Defensive symbionts and me: an unexpected tale about an uneasy alliance

PSS

24/11/22

Outline

Ecology and evolution

Defensive symbionts

Coevolution

What does this all mean?

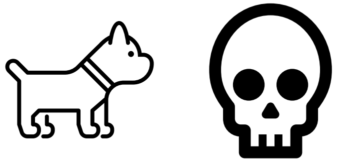
Outline

Ecology and evolution

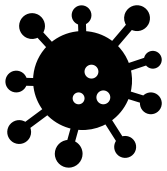
Ecology

“The here and now”

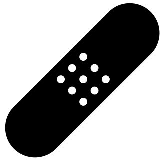
Host demographics



Infections



Recovery



Vaccination

Other host properties

• • •

Ecology

Host demographics

Infections

Recovery

Vaccination

Other host properties

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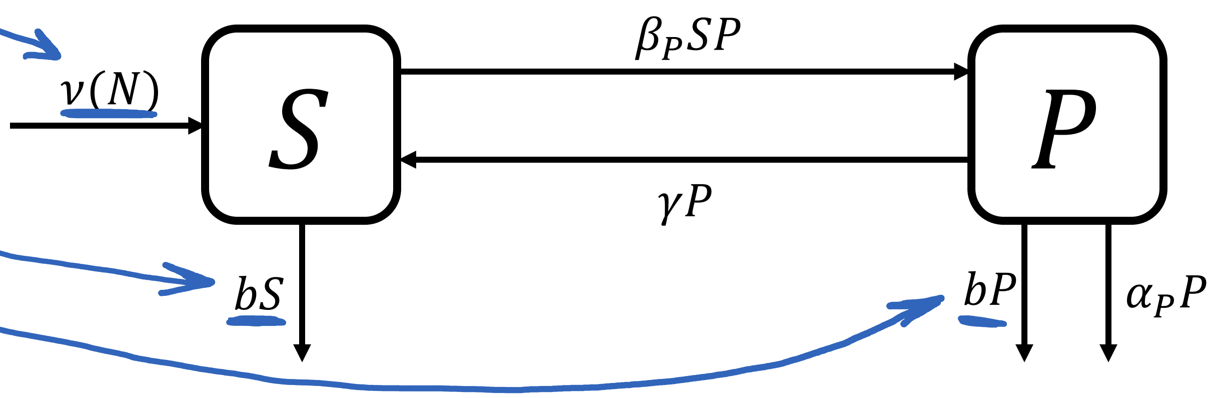
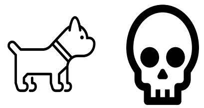


$$\frac{dS}{dt} = \nu(N) - bS$$

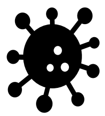
$$\frac{dP}{dt} = -bP$$

Ecology

Host demographics



Infections



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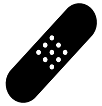
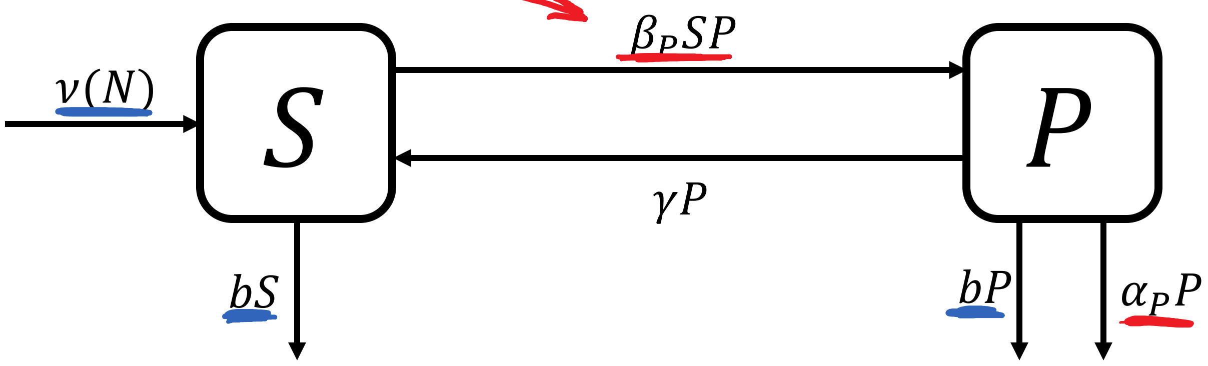


Vaccination

Other host properties

• • •



$$\frac{dS}{dt} = \nu(N) - bS - \beta_P SP$$

$$\frac{dP}{dt} = -bP + \beta_P SP - \alpha_P P$$

Ecology

- Host demographics
- Infections
- Recovery
- Vaccination
- Other host properties

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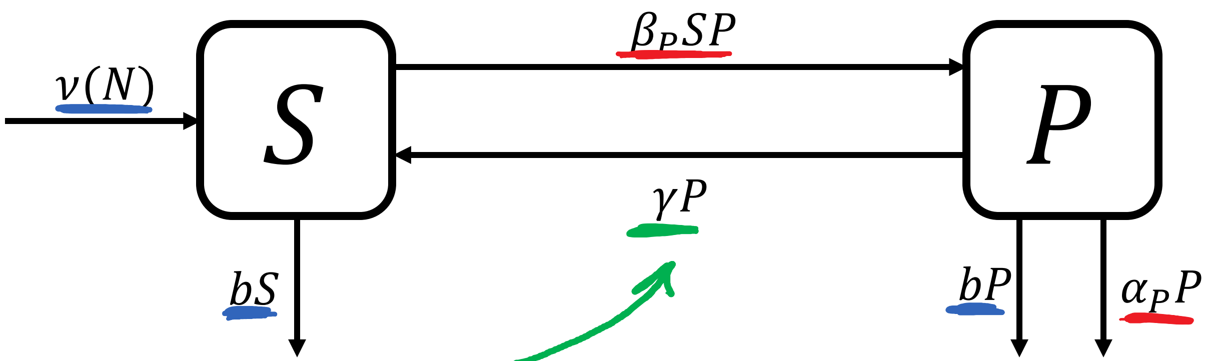

$$\frac{dS}{dt} = \nu(N) - bS - \beta_P SP + \gamma P$$

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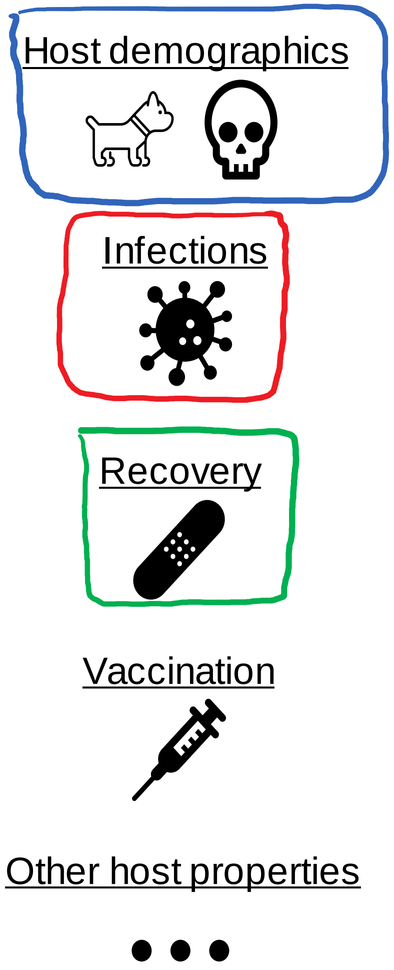
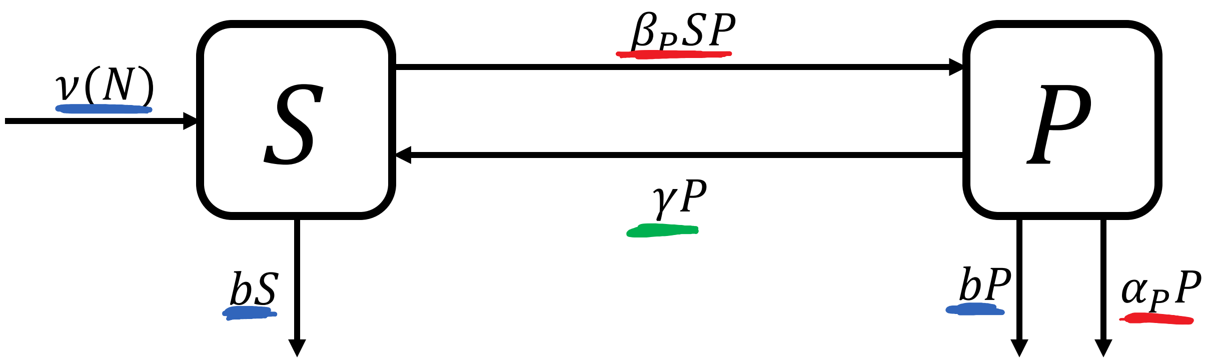
Ecology





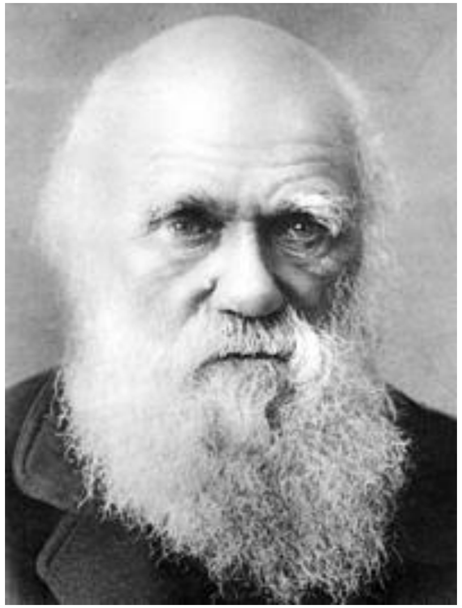
$$\frac{dS}{dt} = \nu(N) - bS - \beta_P SP + \gamma P = \nu(N) - [b + \beta_P P]S + \gamma P$$

$$\frac{dP}{dt} = -bP + \beta_P SP - \alpha_P P - \gamma P = [\beta_P S - b - \alpha_P - \gamma]P$$

Evolution

This is <u>not</u> what I am talking about:

Instead, we are talking about this guy:



Evolution

What is evolution?

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Evolution

From Wikipedia, the free encyclopedia

This article is about evolution in biology. For related articles, see Outline of evolution. For other uses, see Evolution (disambiguation).

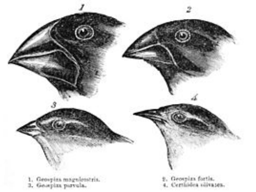
For a more accessible and less technical introduction to this topic, see Introduction to evolution.

Evolution is change in the heritable characteristics of biological populations over successive generations.[1][2] These characteristics are the expressions of genes that are passed on from parent to offspring during reproduction. Different characteristics tend to exist within any given population as a result of mutation, genetic recombination and other sources of genetic variation.[3] Evolution occurs when evolutionary processes such as natural selection (including sexual selection) and genetic drift act on this variation, resulting in certain characteristics becoming more common or rare within a population.[4] The evolutionary pressures that determine whether a characteristic would be common or rare within a population constantly change, resulting in a change in heritable characteristics arising over successive generations. It is this process of evolution that has given rise to biodiversity at every level of biological organisation, including the levels of species, individual organisms and molecules.[5][6]

The theory of evolution by natural selection was conceived independently by Charles Darwin and Alfred Russel Wallace in the mid-19th century and was set out in detail in Darwin's book *On the Origin of Species*.[7] Evolution by natural selection was first demonstrated by the observation that more offspring are often produced than can possibly survive. This is followed by three observable facts about living organisms: (1) traits vary among individuals with respect to their morphology, physiology and behaviour (phenotypic variation), (2) different traits confer different rates of survival and reproduction (differential fitness) and (3) traits can be passed from generation to generation (heritability of fitness).[8] Thus, in successive generations members of a population are more likely to be replaced by the progenies of parents with favourable characteristics that have enabled them to survive and reproduce in their respective environments. In the early 20th century, other competing ideas of evolution such as mutationism and orthogenesis were refuted as the modern

Part of a series on

Evolutionary biology



Darwin's finches by John Gould

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Glossary · Evidence · History

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Natural history	[show]
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Evolutionary biology portal ·

Evolution

What is evolution?

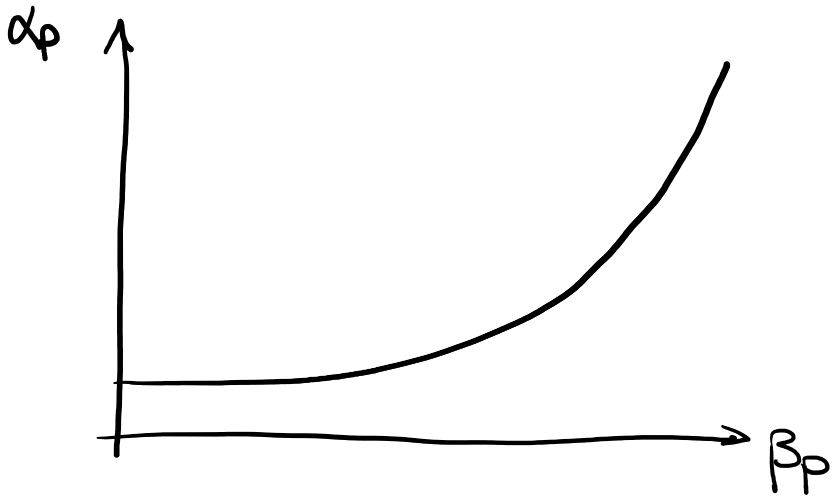
Evolution is change in the heritable characteristics of biological populations over successive generations.[1][2] These characteristics are the expressions of genes that are passed on from parent to offspring during reproduction. Different characteristics tend to exist within any given population as a result of mutation, genetic recombination and other sources of genetic variation.[3] Evolution occurs when evolutionary processes such as natural selection (including sexual selection) and genetic drift act on this variation, resulting in certain characteristics becoming more common or rare within a population.[4] The evolutionary pressures that determine whether a characteristic would be common or rare within a population constantly change, resulting in a change in heritable characteristics arising over successive generations. It is this process of evolution that has given rise to biodiversity at every level of biological organisation, including the levels of species, individual organisms and molecules.[5][6]

Ecology and evolution: Adaptive dynamics

Simple SI dynamics:
$$\dot{S} = N(a - qN) - [b + \beta_P P]S + \gamma P.$$
$$\dot{P} = [\beta_P S - b - \alpha_P - \gamma]P.$$

Evolving trait: Parasite transmission, $\beta_P \geq 0$.

Trade-off: Increasing transmission increases virulence, $\alpha_P(\beta_P)$.



Mutant dynamics:
$$\dot{P}^m = [\beta_P^m S^* - b - \alpha_P^m - \gamma]P^m.$$

Parasite maximises "fitness":
$$w(\beta_P^m, \beta_P) = \beta_P^m S^*(\beta_P) - b - \alpha_P^m - \gamma.$$

Singular strategies and classification

Parasite maximises “fitness”:

$$w(\beta_P^m, \beta_P) = \beta_P^m S^*(\beta_P) - b - \alpha_P^m - \gamma.$$

Singular strategies satisfy:

$$0 = s(\beta_P^*) = \frac{\partial w}{\partial \beta_P^m}(\beta_P^m, \beta_P)\bigg|_{\beta_P^m = \beta_P = \beta_P^*}$$

Singular strategies can be classified by looking at different second derivatives of the fitness function

		Convergence stable – can approach through small mutations	
		Convergence stable	Not convergence stable
Evolutionary stable – Cannot be invaded by nearby mutants	Evolutionary stable		
	Not evolutionary stable		

Singular strategies and classification

Parasite maximises "fitness":

$$w(\beta_P^m, \beta_P) = \beta_P^m S^*(\beta_P) - b - \alpha_P^m - \gamma.$$

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Singular strategies can be classified by looking at different second derivatives of the fitness function

		Convergence stable – can approach through small mutations	
		Convergence stable	Not convergence stable
Evolutionary stable – Cannot be invaded by nearby mutants	Evolutionary stable	Continuously stable strategy	
	Not evolutionary stable		

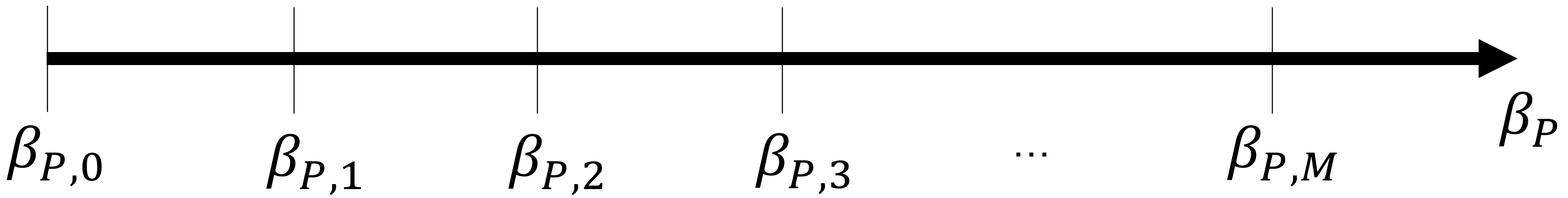
Simulation techniques

$$\dot{S} = N(a - qN) - [b + \beta_P P]S + \gamma P.$$
$$\dot{P} = [\beta_P S - b - \alpha_P - \gamma]P.$$

Parasite transmission, $\beta_P \geq 0$.

Increasing transmission increases virulence, $\alpha_P(\beta_P)$.

Set bounds on trait range and discretise.



Simulation techniques

Initialise a small number of infected individuals with a transmission value, e.g. $\beta_P = \beta_{P,2}$.

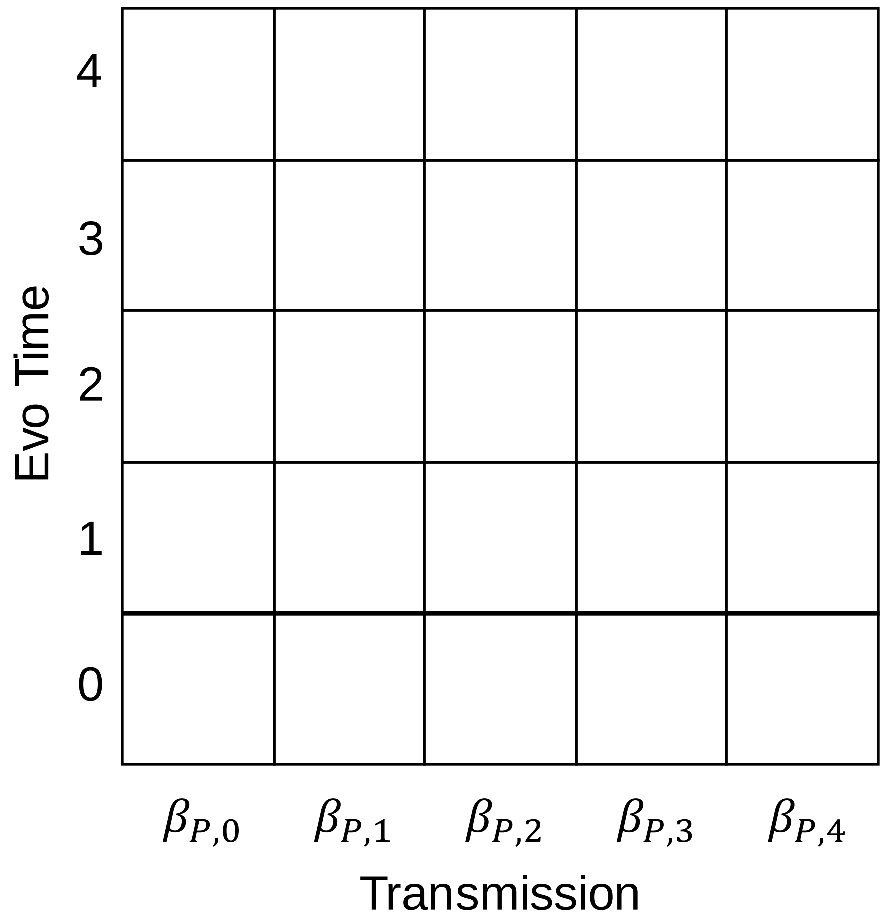
Run the ecological dynamics to steady state:

$$\frac{dS}{dt} = N(a - qN) - \left(\beta_{P,2}P_2 + b\right)S + \gamma P_2$$

$$\frac{dP_2}{dt} = \left(\beta_{P,2}S - \left(b + \alpha_P\left(\beta_{P,2}\right) + \gamma\right)\right)P_2,$$

with initial condition $(S, P_2) = (\tilde{S}, \tilde{P}_2)$.

Introduce a rare mutant at $\beta_{P,2\pm1}$ uniformly at random (say $\beta_{P,1}$ chosen).



Simulation techniques

Introduce a rare mutant at $\beta_{P,2\pm1}$ uniformly at random (say $\beta_{P,1}$ chosen).

Run the ecological dynamics to steady state:

$$\frac{dS}{dt} = N(a - qN) - \left(\beta_{P,1}P_1 + \beta_{P,2}P_2 + b\right)S + \gamma P_1 + \gamma P_2$$

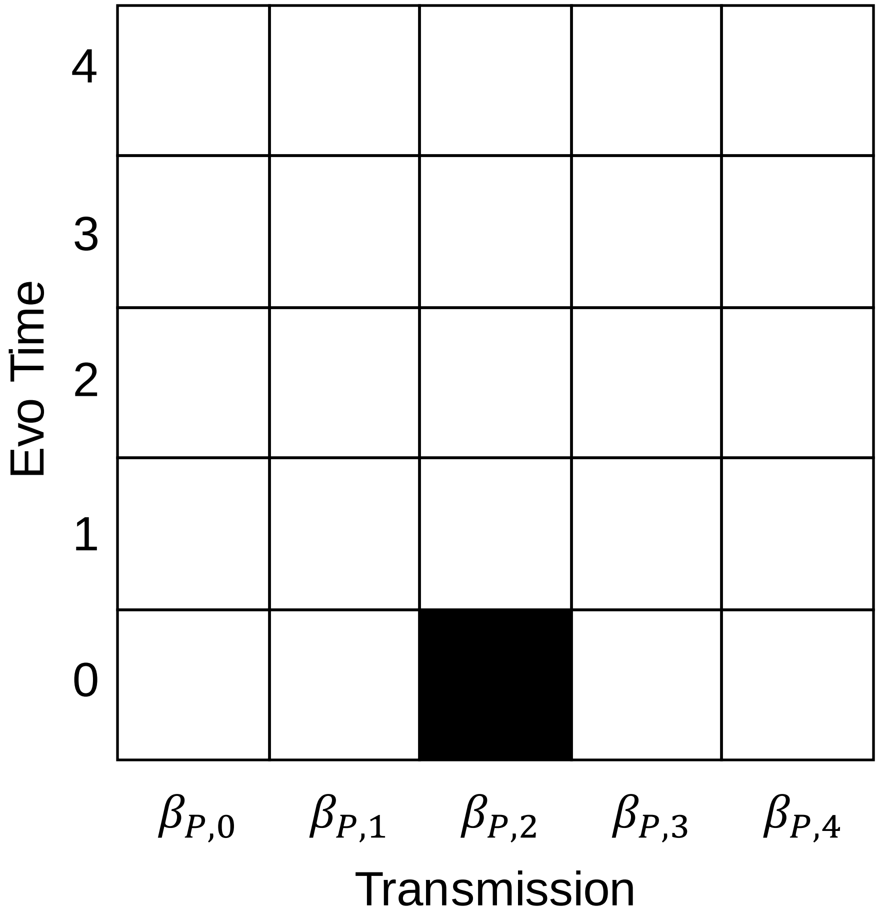
$$\frac{dP_1}{dt} = \left(\beta_{P,1}S - \left(b + \alpha\left(\beta_{P,1}\right) + \gamma\right)\right)P_1,$$

$$\frac{dP_2}{dt} = \left(\beta_{P,2}S - \left(b + \alpha(\beta_{P,2}) + \gamma\right)\right)P_2,$$

with initial condition $(S, P_1, P_2) = (S^*, \epsilon, P_2^*)$.

Remove any mutants below a threshold.

Repeat



Outline

Ecology and evolution

Defensive symbionts

Coevolution

What does this all mean?

Outline

Defensive symbionts

What is a defensive symbiont?

Defensive symbiont

Defensive

Devoted to resisting or preventing aggression or attack.

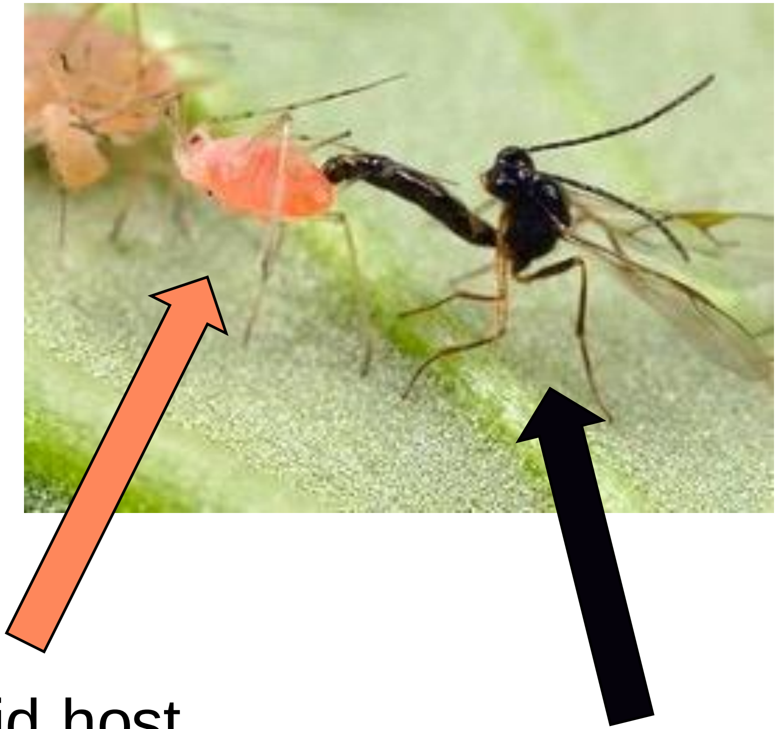
Sentence: Cameron is a footballing defensive powerhouse…
Said nobody ever!

symbiont

An organism living in symbiosis.

Symbiosis: A cooperative relationship (as between two persons or groups).

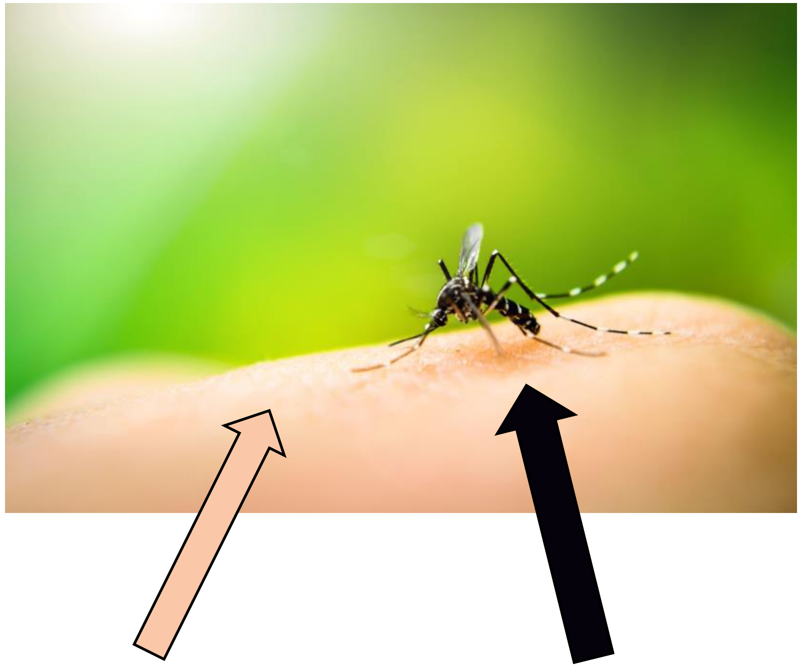
Some examples



Aphid host

Parasitic wasp

Protective bacteria: *Hamiltonella defensa*



Human host

Mosquito

Protective bacteria: *Wolbachia*

Types of defence

Types of defence

Tolerance

Tolerance shields the host from the harmful effects of the parasite.

Two forms of tolerance – “Fecundity tolerance” and “mortality tolerance”.

Fecundity tolerance prevents new births with the parasite, mortality tolerance reduces virulence.

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Fecundity tolerance prevents new births with the parasite, mortality tolerance reduces virulence.

Resistance

Resistance reduces the rate at which the parasite is transmitted to new hosts.

There are a few experimental organisms which demonstrate resistance.

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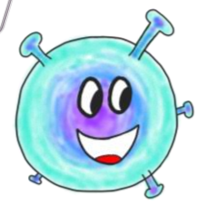
Meet the characters for today

Pathogen registration form



Subject #796

Name:

TBC

Type:

DEFENSIVE SYMBIONT

Philosophy:

"PROTECC OR ATTACC, I'VE GOT YOUR BACK!"

Pathogen registration form

Subject #727

Name:

TBC

Type:

PARASITE

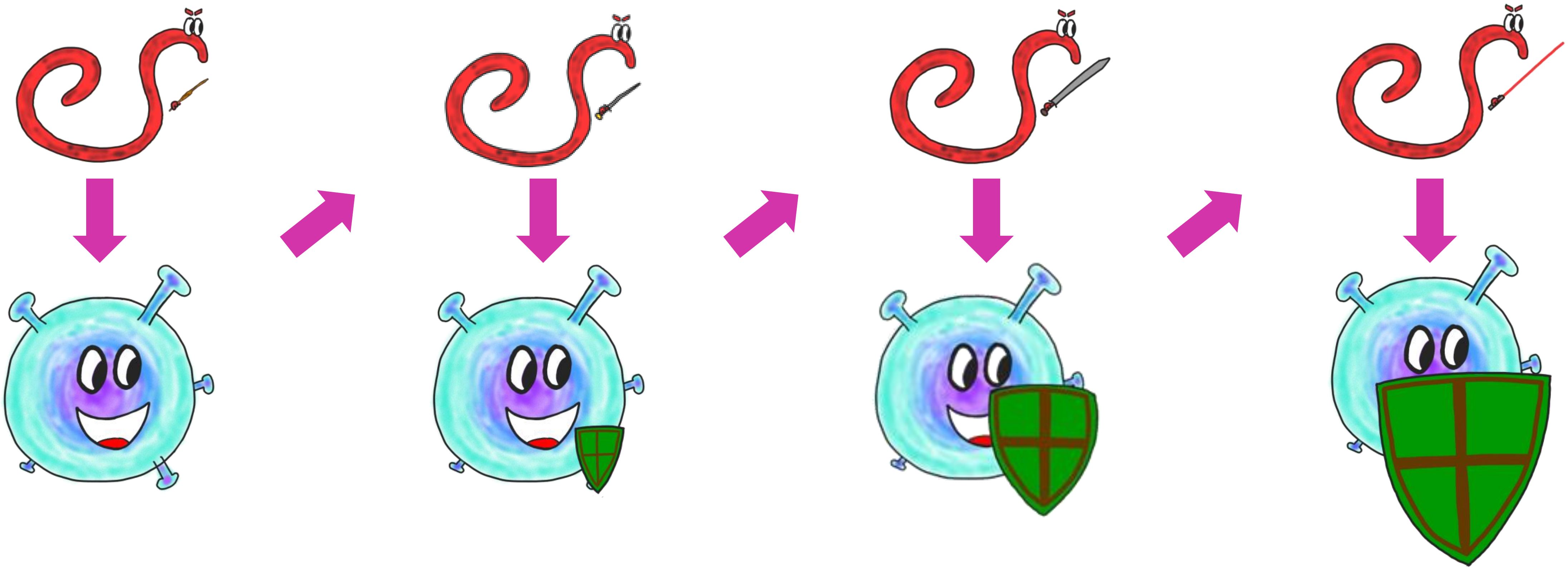
Philosophy:

"I HAVE A STICK AND I'M NOT AFRAID TO USE IT"

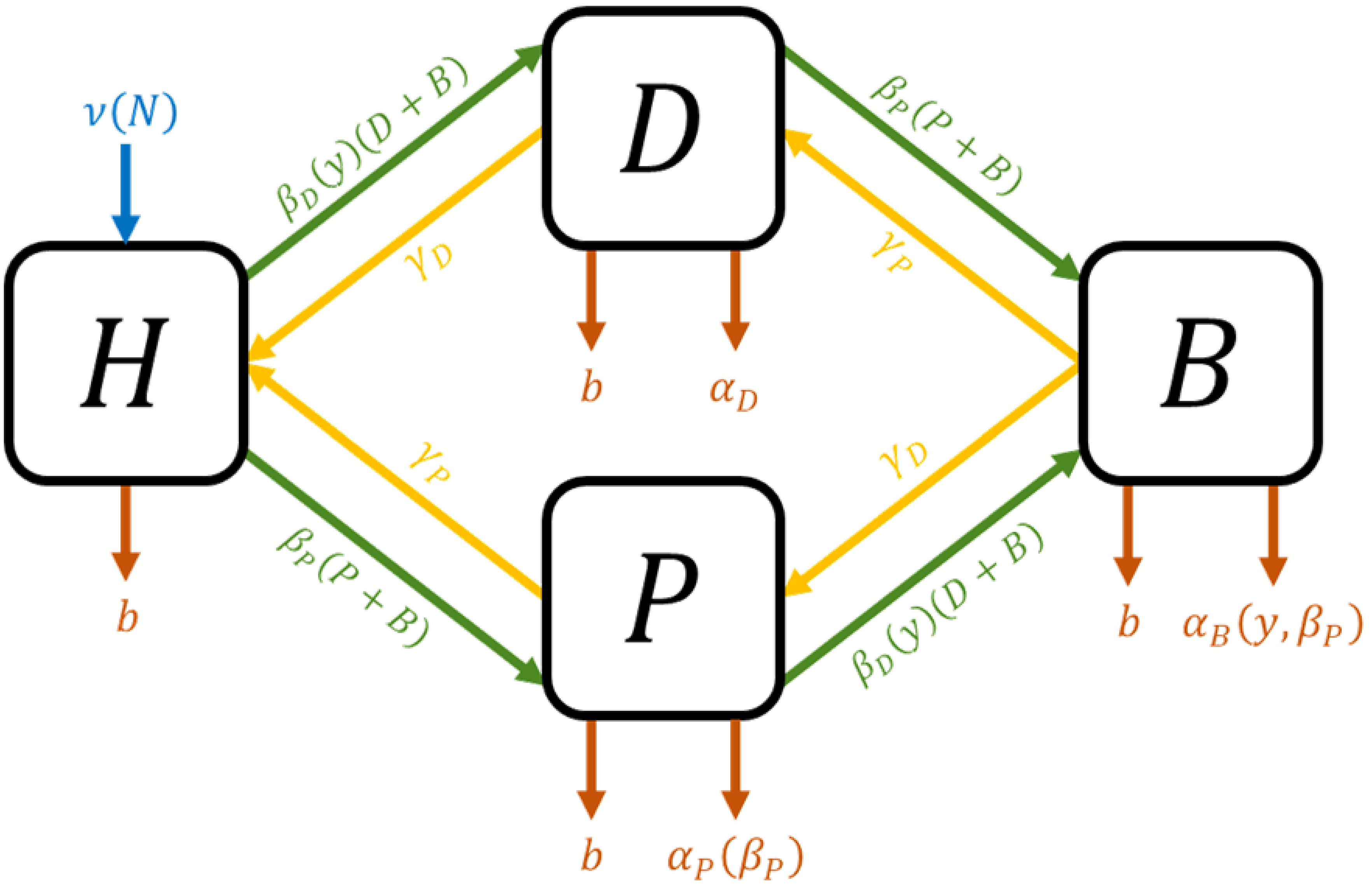
Coevolution

The response and counter-response between more than one organism.

We want to see how a defensive symbiont affects the host-parasite interaction.



Coevolution: Ecological dynamics



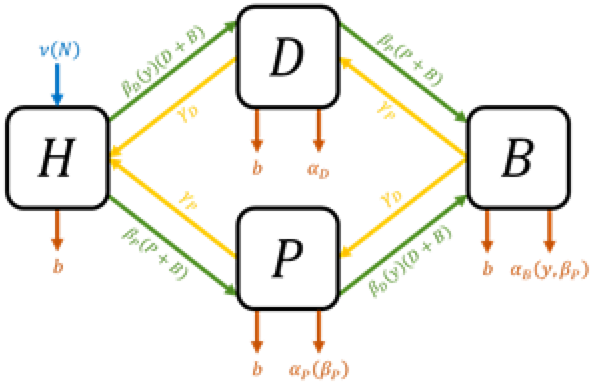
Blue: Births

Green: Transmission

Red: Deaths

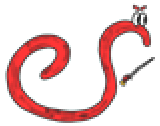
Yellow: Recovery

Coevolution: Evolutionary dynamics



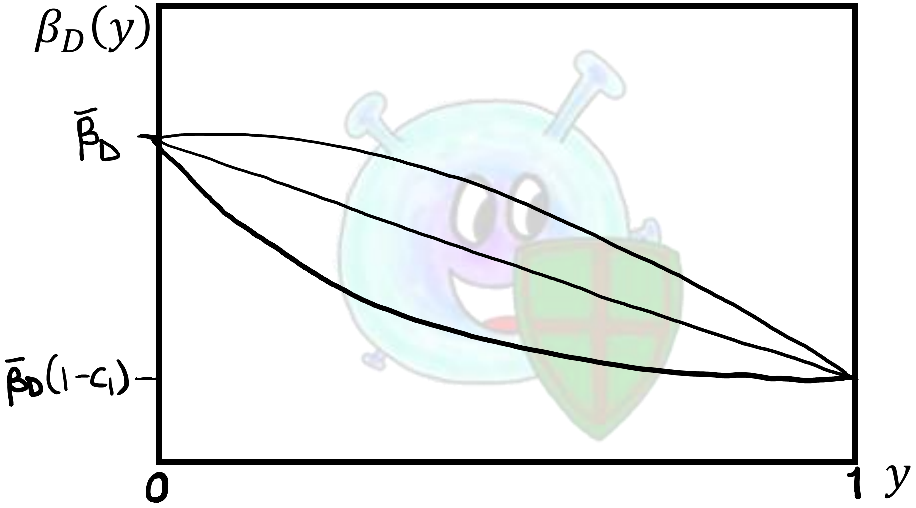
Evolving parameters

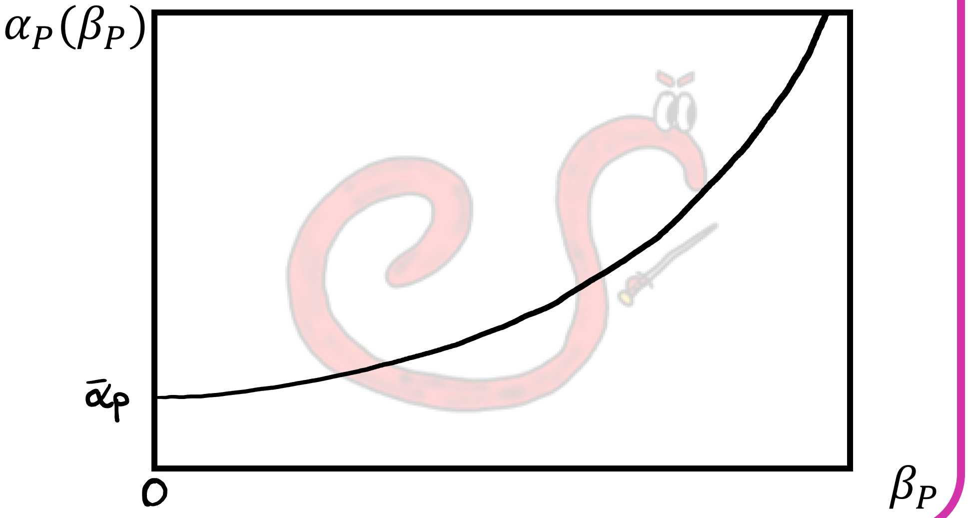
"Effort"
$y \in (0,1)$



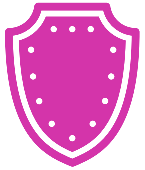
Transmissibility
$\beta_P > 0$

Trade-offs





Protection



Mortality tolerance

$$\alpha_B(y, \beta_P) = \alpha_D + (1 - y)\alpha_P(\beta_P)$$

Audience participation time!

Imagine that you work in a lab, and you are tasked with creating a defensive symbiont to release into a population of hosts.

You have the ability to decide the level to which it initially helps the host, i.e. you can choose $y \in (0,1)$, where $y = 0$ corresponds to no help and maximal transmission, and $y = 1$ is maximum help but minimal transmission.

Where do you initialise?

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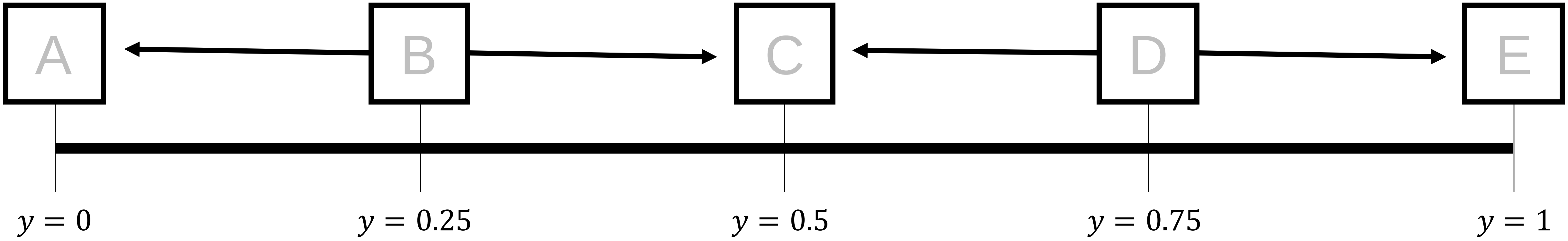

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Outline

What does this all mean?

Otherwise known as: results

1. Defensive symbionts that confer tolerance always select for higher virulence.

2. Defensive symbionts can drive parasite diversity.

3. Symbiont-parasite coevolution can be detrimental to the host population.

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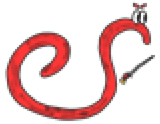
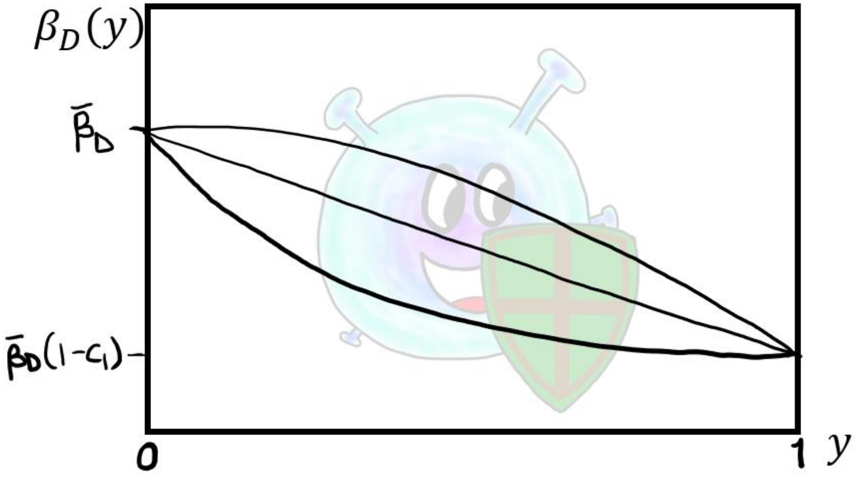
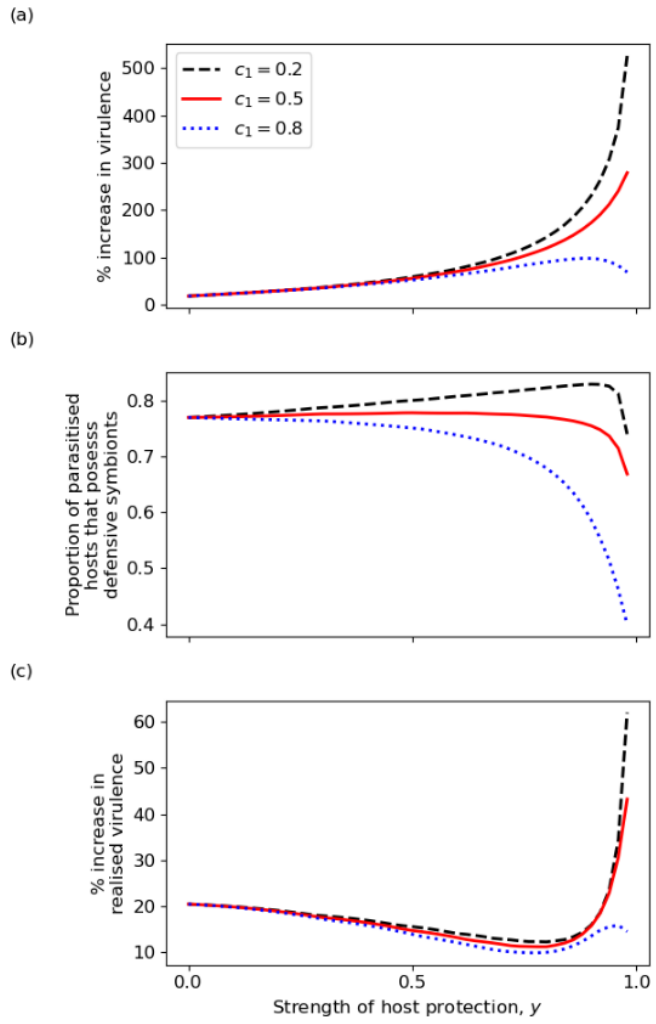
Not evolving



Evolving





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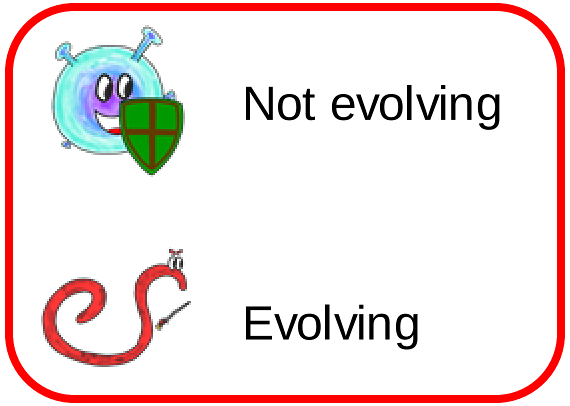

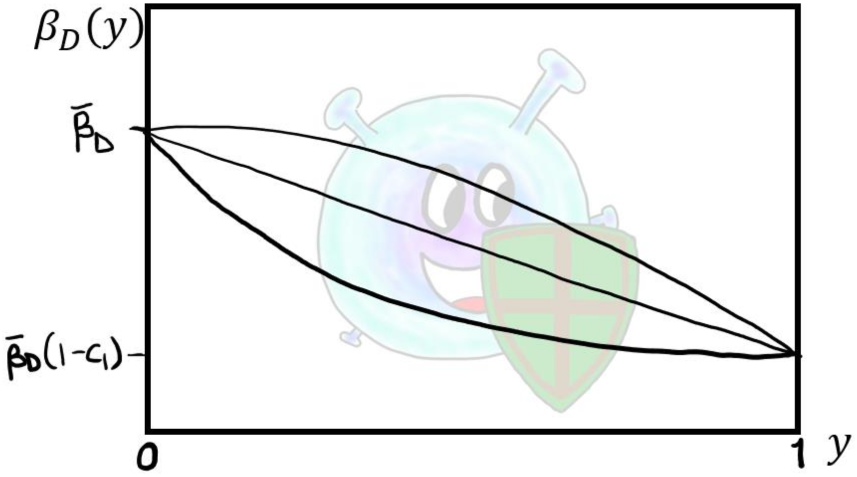

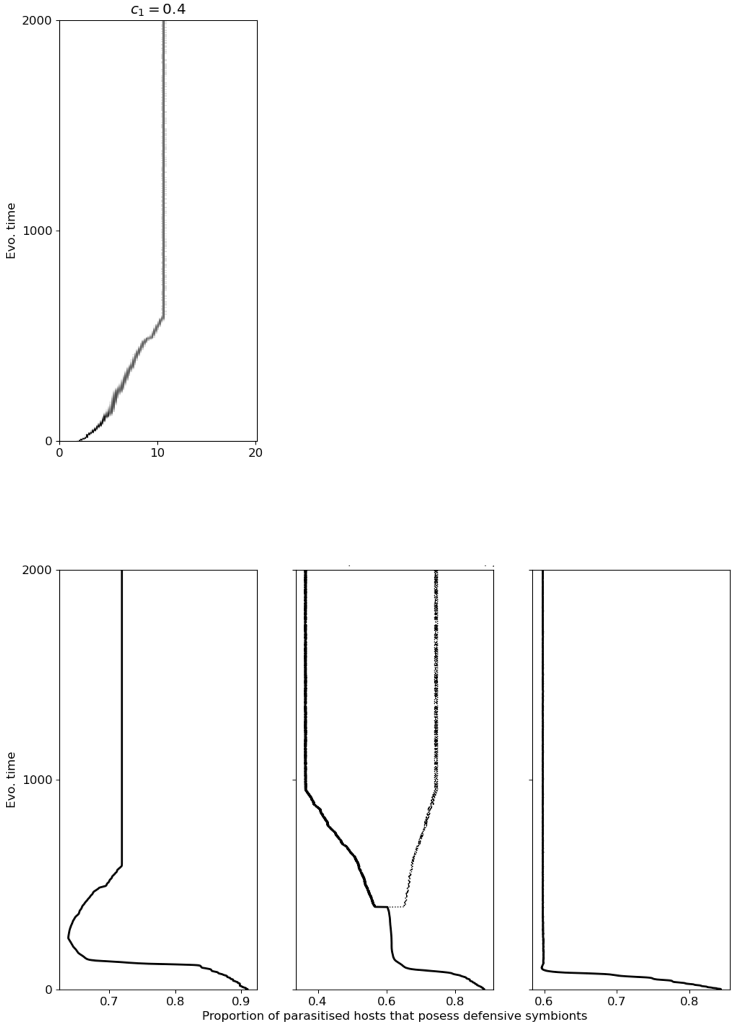

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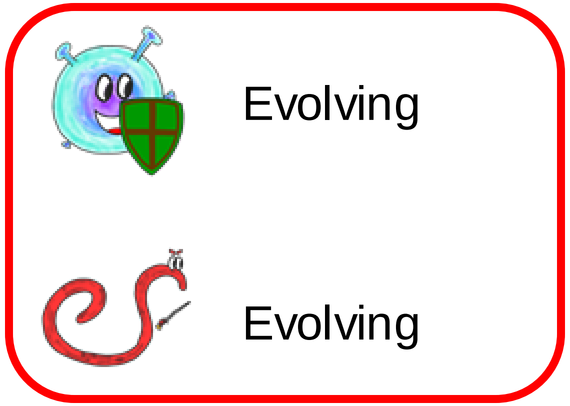

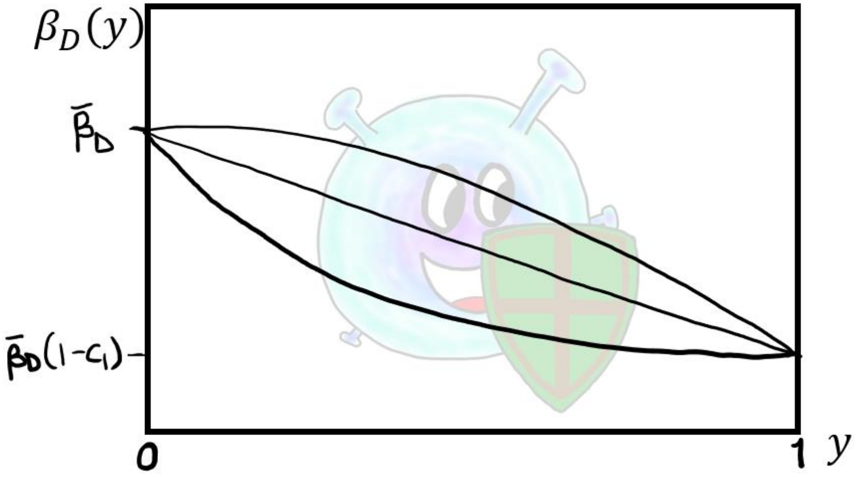

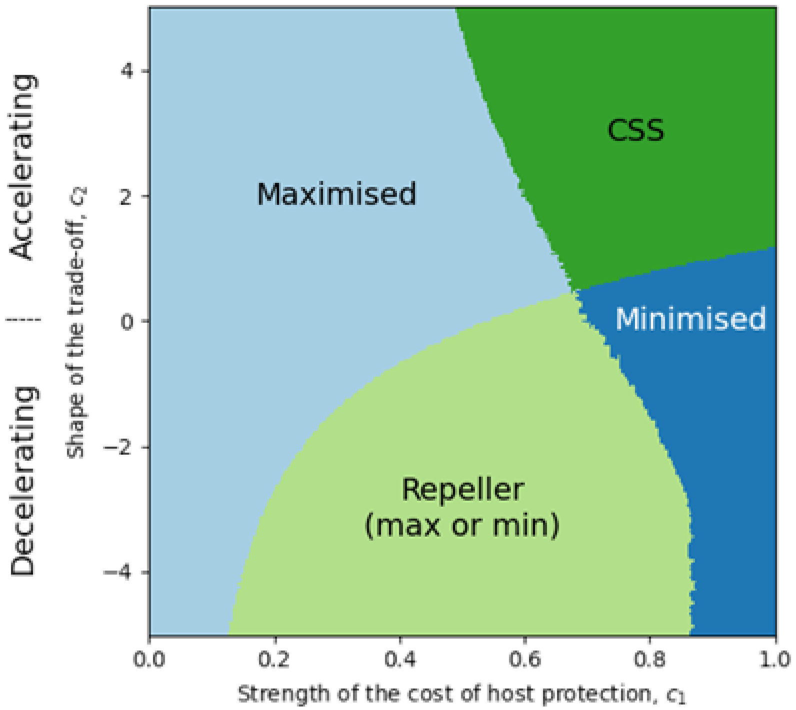

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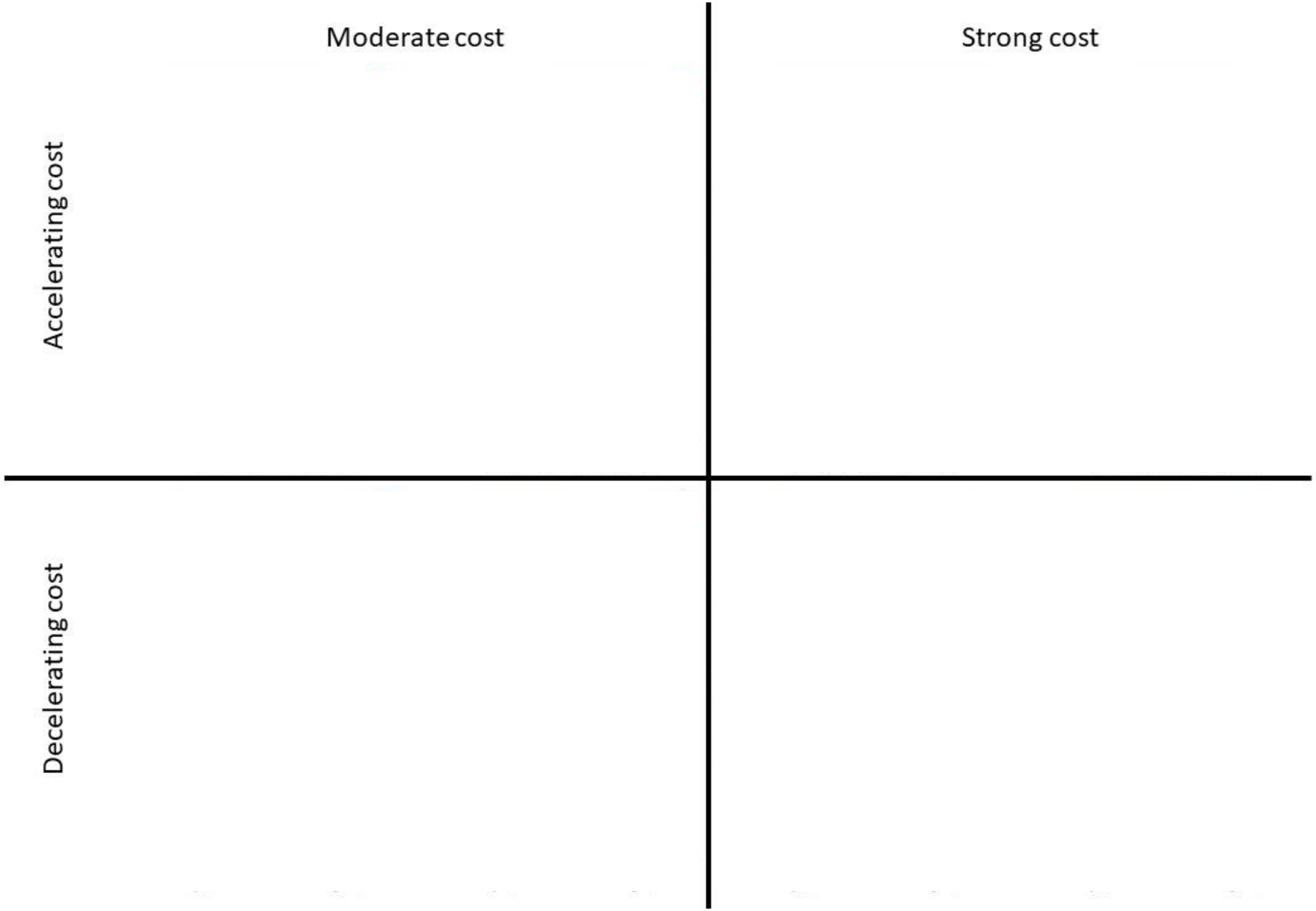
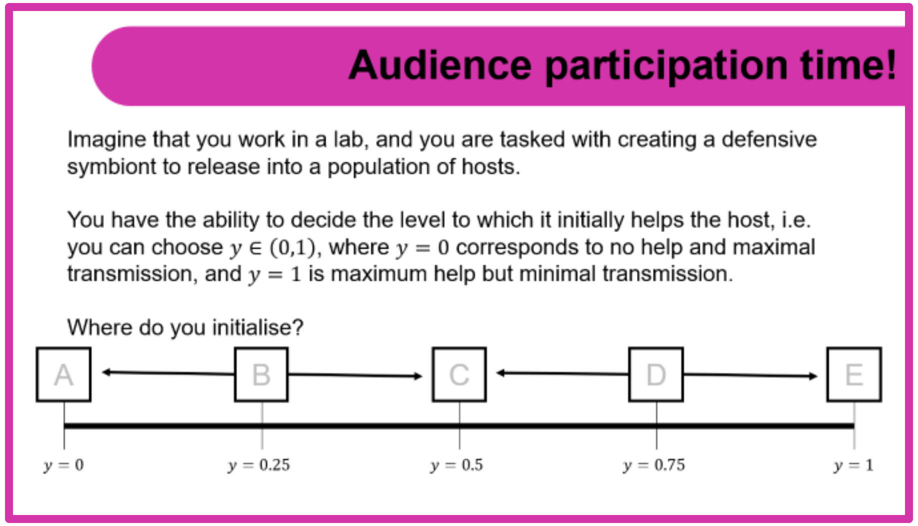


Discussion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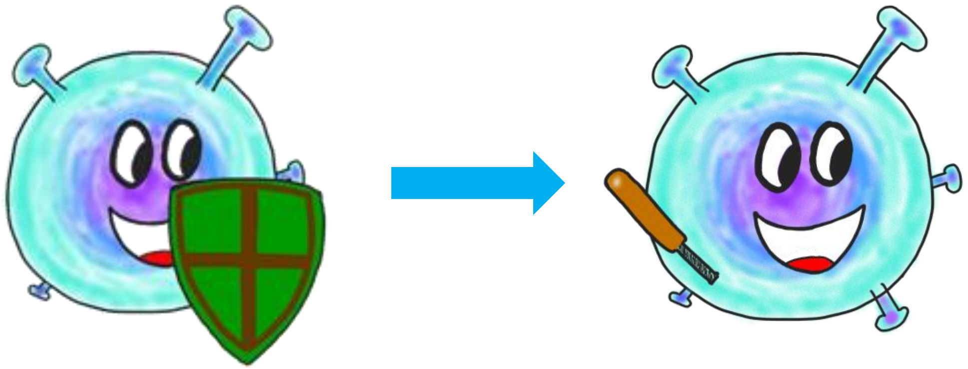
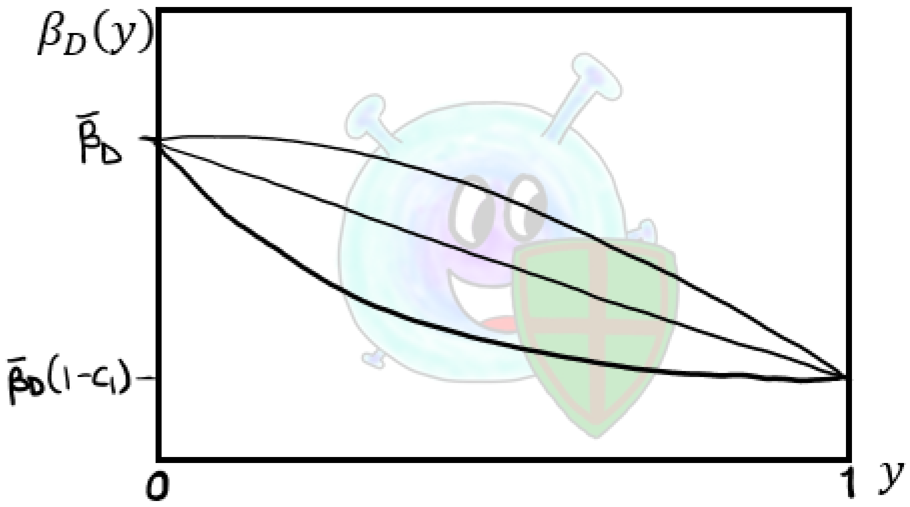
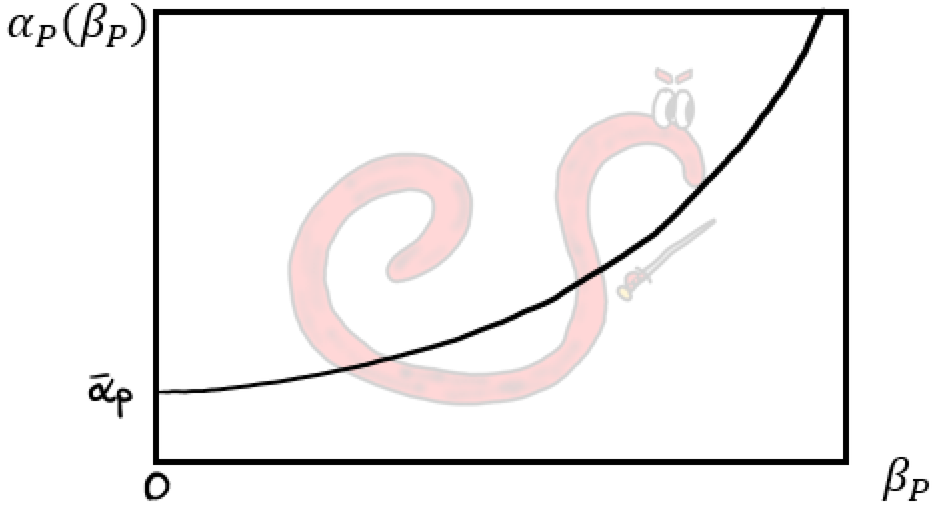
Where do you initialise?
A
B
C
D
E
$y = 0$
$y = 0.25$
$y = 0.5$
$y = 0.75$
$y = 1$

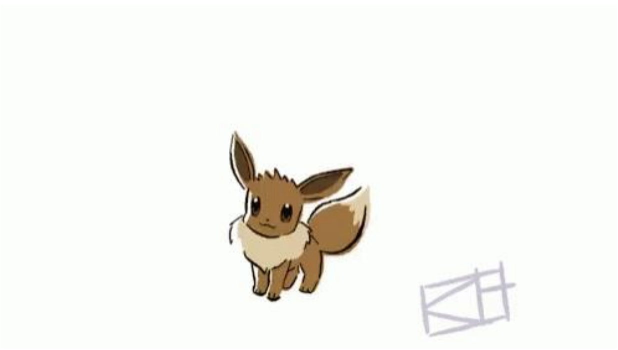


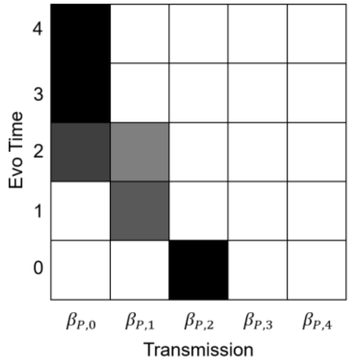

$\beta_D(y)$
$\bar{\beta}_D$
$\bar{\beta}_D(1-c_1)$
0
1
y


$\alpha_P(\beta_P)$
$\bar{\alpha}_P$
0
β_P

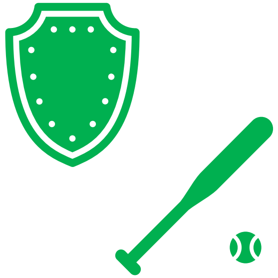
Conclusions

Ecology and Evolution

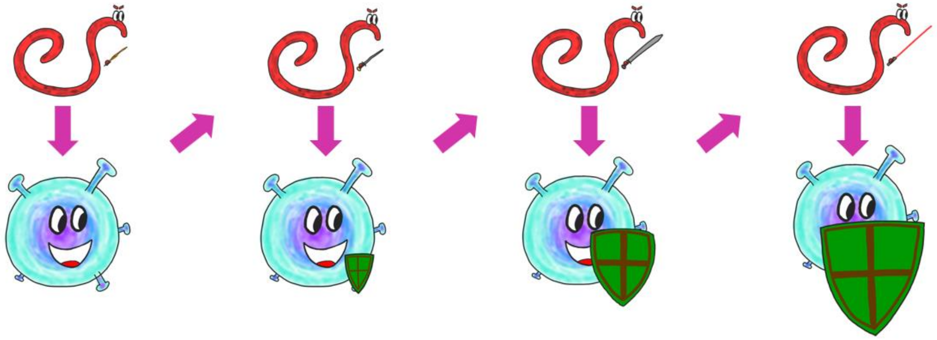




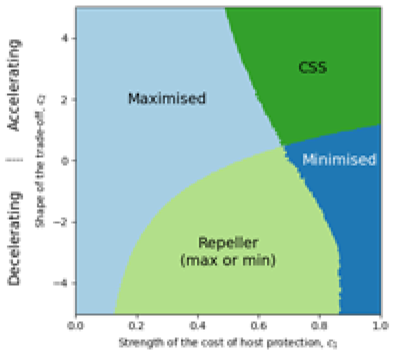
Defensive symbionts

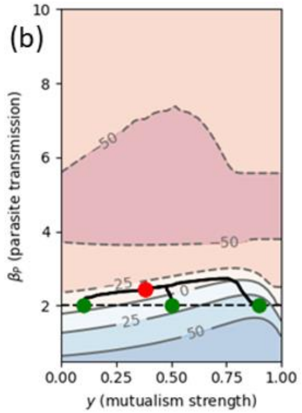


Coevolution



Results





Thank you!

Joint work with Ben Ashby, who left me for SFU.

Any questions?

eco-evo theory

UKRI Natural Environment Research Council

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