Prey infection alters predator diet

Loïc Prosnier, Florence Hulot, David Renault, Christophe Piscart,
Baptiste Bicocchi, Matthieu Lam, Vincent Médoc & Nicolas Loeuille

institute of Ecology and Environmental Sciences - Paris
Equipe de Neuro-Ethologie Sensorielle – Saint-Etienne
Ecologie Systematique Evolution – Orsay
Ecosystème, Biodiversité, Evolution - Rennes

Chaire MMB,
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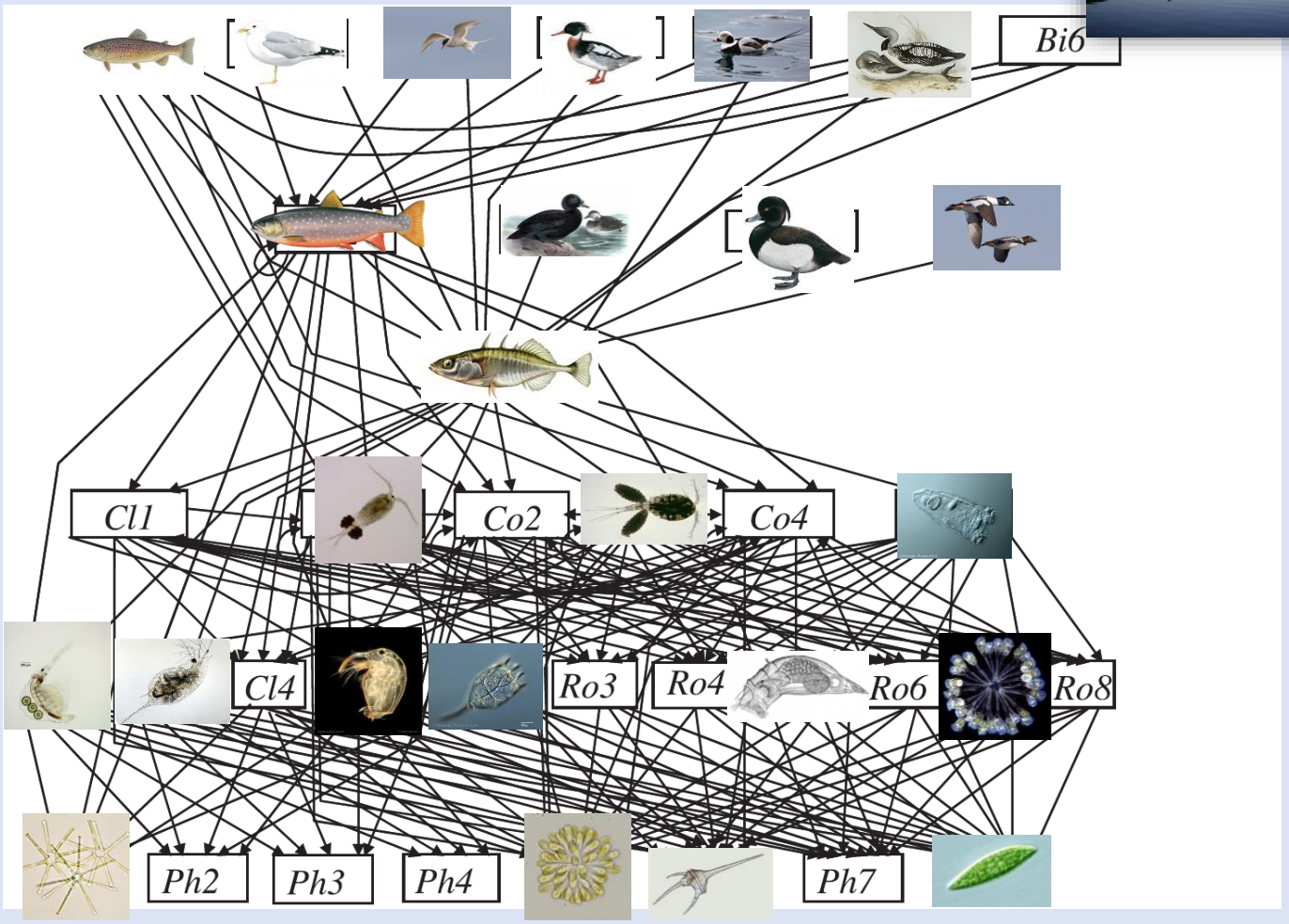
Loïc Prosnier (lprosnier@gmail.com)

From food webs without parasites …

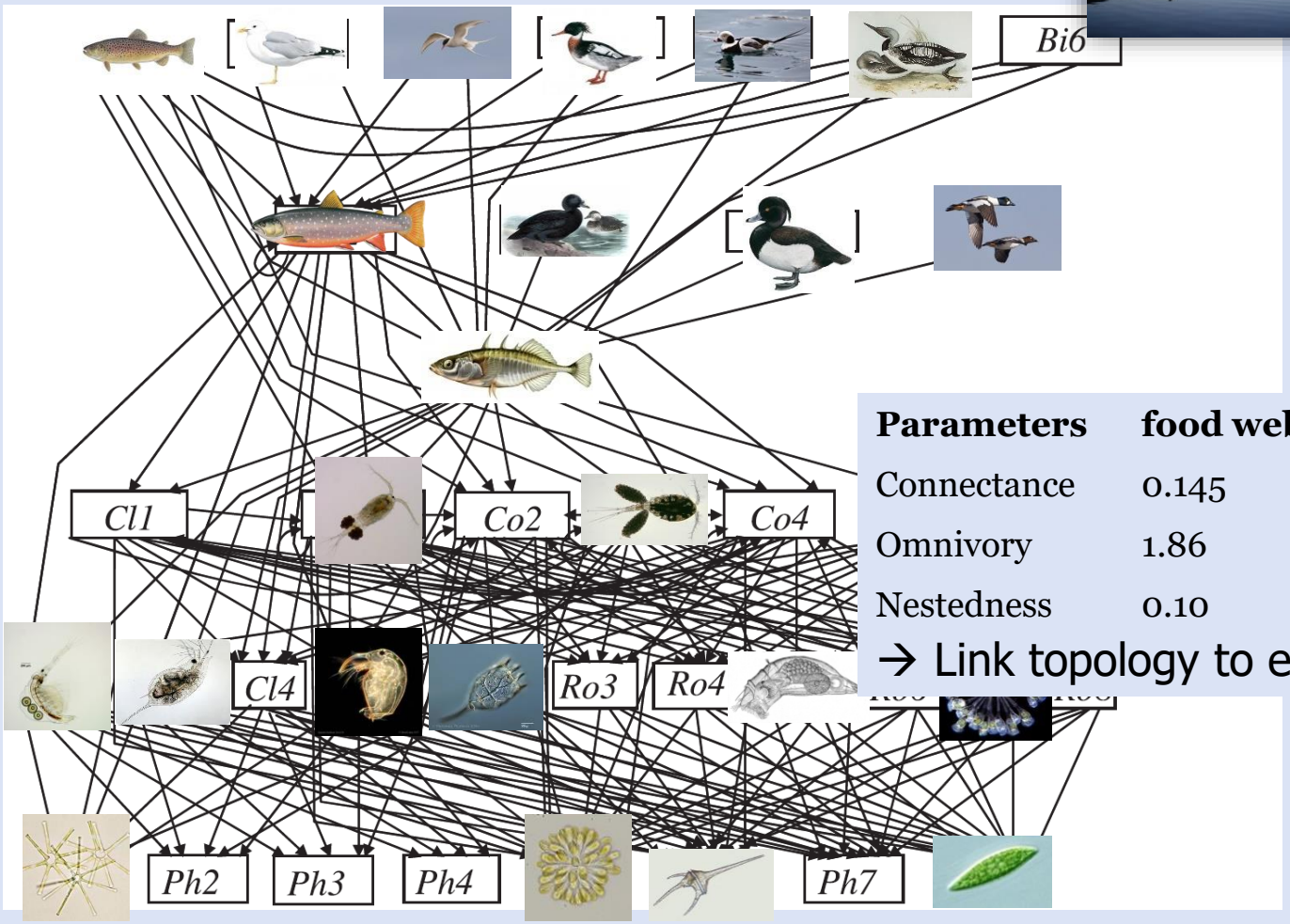
Pelagic food web of the subarctic lake Takvatn



(Amundsen *et al.* 2009)

From food webs without parasites …

Pelagic food web of the subarctic lake Takvatn



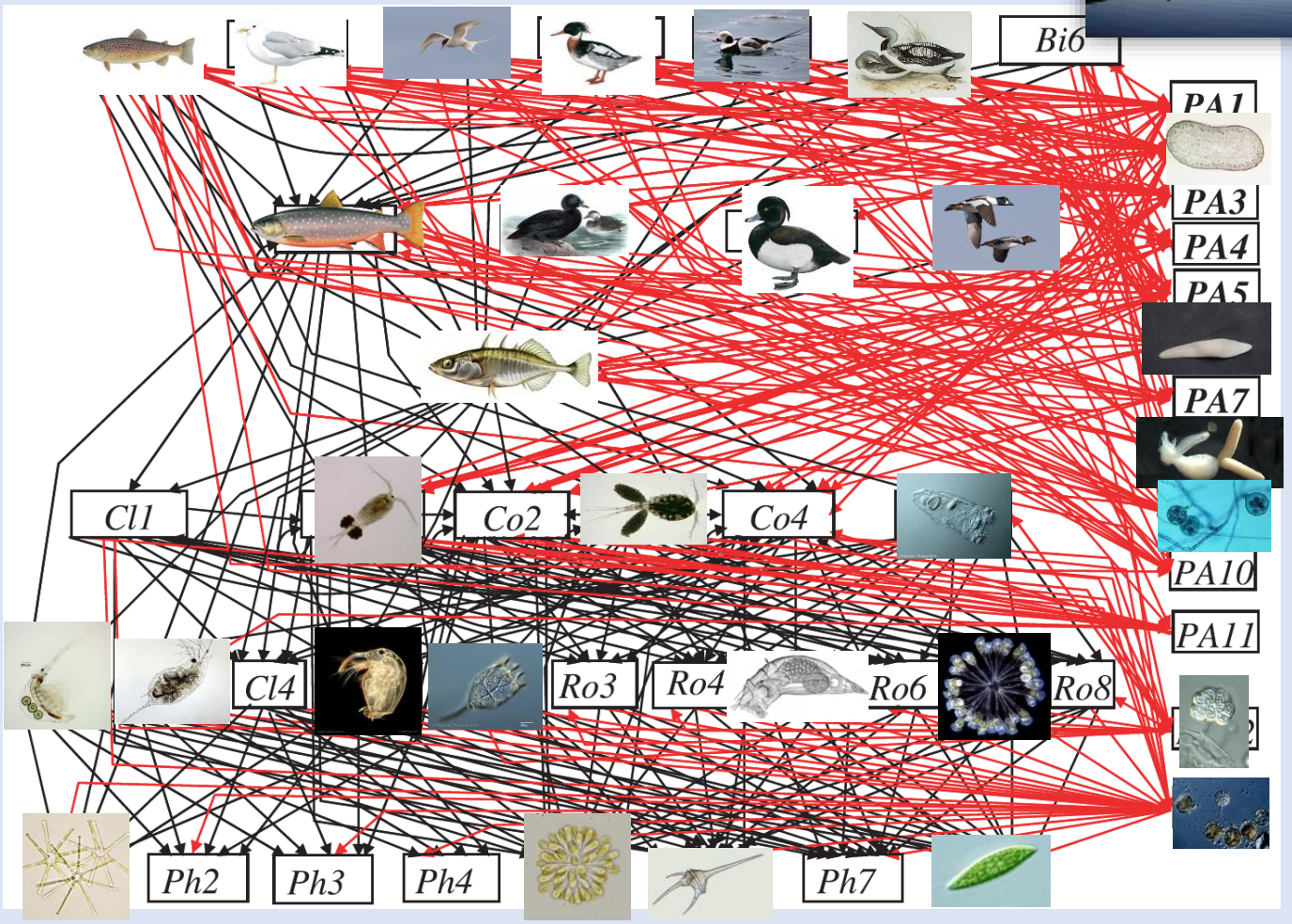
Parameters	food web
Connectance	0.145
Omnivory	1.86
Nestedness	0.10

→ Link topology to ecological property

(Amundsen *et al.* 2009)

… to food webs with parasites

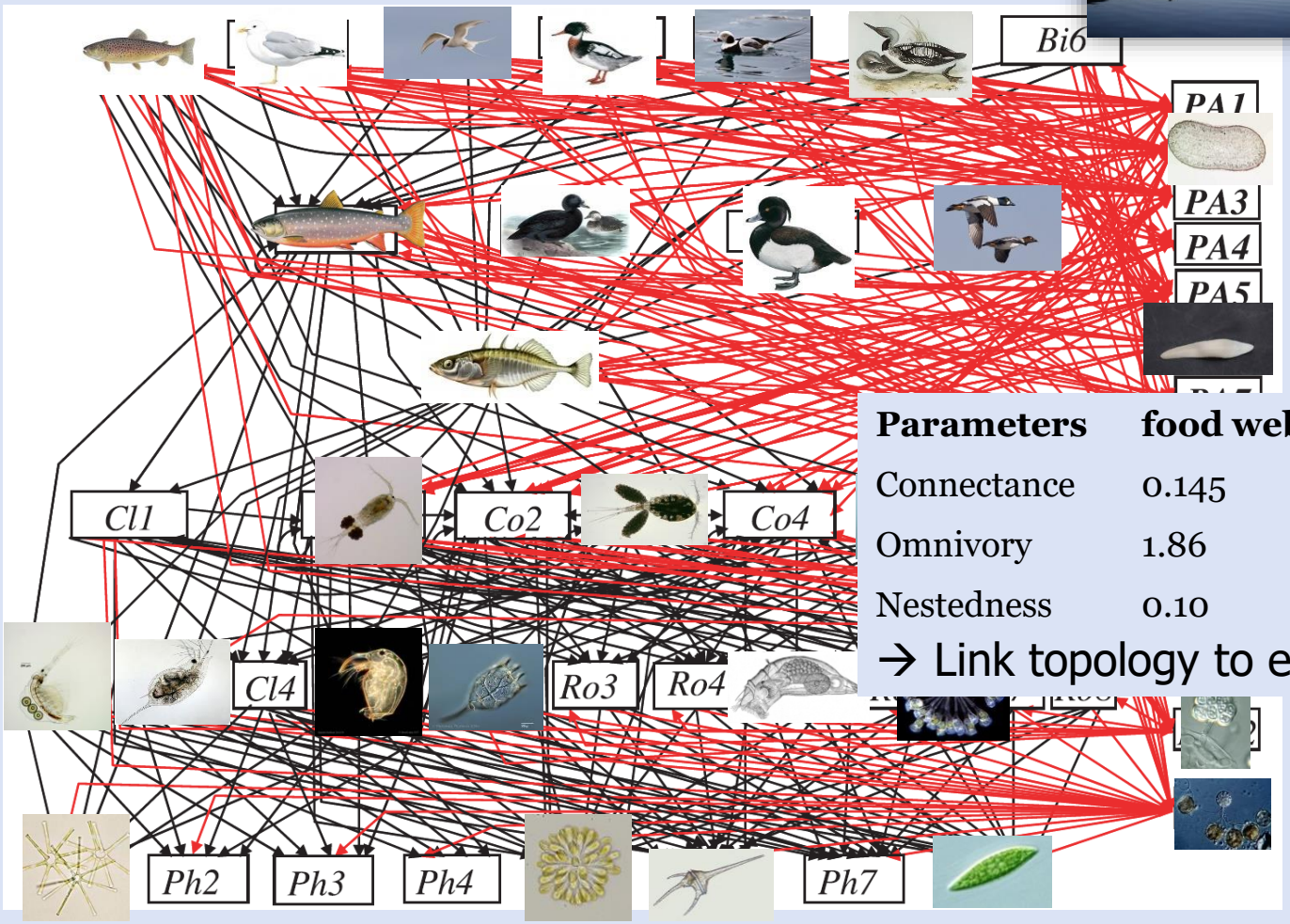
Pelagic food web of the subarctic lake Takvatn



(Amundsen *et al.* 2009)

… to food webs with parasites

Pelagic food web of the subarctic lake Takvatn



Parameters	food web	With parasites
Connectance	0.145	0.173
Omnivory	1.86	2.05
Nestedness	0.10	0.23

→ Link topology to ecological property?

(Amundsen *et al.* 2009)

Parasites

- Host alterations

Parasites

- Host alterations

Virulence effects

- ↗ mortality
- ↘ reproduction

(Schwartz & Cameron, 1993)

Trematodes

Daphnia obtusa

Parasites

- Host alterations

Virulence effects

- ↗ mortality
- ↘ reproduction

(Schwartz & Cameron, 1993)

Trematodes

Daphnia obtusa

Interaction effects

- Infected predator: energy requirement

(Dick *et al.* 2010)

Acanthocephalan

Gammarus pulex

- Infected prey: vulnerability

(Médoc & Beisel, 2011)
(Goren & Ben Ami, 2017)

Acanthocephalan

Asellus aquaticus

Bacterial

Daphnia magna

Parasites

- Host alterations

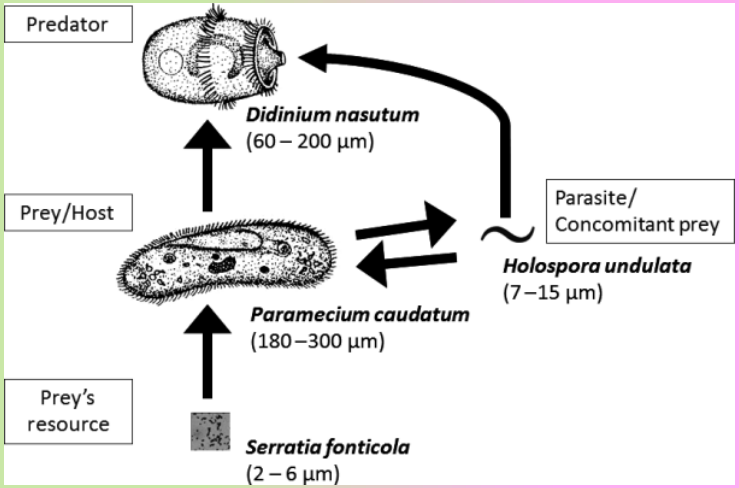
Virulence effects

- ↗ mortality
- ↘ reproduction

(Schwartz & Cameron, 1993)

Interaction effects

- Energy requirement
- Vulnerability



(Banerji *et al.*, 2015)

Parasites

- Host alterations

Virulence effects

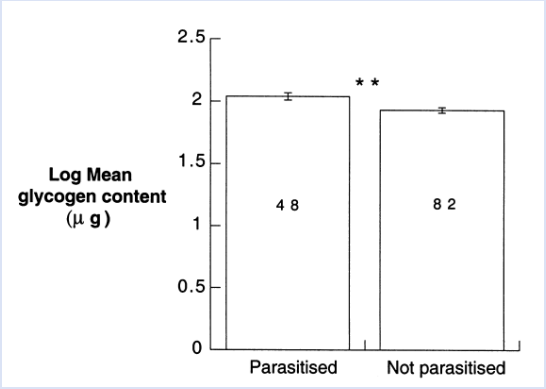
- ↗ mortality
- ↘ reproduction

(Schwartz & Cameron, 1993)

Interaction effects

- Energy requirement
- Vulnerability

- Due to reallocation of host energetic resources



Gammarus pulex

(Plaistow *et al.*, 2001)

Predator diet

- Optimal foraging (Charnov, 1976)

An equation giving the rate of energy intake in a random encounter (non-patchy) situation may be derived as follows. Let E be the energy taken in during a feeding period of length T, which is made up of T_s (time searching) and T_h (time handling all prey items). A net rate of energy intake (En/T) is

$$\frac{En}{T} = \frac{E}{T_h + T_s}.$$

Predator diet

- Optimal foraging (Charnov, 1976)

  → Predators consume the most profitable prey

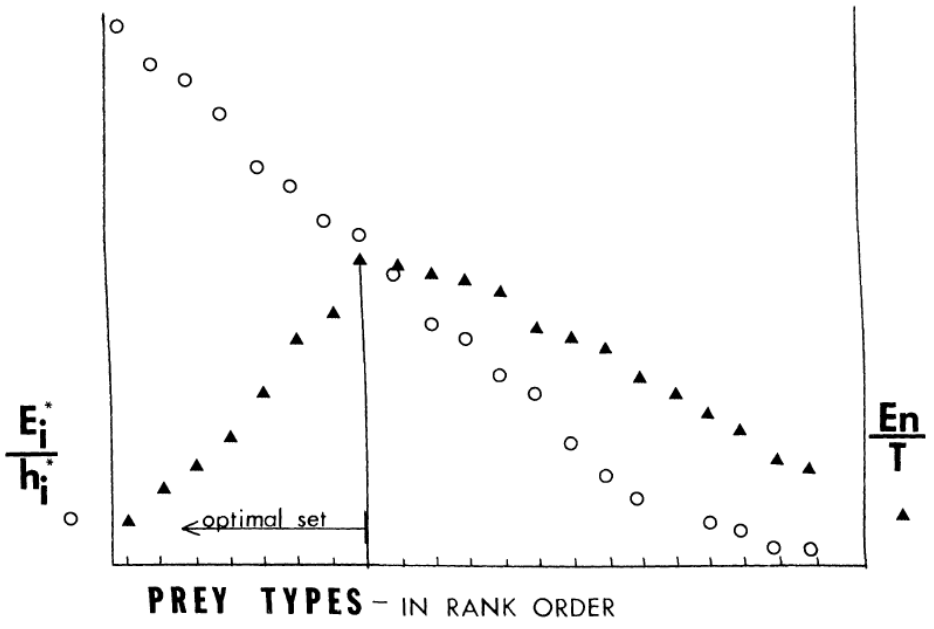


FIG. 1.—Choice of an optimal set of prey types. Prey types are first ranked by the E_i^*/h_i^* ratio, and then the cumulative En/T is calculated by adding prey types to En/T in rank order. En/T is maximized for a set of prey types of rank above the prey type (m) where En/T first becomes $> E_m^*/h_m^*$.

Predator diet

- Optimal foraging (Charnov, 1976)

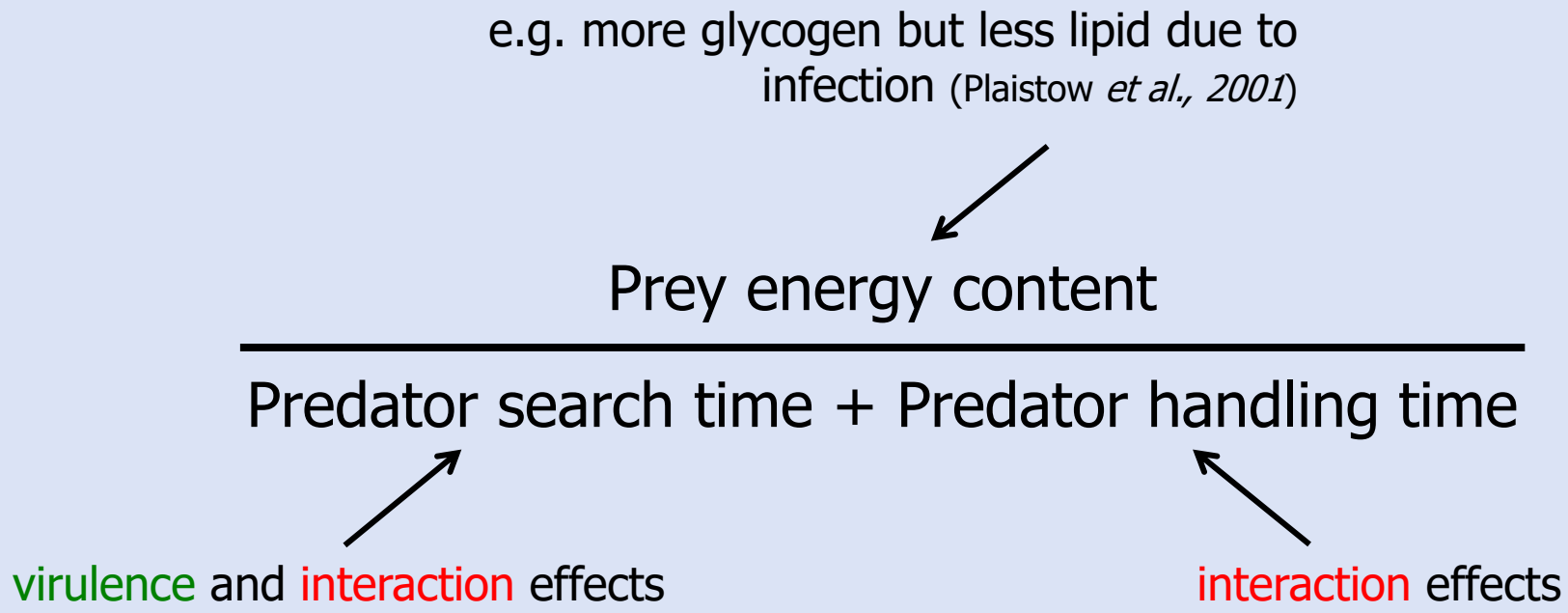
  → Predators consume the most profitable prey

$$\frac{\text{Prey energy content}}{\text{Predator search time + Predator handling time}}$$

Predator diet

- Optimal foraging (Charnov, 1976)

  → Predators consume the most profitable prey

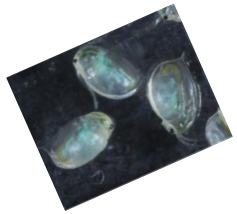


The prey infection: experiments

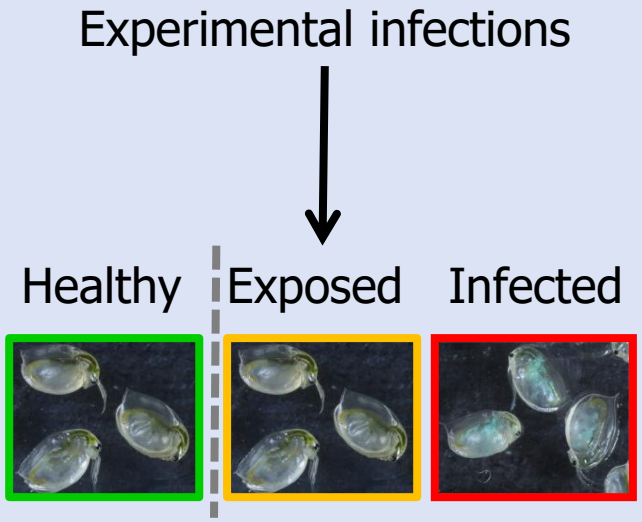
- Various measures on a parasite-host couple:
  - *Daphnia magna* and DIV-1 (White Fat Cell Disease)

  - Predator: *Notonecta sp.*

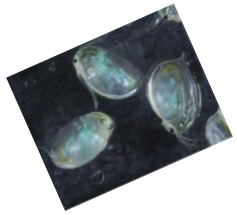
Assessment of virulence effects



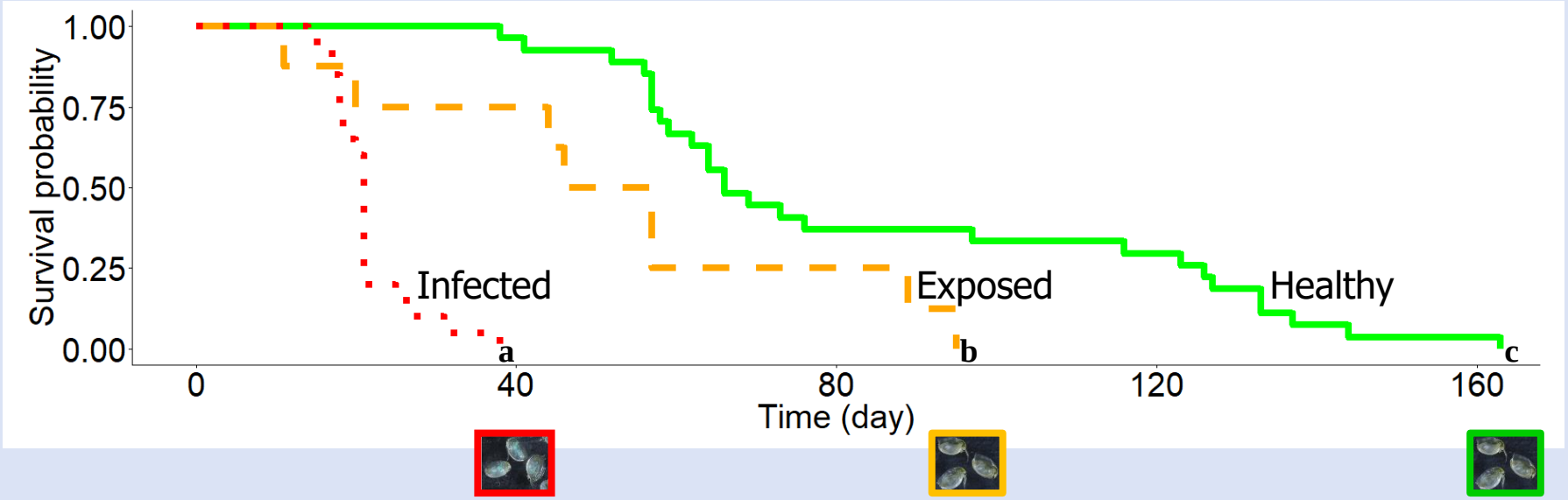
- Measures:
  - **Mortality**
  - **Fecundity**
  - **Fitness**



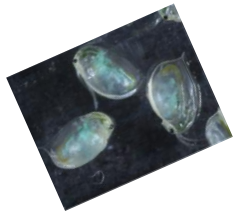
Virulence effects



- Mortality
  - Increase of mortality

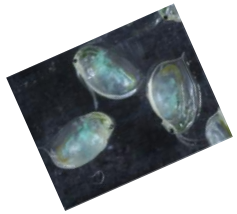


Virulence effects



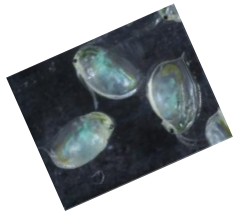
- Mortality
  - Increase of mortality
  - No modification of juvenile mortality

Virulence effects

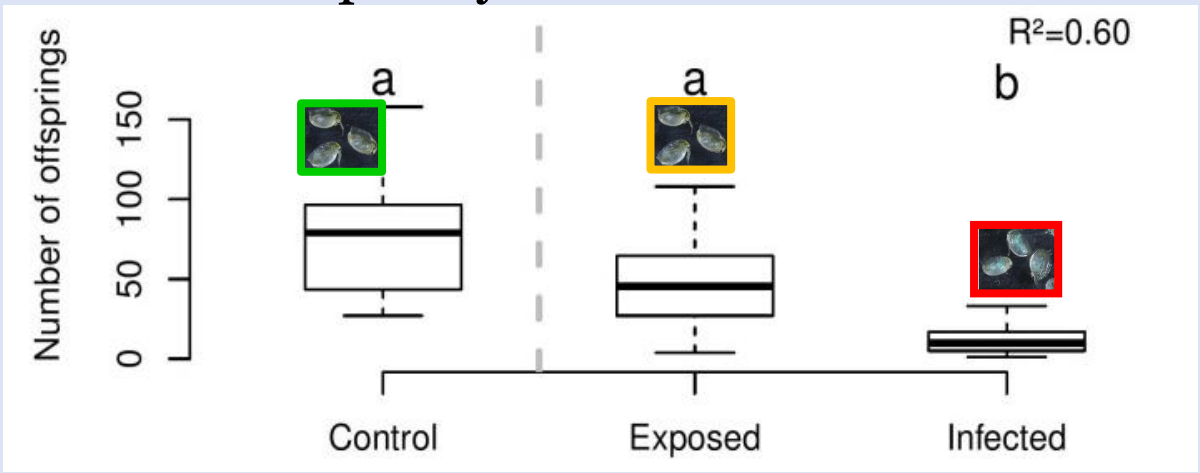


- Mortality
  - Increase of mortality
  - No modification of juvenile mortality
- Fecundity
  - Early first clutch of infected (age at maturity)
  - No modification of Clutches frequency and Mean clutches size

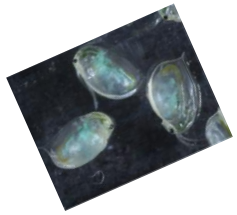
Virulence effects



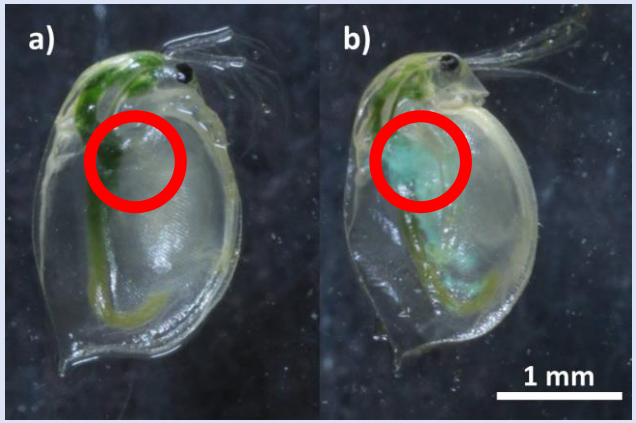
- Mortality
  - Increase of mortality
  - No modification of juvenile mortality
- Fecundity
  - Early first clutch of infected (age at maturity)
  - No modification of Clutches frequency and Mean clutches size
- Fitness
  - **Reduction of host fitness**



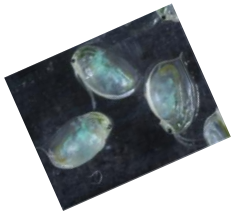
Assessment of visual alteration



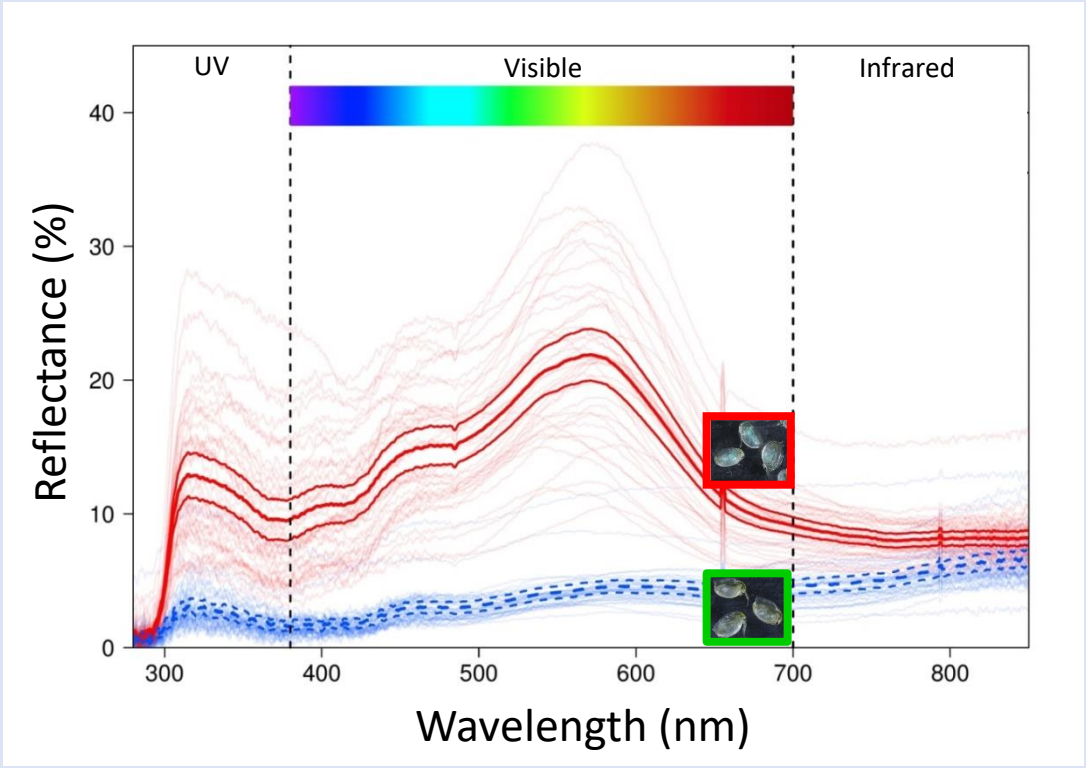
- Measures:
  - Mortality
  - Fecundity
  - Fitness
  - **Reflectance** → In UV and Visible



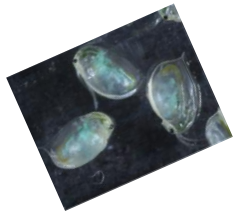
Interaction effects: reflectance



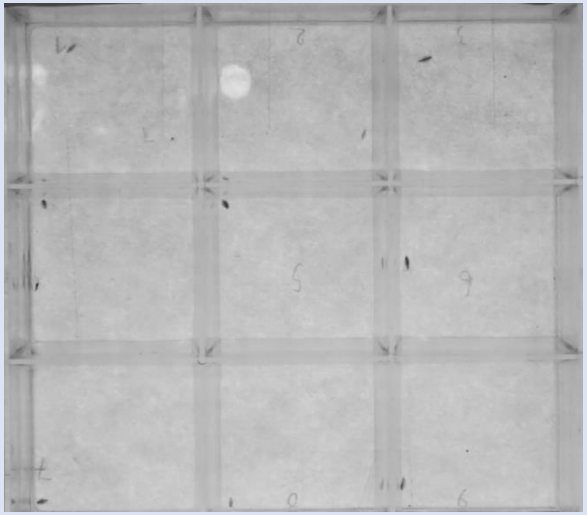
→ Higher reflectance of infected (UV and Visible)



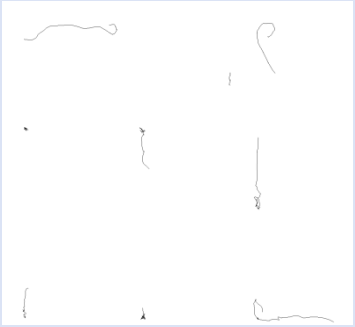
Assessment of visual alteration



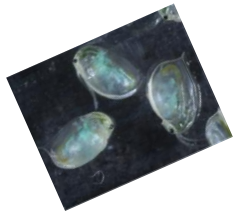
- Measures:
  - Mortality
  - Fecundity
  - Fitness
  - Reflectance
  - **Behaviour**



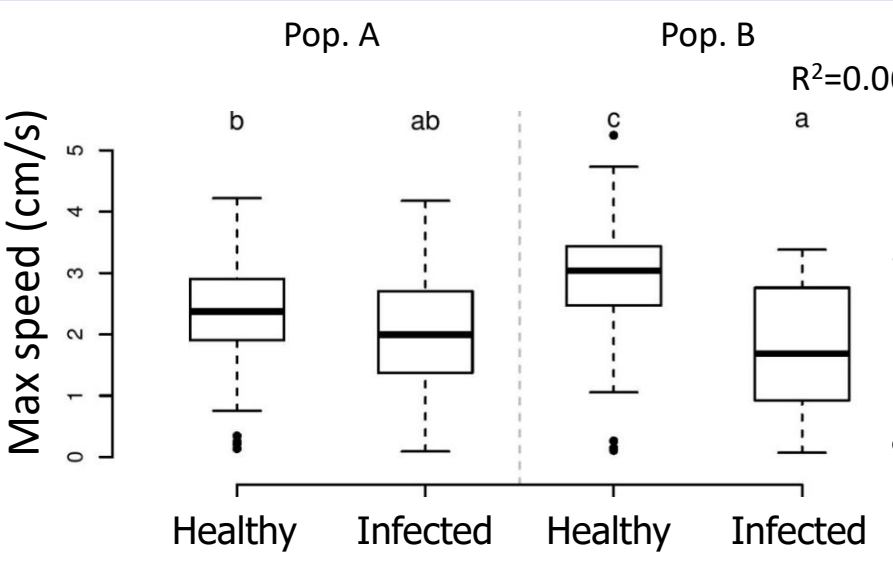
Day 14th

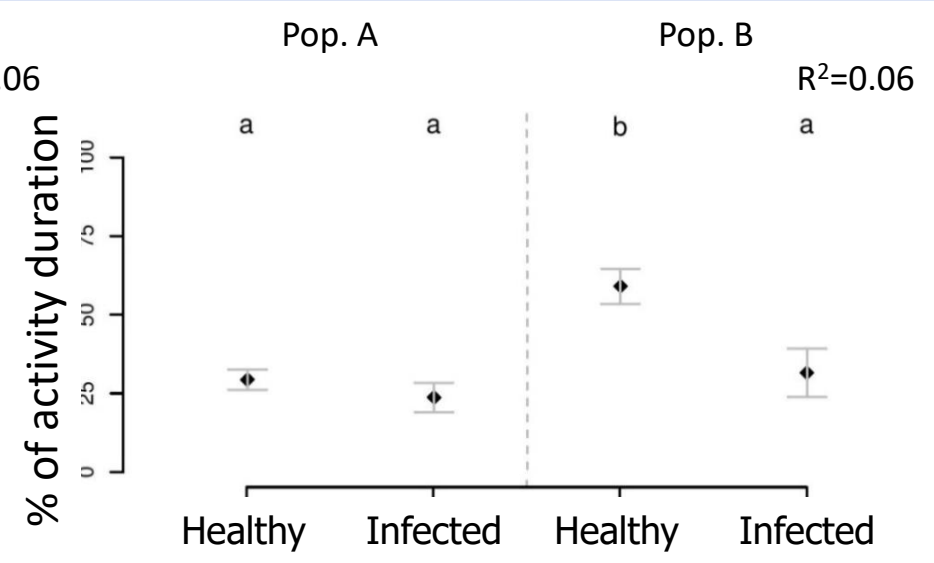


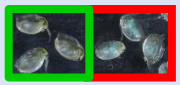
Interaction effects: behaviour

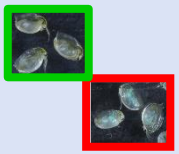


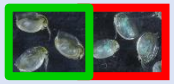
→ No effect or Lower activity of infected

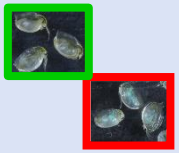




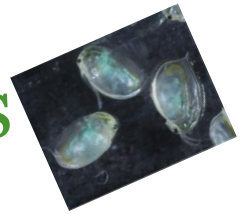






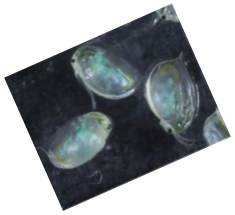


Assessment of interaction effects

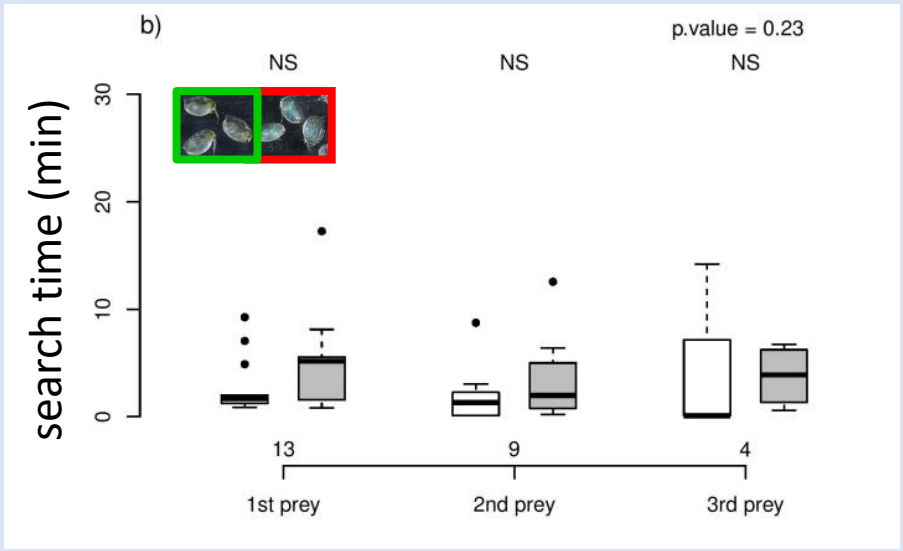


- Measures:
  - Mortality
  - Fecundity
  - Fitness
  - Reflectance
  - Behaviour
  - **Search time**
  - **Handling time**
  - **Predator preference**

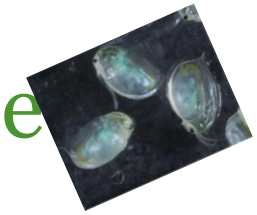
Interaction effects: search time



→ No modification of search time

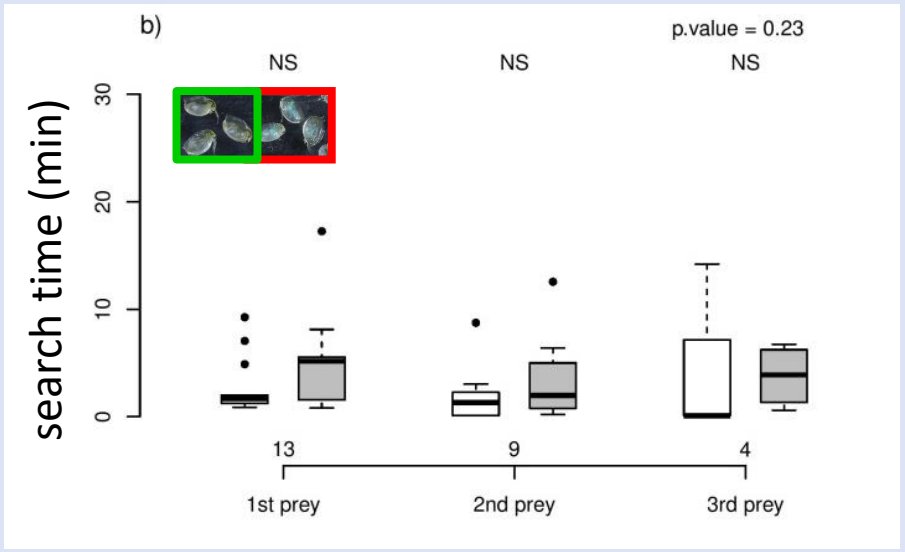


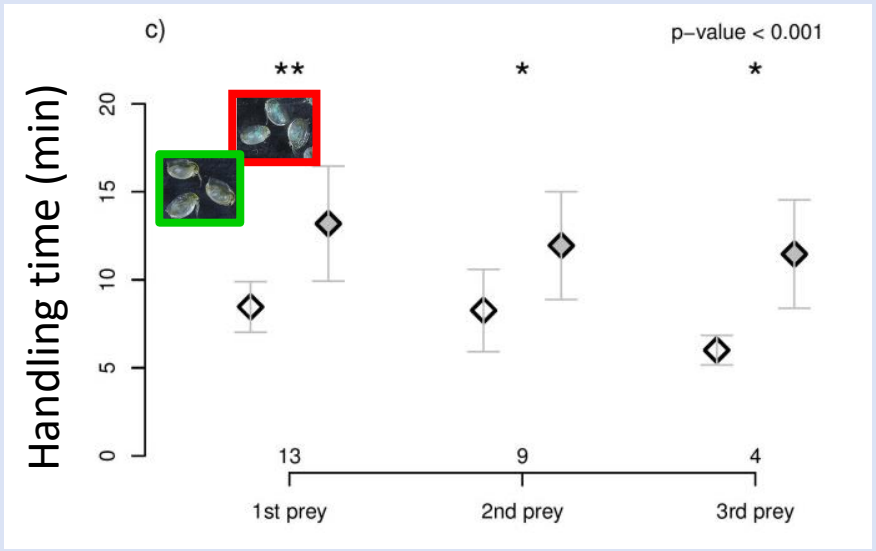
Interaction effects: handling time



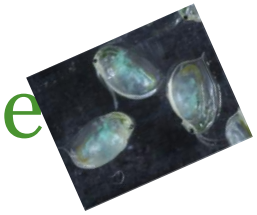
→ No modification of search time

→ Increased handling time





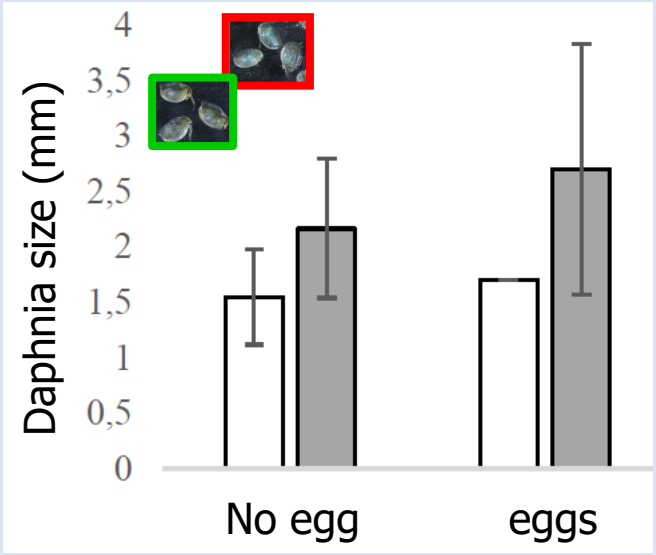
Interaction effects: handling time



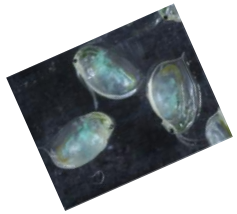
→ Increased handling time

→ Due to higher size?

Field observations:

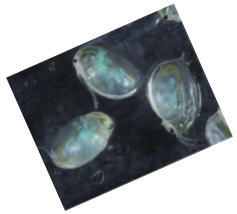


Assessment of profitability

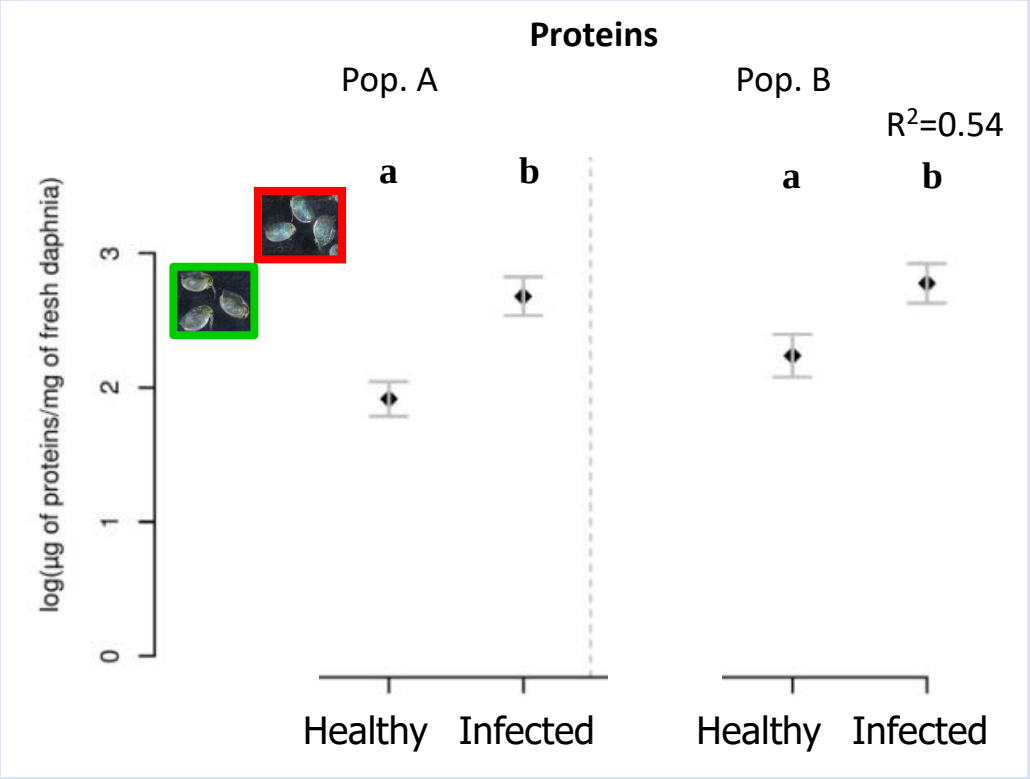


- Measures:
  - Mortality
  - Fecundity
  - Fitness
  - Reflectance
  - Behaviour
  - Search time
  - Handling time
  - Predator preference
  - **Energy content** → Proteins, Carbohydrates, Lipids

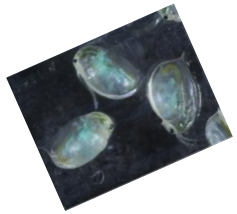
Host energy content



→ Higher protein contents

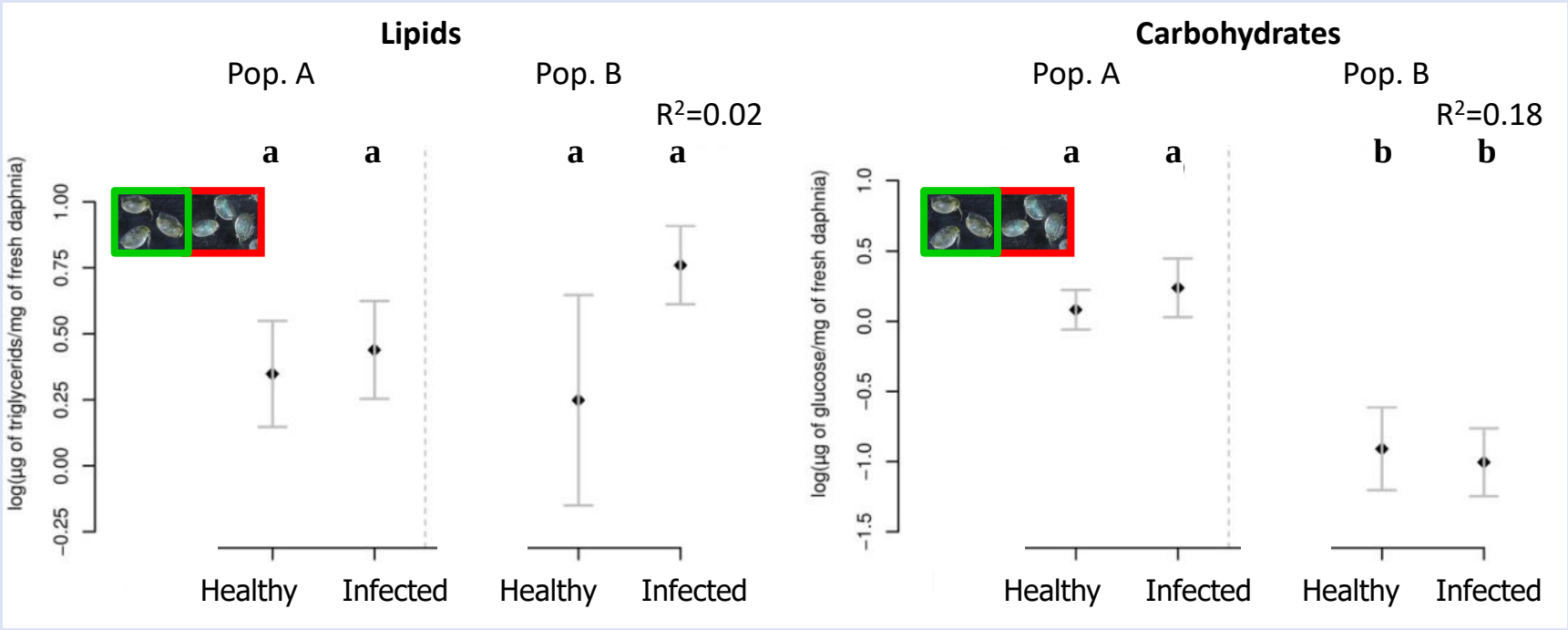


Host energy content

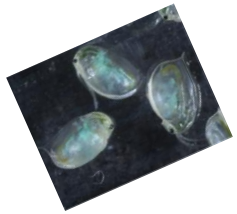


→ Higher protein contents

→ No modification of lipid and carbohydrate contents



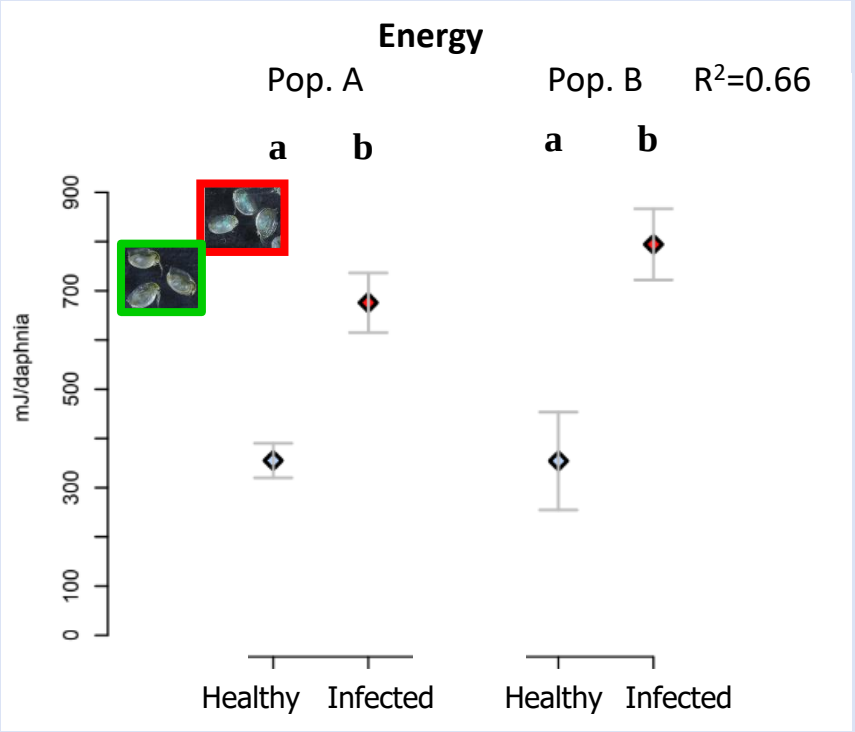
Host energy content



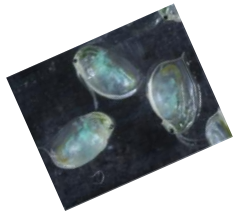
→ Higher protein contents

→ No modification of lipid and carbohydrate contents

→ Higher energy content



Host profitability



→ Higher handling time

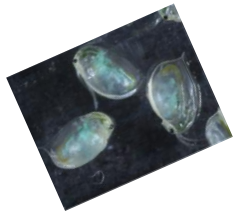
→ Higher energy content

→ Higher profitability

Heathy : 30 mJ/s

Infected : 37 mJ/s

Interaction effects: Preference



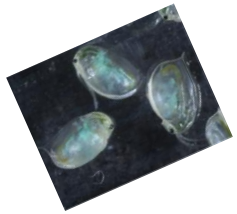
→ Tendency for preference for infected

Preference for infected

No preference

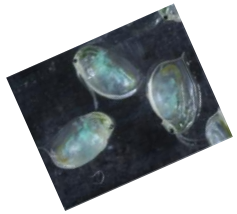
Preference for healthy

Conclusions



- Effects of DIV-1
  - Virulence effect > Interaction effect
  - Increase energy content
    → affect profitability

Host profitability



Proteins, Carbohydrates, Lipids

(+)

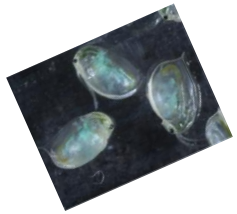
Prey energy content

Predator search time + Predator handling time

(0) interaction effects

(+) interaction effects

Host profitability



Proteins, Carbohydrates, Lipids

(+)

Prey energy content

Predator search time + Predator handling time

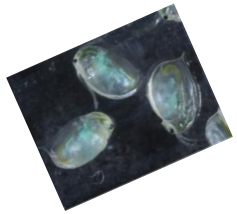
(+) (O)

virulence and interaction effects

(+)

interaction effects

Host profitability



Proteins, Carbohydrates, Lipids

(+)

Prey energy content

Predator search time + Predator handling time

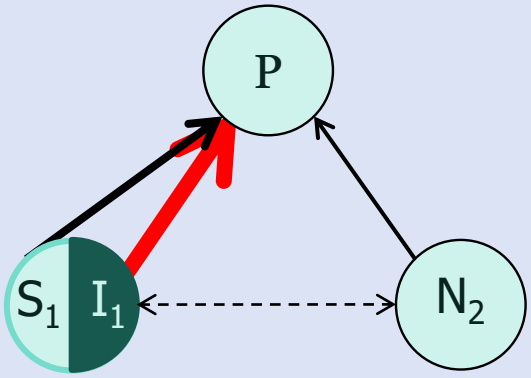
(+) (O) virulence and interaction effects

(+) interaction effects

Effects of DIV-1 on predator diet?

Infected prey: the structured model

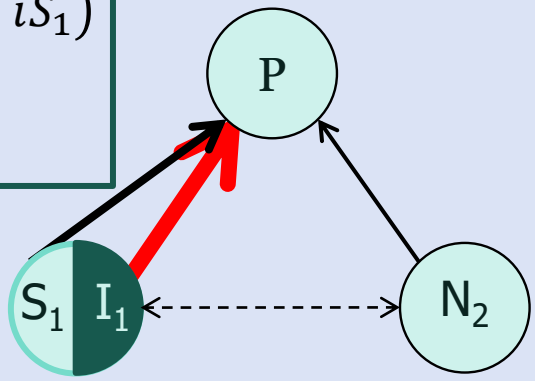
- Infected prey in Susceptible and Infected (SI)



Infected prey: the structured model

- Infected prey in Susceptible and Infected (SI)

$$\begin{cases} \dfrac{dS_1}{dt} = S_1(f_1 - m_1 - b_{11}N_1 - b_{12}N_2 - a_1P) + I_1\big((f_1 - n) - iS_1\big) \\ \dfrac{dI_1}{dt} = I_1(iS_1 - b_{11}N_1 - b_{12}N_2 - (a_1 + j)P - m_1) \\ \dfrac{dN_2}{dt} = N_2(r_2 - b_{21}N_1 - b_{22}N_2 - a_2P) \\ \dfrac{dP}{dt} = P(ea_1N_1 + ejI_1 + ea_2N_2 - m) \end{cases}$$



- Virulence, n (reduction of fecundity)
- Interaction, j (increase of vulnerability)

(Prosnier et al, 2018)

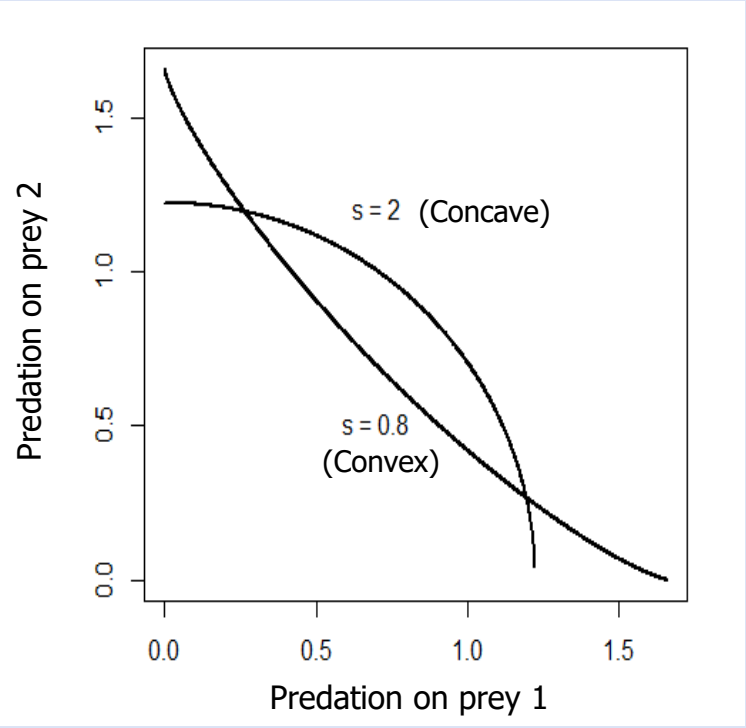
The Evolutionary model: adaptive foraging

- Adding a trade-off for predation (prey choice)

The Evolutionary model: adaptive foraging

- Adding a trade-off for predation (prey choice)

$$a_1{}^s + a_2{}^s = k_0$$



The Evolutionary model: adaptive foraging

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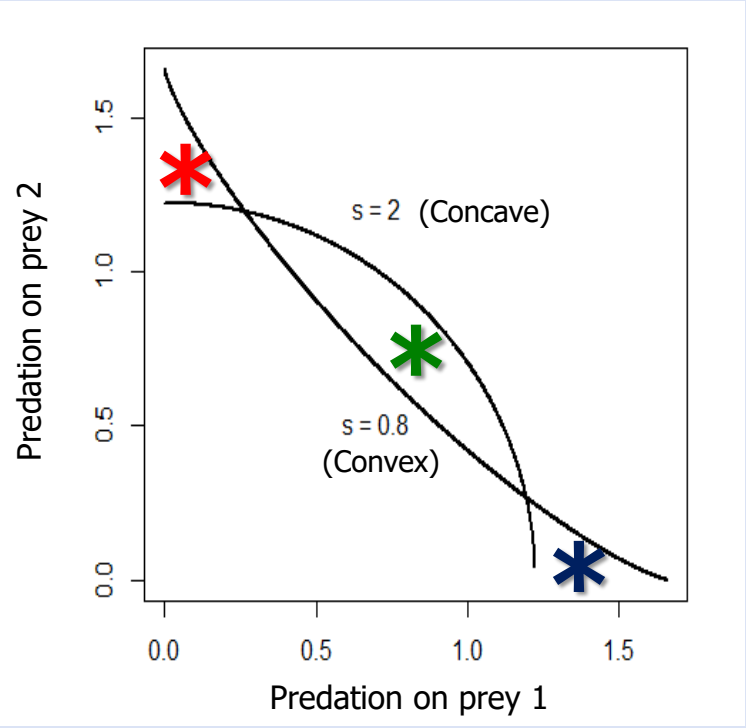
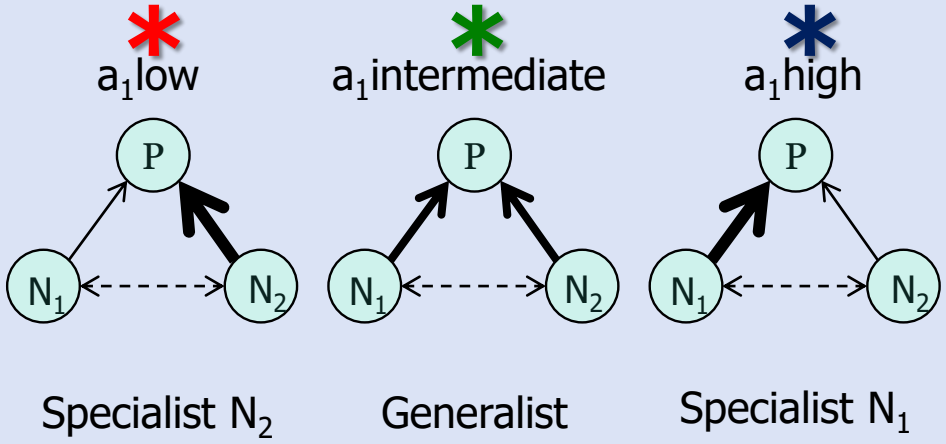




Adaptive dynamics

- Hypothesis:
  - clonal reproduction
  - Slow evolution compared to ecological dynamics
  - Rare mutations
  - Small mutation

(Dieckmann and Law, 1996)

Adaptive dynamics

- Canonical equation

Trade-off of predation

$$a_1{}^s + a_2{}^s = k_0$$

Evolution of attack rate on N_1

Relative fitness of mutants

$$\frac{da_1}{dt} = \frac{1}{2}\mu\,\sigma^2 P^*(a_1)\left.\frac{\partial\omega(a_{1m}, a_1)}{\partial a_{1m}}\right|_{a_{1m}\to a_1}$$

Selection gradient

- Singularities

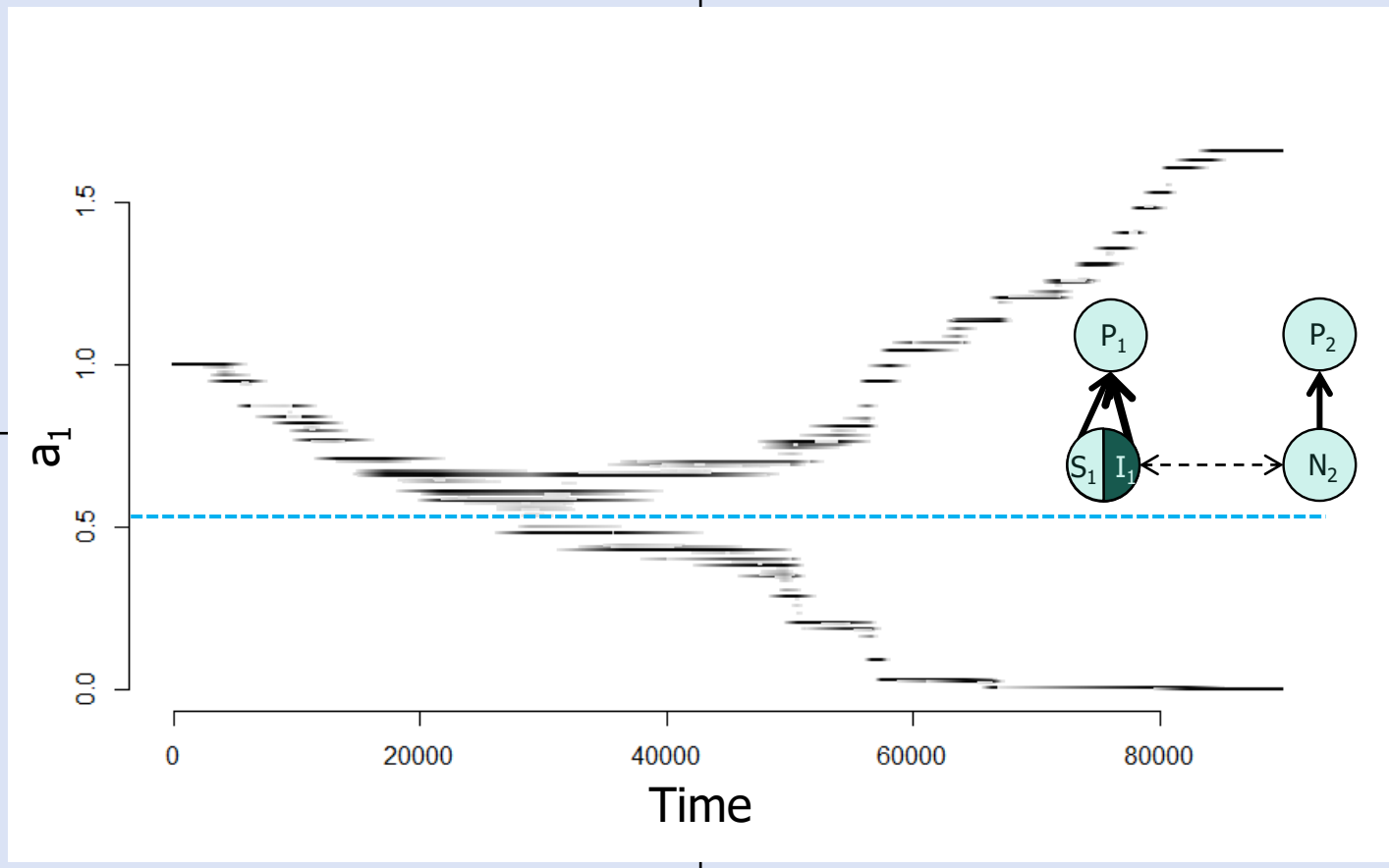
$$\left.\frac{\partial\omega(a_{1m}, a_1)}{\partial a_{1m}}\right|_{a_{1m}\to a_1\to\overline{a_1}} = 0$$

(Dieckmann and Law, 1996)

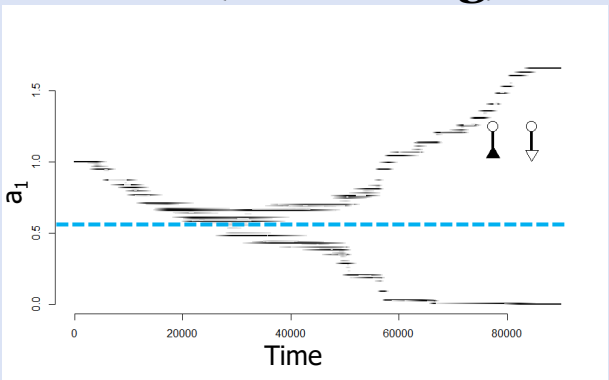
Singularities

	Convergent	Non-convergent
Invasible	**EBP (Branching)**	**Repellor**
Non-invasible	**CSS (Continuously Stable)**	Not observed

Singularities

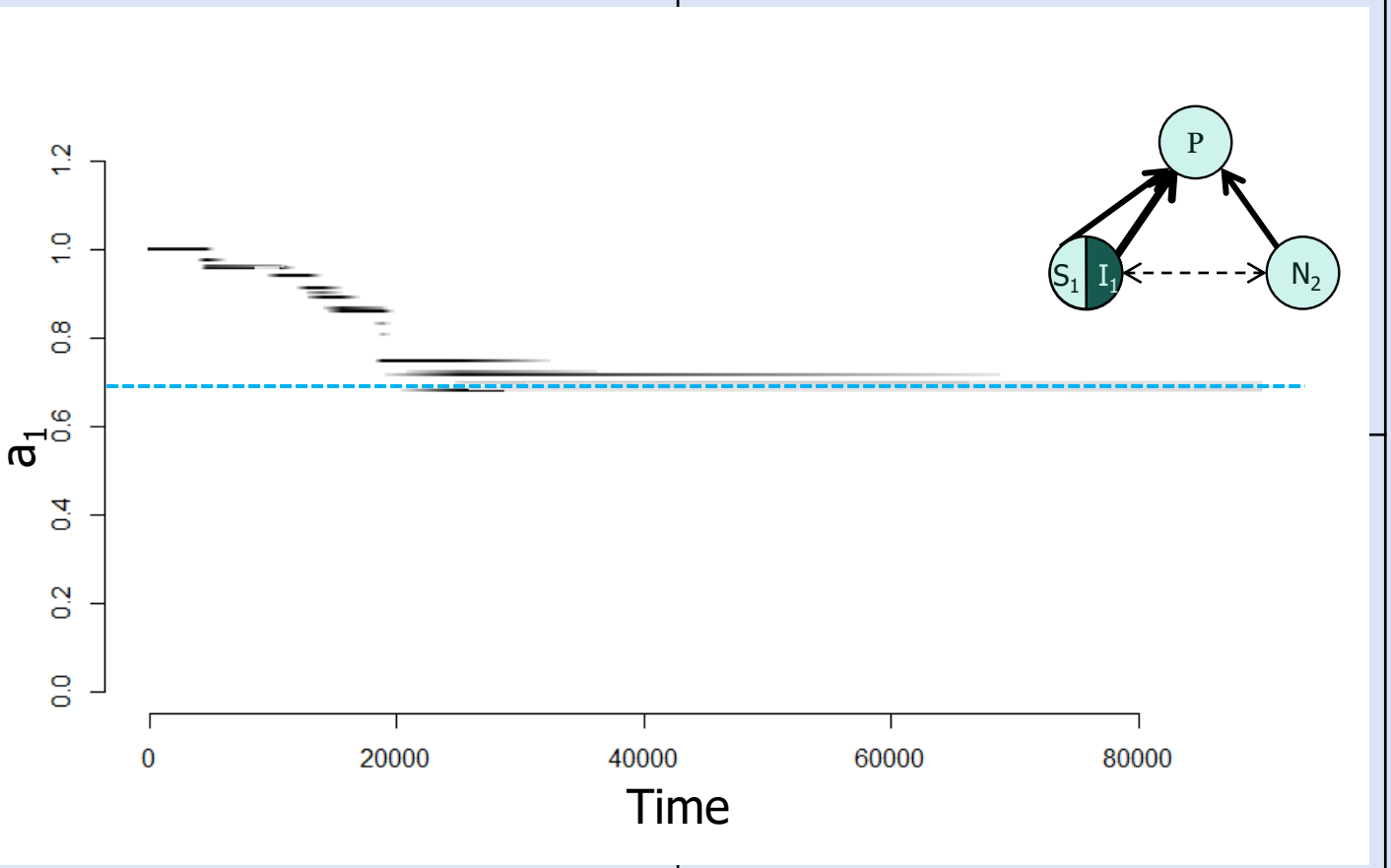
	Convergent	Non-convergent
Invasible		
Non-invasible		

Singularities

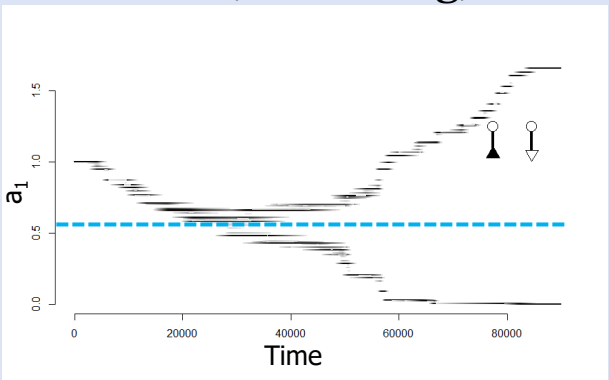
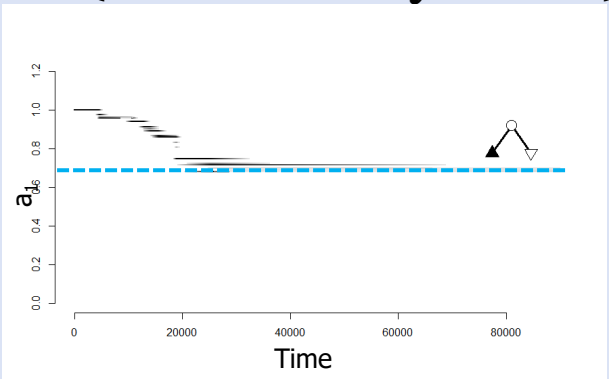
	Convergent	Non-convergent
Invasible	**EBP (Branching)** 	Repellor
Non-invasible	CSS (Continuously Stable)	Not observed

Singularities

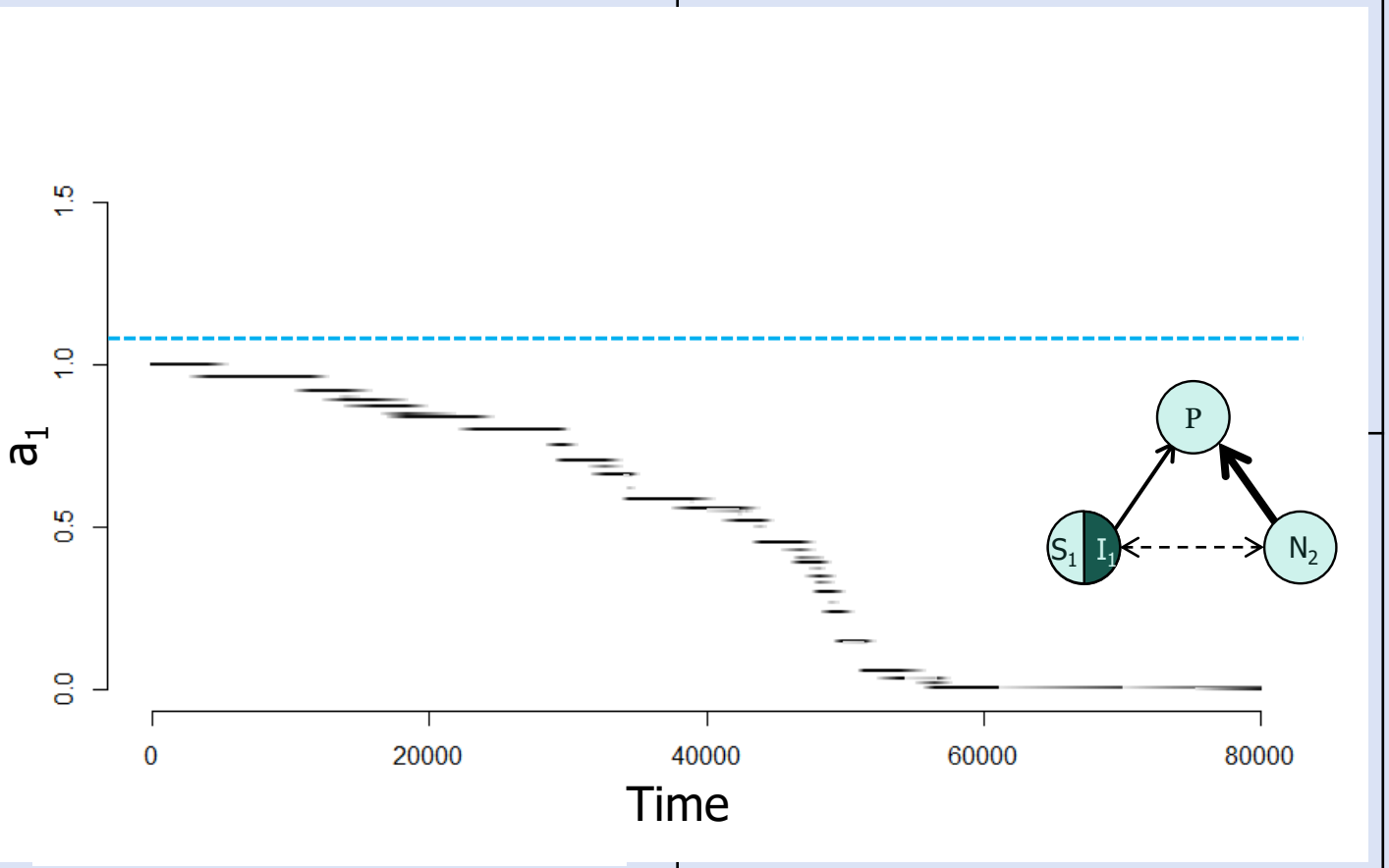
	Convergent	Non-convergent
Invasible		
Non-invasible		



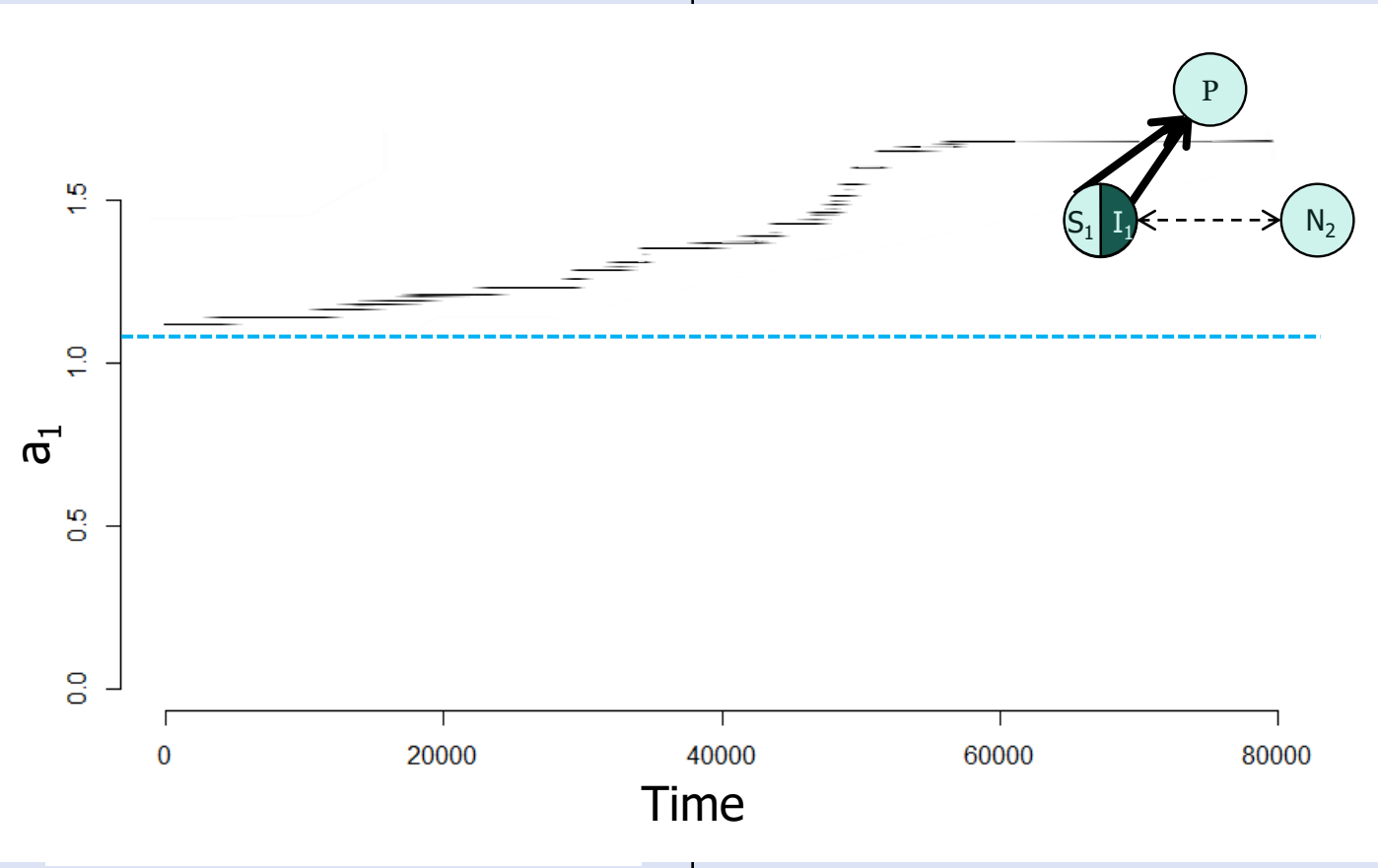
Singularities

	Convergent	Non-convergent
Invasible	EBP (Branching) 	Repellor
Non-invasible	**CSS (Continuously Stable)** 	Not observed

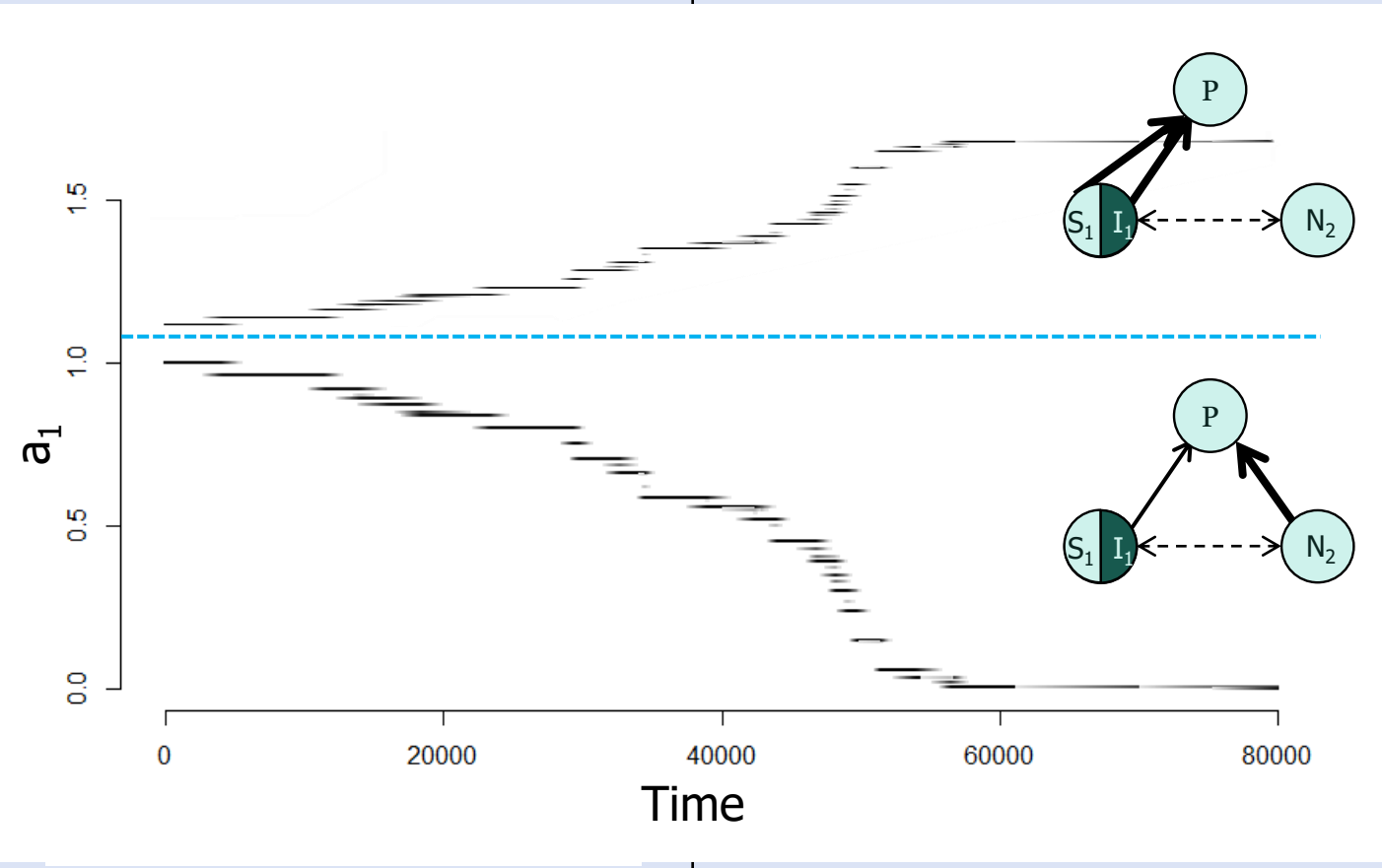
Singularities

	Convergent	**Non-convergent**
Invasible		
Non-invasible		

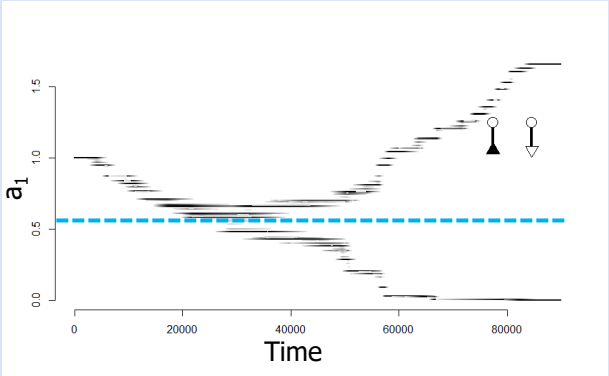
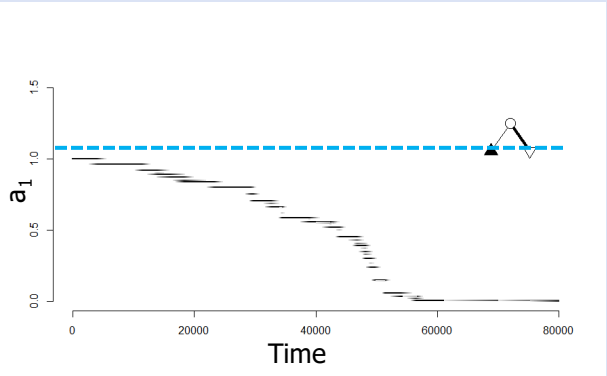
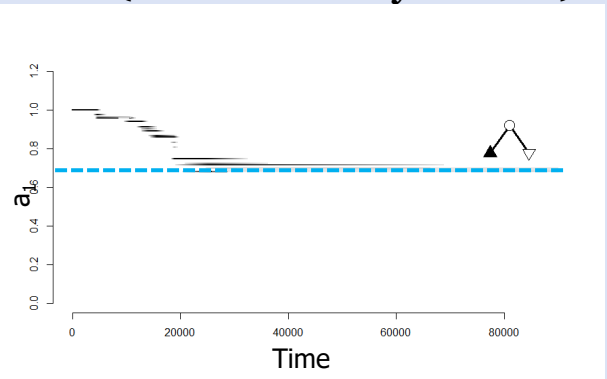
Singularities

	Convergent	**Non-convergent**
Invasible		
Non-invasible		

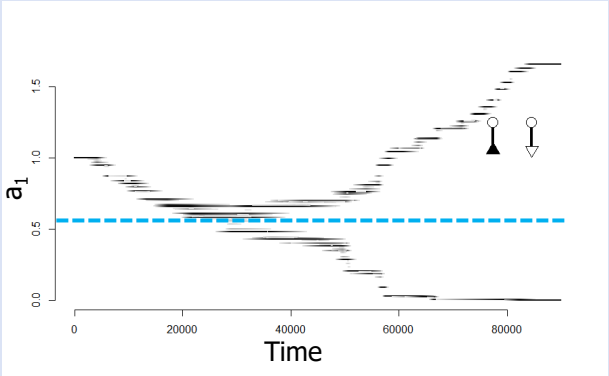
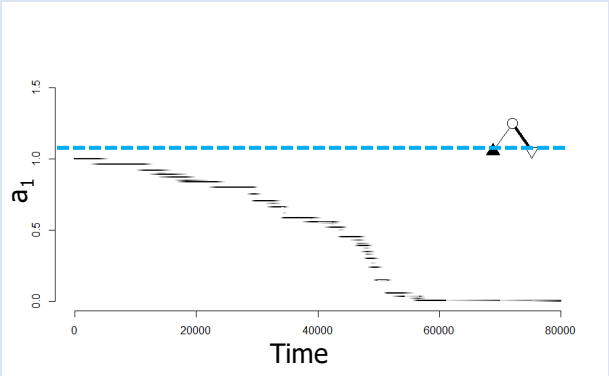
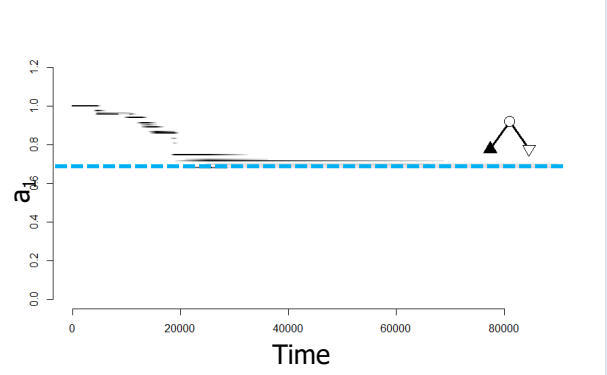
Singularities

	Convergent	**Non-convergent**
Invasible		
Non-invasible		

Singularities

	Convergent	**Non-convergent**
Invasible	EBP (Branching) 	**Repellor** 
Non-invasible	CSS (Continuously Stable) 	Not observed

Singularities

	Convergent	Non-convergent
Invasible	**EBP (Branching)** 	**Repellor** 
Non-invasible	**CSS (Continuously Stable)** 	Not observed

Adaptive dynamics

- Singularities

Trade-off of predation

$$a_1{}^s + a_2{}^s = k_0$$

$$\left.\frac{\partial \omega(a_{1m}, a_1)}{\partial a_{1m}}\right|_{a_{1m}\to a_1\to \overline{a_1}} = 0$$

- Non-invasible

$$c_{22} = \left.\frac{\partial^2 \omega}{\partial {a_{1m}}^2}\right|_{a_{1m}\to a_1\to \bar{a}_1} < 0$$

$$-\bar{a}_1{}^{s-2} k_0 (k_0 - \bar{a}_1{}^s)^{\frac{1}{s}-2} N_2^* (s-1) < 0$$

$s > 1$ → Concave-trade-off

Adaptive dynamics

Trade-off of predation

$$a_1{}^s + a_2{}^s = k_0$$

- Singularities

$$\left.\frac{\partial \omega(a_{1m}, a_1)}{\partial a_{1m}}\right|_{a_{1m}\to a_1\to \overline{a_1}} = 0$$

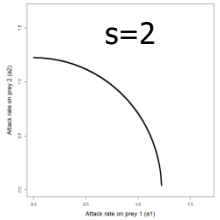
- Non-invasible

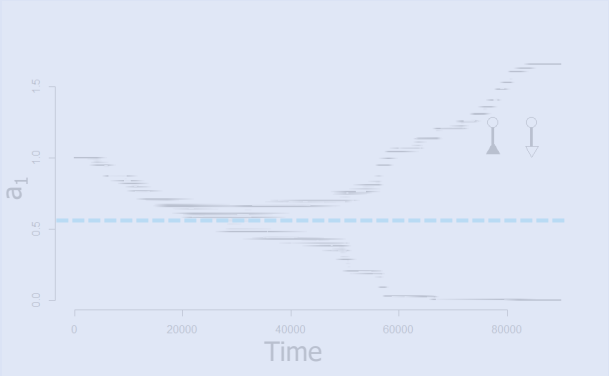
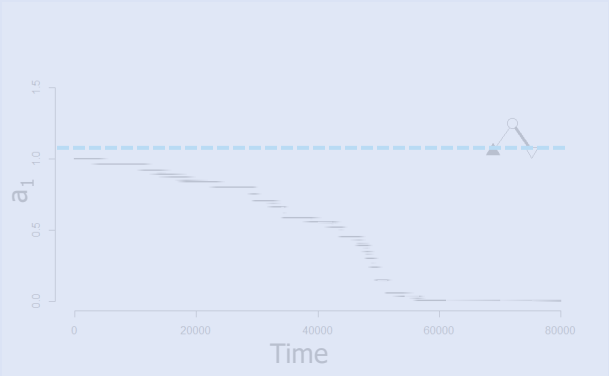
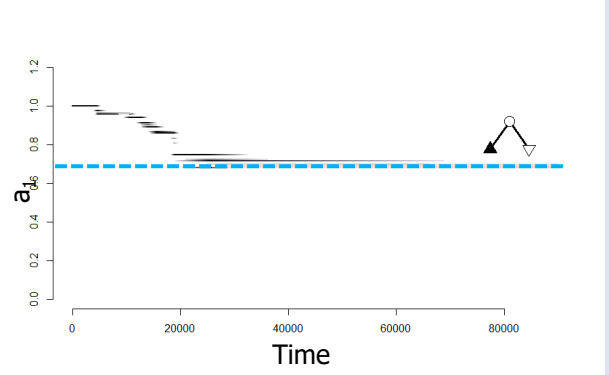
$$c_{22} = \left.\frac{\partial^2 \omega}{\partial {a_{1m}}^2}\right|_{a_{1m}\to a_1\to \bar{a}_1} < 0$$

- Convergent

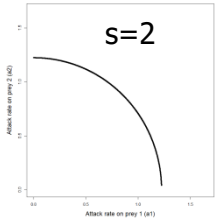
$$c_{12} + c_{22} < 0$$

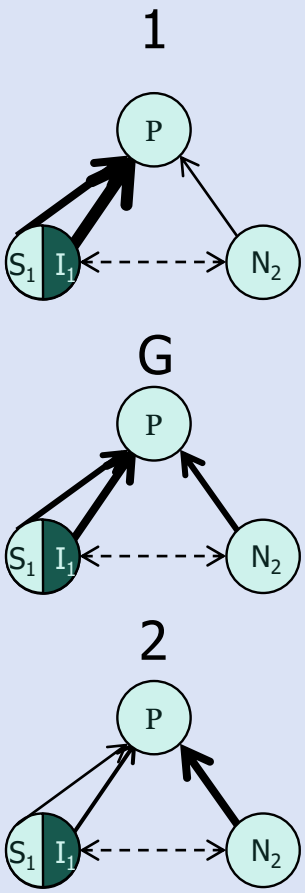
Predator diet: concave trade-off

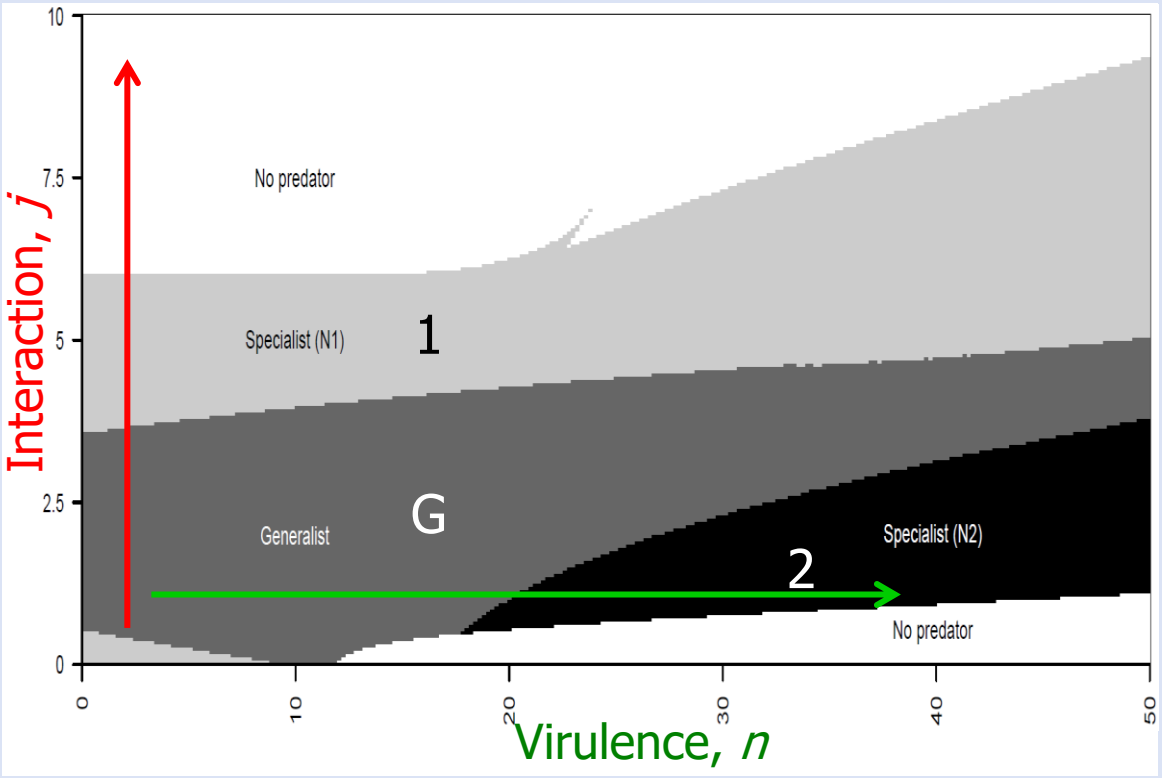


	Convergent	**Non-convergent**
Invasible	**EBP (Branching)** 	**Repellor** 
Non-invasible	**CSS (Continuously Stable)** 	Not observed

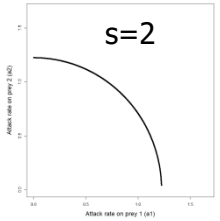
Predator diet: concave trade-off

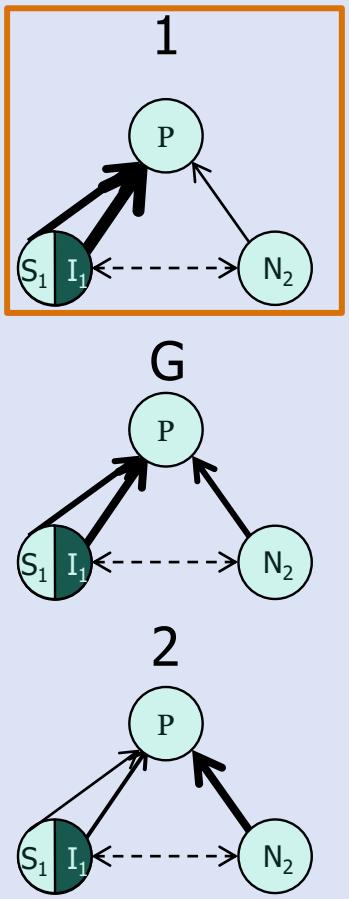


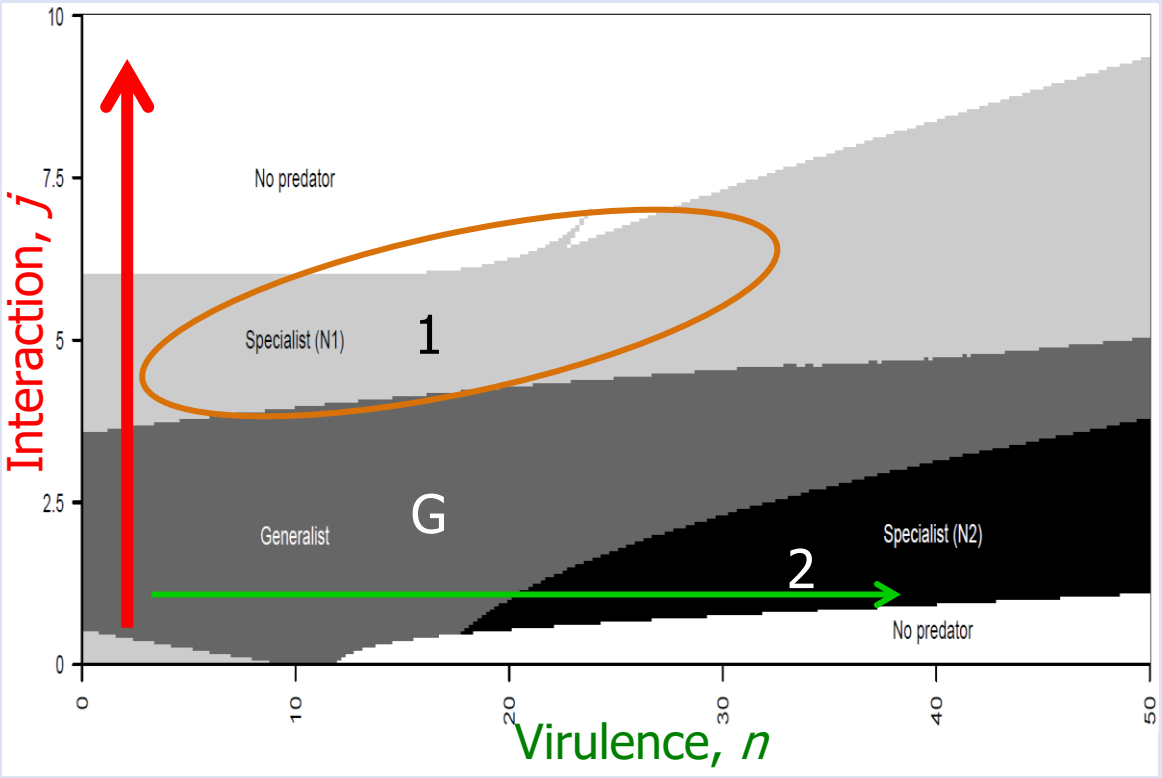




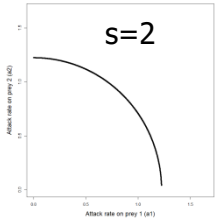
Predator diet: concave trade-off

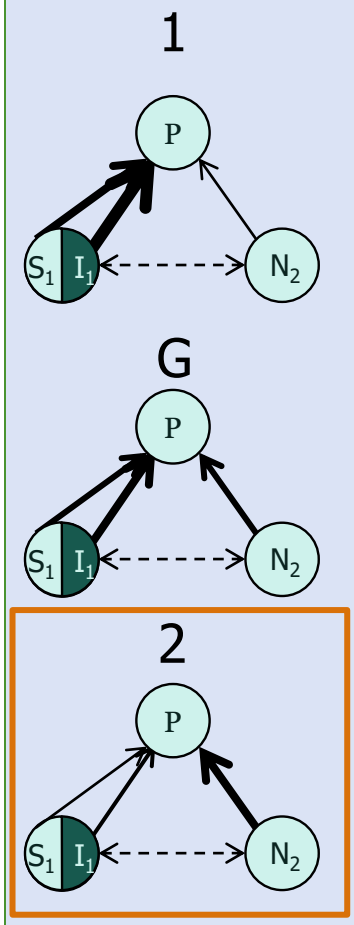


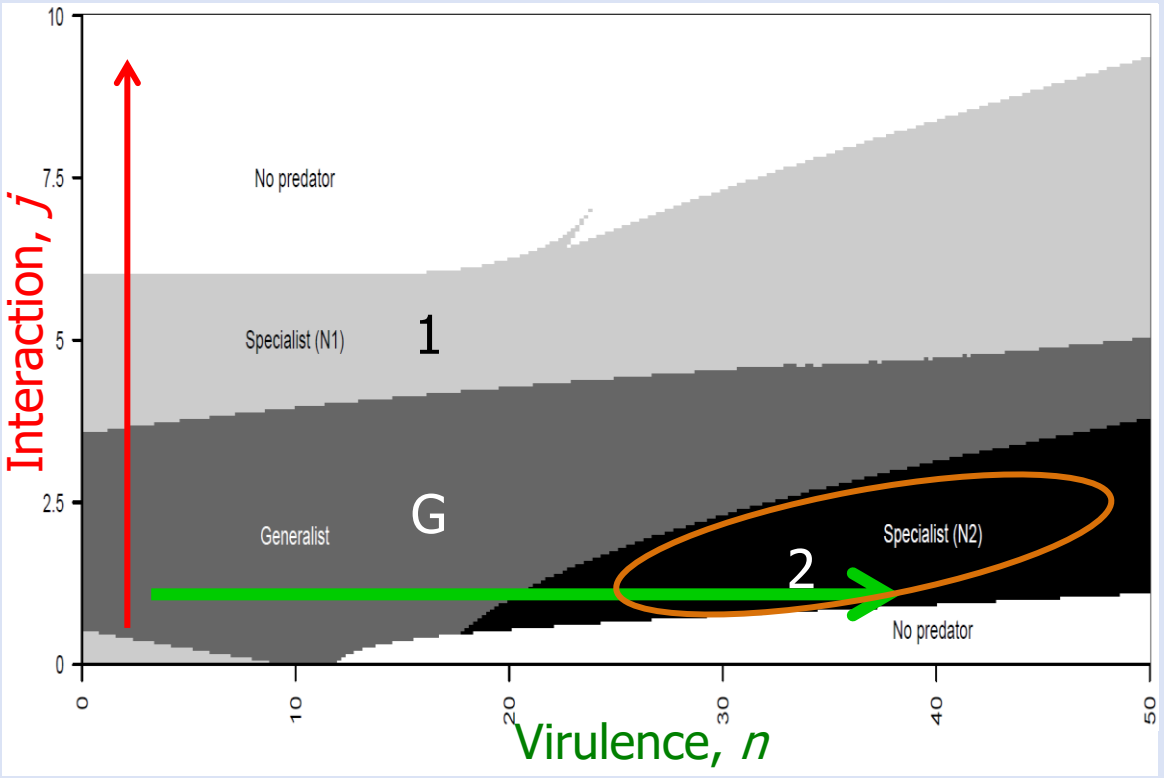




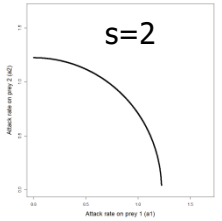
Predator diet: concave trade-off

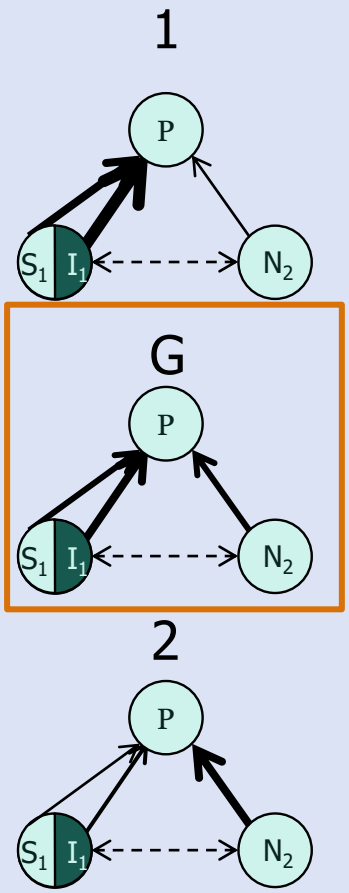


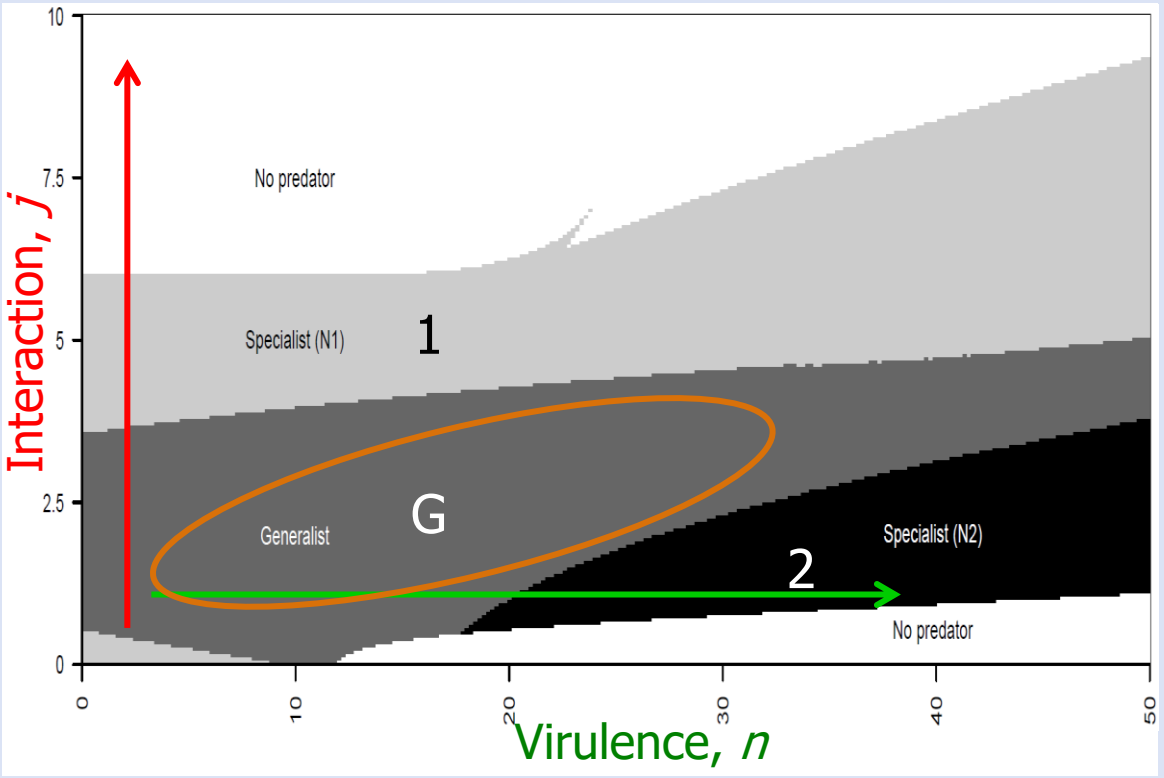




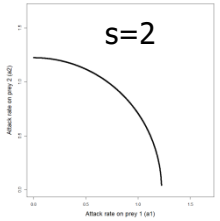
Predator diet: concave trade-off

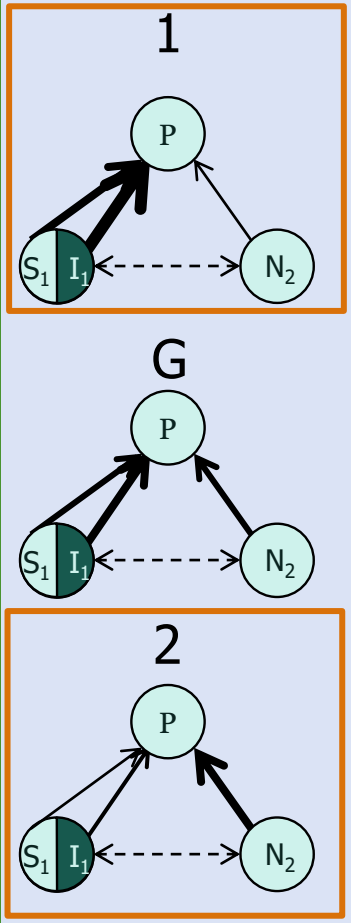


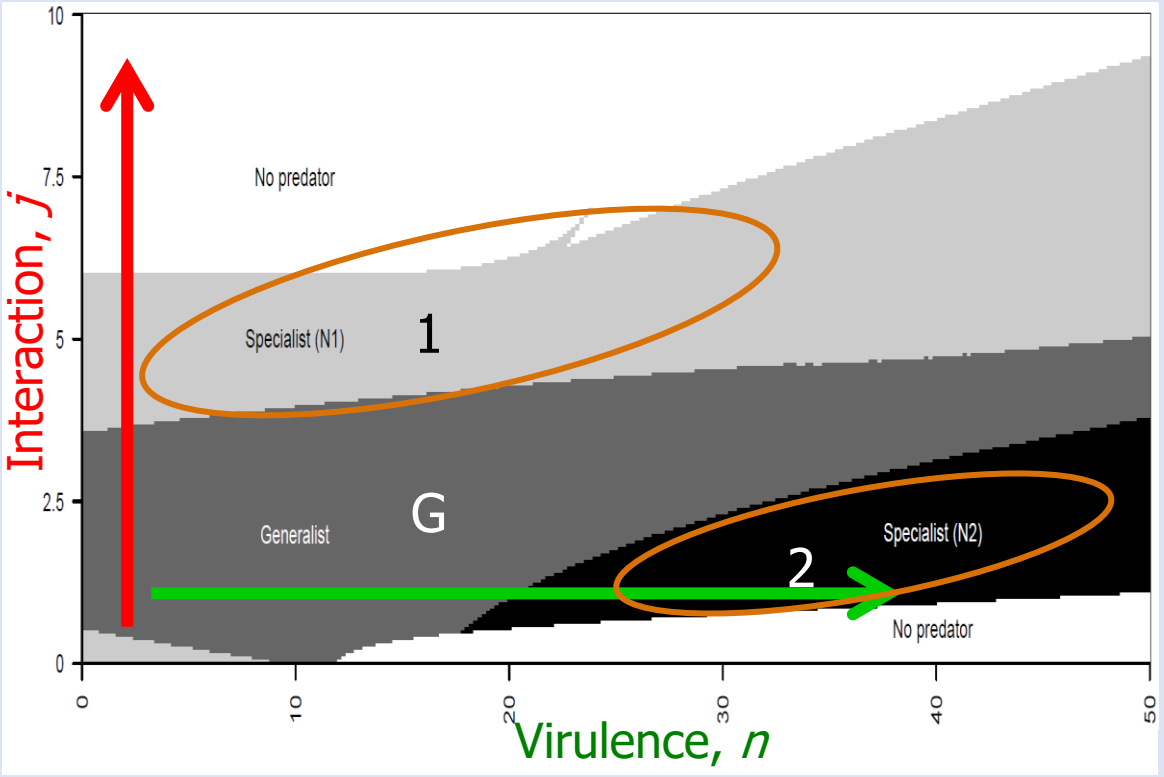




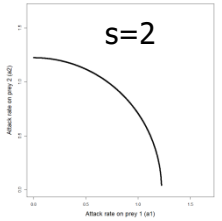
Predator diet: concave trade-off

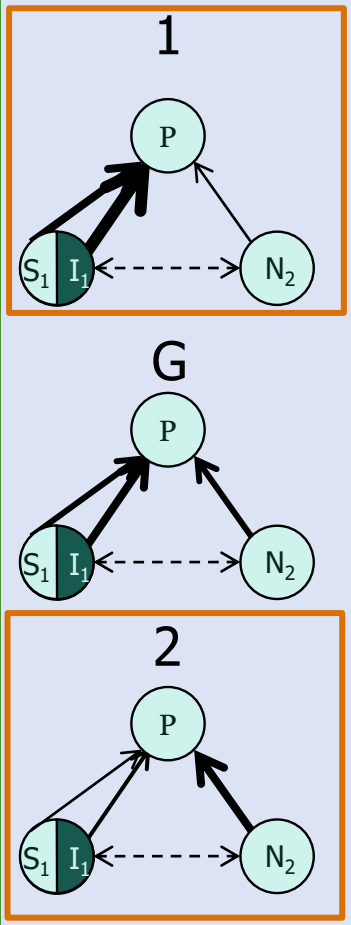


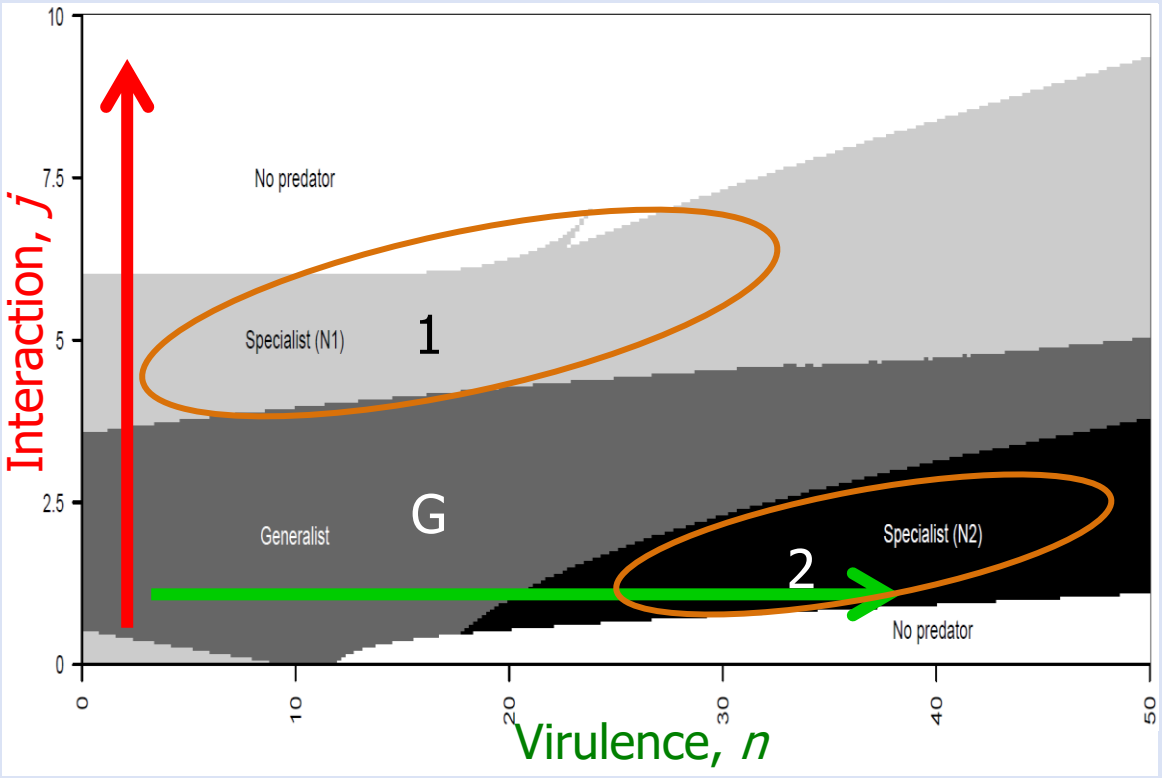




Predator diet: concave trade-off

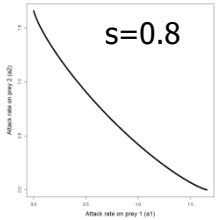


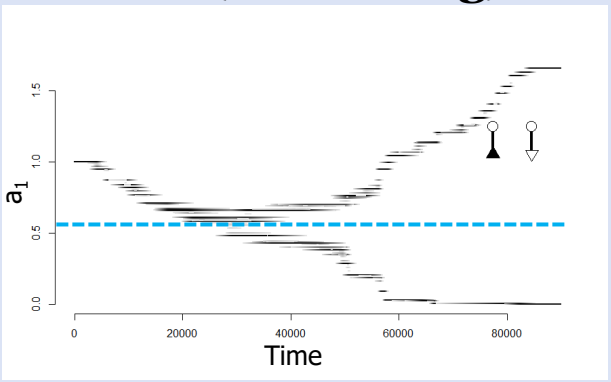
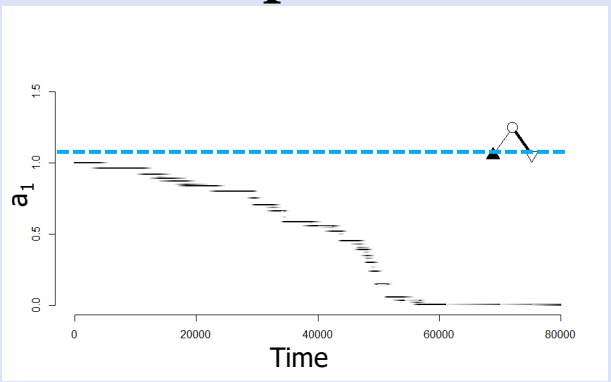
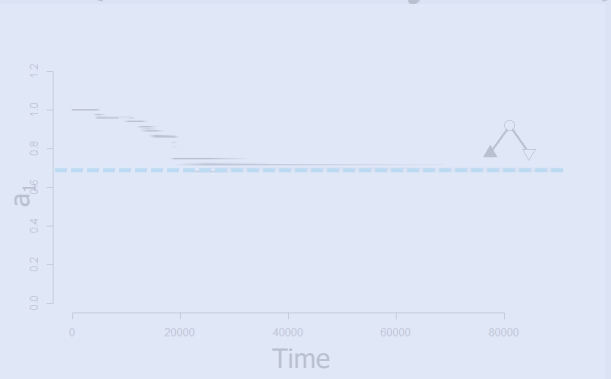




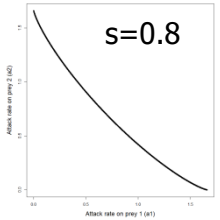
Virulence and interaction effects on profitability

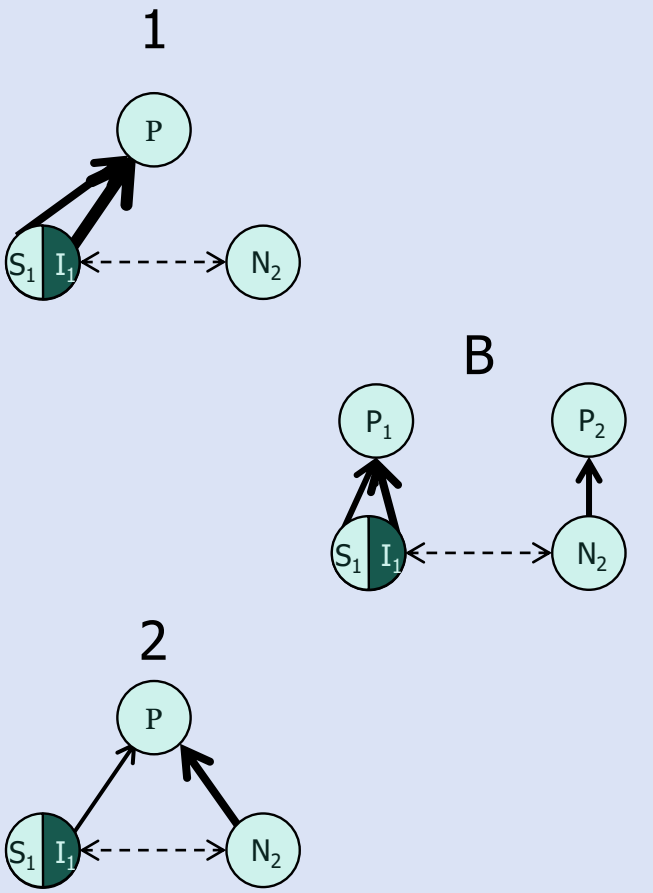
Predator diet: convex trade-off

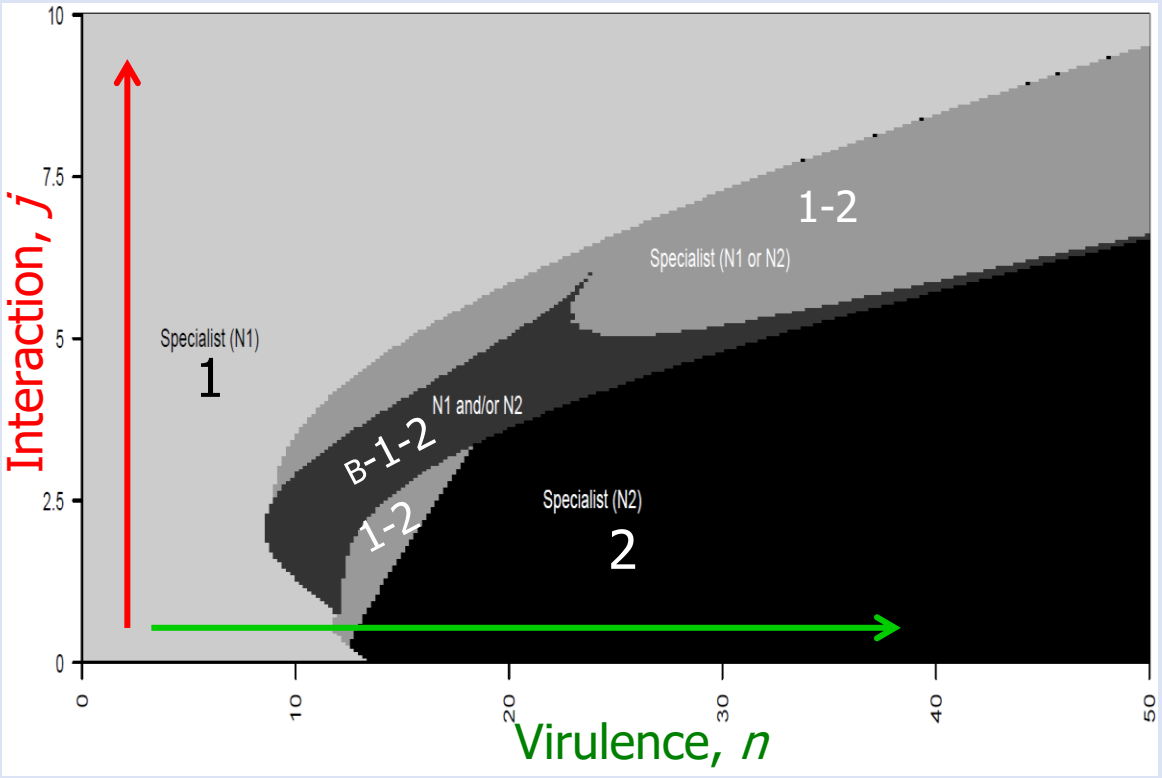


	Convergent	Non-convergent
Invasible	**EBP (Branching)** 	**Repellor** 
Non-invasible	**CSS (Continuously Stable)** 	Not observed

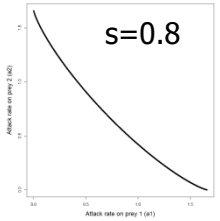
Predator diet: convex trade-off

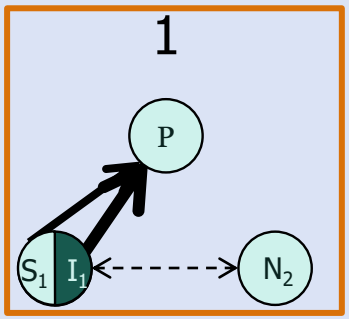


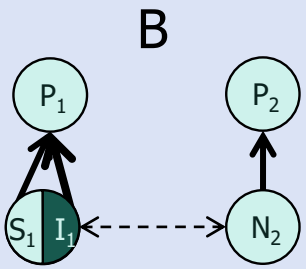


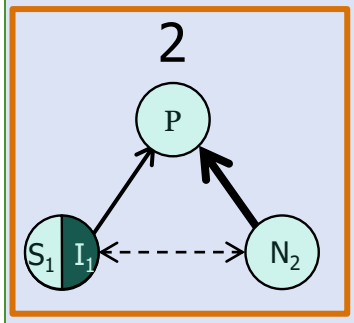


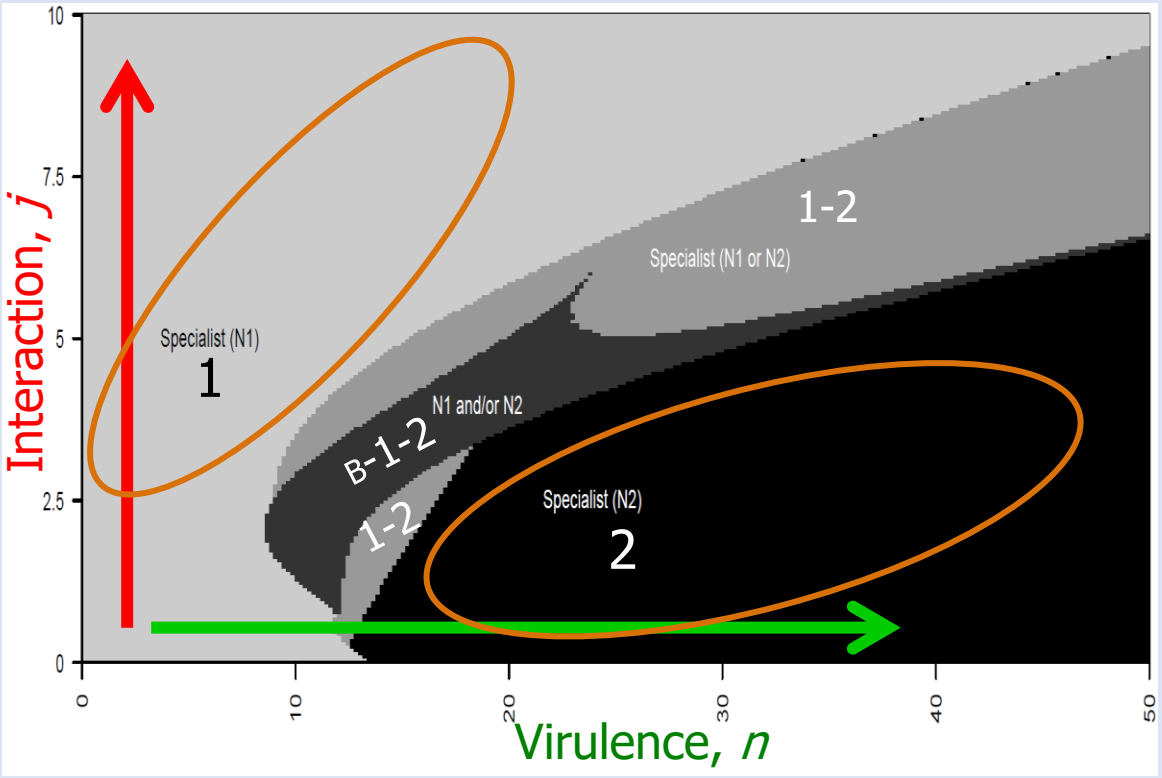
Predator diet: convex trade-off



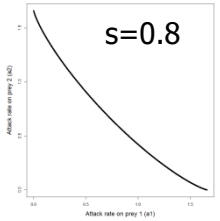


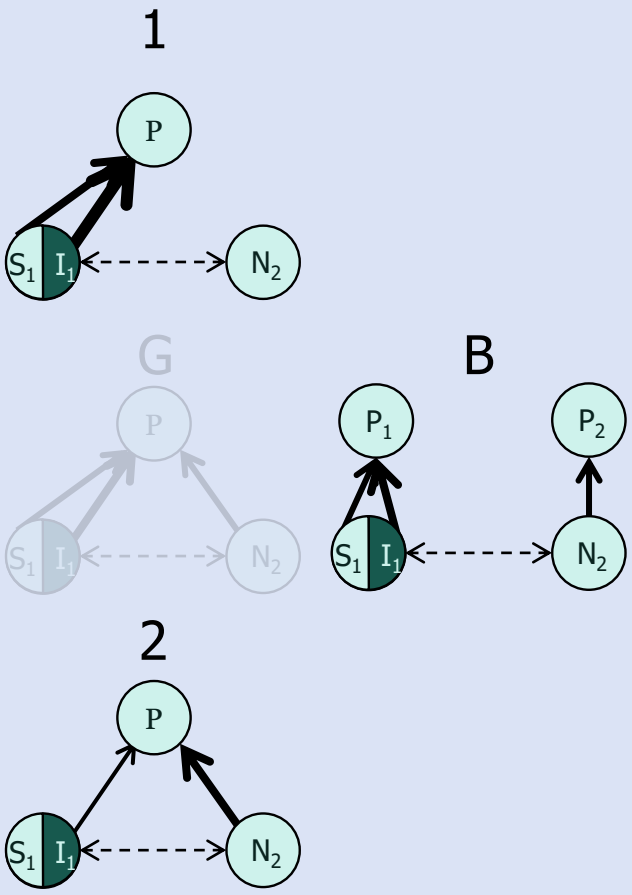


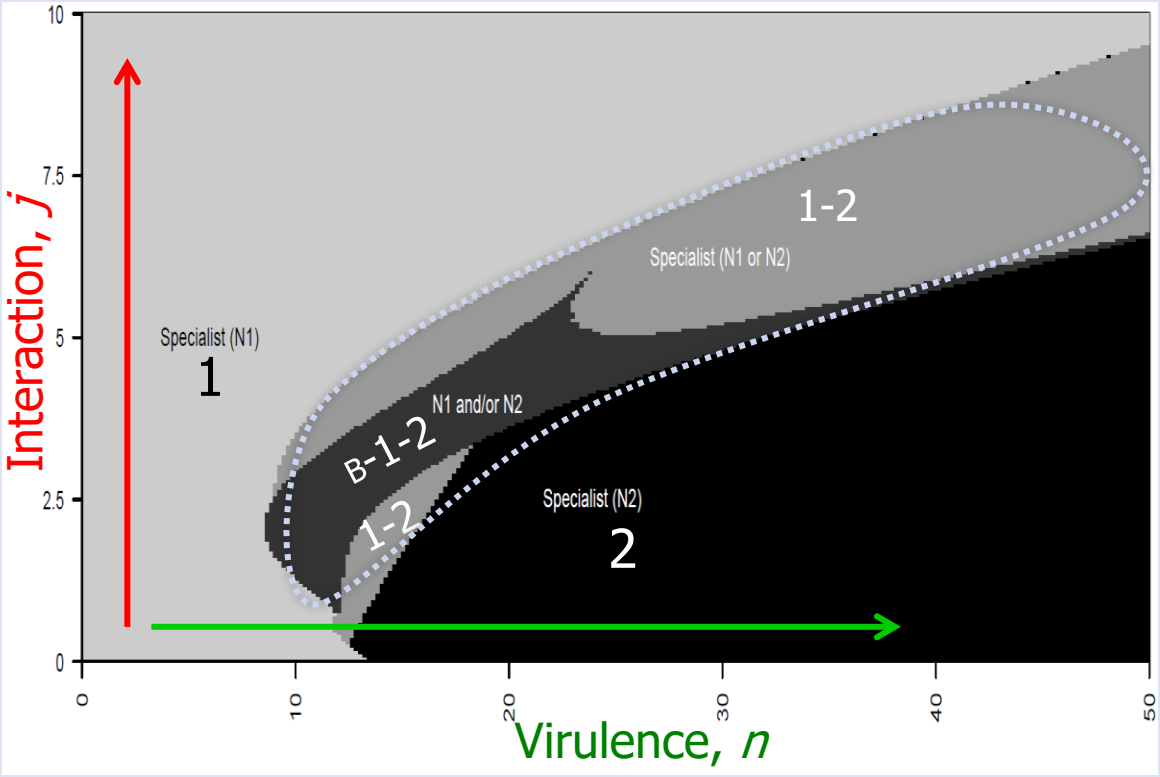




Predator diet: convex trade-off

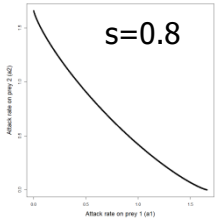


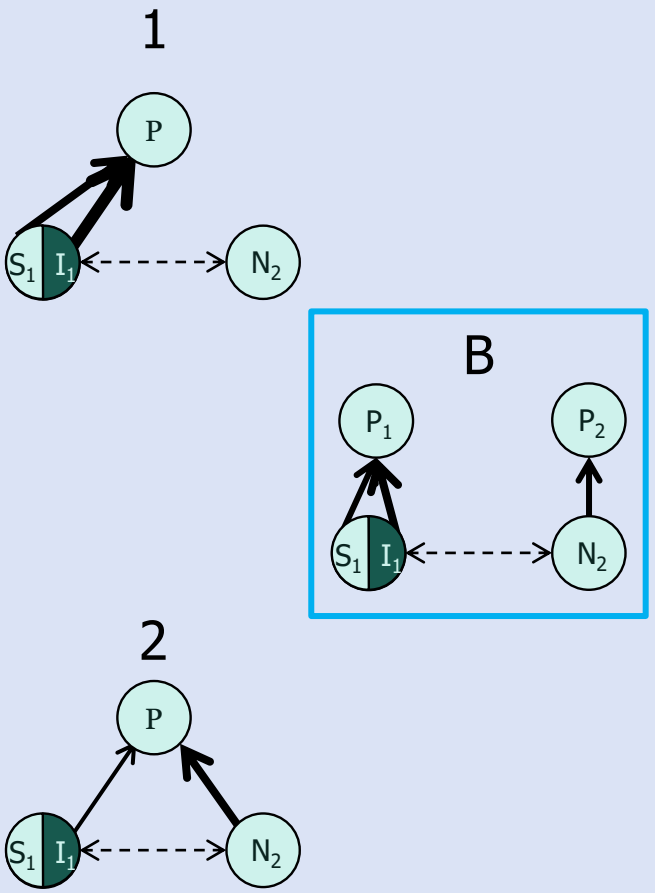


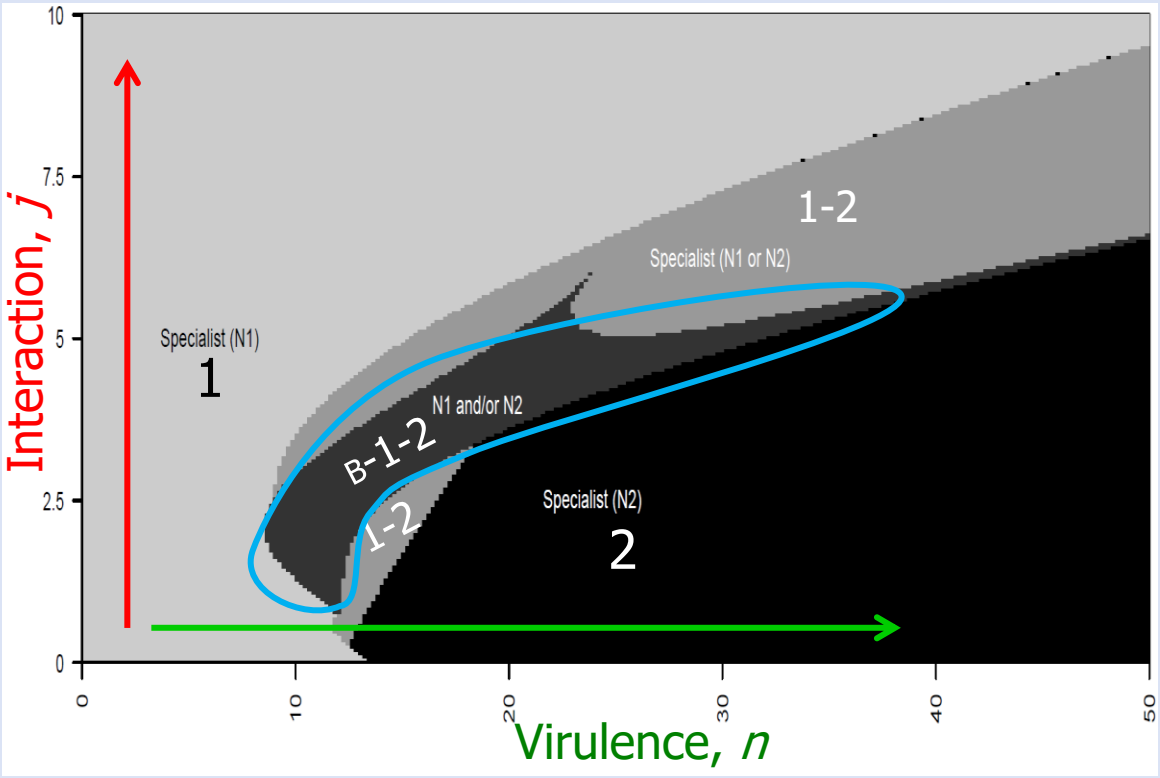


No generalist

Predator diet: convex trade-off

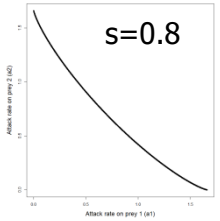


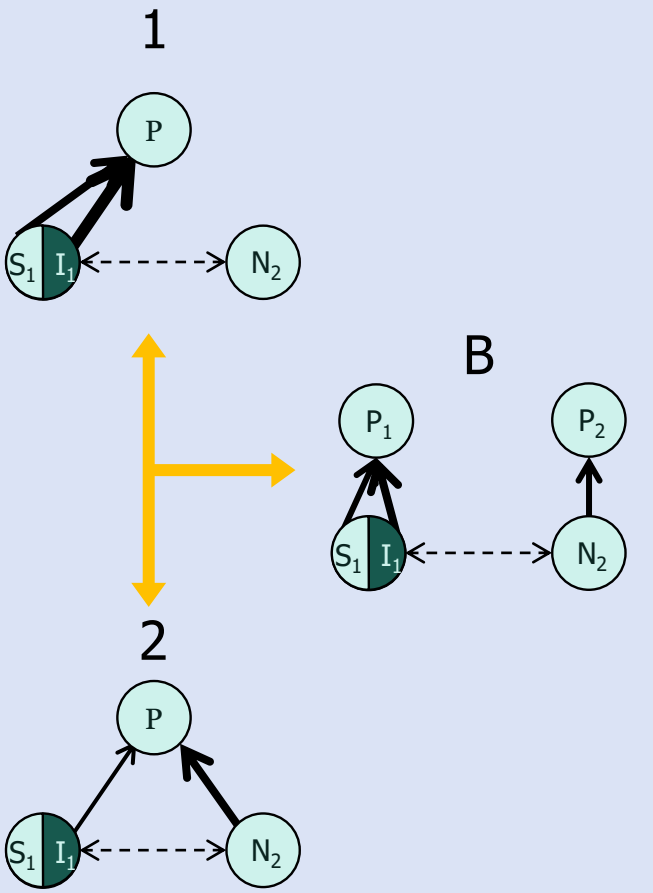


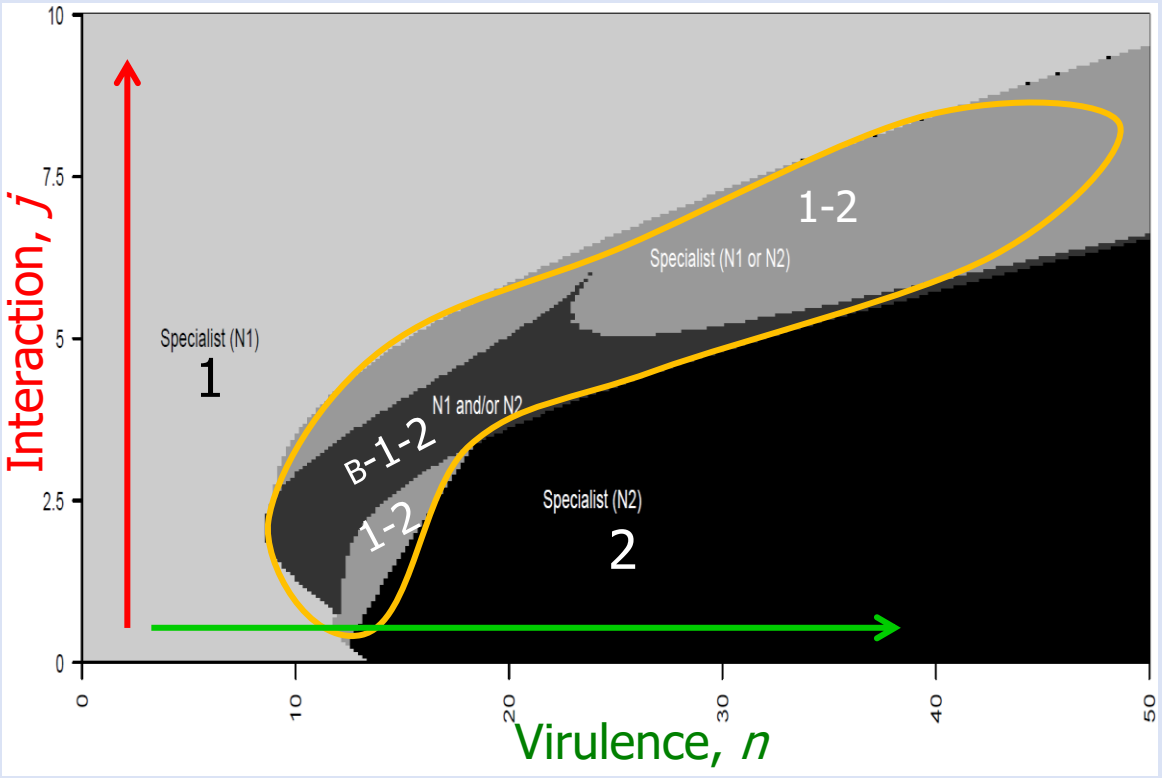


Diversification

Predator diet: convex trade-off

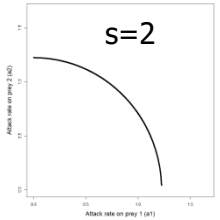


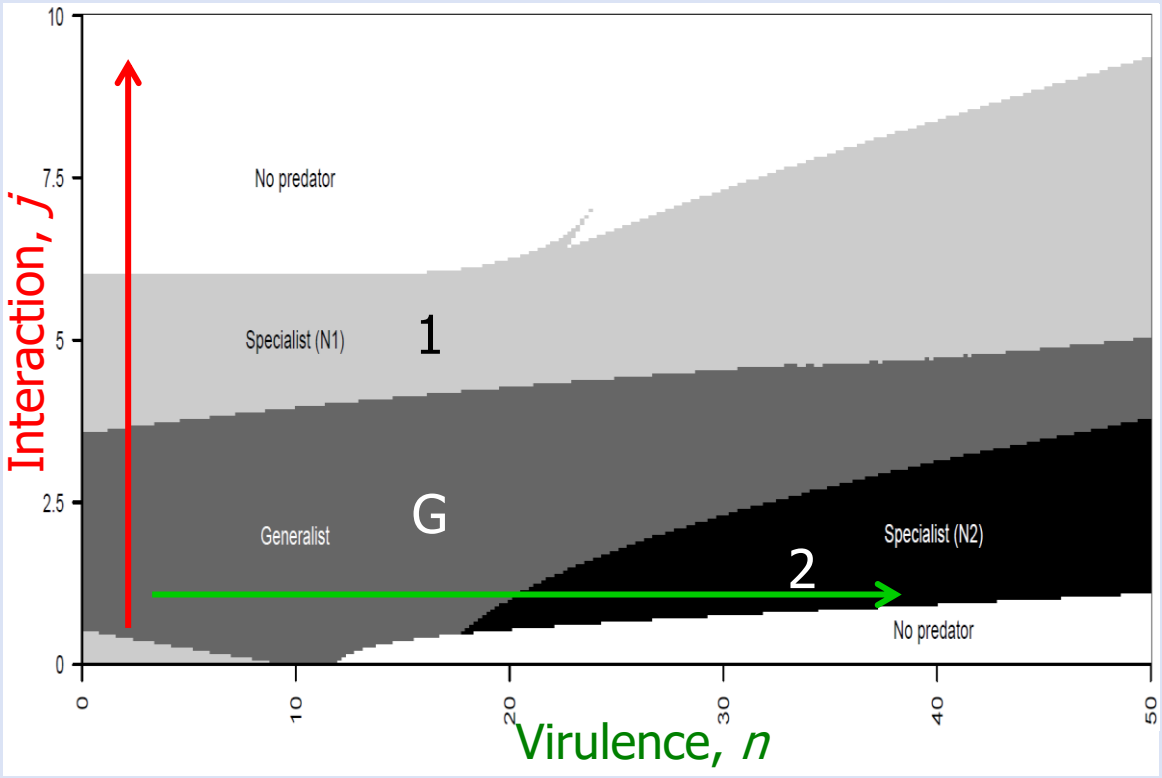




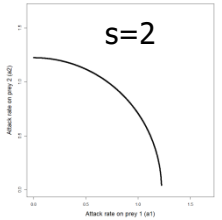
Evolutionary Multistability

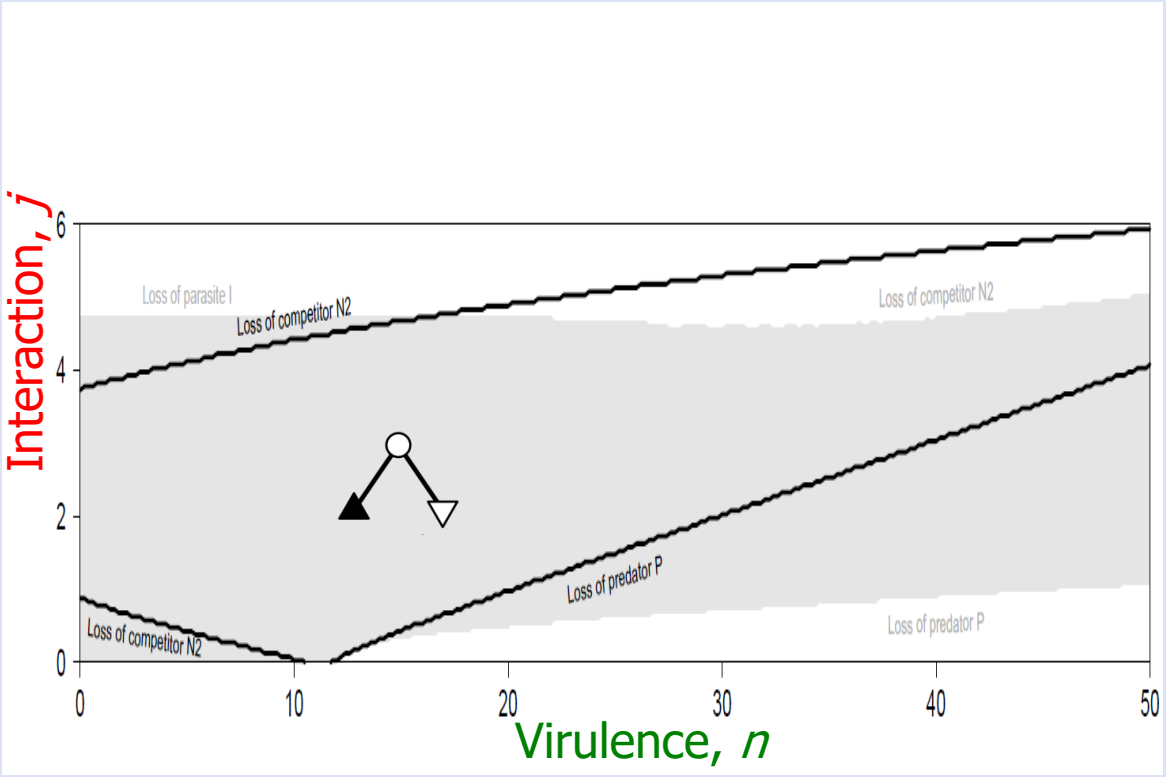
Coexistence: concave trade-off



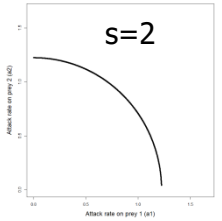


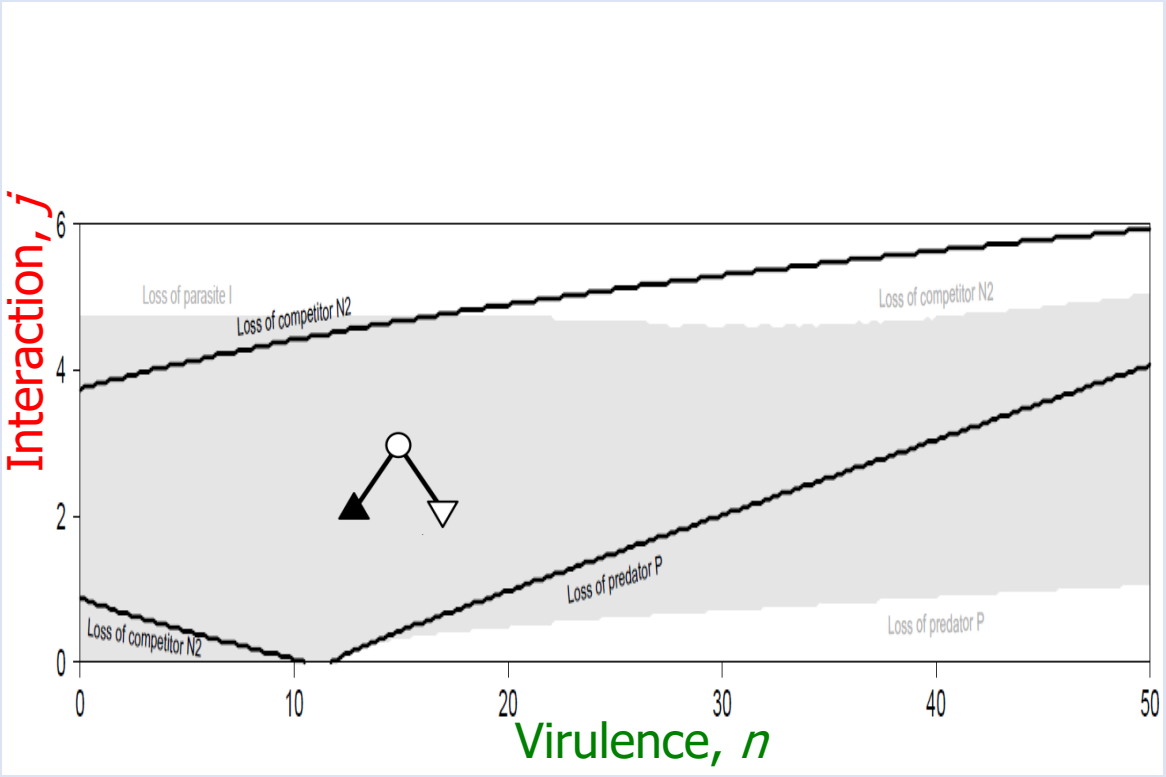
Coexistence: concave trade-off





Coexistence: concave trade-off





Adaptive foraging increase coexistence

Conclusions

- Prey infection and adaptive foraging
  - Interaction effect: predation on host
  - Virulence effect: predation alternative prey

  - Including evolution increases coexistence

Conclusions

- Prey infection and adaptive foraging
  - Interaction effect: predation on host
  - Virulence effect: predation alternative prey
  - Including evolution increases coexistence
- DIV-1 infection
  - Increase profitability but high virulence effect
    - Expected niche separation allowing coexistence

Prey infection alters predator diet

Thank you for your attention

Nicolas Loeuille & Vincent Médoc
Florence Hulot, David Renault, Christophe Piscart
Baptiste Bicocchi, Matthieu Lam

Loïc Prosnier (lprosnier@gmail.com)