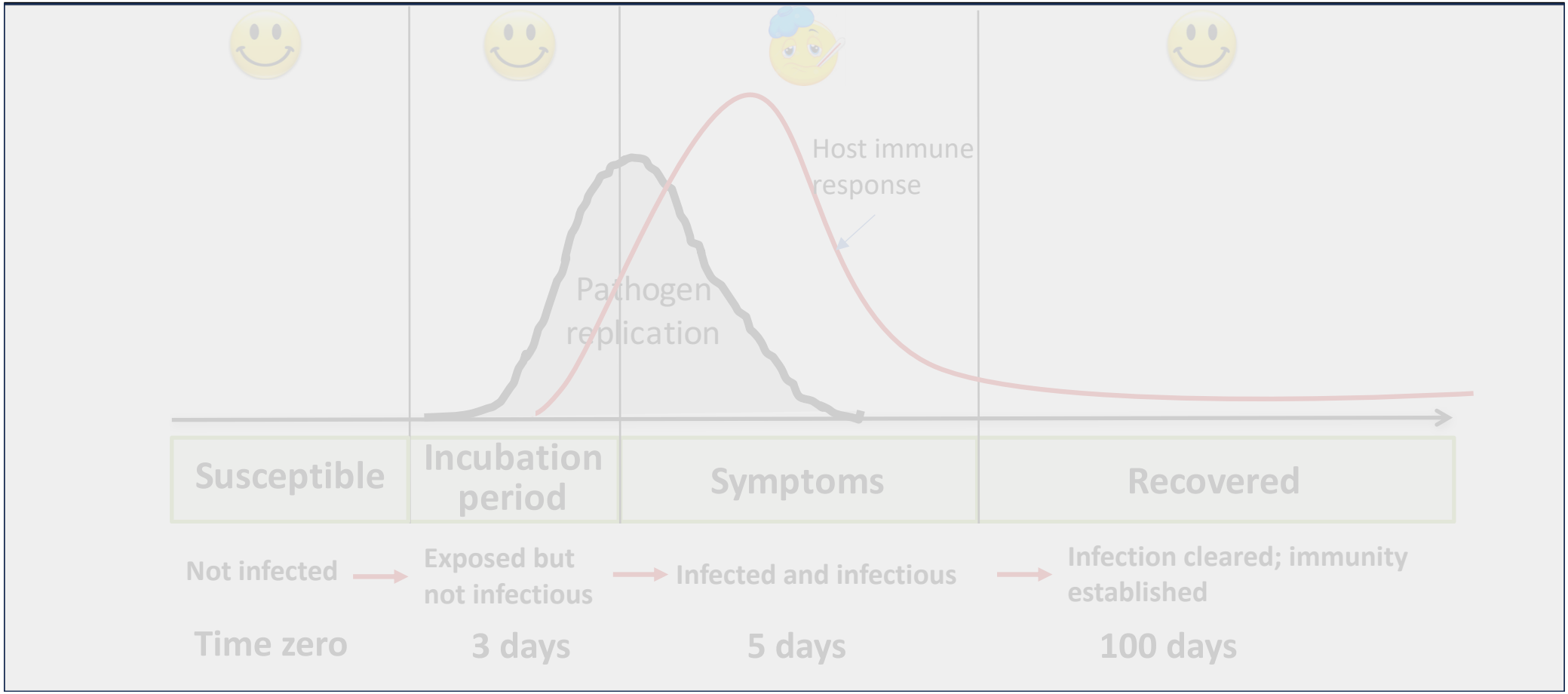
Vector-host contact

What are the avenues of climate modulation?

Vector population

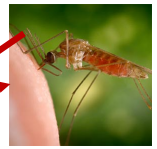
1) Gonotrophic cycle





Avenues of climate modification?

Adult female acquires blood meal



Resting/egg development

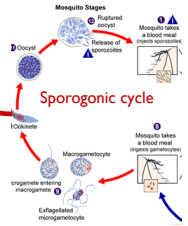
Search for oviposition site

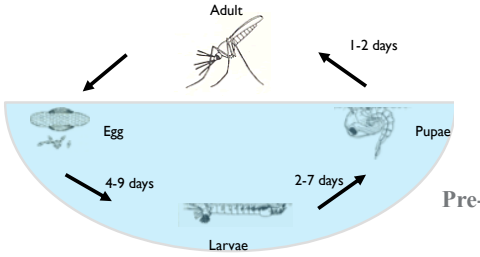
Oviposition

1 Gonotrophic cycle

2 Sporogonic cycle

Completes Sporogonic cycle



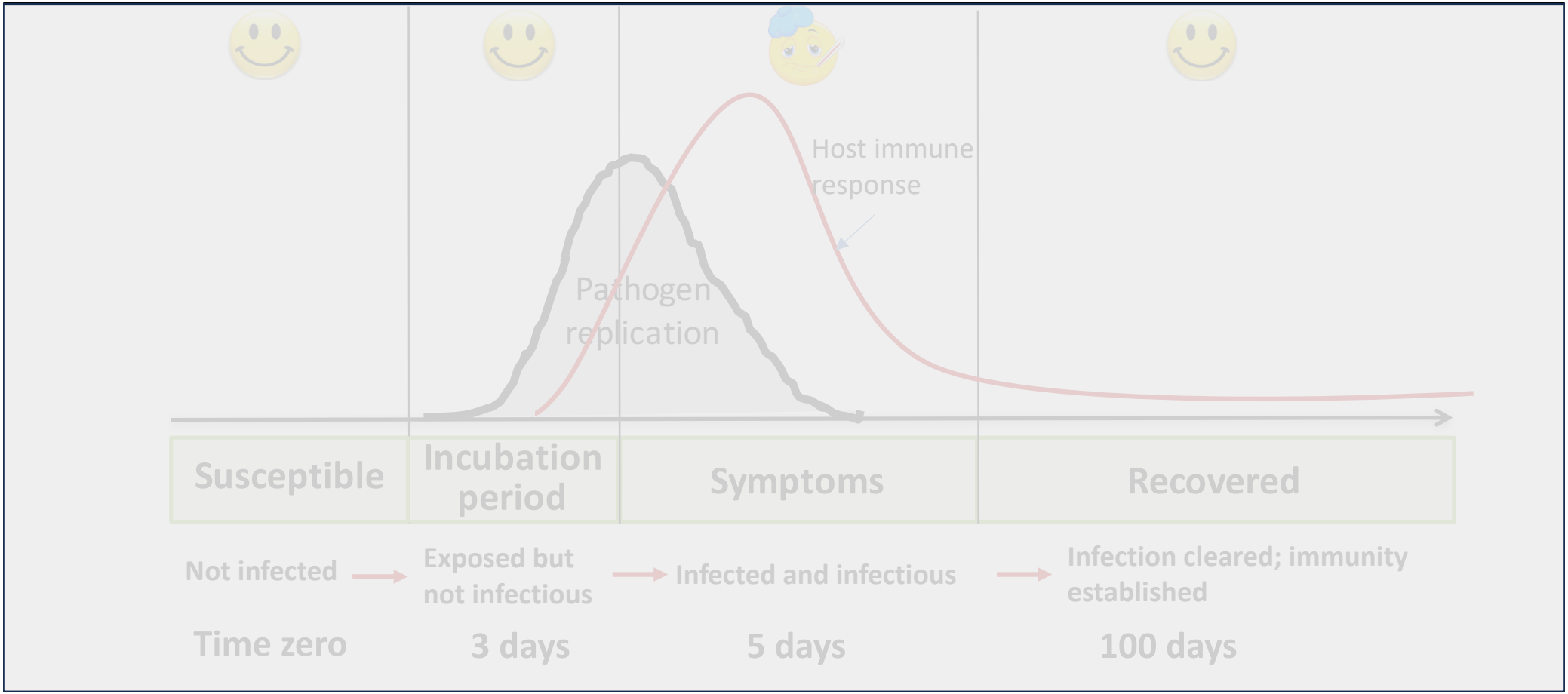


Pre-adult stages (aquatic)

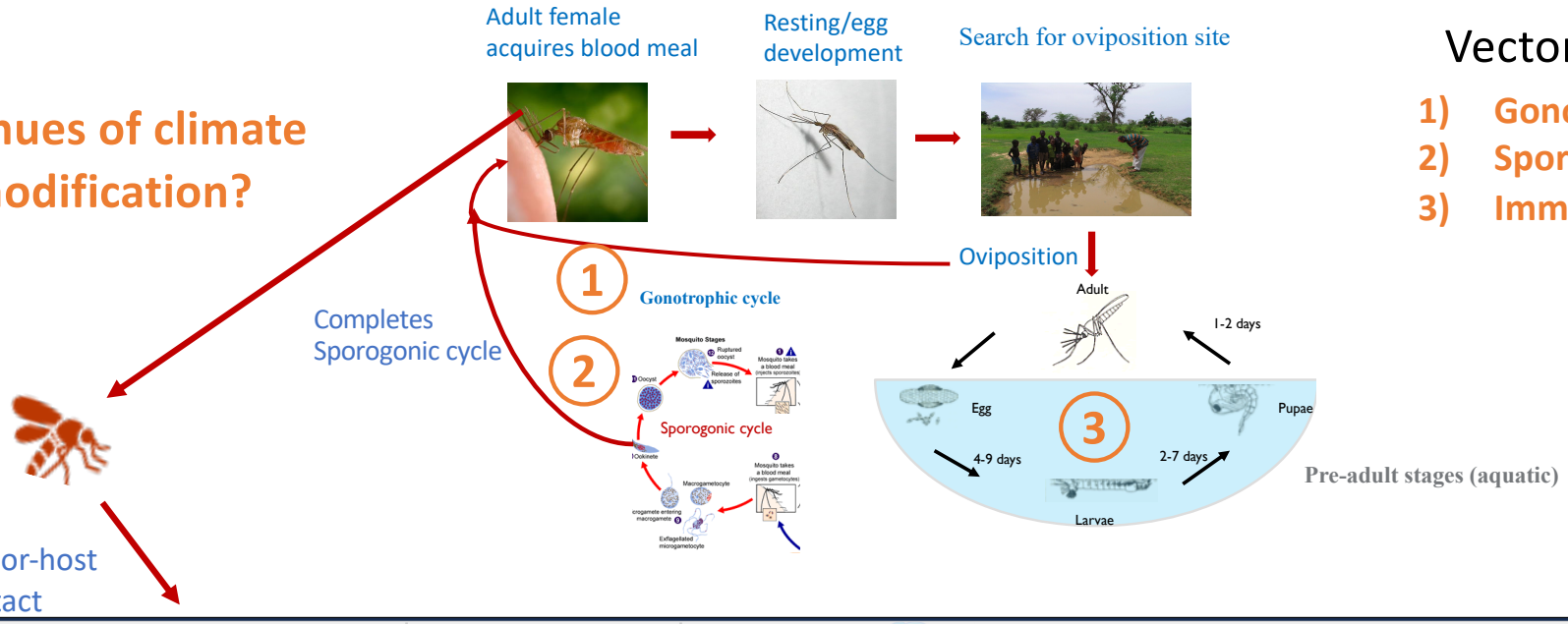
Vector-host contact

Vector population

1) Gonotrophic cycle
2) Sporogonic cycle

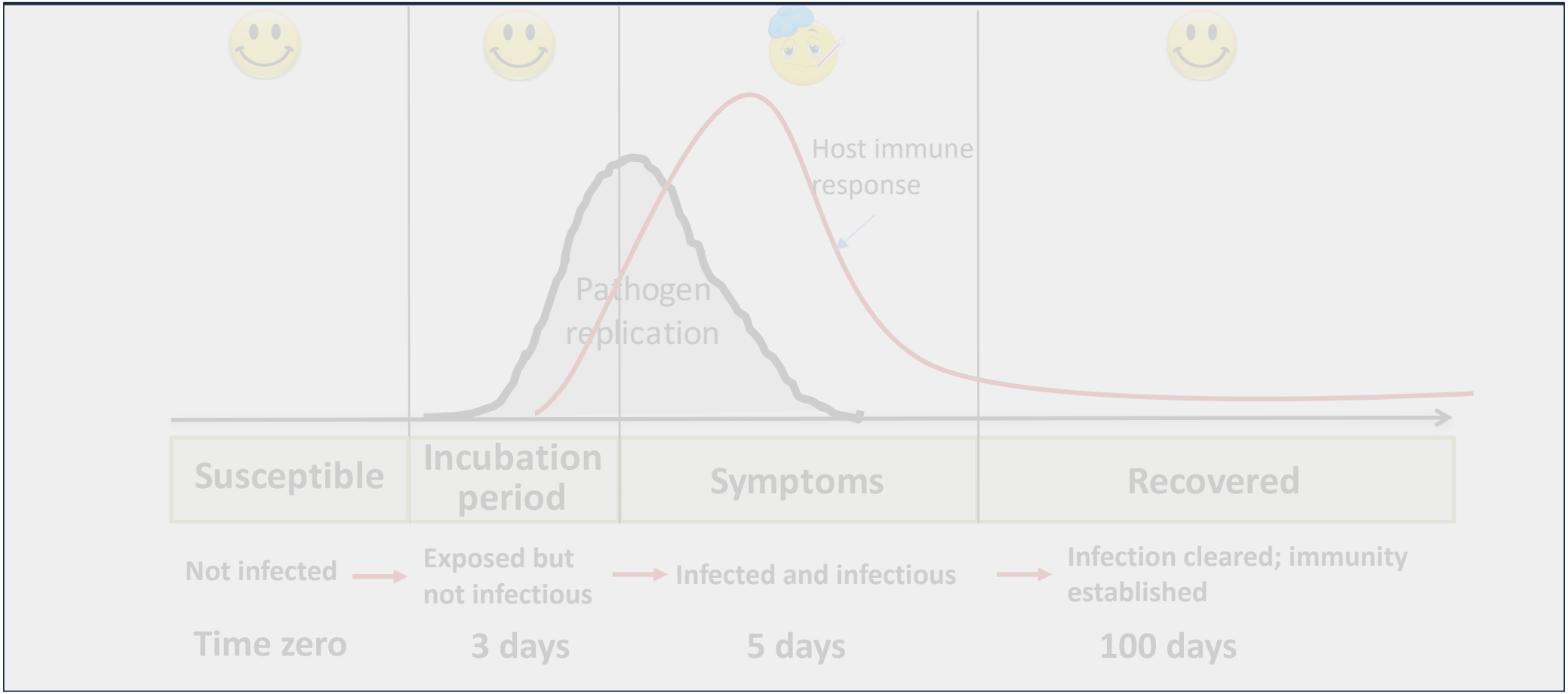


Avenues of climate modification?

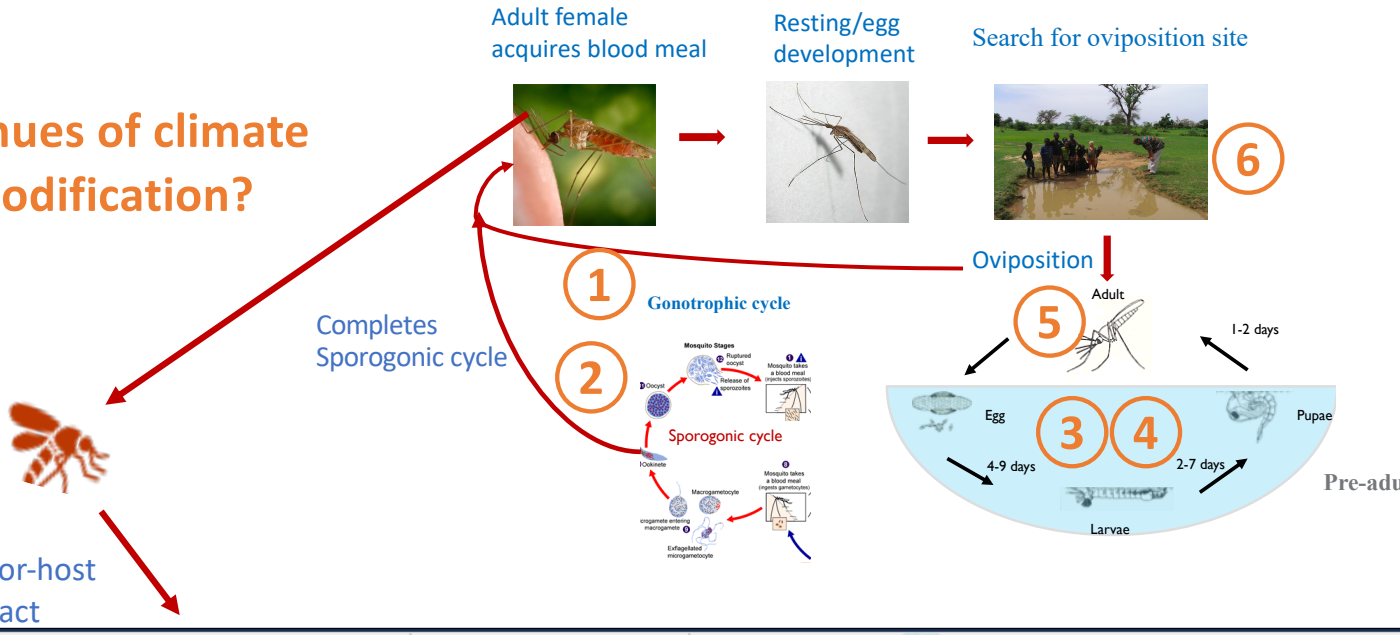


Vector population

1) Gonotrophic cycle
2) Sporogonic cycle
3) Immature development

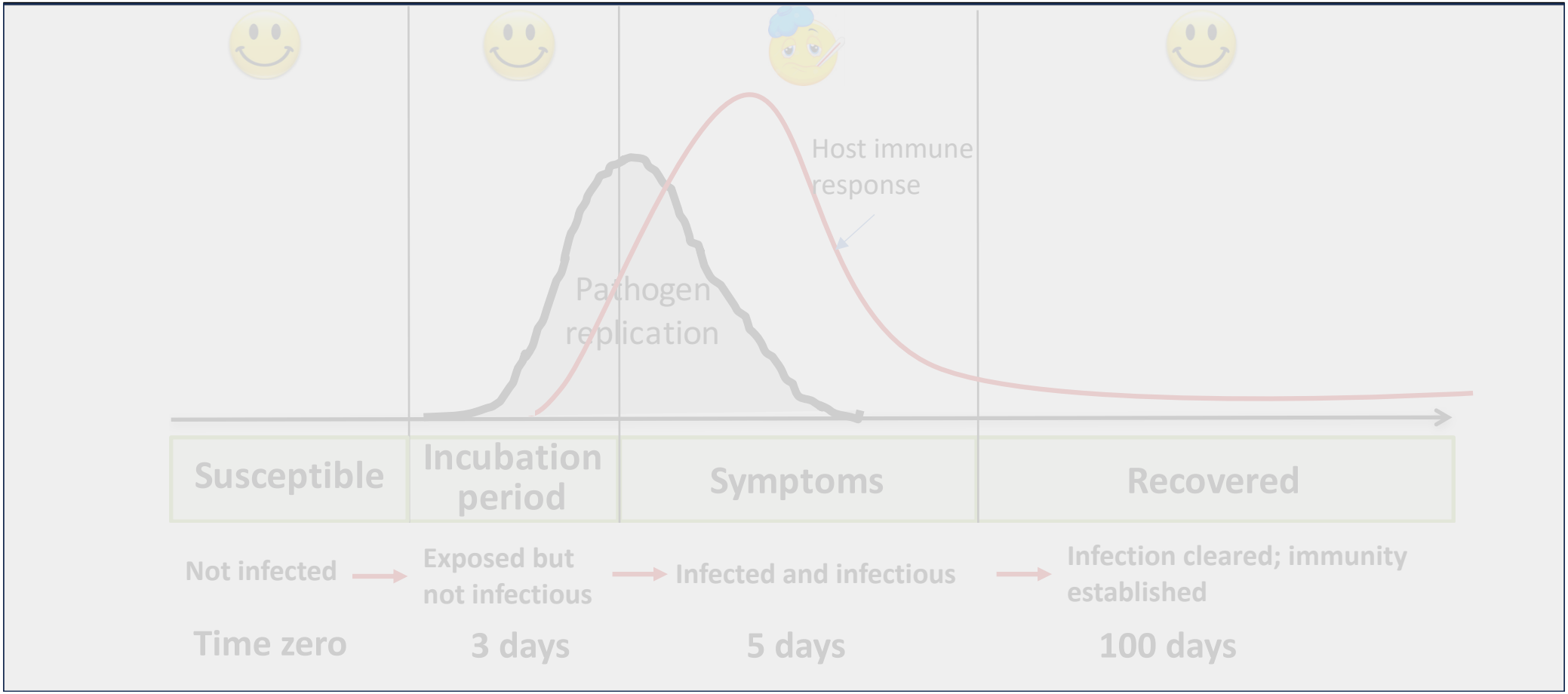


Avenues of climate modification?

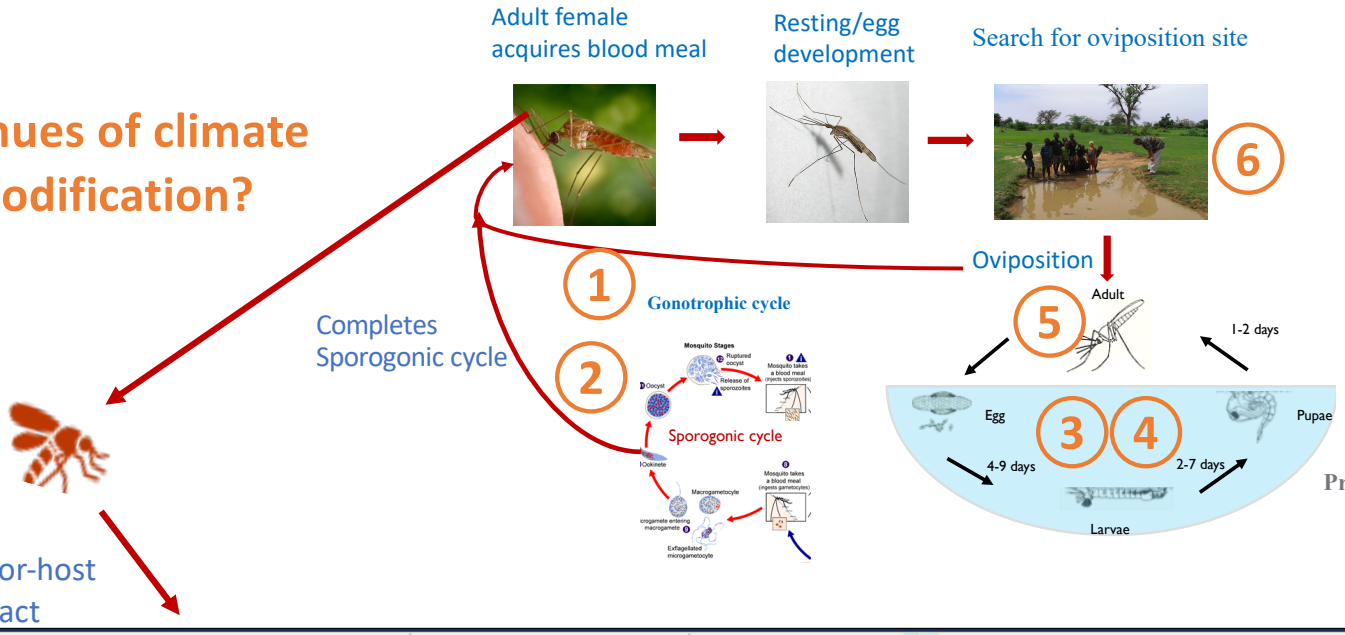


Vector population

1) Gonotrophic cycle
2) Sporogonic cycle
3) Immature development
4) Immature survival
5) Adult mosquito lifespan
6) Oviposition

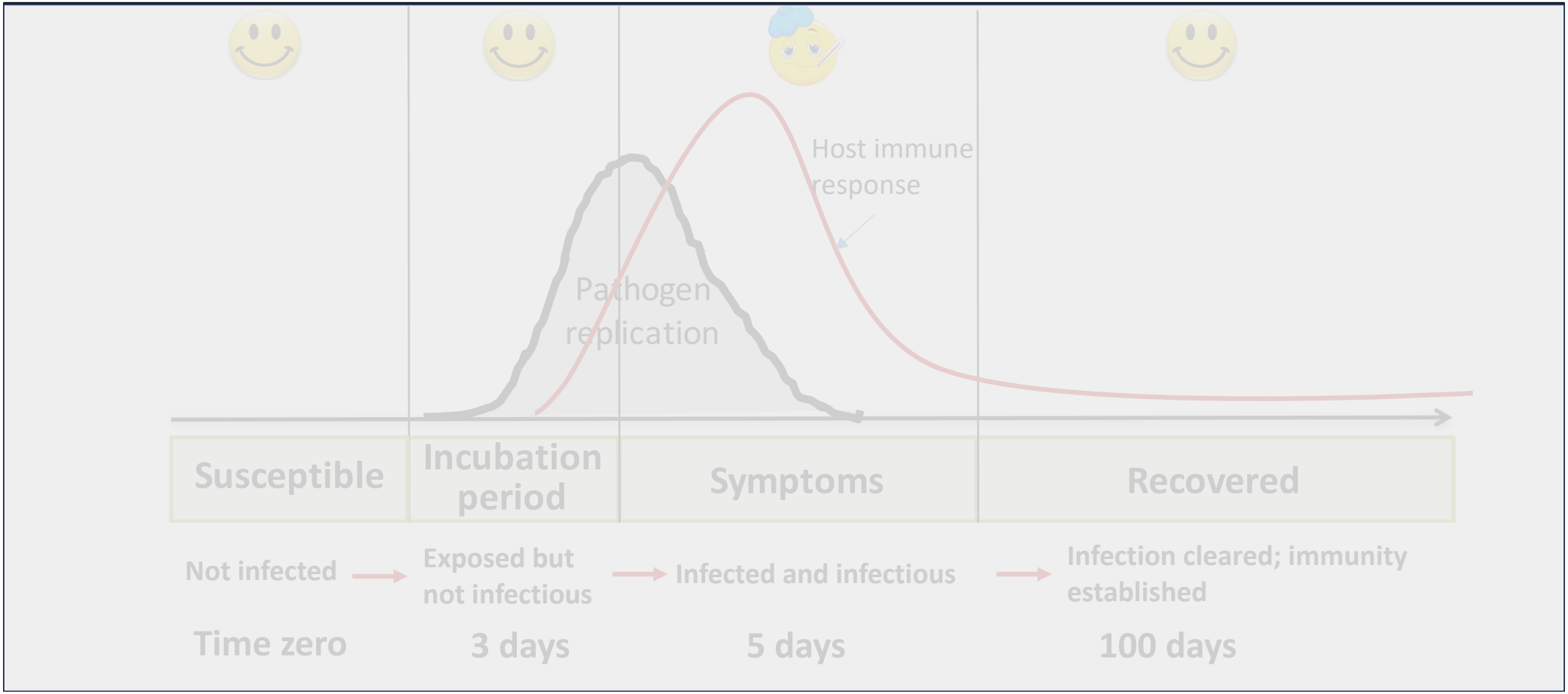


Avenues of climate modification?



Vector population

1) Gonotrophic cycle
2) Sporogonic cycle
3) Immature development
4) Immature survival
5) Adult mosquito lifespan
6) Oviposition
7) **Malaria parameters**
   1) **Vectorial capacity (VC)**
   2) **Entomological inoculation rate (EIR)**
   3) **Reproduction number (R0)**

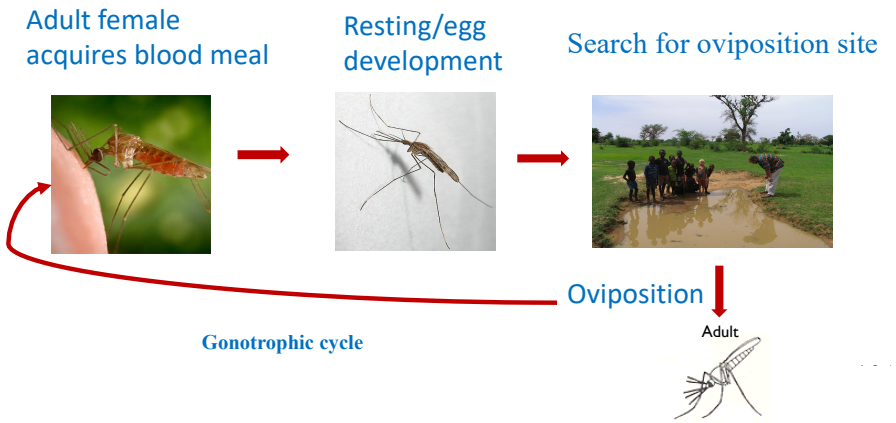


How do we formulate a climate-vector relationship?

Example 1: The Gonotrophy-temperature relationship

Entomological study

Literature



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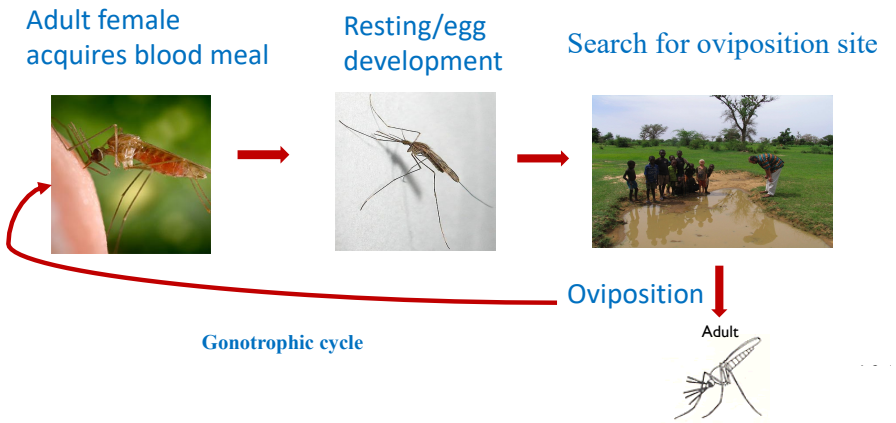


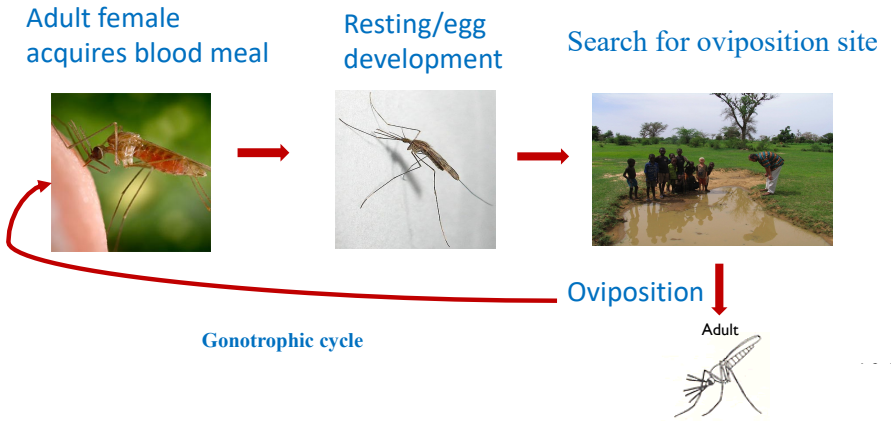
Entomological study

1. Rear *Anopheles* eggs to adults
2. House adults at key constant temperature values
3. Allow bloodmeal, resting, & egg laying
4. Measure time to next bloodmeal after ovipositing
5. Fit temperature to duration of bloodmeal cycle

Literature

How do we formulate a climate-vector relationship?

Example 1: The Gonotrophy-temperature relationship



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1. Review primary literature
2. Obtain fittings of temperature
3. Compare results to similar studies

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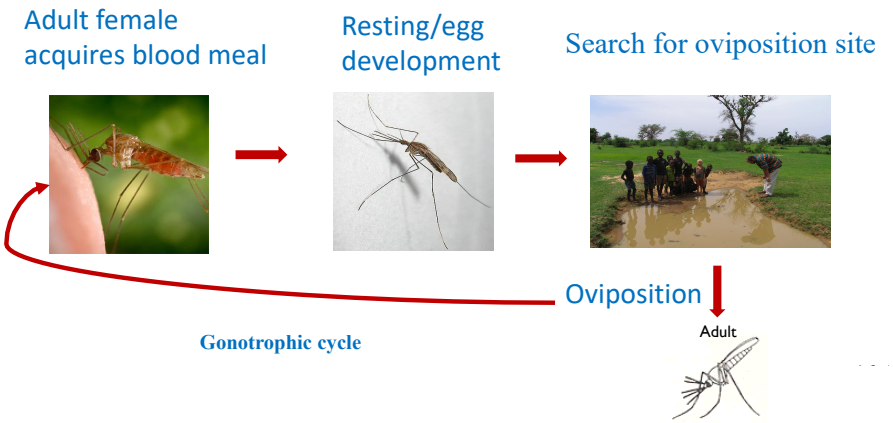

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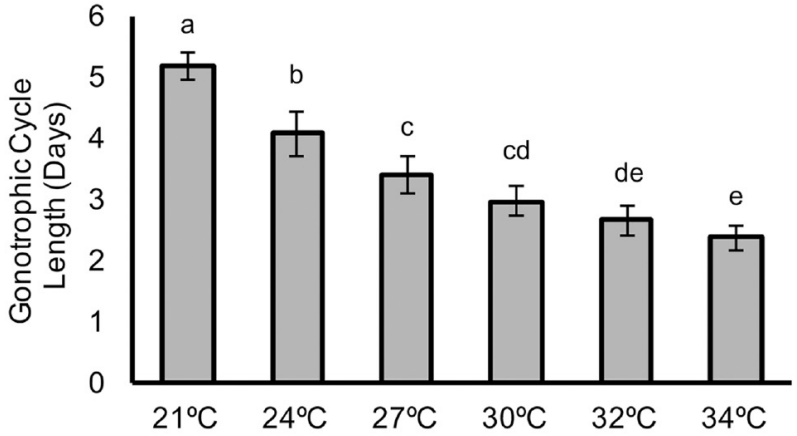
5. Fit temperature to duration of bloodmeal cycle

Literature

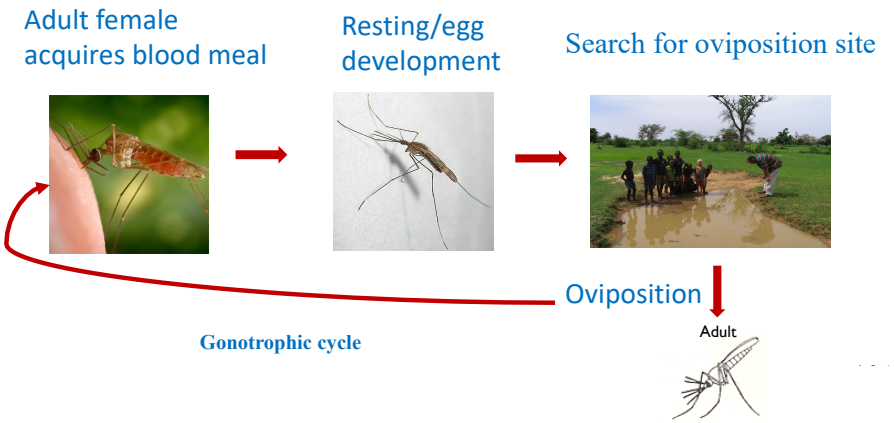
1. Review primary literature
2. Obtain fittings of temperature
3. Validate with independent mosquito data
4. Pooled results over multiple datasets provide more robust estimates of relationships

Temperature-regulated gonotrophy



How do we formulate a climate-vector relationship?

Example 1: The Gonotrophy-temperature relationship



Entomological study

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Literature

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2. Obtain fittings of temperature to gonotrophy
3. Compare results to similar studies
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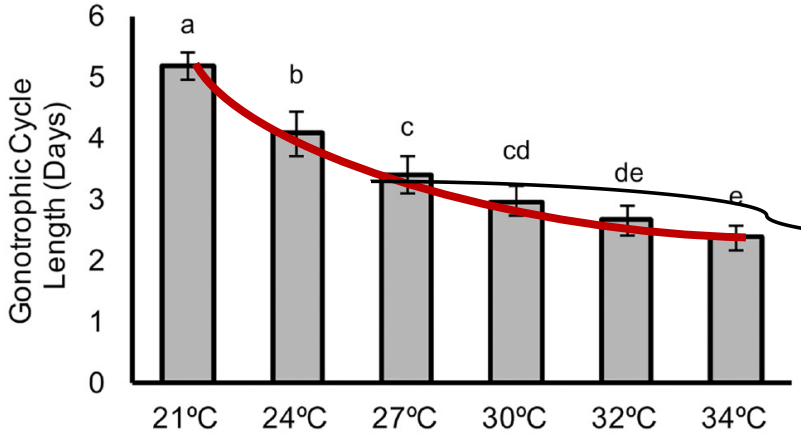
Temperature-regulated gonotrophy



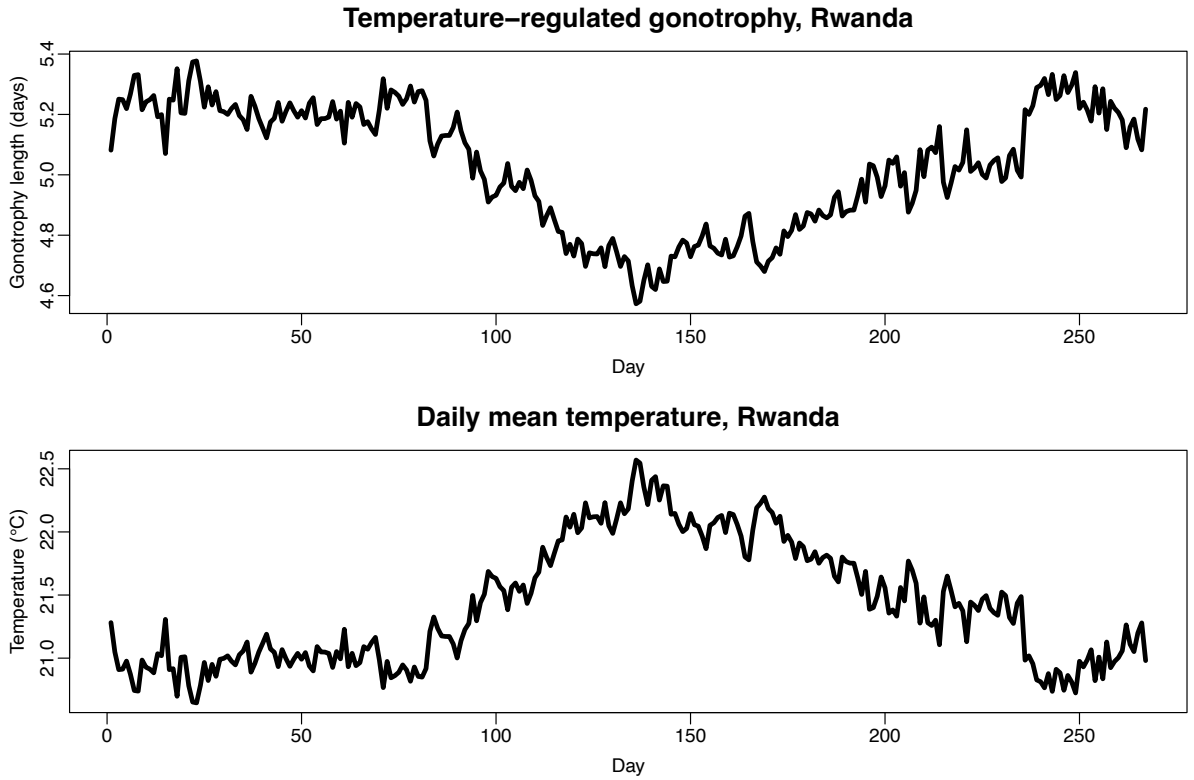
$$GP = \frac{1}{(0.017 * T) - 0.165}$$

Shapiro et al 2017.

How do we formulate a climate-vector relationship?

Example 1: The Gonotrophy-temperature relationship

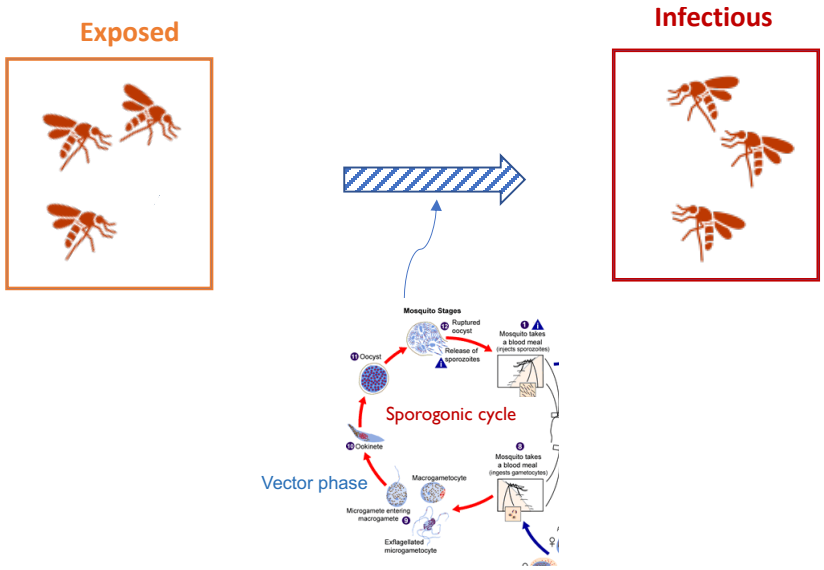
$$GP = \frac{1}{(0.017 * T) - 0.165}$$

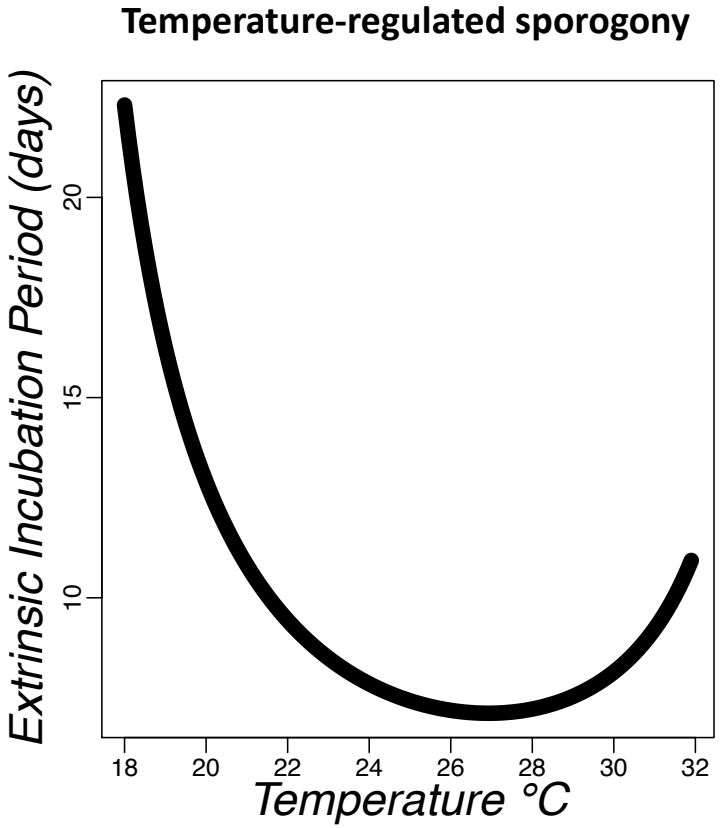


Shapiro et al 2017.

How do we formulate a climate-vector relationship?

Example 2: The sporogony-temperature relationship





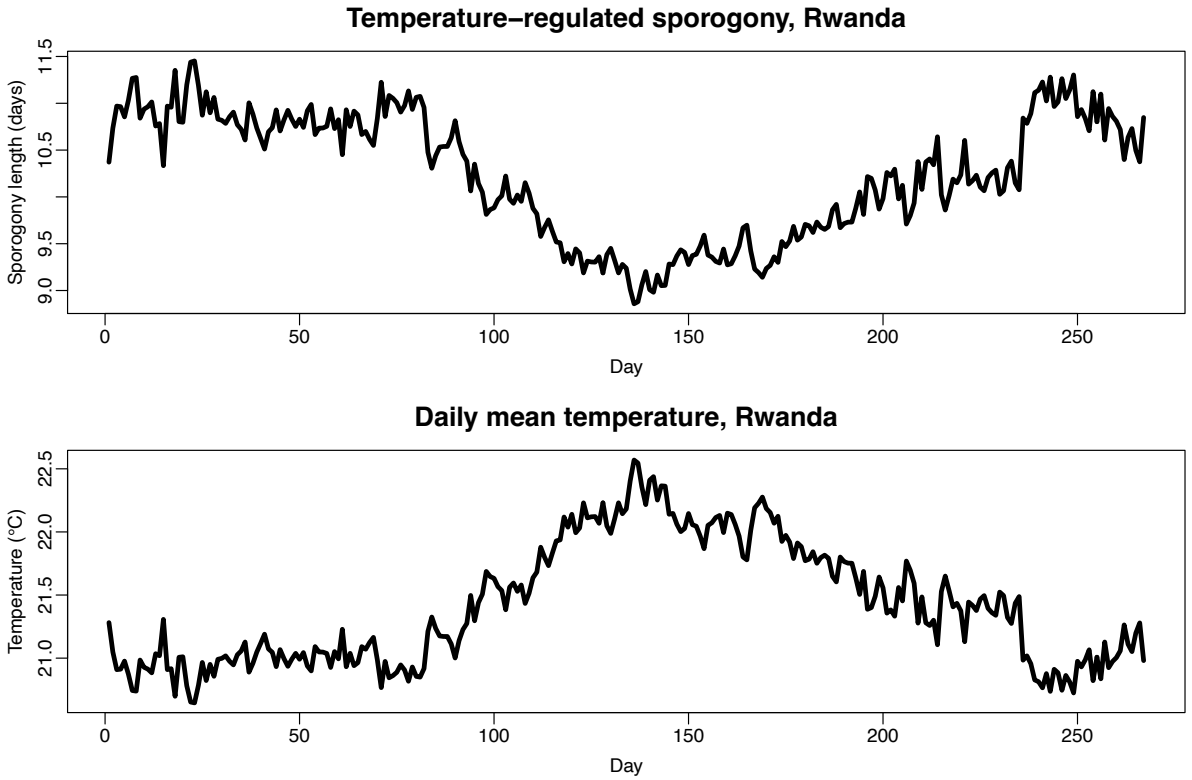
$$EIP = 0.000112T(T - 15.384)\sqrt{(35 - T)}$$

Paaijmans et al 2009.

How do we formulate a climate-vector relationship?

Example 2: The sporogony-temperature relationship

$$EIP = 0.000112T(T - 15.384)\sqrt{(35 - T)}$$



Paaijmans et al 2009.

So far

- Several aspects of vector and parasite ecology for for climate modification

- From entomology to generalized relationship

  - Primary studies: address questions specific to researchers needs. First data collection, more accurate

  - Literature review: crucial to compare results to similar studies. Advantageous for pooling multiple studies and yields more robust estimates of climate relationships

Short break

Example 3: group work and presentation

Example 3

RESEARCH Open Access

How malaria models relate temperature to malaria transmission

Torleif Markussen Lunde[1,2,4*], Mohamed Nabie Bayoh[3] and Bernt Lindtjørn[2]

Abstract

Background: It is well known that temperature has a major influence on the transmission of malaria parasites to their hosts. However, mathematical models do not always agree about the way in which temperature affects malaria transmission.

Methods: In this study, we compared six temperature dependent mortality models for the malaria vector *Anopheles gambiae* sensu stricto. The evaluation is based on a comparison between the models, and observations from semi-field and laboratory settings.

Results: Our results show how different mortality calculations can influence the predicted dynamics of malaria transmission.

Conclusions: With global warming a reality, the projected changes in malaria transmission will depend on which mortality model is used to make such predictions.

Keywords: *Anopheles gambiae* sensu stricto, Climate, Temperature, Mathematical model

- Literature review assignment
  1. Students have been assigned the above paper
  2. You will work in groups to explore how temperature-mortality relationships impact transmission at the population level

Example 3

- Group work & presentation: Adult mosquito survivorship

1. Each group has been randomly assigned one equation formulating the relationship between temperature and adult mosquito survival probability.

2. Using the daily mean temperature data provided for Rwanda,
   a) Generate the survival probability of adult mosquitoes based on your assigned formulation.
   b) Plot the temperature-regulated survival probability over time (x axis =time; yaxis=probability)
   c) Describe the nature of adult mosquito survivorship in Rwanda through the year

3. Convert the survival probability to mortality rates

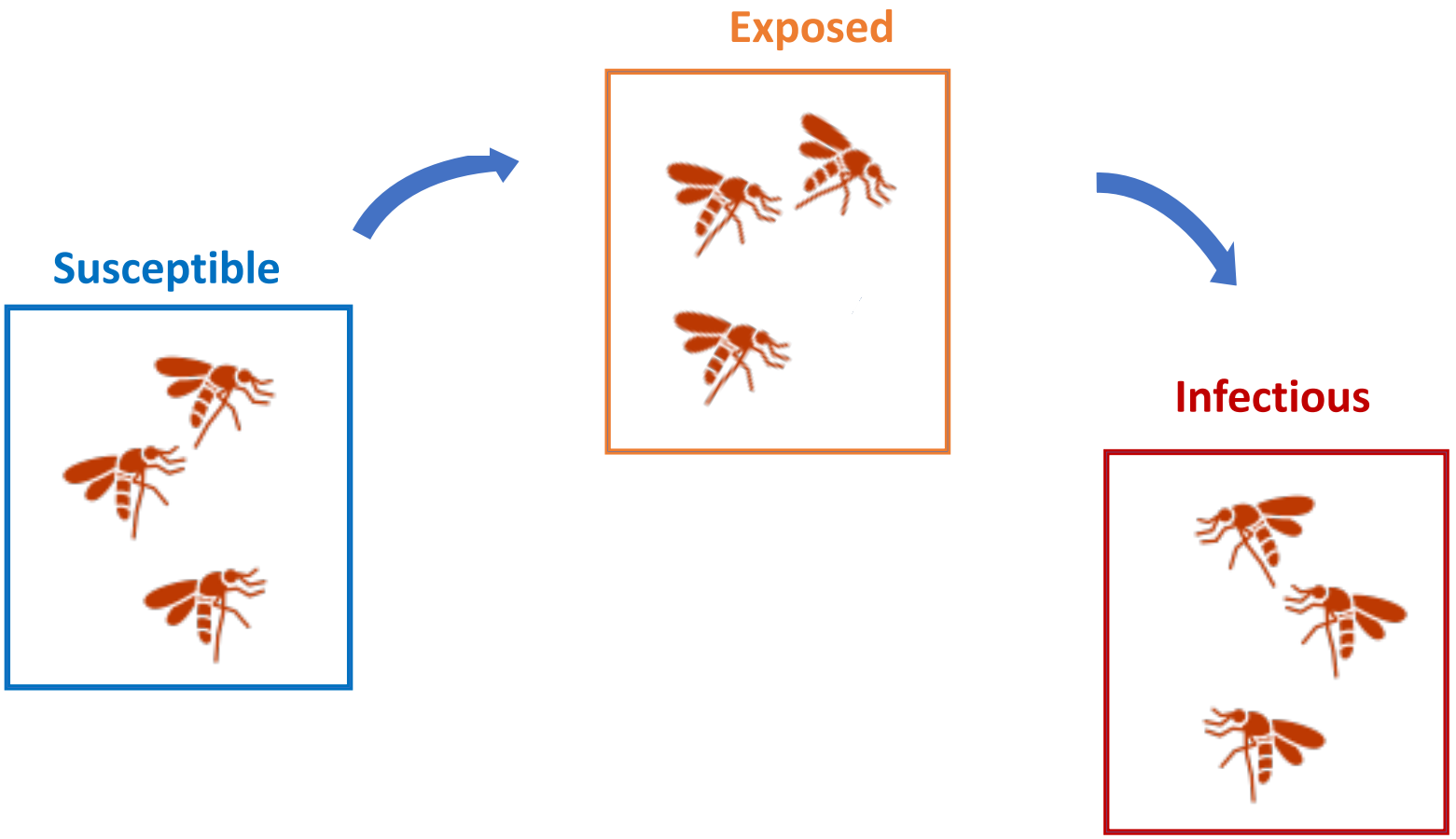
4. Complete the provided SEI model for malaria in the mosquito population, by adding mortality to the system.

5. Run the model using the temperature-regulated mortality rates, together with other provided parameters and state conditions. Note: download the R files containing the model, parameters and initial state values.

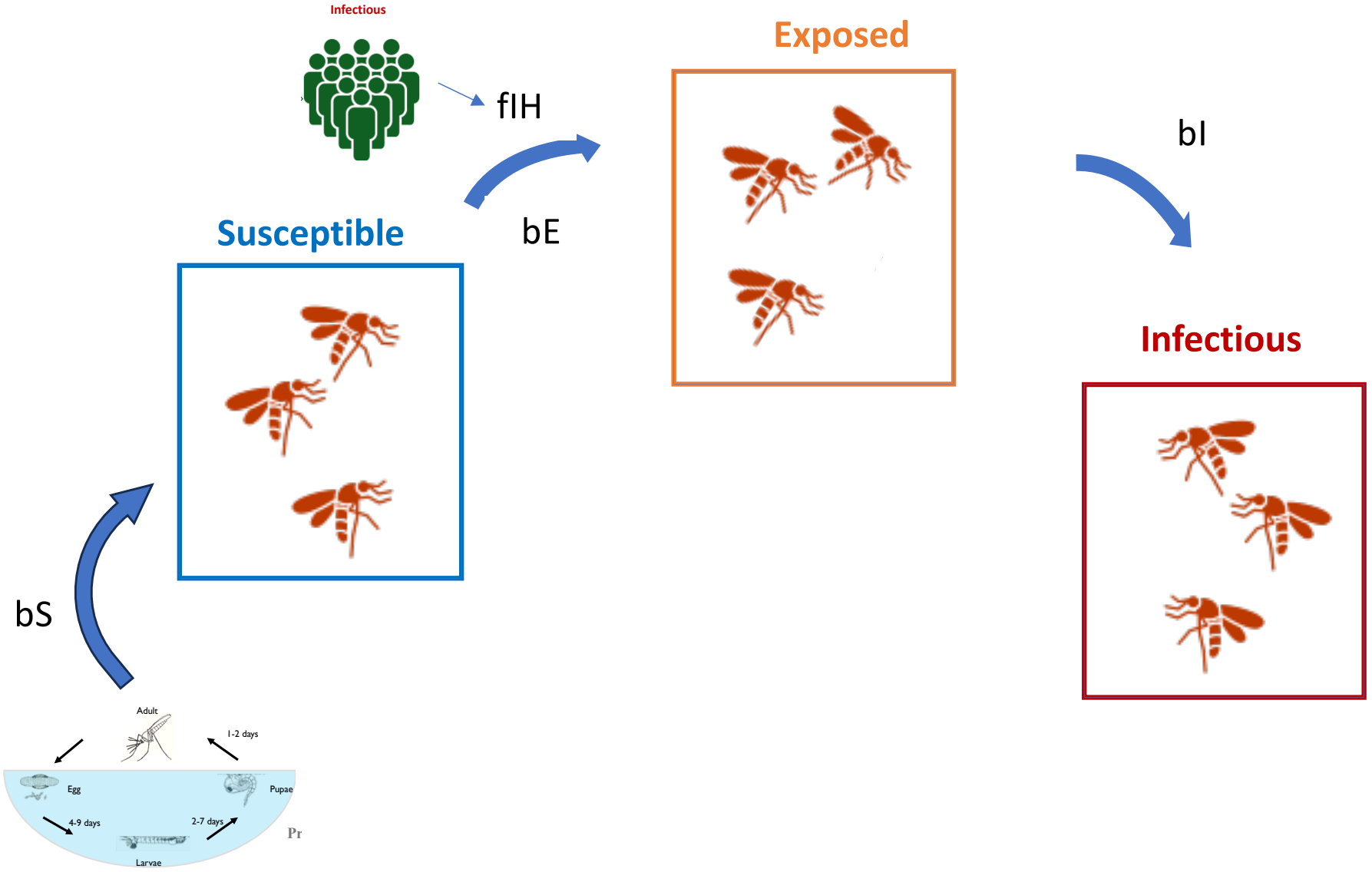
6. Plot the simulated number of infectious mosquitoes over time

7. Each group will present the results from their work to the class in a 5 minute presentation. In your presentation be sure to include:
   1. The reason the authors to conducted this research
   2. The mortality model you used. How did the original authors calibrate the temperature mortality model?
   3. Result on the temperature-regulated daily mortality rates over time for Rwanda
   4. Your completed SEI model system
   5. Result from your model simulation

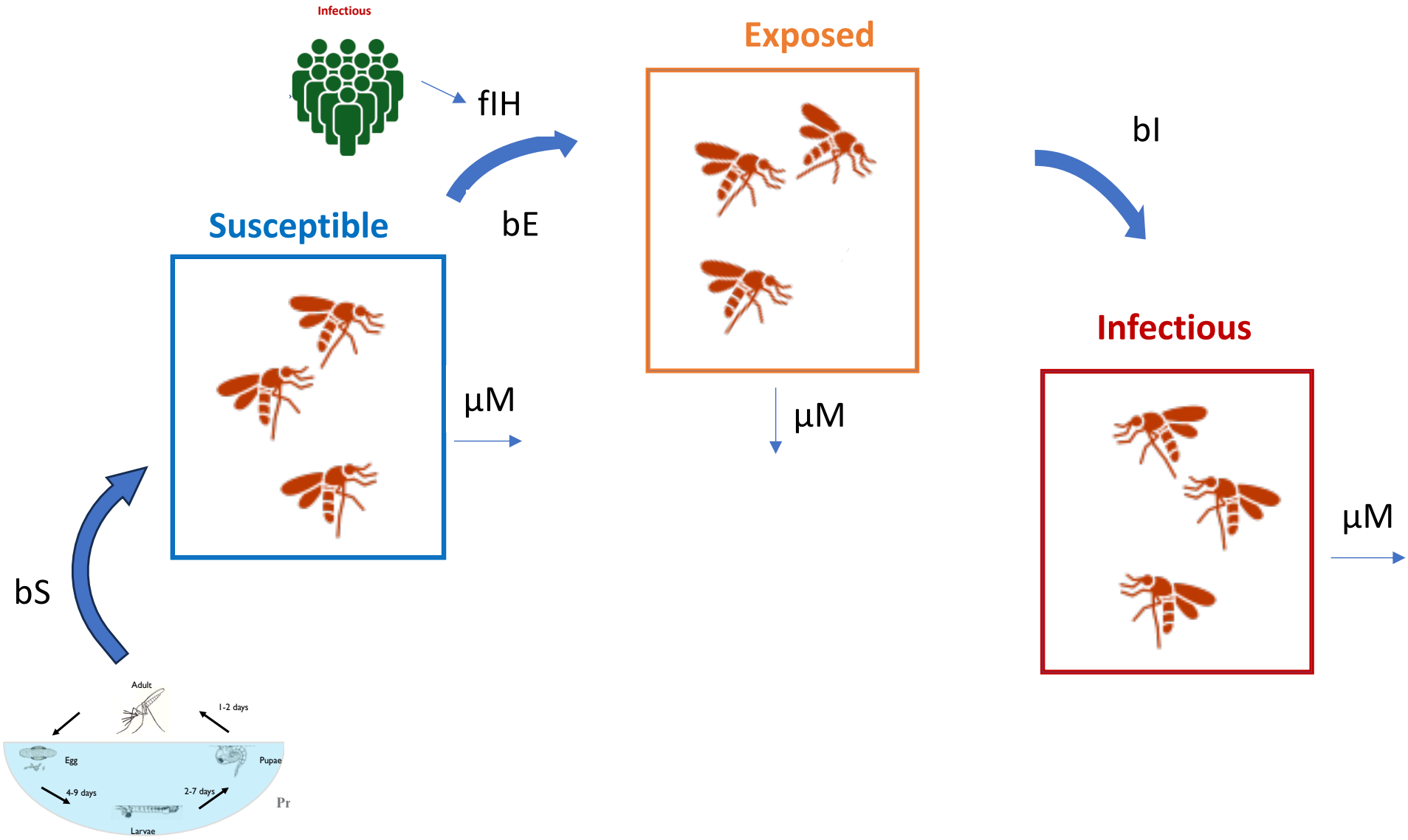
Simple malaria transmission in mosquito population



Simple malaria transmission in mosquito population



Simple malaria transmission in mosquito population



Class presentation and discussion

- Present the results from your group's work to the class in a 5 minute presentation

- Class vote on models & discussion

Begin group work & presentation preparation (60 minutes)

Short break

Class presentation and discussion

- Present the results from your group's work (steps 1–6) to the class in a 5-minute presentation

- Class vote on models & discussion
  - Based on the SEI model outcomes, class votes on which temperature-longevity relationship you would you pick for adult *Anopheles*. And why? How would you improve the estimate for the fitting?

Next session: March 28th

- Example 4: Climate and Mosquito population model
- Group work

Reading assignment for March 28th

White *et al. Parasites & Vectors* 2011, **4**:153
http://www.parasitesandvectors.com/content/4/1/153

RESEARCH Open Access

Modelling the impact of vector control interventions on *Anopheles gambiae* population dynamics

Michael T White*, Jamie T Griffin, Thomas S Churcher, Neil M Ferguson, María-Gloria Basáñez and Azra C Ghani