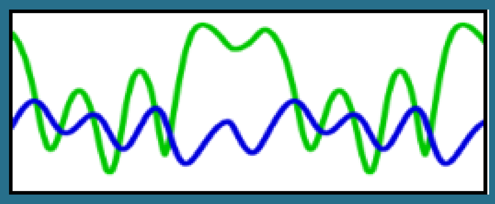
Explaining antiphase predator-prey cycles



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The question

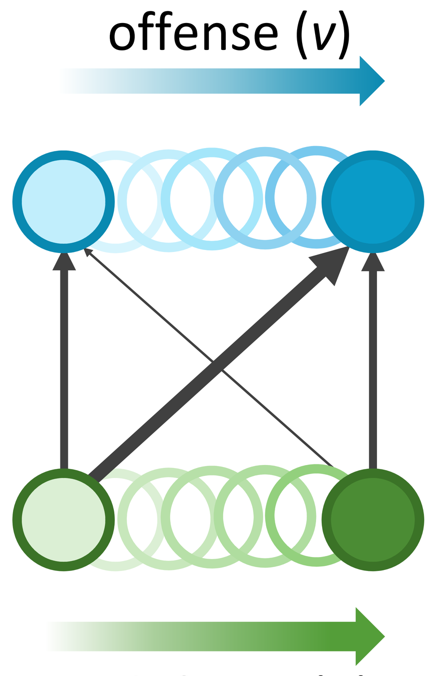
The complexity of predator-prey models with mutual adaptation (defense vs. offense) implies that their effectson predator-prey dynamics remain poorly understood.

The speed of adaptation[1,2,3] and costs for defense and offense[4,5] may both impact the predator-prey phase relationship, but what is missing is the understanding of **how** and **why**.

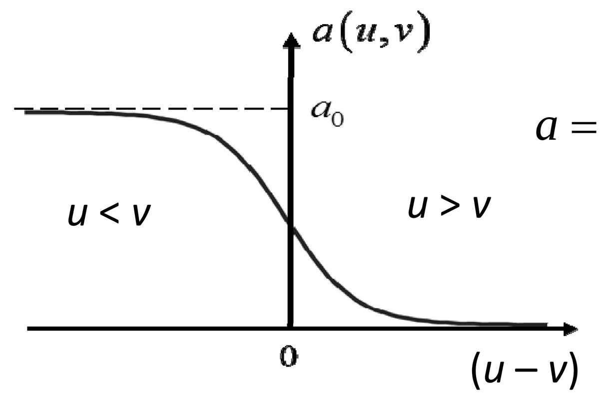
For this, we analyze the impact of mutual adaptation in a novel way.

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

Predator-prey model

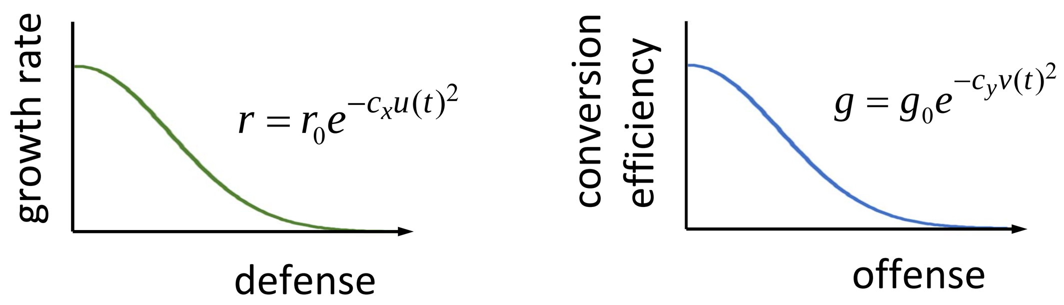


offense and defense determine **attack rate**



$$a = \frac{a_0}{1+e^{\theta(u(t)-v(t))}}$$

costs of defense and offense



$$r = r_0 e^{-c_x u(t)^2} \qquad g = g_0 e^{-c_y v(t)^2}$$

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

$$\frac{dx}{dt} = x(t)\left(r(u)\left(1-\frac{x(t)}{K}\right)-\frac{ay(t)}{1+hax(t)}\right)$$

$$\frac{dy}{dt} = y(t)\left(g(v)\frac{ay(t)}{1+hax(t)}-d(v)\right)$$

$$\frac{du}{dt} = G_x\frac{1}{x(t)}\frac{dx}{du}\cdot e^{-\varepsilon/(u(t))^2}$$

$$\frac{dv}{dt} = G_y\frac{1}{y(t)}\frac{dy}{dv}\cdot e^{-\varepsilon/(v(t))^2}$$

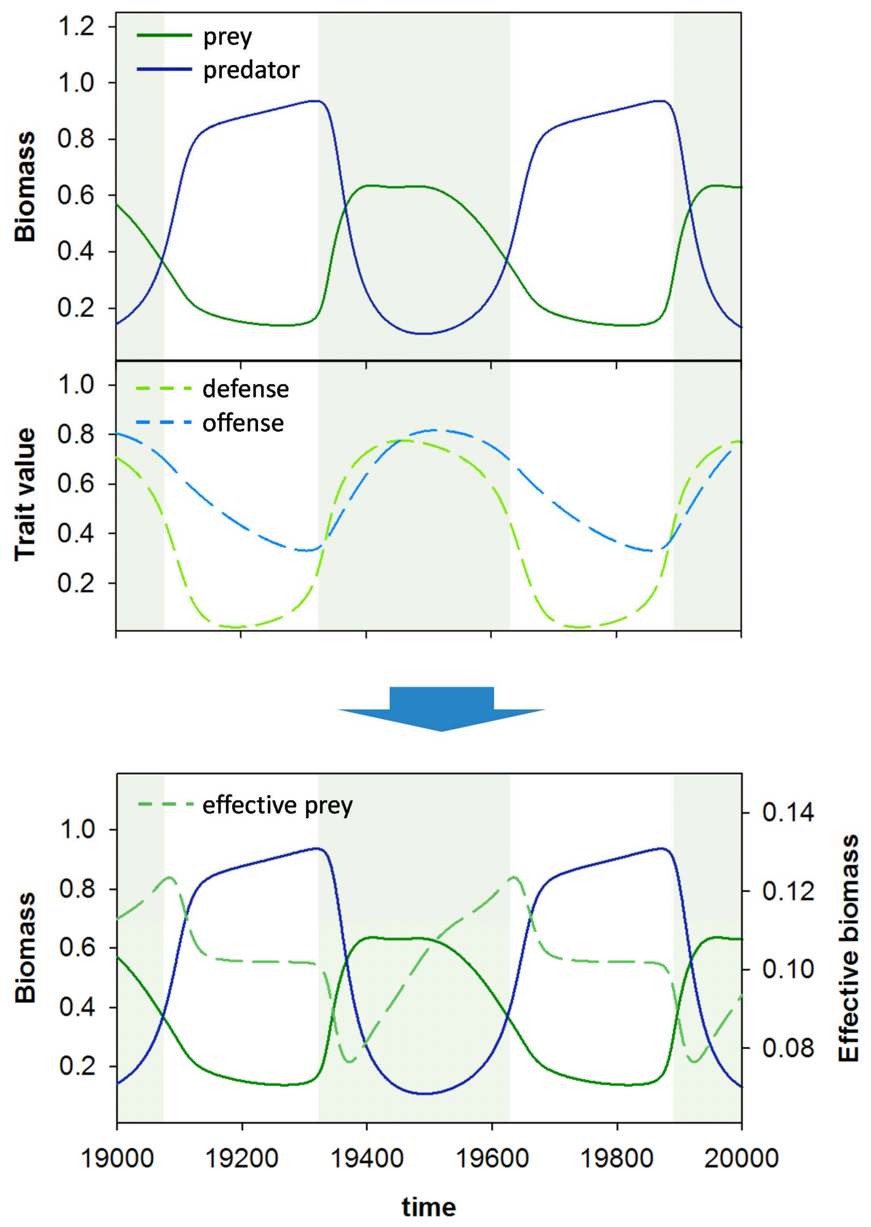
A Slow predator adaptation results in antiphase cycles

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

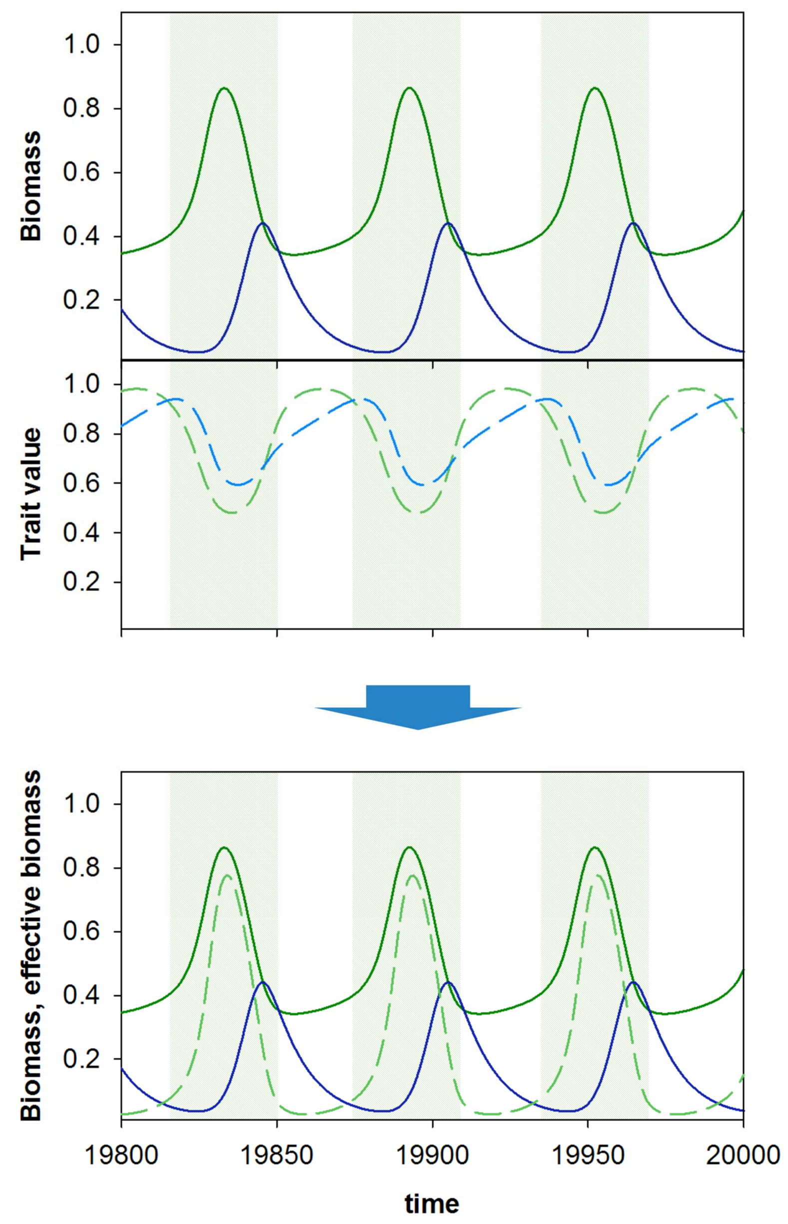
The positive impact on prey fitness causes an increase in prey biomass.

- 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 cycles



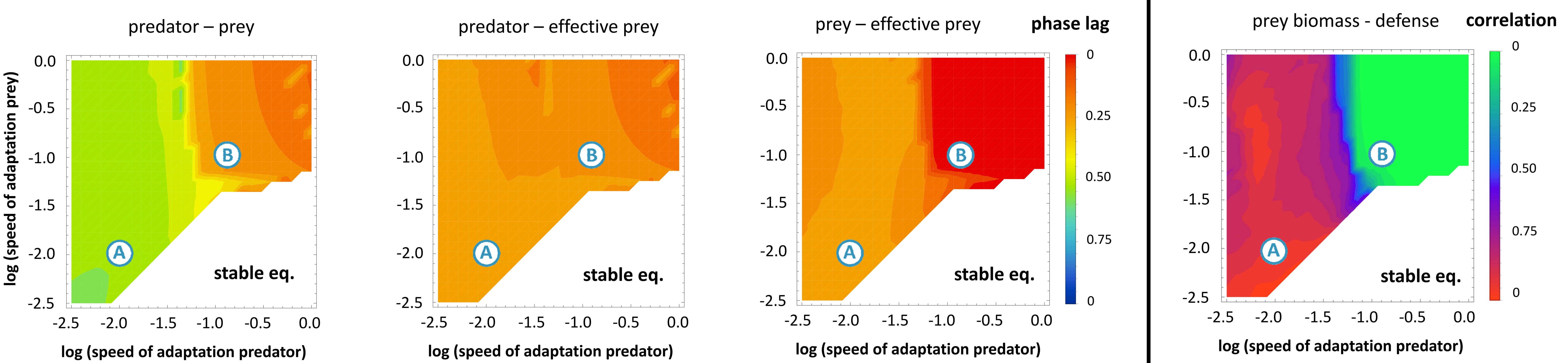
Arms race between offense and defense results in small-amplitude oscillations in defense, with a high mean trait value.

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**

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

What determines effective prey?



Slow predator adaptation results in antiphase cycles, while rapid prey 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

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

References

1. Mougi & Iwasa, *Proc. B* **277** (2010) 3163-3171
2. Mougi & Iwasa, *JTB* **277** (2011) 83-89
3. Mougi, *Theor Pop Biol* **81** (2012) 113-118
4. Cortez & Weitz, *PNAS* **111** (2014), 7486-7491
5. Cortez, *Theor Ecol* **8** (2015), 369-382

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

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