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An agent-based model of schistosomiasis transmission and water temperature

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An agent-based model of schistosomiasis transmission and water temperature

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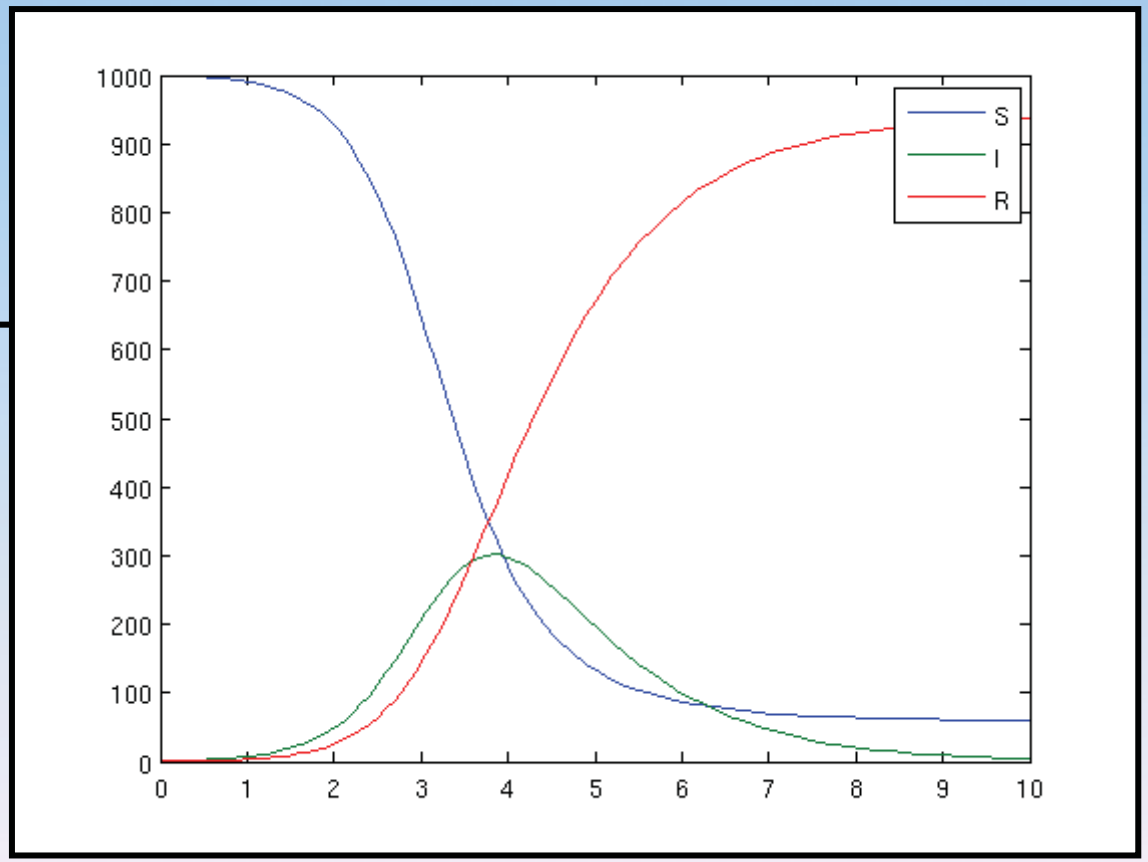
Outline

1. **Agent-based vs population-based models.**
2. My schistosomiasis model.

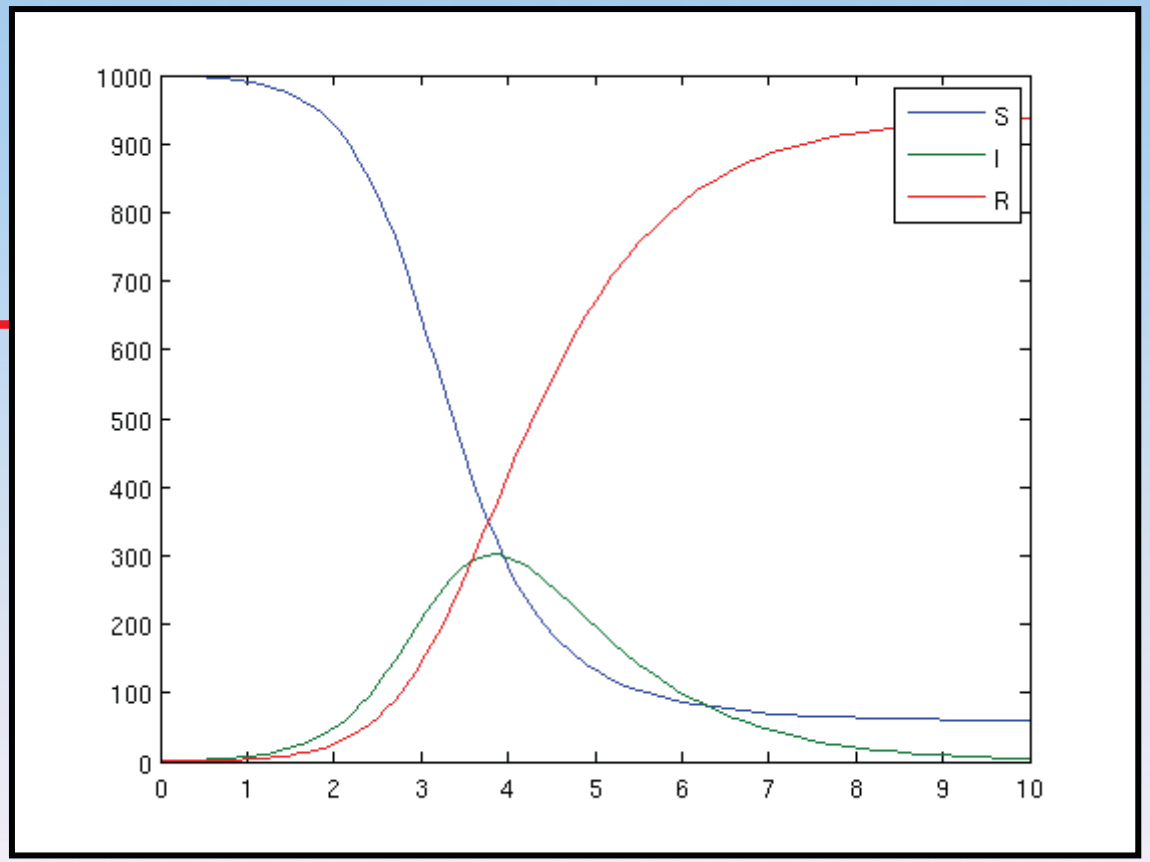
Population-based models
(aka compartmental)

- Model populations of individuals (e.g. suceptibles, infecteds, recovereds).
- Mutually exclusive groups.
- Homogeneity within groups.
- Can subdivide to create more groups:
  - Sex
  - Age
  - Location (“metapopulation” or “patch” models)
- Tend to be deterministic.

- $dS/dt = -\beta SI$
- $dI/dt = \beta SI - \gamma I$
- $dR/dt = \gamma I$



- dS/dt = -βSI
- dI/dt = βSI − γI
- dR/dt = γI



Agent-based models

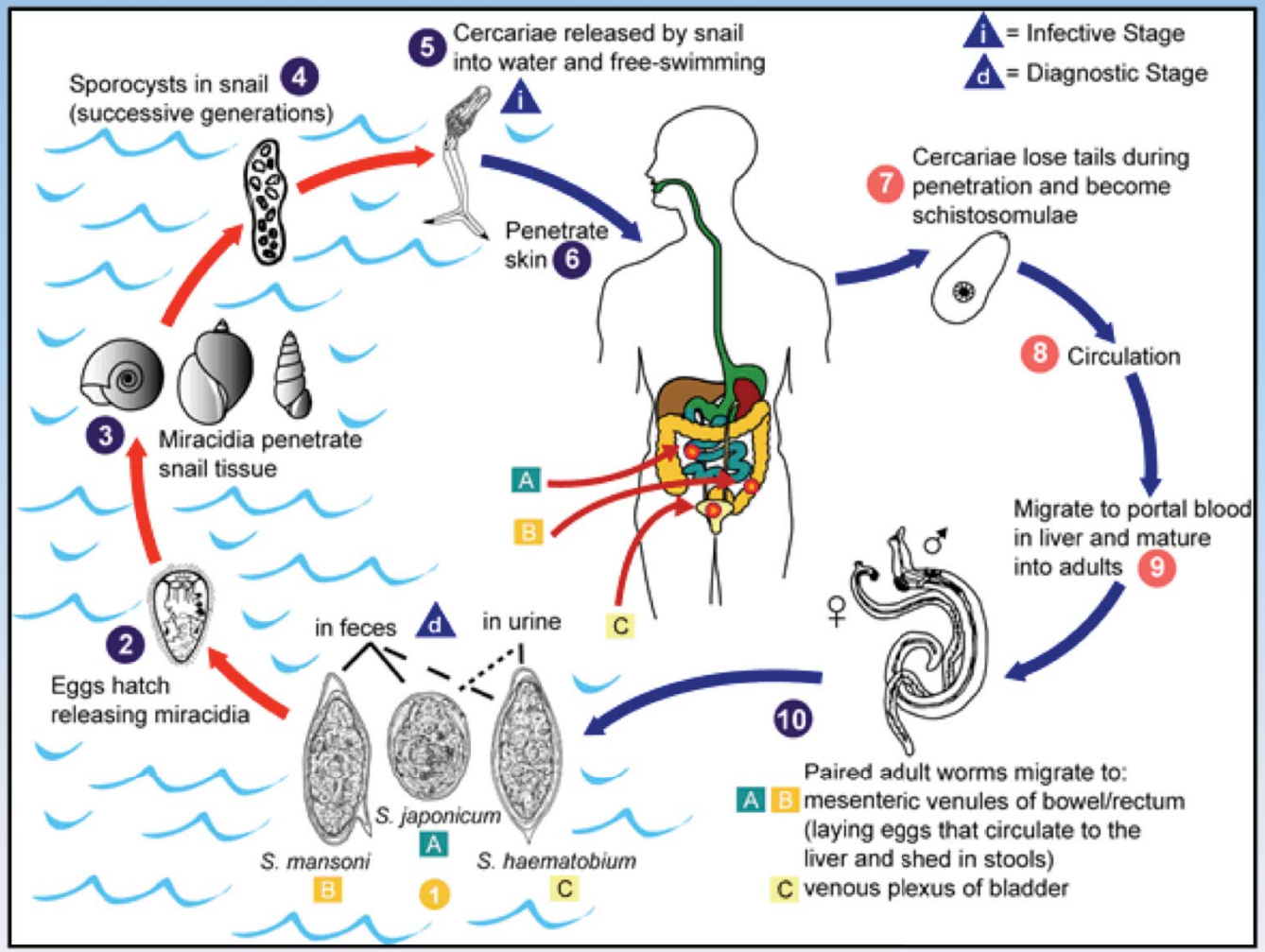
(aka individual-based, microsimulation)

- Models individuals in the population.
- Each individual has:
  - An ID.
  - One or more states (e.g. age, sex, infection status, immunity).
- Characteristics of each individual are tracked through time.
  - Some do not change (e.g. sex).
  - Others do (e.g. infection status).
- Tend to be stocastic.
- Can include more information at the individual level.
- Have much more control over characteristics of individuals (e.g. prepatent periods).
- Can be much slower to run and require more computing power.

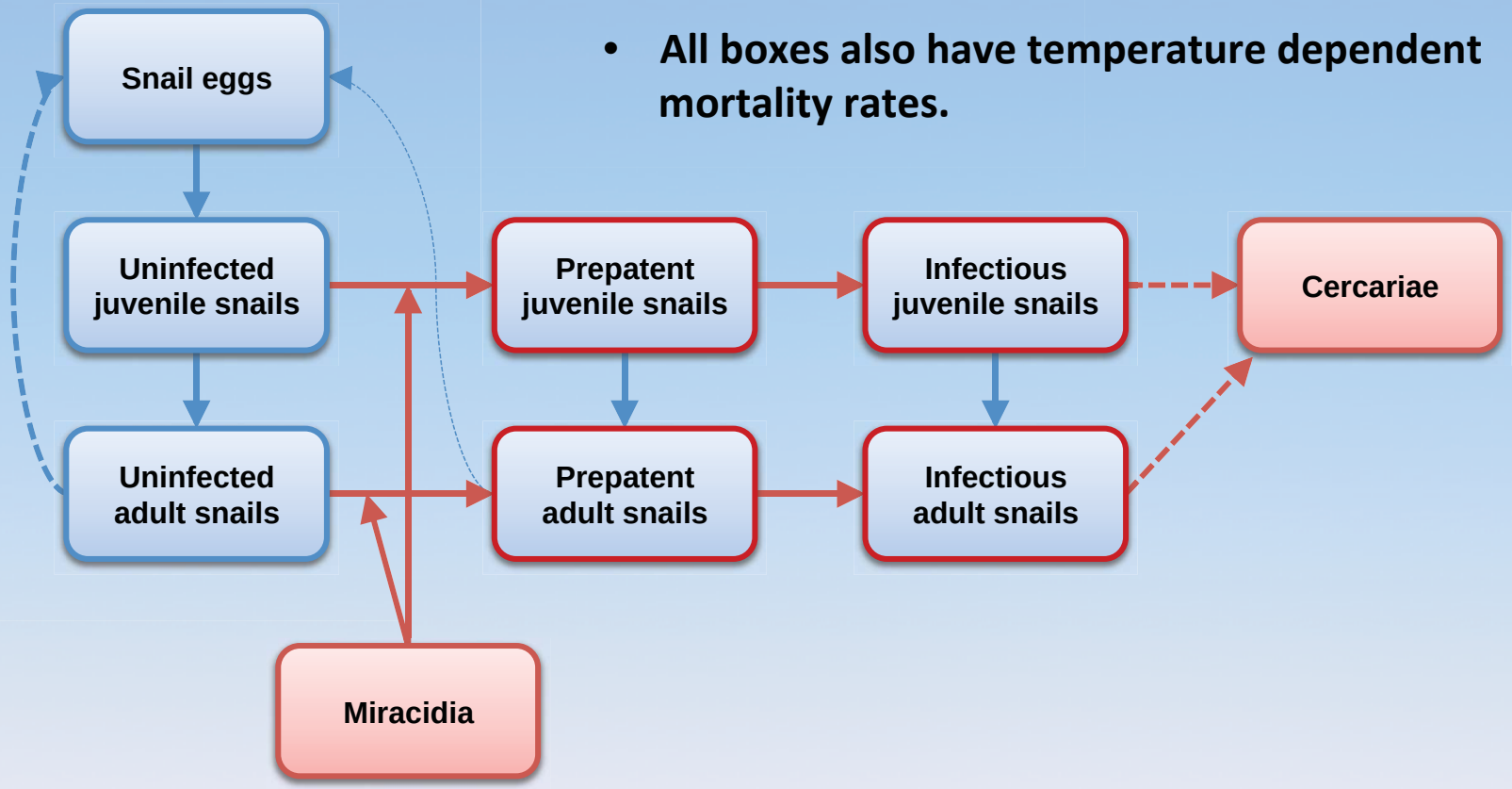
Outline

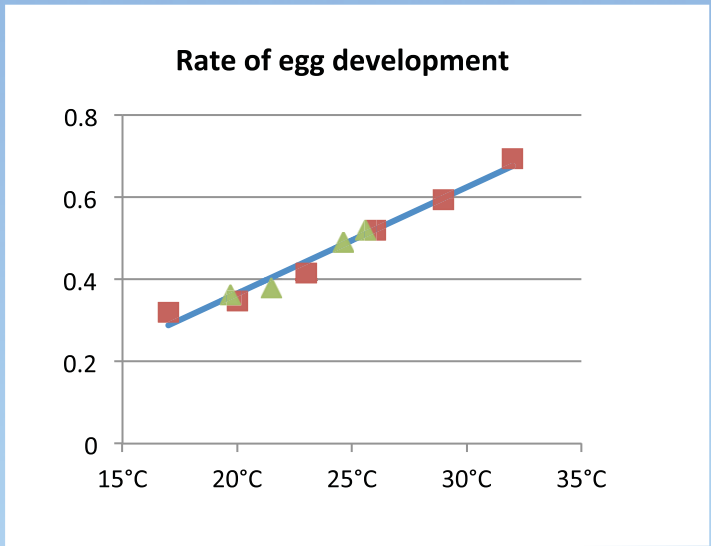
1. Agent-based vs population-based models.
2. **My schistosomiasis model.**

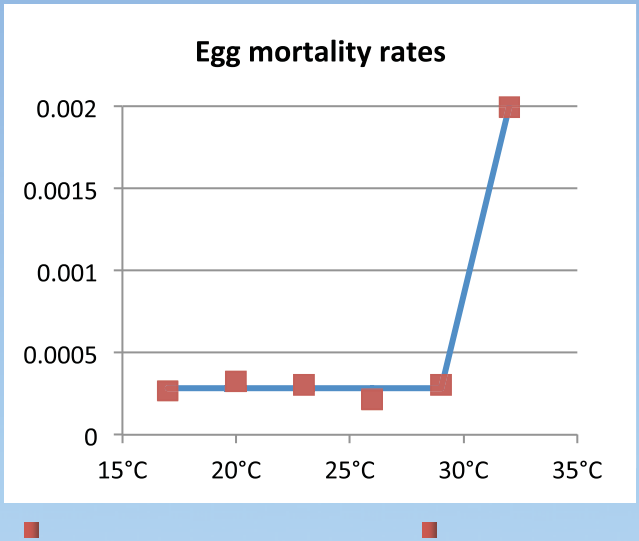
Schistosoma lifecycle

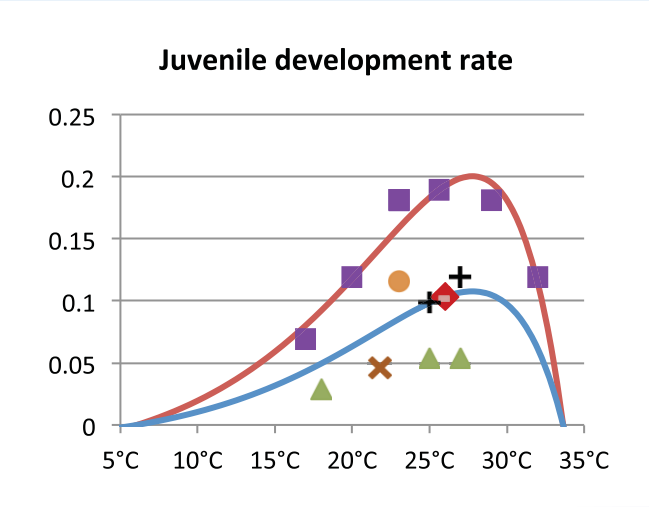


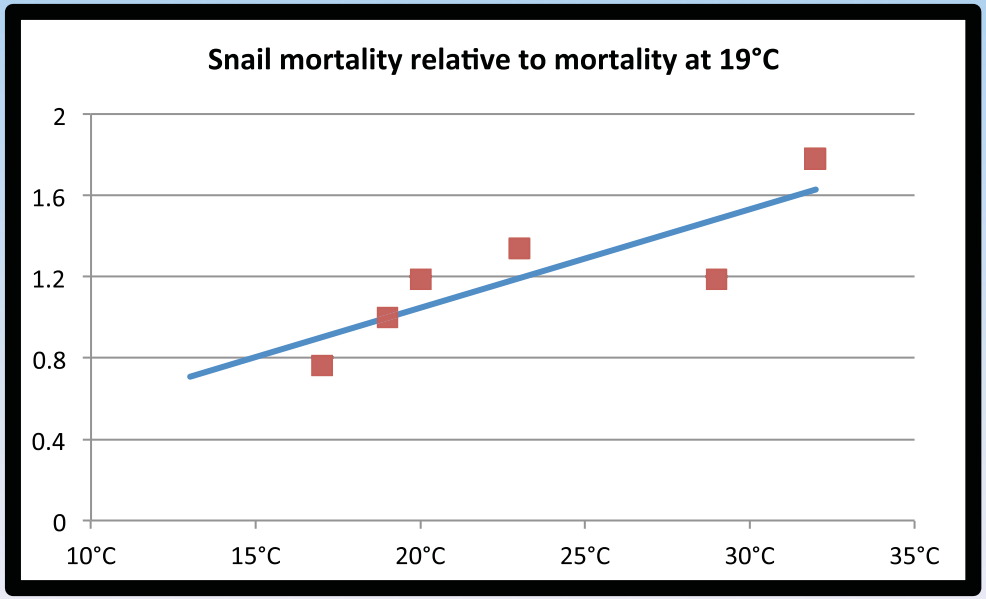
- All arrows indicate temperature dependent rates.
- All boxes also have temperature dependent mortality rates.

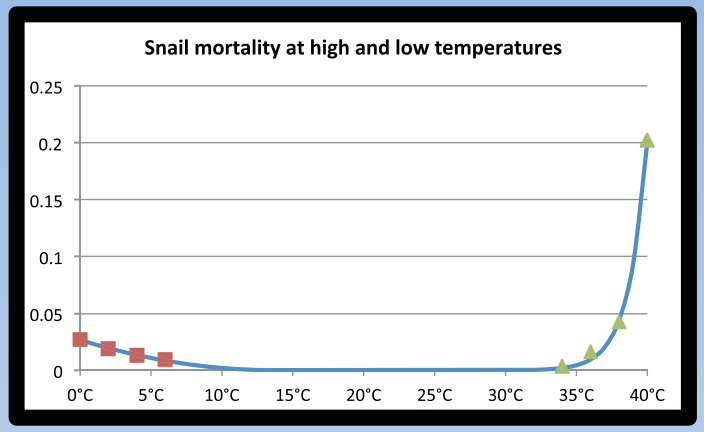


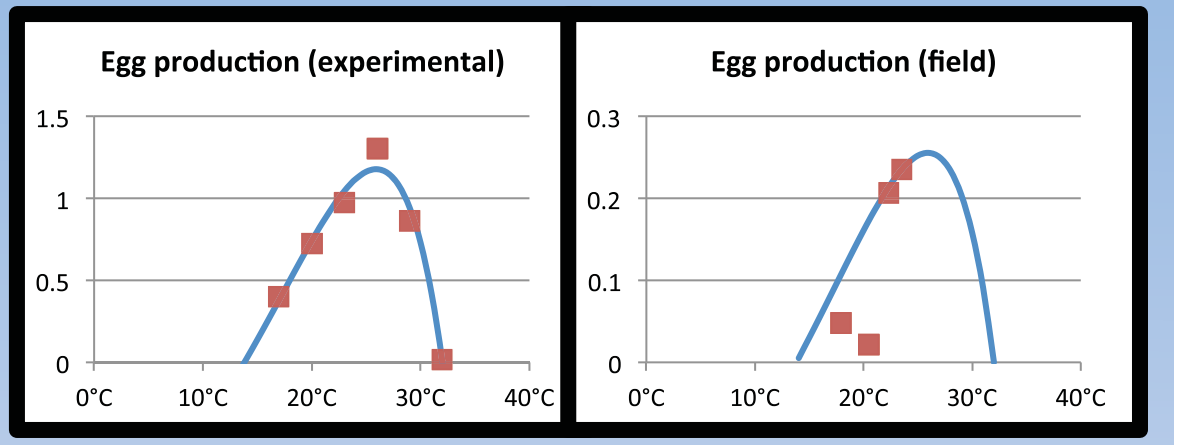

Rate of egg development
0.8
0.6
0.4
0.2
0
15°C
20°C
25°C
30°C
35°C

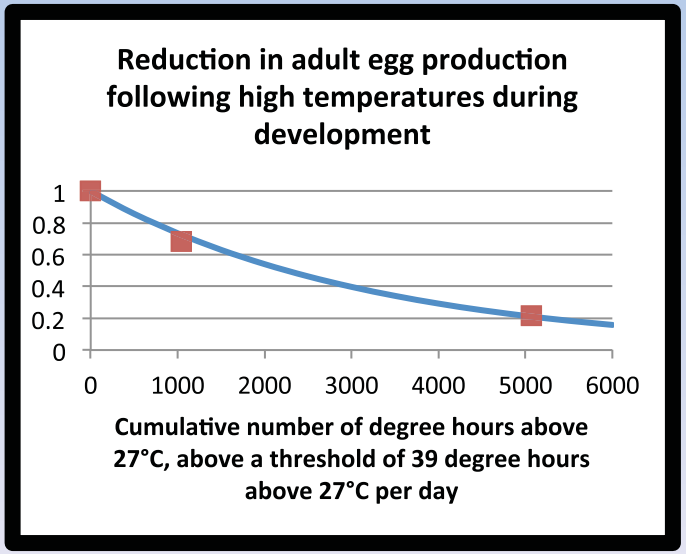

Egg mortality rates
0.002
0.0015
0.001
0.0005
0
15°C
20°C
25°C
30°C
35°C

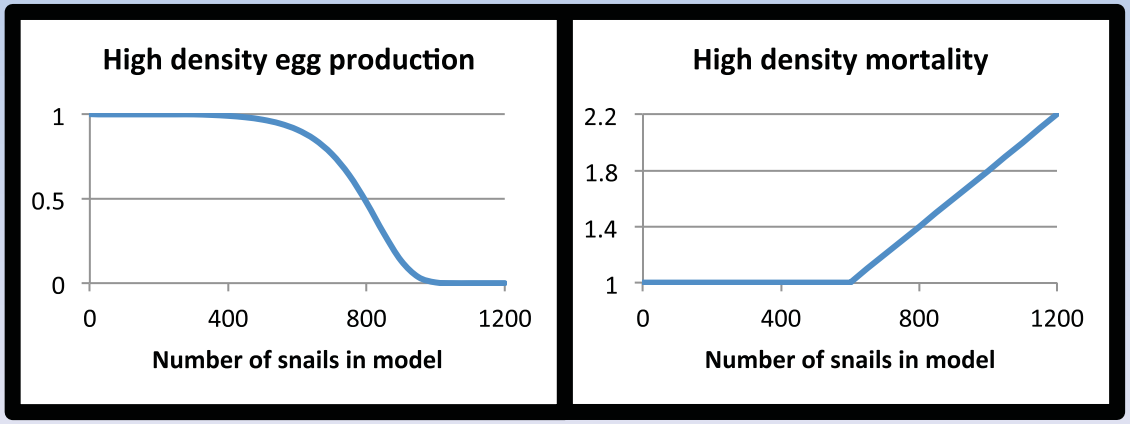

Juvenile development rate
0.25
0.2
0.15
0.1
0.05
0
5°C
10°C
15°C
20°C
25°C
30°C
35°C

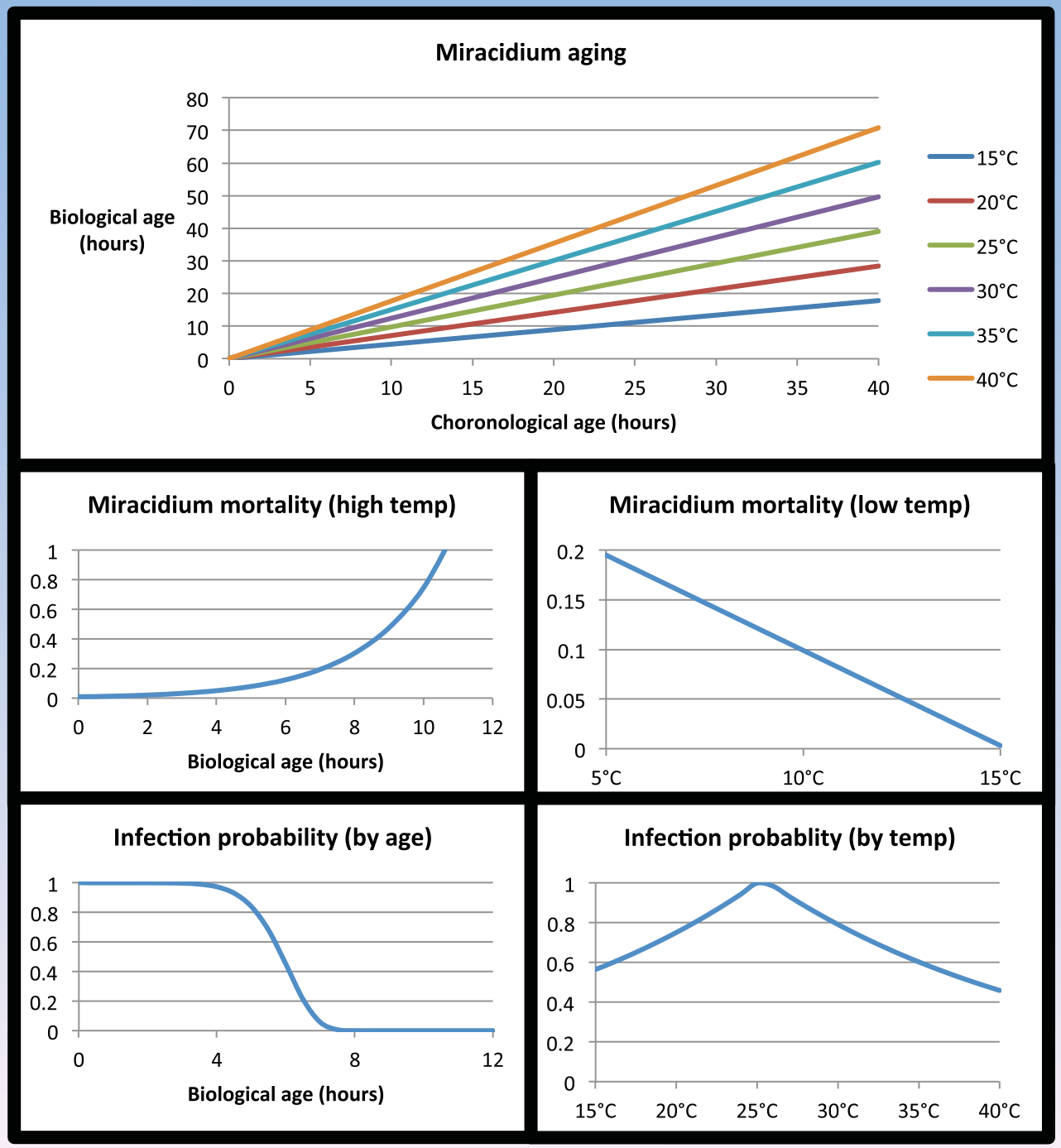

Snail mortality relative to mortality at 19°C
2
1.6
1.2
0.8
0.4
0
10°C
15°C
20°C
25°C
30°C
35°C

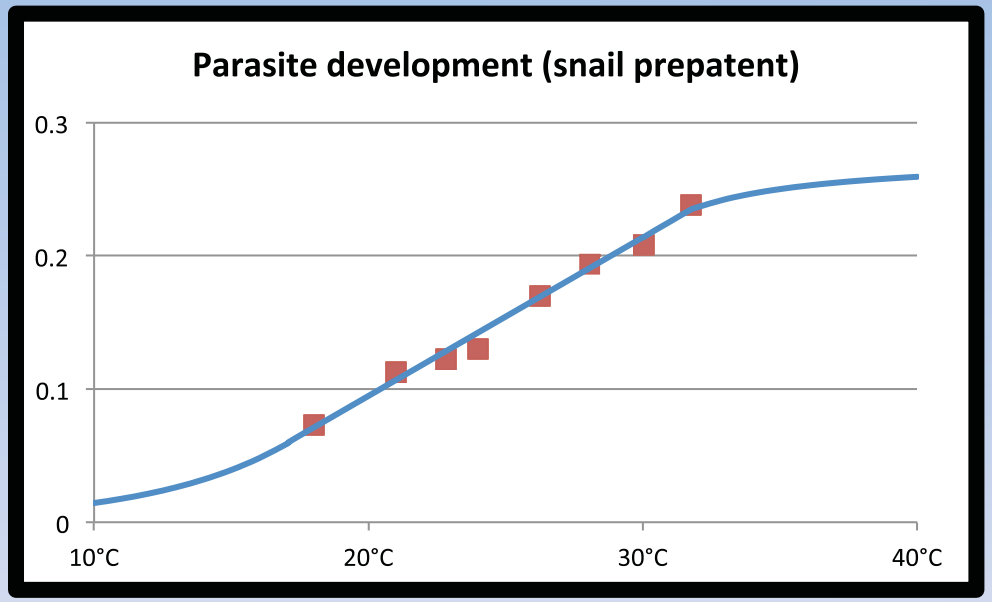

Snail mortality at high and low temperatures
0.25
0.2
0.15
0.1
0.05
0
0°C
5°C
10°C
15°C
20°C
25°C
30°C
35°C
40°C

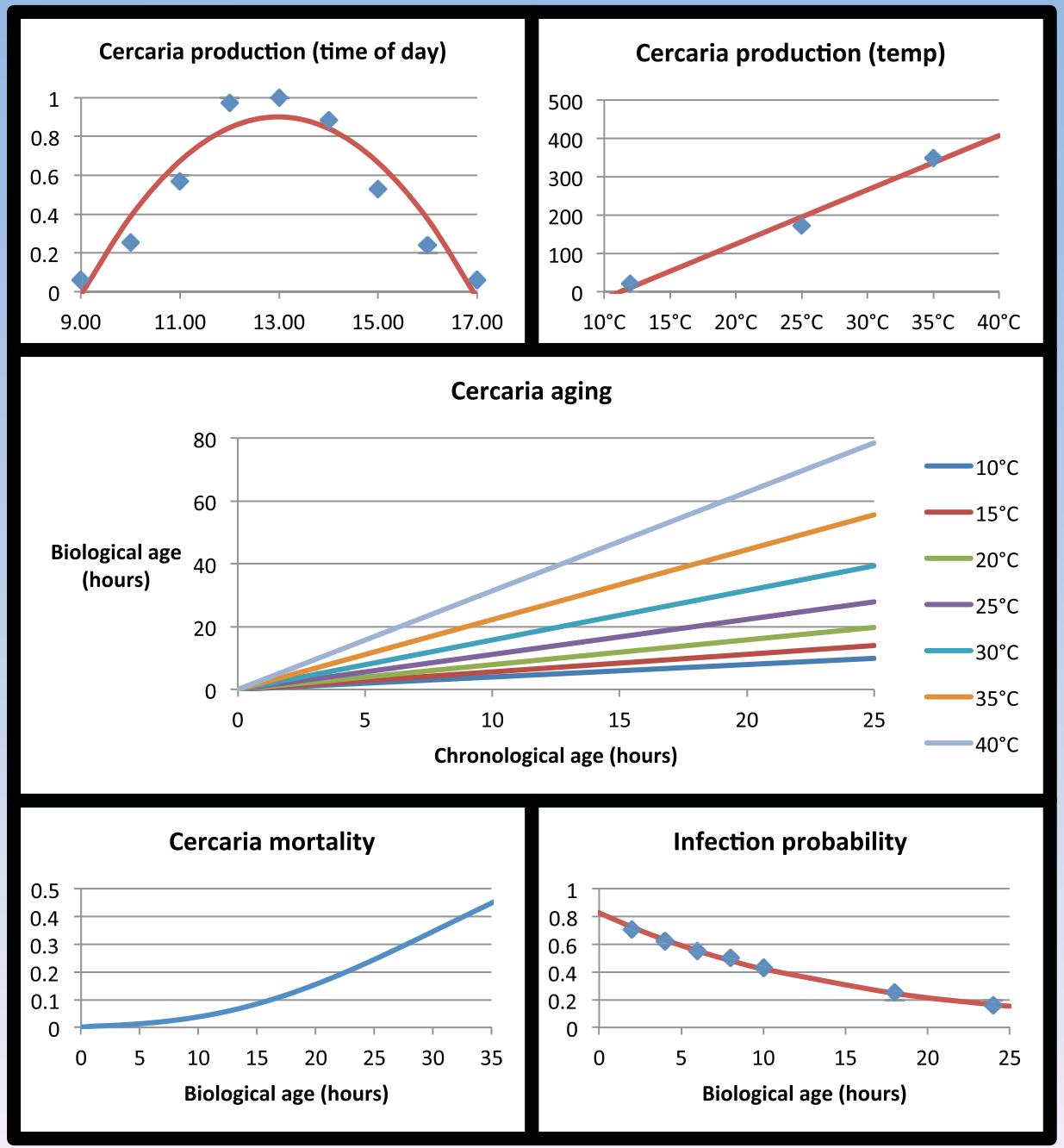

Egg production (experimental)
1.5
1
0.5
0
0°C
10°C
20°C
30°C
40°C
Egg production (field)
0.3
0.2
0.1
0
0°C
10°C
20°C
30°C
40°C

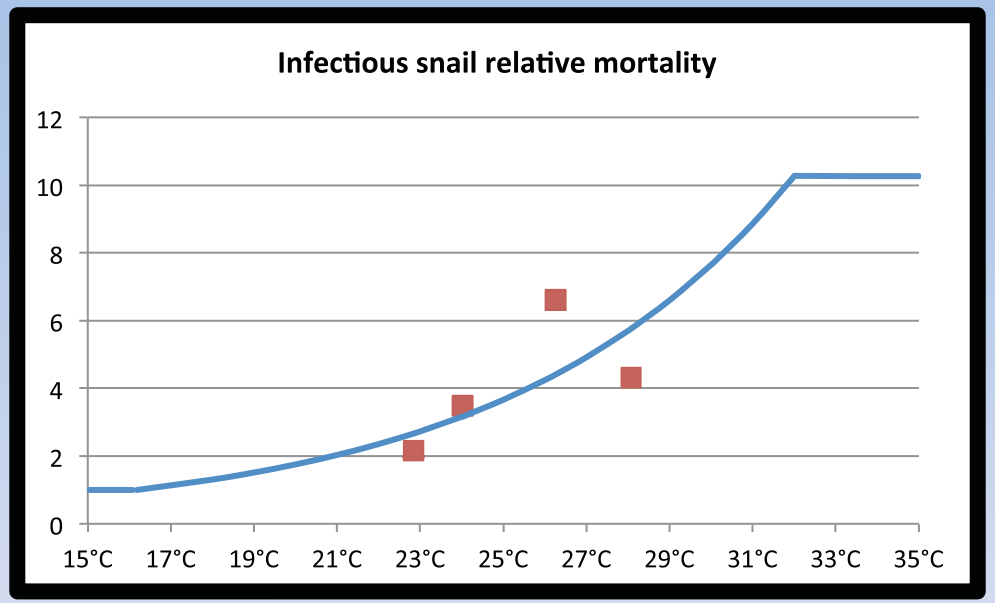

Reduction in adult egg production following high temperatures during development
1
0.8
0.6
0.4
0.2
0
0
1000
2000
3000
4000
5000
6000
Cumulative number of degree hours above 27°C, above a threshold of 39 degree hours above 27°C per day


High density egg production
1
0.5
0
0
400
800
1200
Number of snails in model
High density mortality
2.2
1.8
1.4
1
0
400
800
1200
Number of snails in model


Miracidium aging
Biological age (hours)
80
70
60
50
40
30
20
10
0
0
5
10
15
20
25
30
35
40
Choronological age (hours)
15°C
20°C
25°C
30°C
35°C
40°C
Miracidium mortality (high temp)
1
0.8
0.6
0.4
0.2
0
0
2
4
6
8
10
12
Biological age (hours)
Miracidium mortality (low temp)
0.2
0.15
0.1
0.05
0
5°C
10°C
15°C
Infection probability (by age)
1
0.8
0.6
0.4
0.2
0
0
4
8
12
Biological age (hours)
Infection probablity (by temp)
1
0.8
0.6
0.4
0.2
0
15°C
20°C
25°C
30°C
35°C
40°C


Parasite development (snail prepatent)
0.3
0.2
0.1
0
10°C
20°C
30°C
40°C

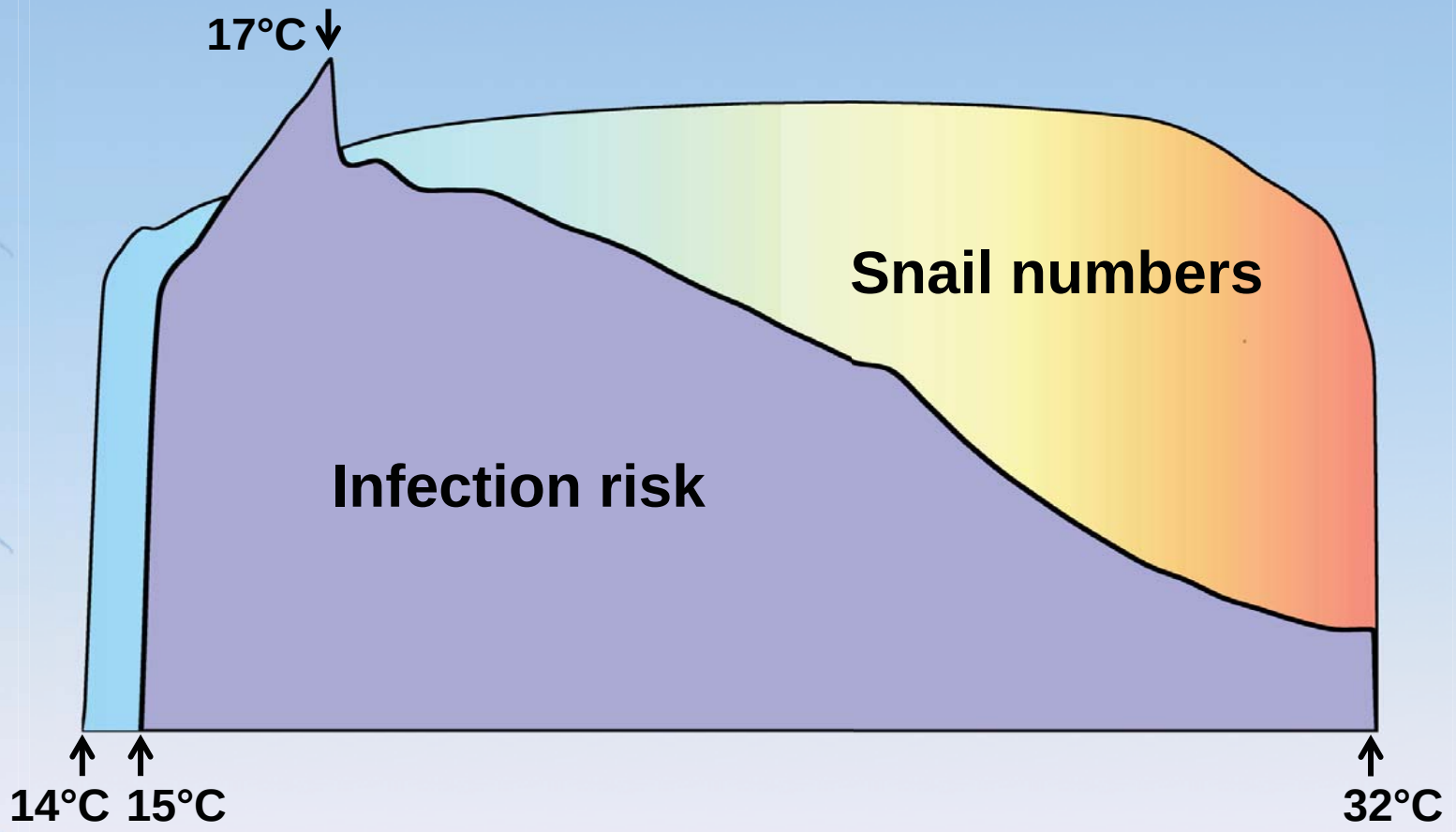

Cercaria production (time of day)
1
0.8
0.6
0.4
0.2
0
9.00
11.00
13.00
15.00
17.00
Cercaria production (temp)
500
400
300
200
100
0
10°C
15°C
20°C
25°C
30°C
35°C
40°C
Cercaria aging
Biological age (hours)
80
60
40
20
0
0
5
10
15
20
25
Chronological age (hours)
10°C
15°C
20°C
25°C
30°C
35°C
40°C
Cercaria mortality
0.5
0.4
0.3
0.2
0.1
0
0
5
10
15
20
25
30
35
Biological age (hours)
Infection probability
1
0.8
0.6
0.4
0.2
0
0
5
10
15
20
25
Biological age (hours)


Infectious snail relative mortality
12
10
8
6
4
2
0
15°C
17°C
19°C
21°C
23°C
25°C
27°C
29°C
31°C
33°C
35°C

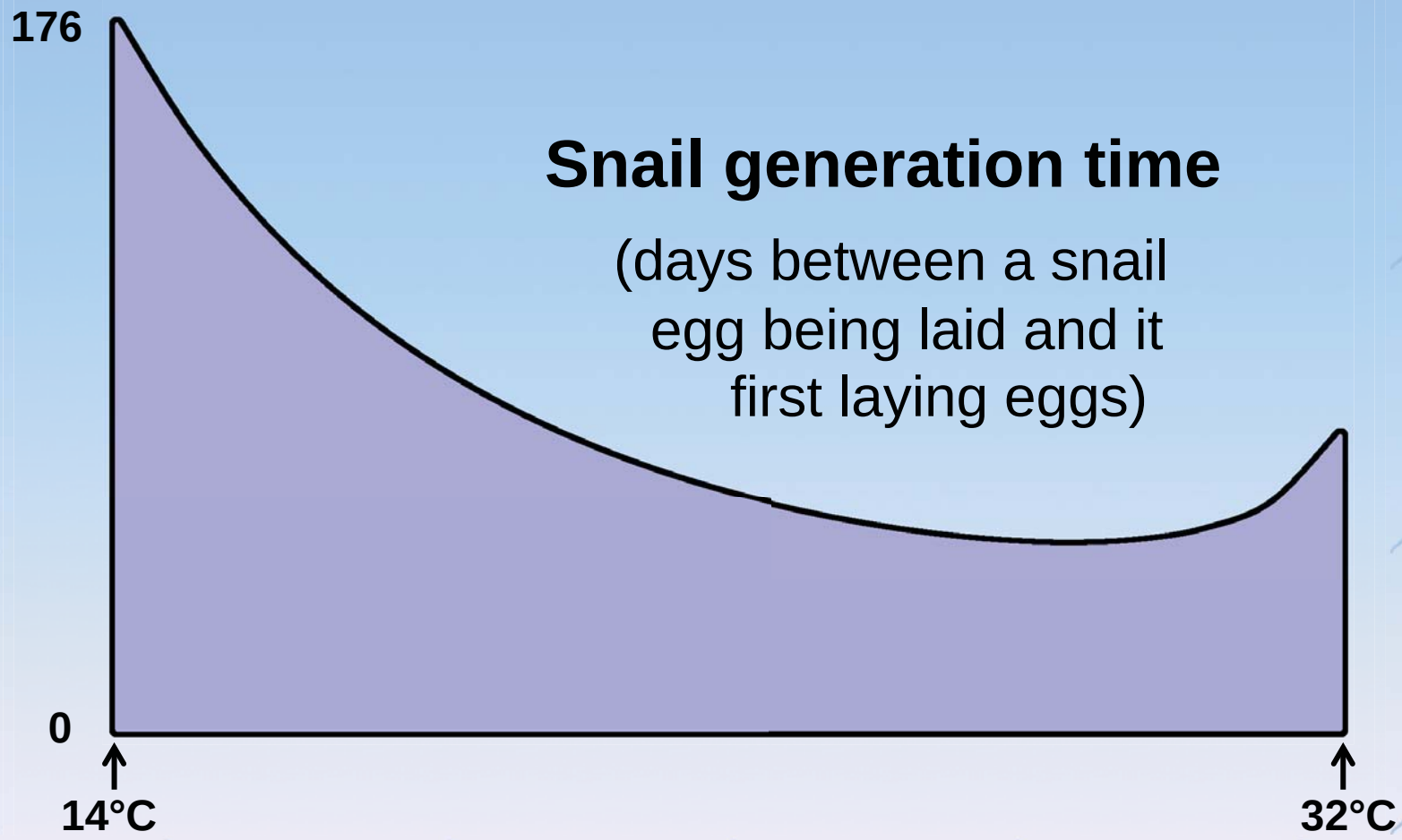
Methods

- The model was run using constant water temperatures and results were averaged over 200 runs.
- Infection risk is measured as the mean number of cercariae in the model, adjusted for their decreasing probability of causing infection with increasing biological age.

Results



Results


176
Snail generation time
(days between a snail egg being laid and it first laying eggs)
0
14°C
32°C

Conclusions

- Our results suggest that in most areas where *S. mansoni* is found, infection risk will decrease slightly as temperatures increase, but the difference will not be substantial.
- Snail generation times will decrease however, meaning that snail populations will recover faster from reductions in their numbers.
- In areas where *B. pfeifferi* snails are currently found but where low temperatures prevent sustained transmission, infection risk may increase dramatically over coming years and decades leading to epidemics of schistosomiasis.
- These areas will fall outside current control programs and people at risk may have little or no knowledge of or immunity to schistosomiasis.
- There is an urgent need for these areas to be monitored to minimise the impact of future epidemics.

What next?

- Incorporate real current and predicted future temperature data into the model.
- Produce relative risk maps.