Weaker predation in well-protected plants

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Introduction

Plants developed a diverse **weaponry against herbivory**. Top-down control by predators is also very important to keep the population of many herbivores in check.

Interestingly, recent works have shown that there could be an **indirect effect of plant's defense** in the **behavior** of predator-prey dynamics in a tri-trophic system.

Introduction

- To adress this question, Kaplan & Thaler (2010) studied a tri-trophic system:
  - **Caterpillars** of the species *Manduca sexta* feed on the leaves of **tomato plants** (*Solanum lycopersicum*), and are also eaten by **stink bugs** (*Podisus maculiventris*).
  - Jasmonate (**hormone that regulates toxicity**) levels were varied, and levels of predation and feeding were evaluated.

Figure: A tobacco hornworm caterpillar and a stink bug predator. [3]

Paper's highlights

- **Concepts:**
  - Consumptive effects → actual predation → **killing**
  - Non-consumptive effects → **fear** → less movement, less eating → death by **starvation**
- **Kaplan & Thaler's observation**: The number of caterpillars is regulated both by plant chemical defences and by bugs.
  → **Predation** seemed to be **weakened** in systems with **protected plants**.

Raised questions

Will increasing levels of toxicity weakens predation?

How is the caterpillar's "fear" response affected by different levels of hormone?

Assumptions and guidelines

- The plant's **toxic** defence is a **parameter** h (fixed plant phenotype)
  $\rightarrow$ regulates a carrying capacity $K(1-h)$
  $\rightarrow$ herbivores can incorporate the toxic compounds of plants, making the preys **less edible for predators**: $\uparrow h \Rightarrow \downarrow$ predation

- Comsumptive (**killing**) and non-comsumptive (**fear**) effects
  $\rightarrow$ killing rate b and fear parameter μ
  $\rightarrow \uparrow h \Rightarrow \downarrow$ plant quality $\Rightarrow$ malnourished cat. $\Rightarrow$ cat. less defensive (attenuated fear effect)

- **Lotka-Volterra**-like predator-prey dynamics

- **Specific** predator and herbivore

- **Closed** system

- Parameters considered:

  r: growth rate
  K: carrying capacity
  h: conc. of hormone expressed / toxicity of the plant
  μ: fear level
  k: killing rate (predation of caterpillars)
  b: predation rate (bug feeding)
  d: bug's death rate
  α: encounter rate (between prey and predator)

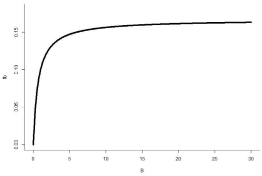
ICTP SAIFR

Suggested Model

- Growth Term

$$\frac{dC}{dt} = rC\left(1 - \frac{C}{K(1-h)}\right) - \frac{\kappa BC}{(1+\mu)} - \frac{\mu\alpha BC}{1 + e\,(1+h)B}$$

$$\frac{dB}{dt} = -d(1+h)B + \frac{bBC}{(1+\mu)}$$



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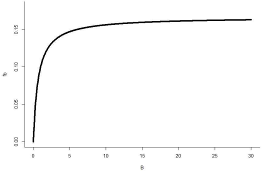
- Predation Term



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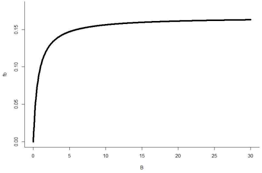
- Predation Term
- "Fear" Term



Suggested Model

- Growth Term

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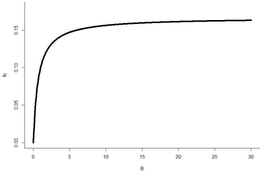
- Predation Term
- “Fear” Term
- Death term



Suggested Model

- Growth Term

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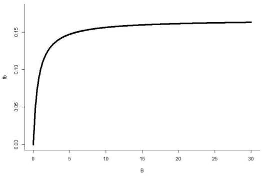
- Predation Term
- "Fear" Term
- Death term



Results

Lotka-Volterra

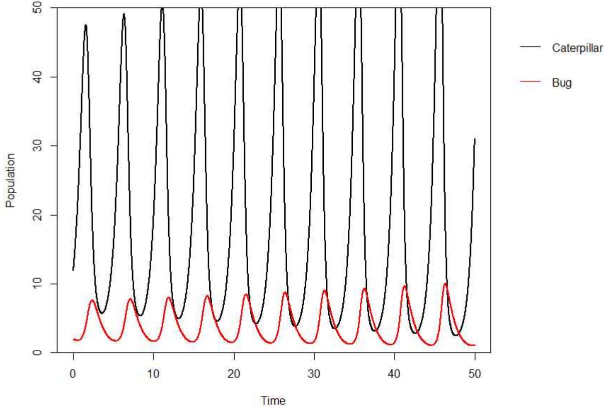


Figure: Lotka-Volterra dynamics obtained putting aside the effect of fear and plant defenses ($\mu = 0$, $h = 0$, $K(1-h) \to \infty$).

Results

Dynamics

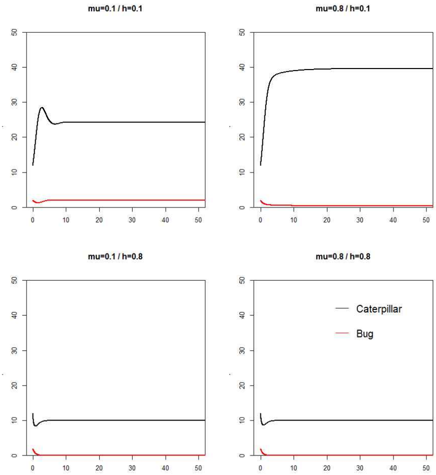


Figure: Populational dynamics for different combinations of fear and toxicity.

Results

Phase space diagrams

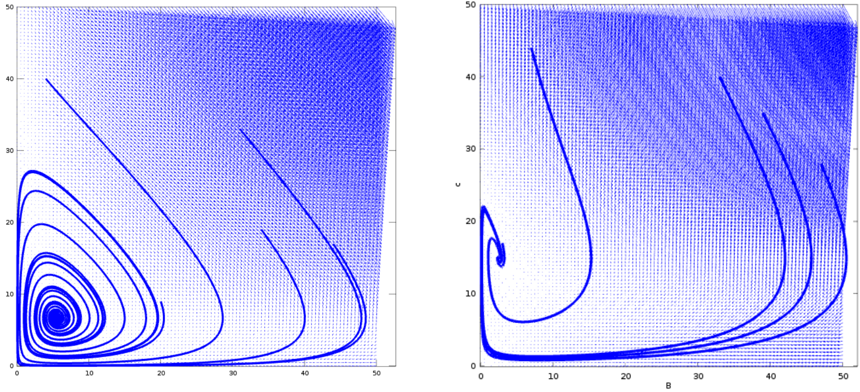


Figure: Phase space for $h = 0$, $\mu = 0$ **(left)** and for $h = 0.4$, $\mu = 0.6$ **(right)**.

Results

Fixed Point: **P = (B(Bugs), C(Caterpillars))**

$$
\begin{aligned}
P_1^* &= (0,0) \\
P_2^* &= (0, k(1-h)) \\
P_3^* &= \left(\frac{A + C}{D}, \; \frac{d}{b}(1+h)(1+\mu) \right)
\end{aligned}
$$

$$A = \frac{re(1+h)[k(1-h)b - d(1+h)(1+\mu)] + kb(1-h)[\mu\alpha(1+\mu) - \kappa]}{kb(1+\mu)(1-\mu)} \quad (1)$$

$$C = \sqrt{\frac{A^2 Kb(1-h) - 4\kappa re(1+h)[Kb - (1+h)]}{Kb(1-h)}} \quad (2)$$

$$D = \frac{2\kappa e(1+h)}{(1+\mu)} \quad (3)$$

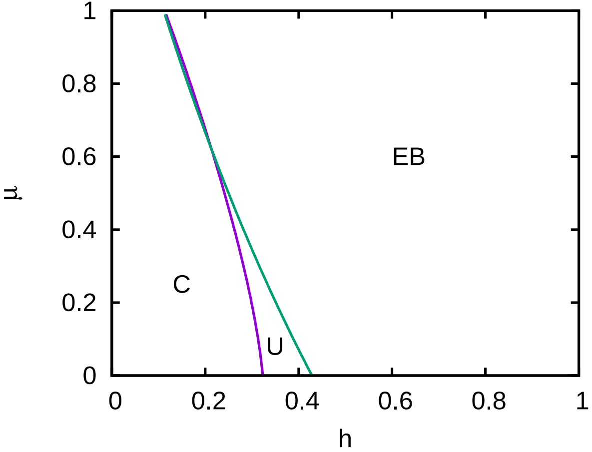


Figure: Stability regions in the parameter space

Results

Bug and Caterpillar stationary populations

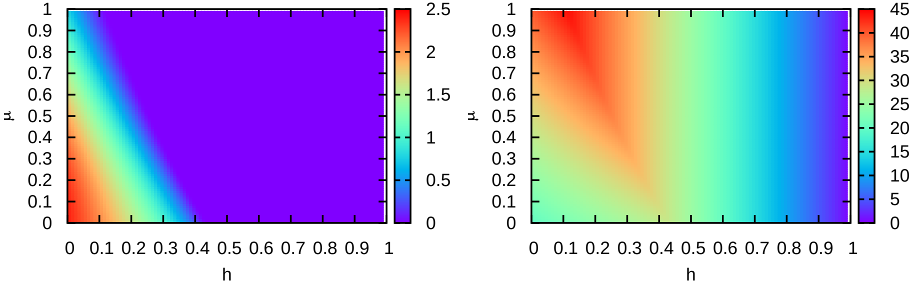


Figure: Mean populations of **bugs (left)** and **caterpillars (right)**, after a transient time.

- We observed that **predator population decreases** with **higher levels of plant defence** $\Rightarrow$ cumulative effect of toxins: $\uparrow\uparrow h \Rightarrow$ extinction.
- Though **intermediate levels** of plant toxicity **increase** the caterpillar population, **highest levels** might lead to **extinction** $\Rightarrow$ possible plague control strategy (definitive)
- **Caterpillars eating protected plants** are more **prone to take risks**, hence the **fear effect is attenuated**.

Glories and Miseries of the model

Glories

- Simple model, with only two variables
- Reproduces the most important mechanisms

Miseries

- We are not taking into account the plant dynamics
- As it is based on Lotka-Volterra model, predation population levels aren't realistic $\longleftarrow$ LV model problem
- Lack of predictability **?**

Perspectives

- Different plant phenotypes could be taken into account
- The plant dynamics could also be explored
- Futher inquiry: plague control strategies

Thank You!

Bibliography

Kaplan, I & Thaler, JS.
Plant resistance attenuates the consumptive and non-consumptive impacts of predators on prey
Oikos 119-7: 1105-1113. 2010.

Murray, JD (2003).
Mathematical Biology. II. Spatial models and Biomedical Applications.
3rd Ed.: 82.

Bug, caterpillar and tobacco plant image:
http://www.news.cornell.edu/stories/2012/07/prey-pay-steep-price-elude-predators

Suppose

$$\begin{aligned}
\frac{dC}{dt} &= C[r_P P_P + r_{NP}(1-P_P)]\left(1-\frac{C}{K}\right) \\
&\quad -\alpha[k_P P_P + k_{NP}(1-P_P)]\frac{BC}{1+\mu} - \frac{\mu\alpha BC}{1+e\alpha C} \\
\frac{dB}{dt} &= -\phi B + \gamma\left(k_P P_P + k_{NP}(1-P_P)\right)\frac{BC}{1+mu} \\
\frac{dP_N}{dt} &= f(P_N, C) \\
\frac{dP_{NP}}{dt} &= g(P_{NP}, C)
\end{aligned}$$

where

$$P_N + P_{NP} = 1\,.$$