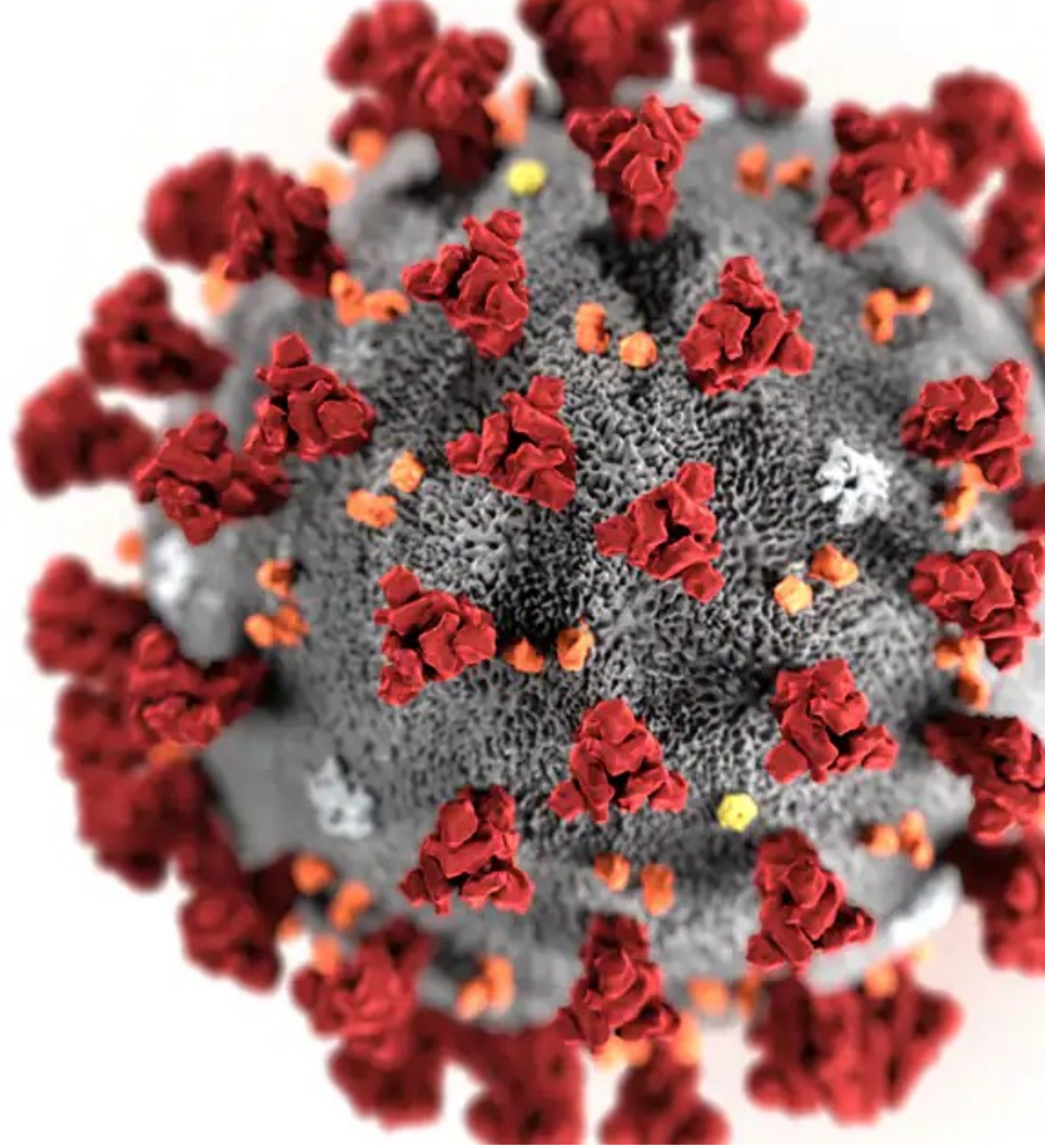


# Coevolução

**BIO 0119**

**Ana Paula Aprígio Assis**

[paulaassis@ib.usp.br](mailto:paulaassis@ib.usp.br)





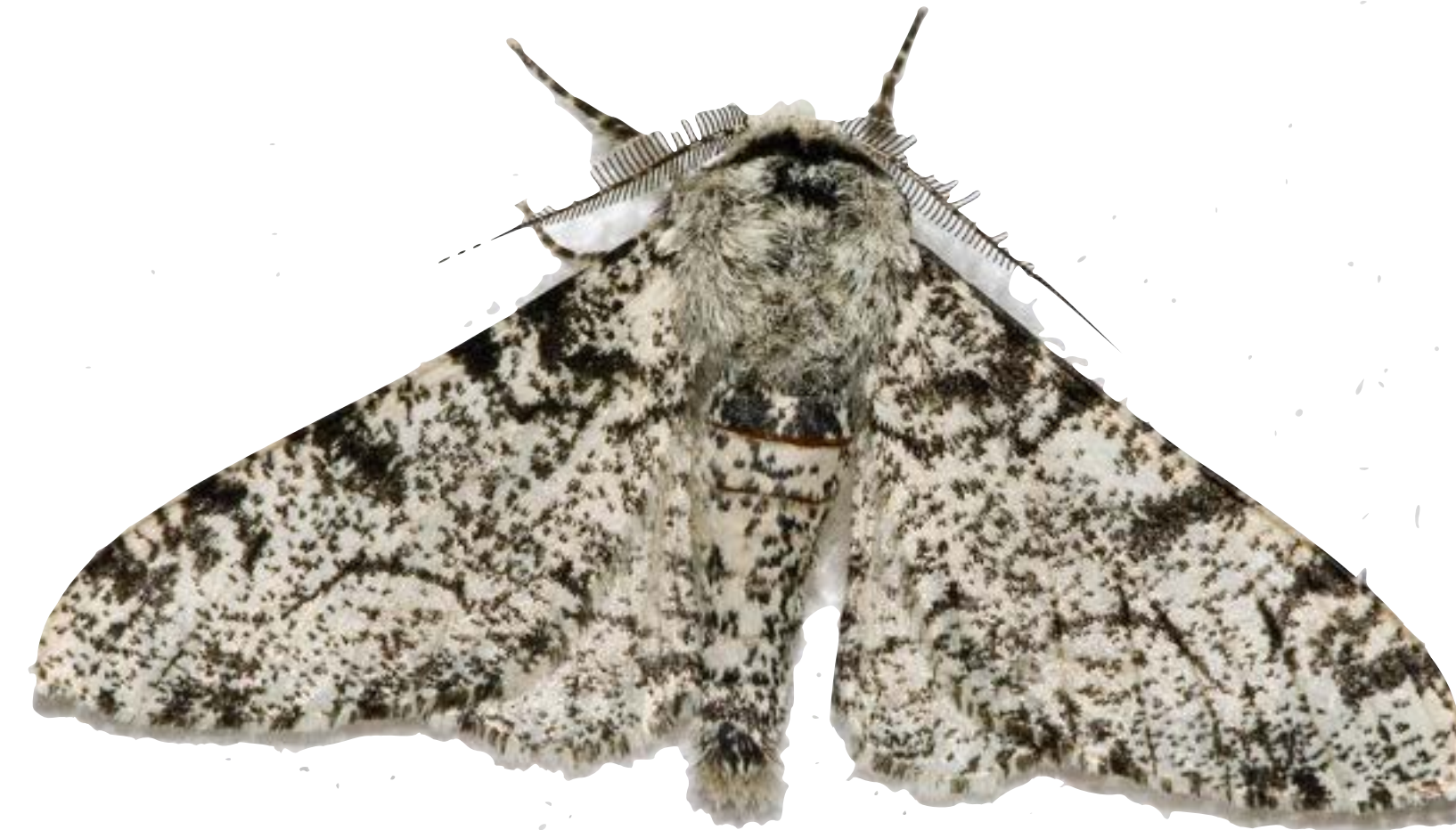
“Todas as manhãs a gazela acorda sabendo que tem que correr mais veloz que o leão ou será morta. Todas as manhãs o leão acorda sabendo que deve correr mais rápido que a gazela ou morrerá de fome. Não importa se és um leão ou uma gazela: quando o sol desponta o melhor é começares a correr.”

**Mia Couto**

# Seleção natural

# Seleção natural

1.) Existe variação

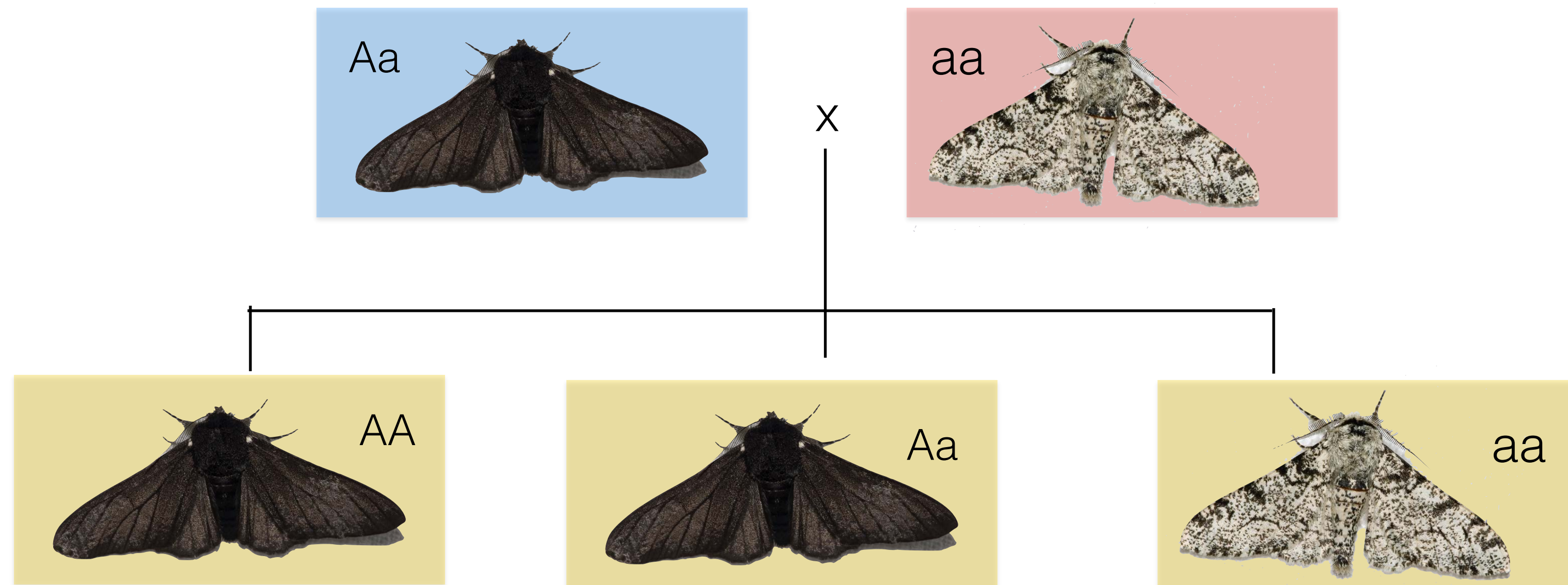


*Biston betularia*

# Seleção natural

2.) Variação é herdável

Herança autossômica dominante

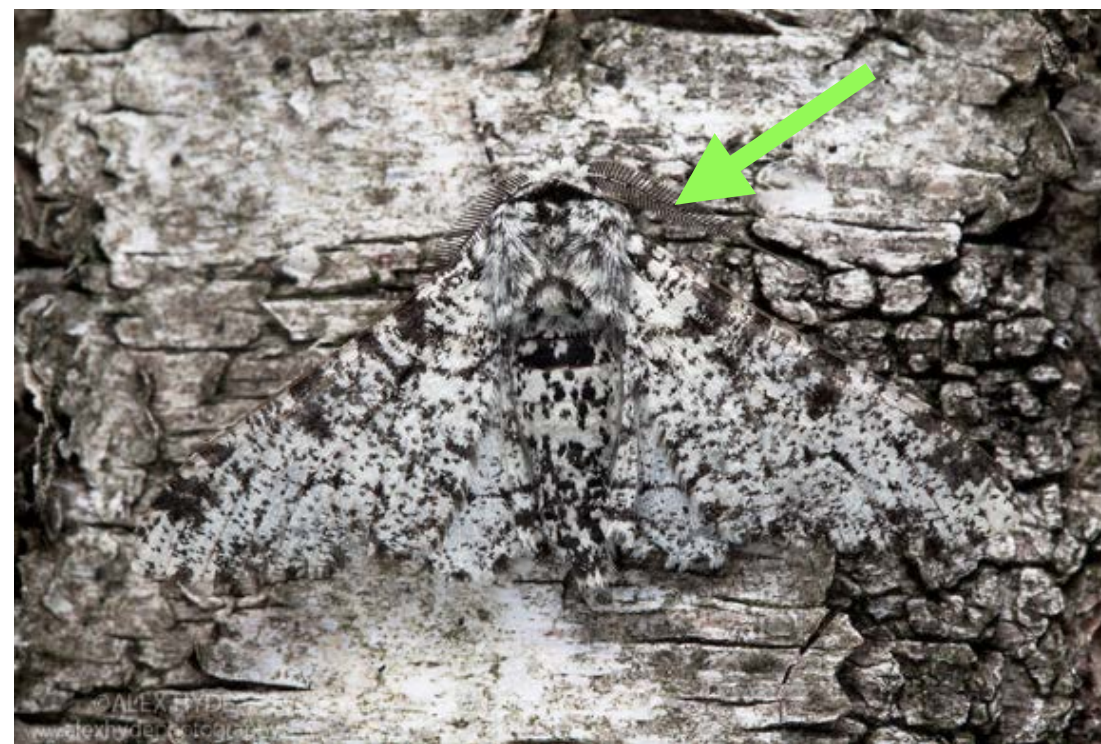


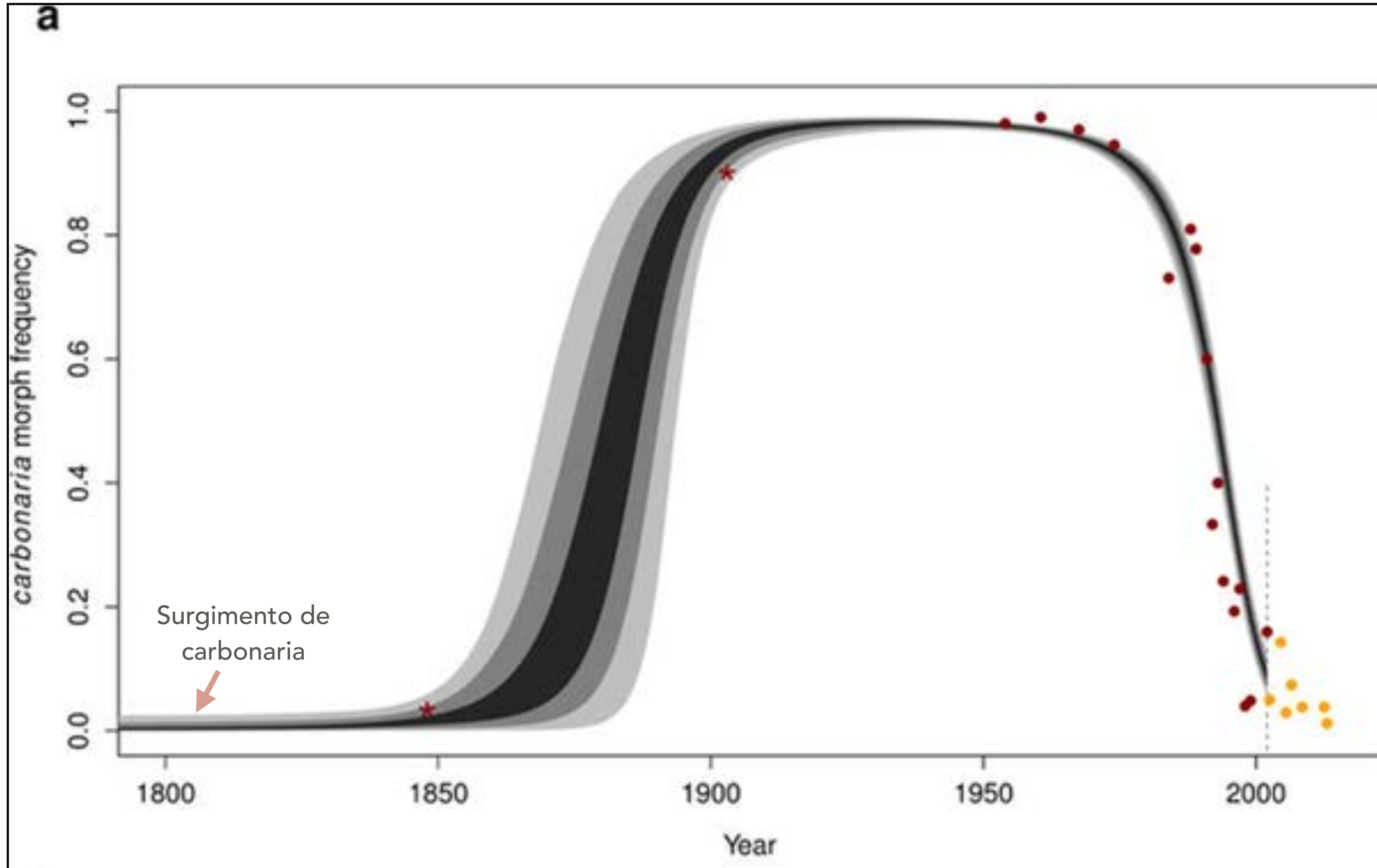
**3 : 1**

# Seleção natural

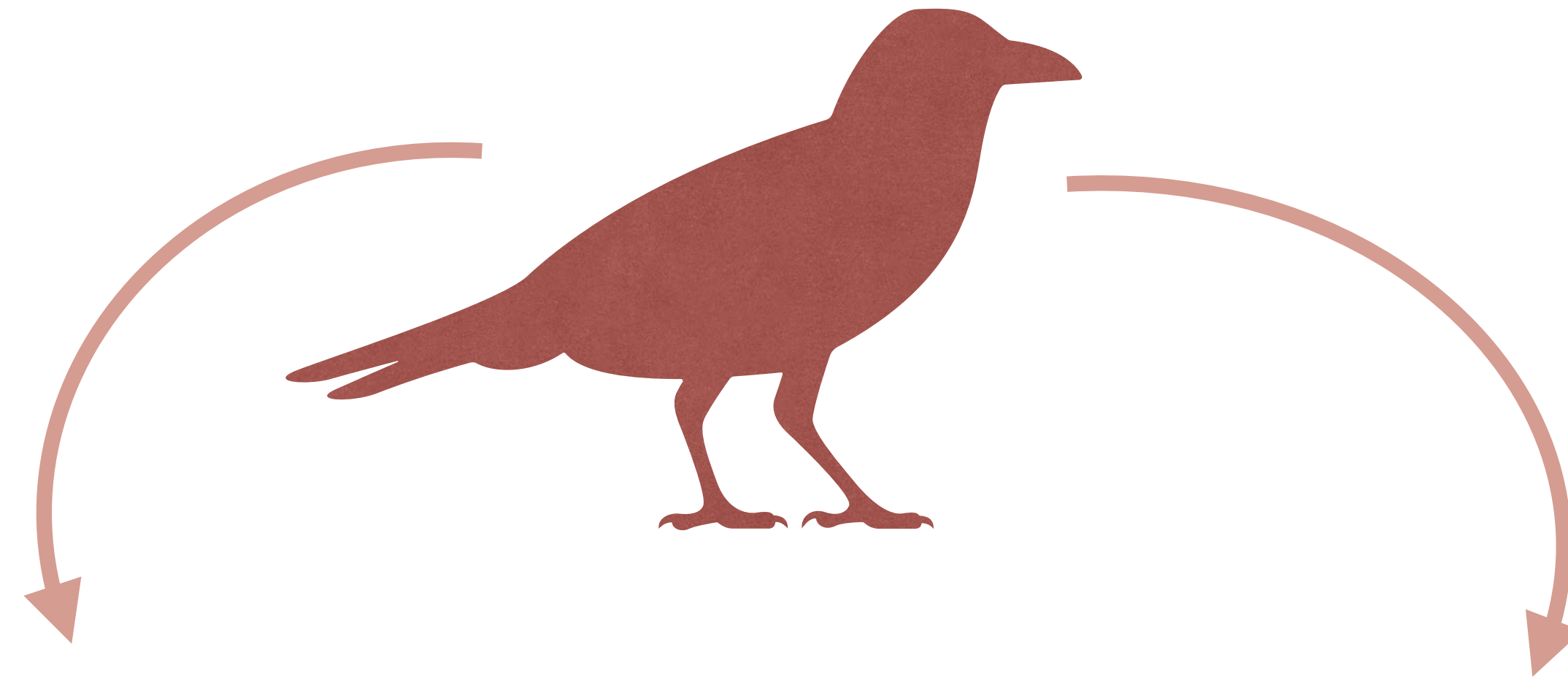
3.) Reprodução/Sobrevivência diferencial

**Revolução industrial**



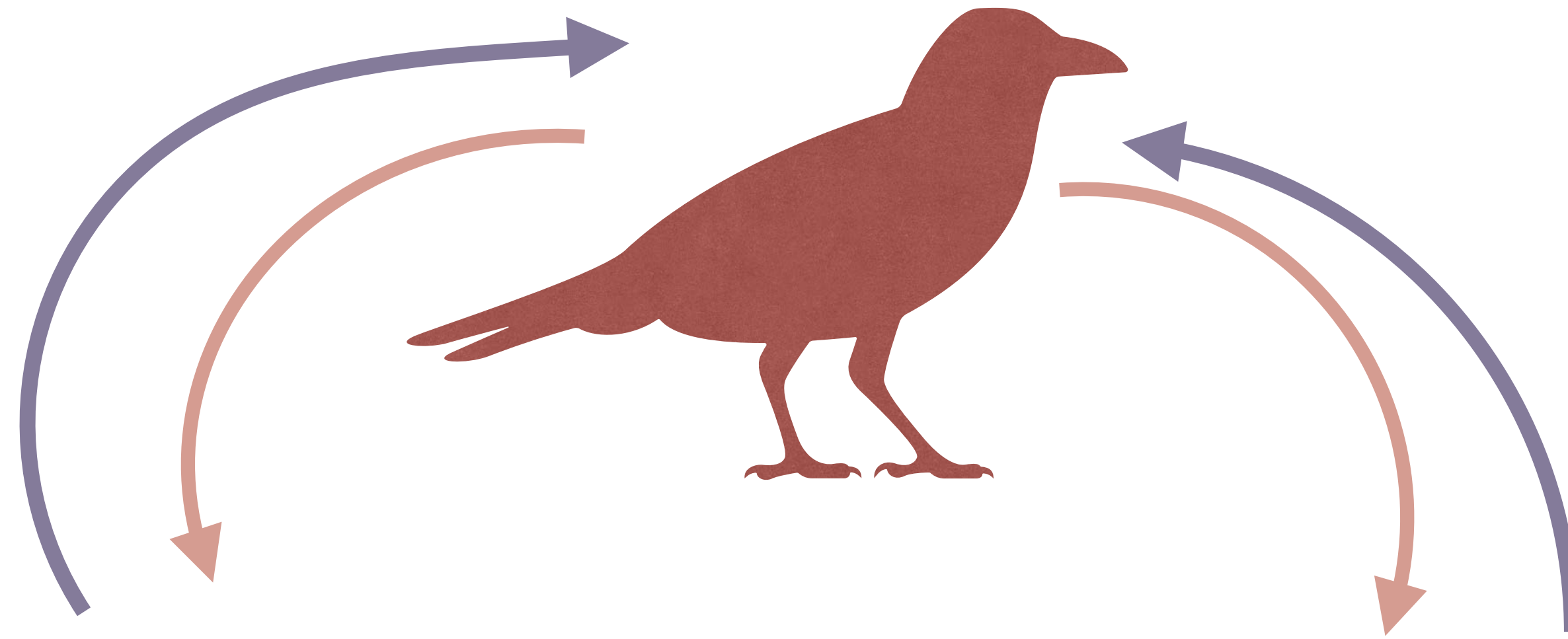


# Mas qual o agente seletivo de carbonaria?





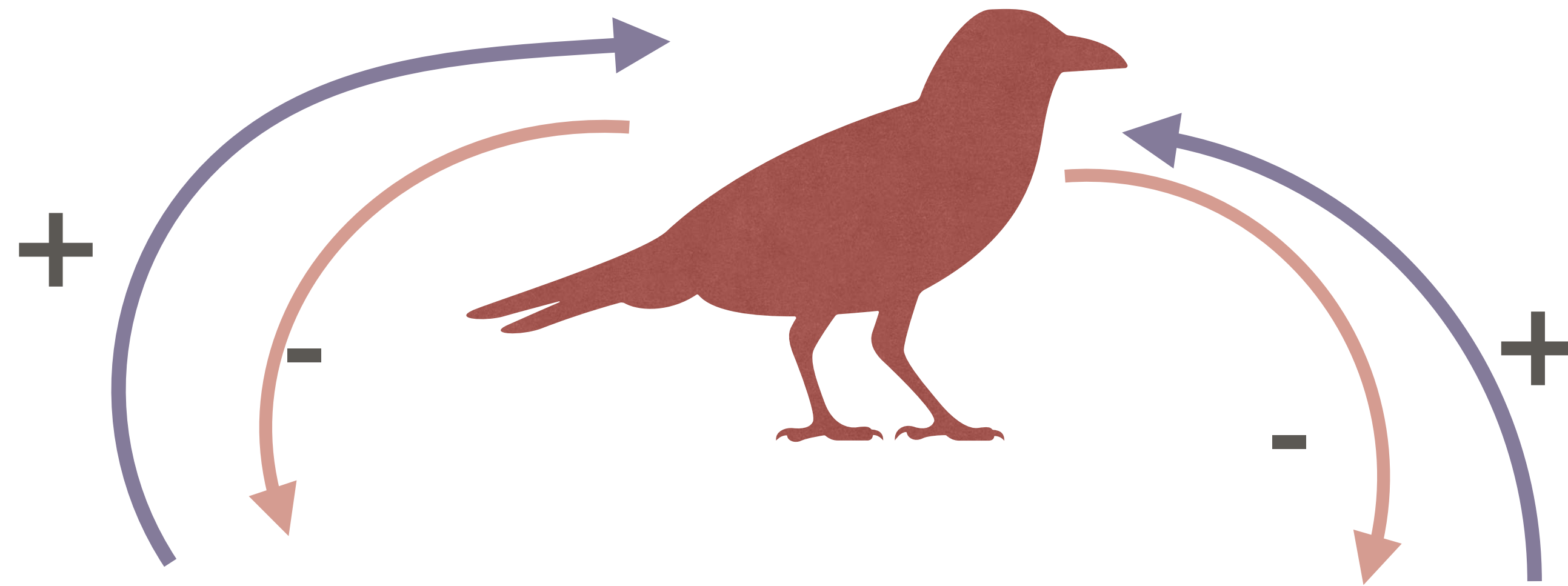
# Mas qual o agente seletivo de carbonaria?



# Coevolução

- Mudança recíproca por seleção natural entre espécies que interagem

# Coevolução

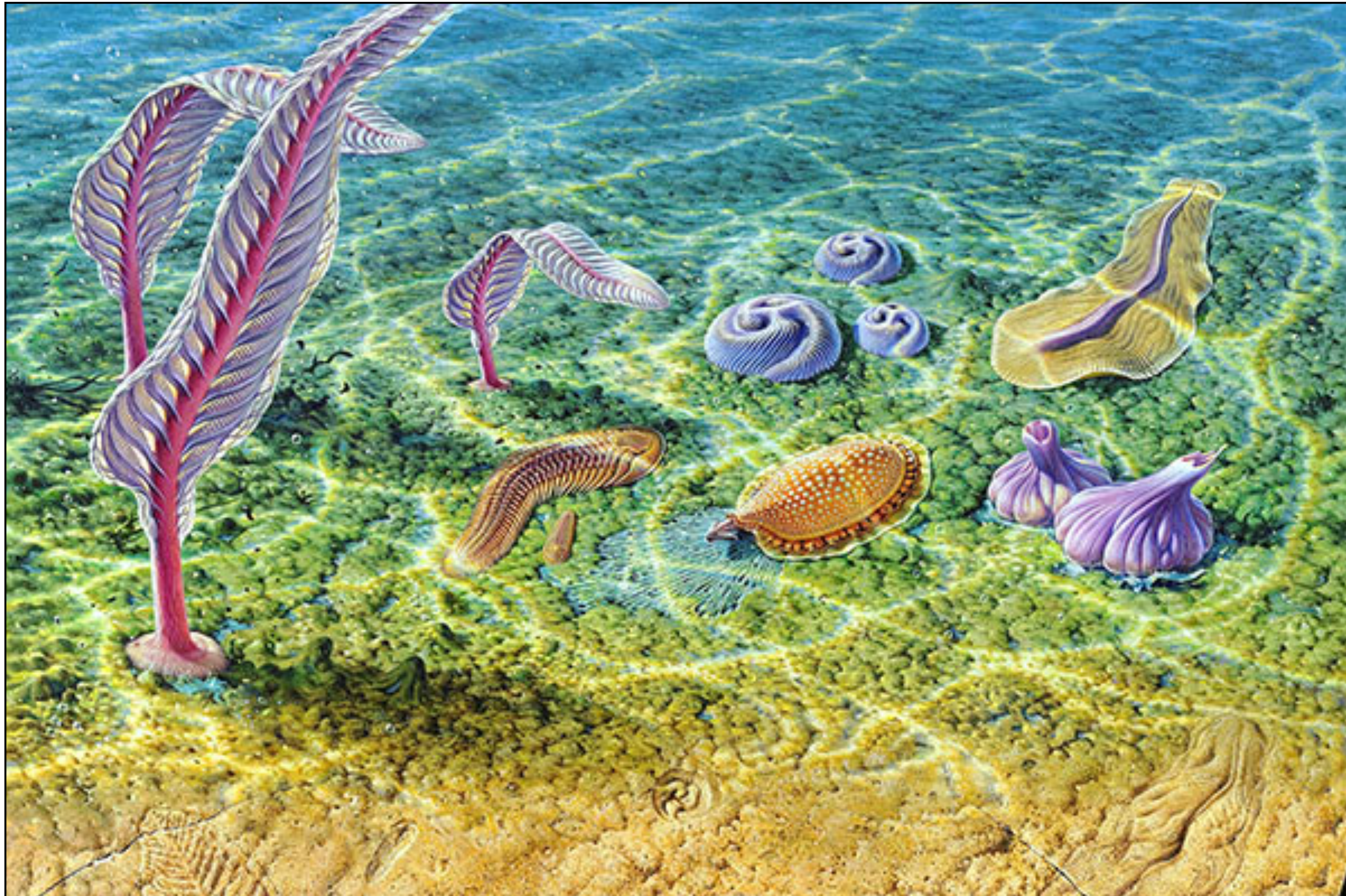


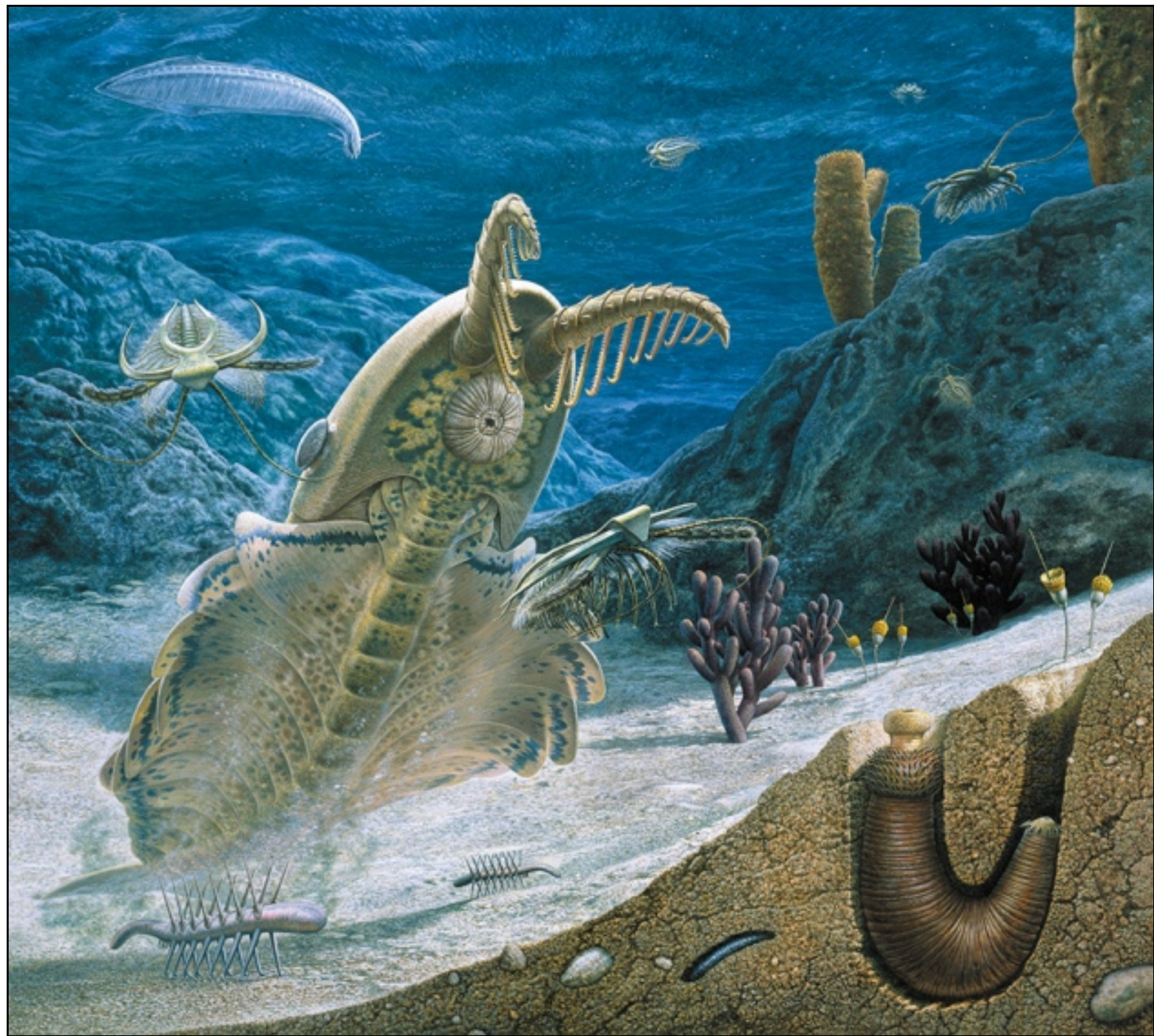
# Antagonismo

- Interação entre indivíduos de espécies diferentes que causa **redução de aptidão** de um dos indivíduos e **aumento na aptidão** do outro indivíduo

**Quão importante são interações antagonistas para evolução??**

# Fauna de Ediacara



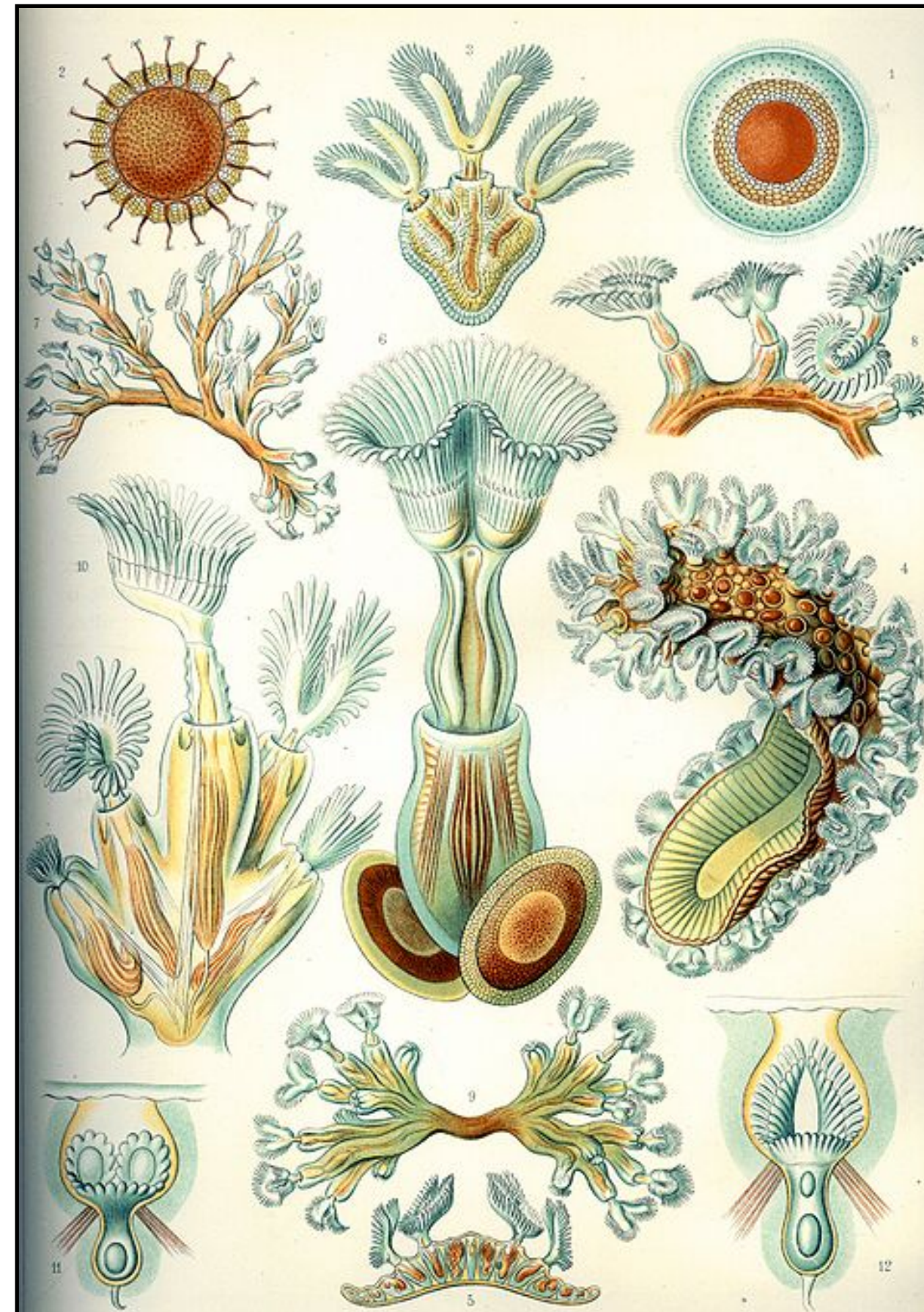


# **Explosão Cambriana**

**~500 milhões de anos atrás**

Em um curto período de 15-30 milhões de anos **todos os atuais filos de animais** (com exceção de um) surgiram no registro fóssil

# Explosão cambriana







**DEFESAS CONTRA INIMIGOS  
NATURAIS**



Como escapar de um predador

## Camuflagem



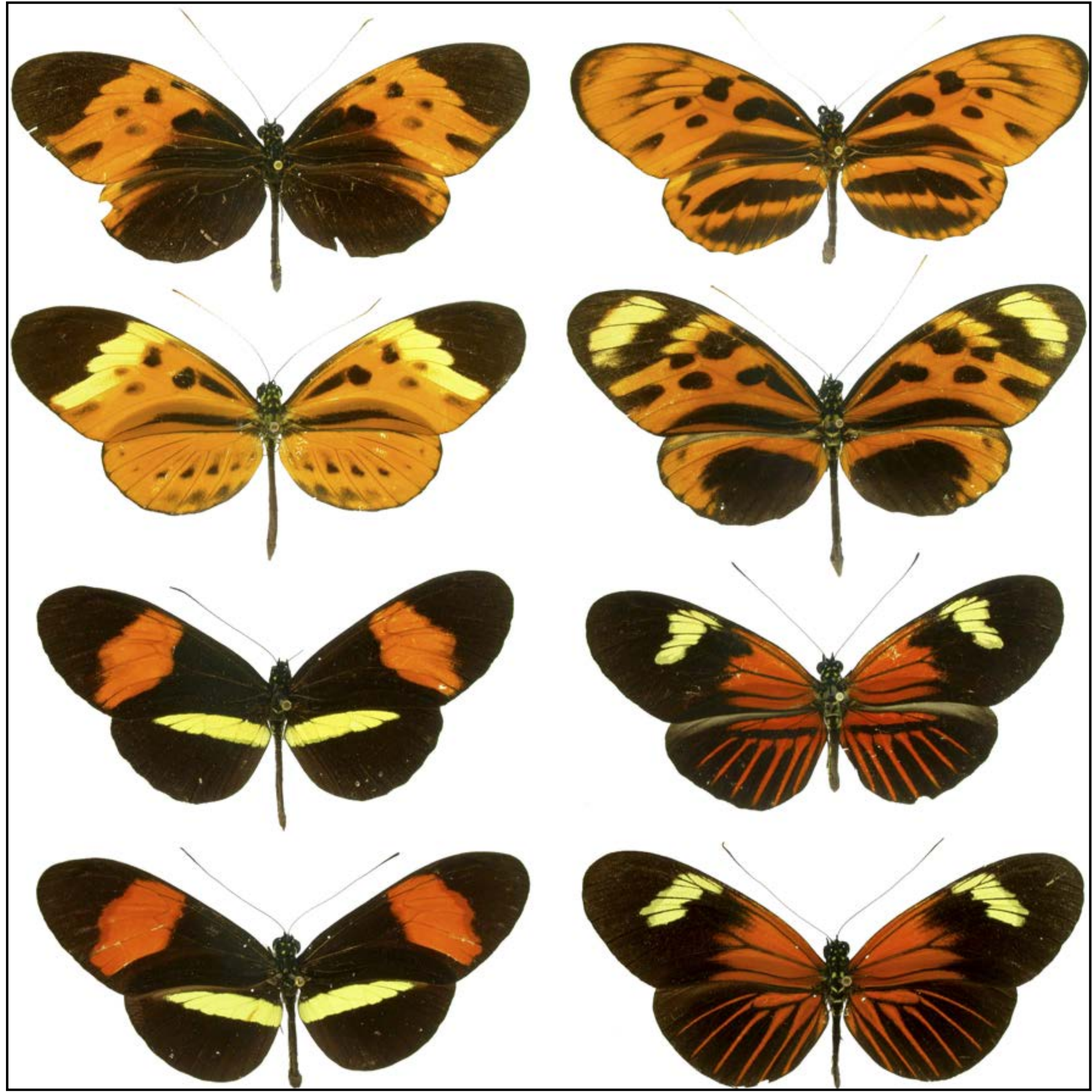
Copyright Brian Freiermuth, insituexsitu.com



Como escapar de um predador

# Aposematismo





Como escapar de um predador

# Mimetismo



# Mimetismo

```
graph TD; A[Mimetismo] --> B[Batesiano]; A --> C[Mulleriano];
```

The diagram illustrates the classification of mimicry. At the top, the word 'Mimetismo' is written in white on a black rectangular background. Two red arrows originate from the bottom center of this box and point downwards and outwards to two separate boxes below. The left box is olive green and contains the word 'Batesiano' in black. The right box is light blue and contains the word 'Mulleriano' in black.

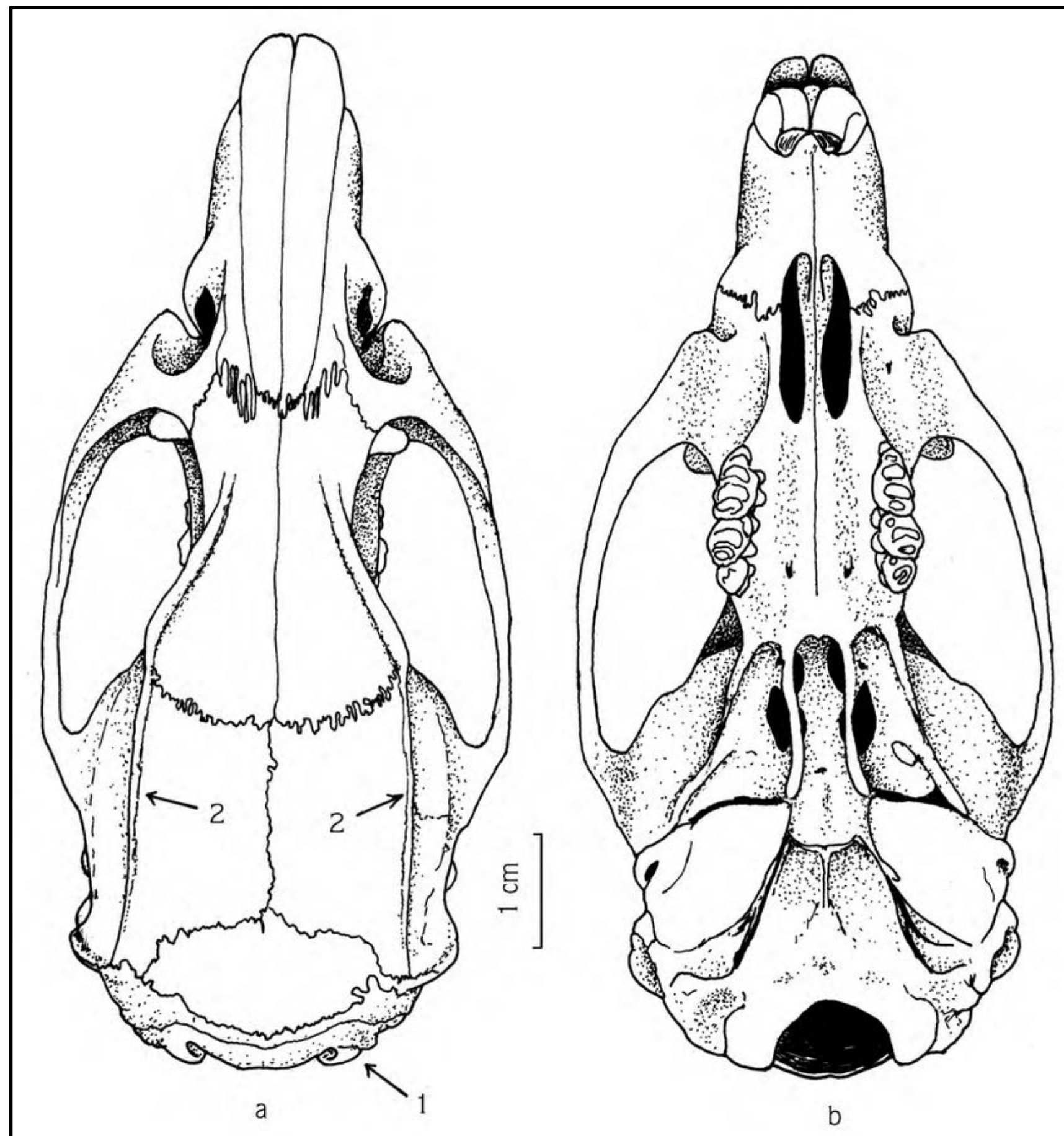
**Batesiano**

**Mulleriano**

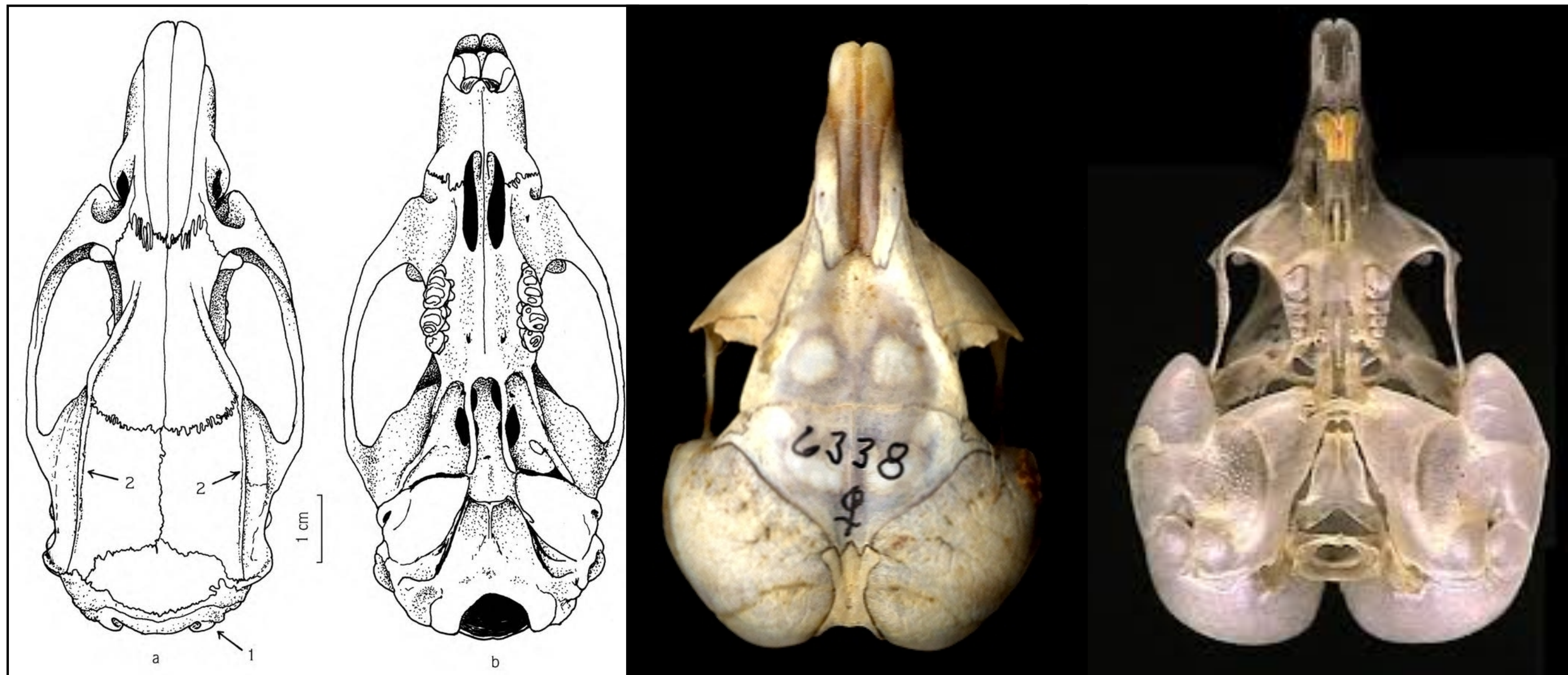


# Como escapar de um predador

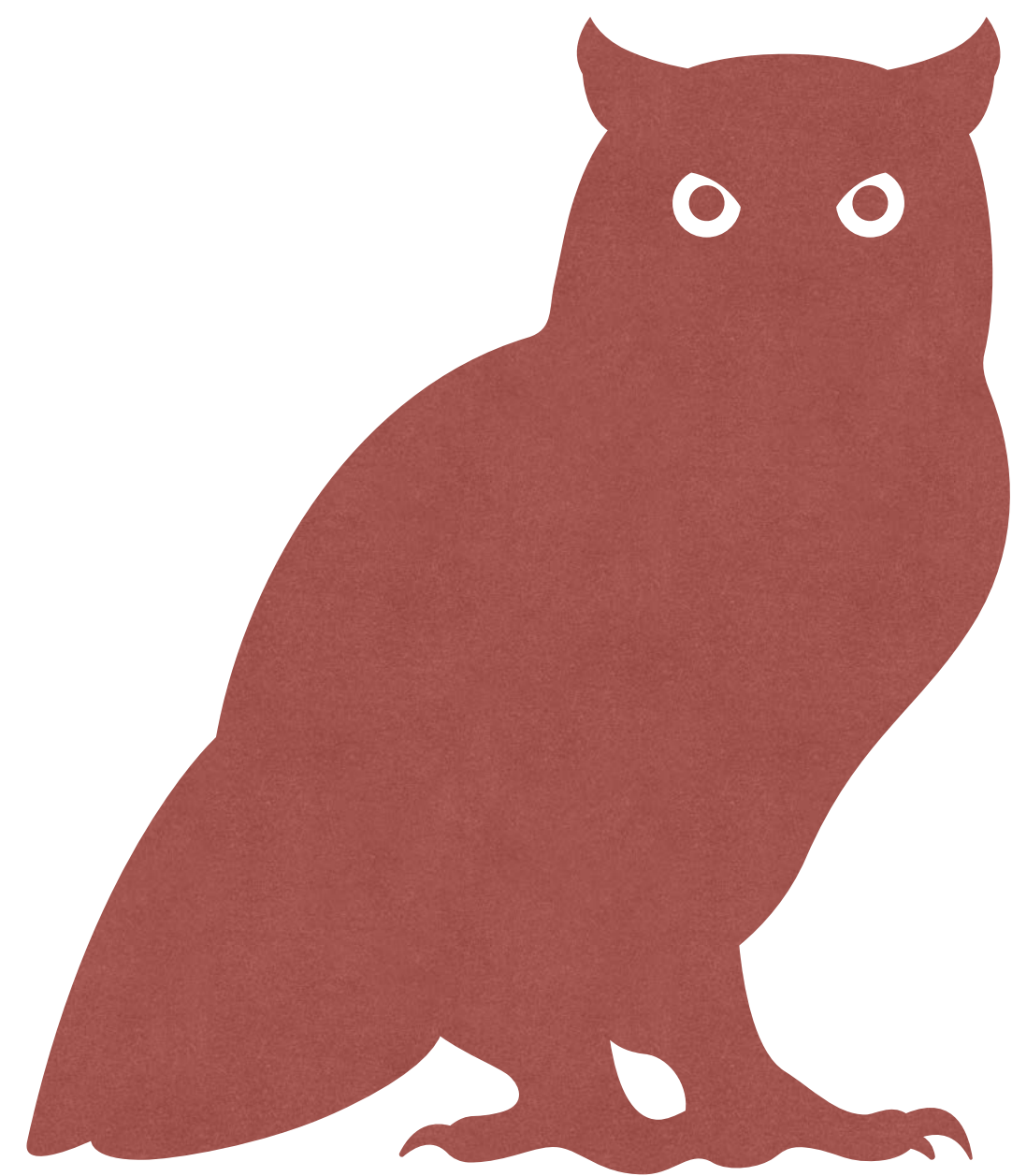
# Como escapar de um predador



# Como escapar de um predador



# Como escapar de um predador

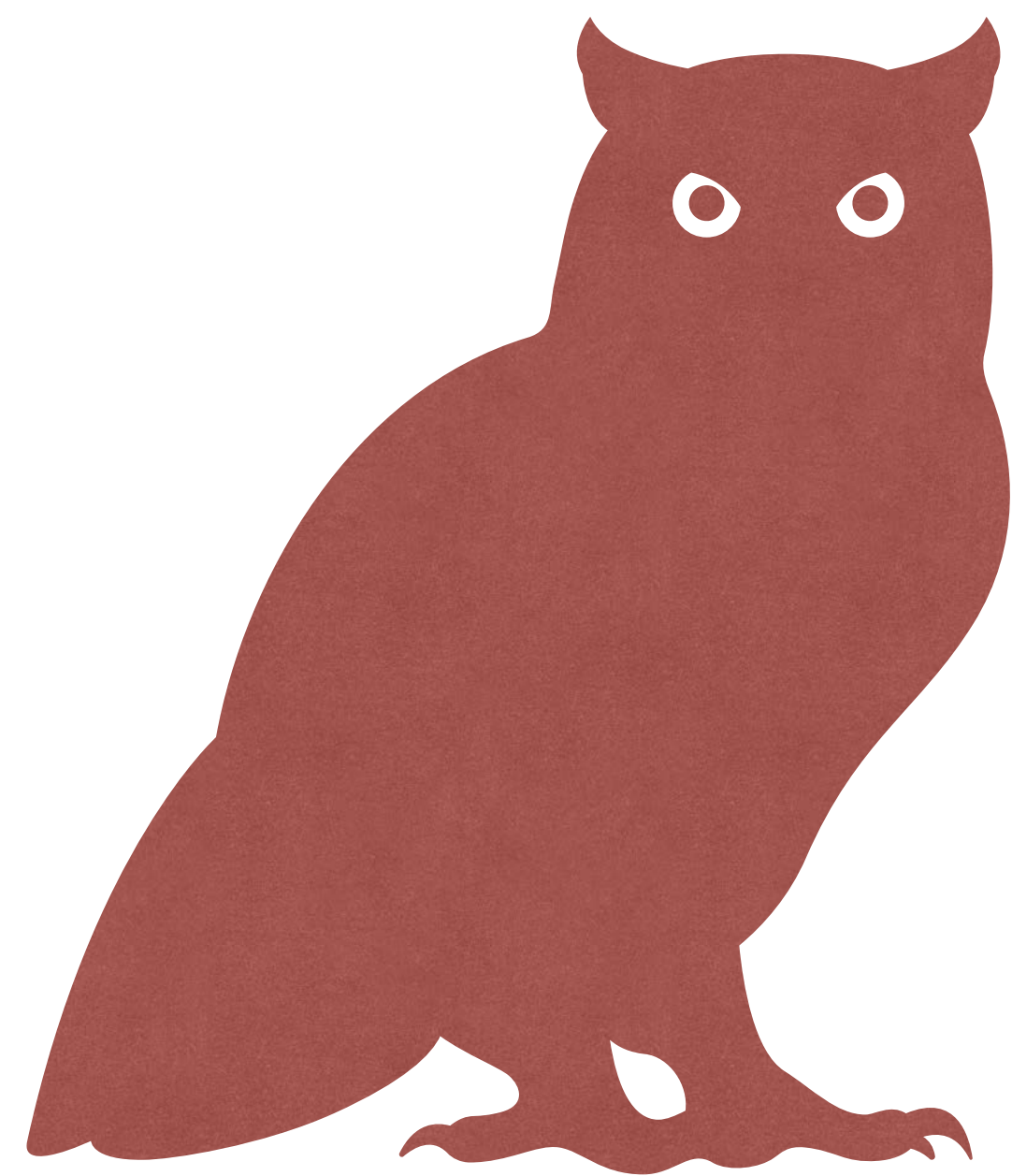


Maior acuidade auditiva!



Webster, 1962

# Como escapar de um predador



Maior acuidade auditiva!

Webster, 1962

# Como escapar de um predador



Hlgham et al., 2017



**Endless forms most beautiful....**

# Interações antagonistas



# Interações antagonistas

Quem são?  
Onde vivem?  
O que comem?





**Predação**



**Parasitismo**



# Parasitismo

Photograph by Darlyne A. Murawski



**Herbivoria**



**Parasitoidismo**

# Interações antagonistas



# Interações antagonistas



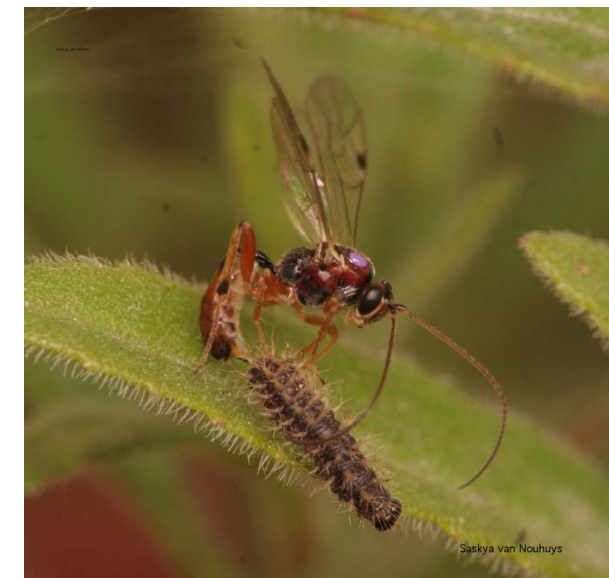
**Resultado**

**intimidade**



# Interações antagonistas

**Resultado**



**intimidade**

# Interações antagonistas

**Morte**



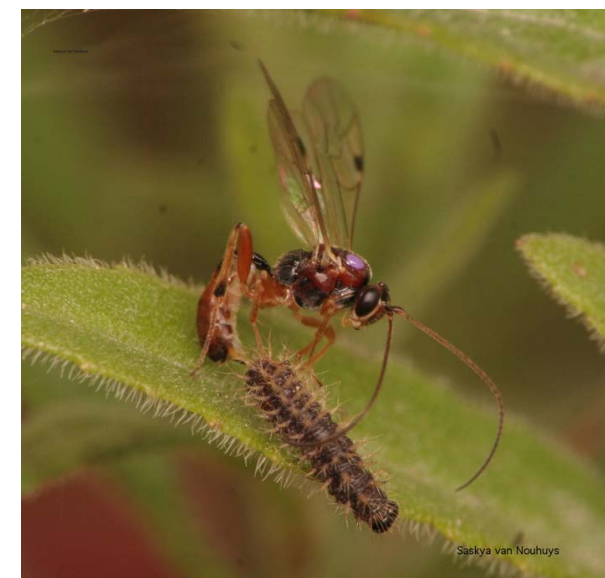
**Dano**



**intimidade**

# Interações antagonistas

**Morte**

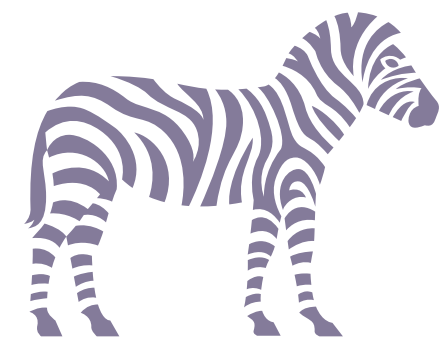
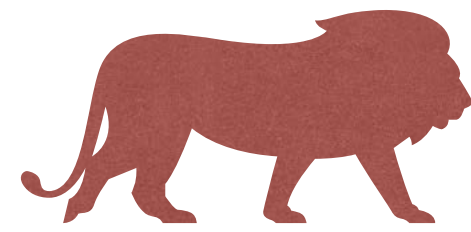


**Dano**



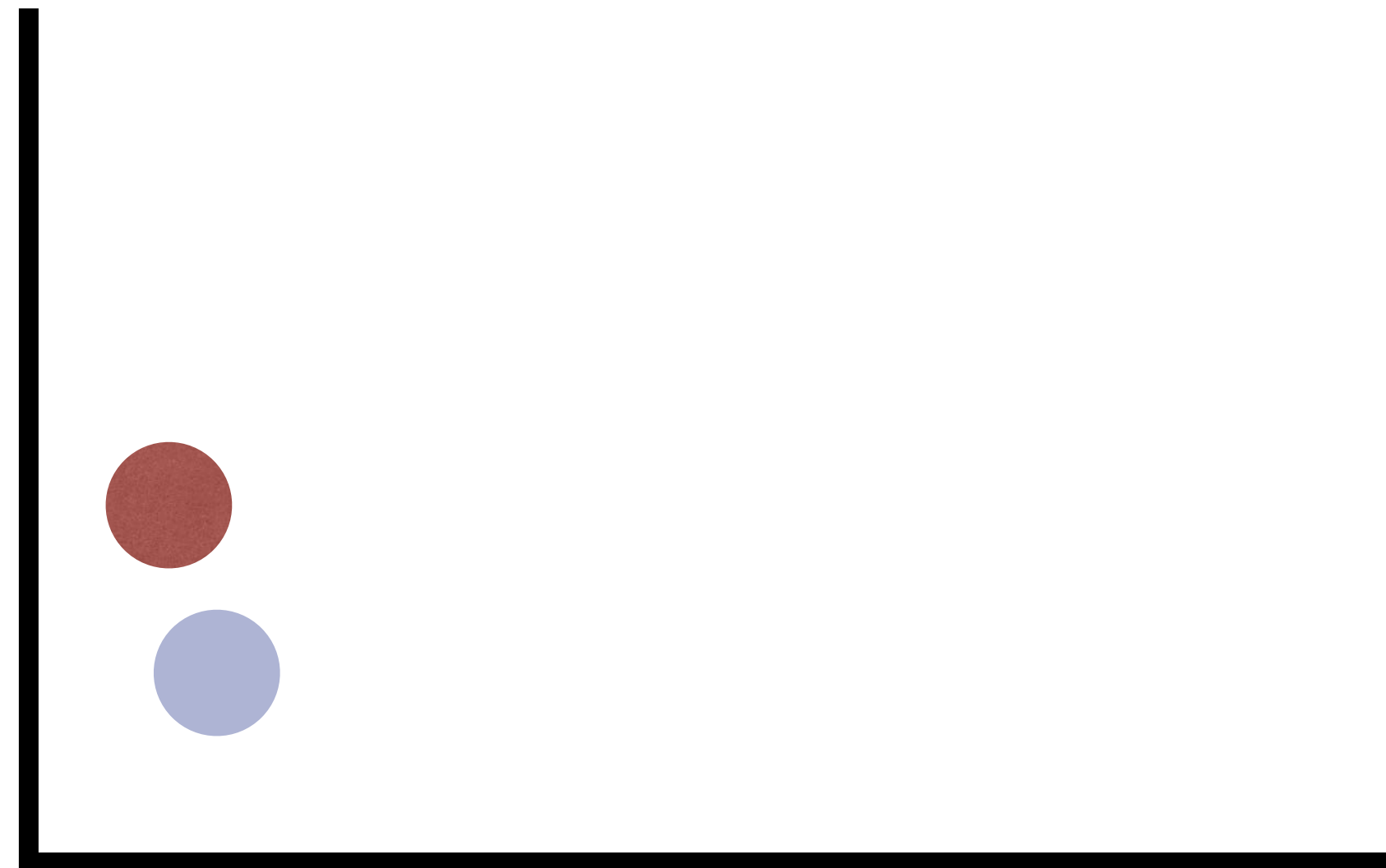
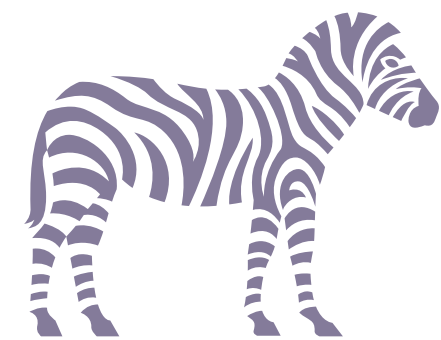
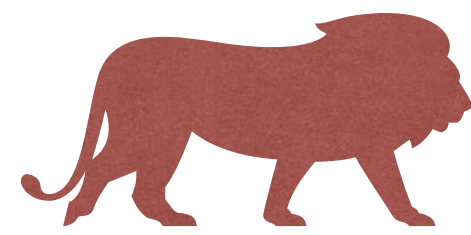
**intimidade**

# Escalonamento



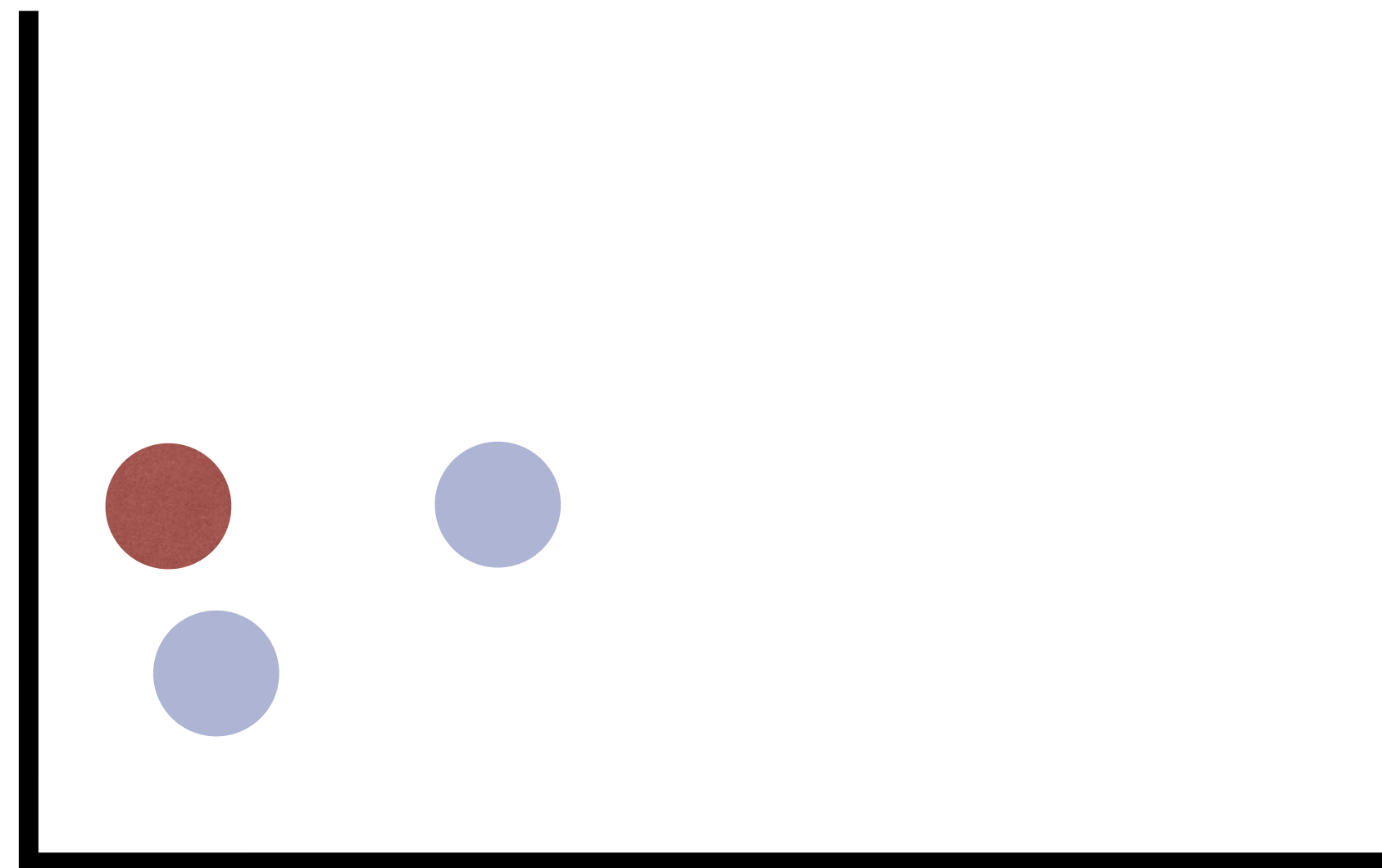
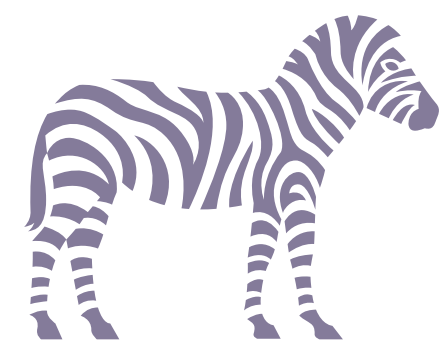
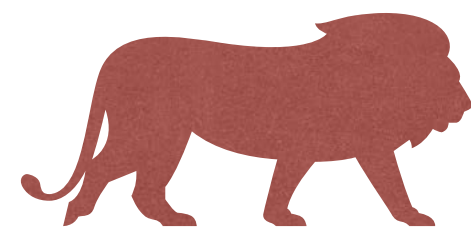
tempo

# Escalonamento



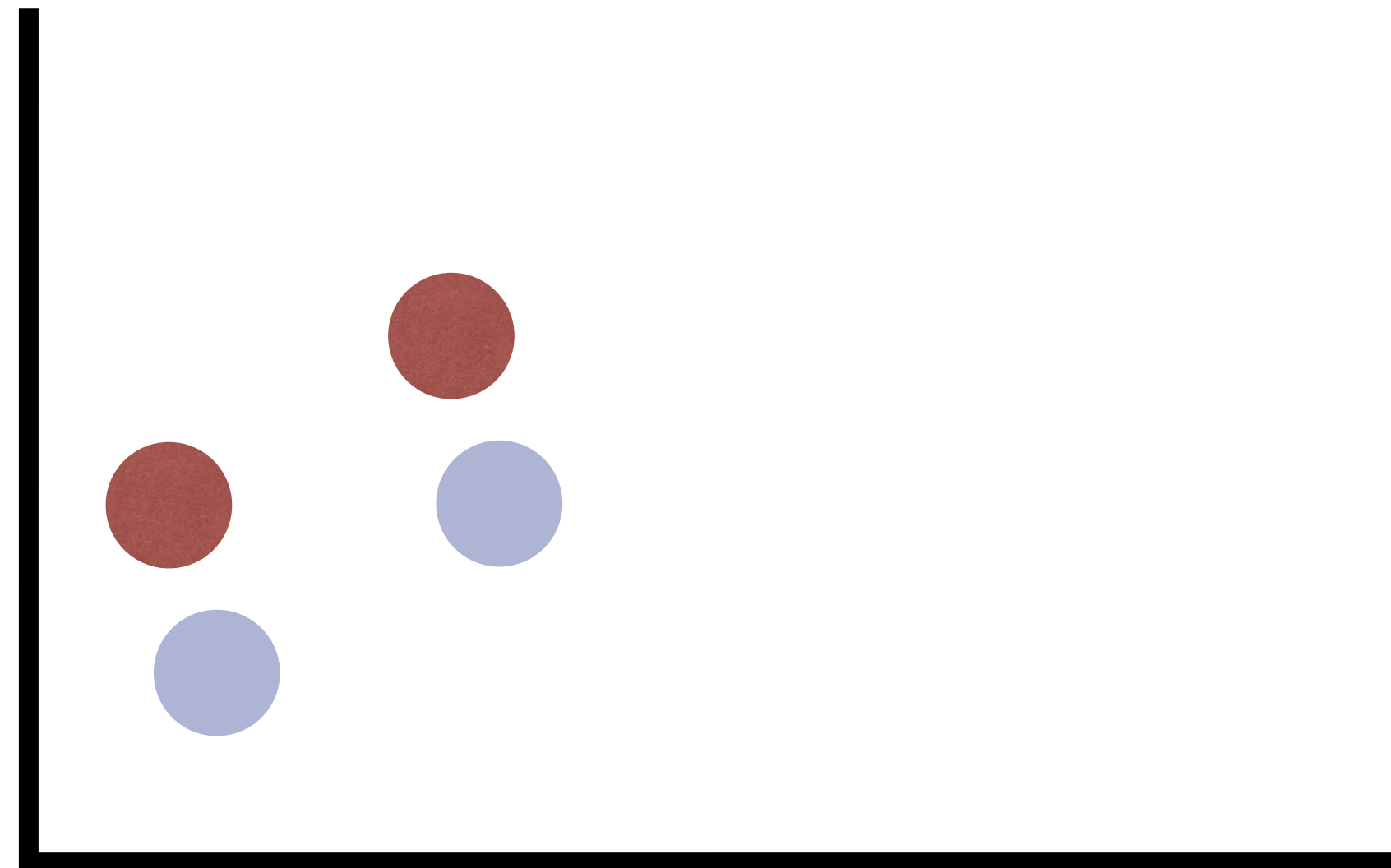
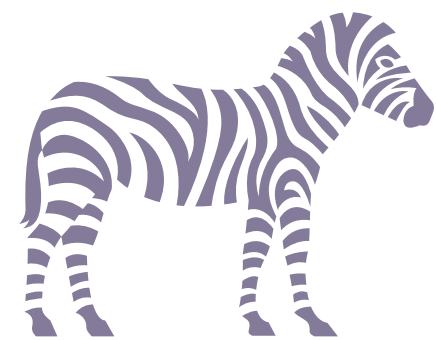
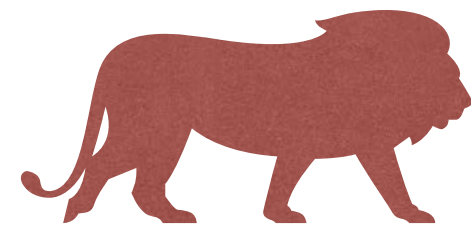
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# Escalonamento



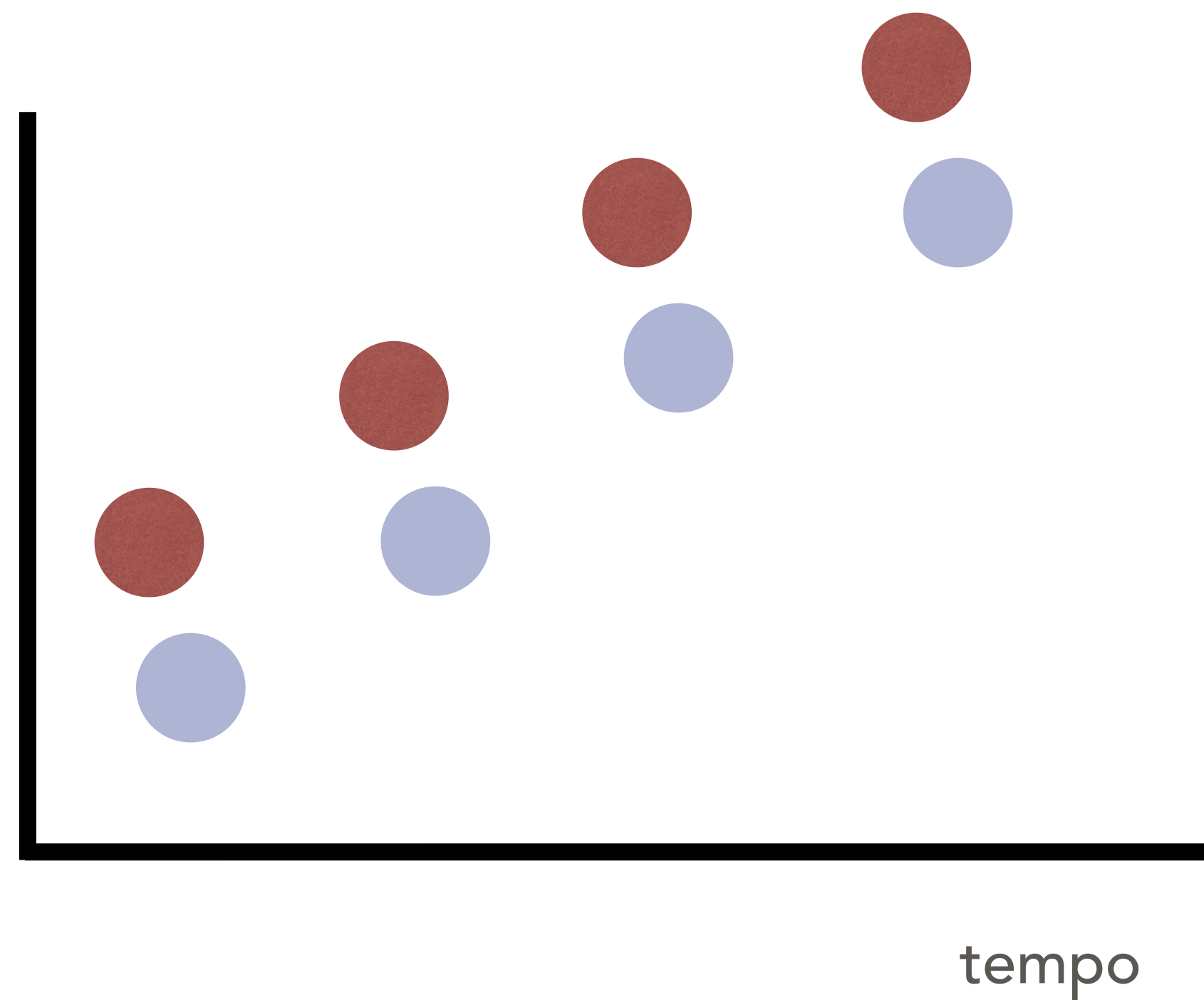
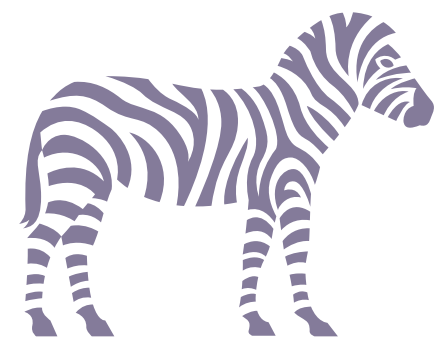
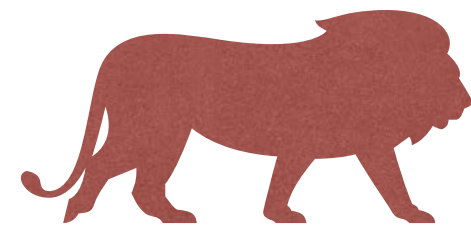
tempo

# Escalonamento



tempo

# Escalonamento



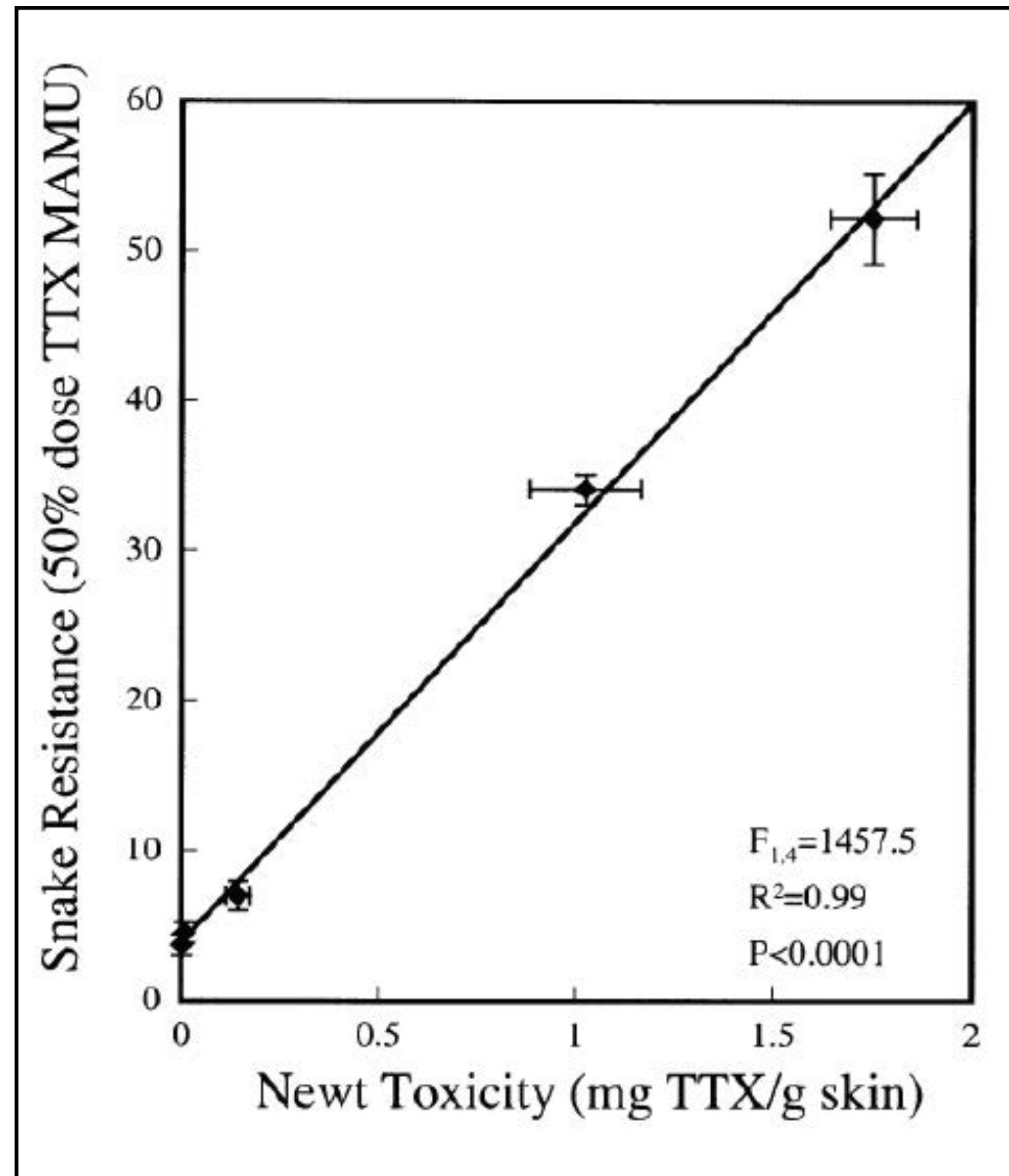
**Corrida  
armamentista**



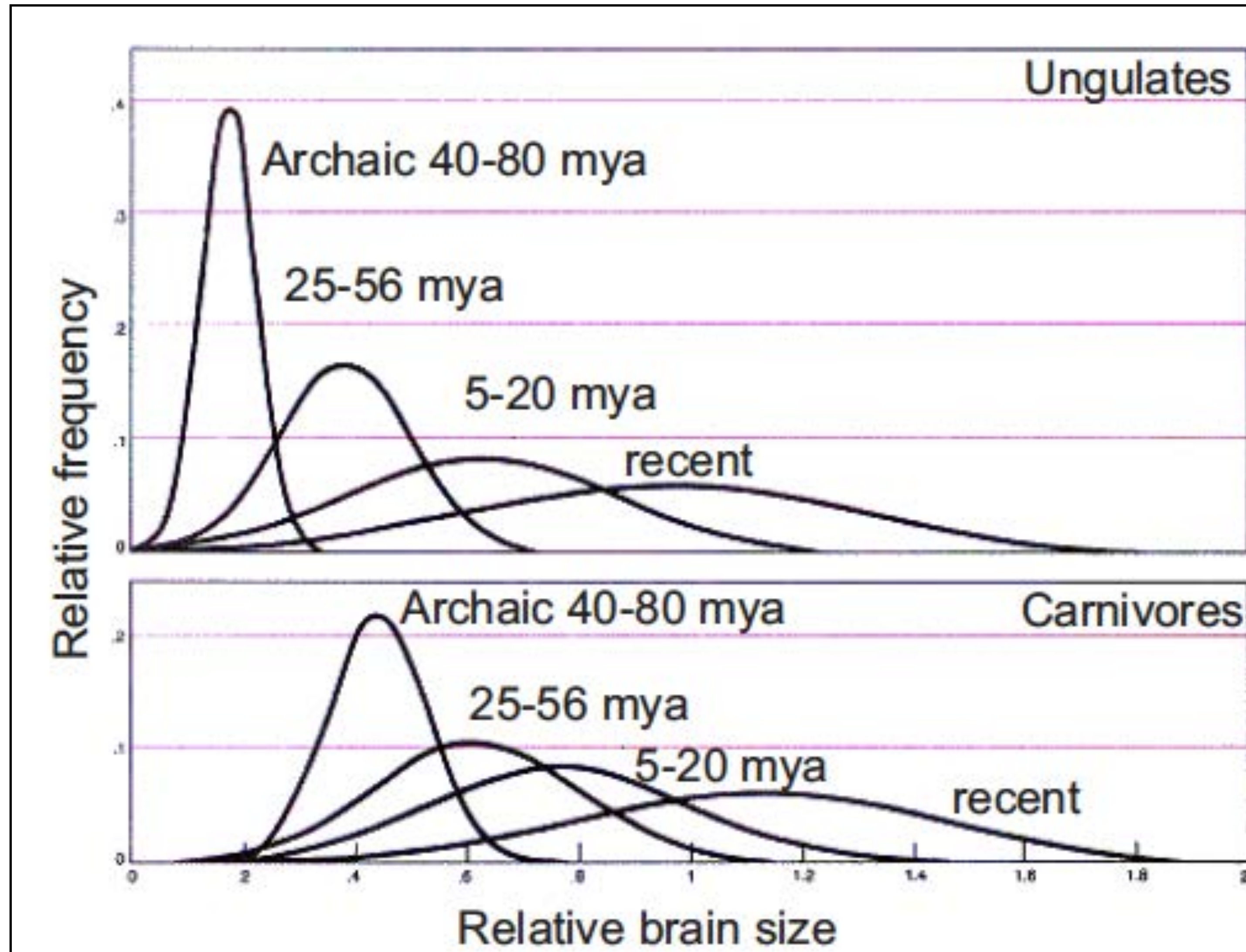




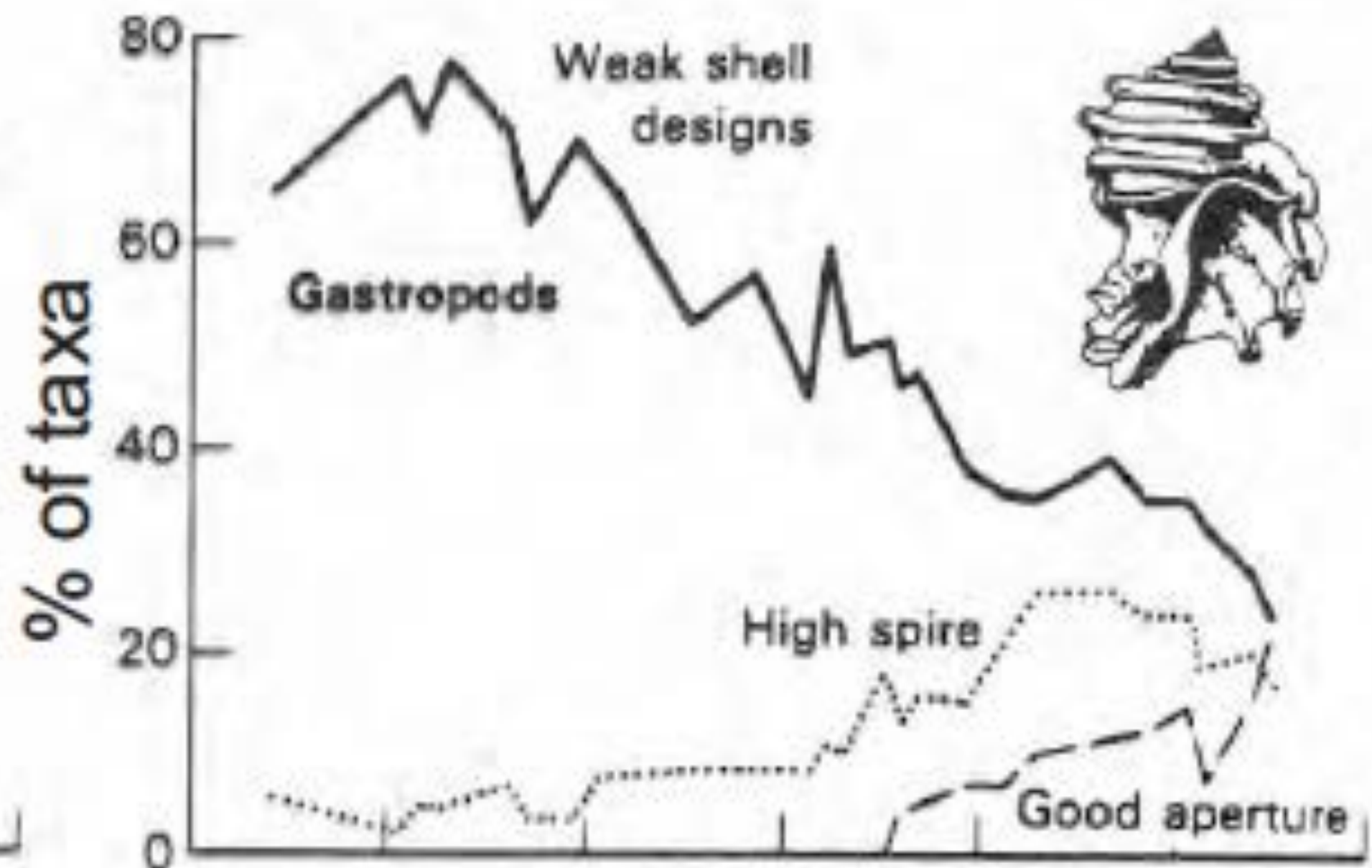
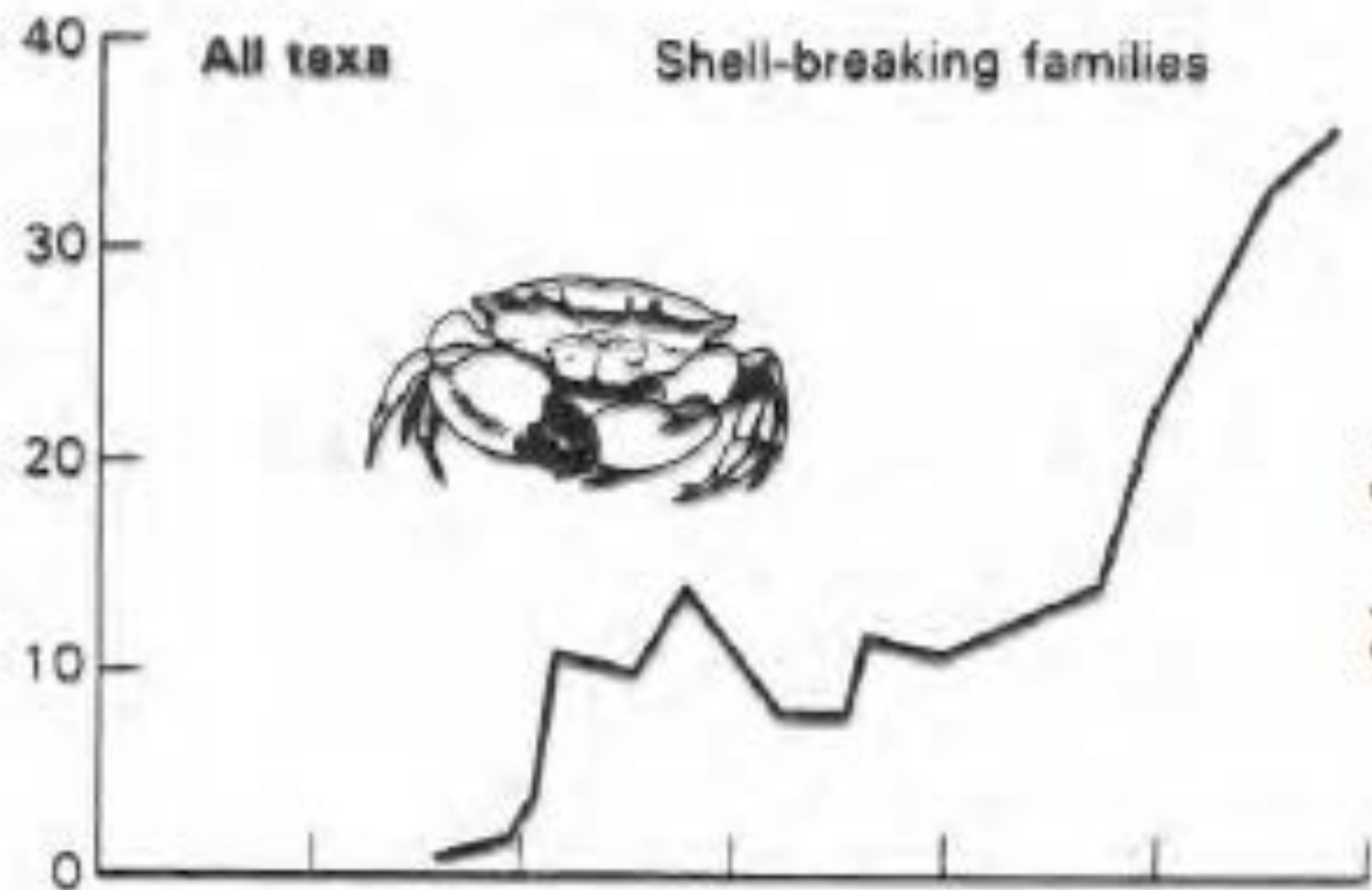
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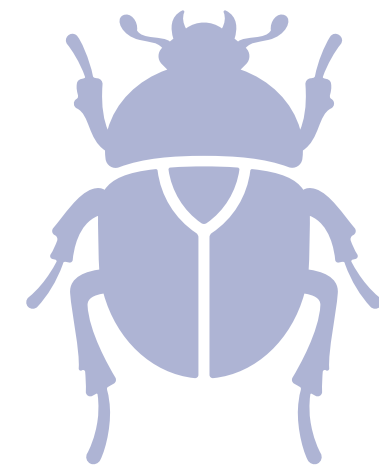
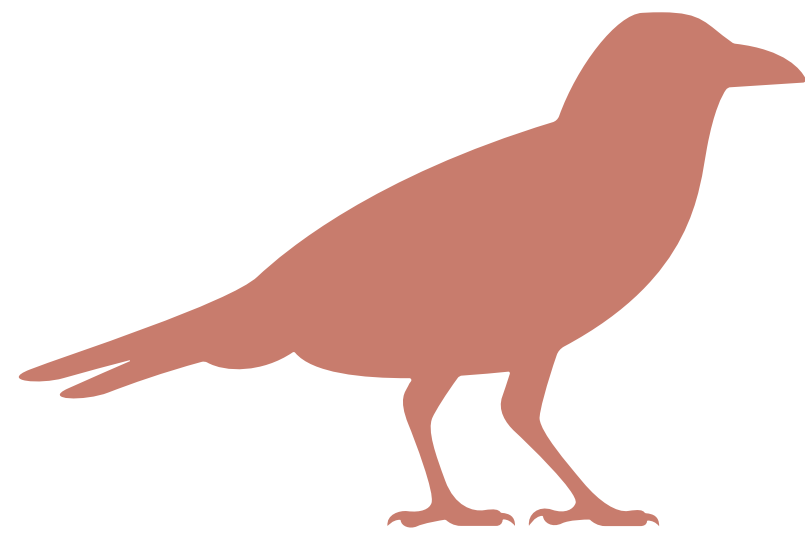




Number of shell-breaking families



# Flutuações

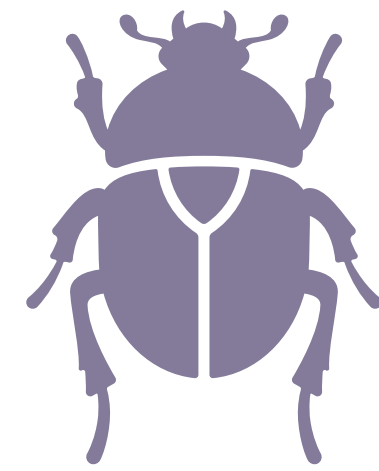
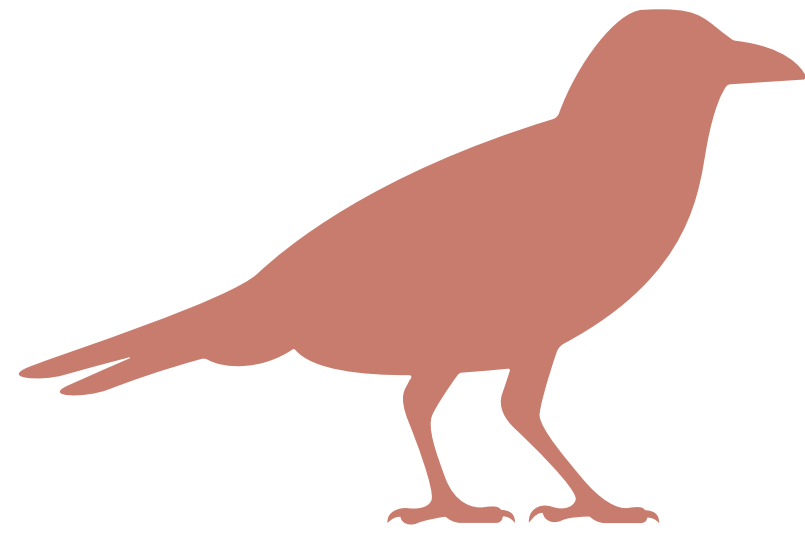


Fitness

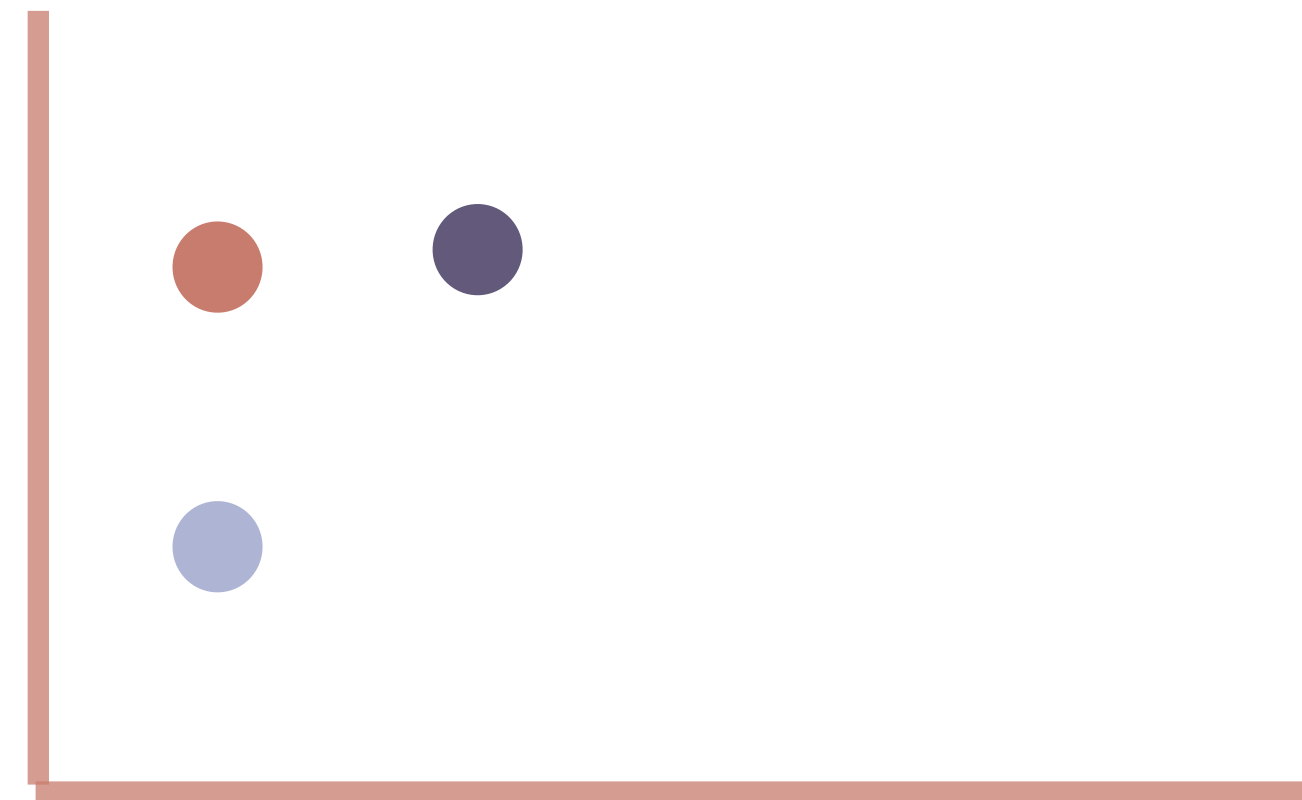


Tempo

# Flutuações



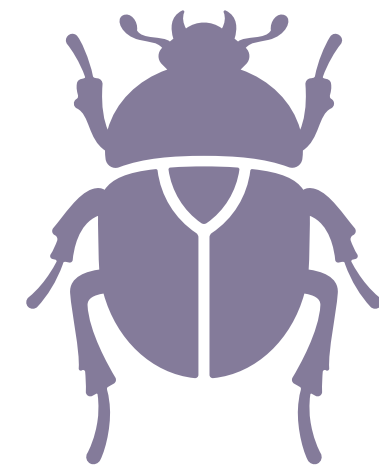
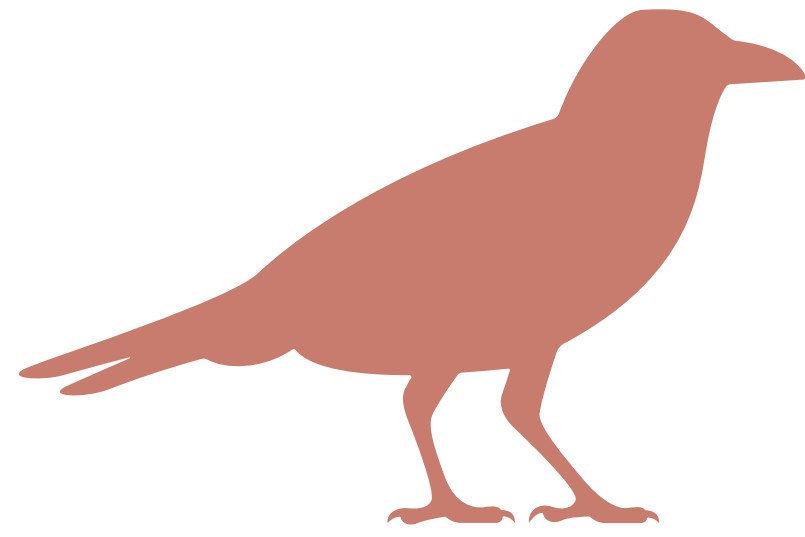
Fitness



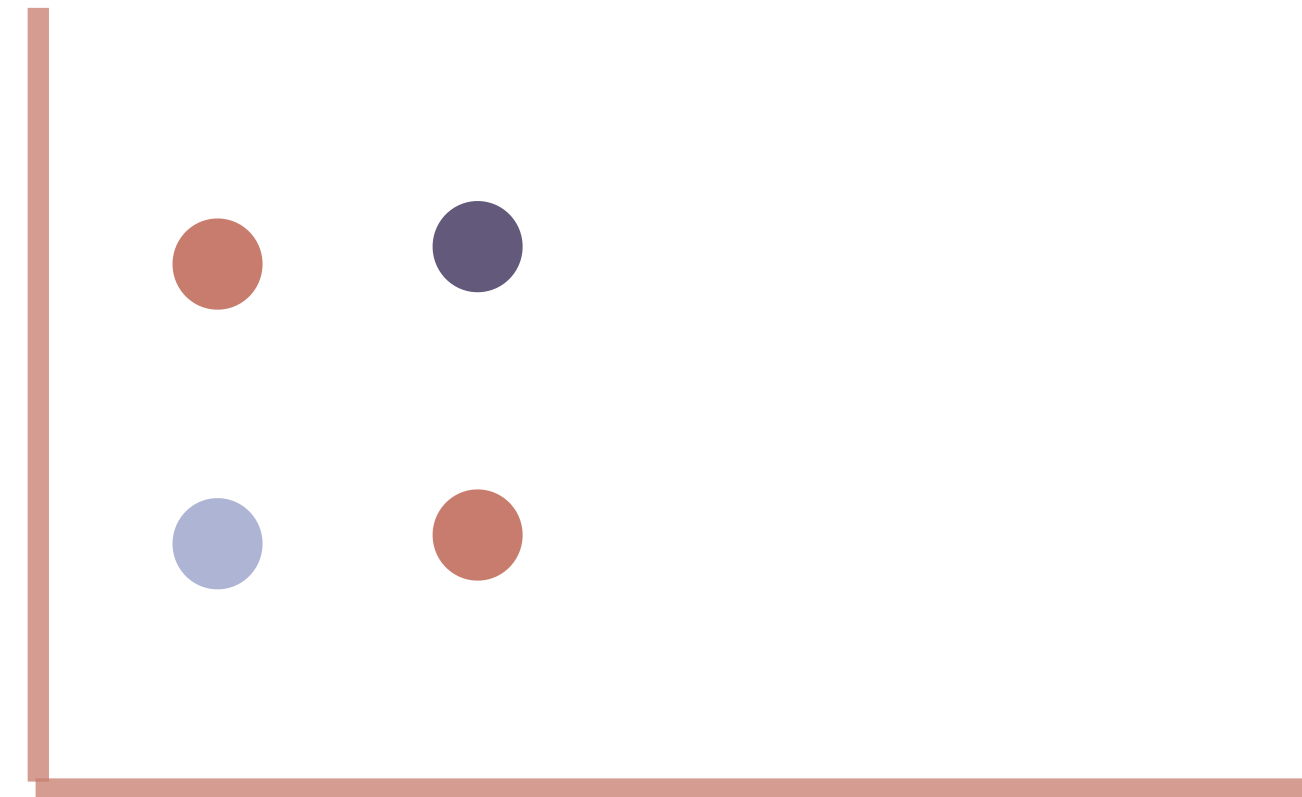
Tempo



# Flutuações

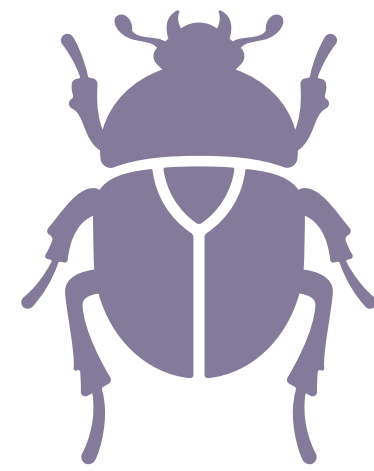
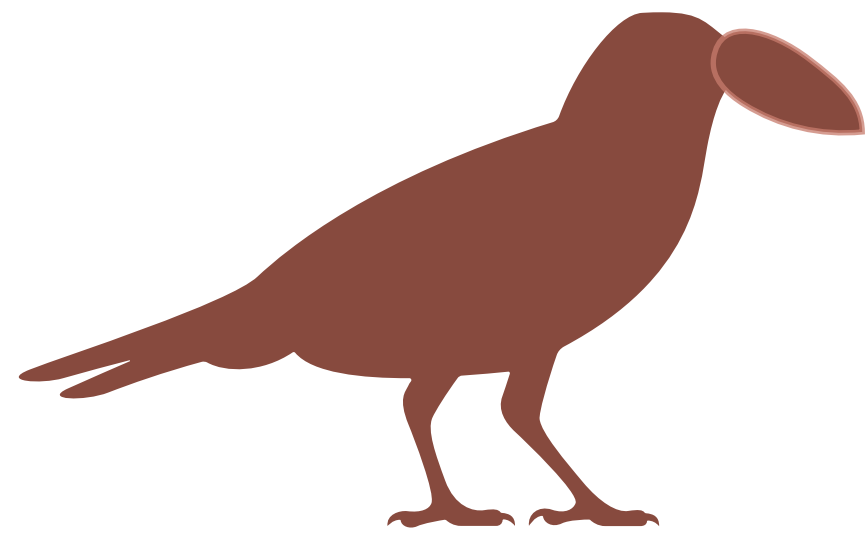


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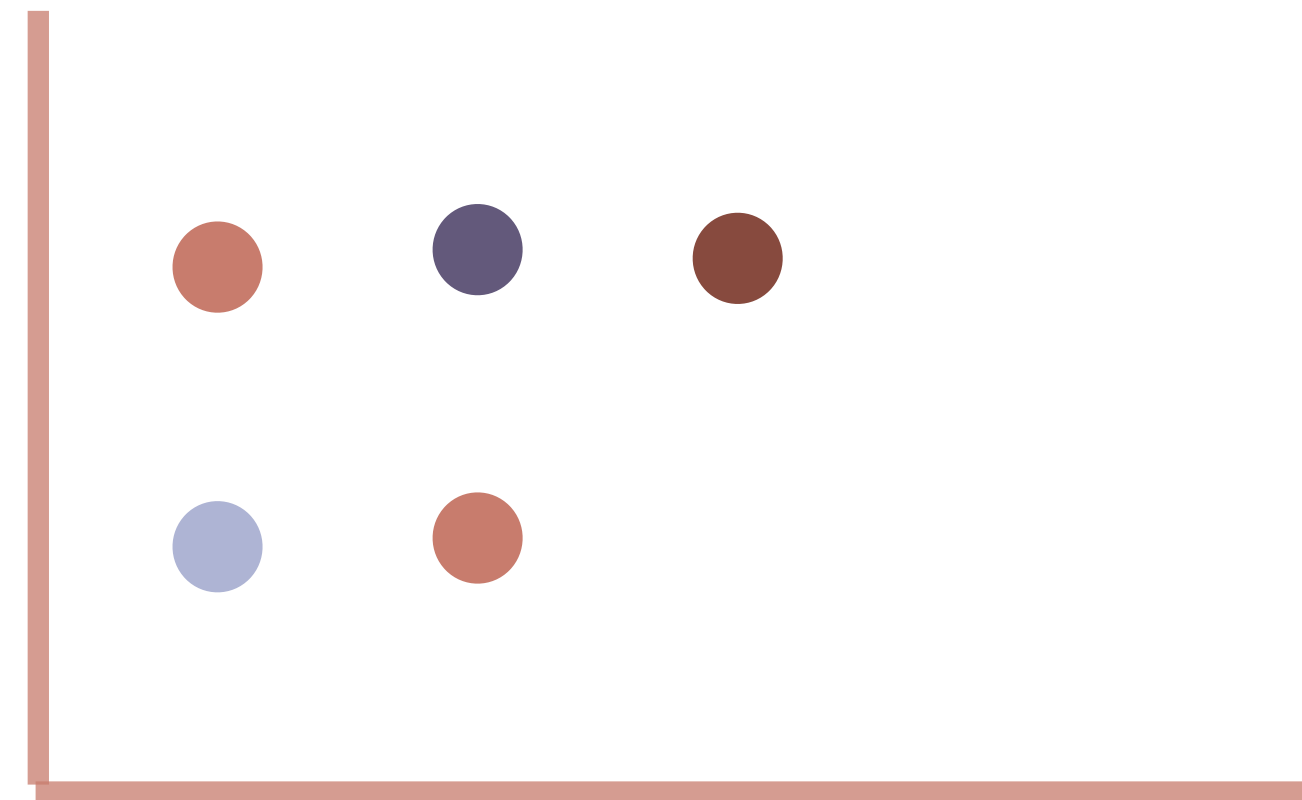


Tempo

# Flutuações

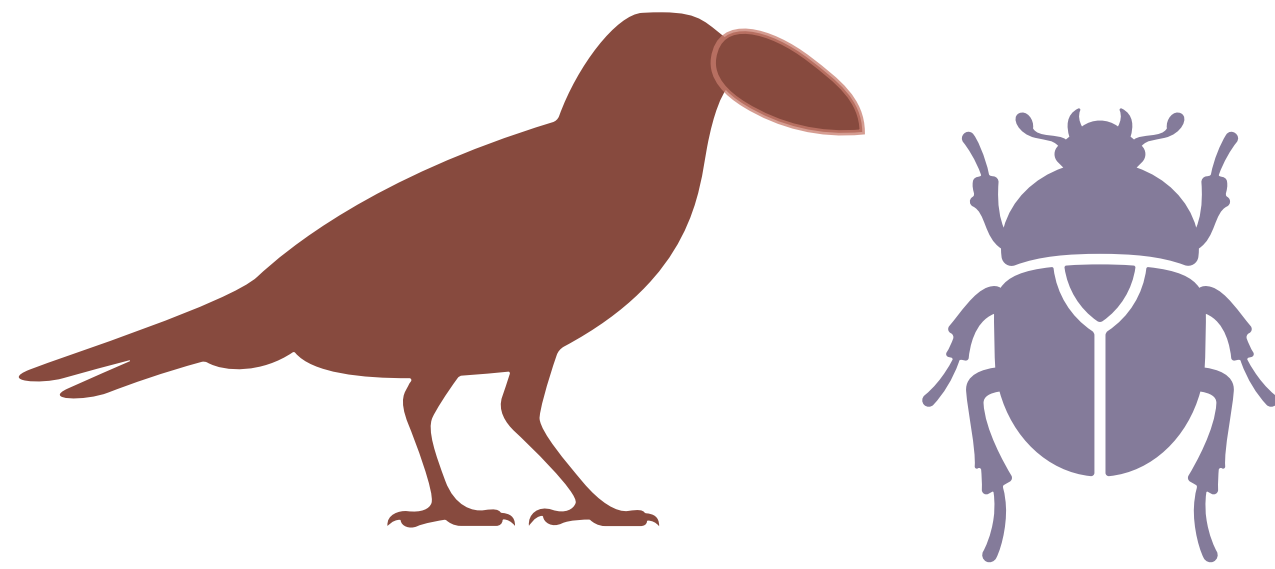


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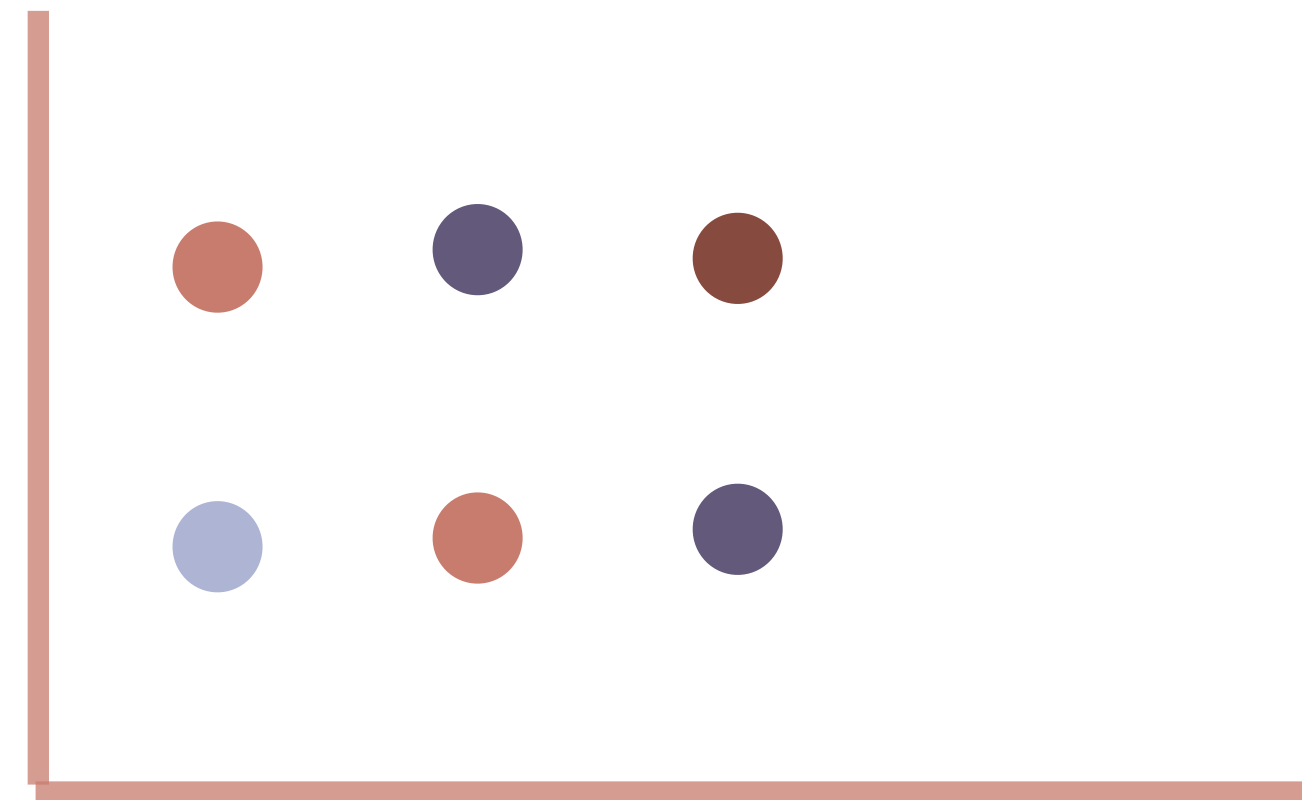


Tempo

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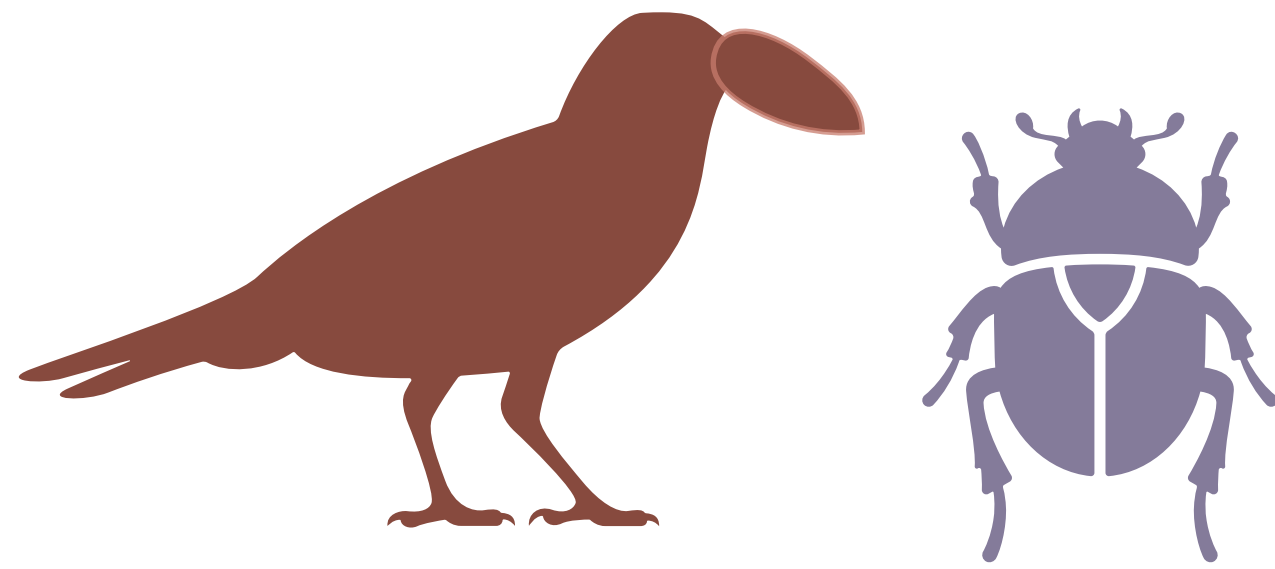


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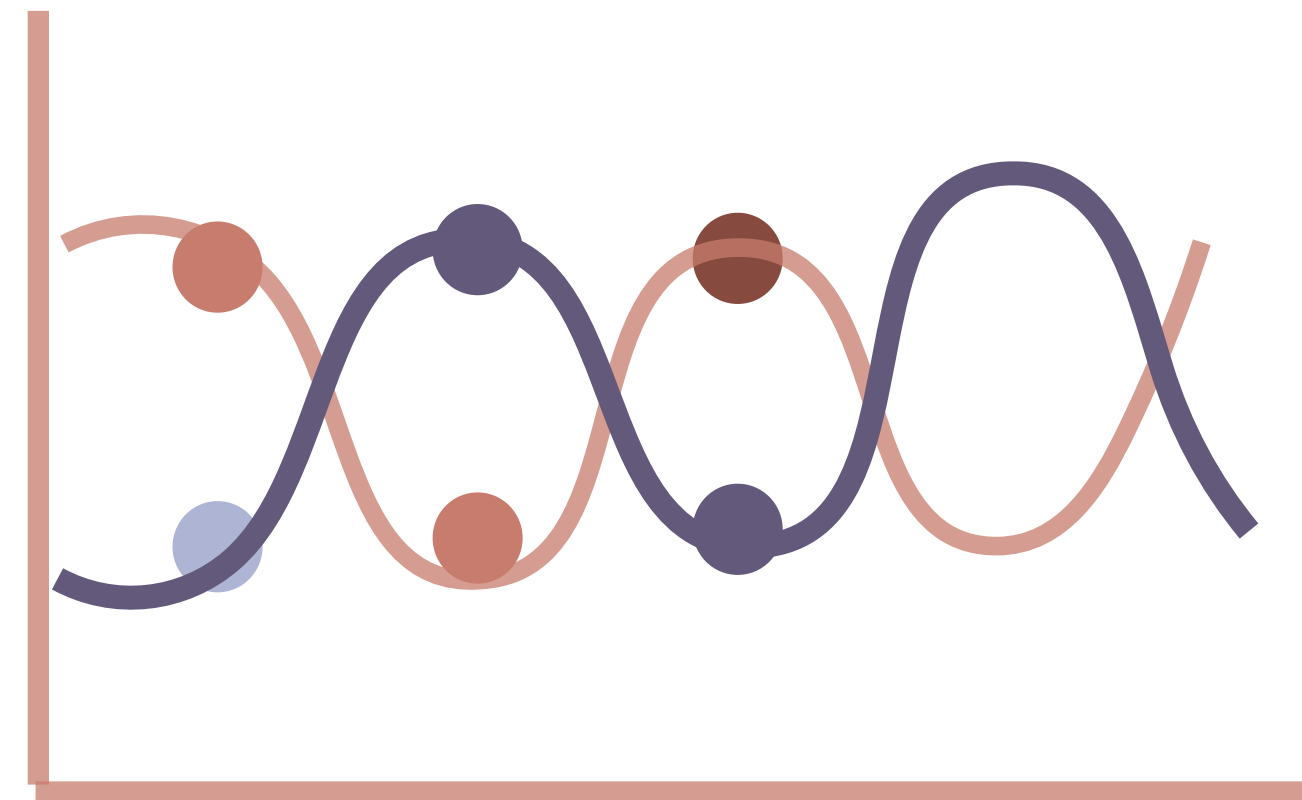


Tempo

# Flutuações

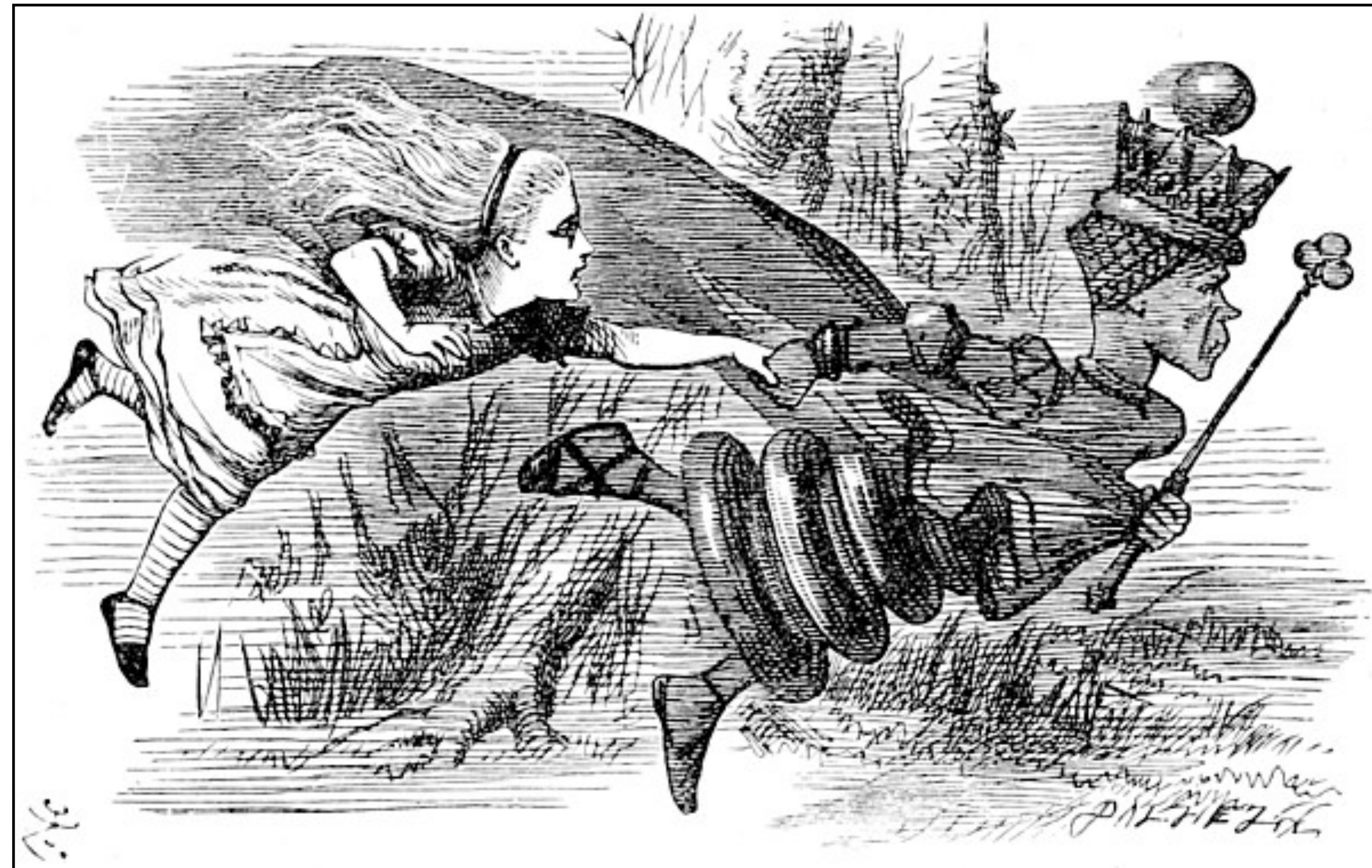


Fitness



Tempo

“Well, in our country,” said Alice, still panting a little, “you'd generally get to somewhere else- if you run very fast for a long time, as we've been doing.”  
“A slow sort of county!” said the Queen. “Now, here, you see, it takes all the running you can do, to keep in the same place.”

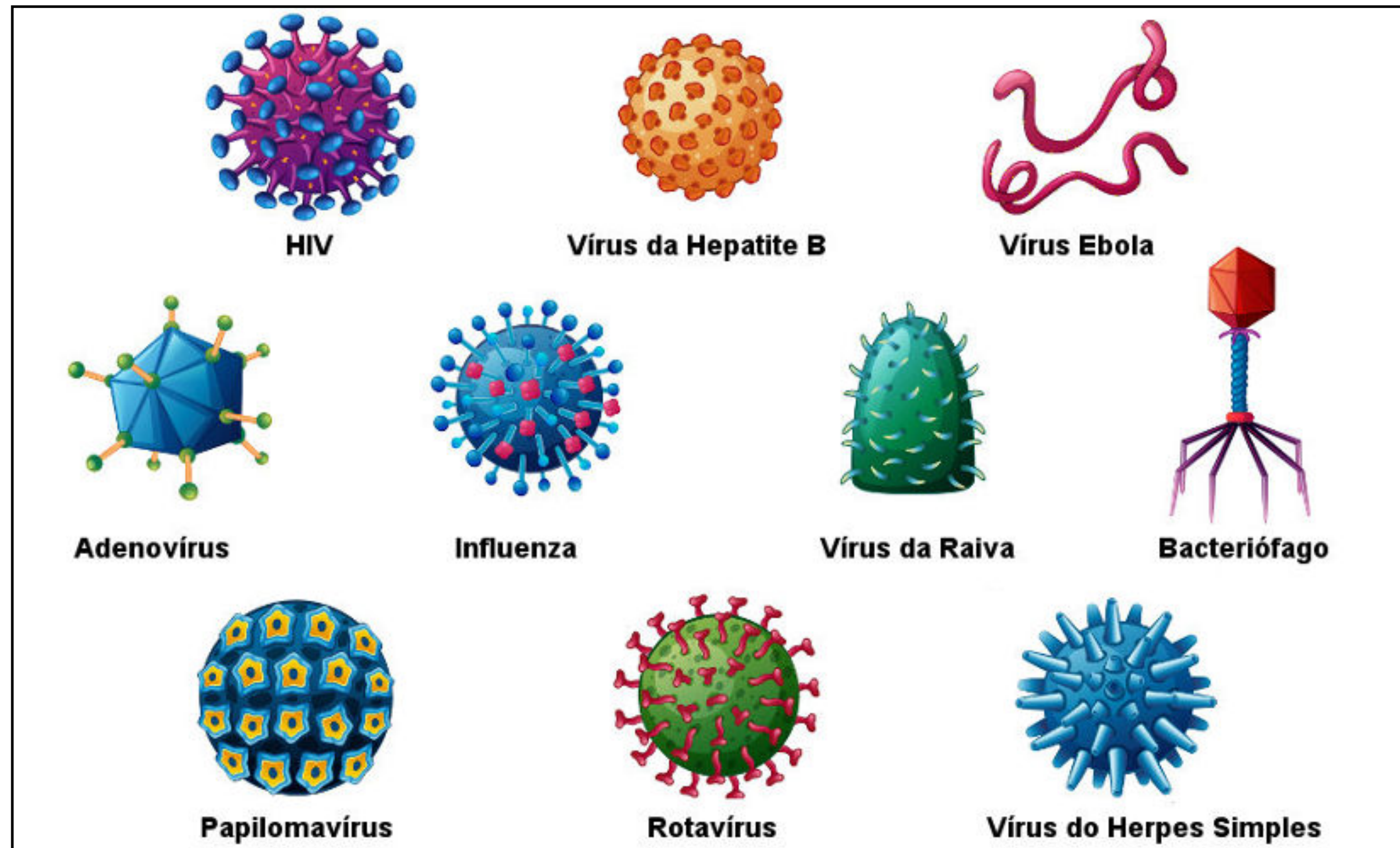


## A hipótese da Rainha Vermelha

Red Queen hypothesis, named in honor of the colorful character in Lewis Carroll's *Through the Looking-Glass* who must run constantly to stay in the same place. According to this hypothesis, all species are in an evolutionary arms race with other species, such as pathogens that are evolving rapidly to defeat their host's defensive systems. This creates a shifting adaptive landscape for the host.



# Interações parasita - hospedeiro



# Interações antagonistas

**Morte**



**Dano**



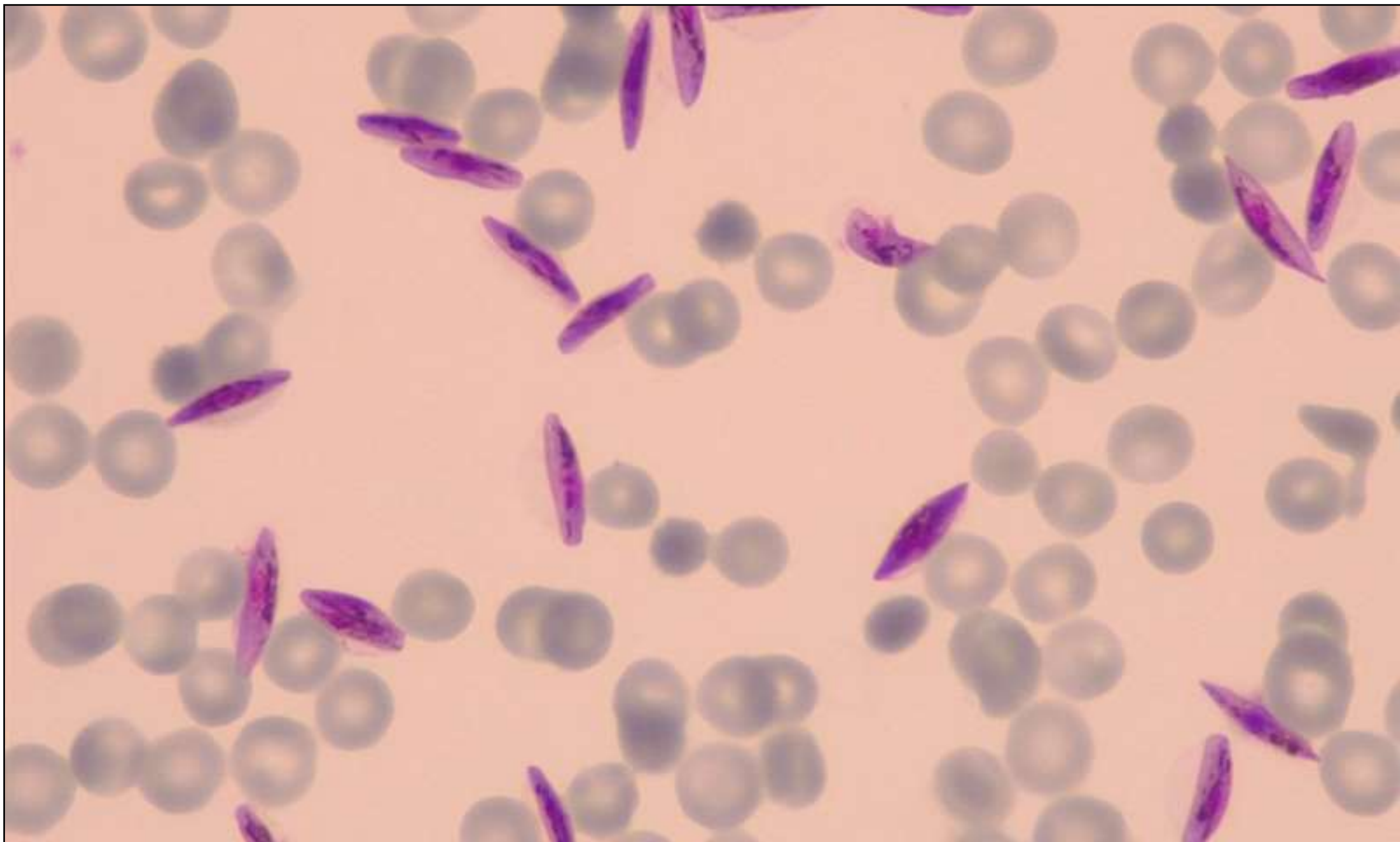
**intimidade**



# Interações parasita - hospedeiro

Parasitas são predadores que comem suas vítimas em unidades de menos de um.

E.O. Wilson











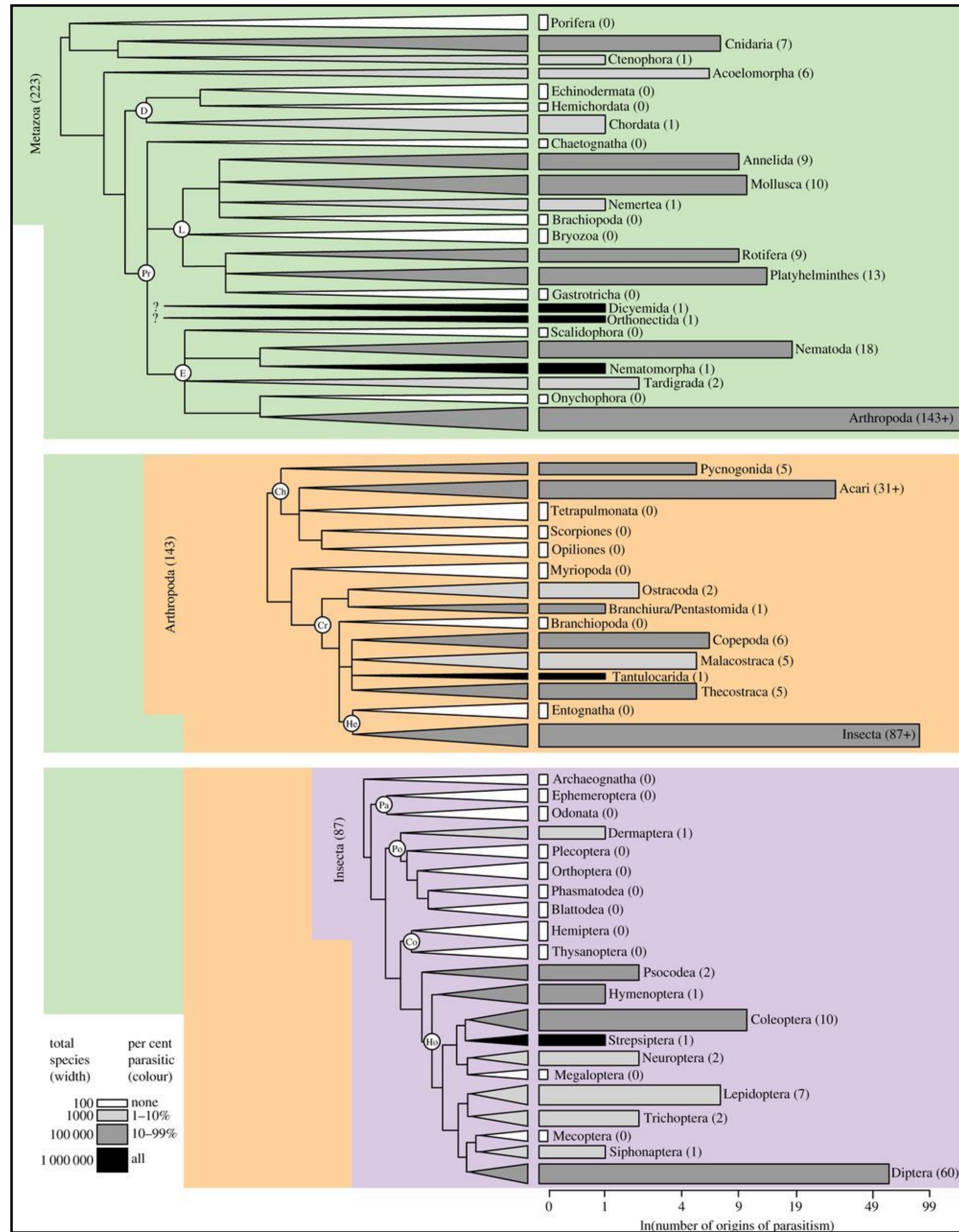
# Interações parasita - hospedeiro

Cerca de \***METADE**\* dos animais  
tem modo de vida parasita!!!

# Interações parasita - hospedeiro

Surgiu pelo menos **223** vezes na história dos animais!





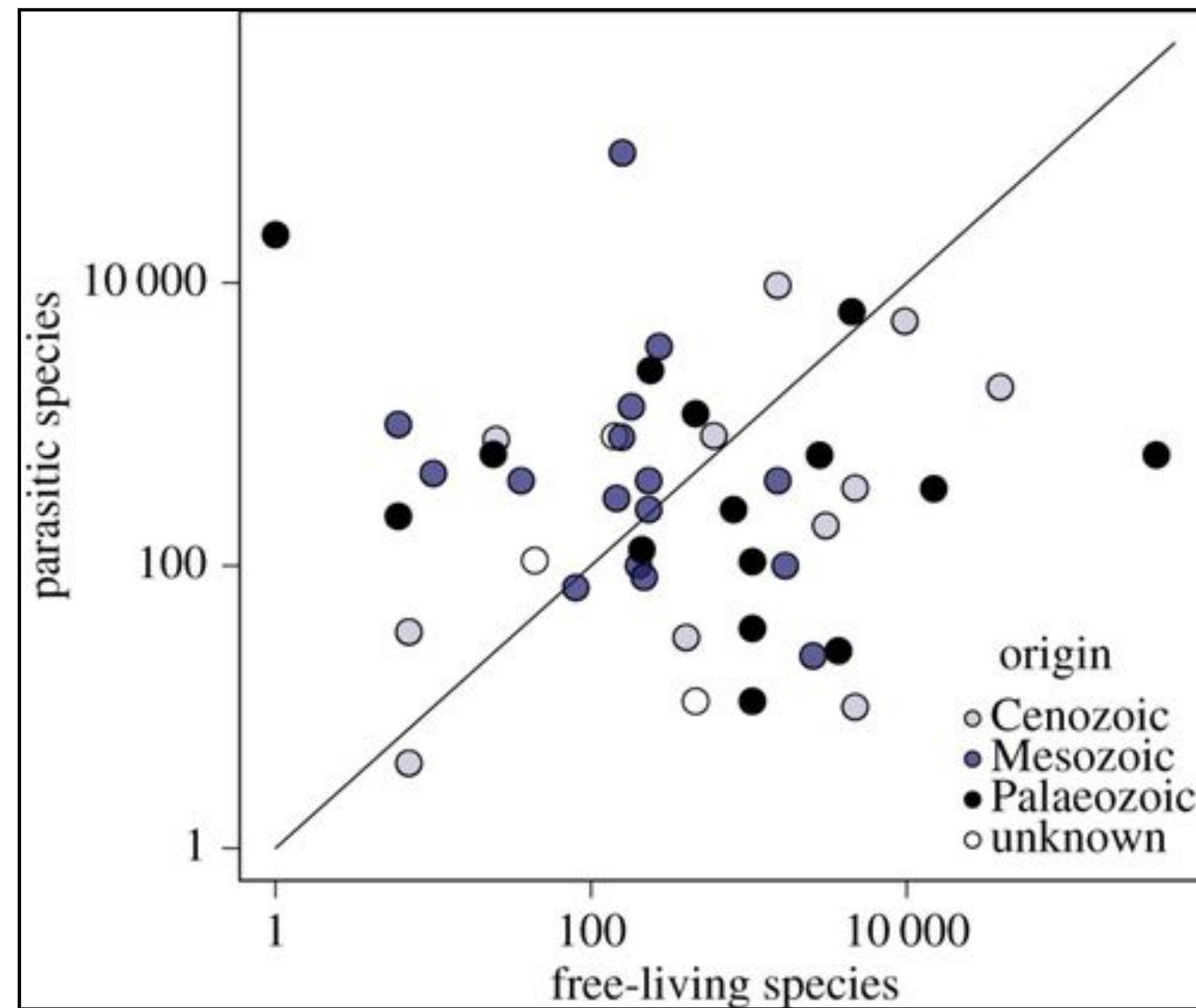
# Interações parasita - hospedeiro

Once you go **parasite** you never  
go back!

# Interações parasita - hospedeiro

Or **Beco evolutivo?** ever  
go back.

# Interações parasita - hospedeiro

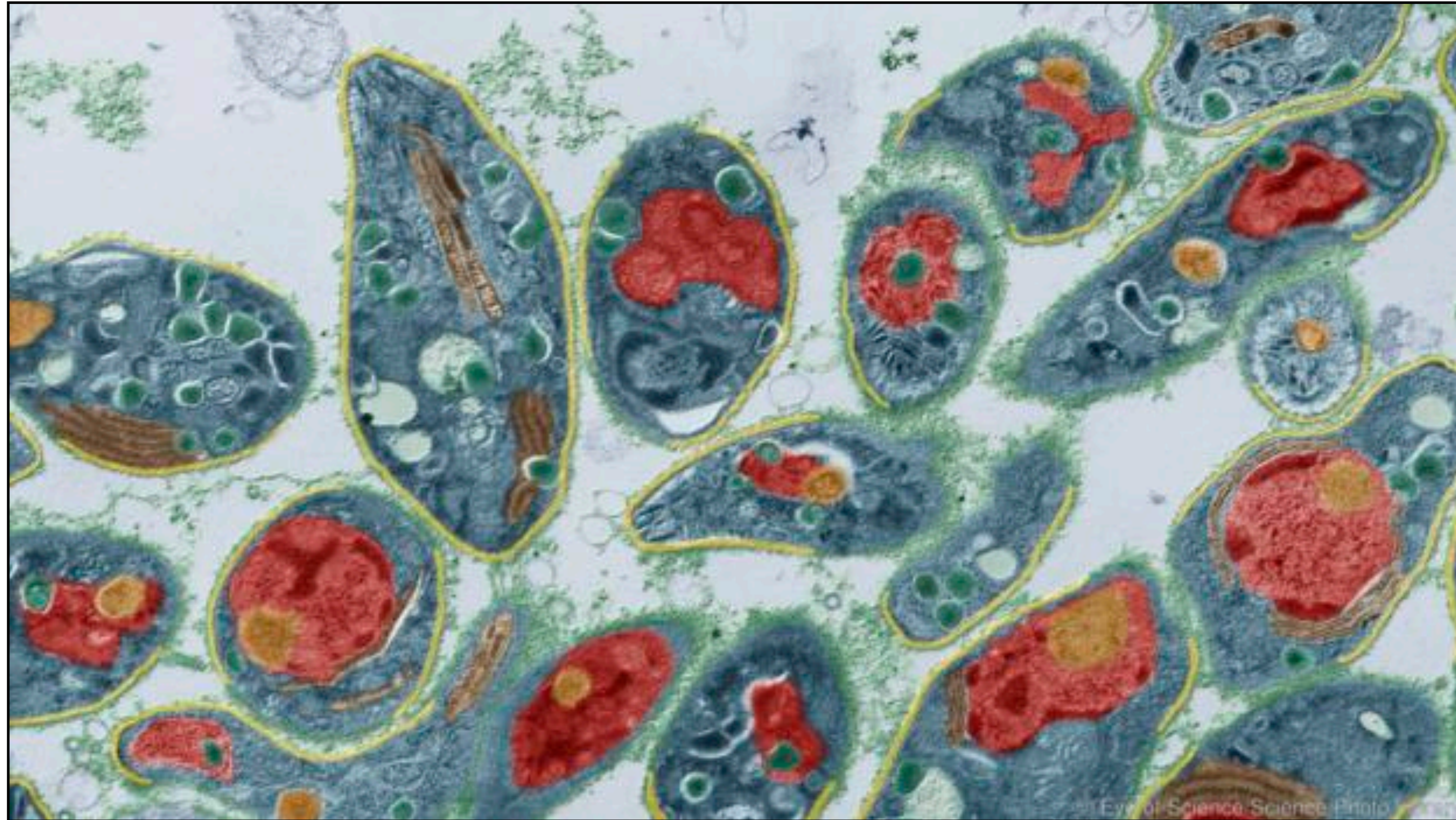


# Interações parasita - hospedeiro

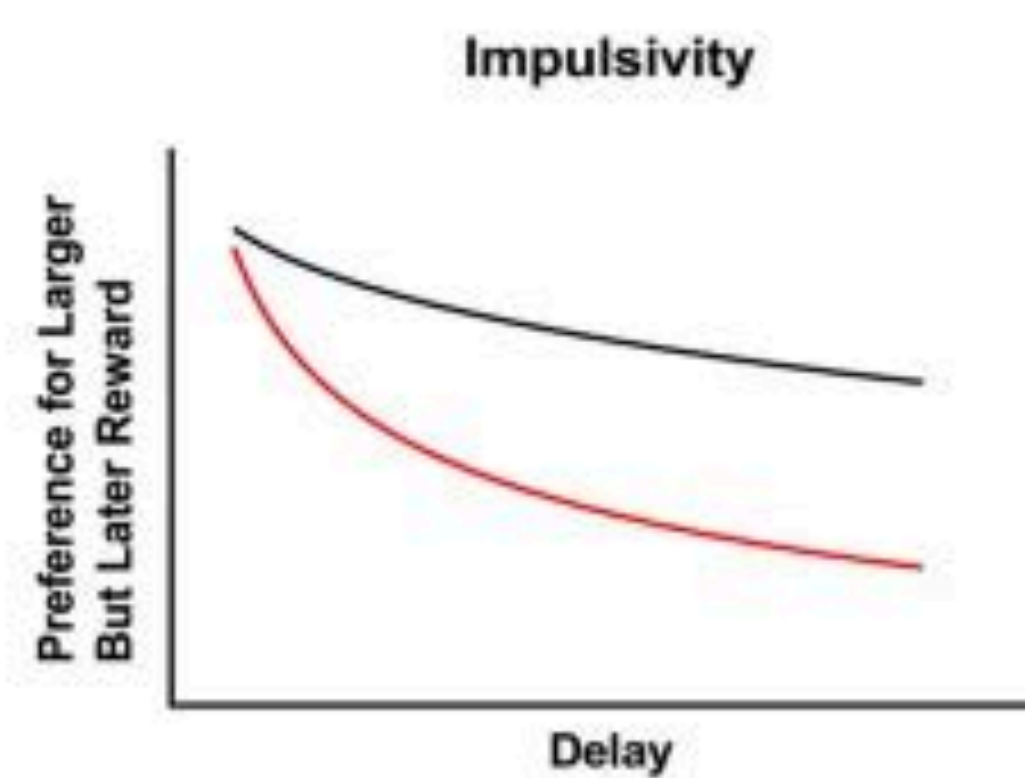
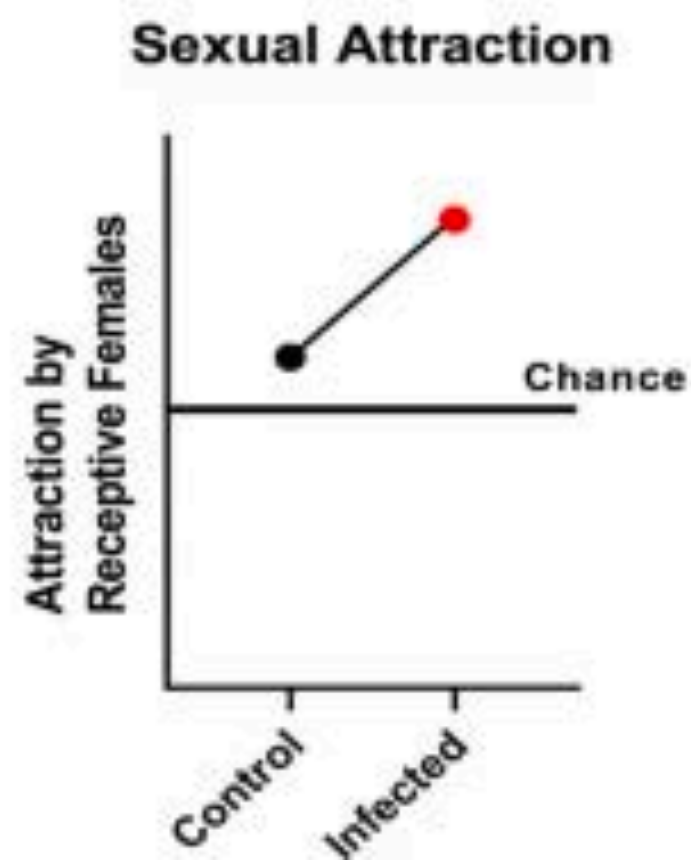
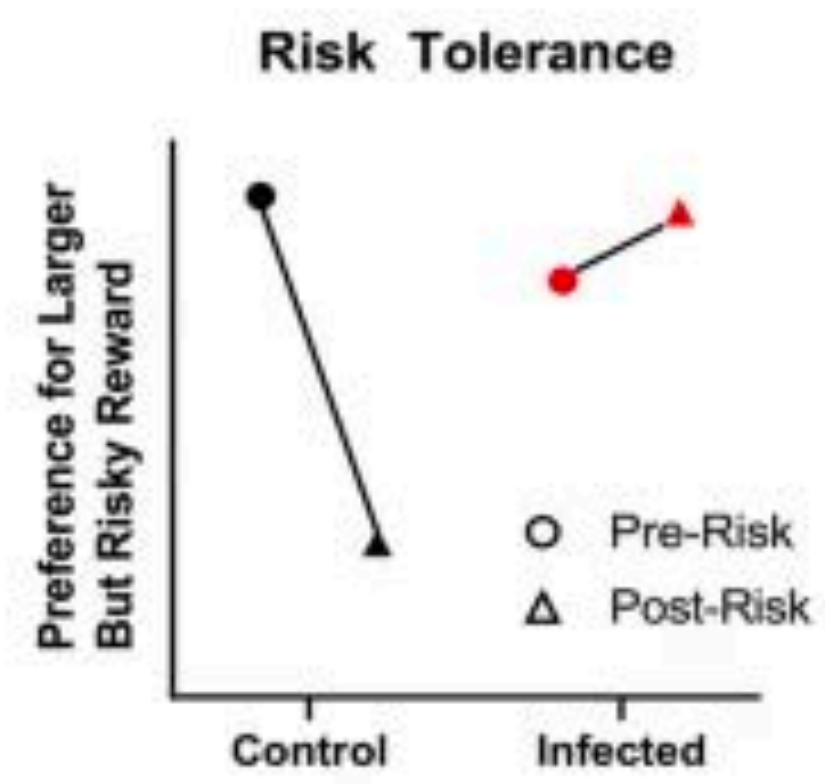
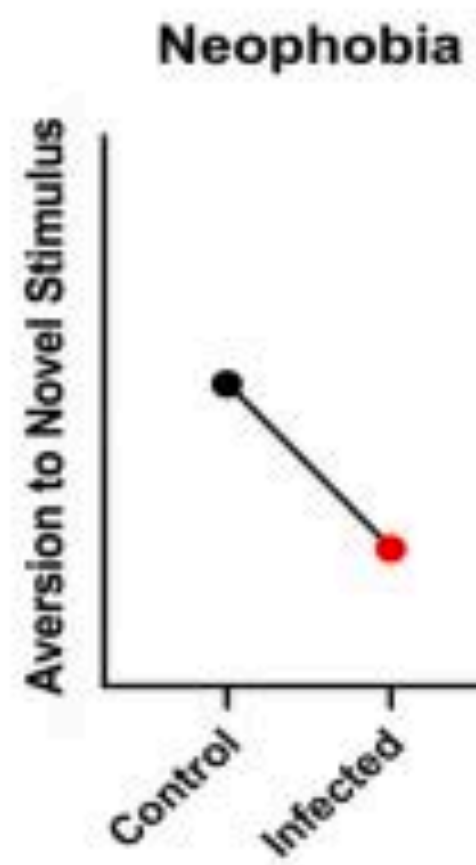
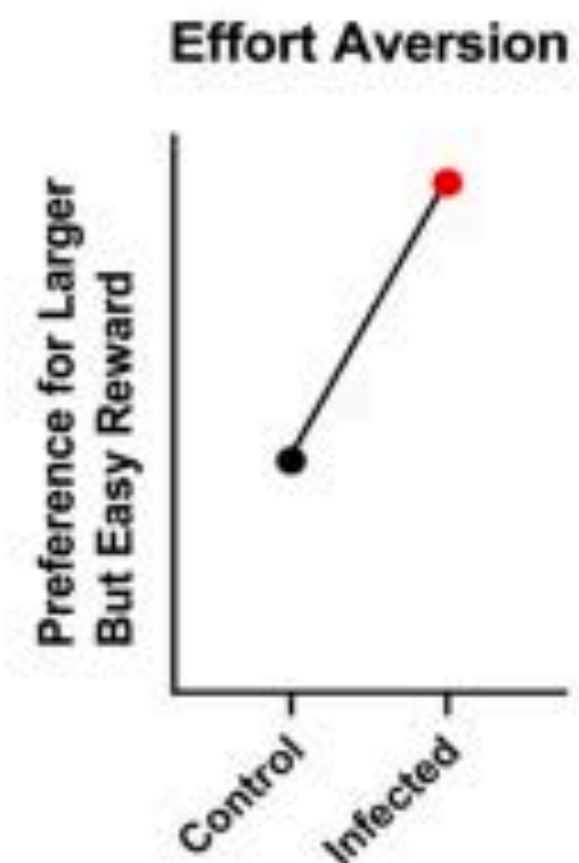
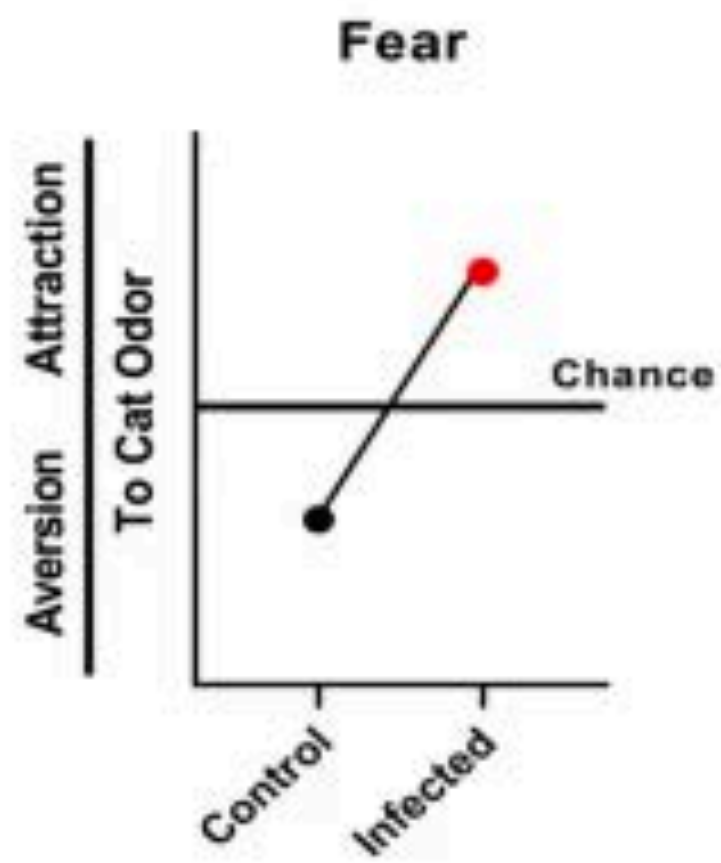
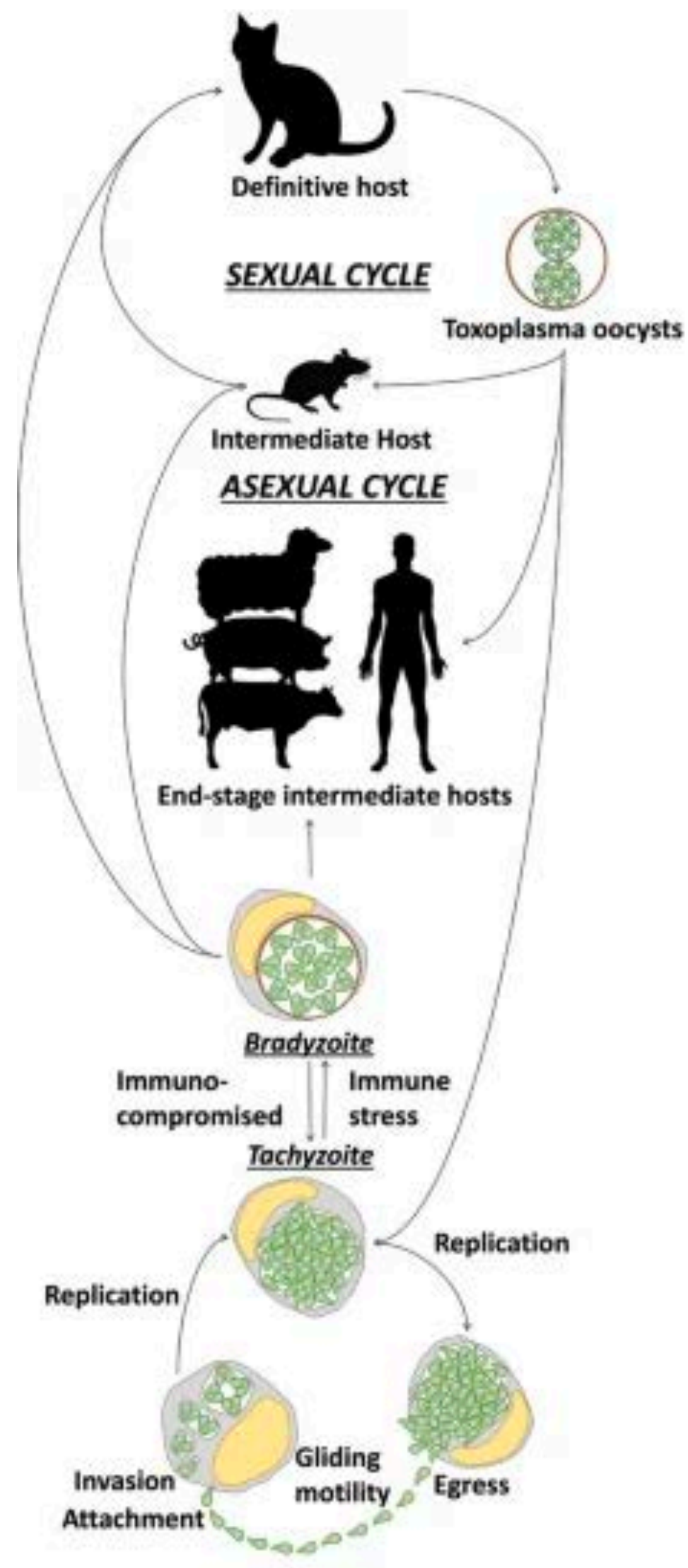


*Paragordius tricuspidatus*

# Interações parasita - hospedeiro



*Toxoplasma gondii*



# communications biology

ARTICLE

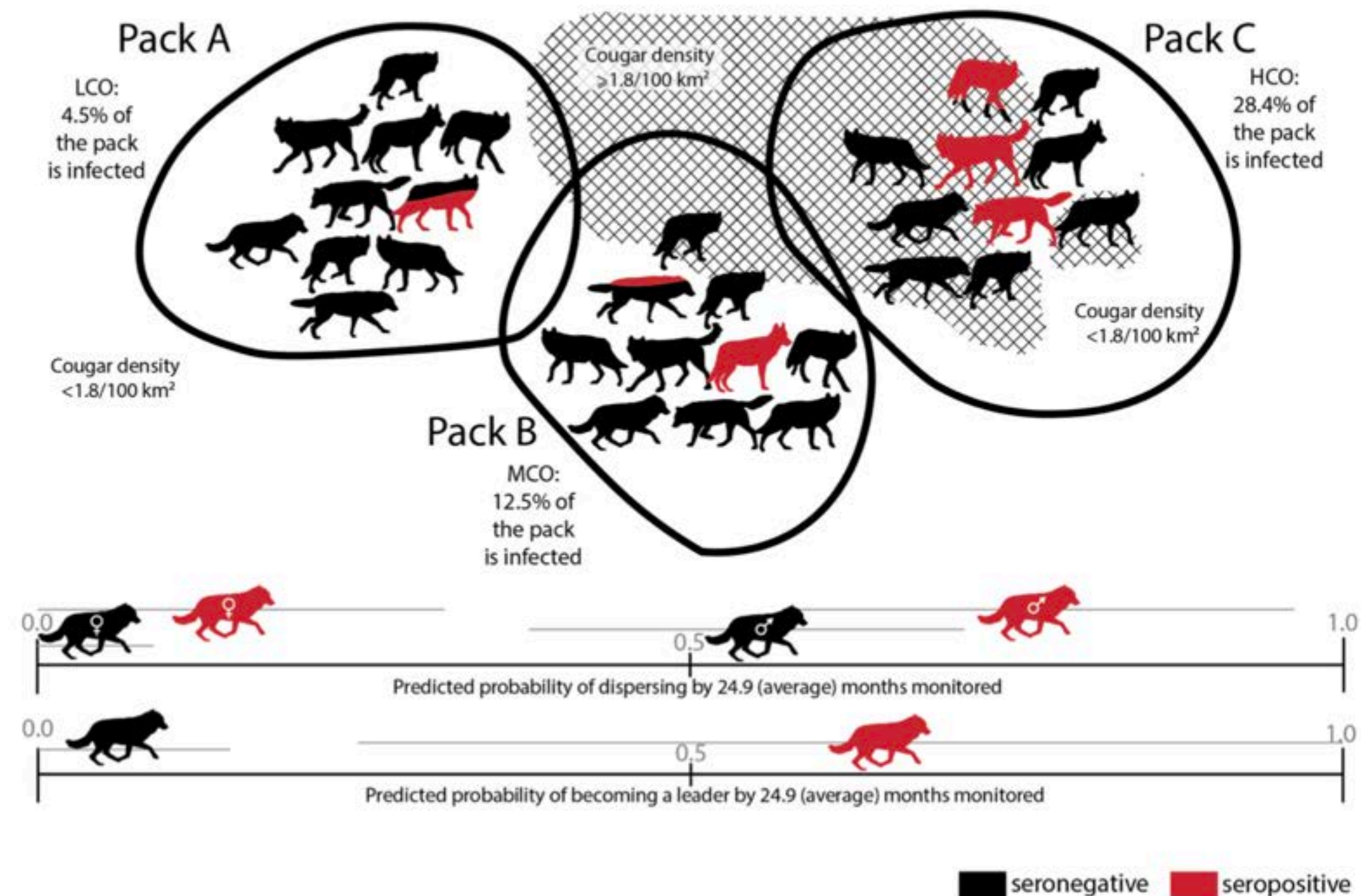
<https://doi.org/10.1038/s42003-022-04122-0>

OPEN



## Parasitic infection increases risk-taking in a social, intermediate host carnivore

Connor J. Meyer<sup>1,2,3</sup>✉, Kira A. Cassidy<sup>1,3</sup>, Erin E. Stahler<sup>1</sup>, Ellen E. Brandell<sup>1</sup>, Colby B. Anton<sup>1</sup>, Daniel R. Stahler<sup>1</sup> & Douglas W. Smith<sup>1</sup>





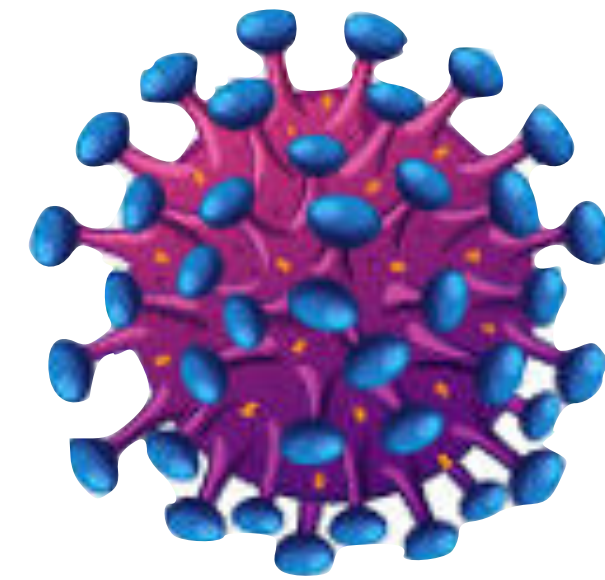
# Interações parasita - hospedeiro

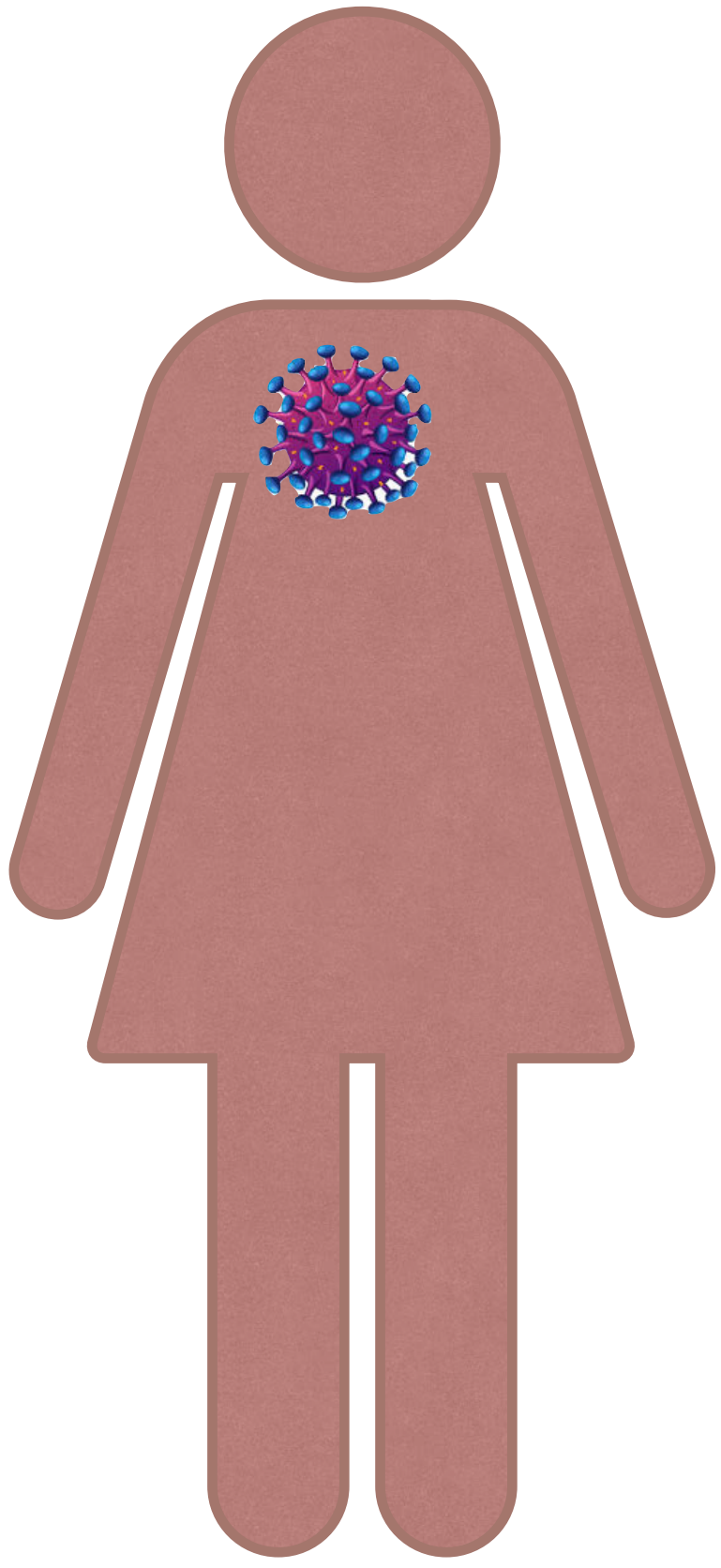


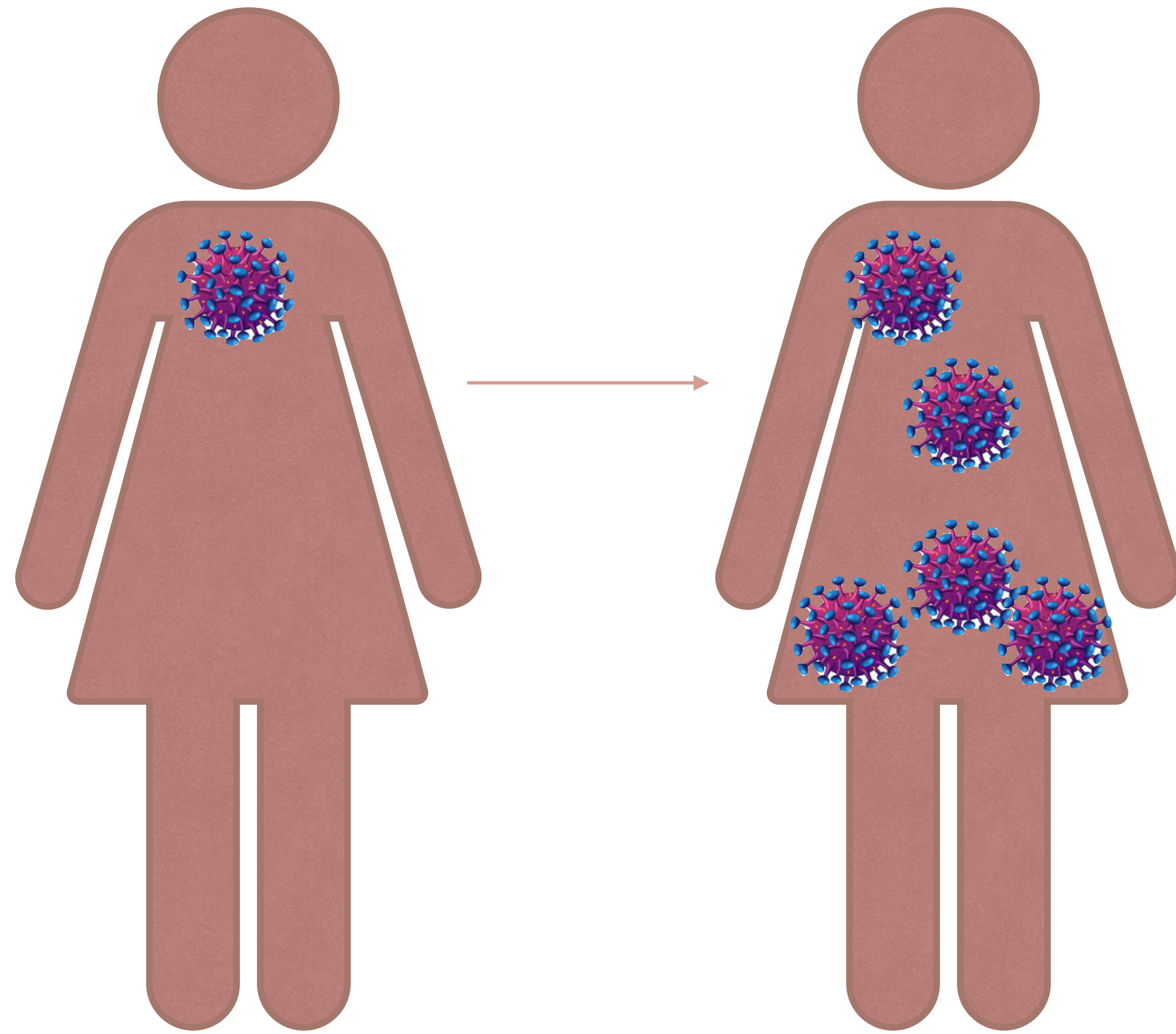
*Hyposoter ebeninus*

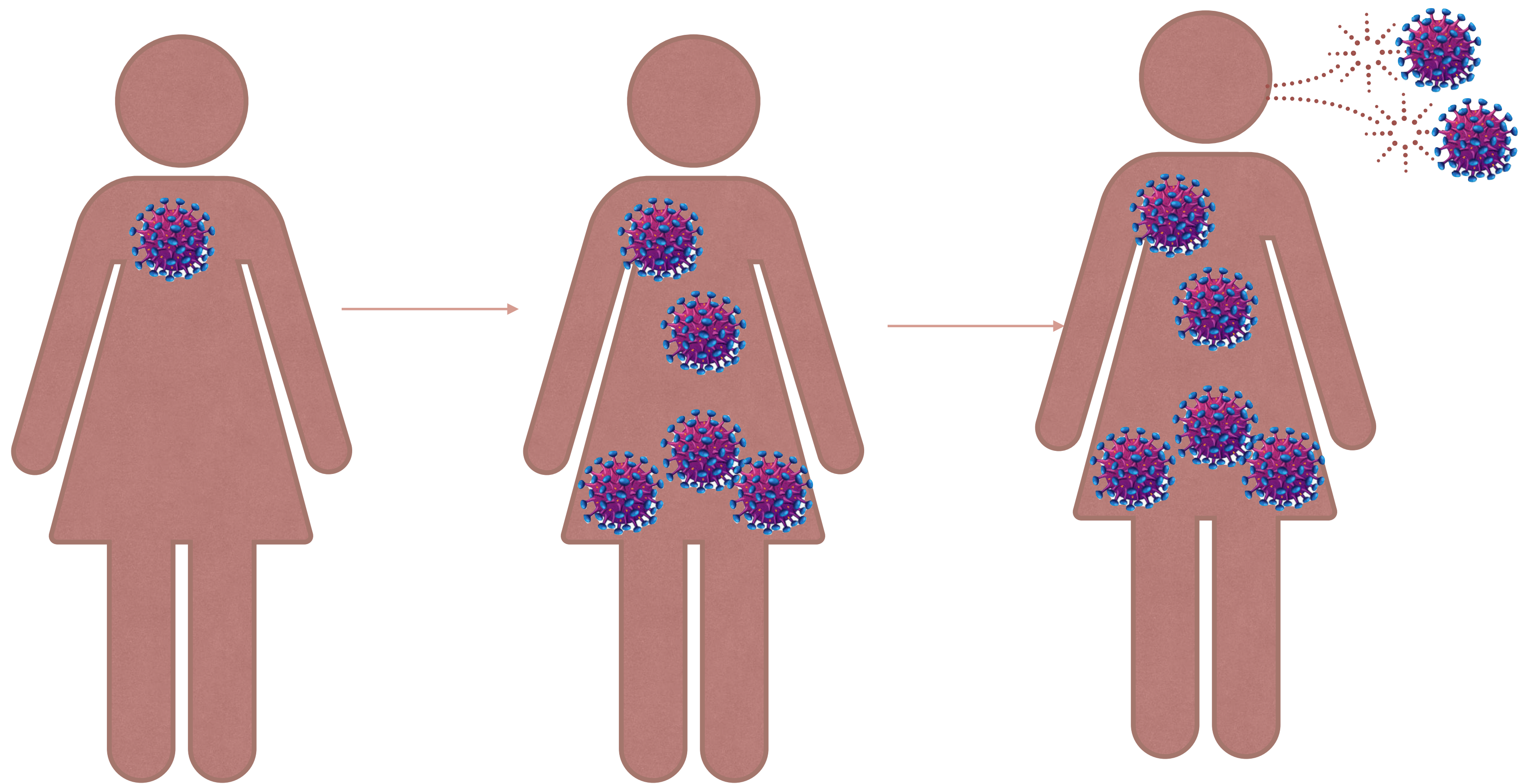
# Evolução da virulência

**Virulência**



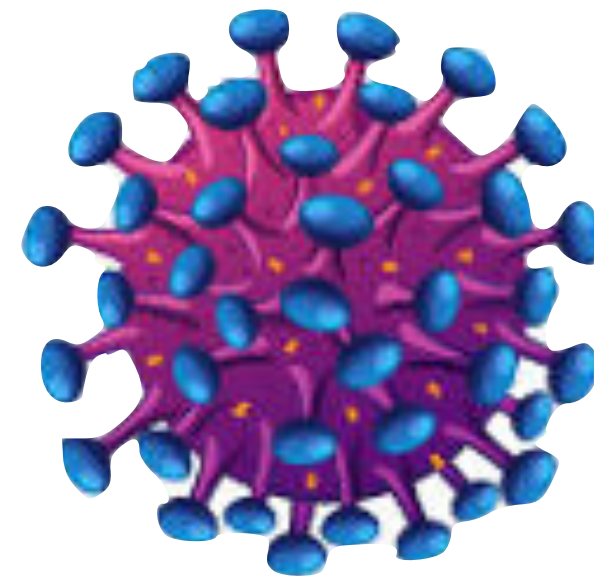






# Evolução da virulência

## Virulência



Diminuição do fitness do hospedeiro causado por uma infecção

## **Evolução da virulência**

**Por que alguns parasitas prejudicam  
seus hospedeiros????**

## **Evolução da virulência**

**Por que alguns parasitas prejudicam  
seus hospedeiros????**

**O que pode acabar prejudicando o  
próprio parasita**



# Evolução da virulência

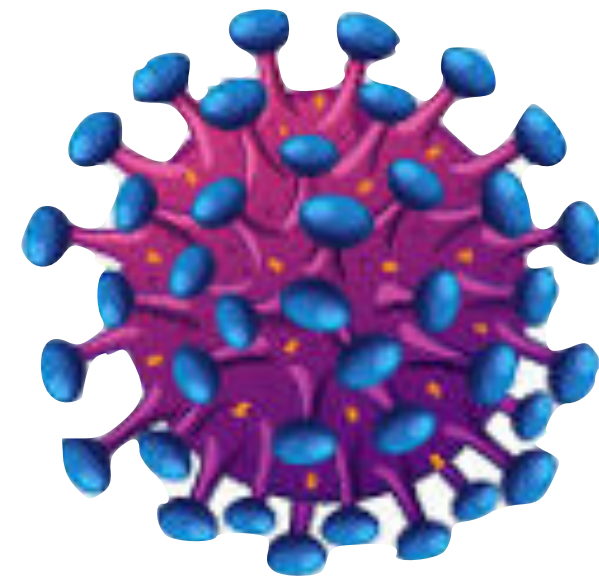
Virulência



Tempo

# Evolução da virulência

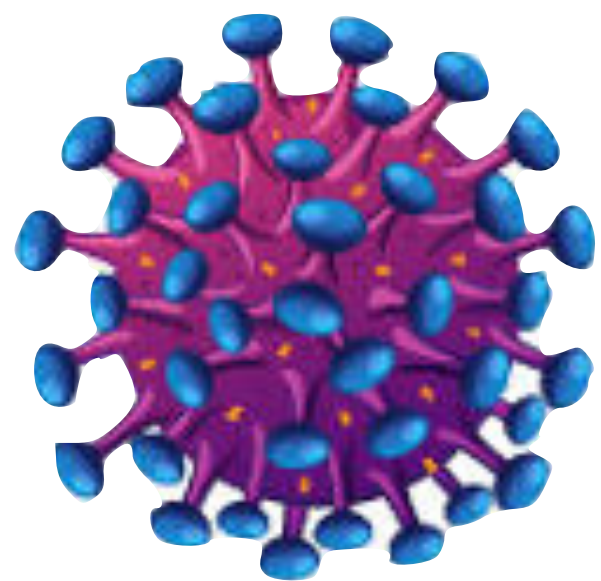
## Virulência



Diminuição do fitness do  
hospedeiro causado por uma  
infecção

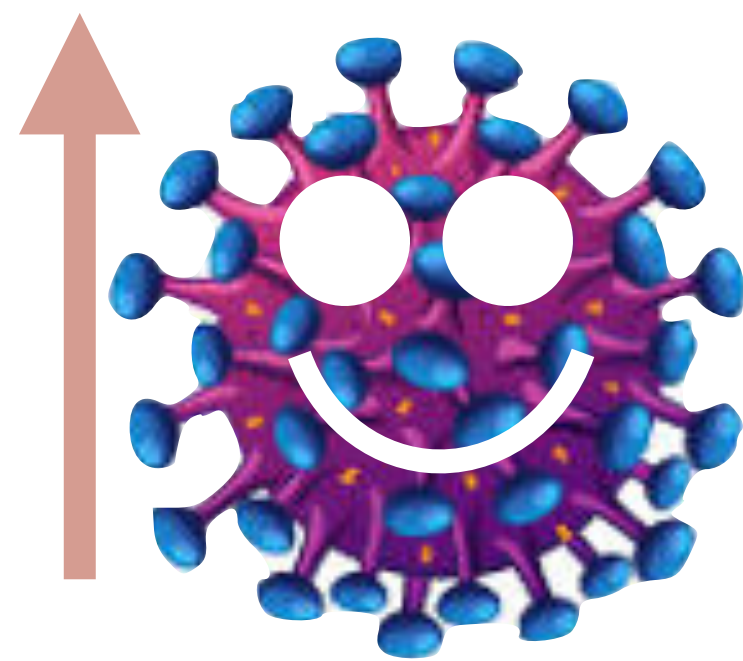
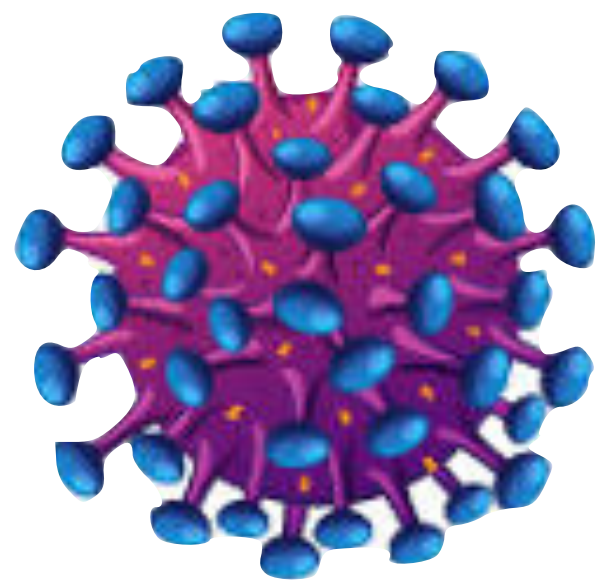
# Evolução da virulência

Virulência



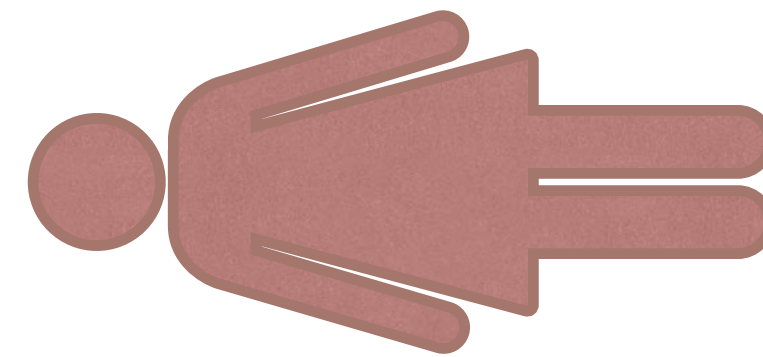
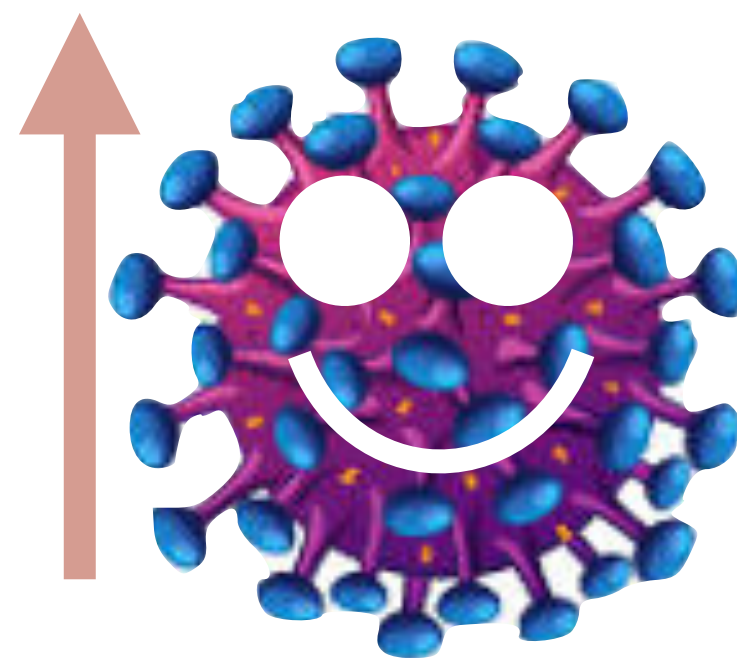
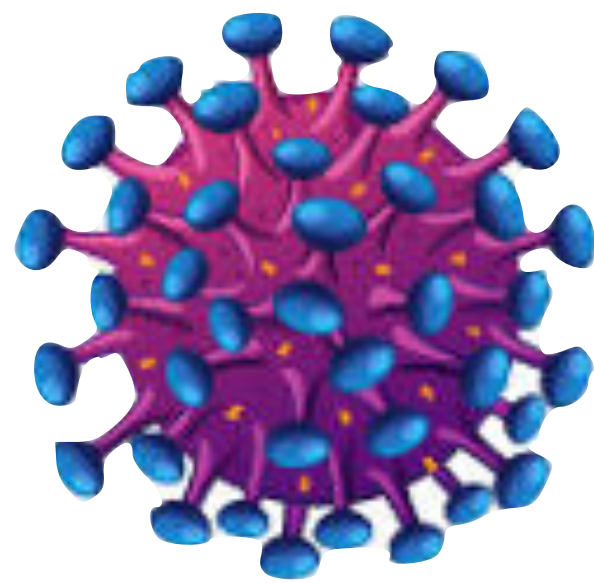
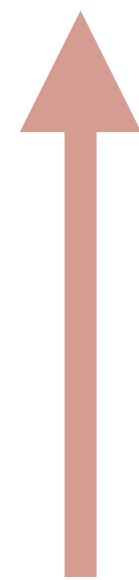
# Evolução da virulência

Virulência



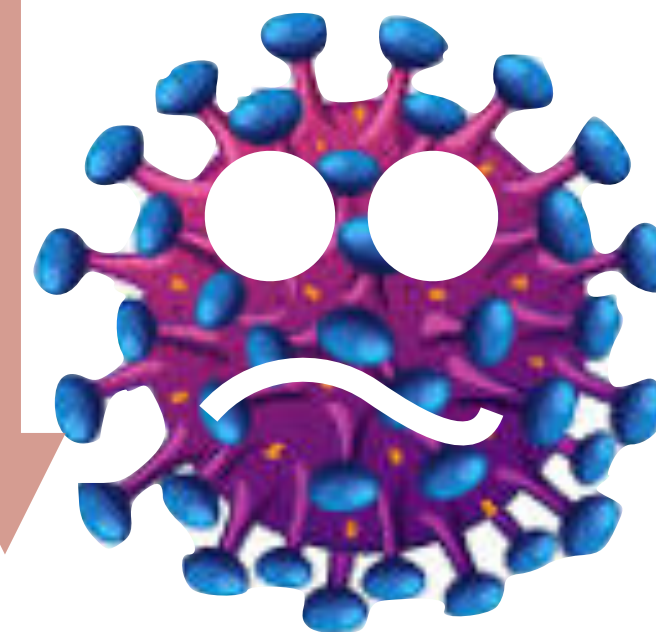
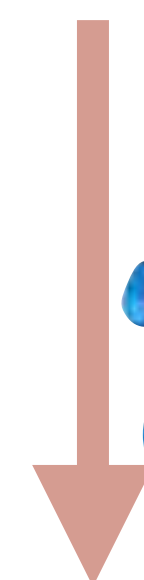
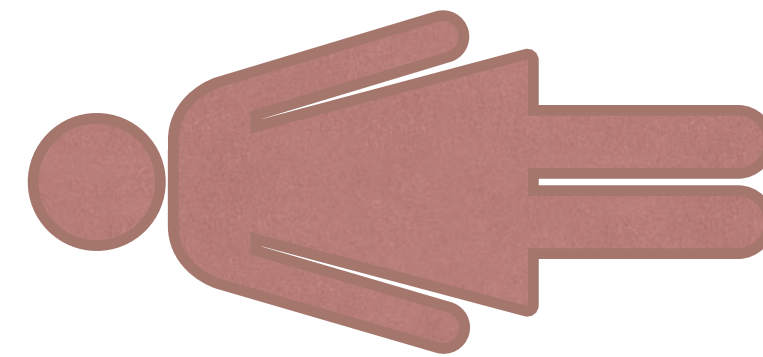
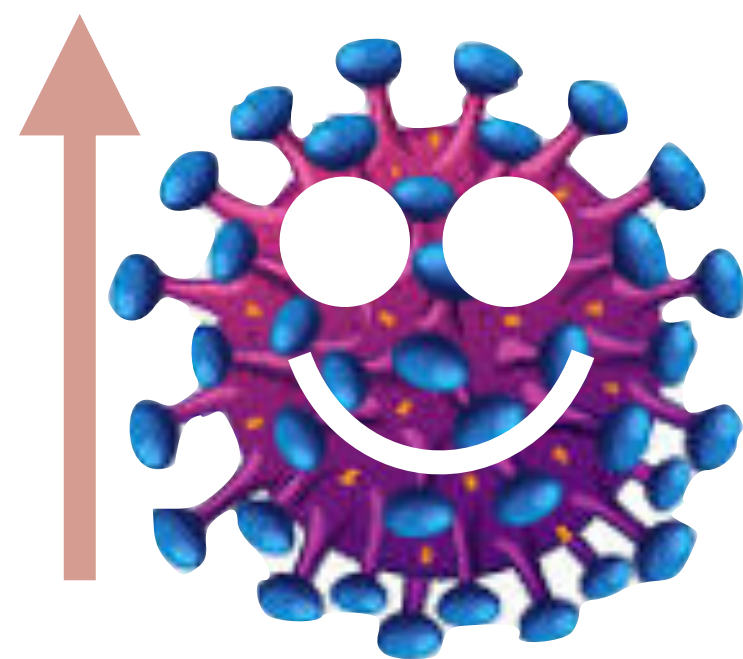
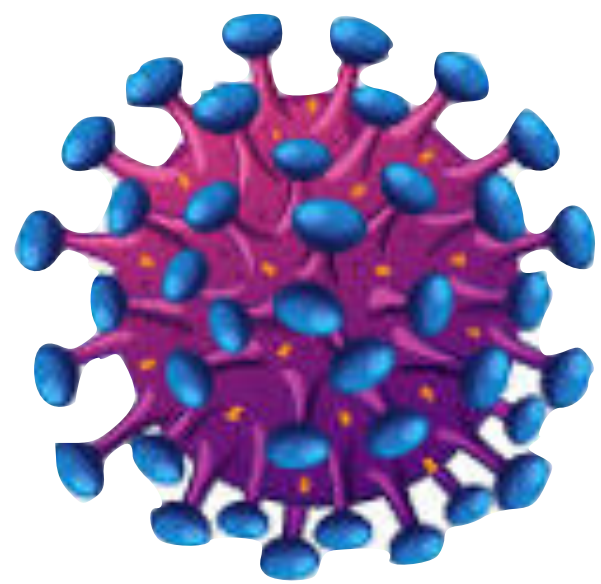
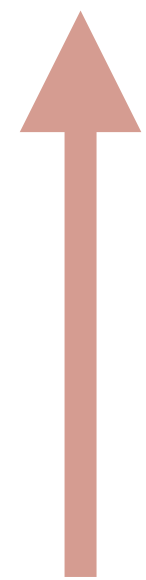
# Evolução da virulência

Virulência



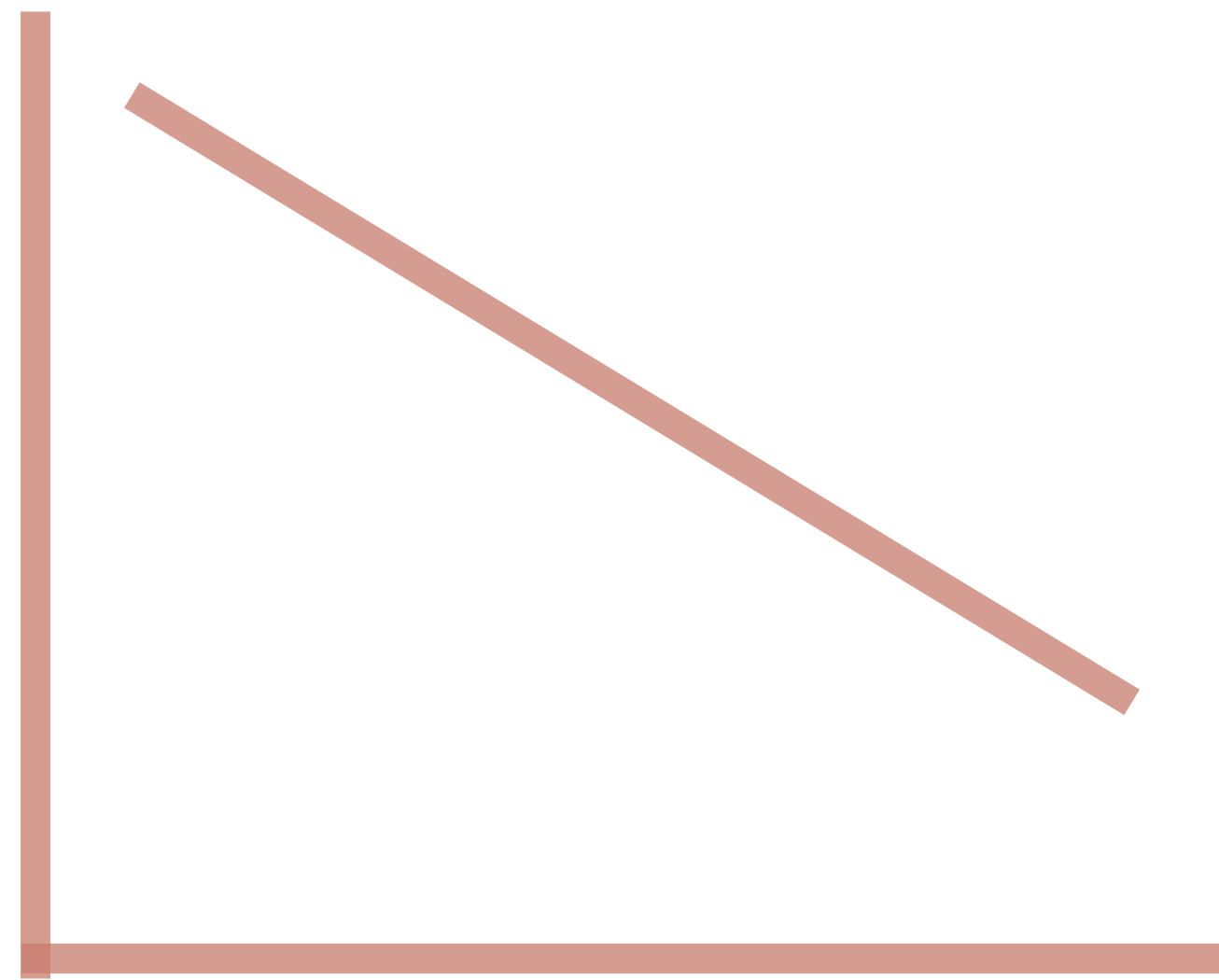
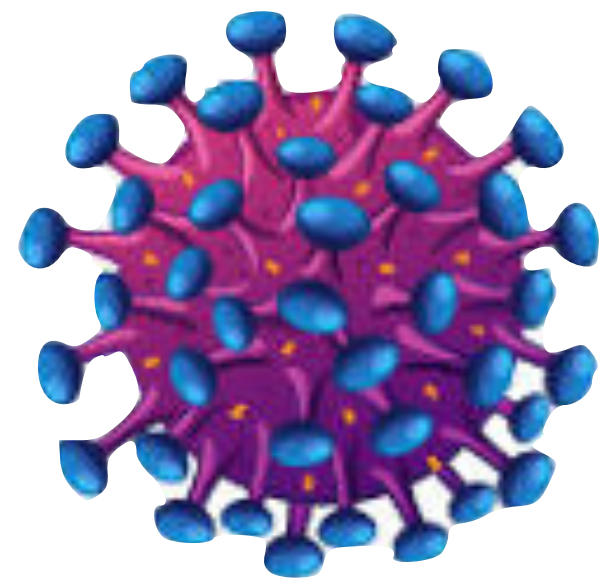
# Evolução da virulência

Virulência



# Evolução da virulência

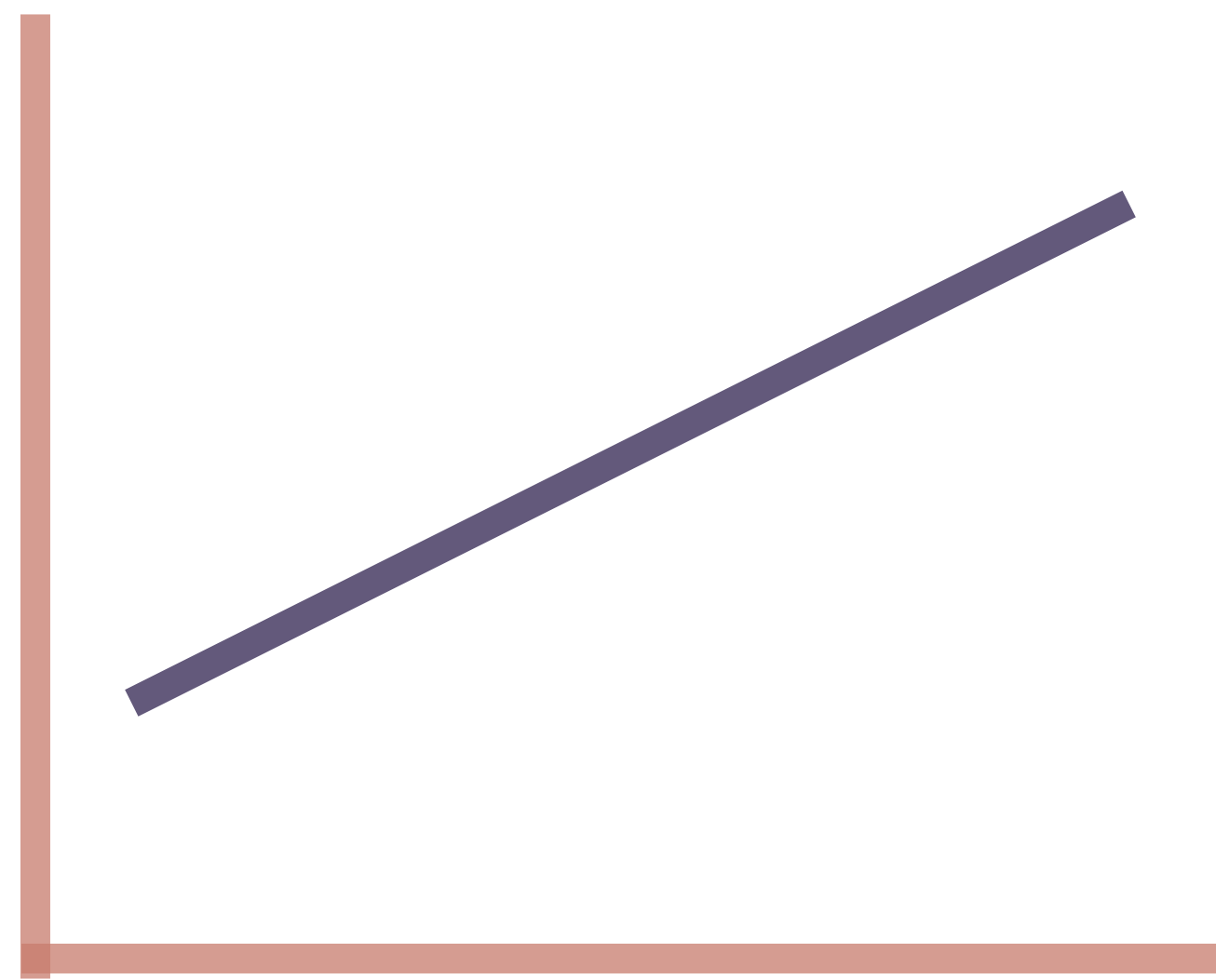
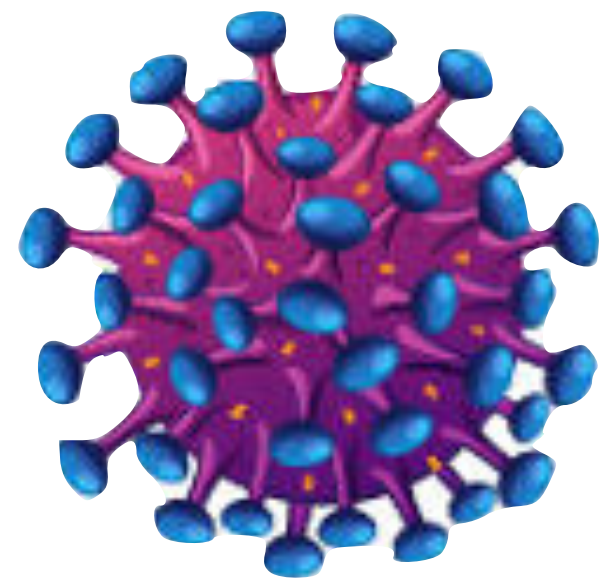
Virulência



Sobrevivência do  
hospedeiro

# Evolução da virulência

Transmissão

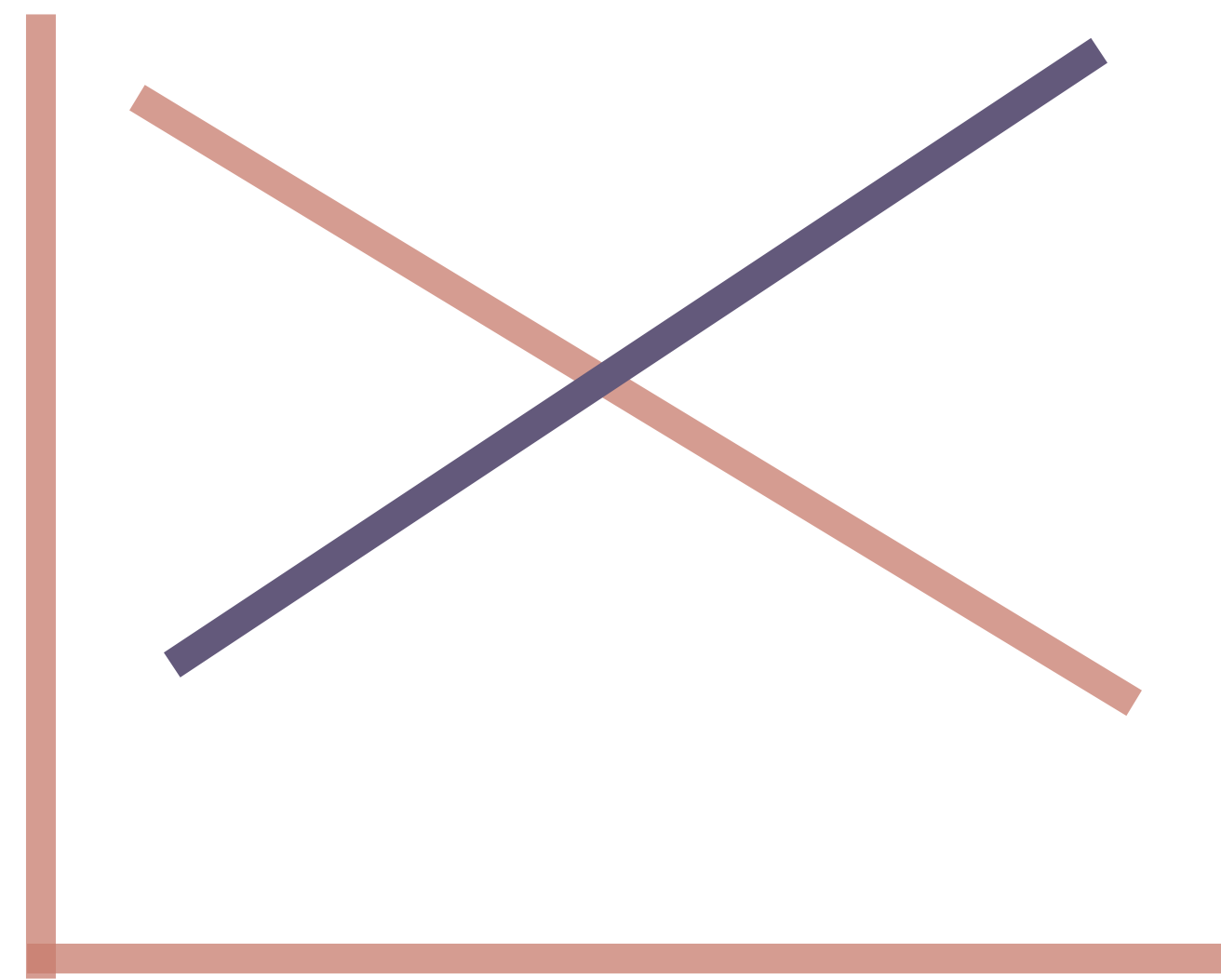
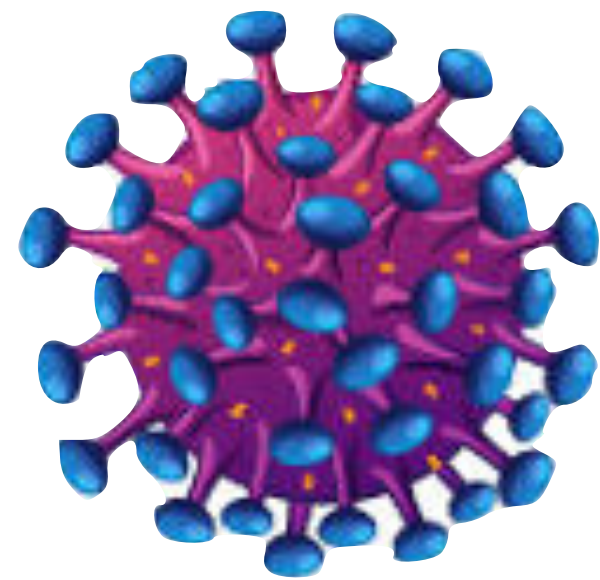


Sobrevivência do  
hospedeiro



# Evolução da virulência

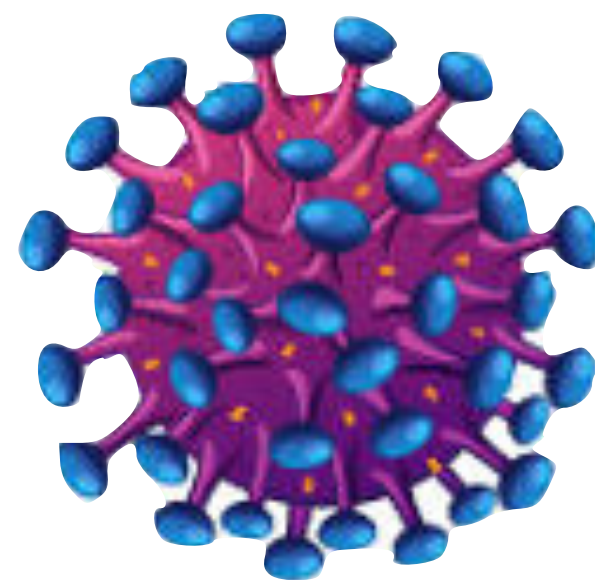
**Virulência**  
**Transmissão**



**Sobrevivência do  
hospedeiro**

# Evolução da virulência

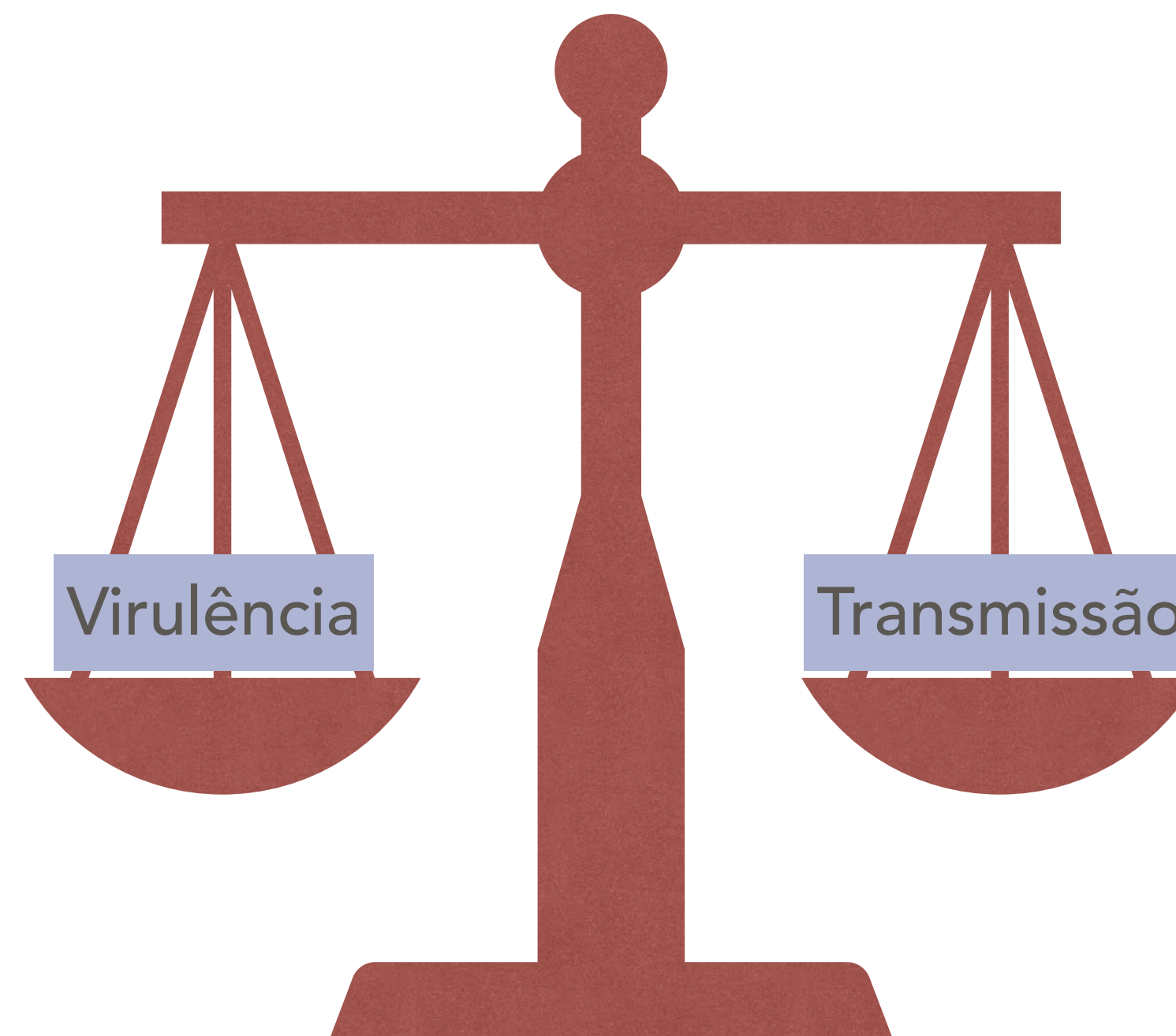
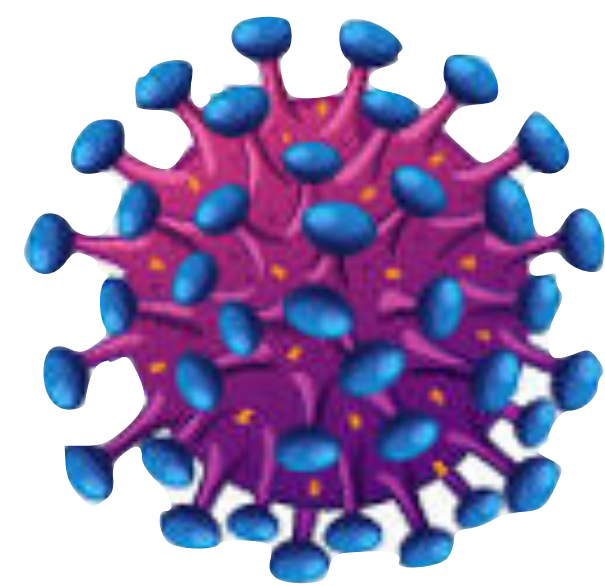
**Virulência**  
**Transmissão**

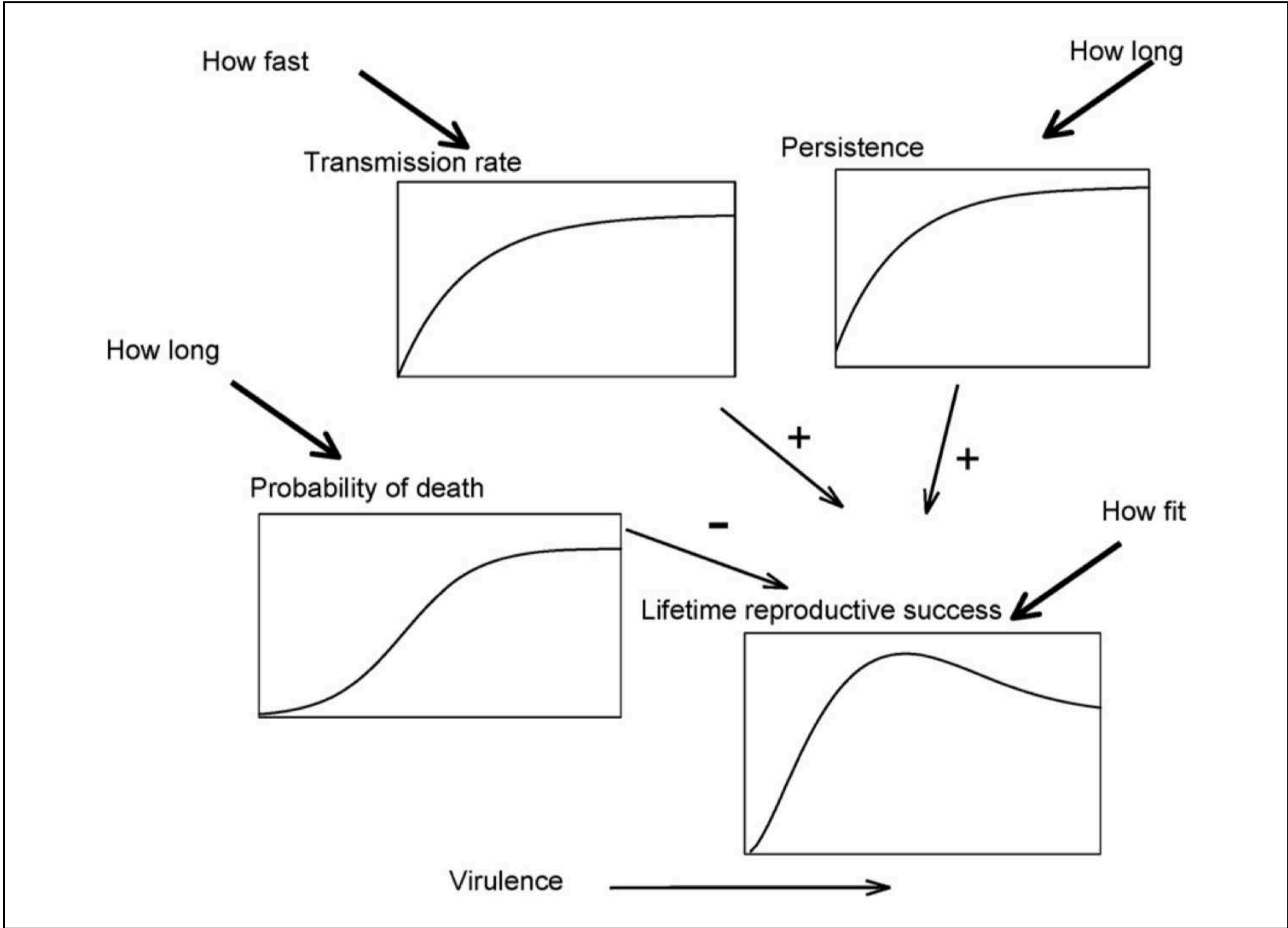


Trade-Off : Uma situação na qual a mudança em um traço causa aumento do fitness, porém leva a mudança em outro traço que reduz o fitness

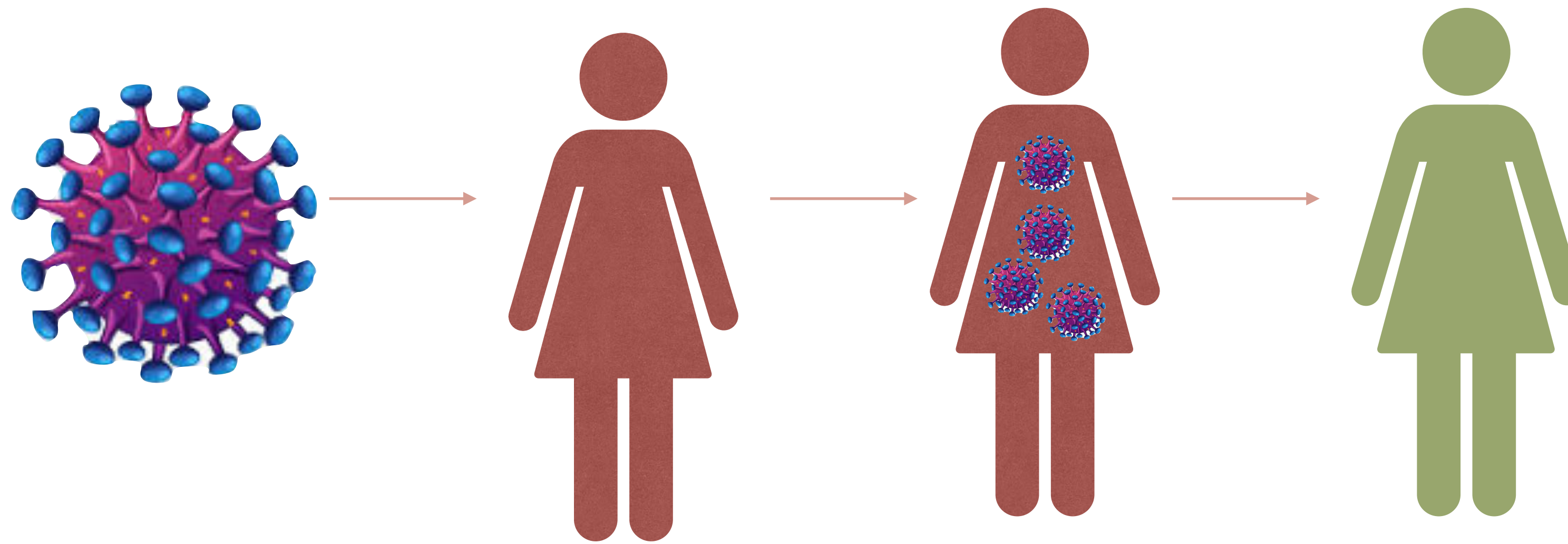
**Sobrevivência do  
hospedeiro**

# Evolução da virulência



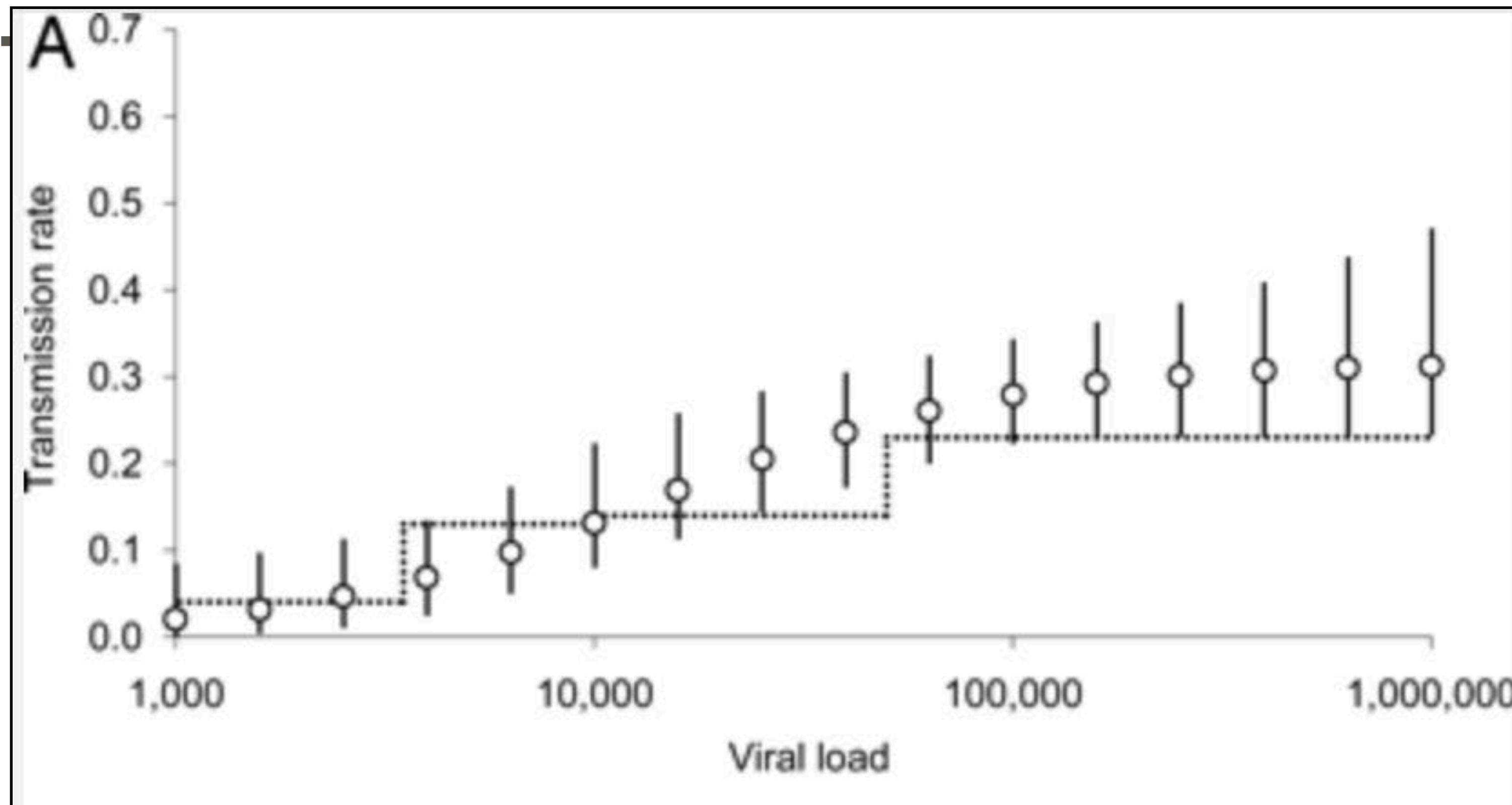


# HIV

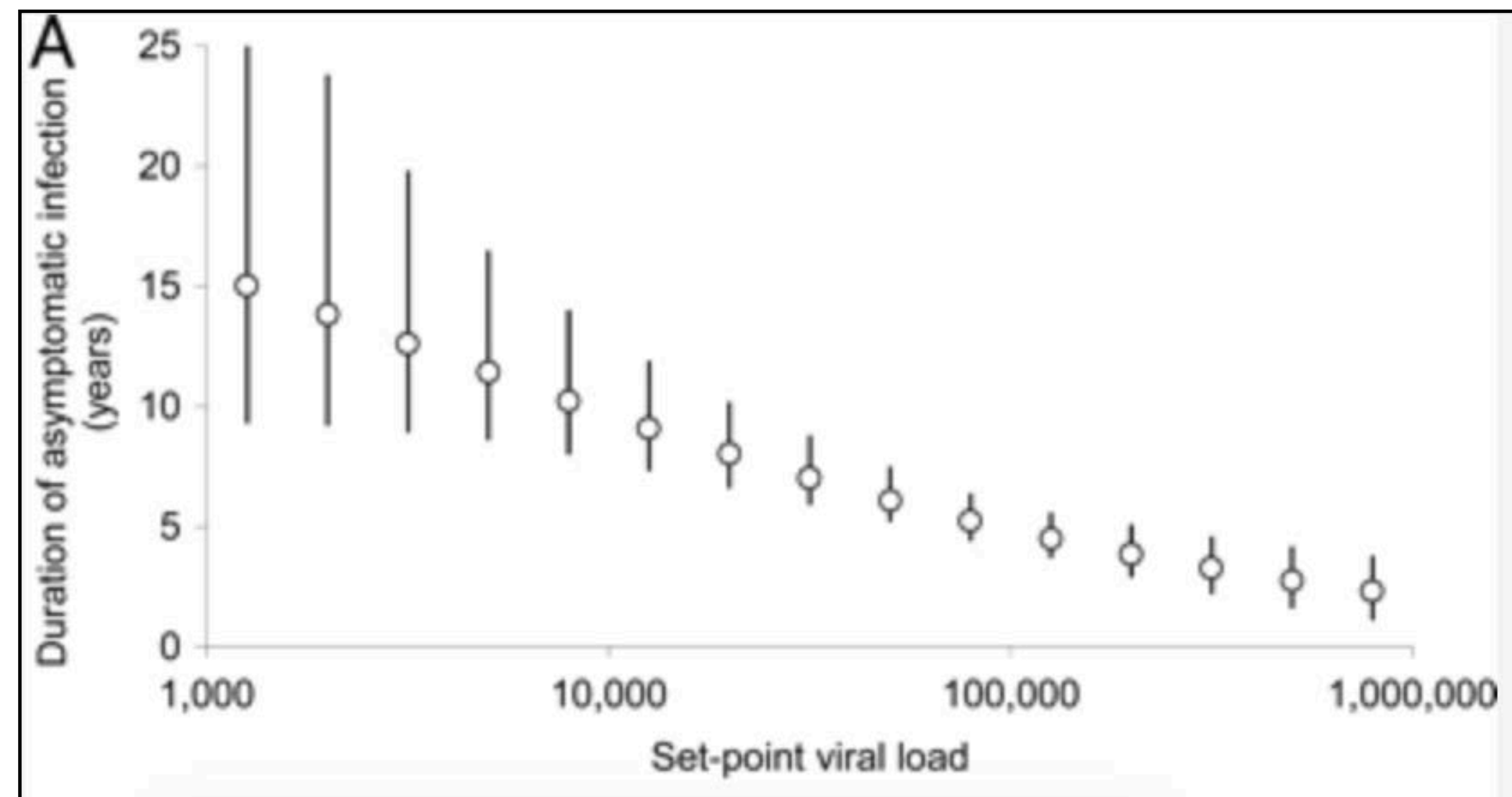
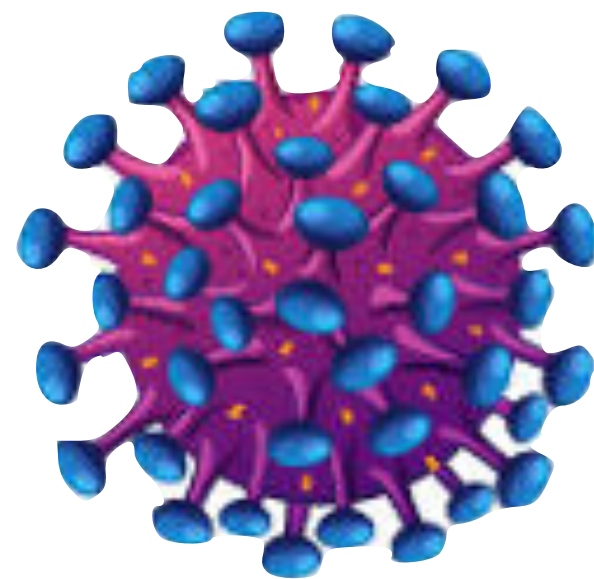


assintomático

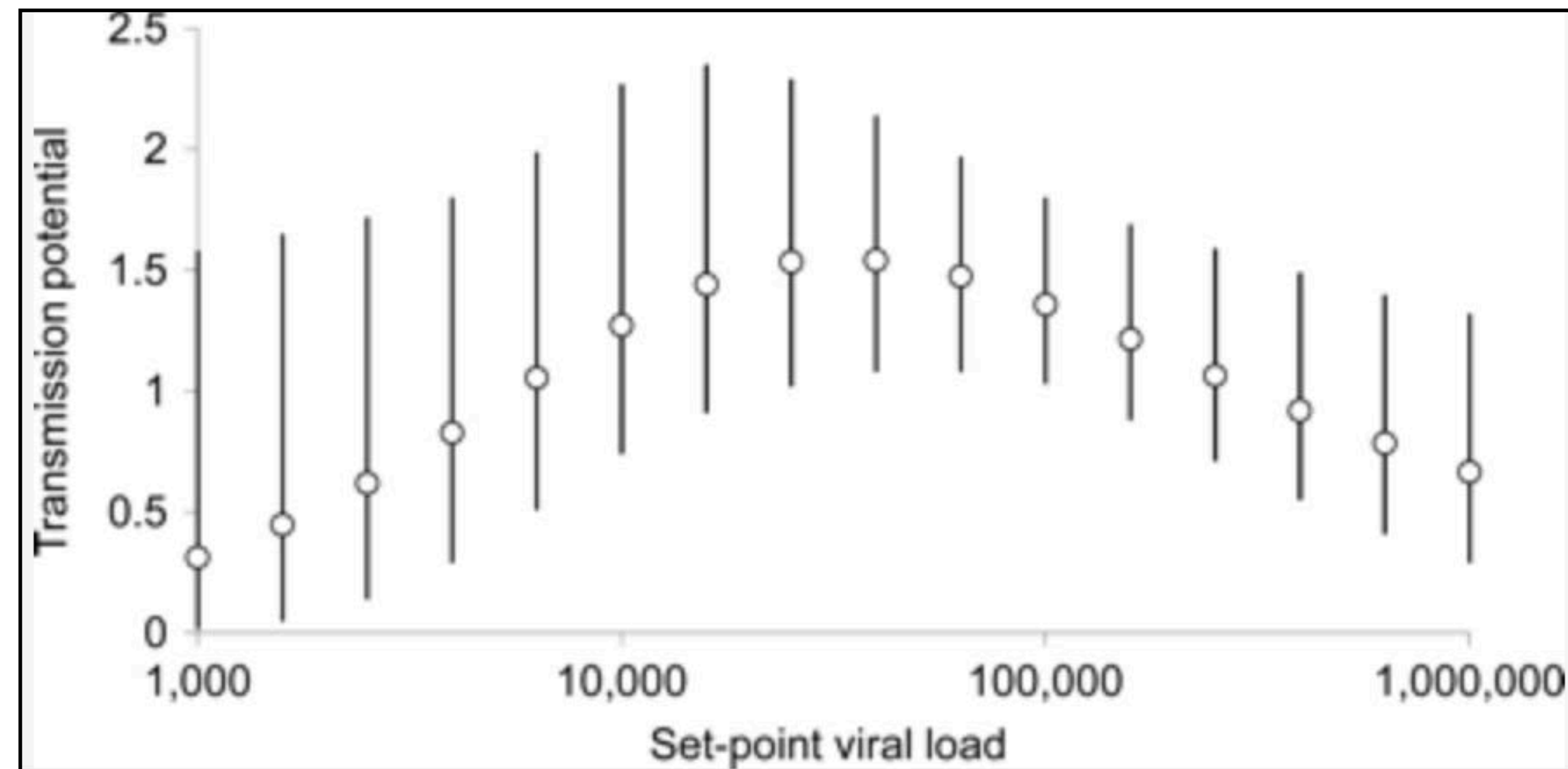
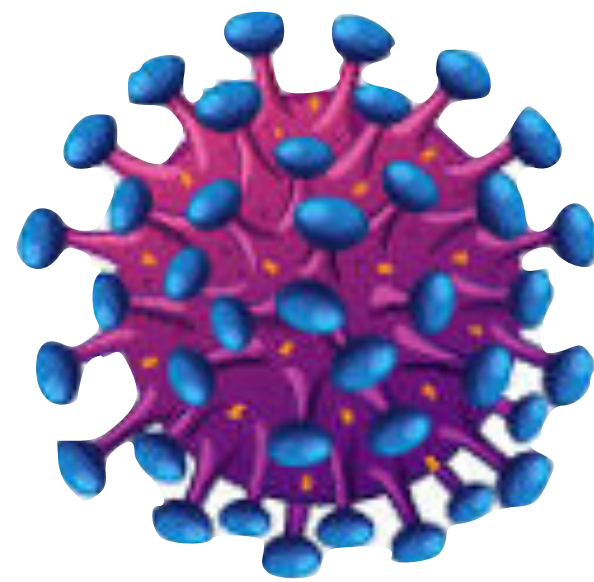
# HIV



# HIV

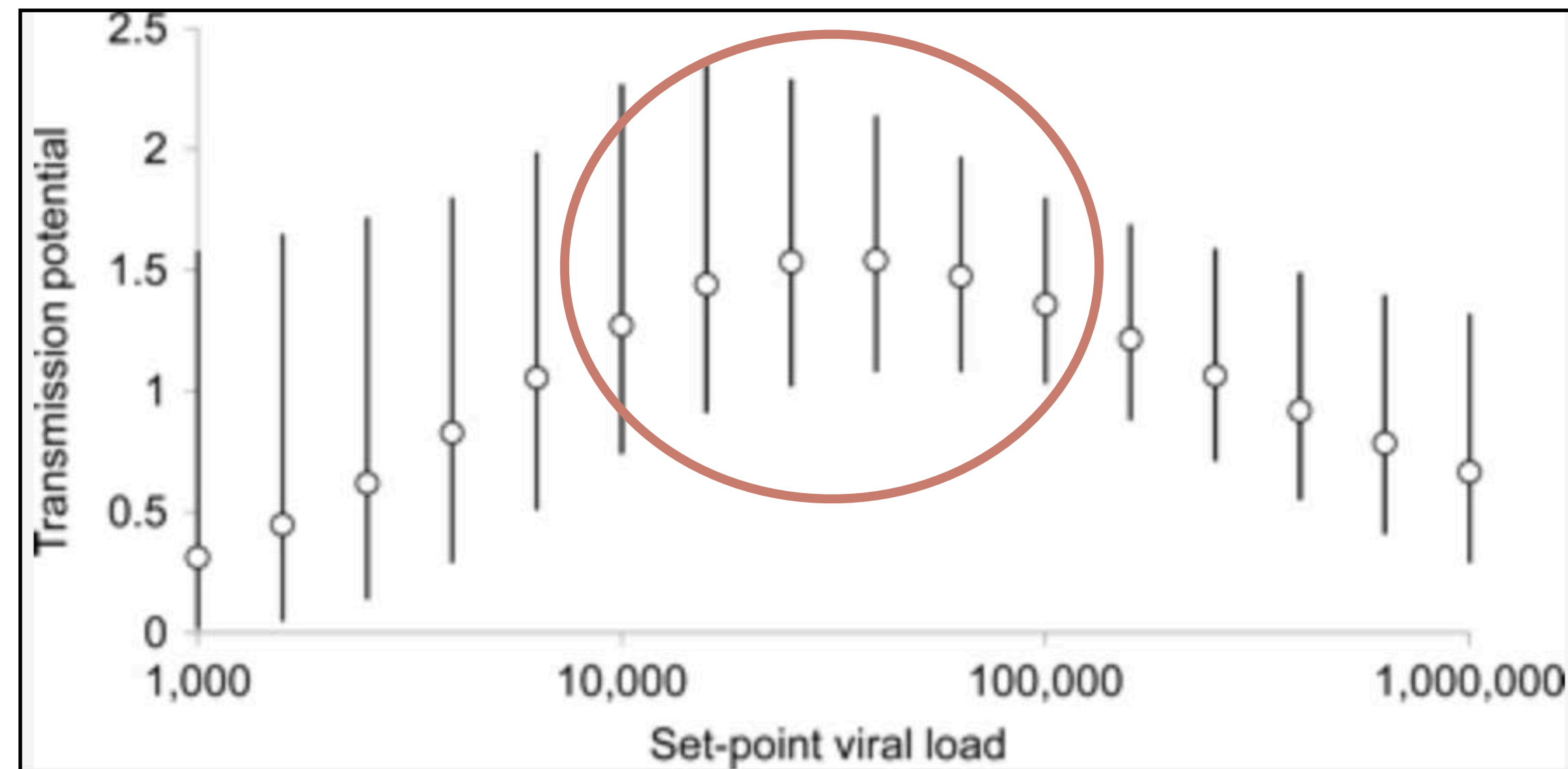
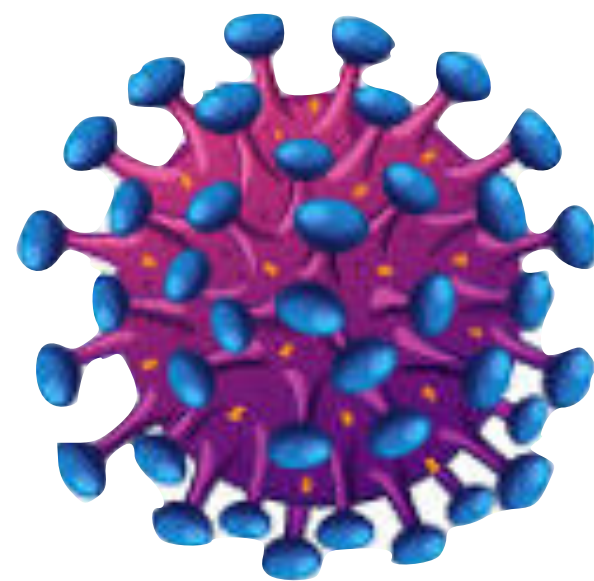


# HIV





# HIV



# Evolução da virulência

Trade-off ente  
virulência e  
transmissão



Virulência em  
níveis  
intermediários

# Evolução da virulência

Trade-off ente  
virulência e  
transmissão



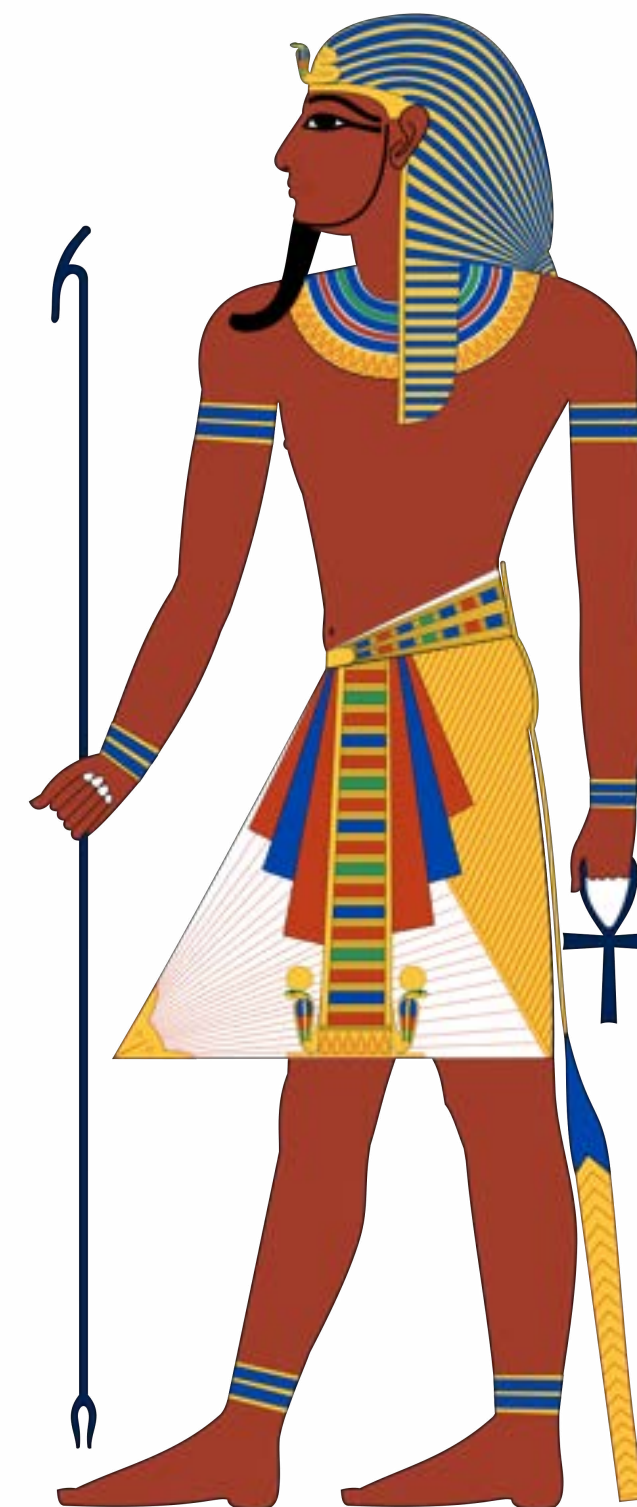
Virulência em  
níveis  
intermediários

Parasitas de  
transmissão direta

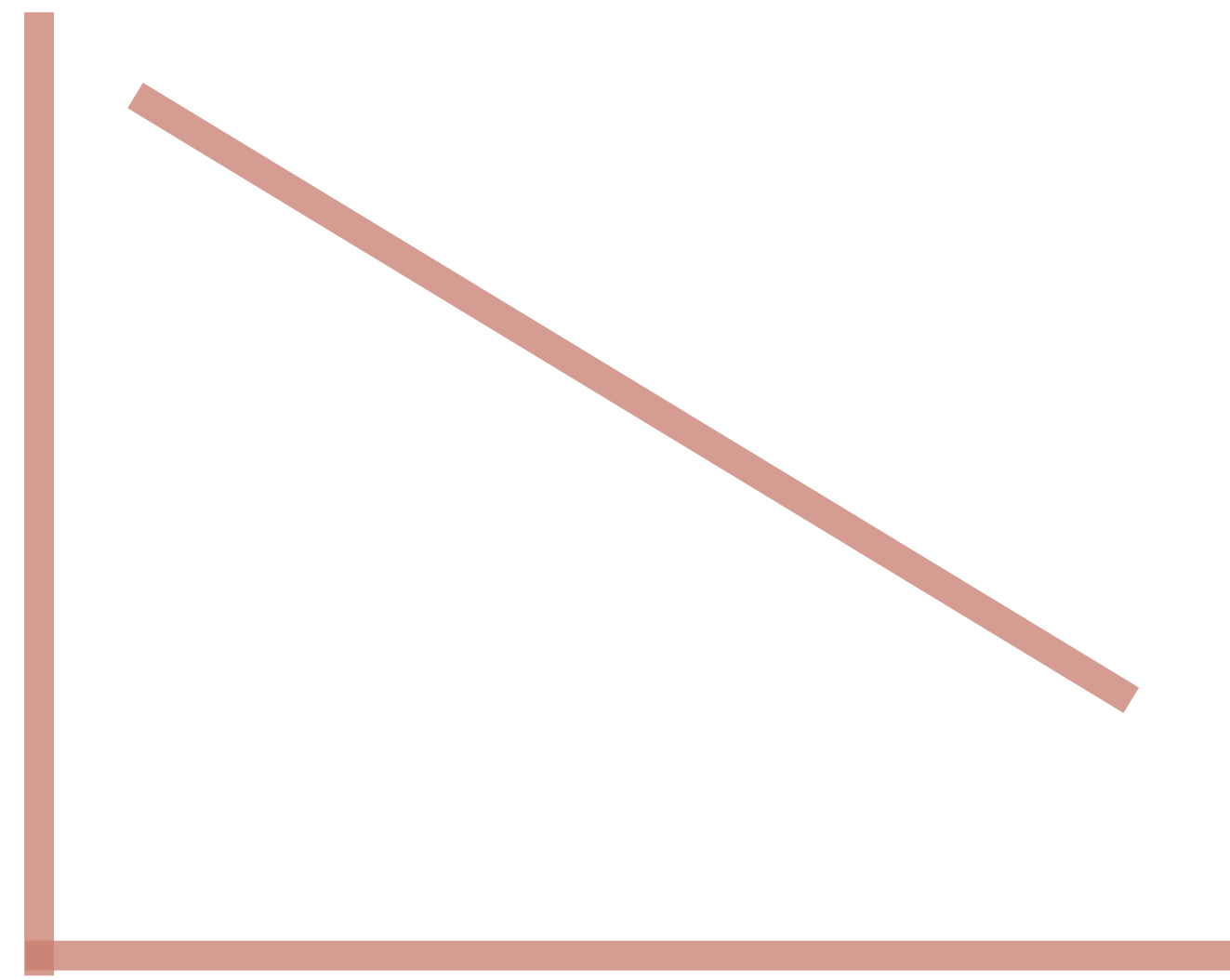
# Evolução da virulência

Parasitas de  
transmissão  
indireta??

# A maldição do faraó

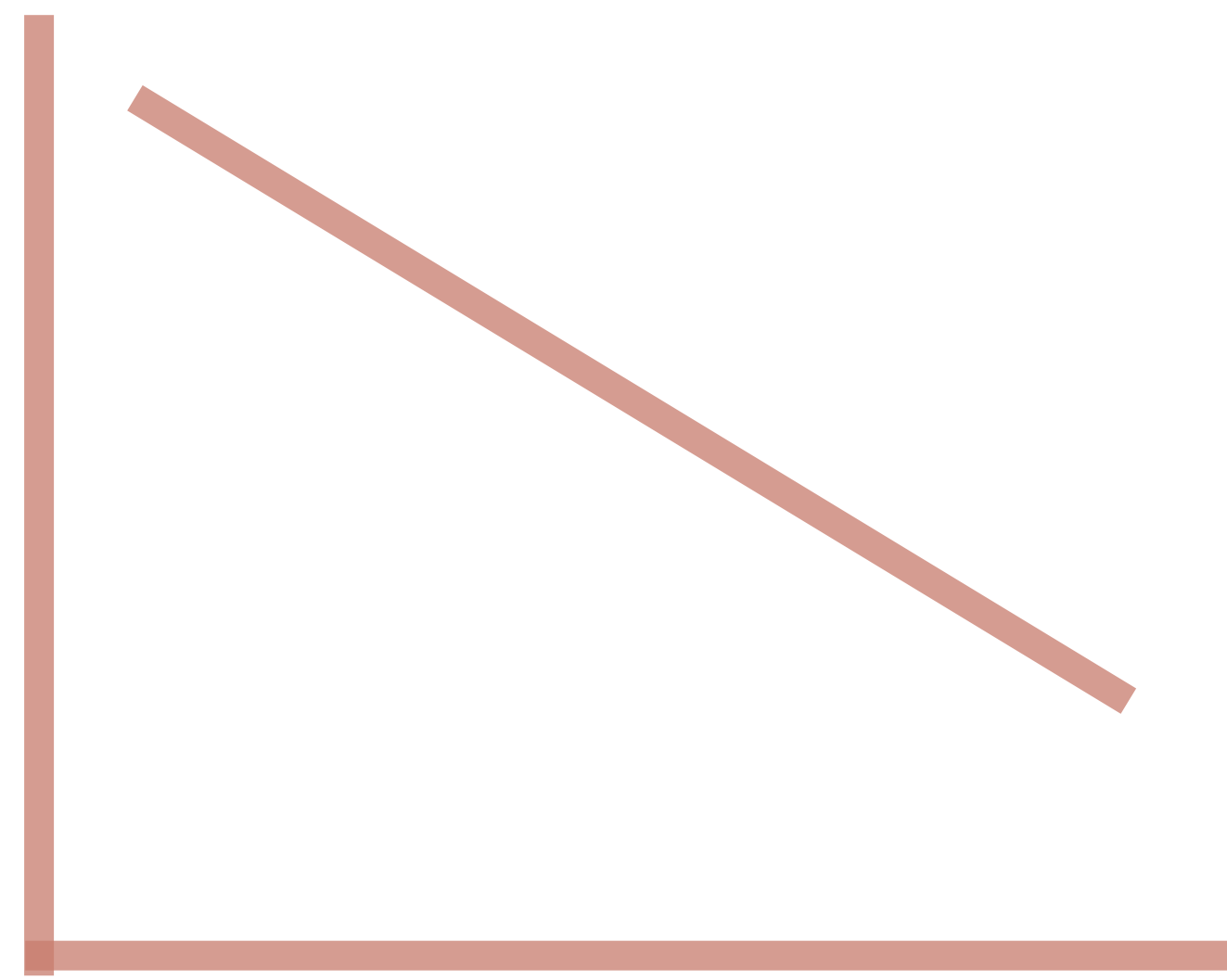


Virulência

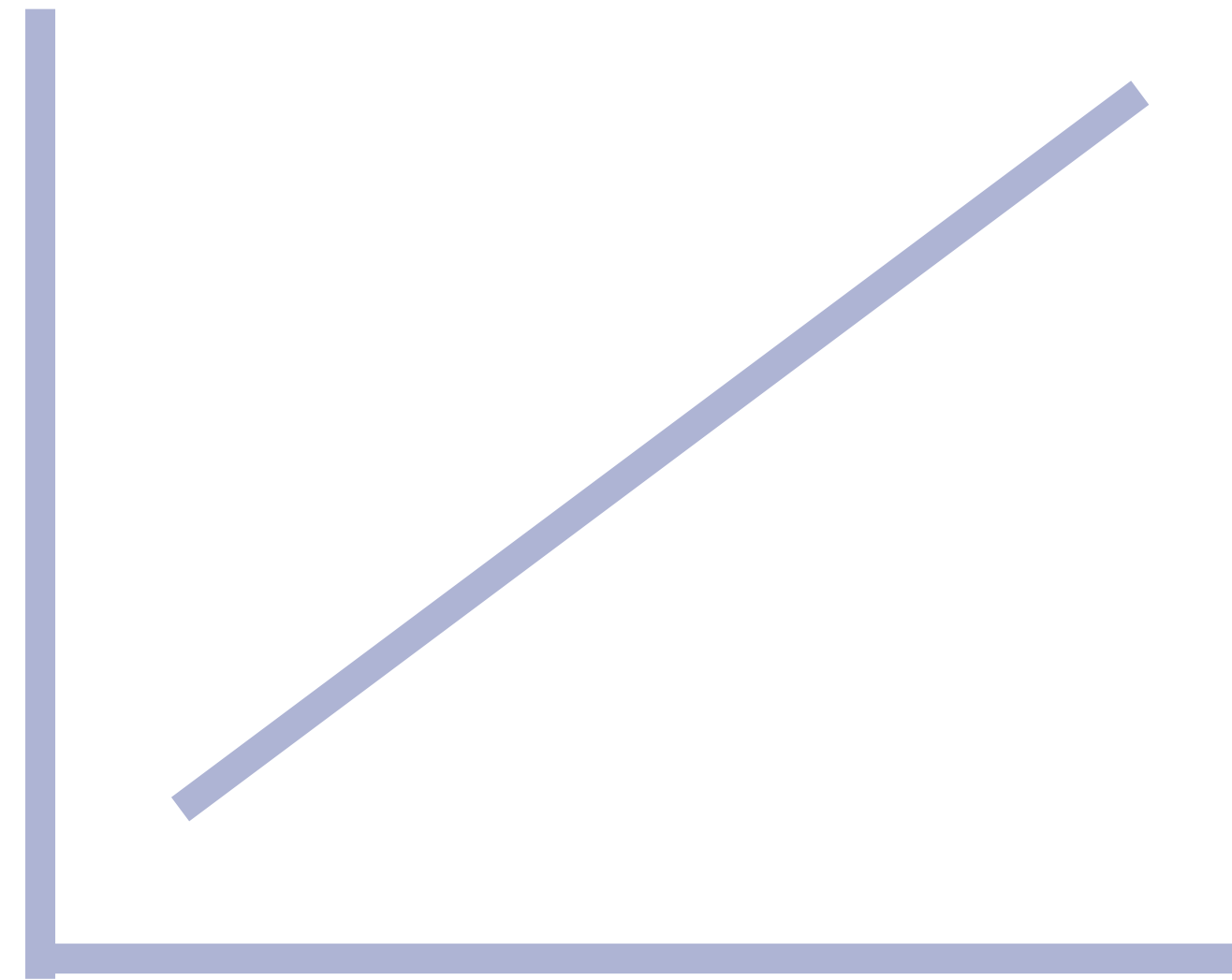


Sobrevivência do  
hospedeiro

Virulência

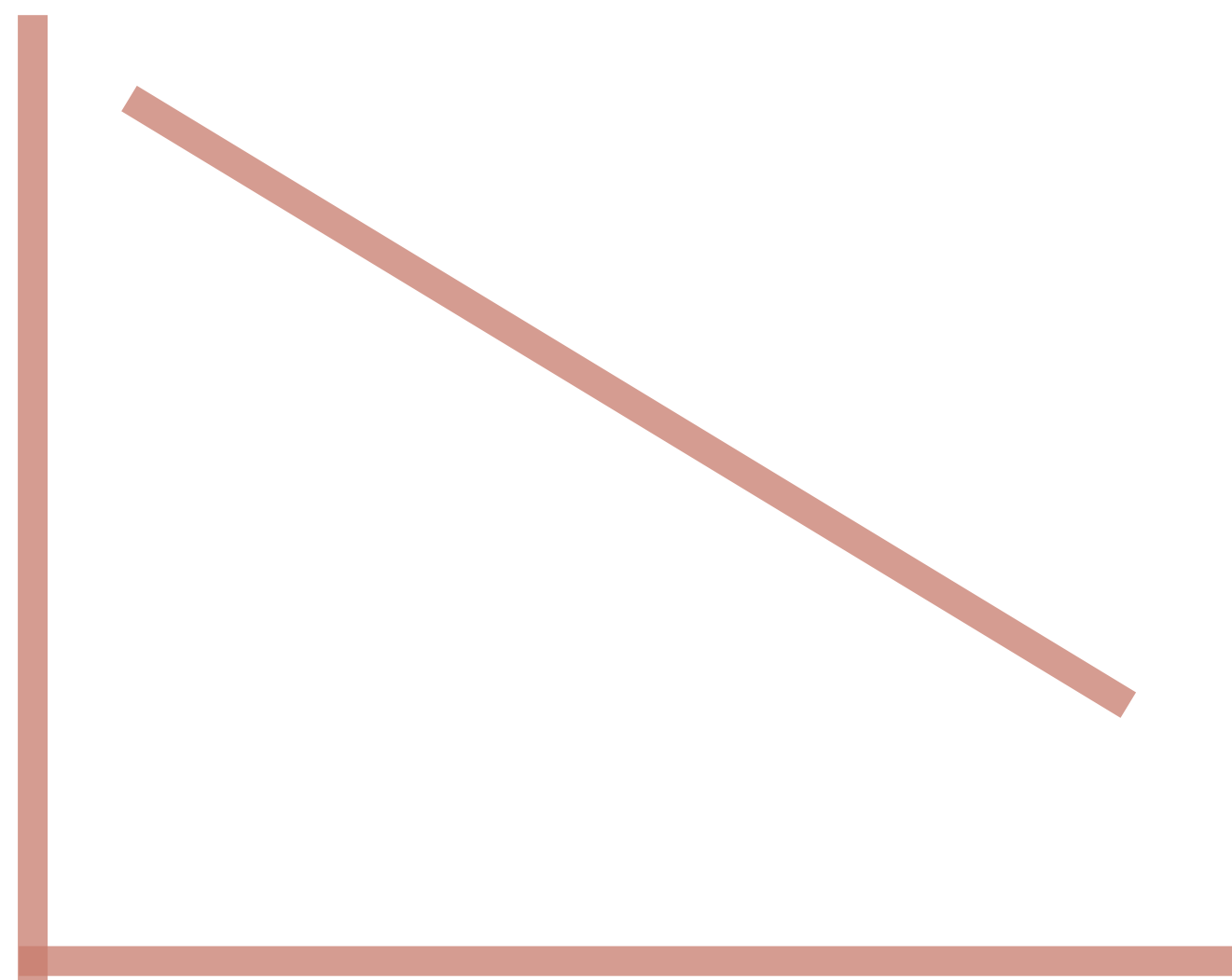


Sobrevivência do  
hospedeiro

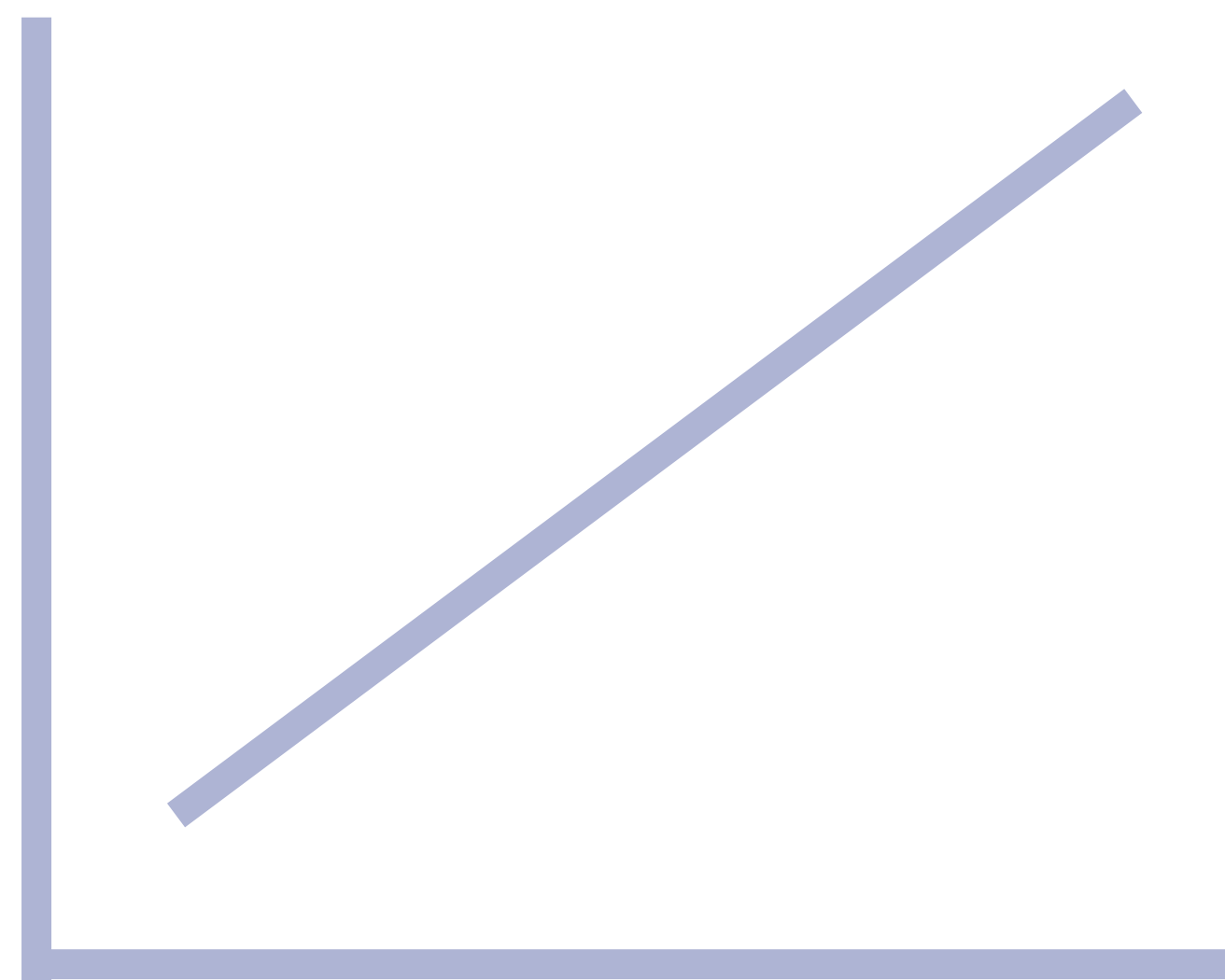


Transmissão

Virulência

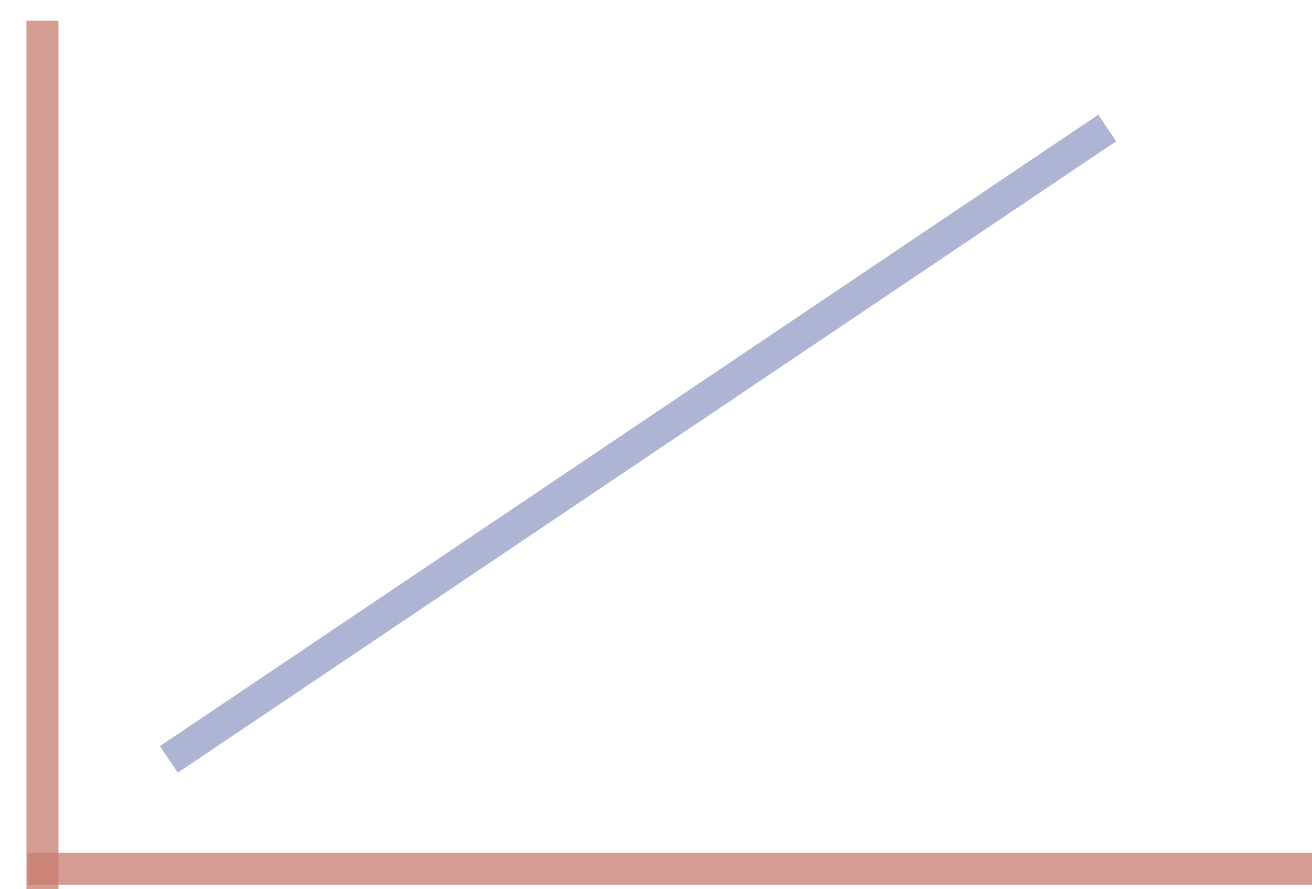


Sobrevivência do  
hospedeiro



Transmissão

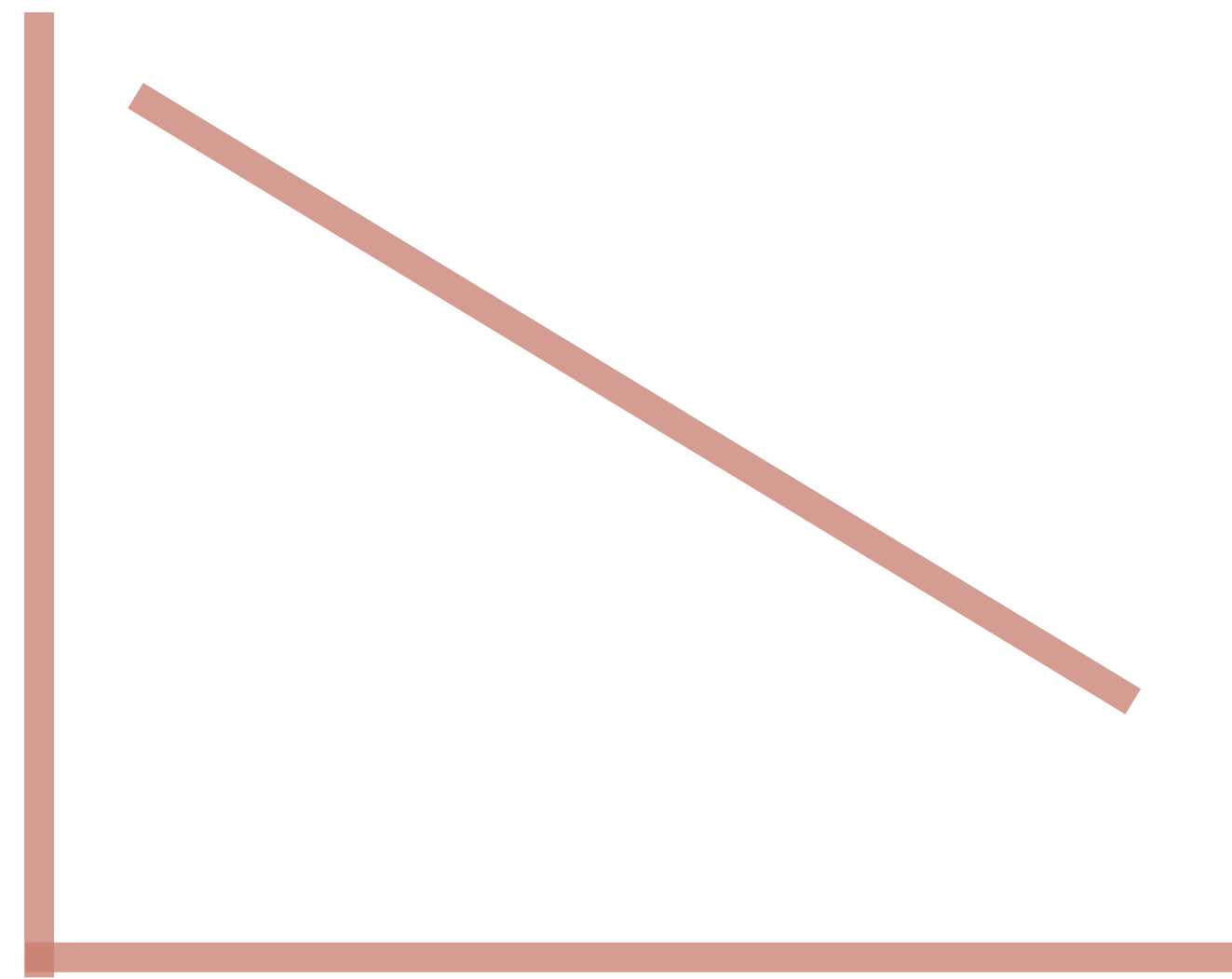
Transmissão



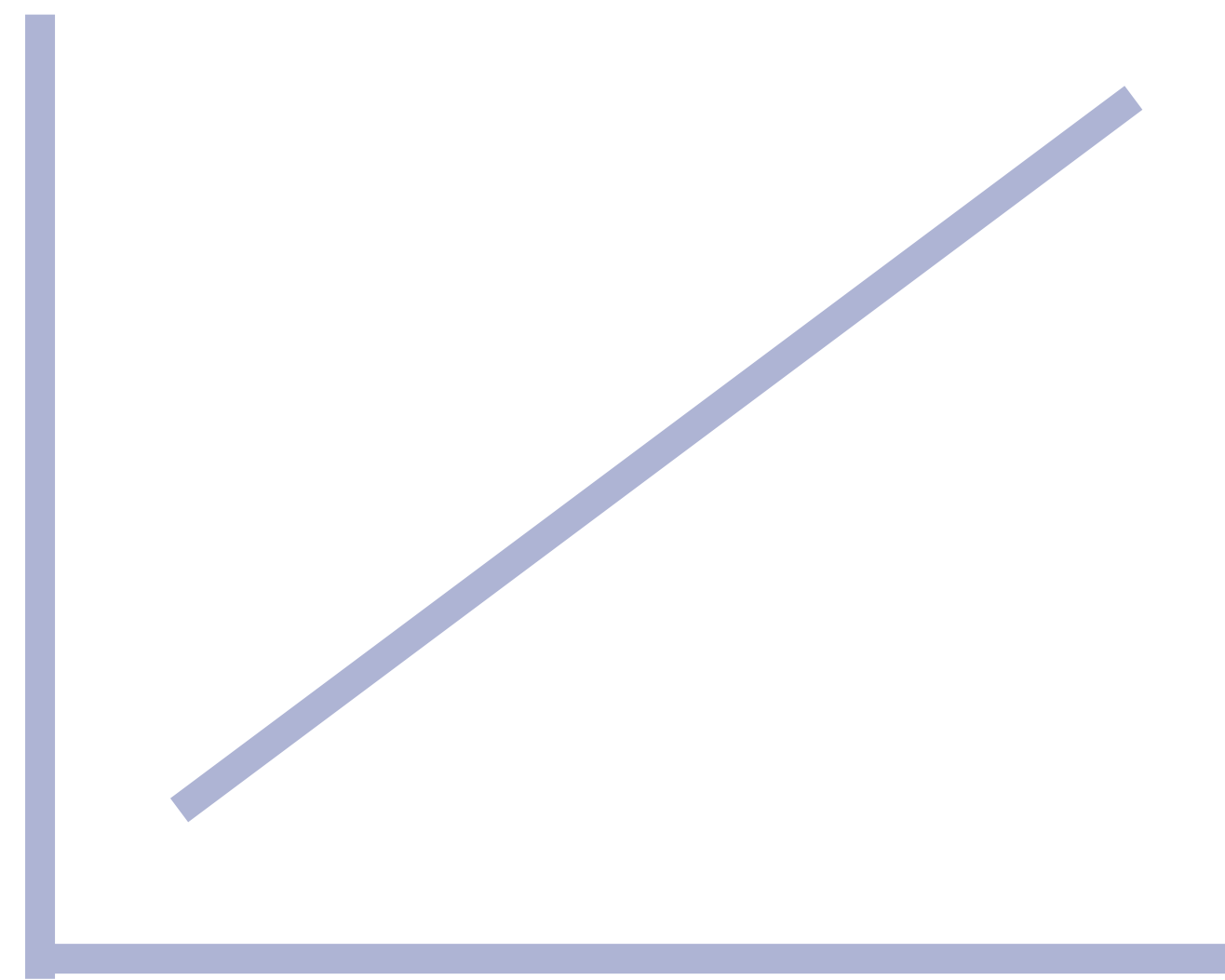
Sobrevivência do  
hospedeiro



Virulência

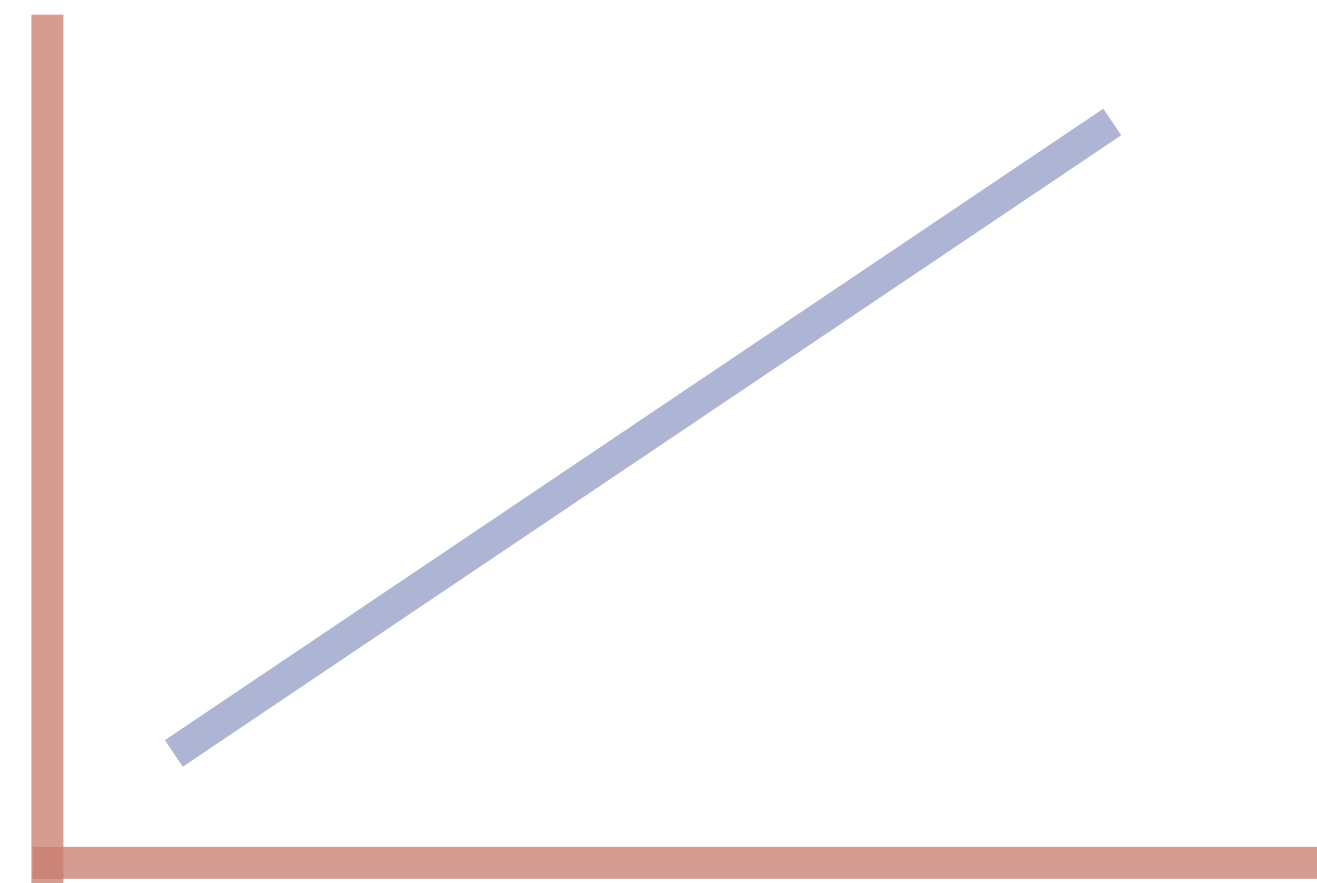


Sobrevivência do  
hospedeiro



Transmissão

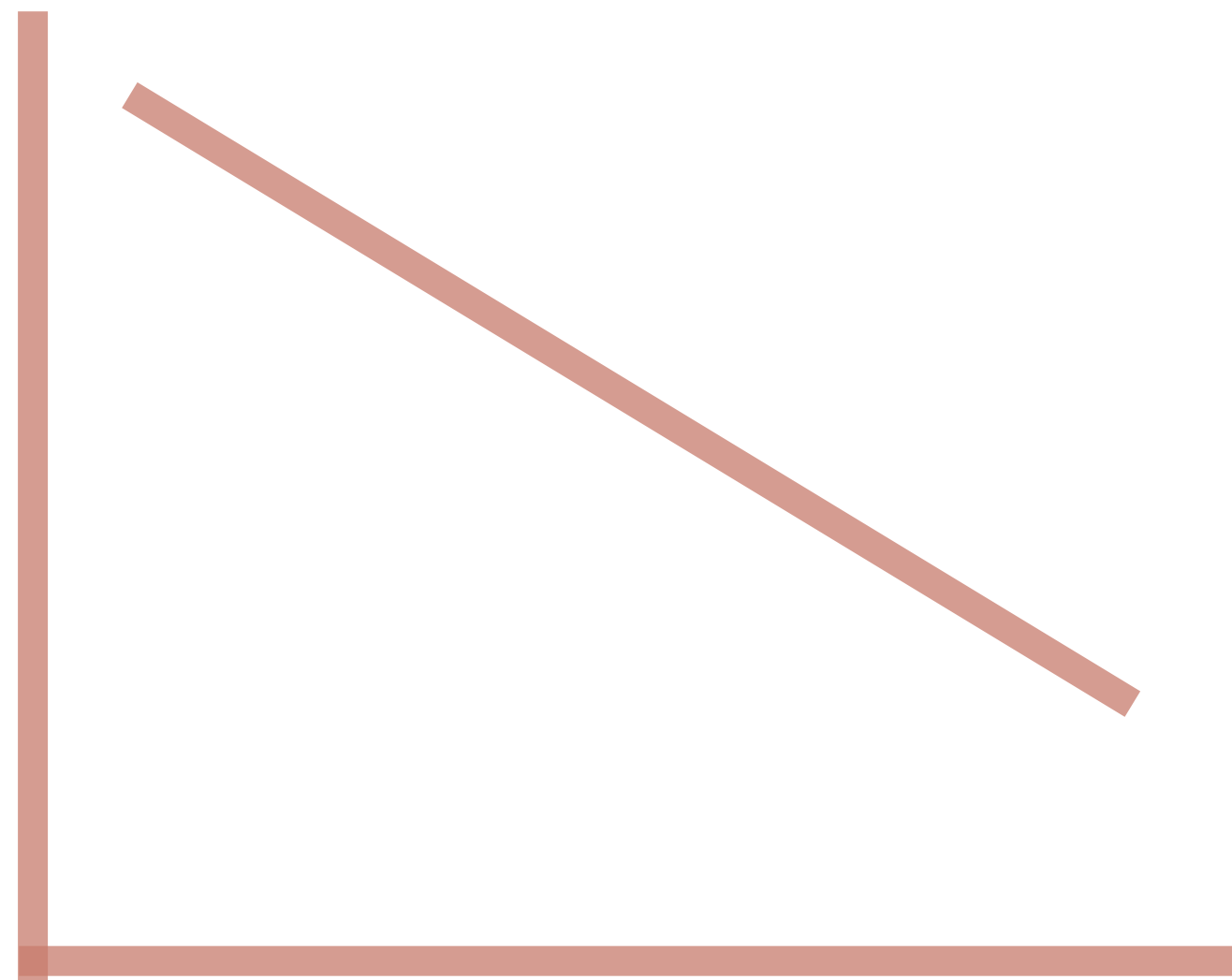
Transmissão



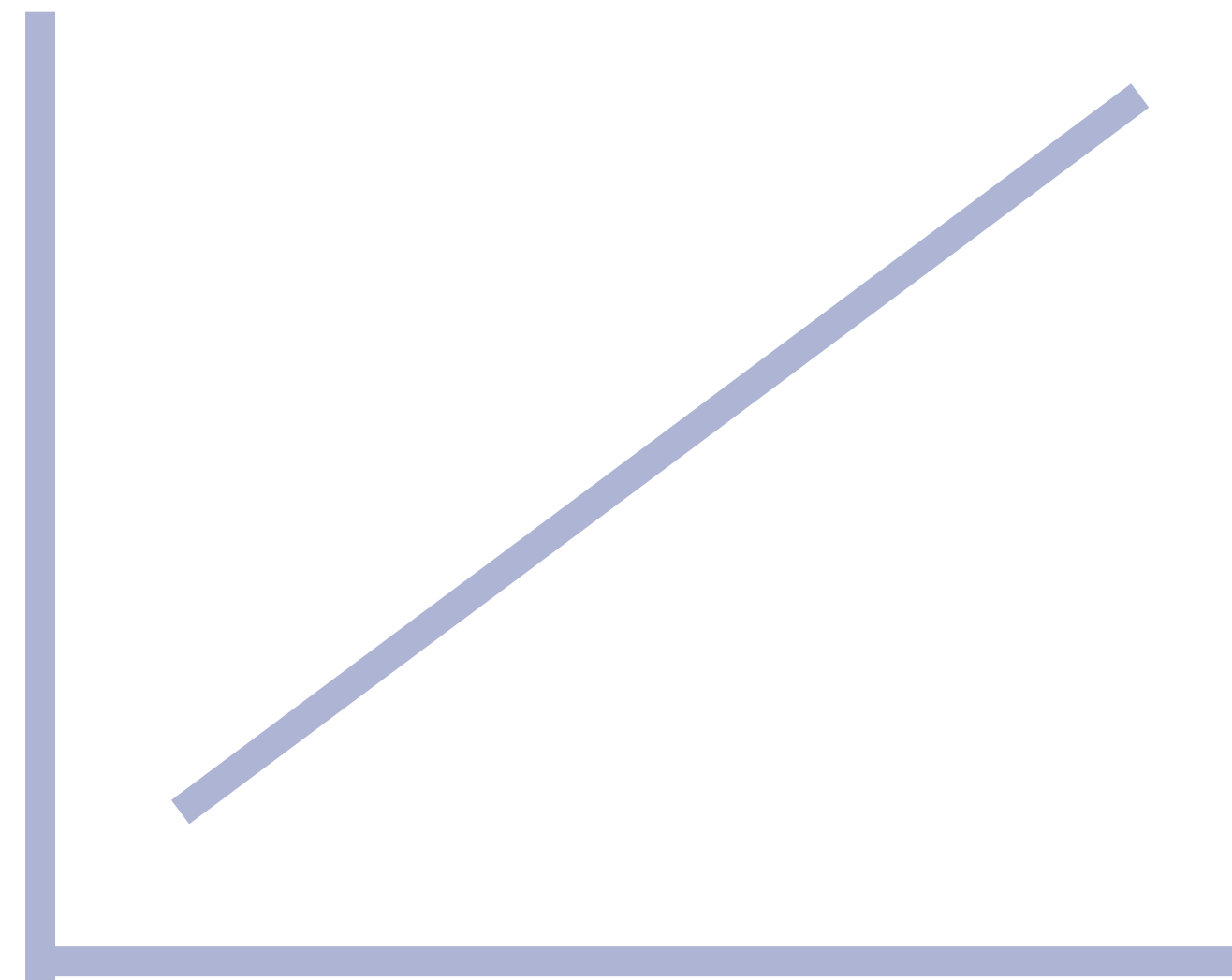
Sobrevivência do  
hospedeiro

Parasitas de  
transmissão direta

Virulência

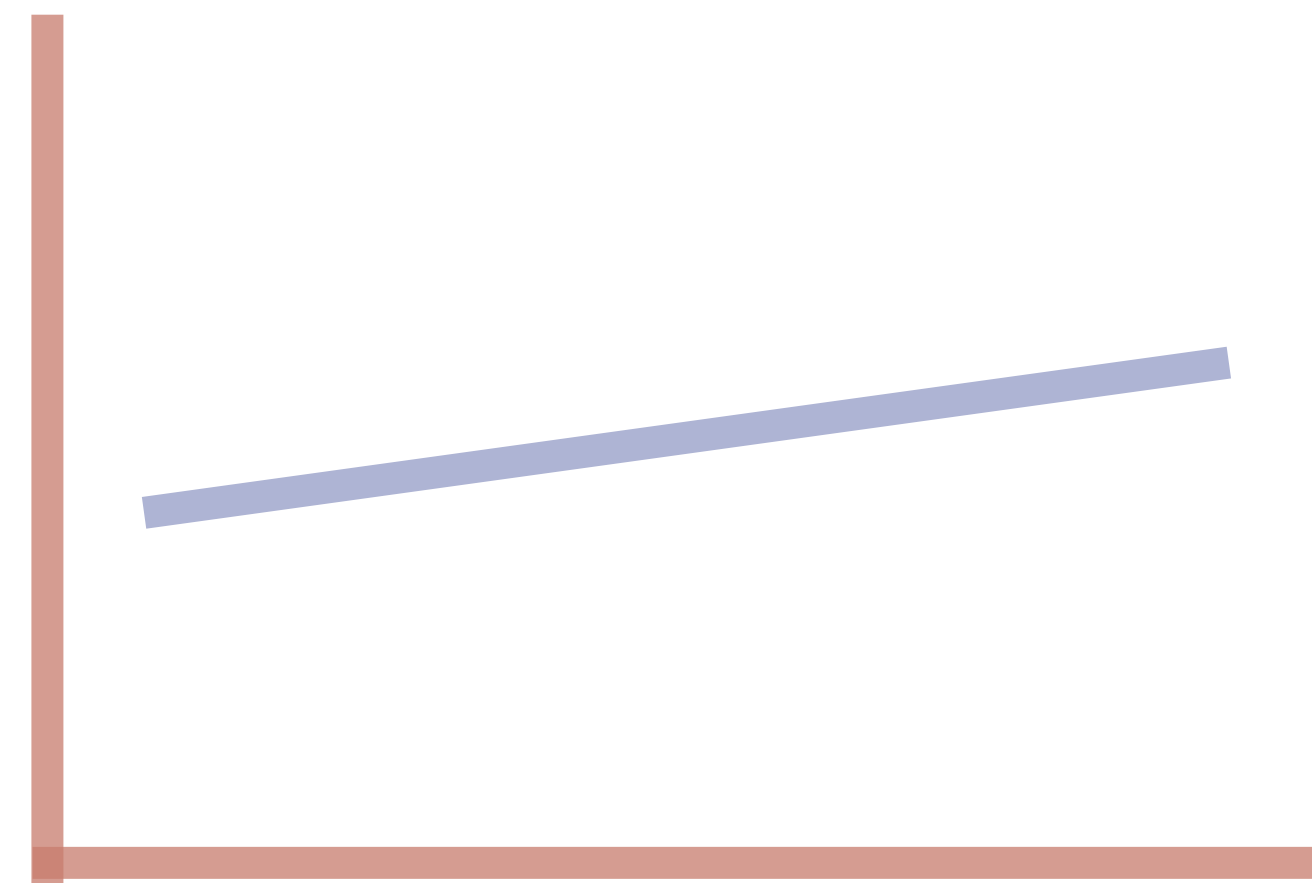


Sobrevivência do  
hospedeiro



Transmissão

Transmissão



Sobrevivência do  
hospedeiro

Parasitas de  
transmissão  
indireta

# A maldição do faraó



↓  
Dependência do  
hospedeiro para  
transmissão

↑  
**Virulência**

# A maldição do faraó

Table 14. *Ranking of mortality and tendencies for waterborne transmission across species*

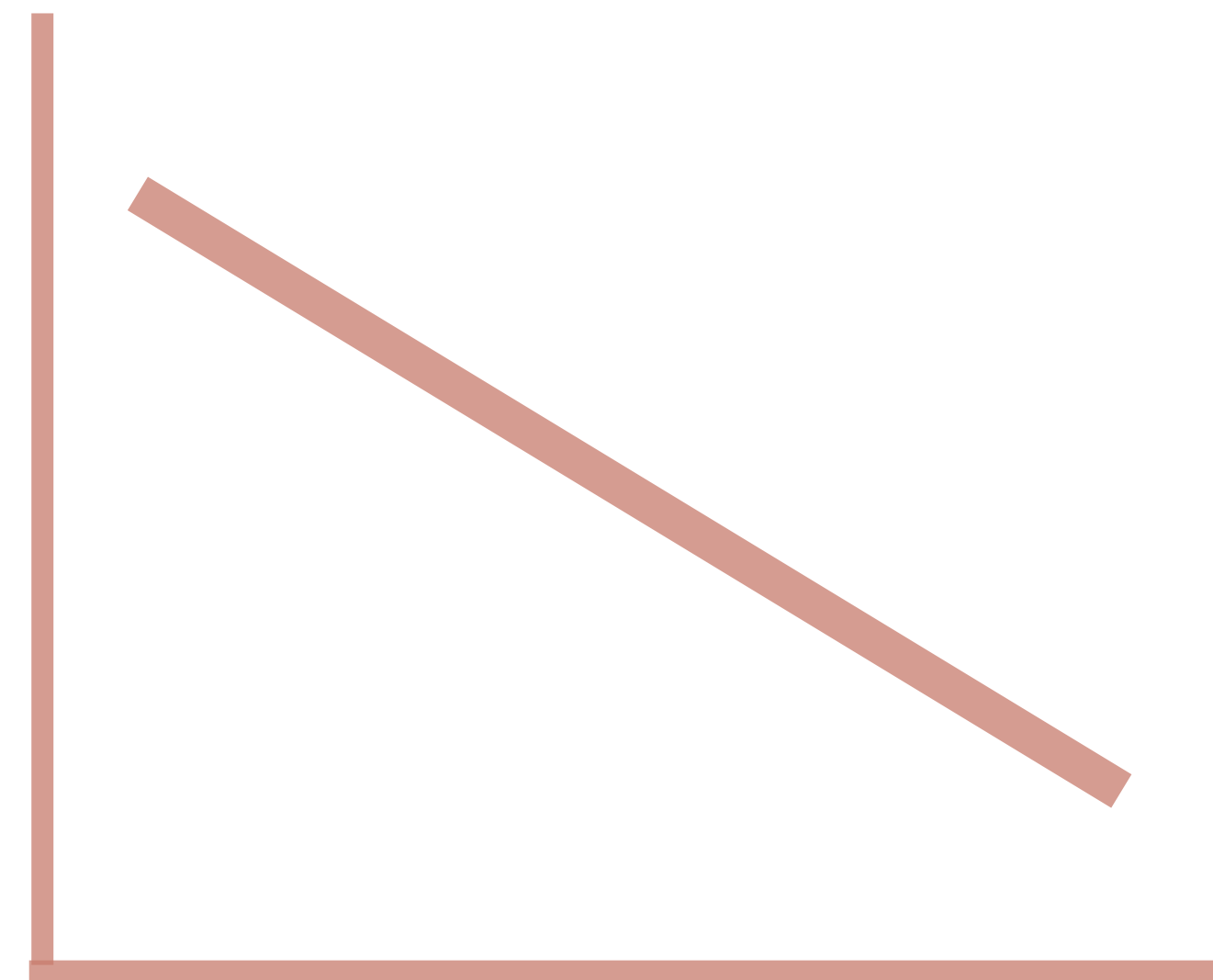
Pathogen	Mortality		Waterborne outbreaks	
	%	rank	%	rank
<i>V. cholerae</i> , classical biotype	15.7	1	83.3	1
<i>Shigella dysenteriae</i> type 1	7.5	2	80.0	2
<i>Salmonella typhi</i>	5.8	3	74.0	3
<i>V. cholerae</i> , el tor biotype	1.44	4	50.0	4
<i>Shigella flexneri</i>	1.32	5	48.3	5
<i>Shigella sonnei</i>	0.65	6	27.8	6
Enterotoxigenic <i>E. coli</i>	< 0.1	8*	20.0	7
<i>Campylobacter jejuni</i>	< 0.1	8*	10.7	8
Non-typhoid salmonella	< 0.1	8*	1.56	9

\* See text for discussion of ranking.

# Vibrio cholerae

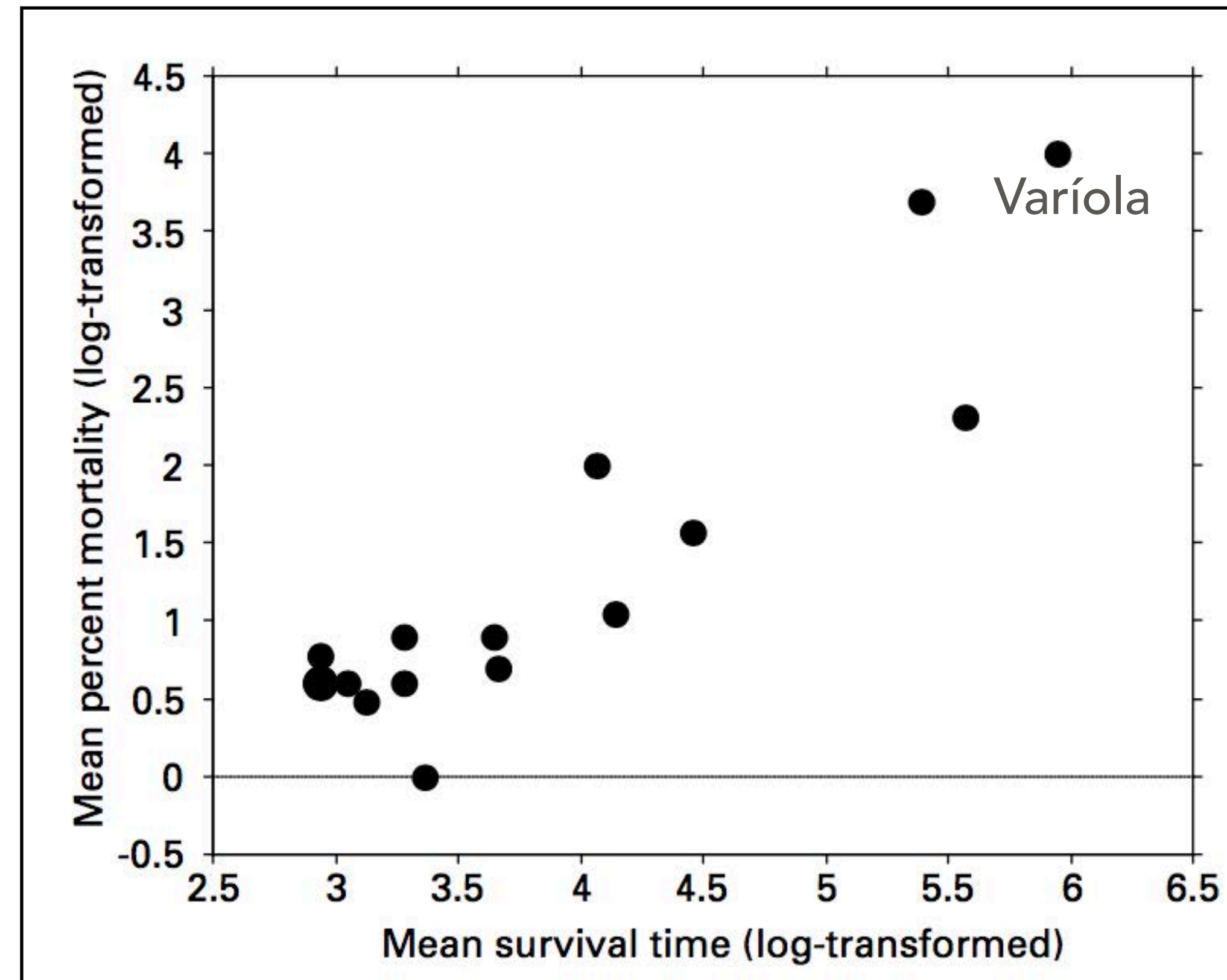


Virulência



Condições sanitárias

# Doenças respiratórias humanas



# Transmissão por vetor- expectativa teórica

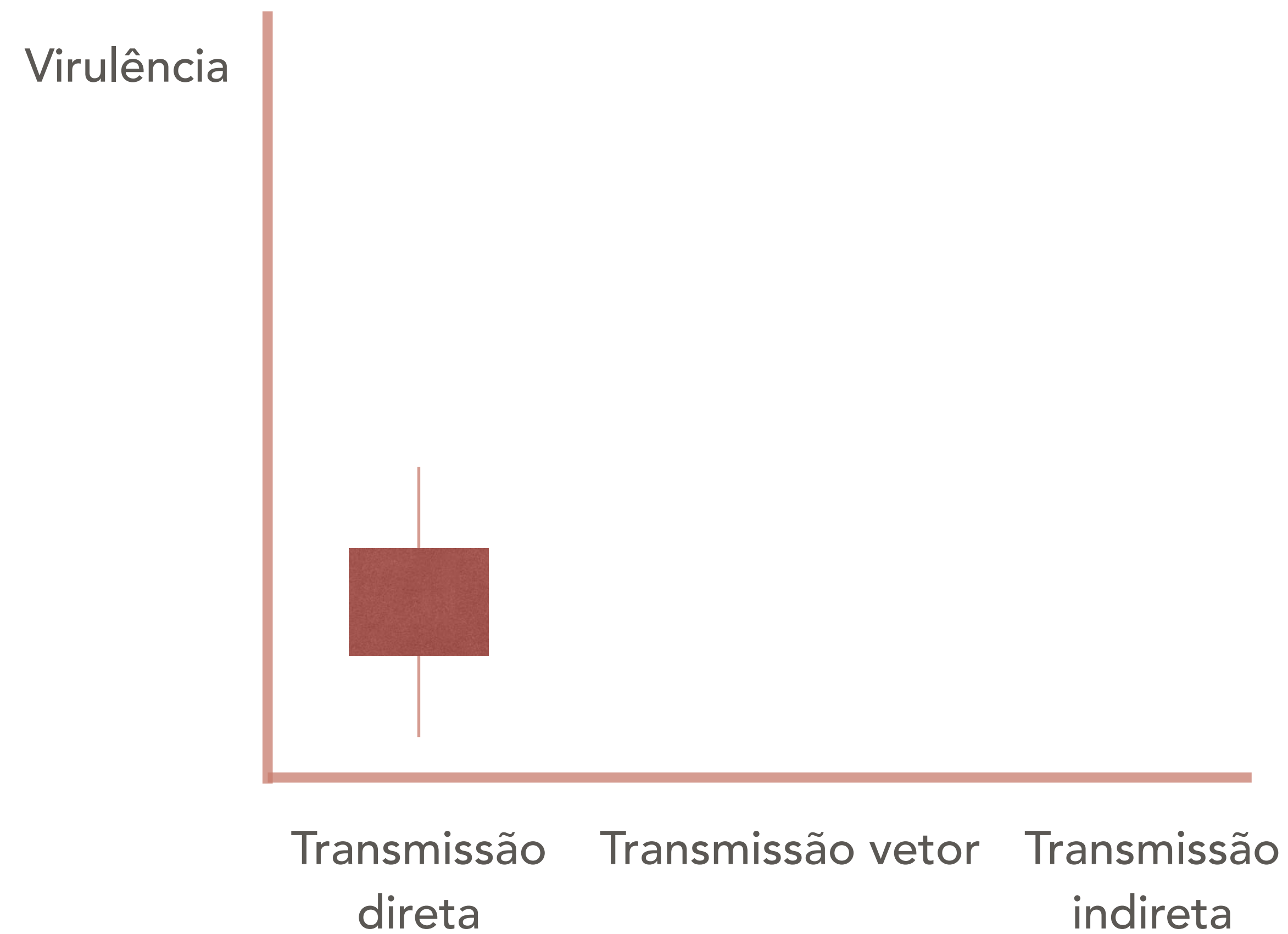
Virulência

Transmissão  
direta

Transmissão vetor

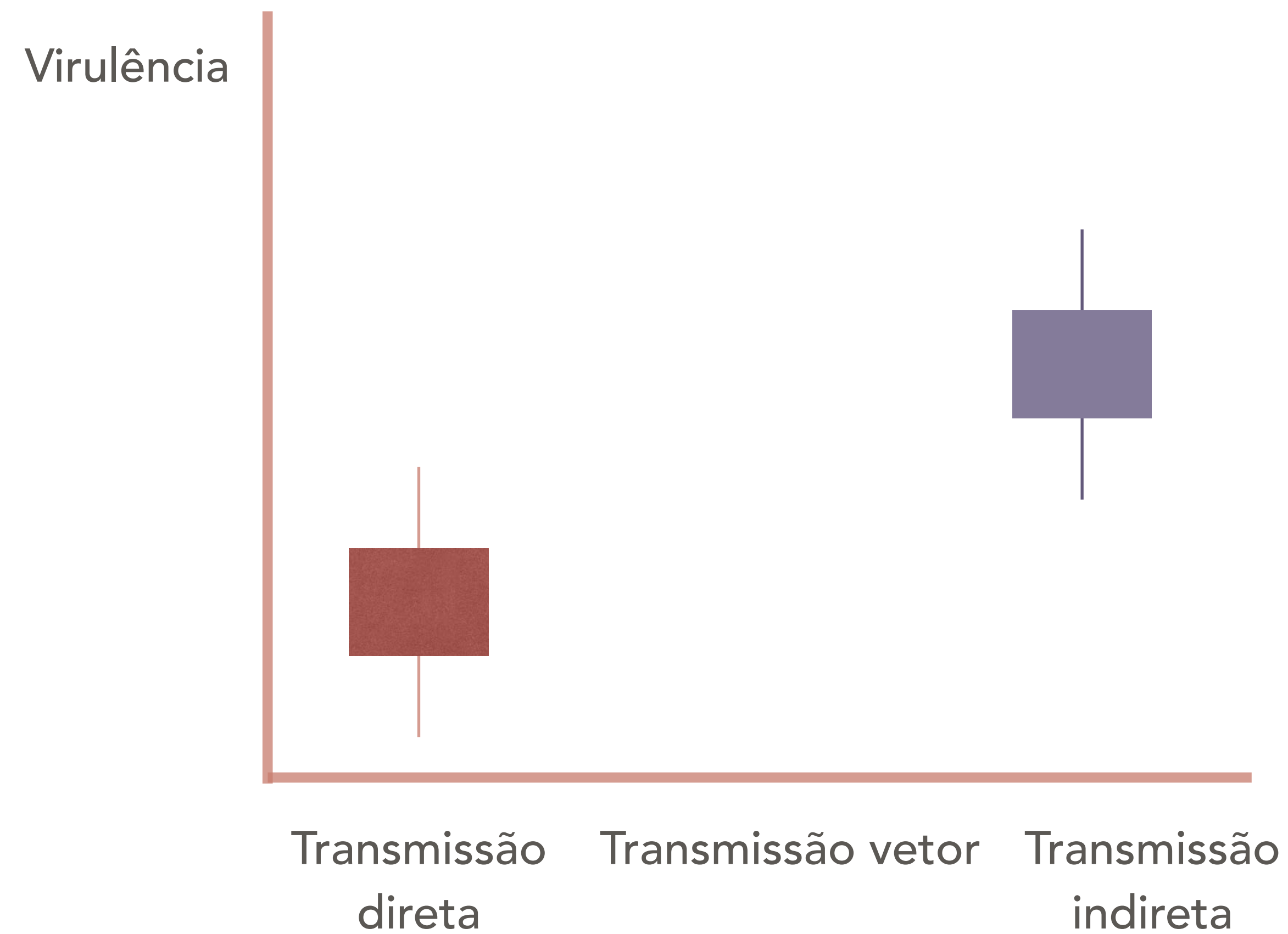
Transmissão  
indireta

# Transmissão por vetor- expectativa teórica

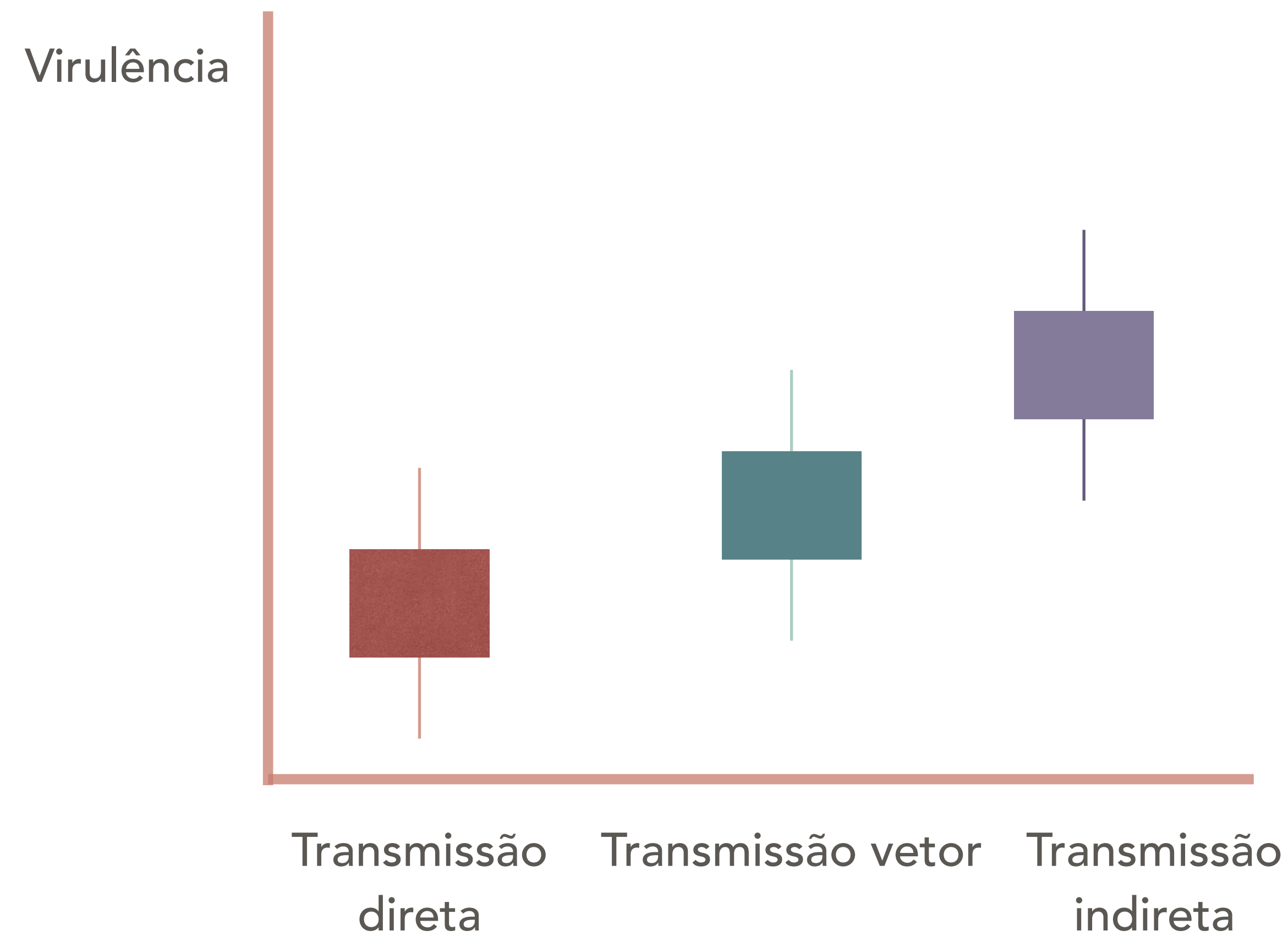




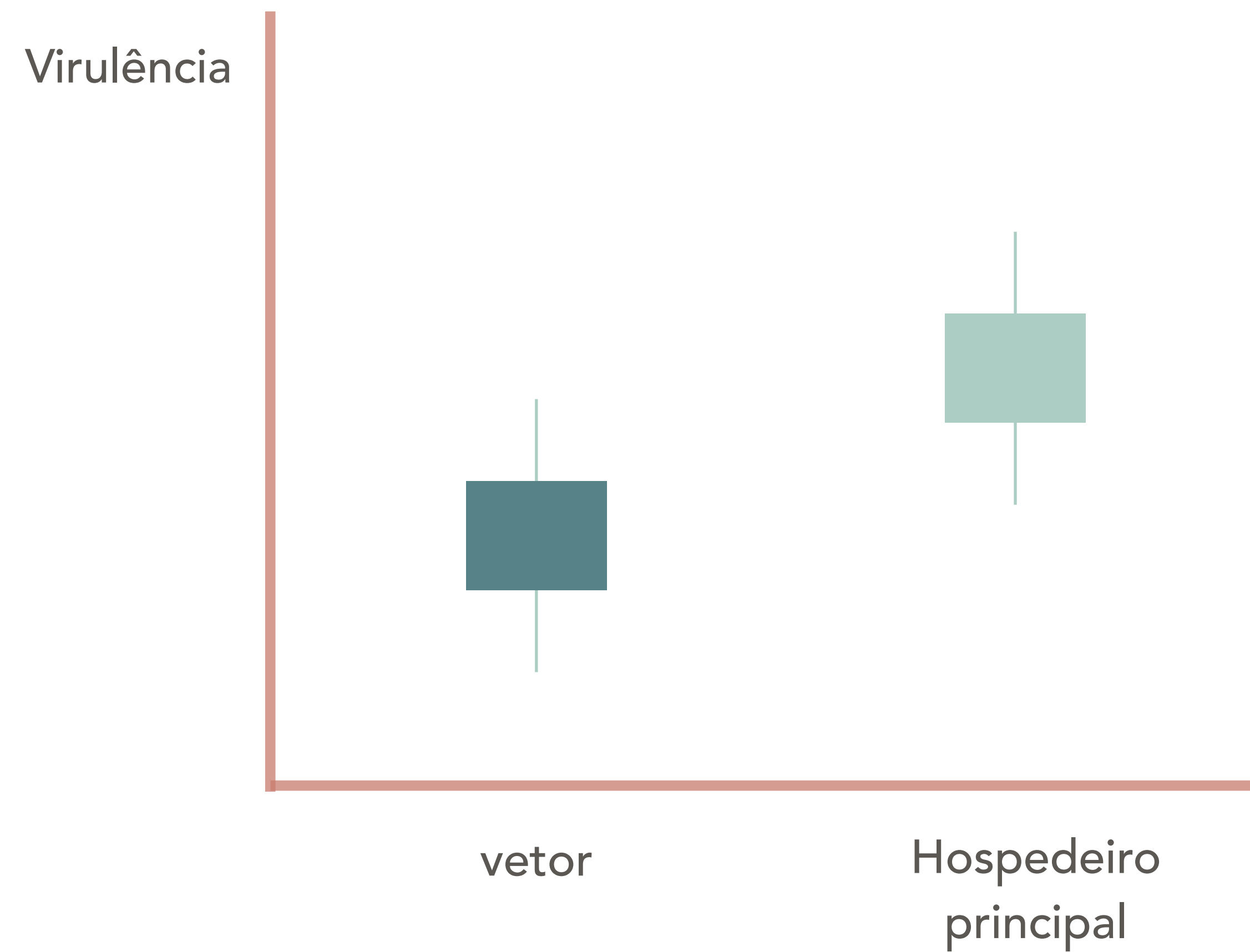
# Transmissão por vetor- expectativa teórica



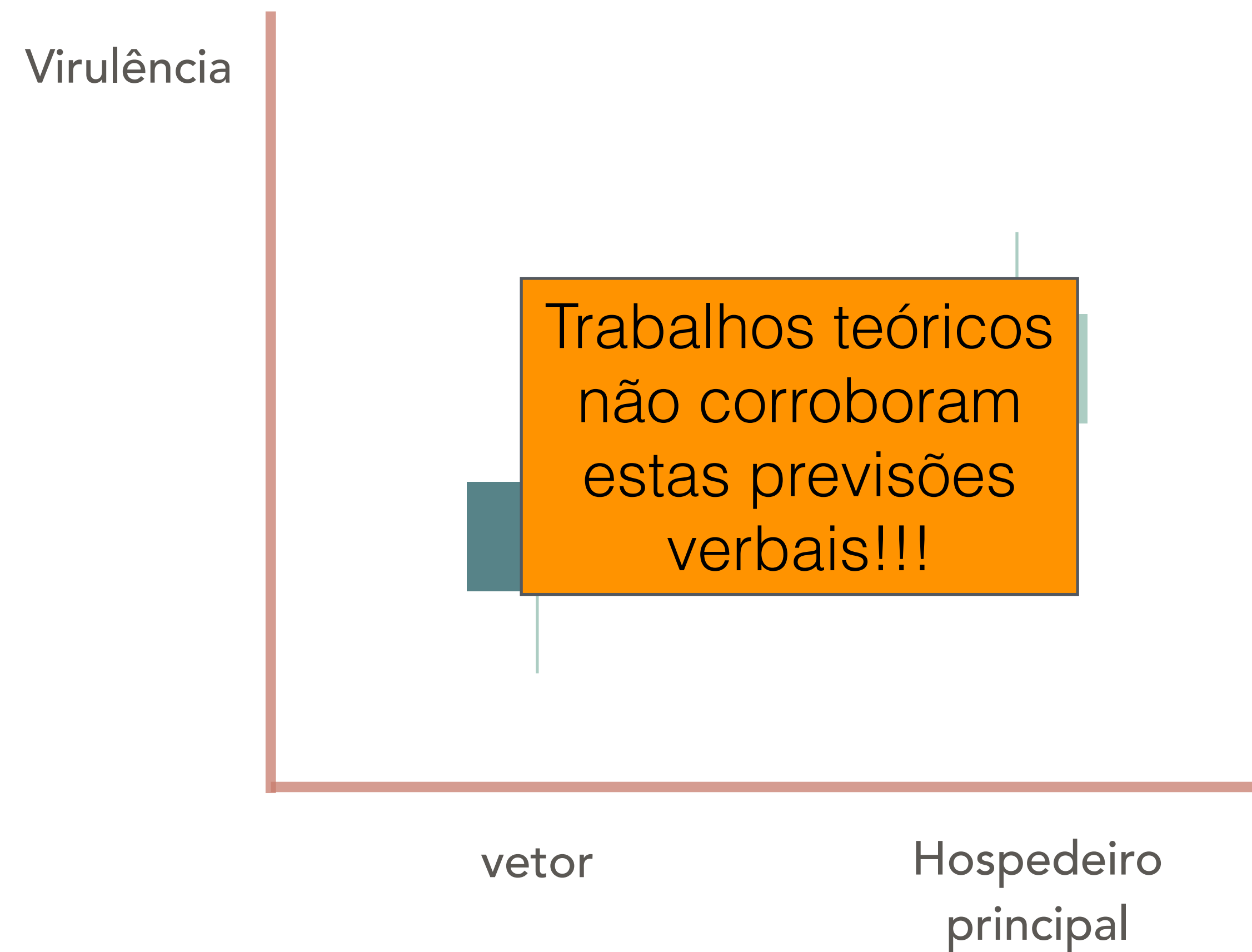
# Transmissão por vetor- expectativa teórica



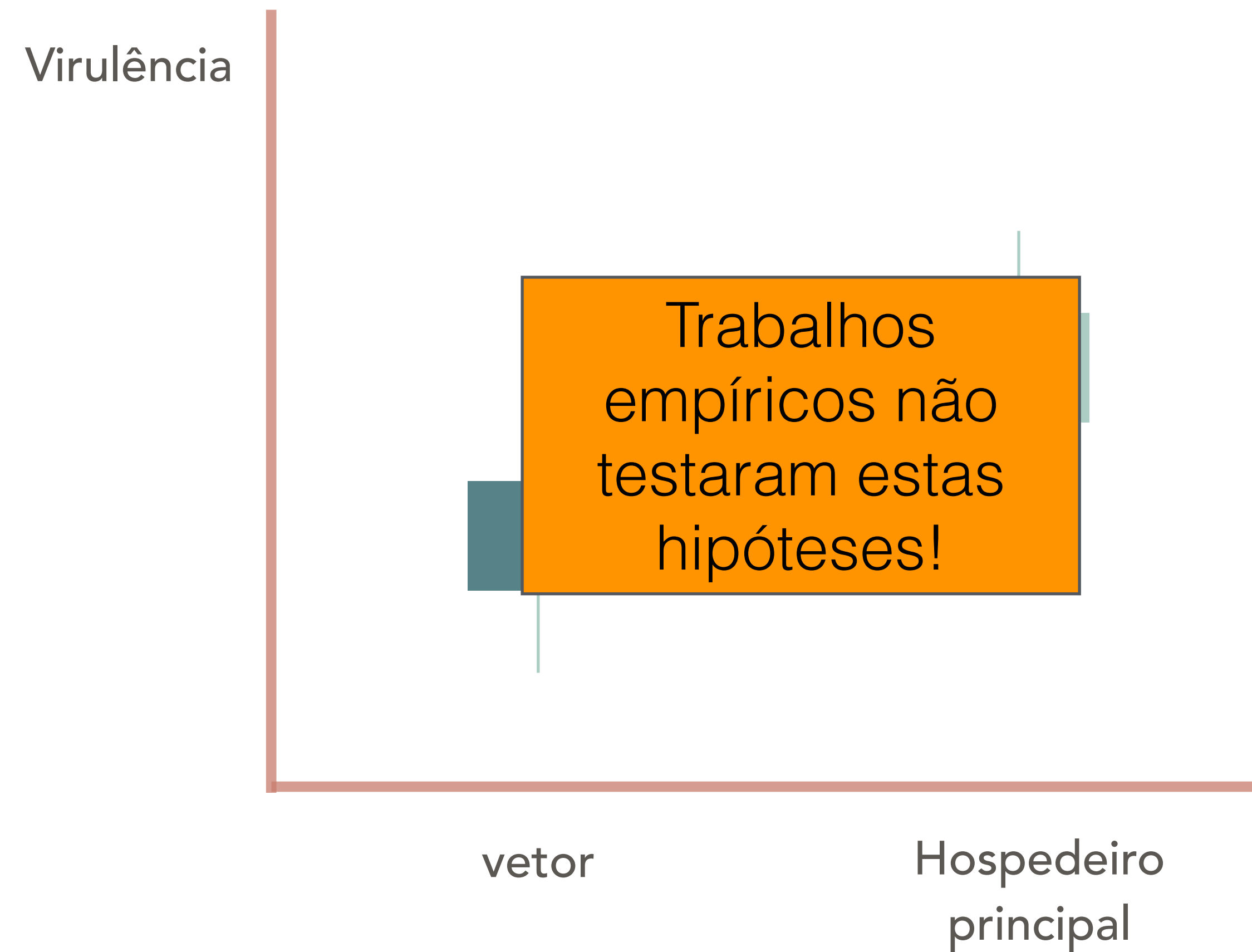
# Transmissão por vetor- expectativa teórica



# Transmissão por vetor- expectativa teórica



# Transmissão por vetor- expectativa teórica



# Doença de Chagas

Parasita

*Trypanosoma cruzi*



Vetor

*Triatoma infestans*



Hospedeiro definitivo

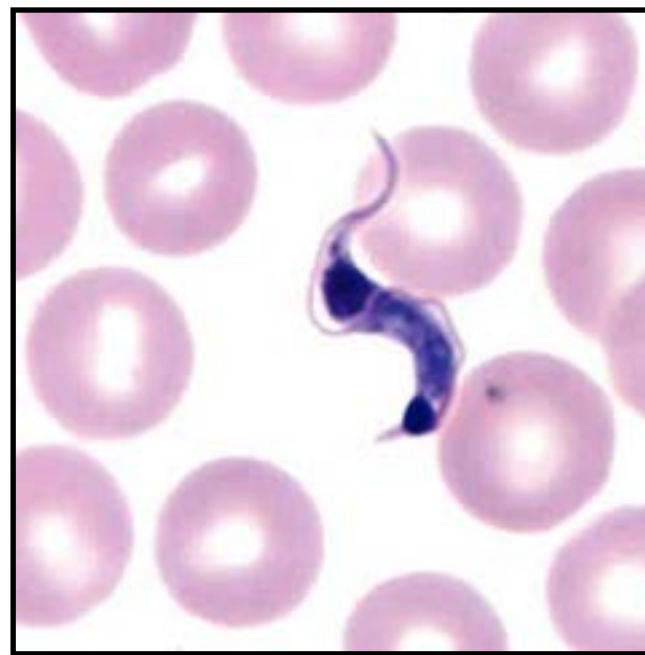
*Homo sapiens*



# Doença de Chagas

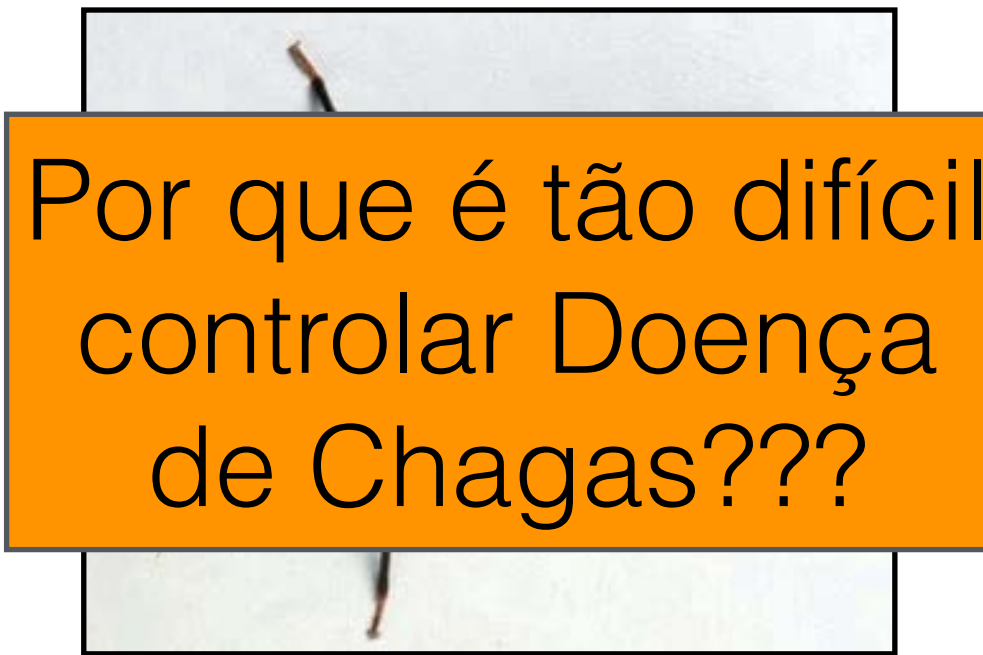
Parasita

*Trypanosoma cruzi*



Vetor

*Triatoma infestans*



Hospedeiro definitivo

*Homo sapiens*



# Doença de Chagas

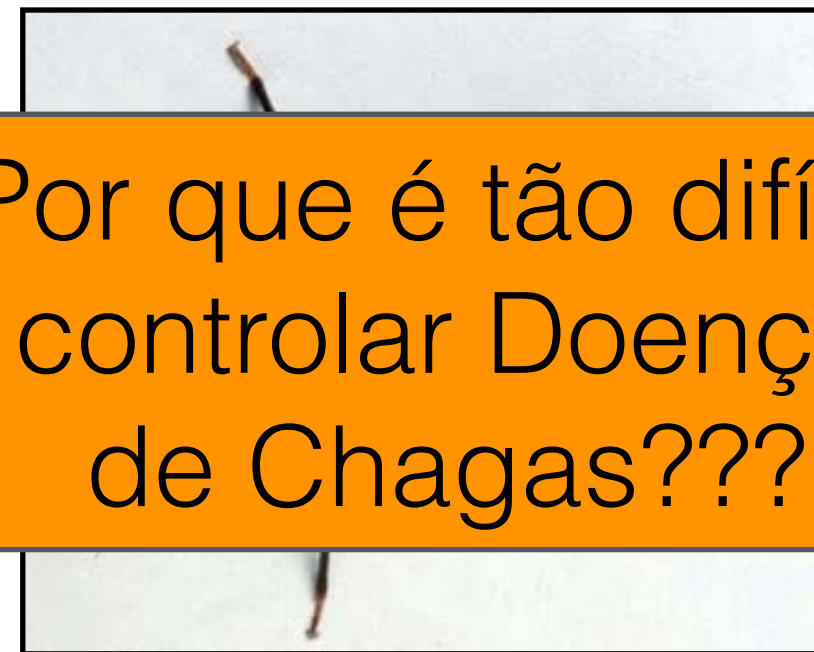
Parasita

*Trypanosoma cruzi*



Vetor

*Triatoma infestans*



Por que é tão difícil controlar Doença de Chagas???

Doença de terceiro mundo?

Hospedeiro definitivo

*Homo sapiens*





# Doença de Chagas

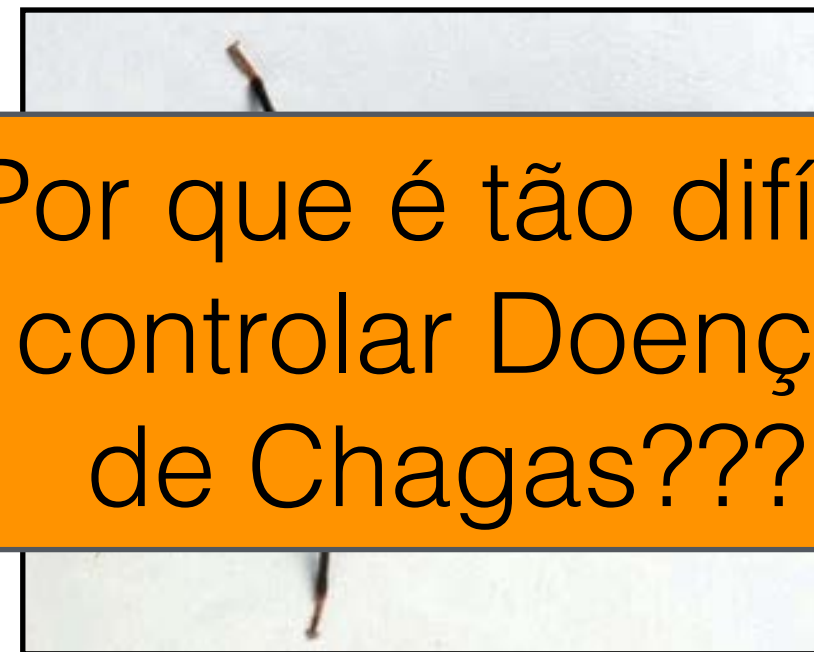
Parasita

*Trypanosoma cruzi*



Vetor

*Triatoma infestans*



Por que é tão difícil controlar Doença de Chagas???

Hospedeiro definitivo

*Homo sapiens*

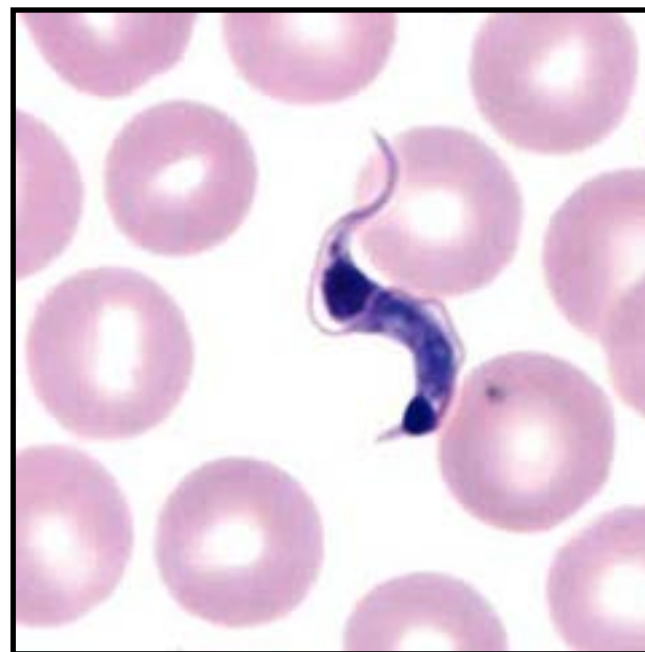


Como eliminar um protozoário?

# Doença de Chagas

Parasita

*Trypanosoma cruzi*



Vetor

*Triatoma infestans*



Hospedeiro definitivo

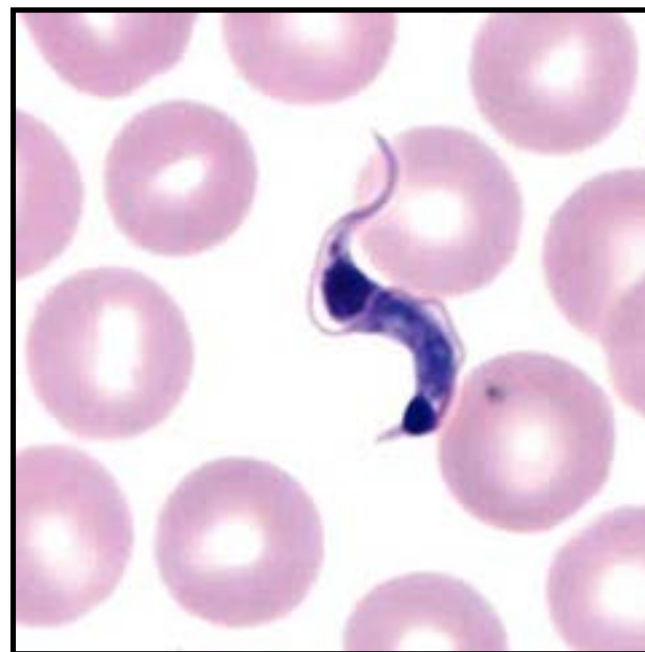
*Homo sapiens*



# Doença de Chagas

Parasita

*Trypanosoma cruzi*



Vetor

*Triatoma infestans*



Aumento de  
resistência a  
inseticida!!!!

Hospedeiro definitivo

*Homo sapiens*



# Doença de Chagas

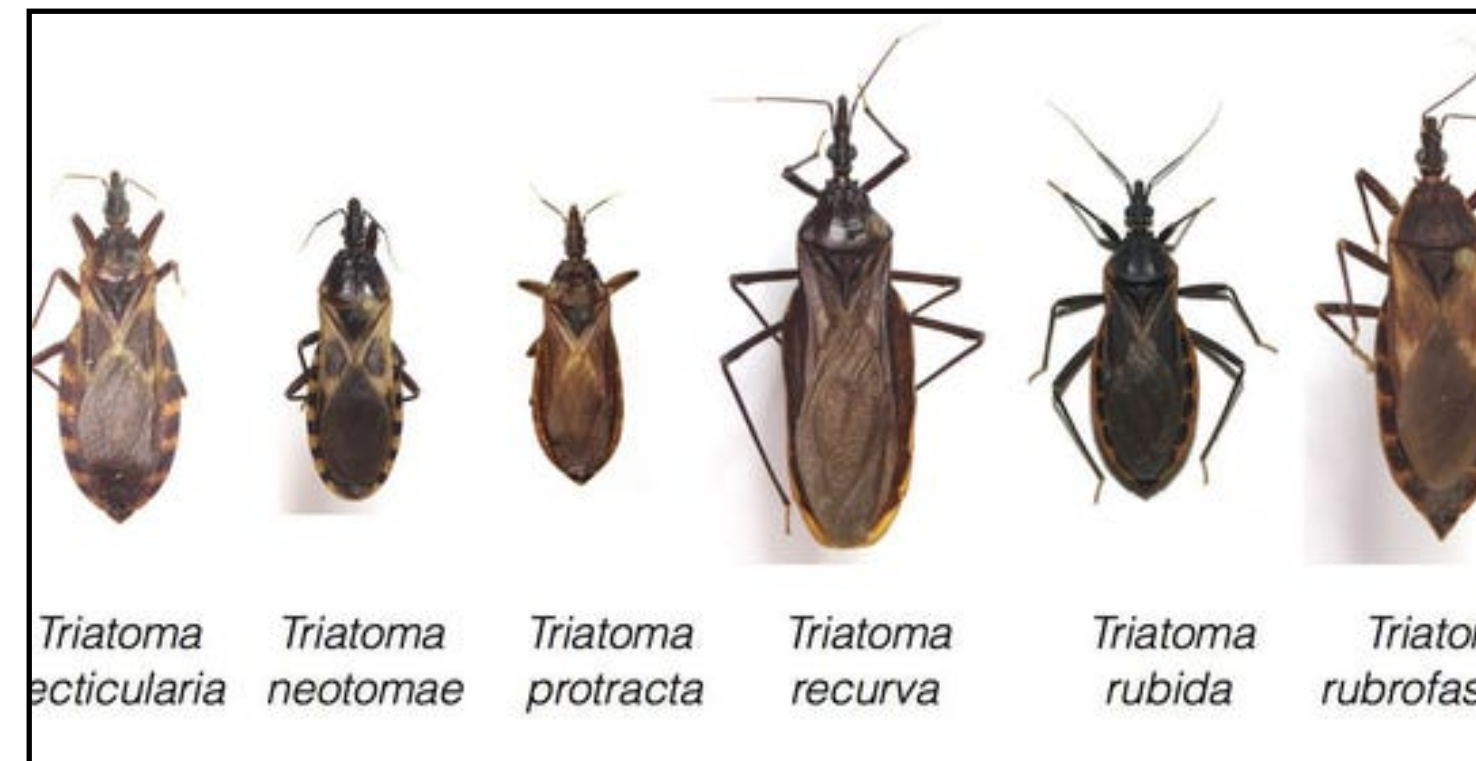
Parasita

*Trypanosoma cruzi*

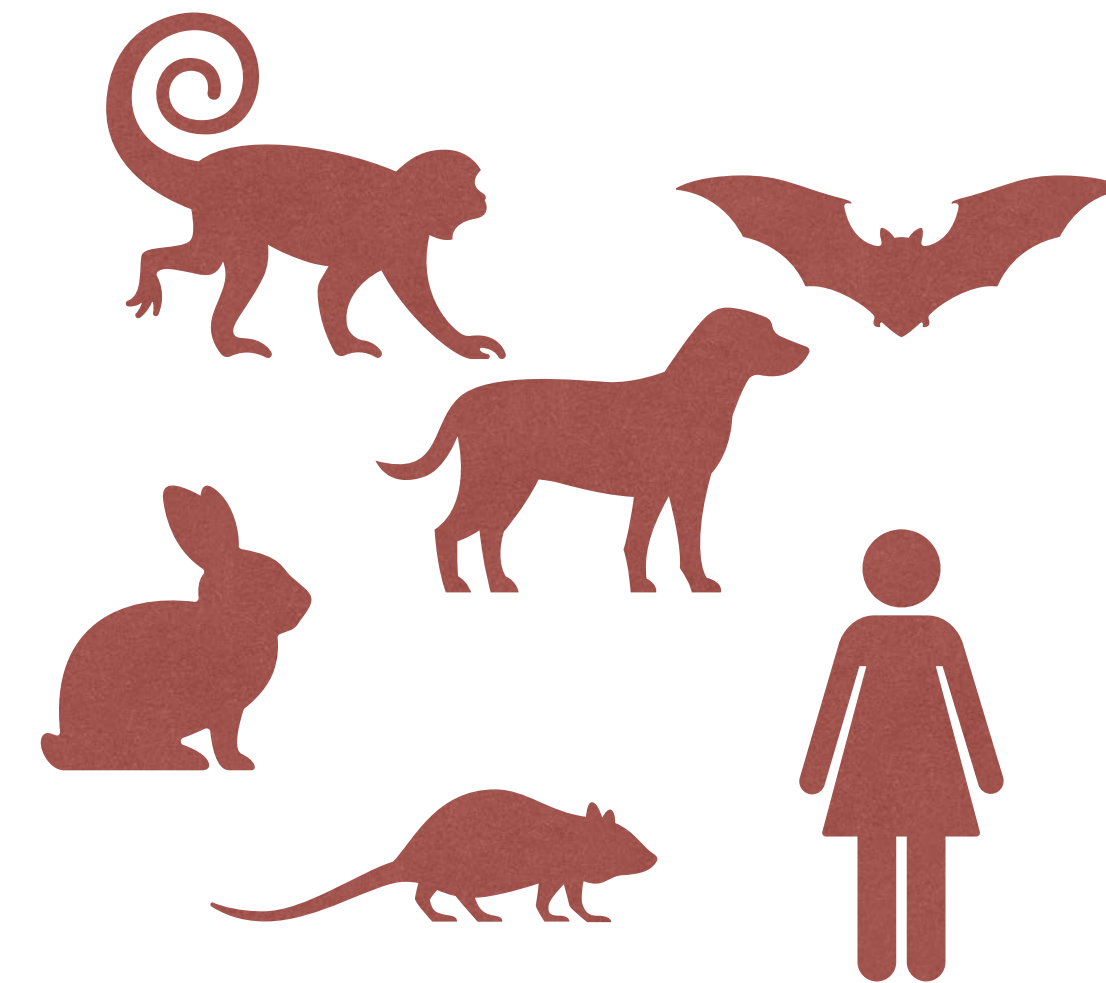


Vetor

Triatominae

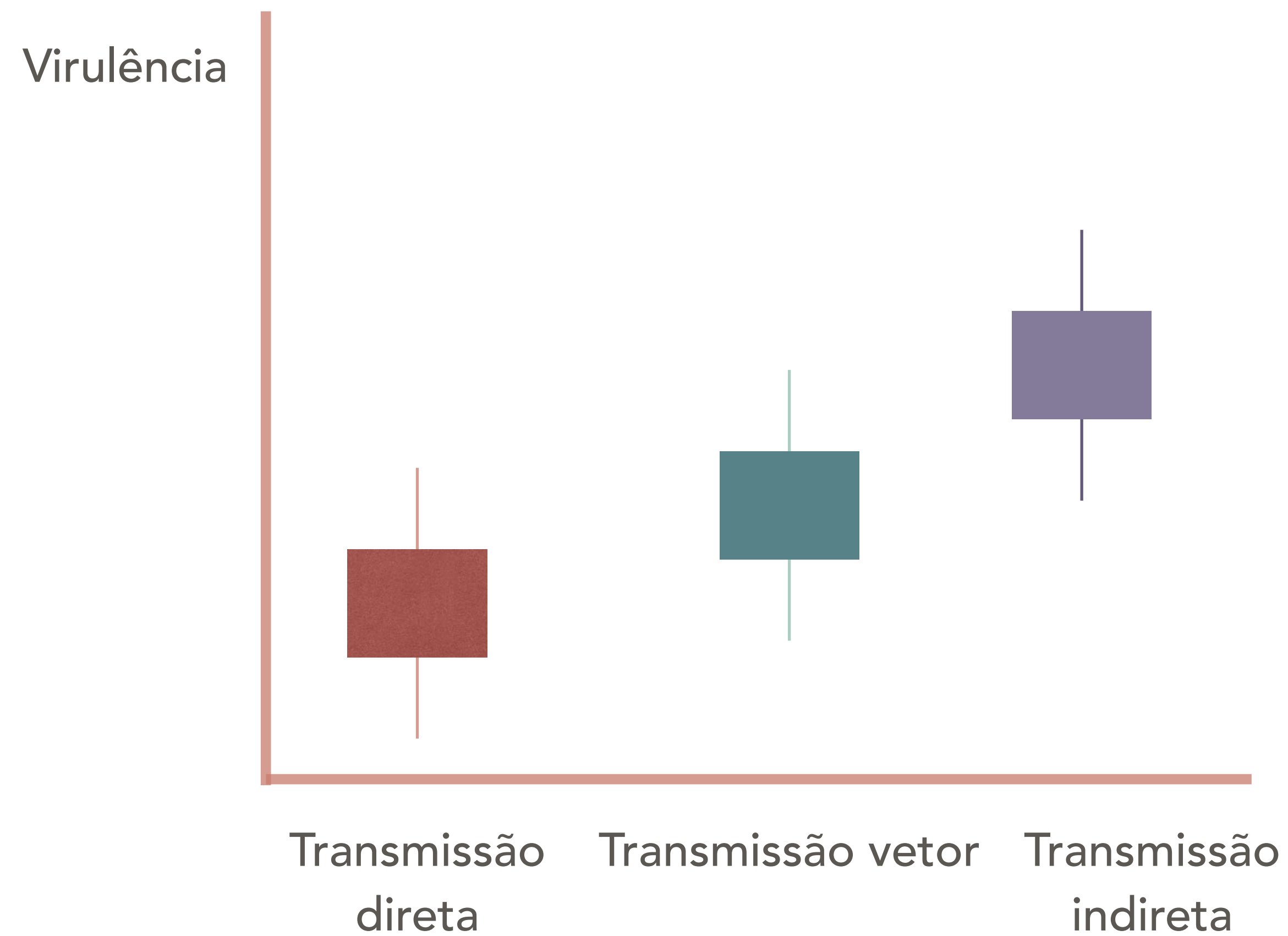


Hospedeiro definitivo



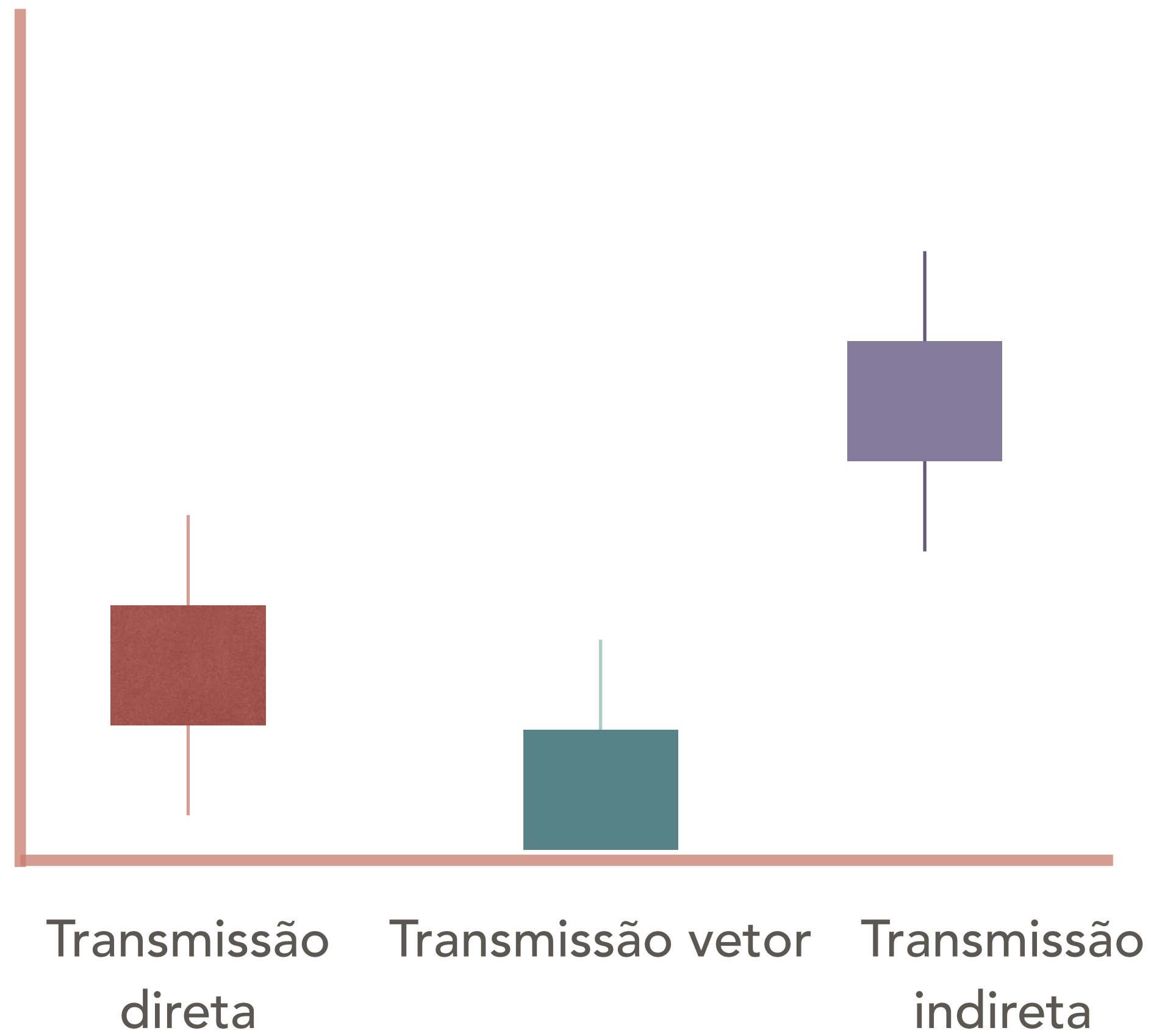
Rede complexas  
de vetores e  
hospedeiros!!!!

# Doença de Chagas- expectativa teórica

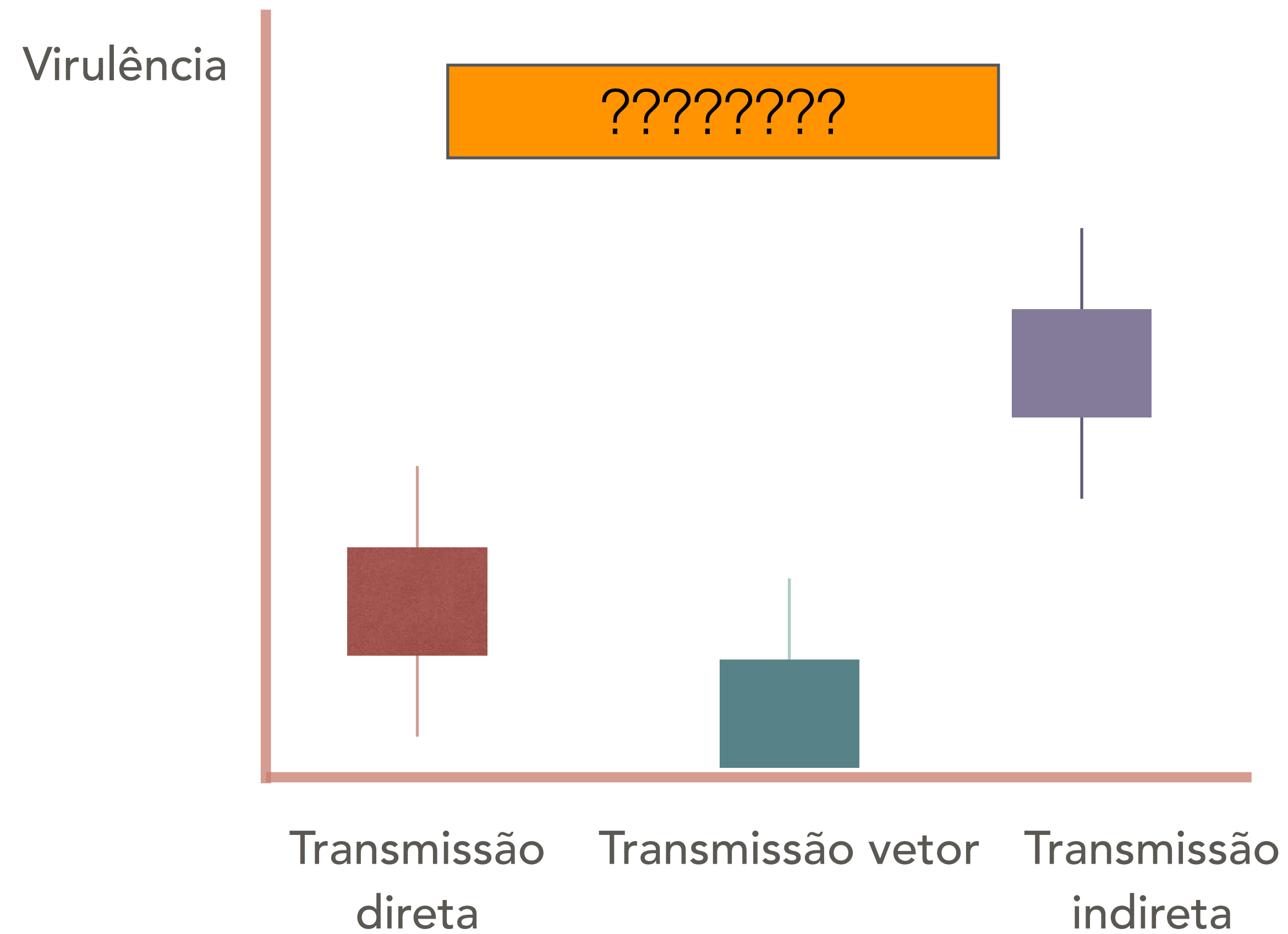


# Doença de Chagas

Virulência



# Doença de Chagas



# Doença de Chagas

Virulência

?????????

The **Bill & Melinda Gates** Foundation today announced four grants totaling **\$68.2 million** to help accelerate research on **neglected tropical diseases**, including hookworm, leishmaniasis, and **trypanosomiasis**, which kill or disable millions of people in the world's poorest countries every year.

Transmissão  
direta

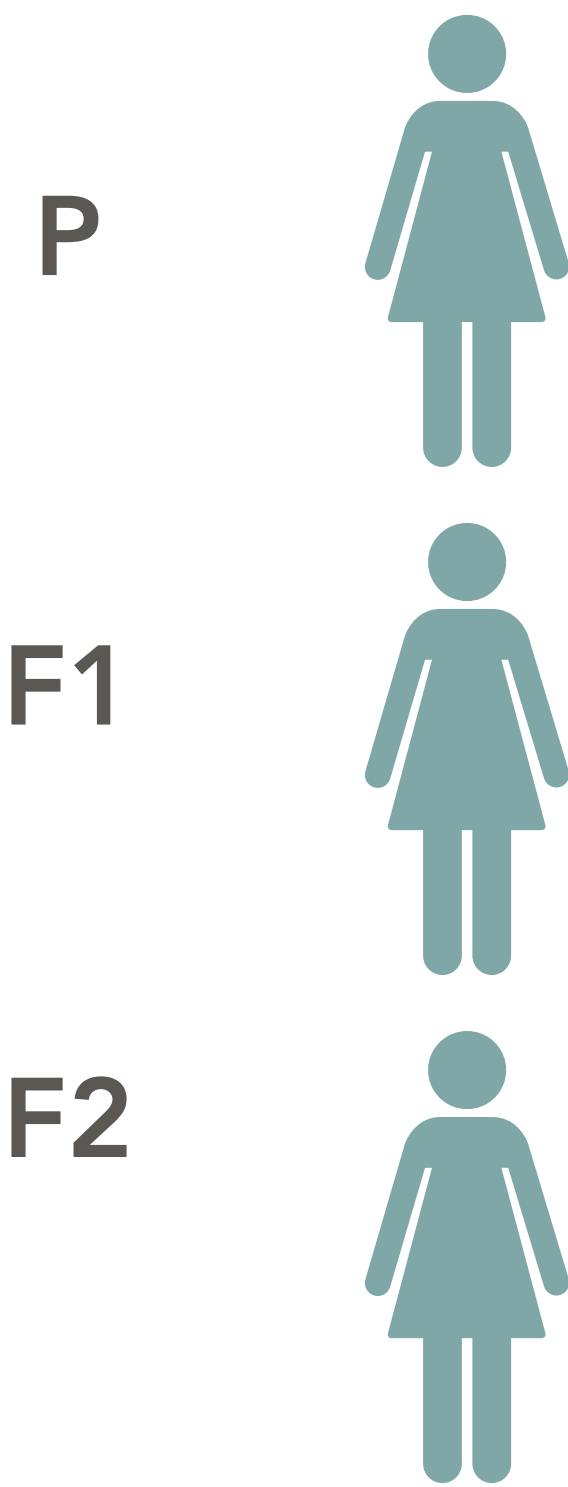
Transmissão vetor

Transmissão  
indireta

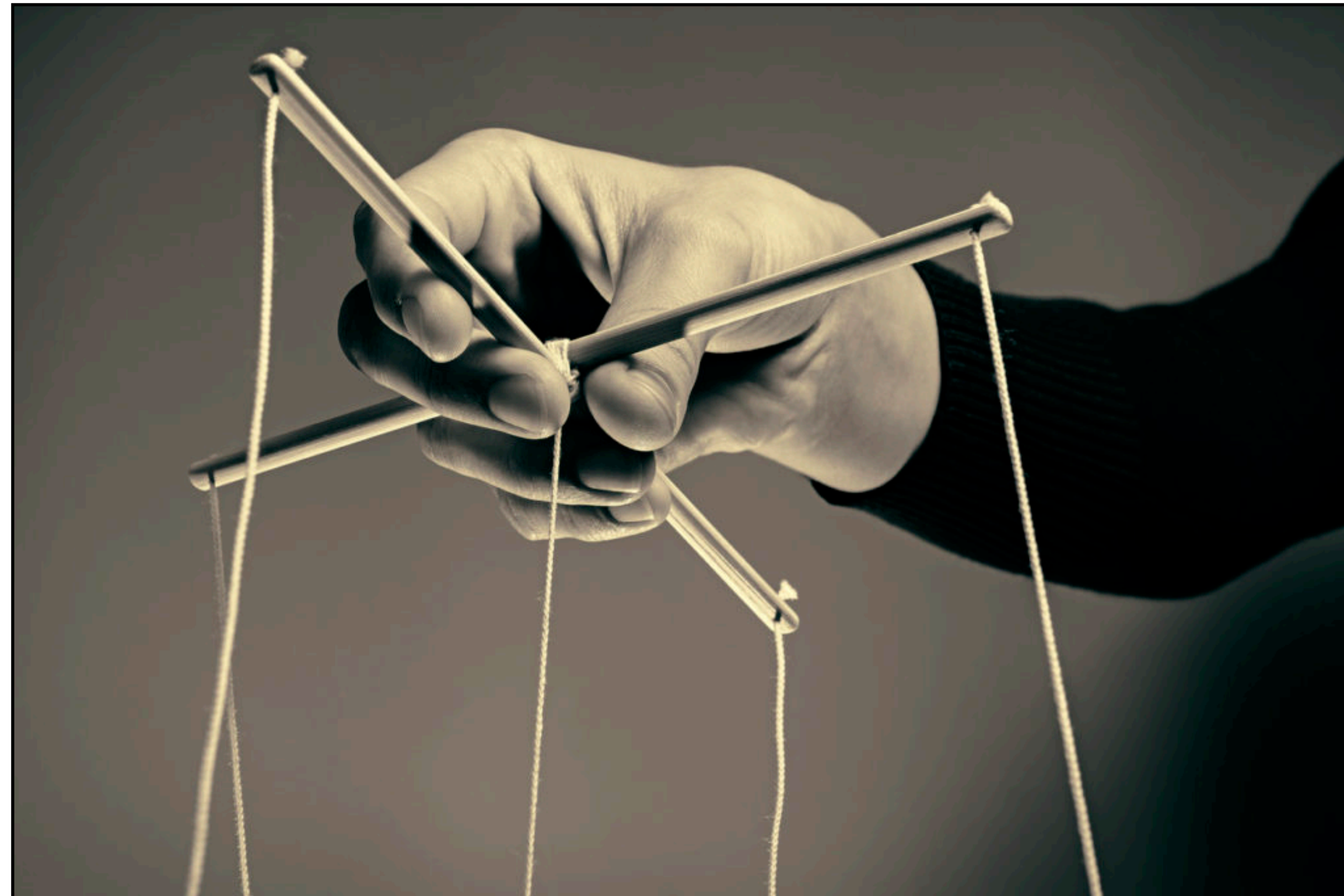


# Transmissão vertical

# Transmissão vertical



# *Wolbachia* - the puppet master

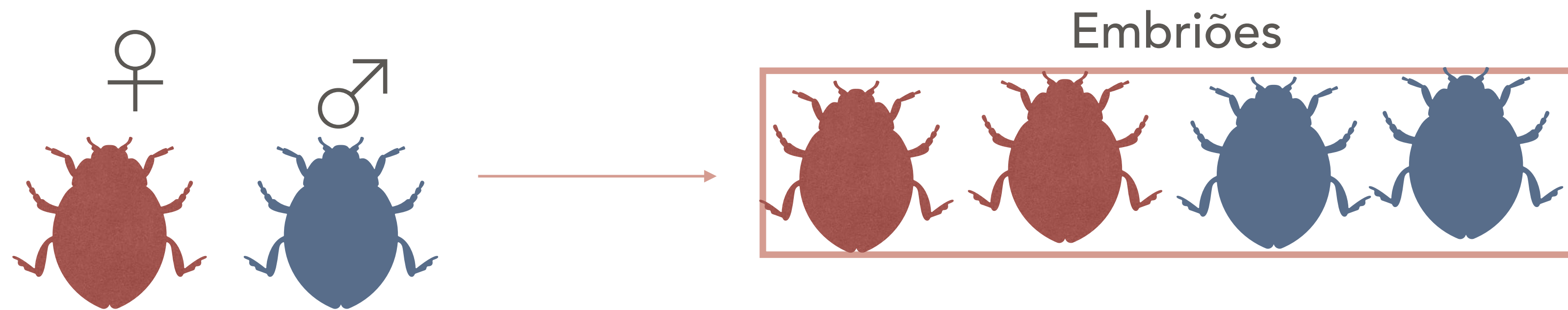


# *Wolbachia* - the puppet master

65% das espécies de insetos!!! Ocorrem também em crustáceos, aracnídeos e nematodos

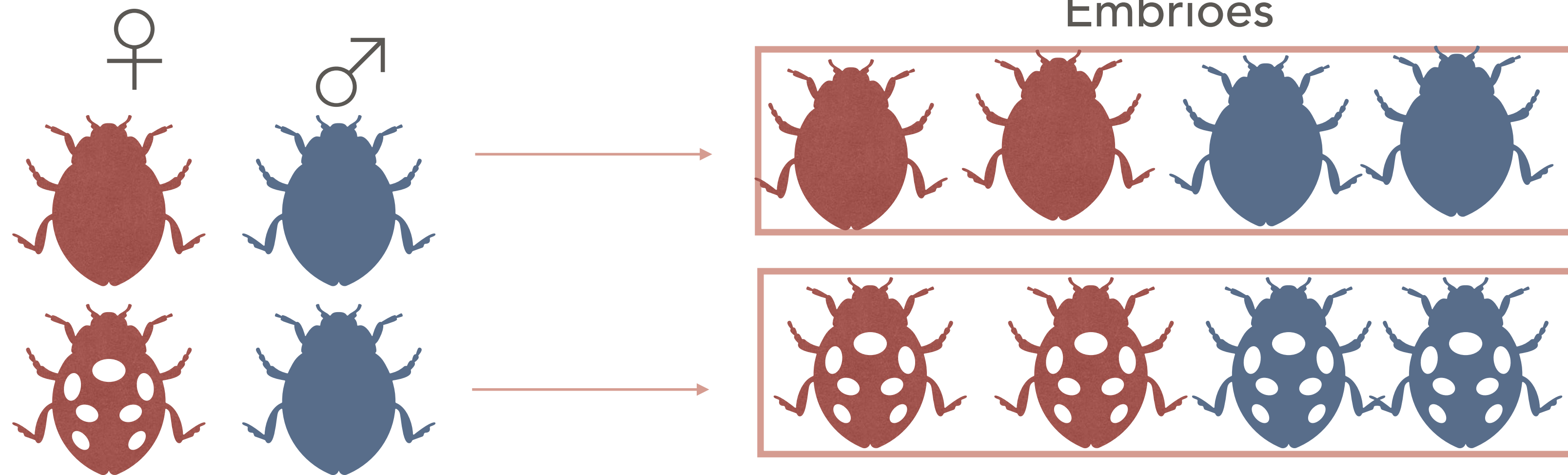
# *Wolbachia* - the puppet master

Manipula a reprodução dos infectados!!!



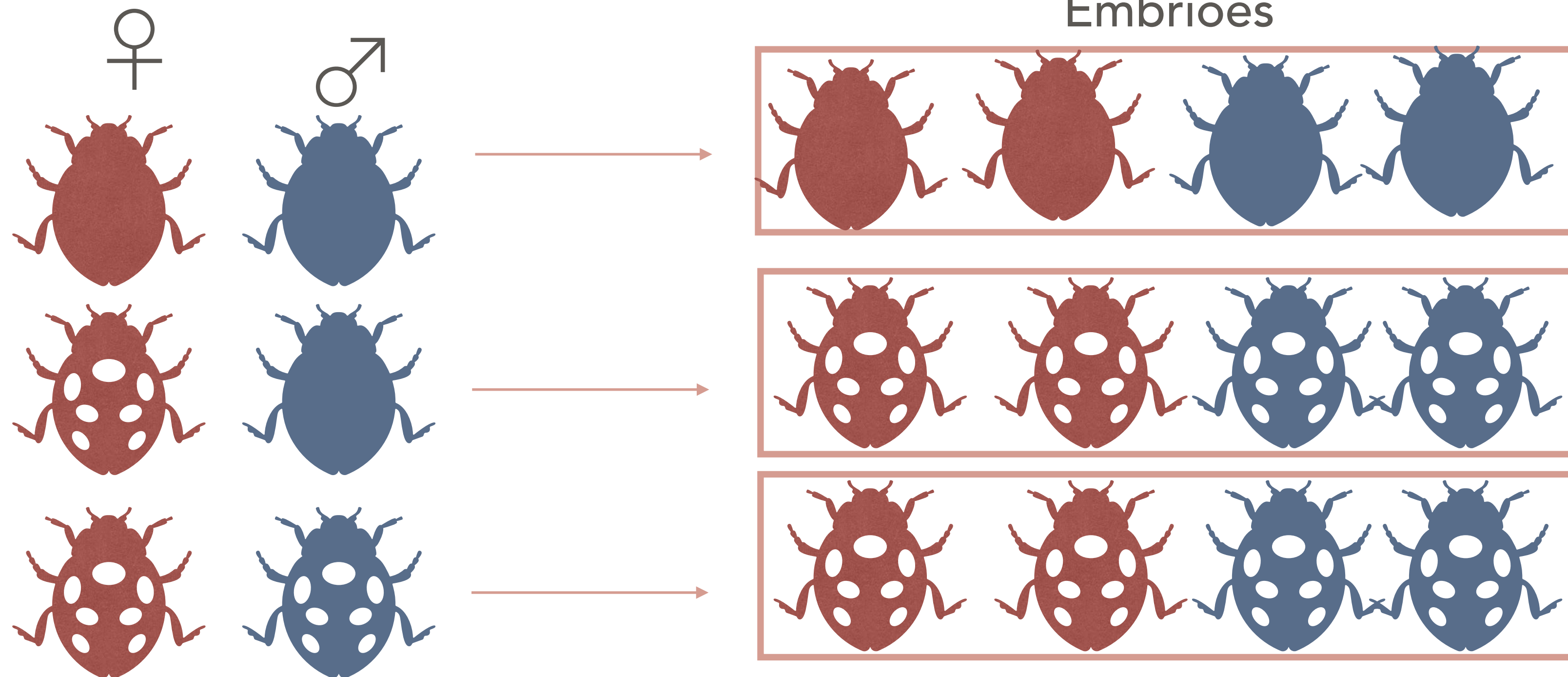
# Wolbachia - the puppet master

Manipula a reprodução dos infectados!!!



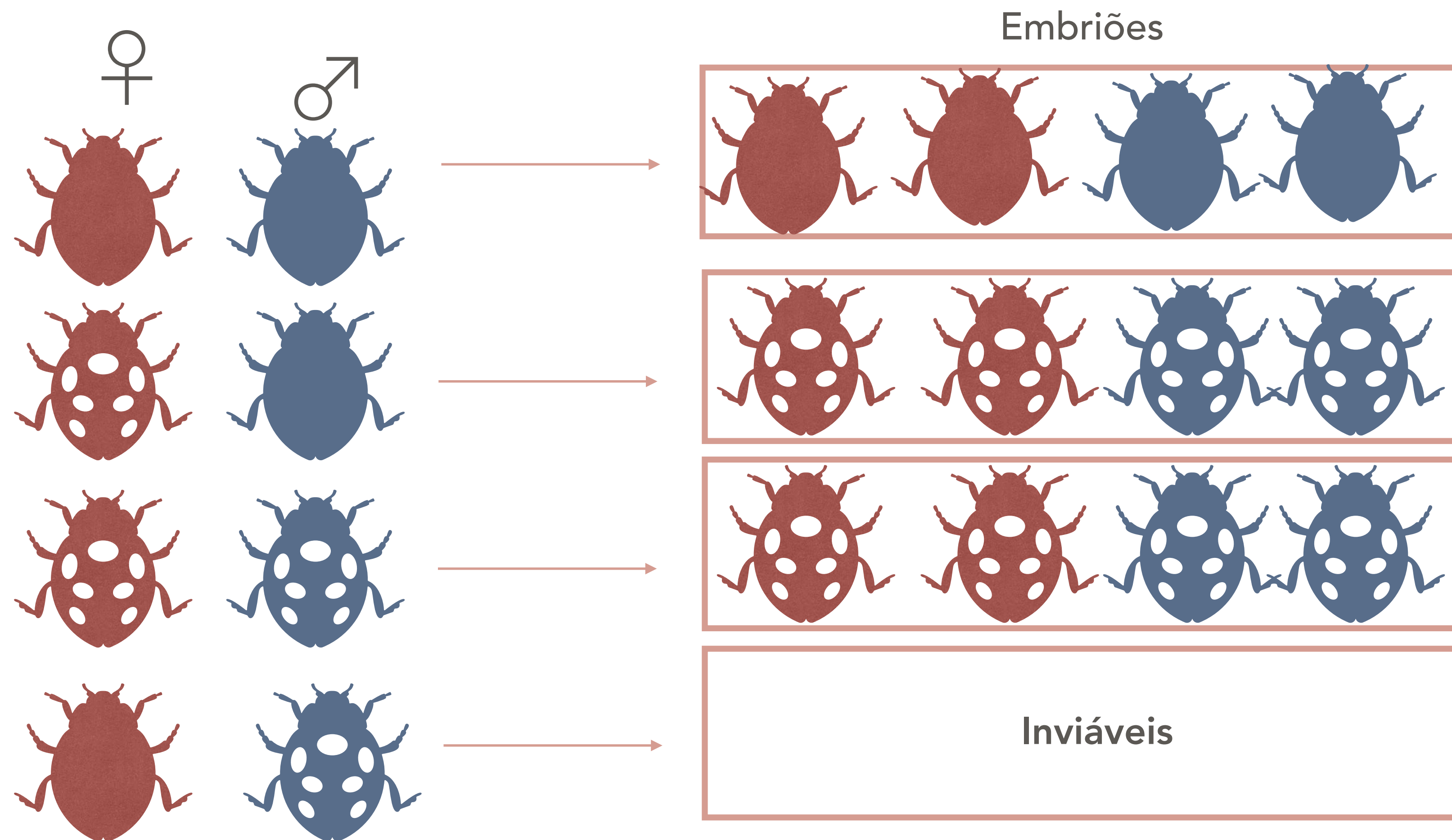
# Wolbachia - the puppet master

Manipula a reprodução dos infectados!!!



# Wolbachia - the puppet master

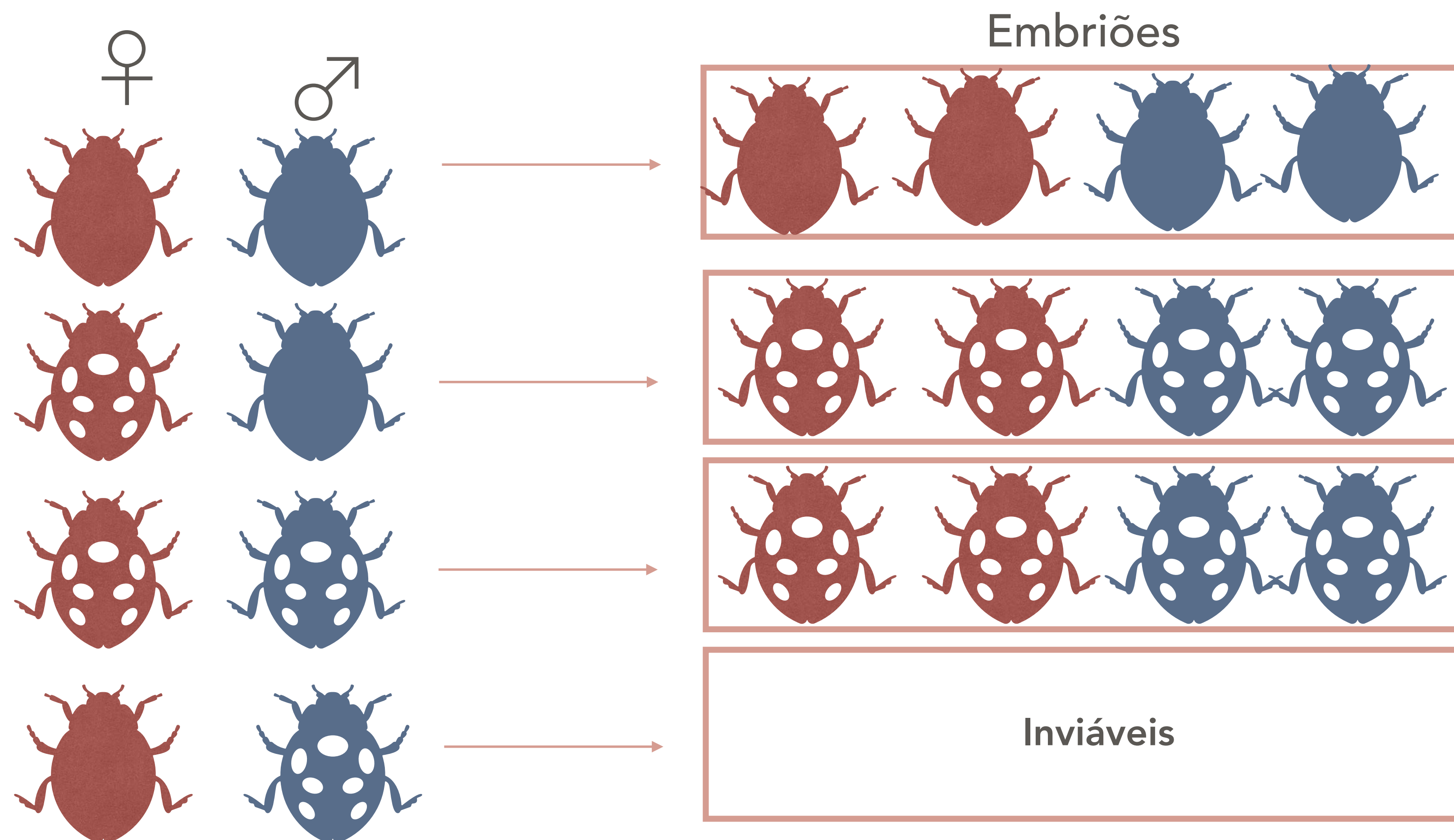
Manipula a reprodução dos infectados!!!





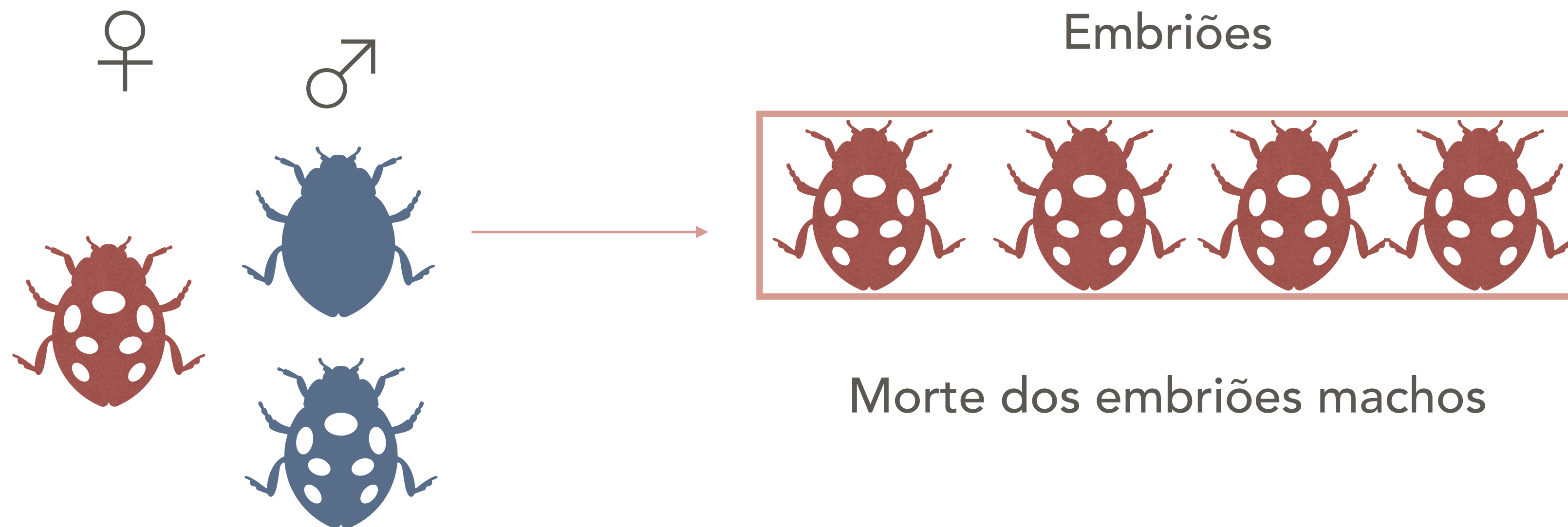
# Wolbachia - the puppet master

Manipula a reprodução dos infectados!!!



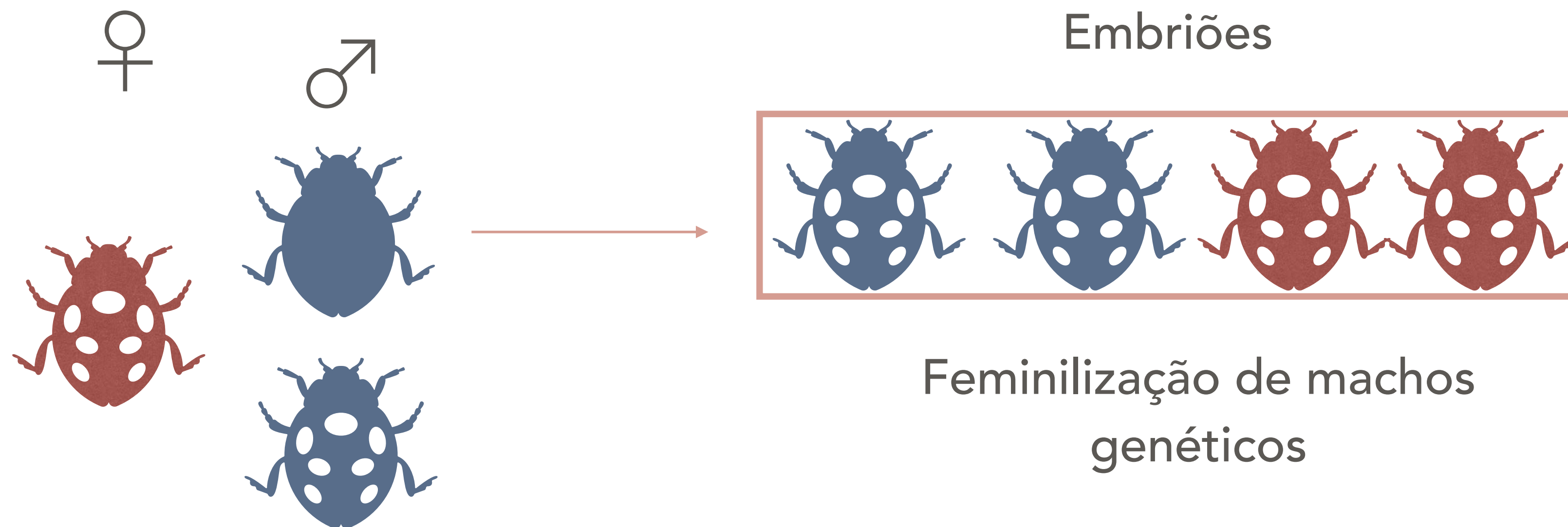
# *Wolbachia* - the puppet master

Manipula a reprodução dos infectados!!!



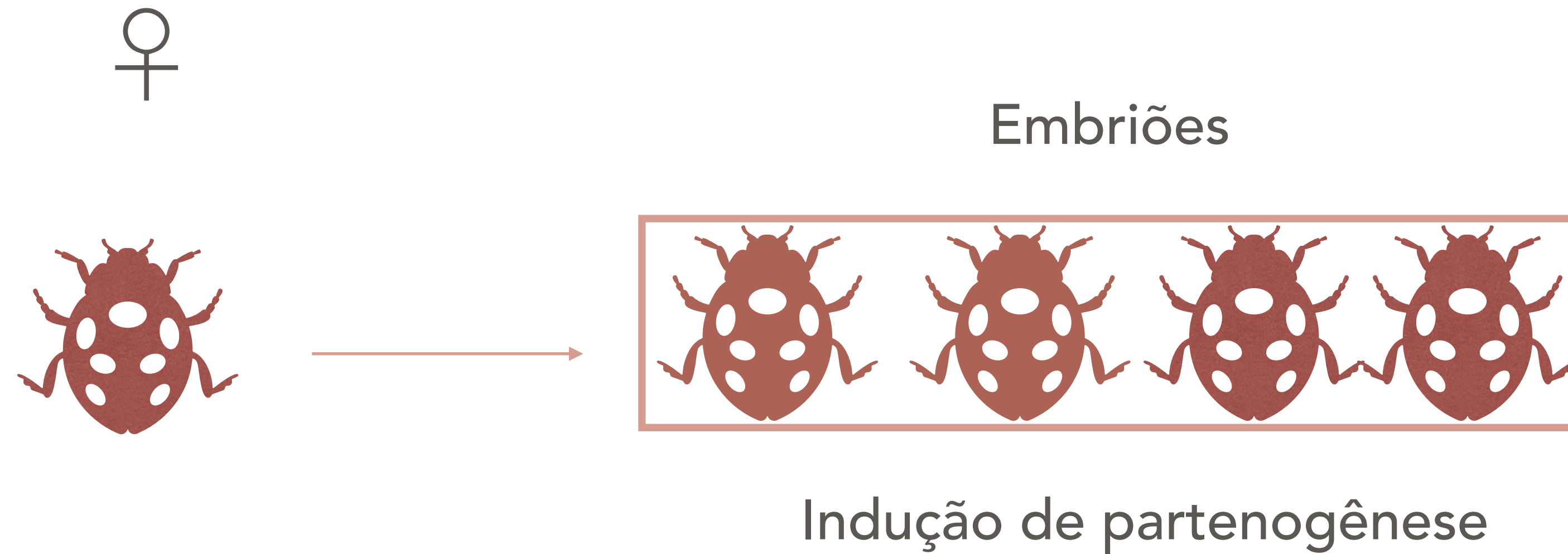
# *Wolbachia* - the puppet master

Manipula a reprodução dos infectados!!!



# *Wolbachia* - the puppet master

Manipula a reprodução dos infectados!!!

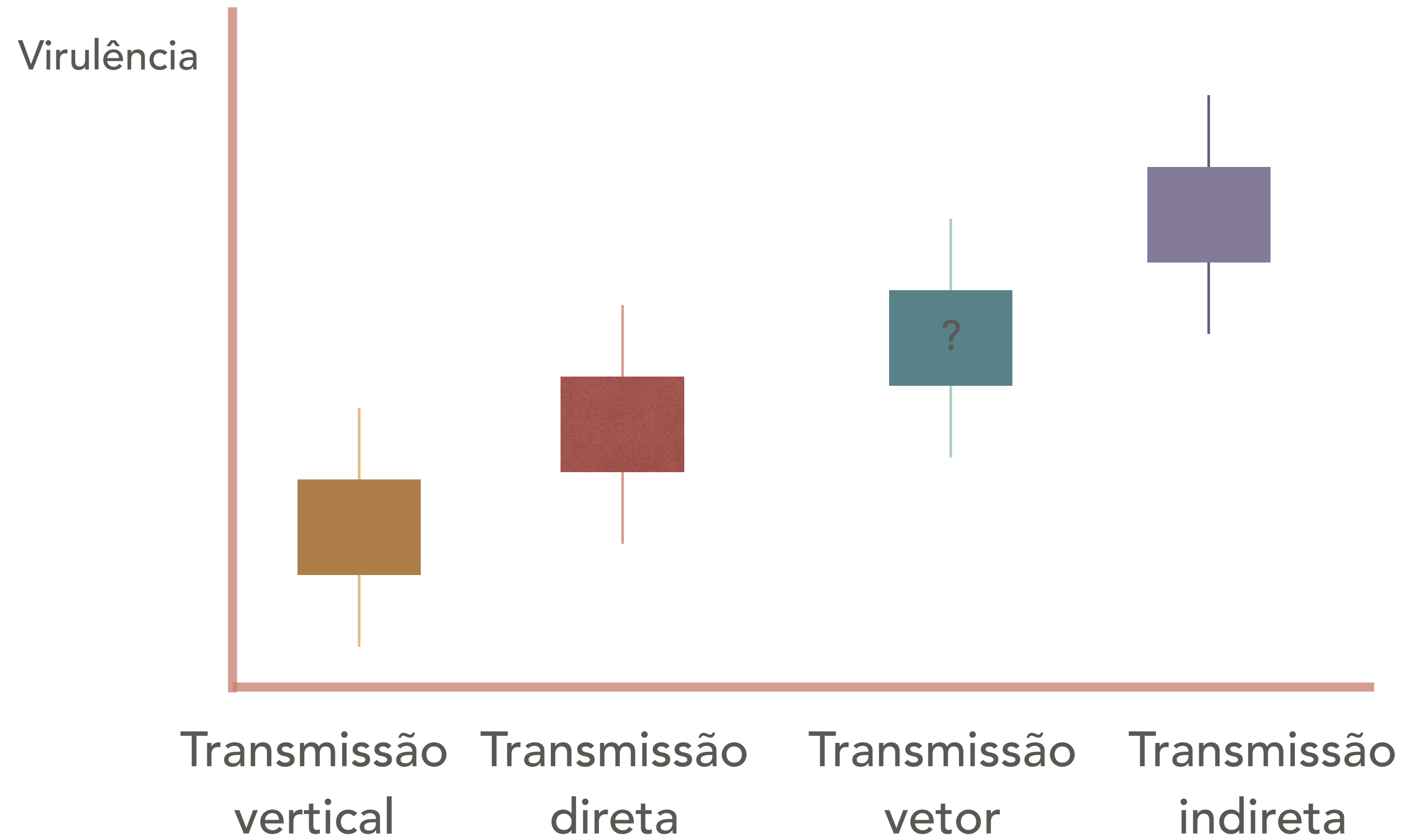


# *Wolbachia* - Controle da dengue

Testes preliminares parecem bastante promissores!

- Mosquitos infectados por *Wolbachia* tem uma custo maior para se reproduzir o que diminui o tamanho populacional
- Competição entre *Wolbachia* e vírus da dengue leva a uma diminuição da frequência do vírus

# Evolução de virulência



# Evolução sexo

# **Evolução sexo**

**Reprodução  
sexuada**

**Reprodução  
assexuada**



# **Evolução sexo**

**Reprodução  
sexuada**

**Reprodução  
assexuada**

**Vamos debater????**

# O custo do macho

# O custo do macho



**MANSPLAIN**  
THE MAGAZINE FOR WOMEN, WRITTEN BY MEN

The *truth* about sexism

*Confused* by politics?  
Find out what to think

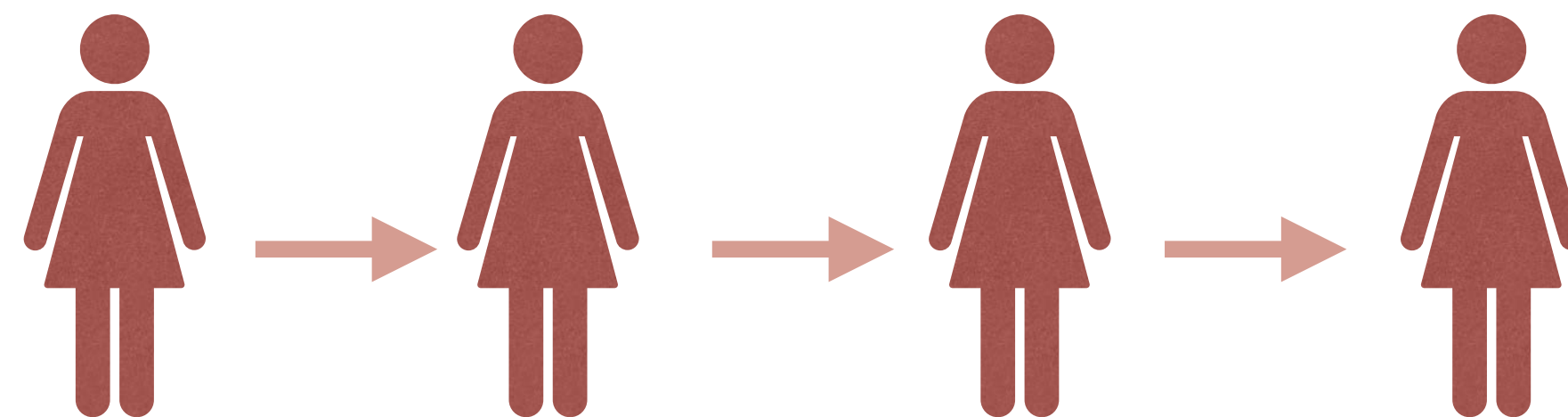
**EVERYTHING YOU KNOW IS WRONG**

*but don't worry your pretty little head about it*

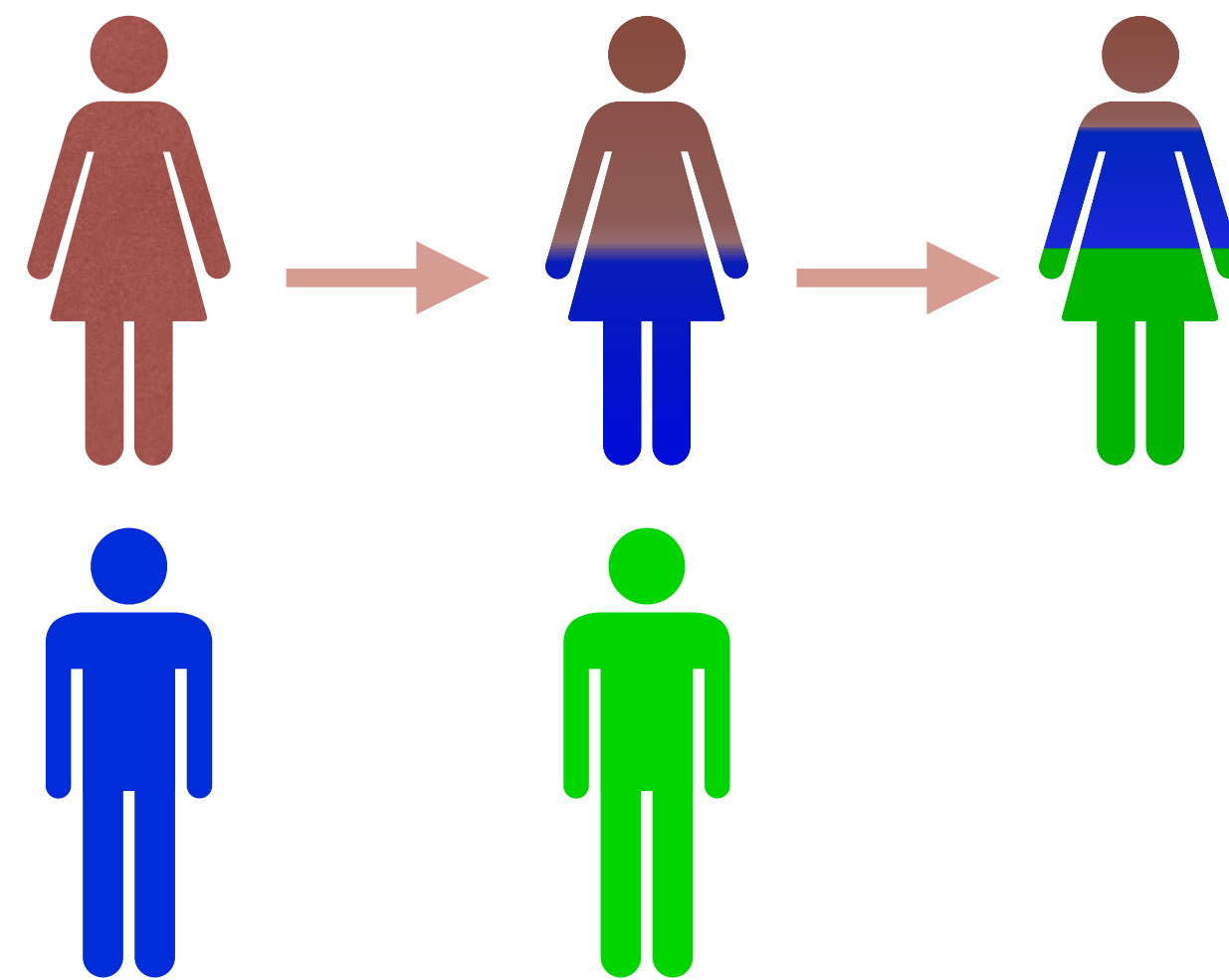
**158** facts & opinions you *must* listen to

**NEW** from the makers of *Actually*, the monthly look at ethics in games journalism

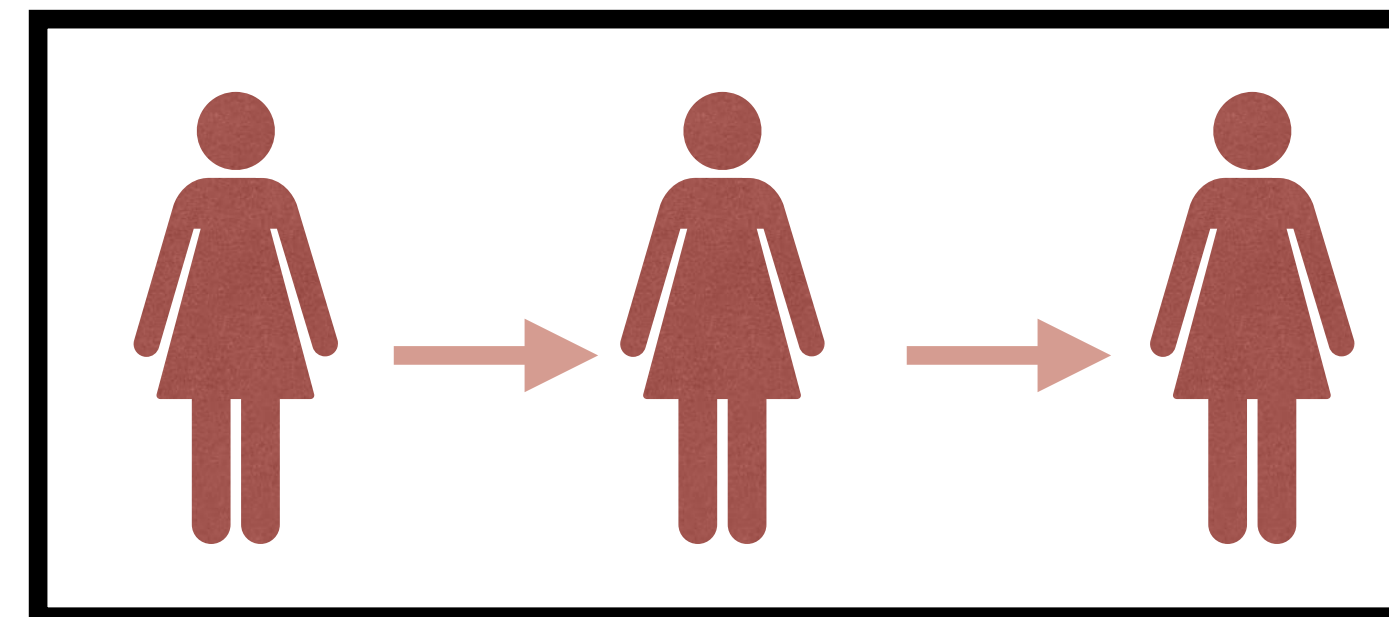
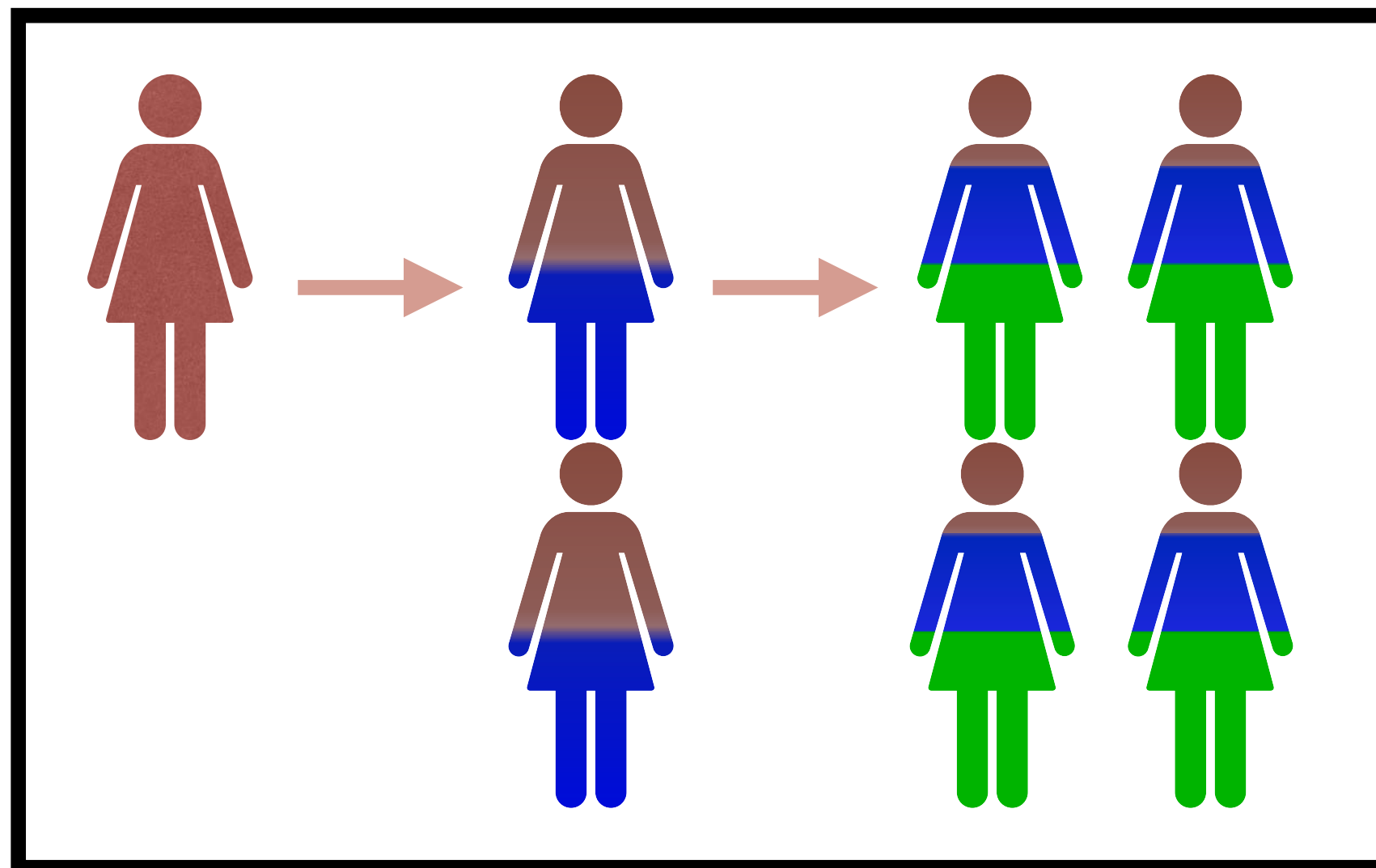
# O paradoxo do sexo



# O paradoxo do sexo

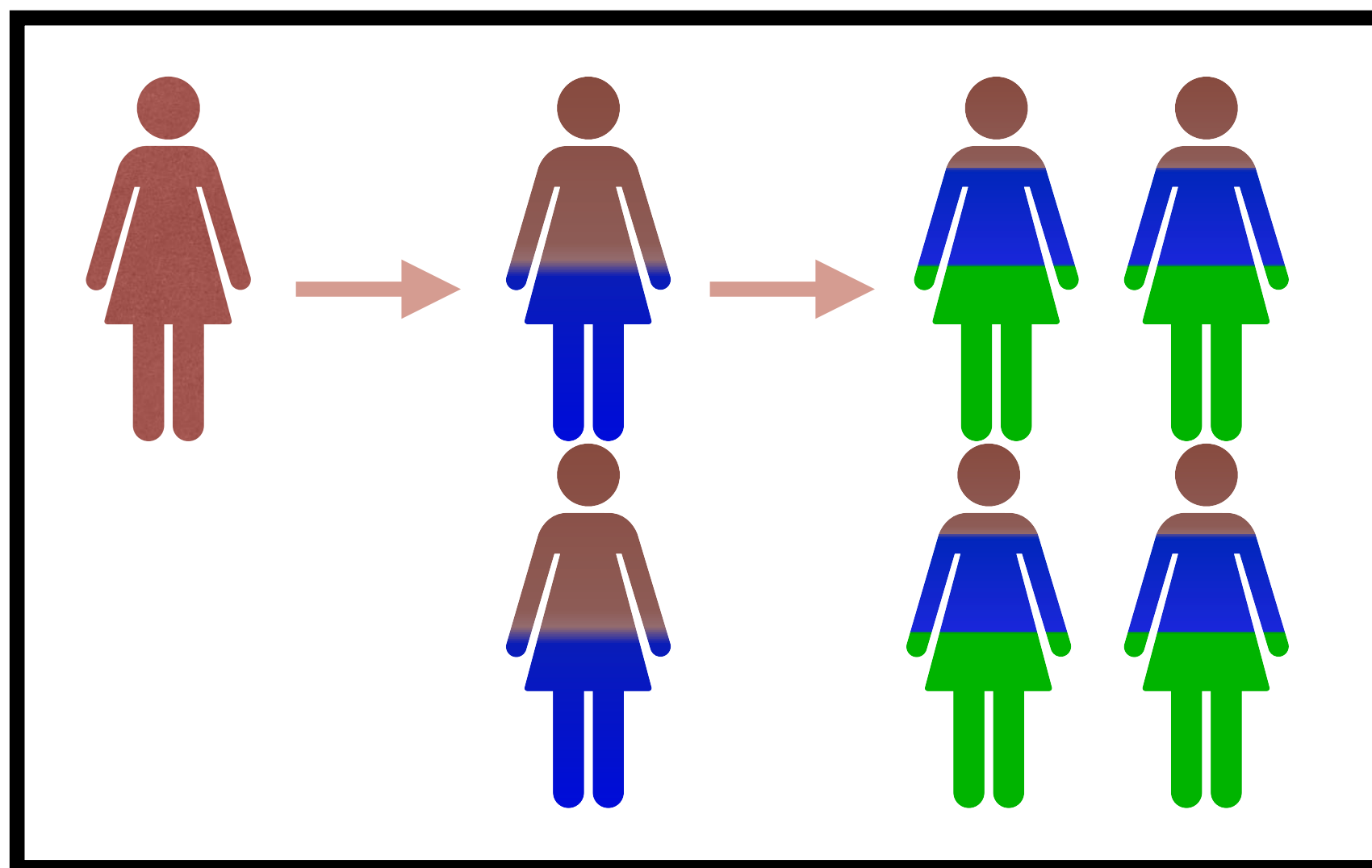


# O paradoxo do sexo

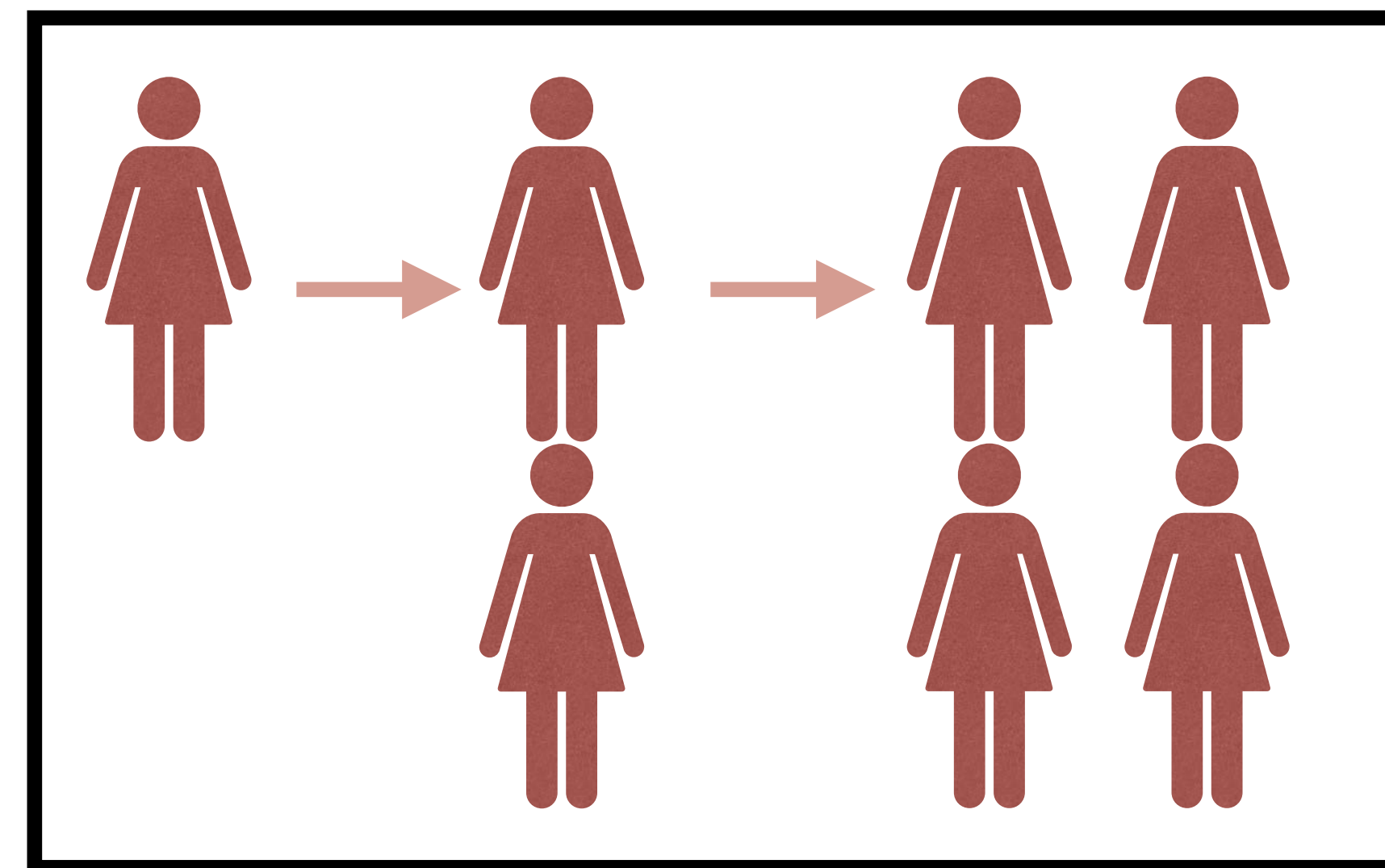


# O paradoxo do sexo

Reprodução sexual

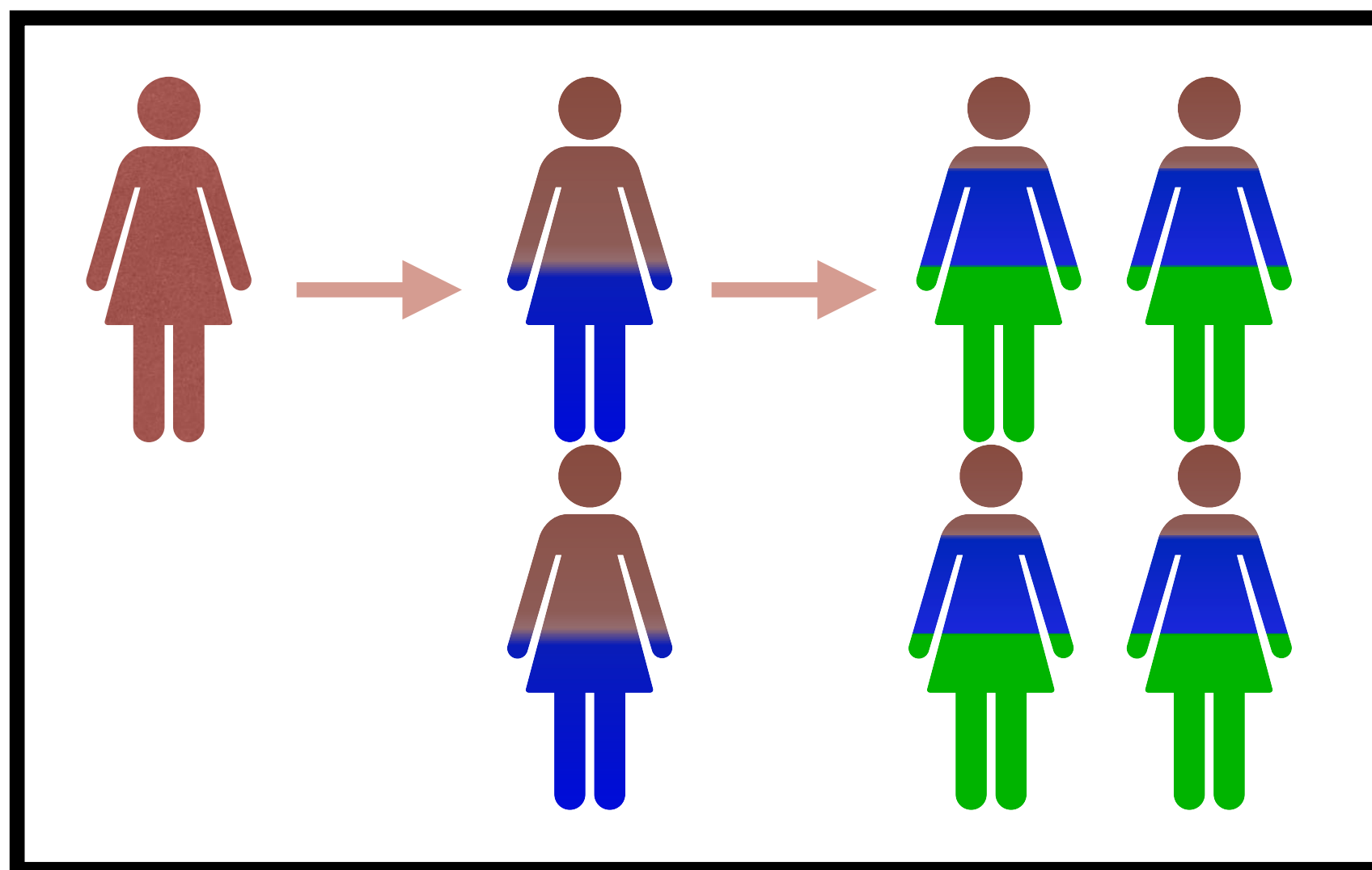


Reprodução assexual

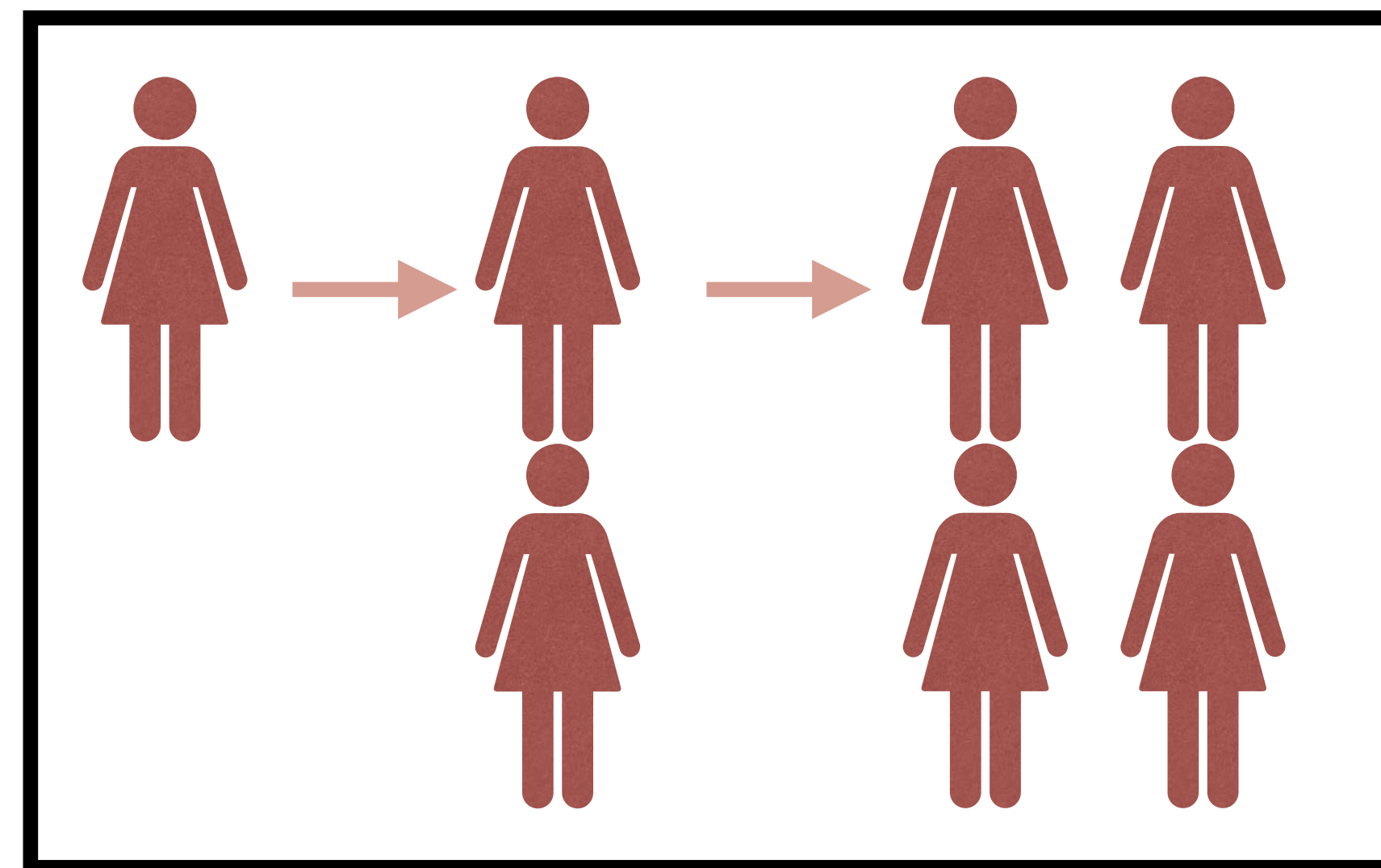


# O paradoxo do sexo

Reprodução sexual



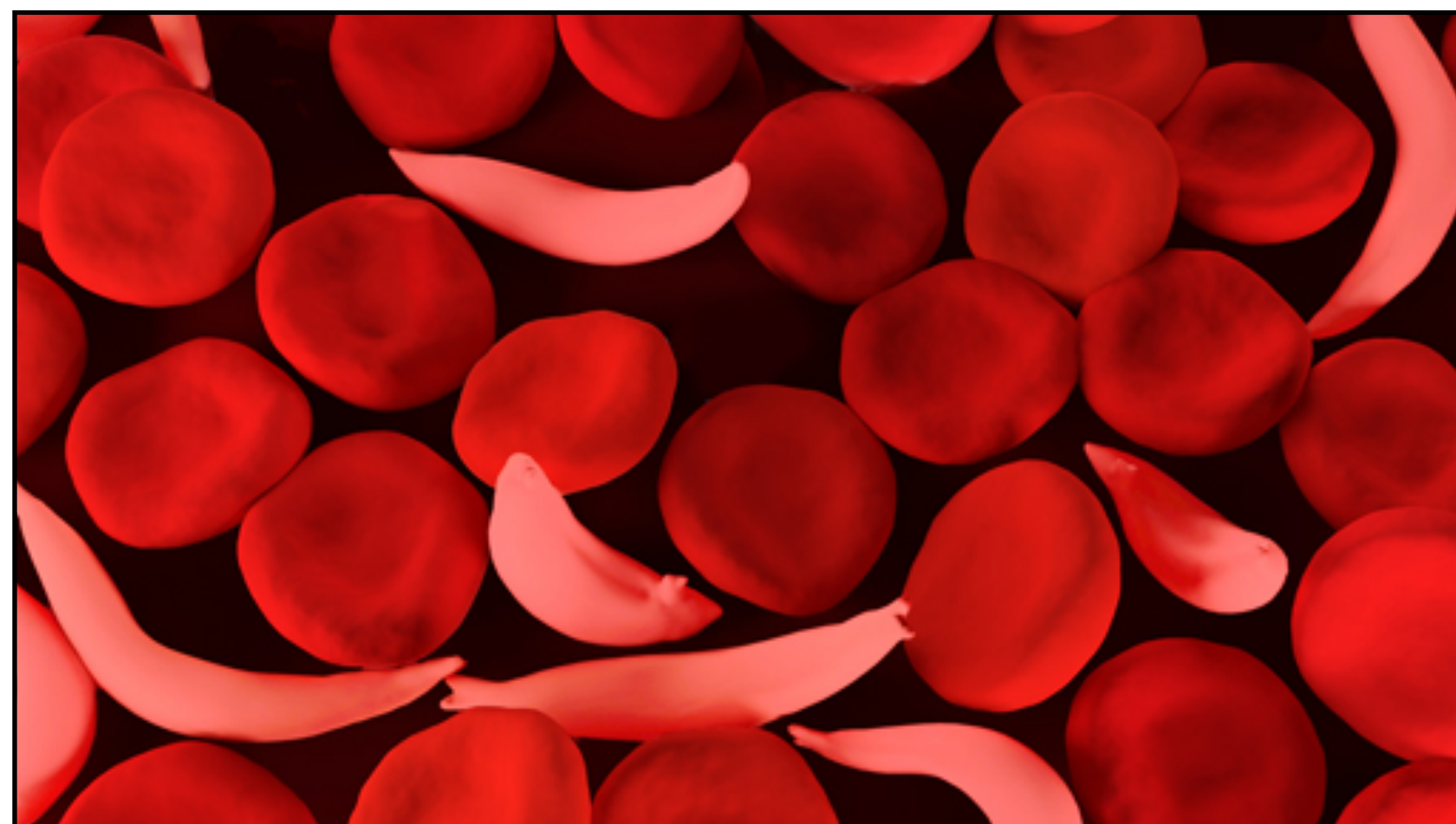
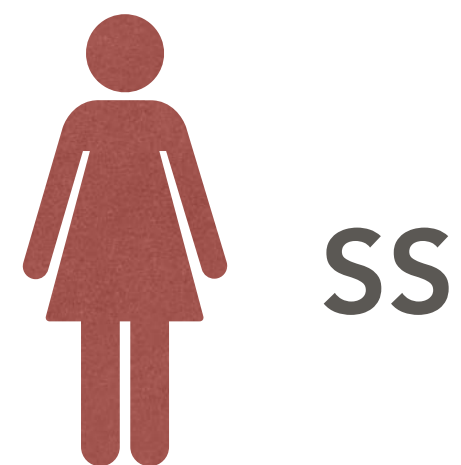
Reprodução assexual





# O paradoxo do sexo

Alelo da anemia falciforme



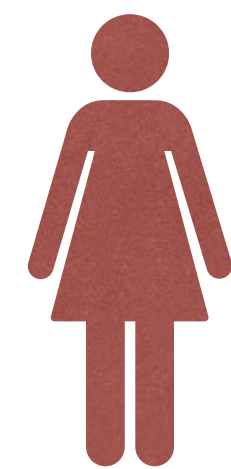
# O paradoxo do sexo

Alelo da anemia falciforme

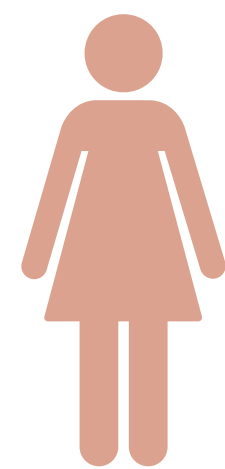


# O paradoxo do sexo

Alelo da anemia falciforme



SS



Ss

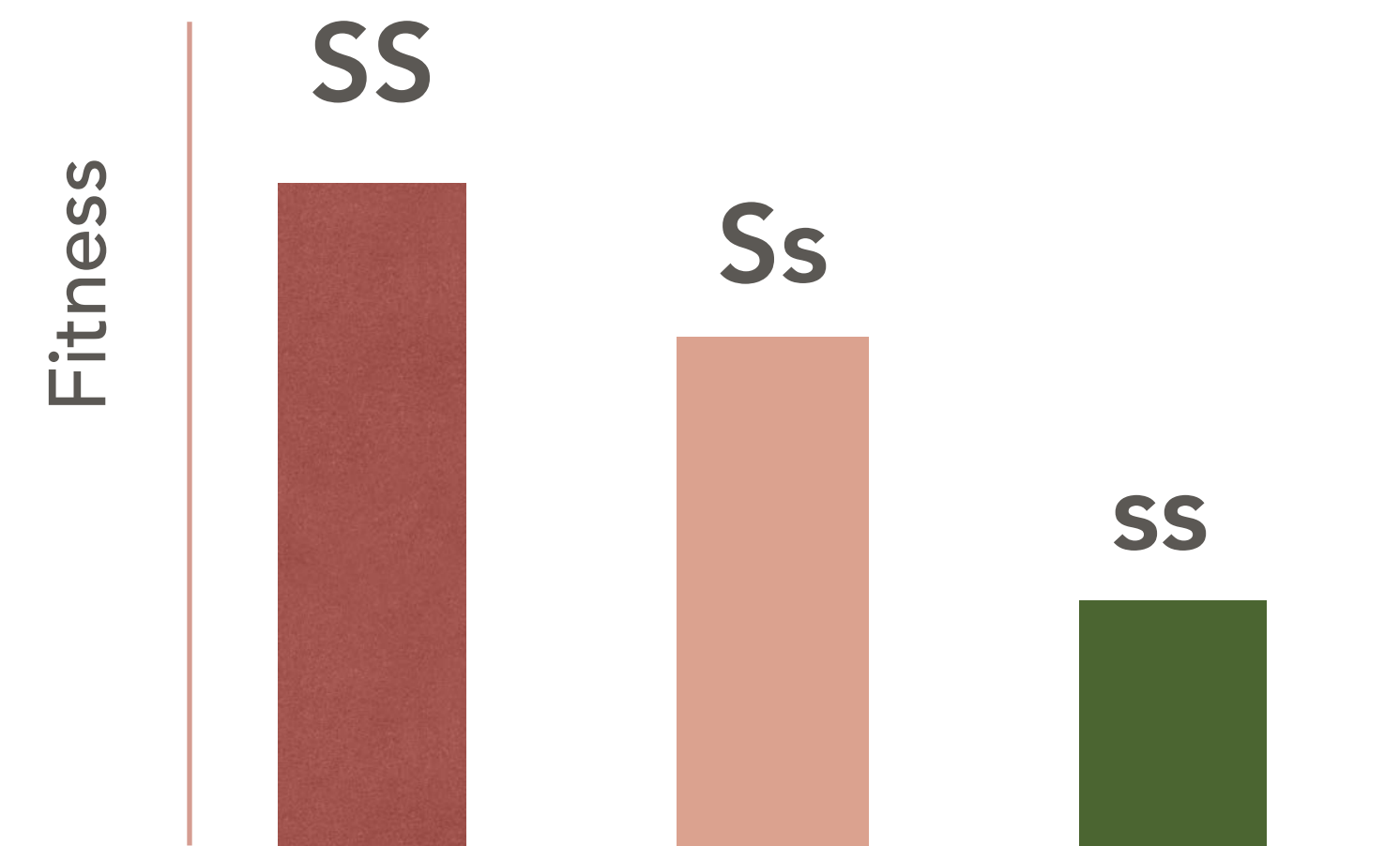
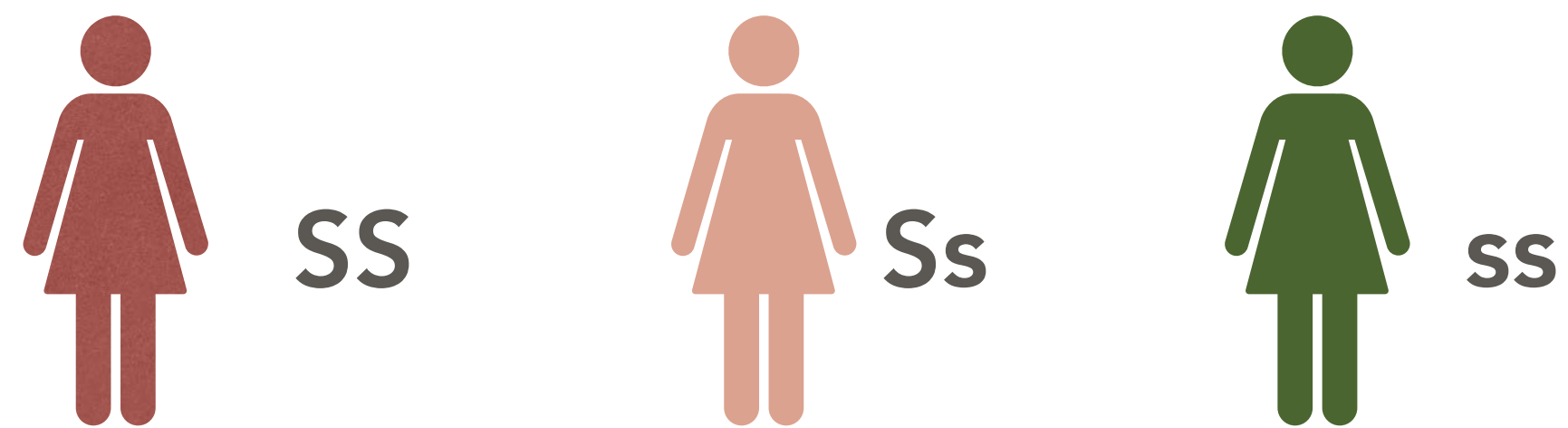


ss



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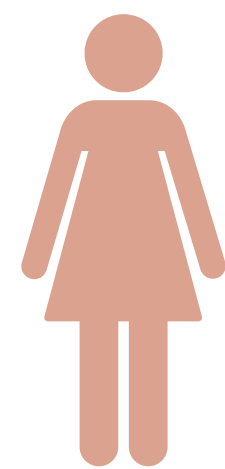


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SS



Ss

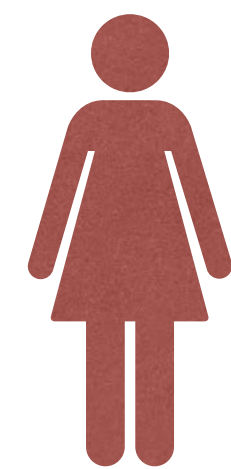


ss

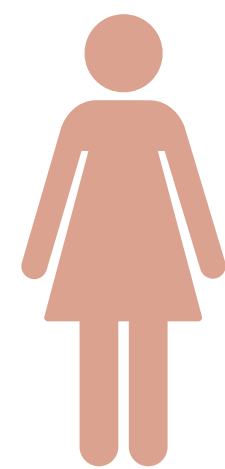


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Alelo da anemia falciforme



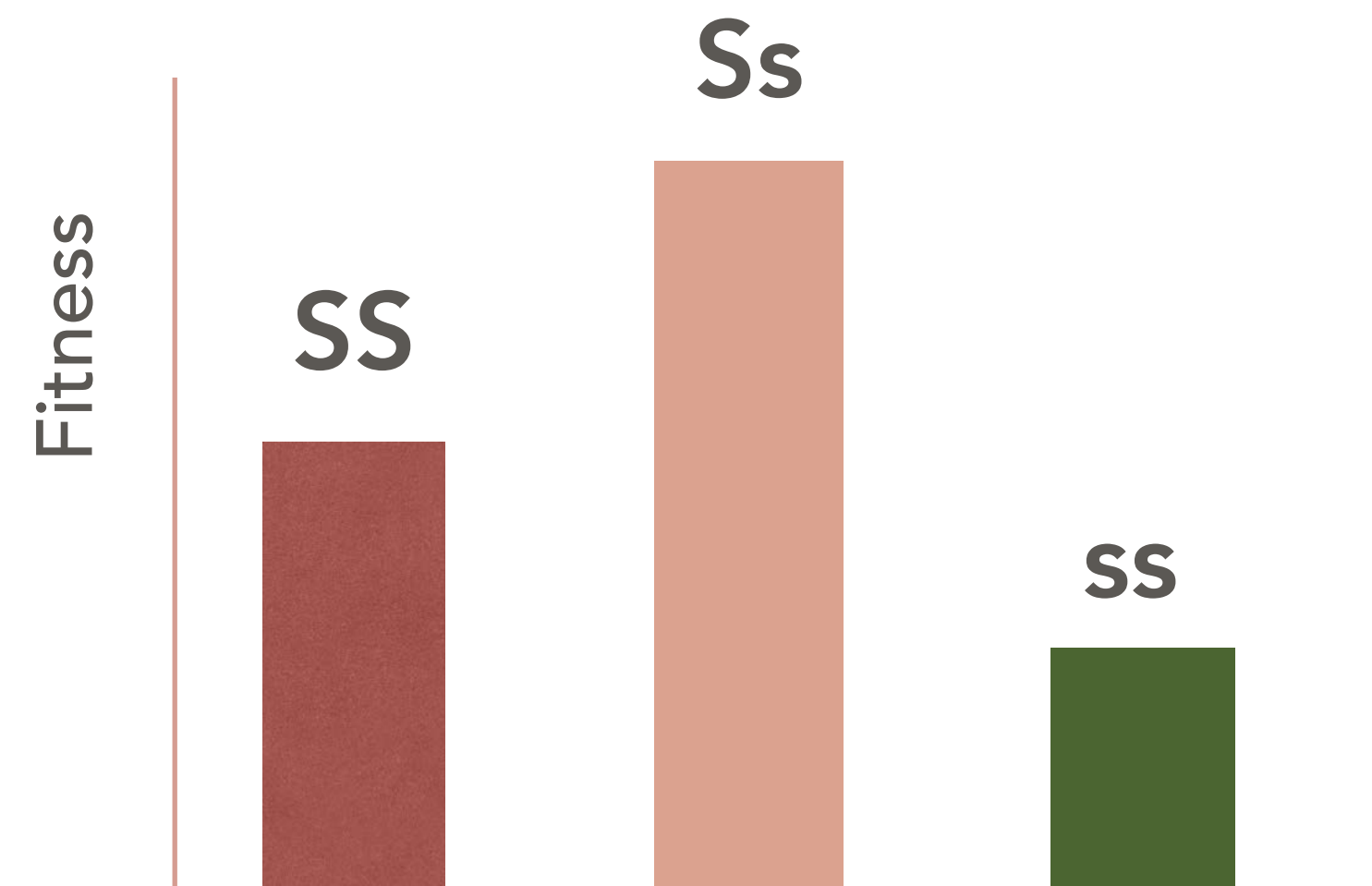
SS



Ss

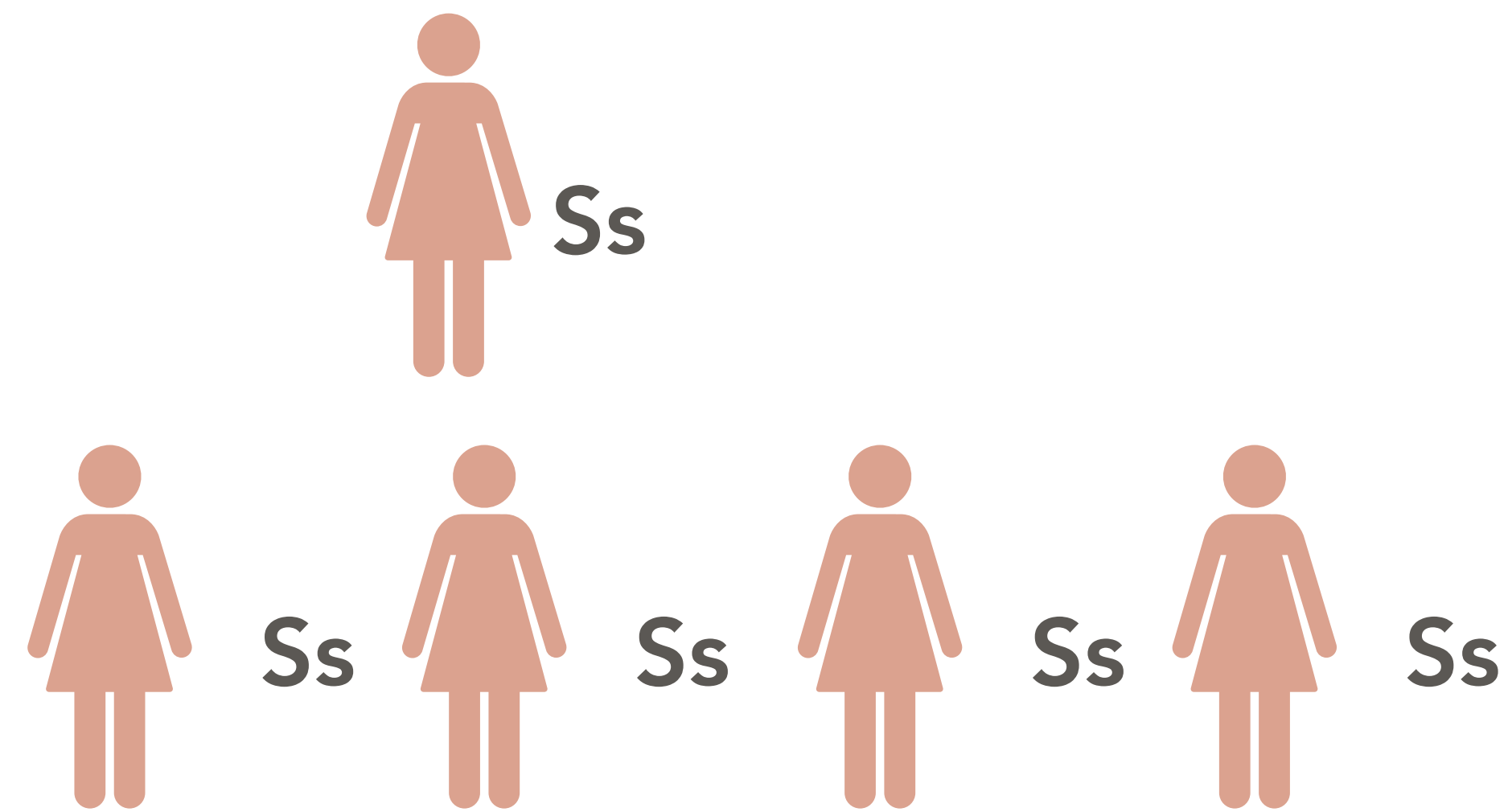


ss



# O paradoxo do sexo

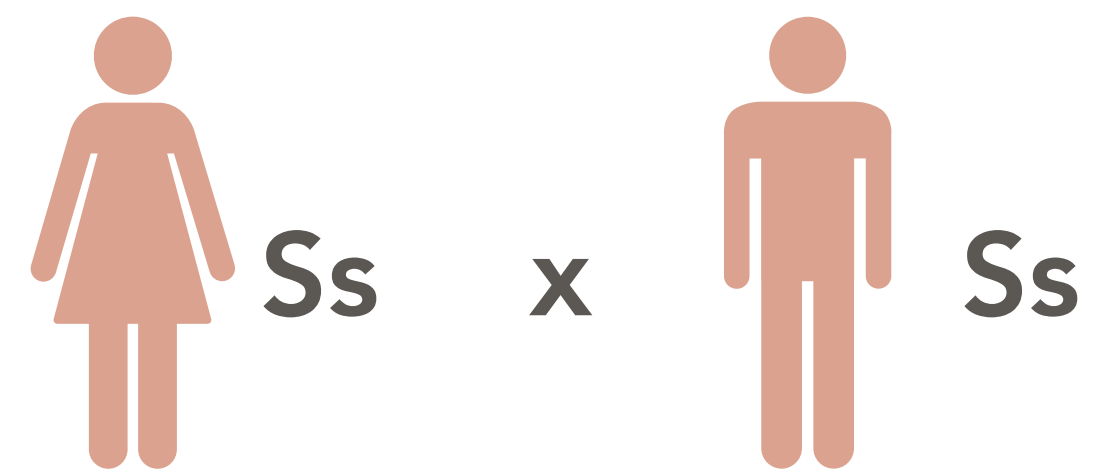
Alelo da anemia falciforme



Custo da segregação

# O paradoxo do sexo

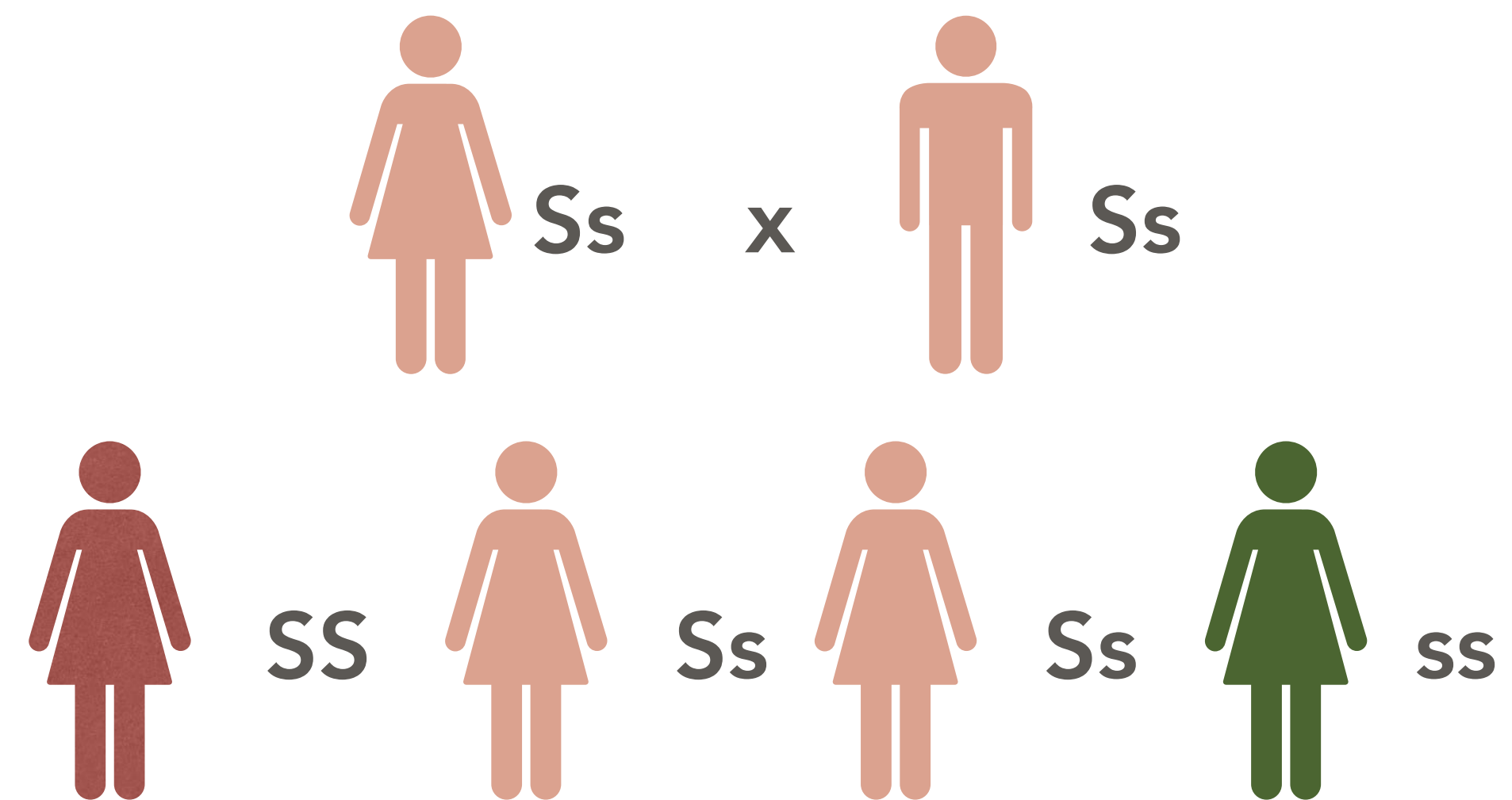
Alelo da anemia falciforme





# O paradoxo do sexo

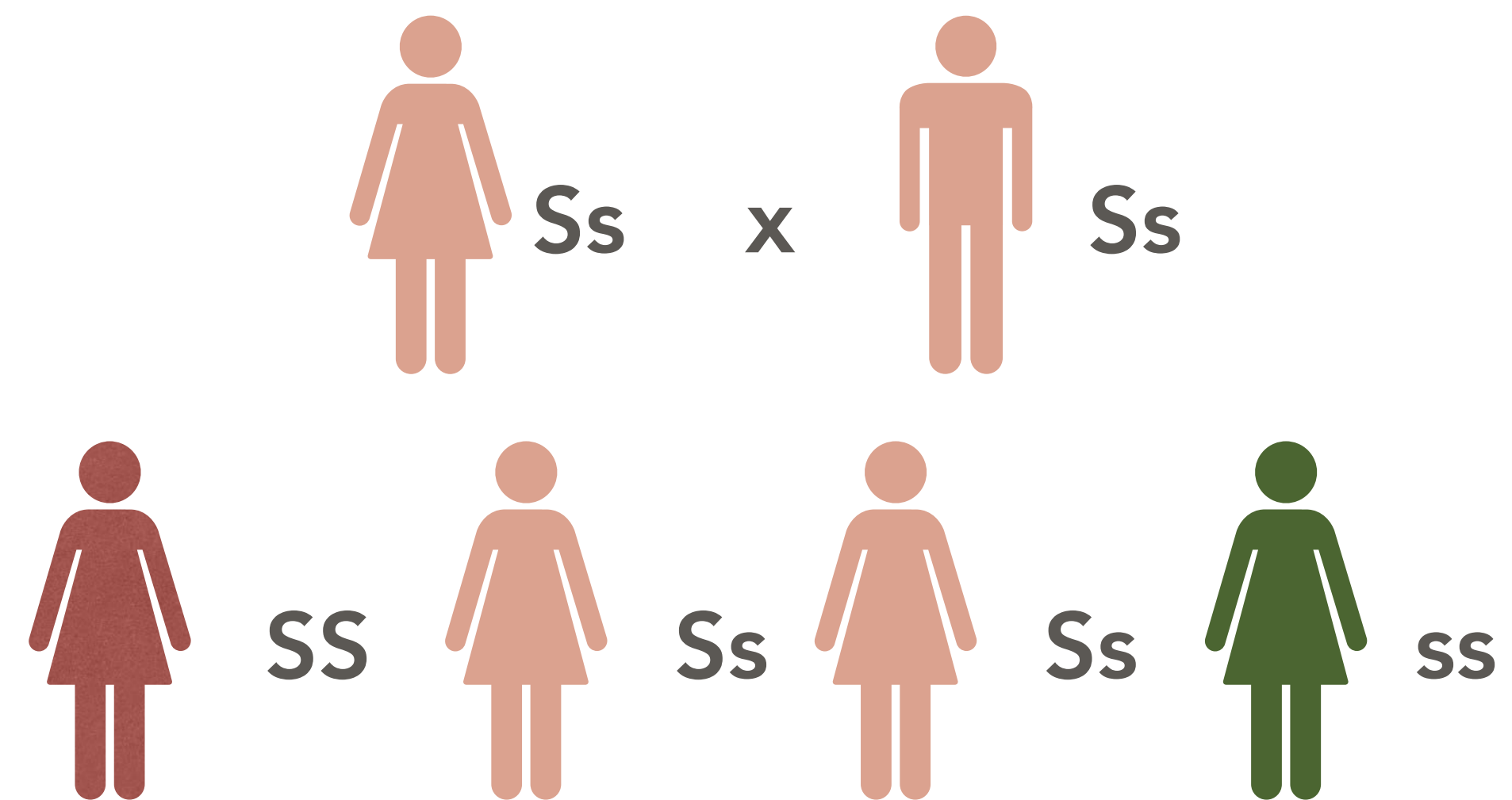
Alelo da anemia falciforme



Custo da segregação

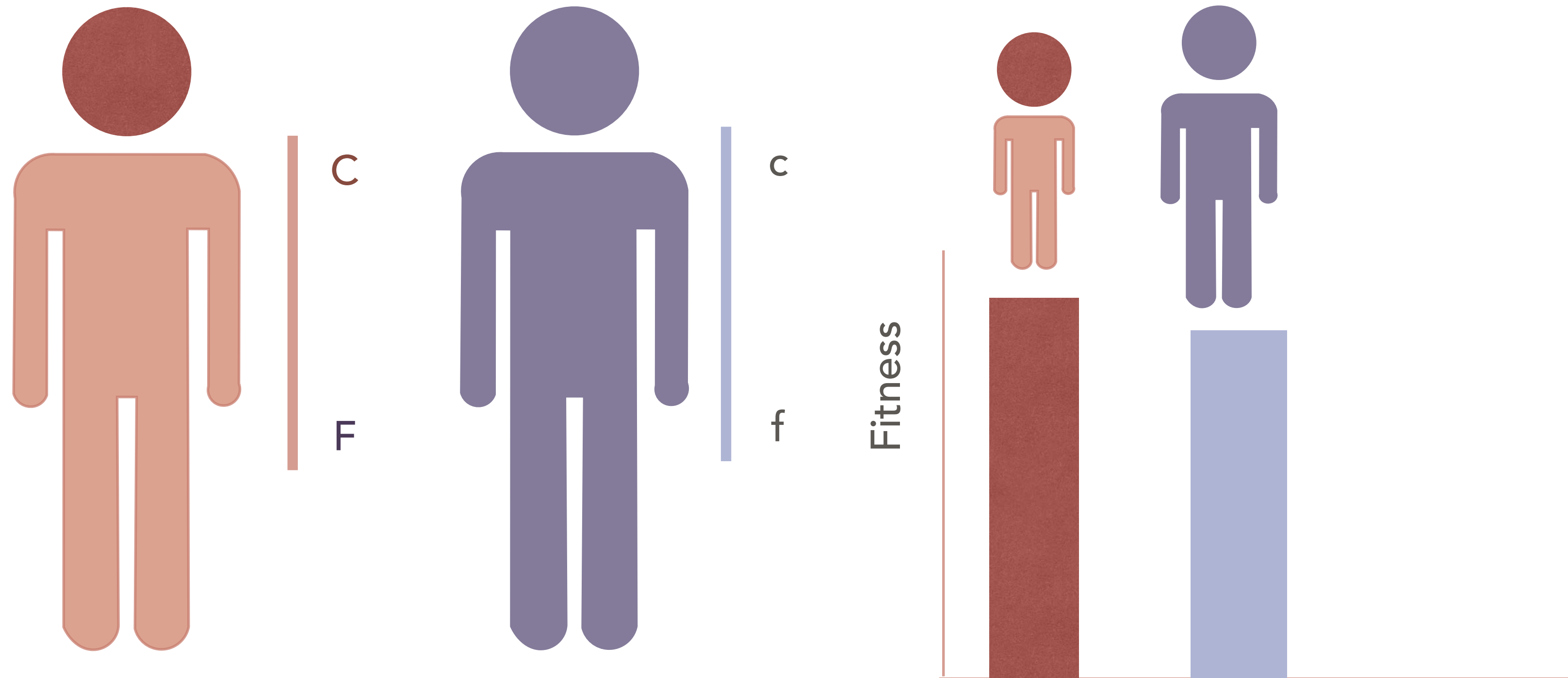
# O paradoxo do sexo

Alelo da anemia falciforme



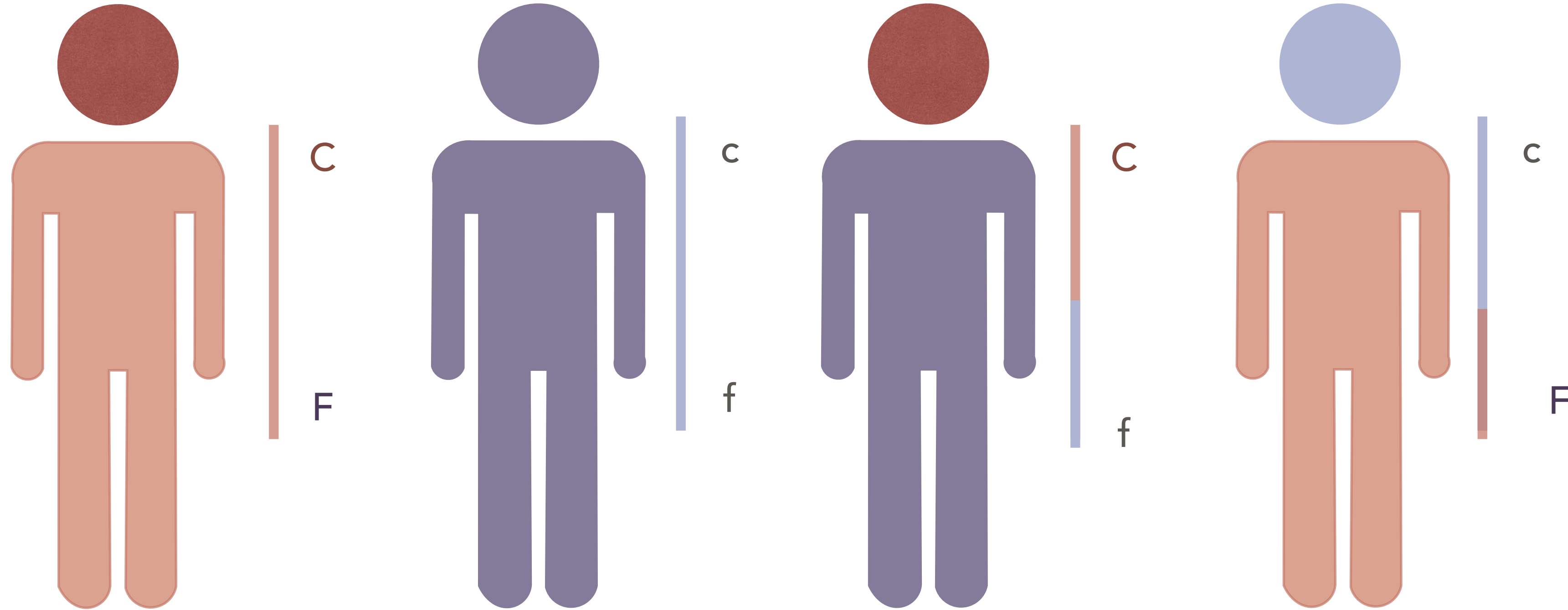
Custo da segregação

# O paradoxo do sexo



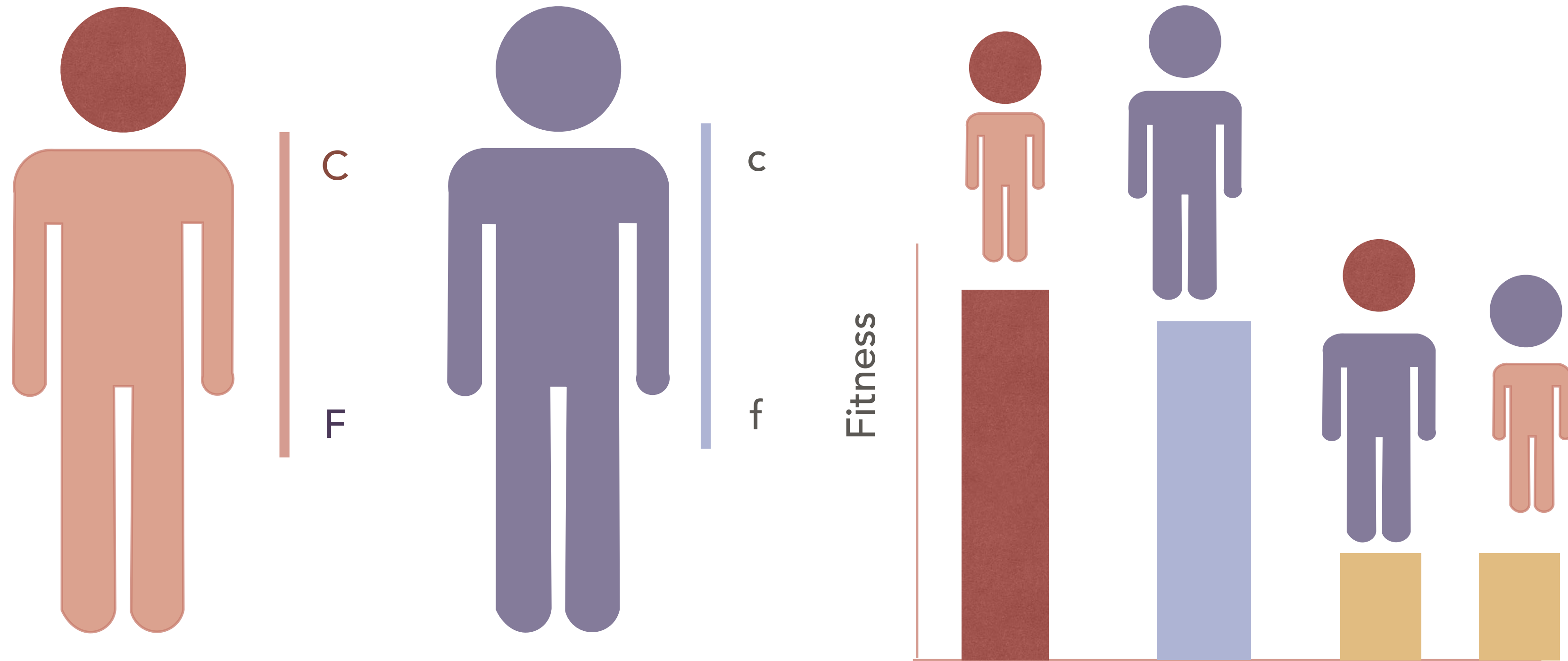
Custo da recombinação

# O paradoxo do sexo



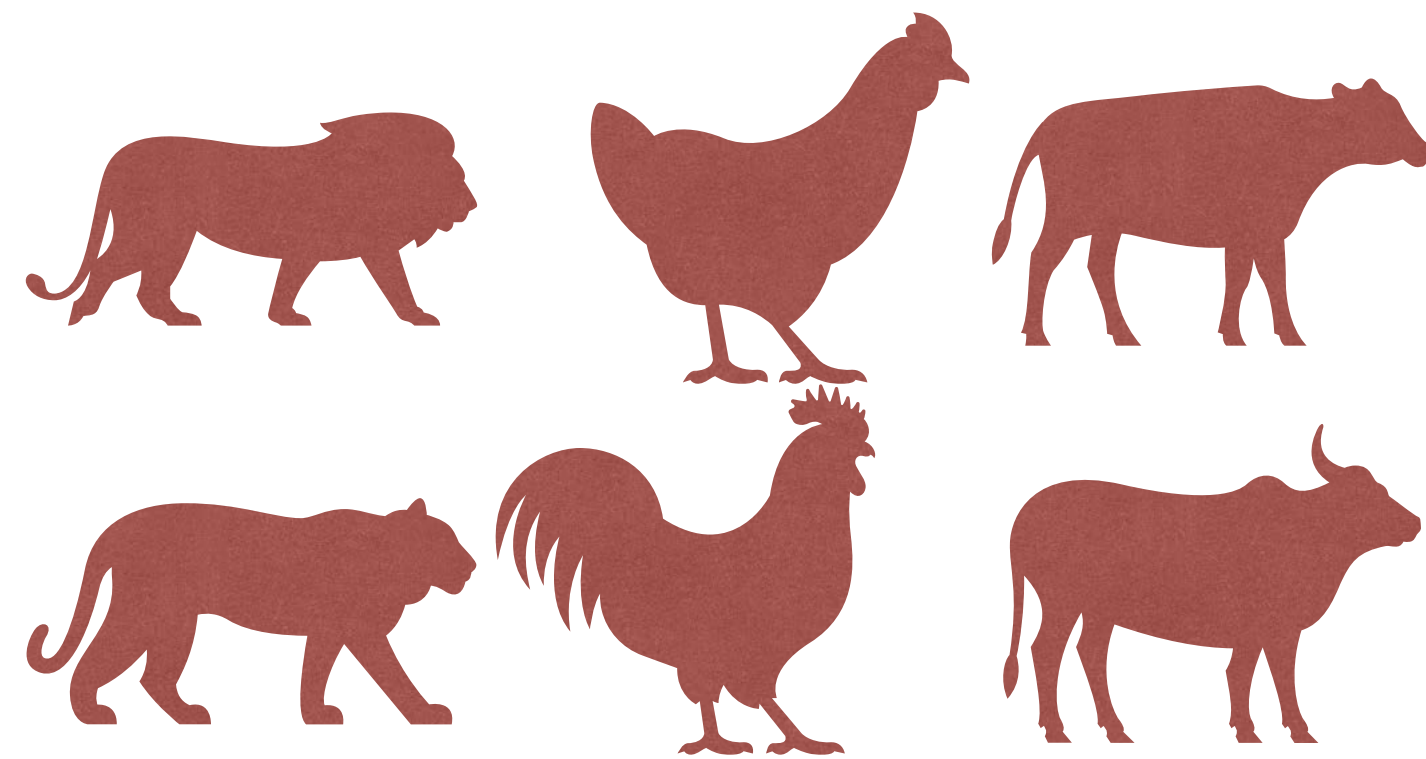
Custo da recombinação

# O paradoxo do sexo



Custo da recombinação

# O paradoxo do sexo



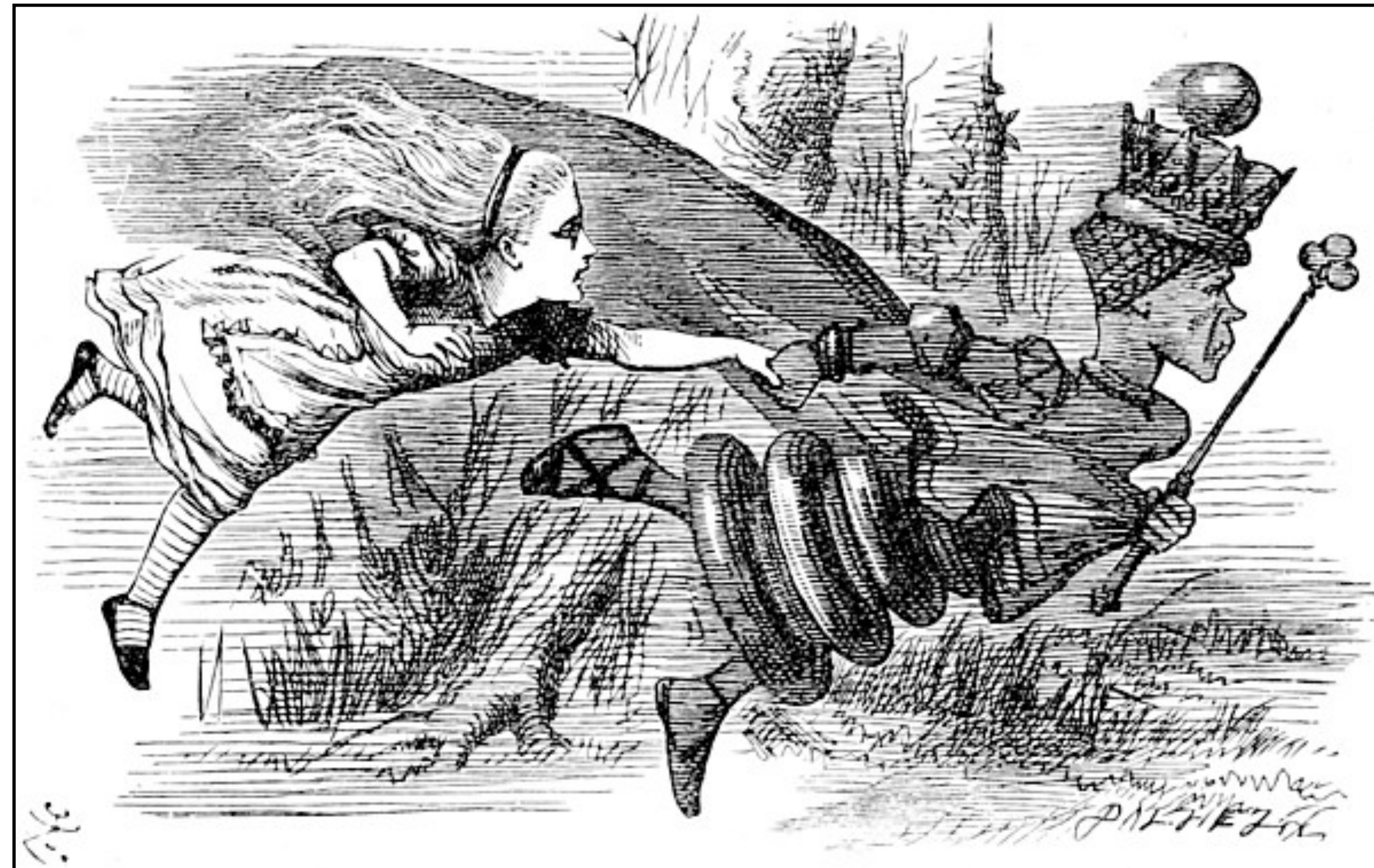
**Porque raios existe sexo?????**

# O paradoxo do sexo

**99% dos eucariotos se reproduzem sexuadamente!**

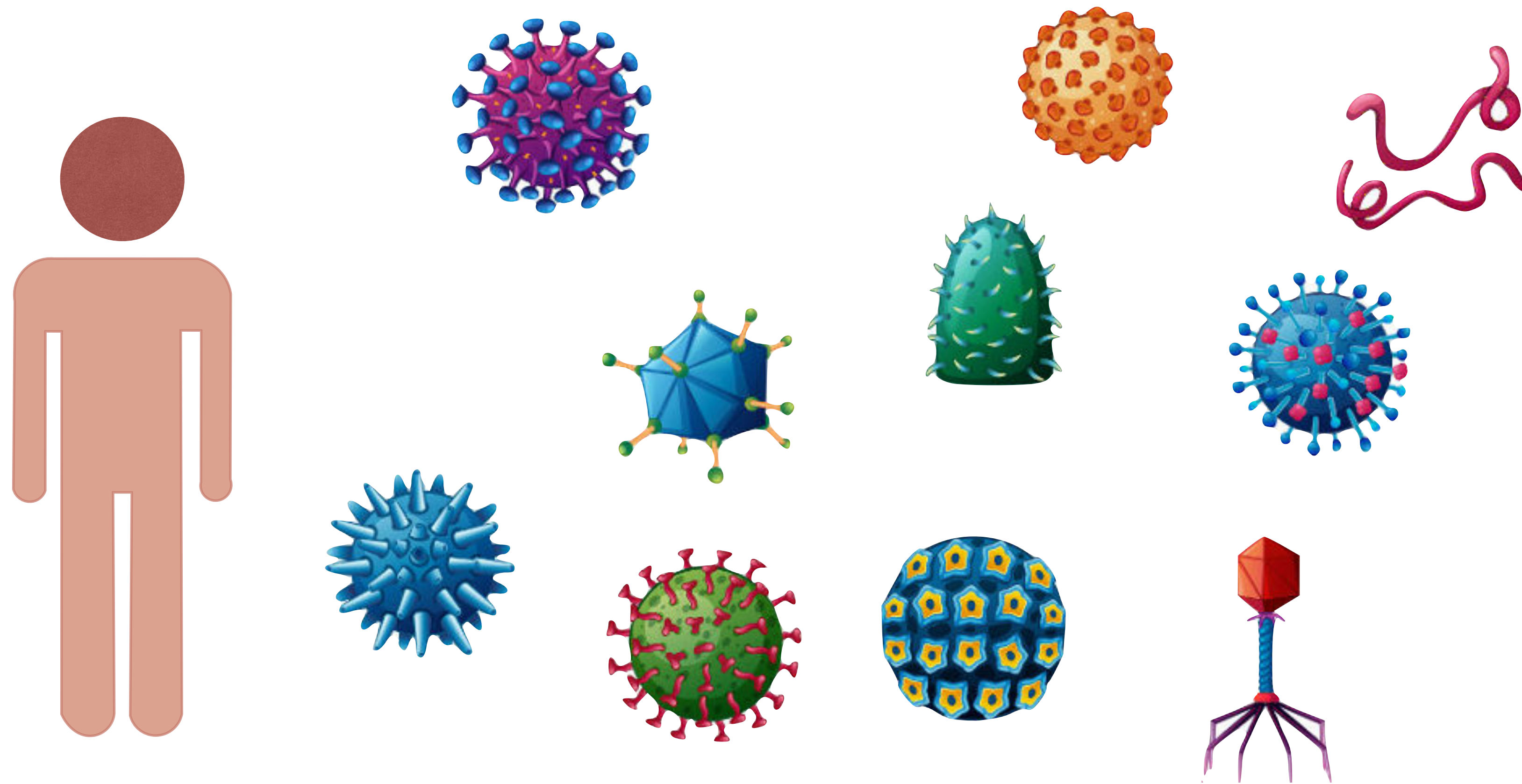
# O paradoxo do sexo

**99% dos eucariotos se reproduzem sexuadamente!**





# Pressões seletivas mudando o tempo inteiro



Sofre mais quem tem o genótipo mais  
comum

Science

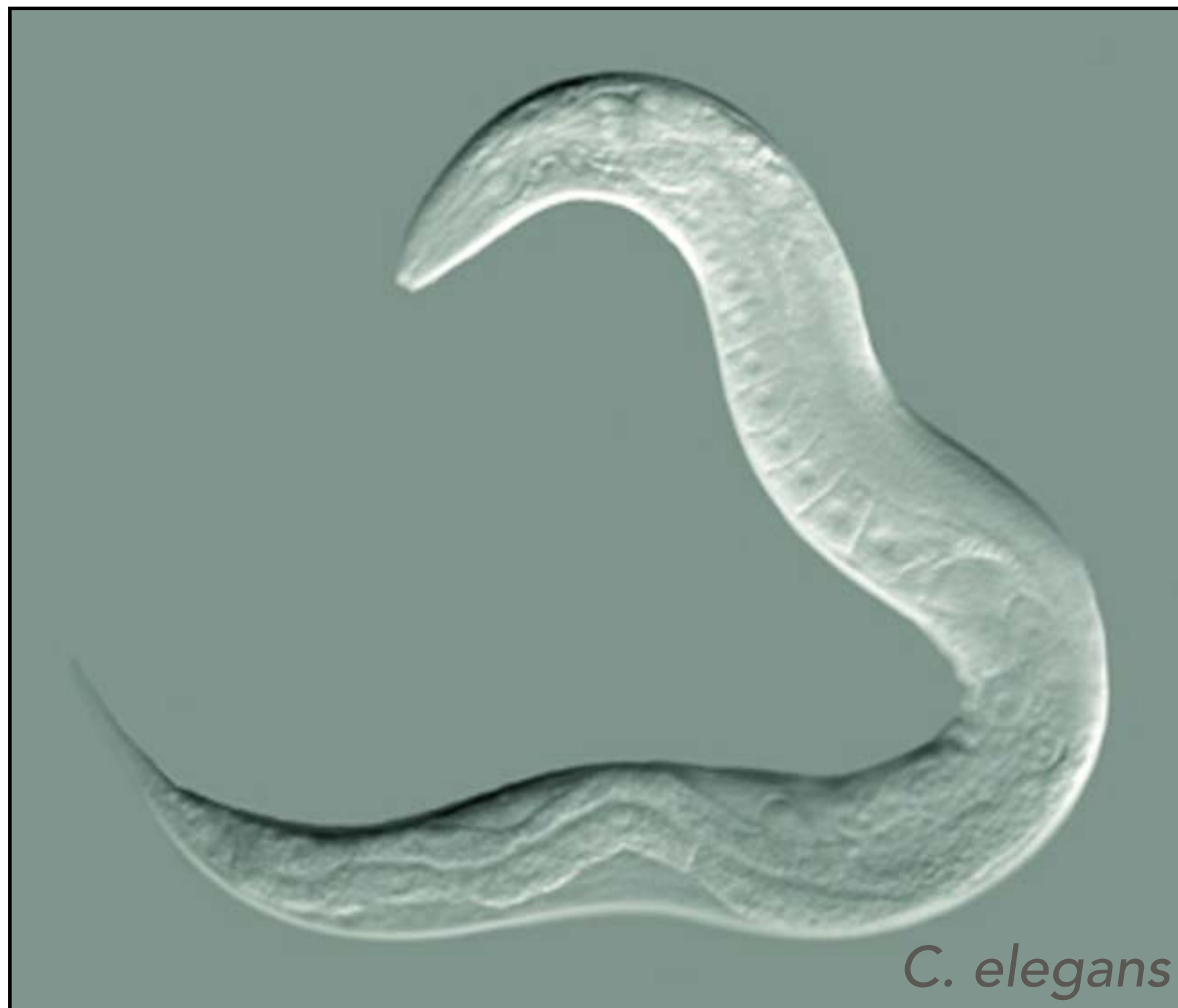
REPORT

# Running with the Red Queen: Host-Parasite Coevolution Selects for Biparental Sex

Levi T. Morran<sup>\*</sup>, Olivia G. Schmidt, Ian A. Gelarden, Raymond C. Parrish II, Curtis M. Lively

+ See all authors and affiliations

# Evolução do sexo



POPULAÇÕES ASSEXUADAS

POPULAÇÕES SEXUADAS

# Evolução do sexo



*Serratia marcescens*



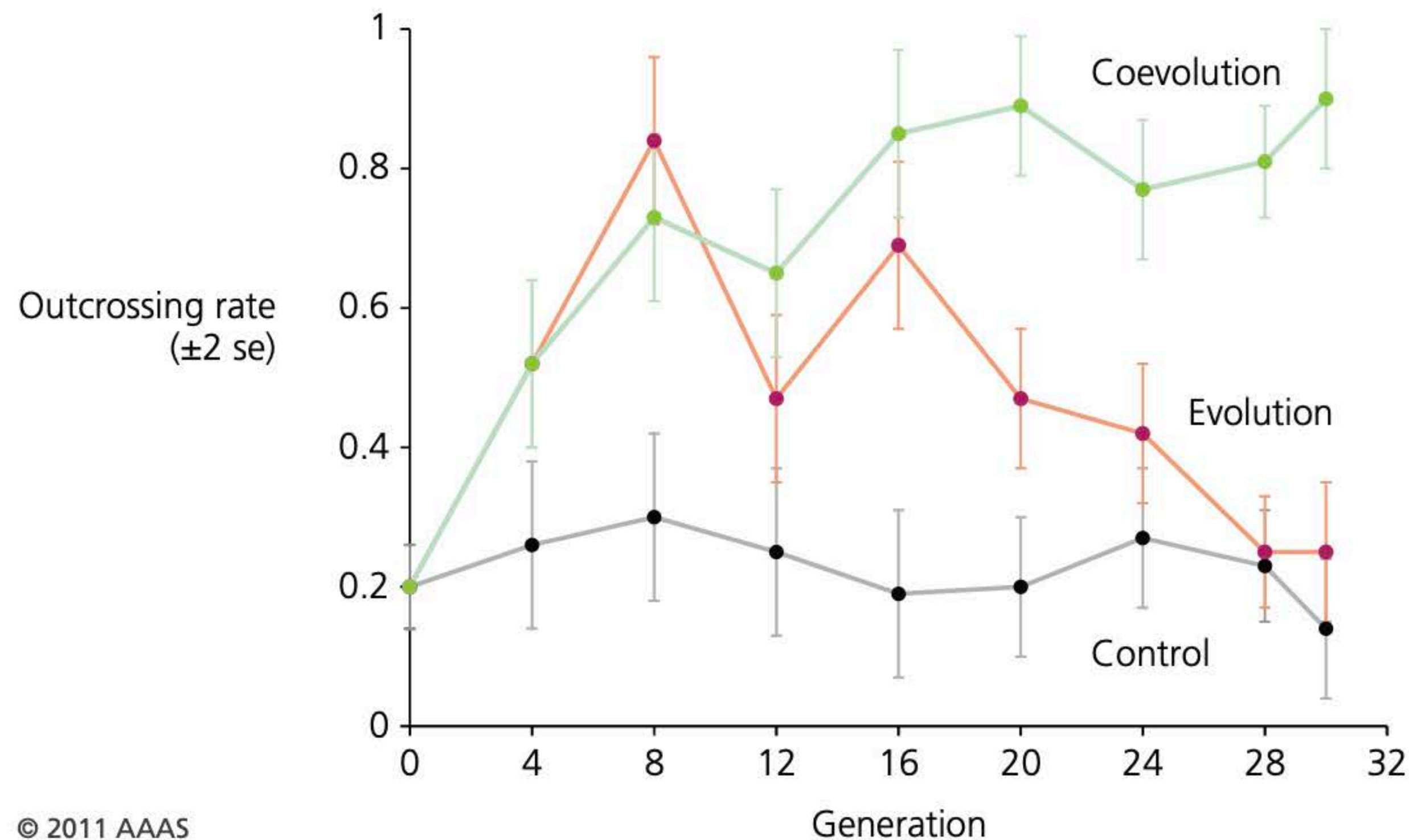
# Evolução do sexo



*Serratia marcescens*



# Evolução do sexo



**Figure 8.29 Pathogens select for outcrossing in *C. elegans*** Frequency of outcrossing in *C. elegans* populations evolving by natural selection in the lab. *Control* populations were exposed to heat-killed pathogenic bacteria, *evolution* populations to pathogenic bacteria from a stock population, and *coevolution* populations to pathogens under selection for their ability to infect and kill the worms. From Morran et al. (2011).

From "Running with the Red Queen: host-parasite coevolution selects for biparental sex." *Science* 333: 216–218. Reprinted with permission from AAAS.

# **Evolução do sexo**

**Reprodução  
sexuada**

**Compensa em um  
mundo com muitos  
inimigos**

## Conclusões

- Interações antagonistas são (foram) extremamente importantes na história evolutiva
- Evolução da virulência depende do modo de vida do parasita
- Entender coevolução é importante para qualquer pessoa que trabalhe com saúde humana