Explaining antiphase predator-prey cycles

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The question
The complexity of predator-prey models with mutual adaptation (defense vs. offense) implies that their effect on predator-prey dynamics remain poorly understood.

1. When does mutual adaptation result in antiphase cycles?
2. How and why does mutual adaptation lead to antiphase cycles?

Predator-prey model

offense (v)

\[ a(u, v) = \begin{cases} a_0 & \text{if } u < v \\ a_1 e^{(v-u)/\theta} & \text{if } u > v \end{cases} \]

costs of defense and offense

\[ y = R e^{v-u-t^2/2} \]

Biomass \((x, y)\) and trait \((u, v)\) dynamics

\[ \frac{dx}{dt} = f(x)(r(x) - \frac{y(x)}{K} + \frac{d(x)}{1+y(x)}) \]

\[ \frac{dy}{dt} = g(v)(\frac{y(x)}{1+y(x)} - d(v)) \]

\[ \frac{du}{dt} = G_1 \frac{du}{dx} \]

\[ \frac{dv}{dt} = G_2 \frac{dv}{dx} \]

References

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General result: predator-prey phase relationship is determined by the effective prey biomass

Slow predator adaptation results in antiphase cycles, while rapid predator adaptation results in ¼-lag cycles

Predator dynamics always follow the effective prey biomass with a ¼-lag

The predator-prey phase lag results from the lag between “real” and effective prey biomass

What determines effective prey?

Delay between real and effective prey biomass occurs when the dynamics of prey biomass and defense have opposing impact on effective prey biomass

Conclusions
The interplay between ecological and evolutionary processes results in complex model dynamics, but the fundamental mechanism driving phase relationships is remarkably simple:

» antiphase dynamics arise when the prey peak is caused by a release from predation
» ¼-lag cycles arise when the prey peak is caused by a release from the costs of defense

A Slow predator adaptation results in antiphase cycles

High-amplitude oscillations in defense result in a strong release from predation when defense is high.

The positive impact on prey fitness causes an increase in prey biomass.

» Prey biomass and defense cycle in phase
» Prey become more abundant as they become better defended
» Increase in prey biomass coincides with a decrease in effective prey biomass
» The peak in effective prey biomass is delayed with a ¼-lag

Predators follow effective prey biomass with ¼-lag » antiphase predator-prey cycles

B Rapid predator adaptation results in ¼-lag

Arms race between offense and defense results in small-amplitude oscillations in defense, with a high mean trait value.

Increasing defense confers small benefit at high cost. Lowering defense has a stronger positive impact on prey fitness.

» Prey biomass and defense cycle in antiphase
» Prey become more abundant as they become better defended
» The dynamics of effective prey biomass are the same as those of actual prey biomass

¼-lag predator-prey cycles