Novel predators and naïve prey: modeling suboptimal responses to introduced predators

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Problem

Anti-predator defense relies on RECOGNITION of predation threat and EFFECTIVE anti-predator response. A novel predator – with whom prey do not share an evolutionary history – may circumvent such defense.

Evolutionary history: Introduced predators, such as the invasive American mink (*Neovison vison*), have devastated ground-nesting island birds that evolved in the absence of terrestrial predators.

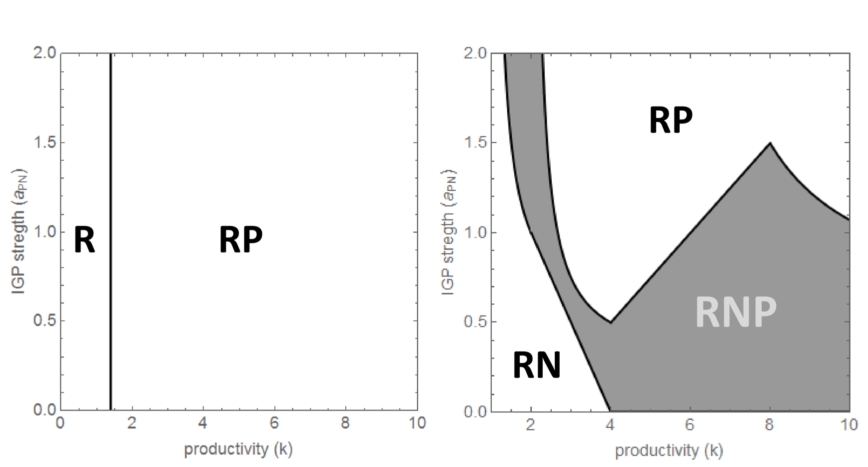
Naïveté: Indo-Pacific red lionfish (*Pterois volitans*) appear not to elicit anti-predatory responses in native Atlantic coral reef fishes. Some prey species allow lionfish to approach closely without fleeing or seeking refuge.

Suboptimal response: Juvenile European green crab (*Carcinus maenas*) employ ineffective anti-predator response towards invasive Asian Shore crab (*Hemigrapsus sanguineus*). Remaining motionless and relying on protective coloration is ineffective against such tactile predators.

Motivation

Adaptive anti-predator defense can promote coexistence in otherwise unstable multi-predator communities

In an intra-guild predation module, 3-species coexistence is possible over a much wider parameter region with adaptive versus fixed anti-predator defense.



Fixed defense equally apportioned among predators (left panel) does not result in coexistence across a large range of productivity (x-axis) and strength of intraguild predation (y-axis). Coexistence (in gray) occurs when basal prey can adaptively vary defense efforts (right panel).

(figures adapted from Nakazawa et al. 2010 Oikos)

Does increased stability rely on perfect perception of predation risk and optimal response by prey ?

Acknowledgments

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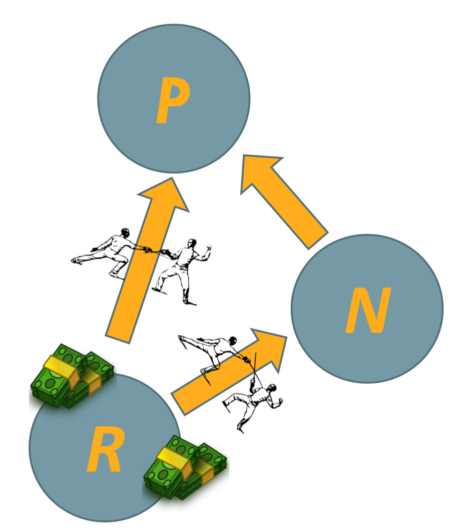
Research Objective

To determine the effects of prey naïveté and suboptimal defenses towards predators on community coexistence using an intraguild predation module with adaptive anti-predator prey response.

Model Formulation



$$\frac{dR}{dt} = R\left(r\,c - \frac{R}{k} - N\,a_{NR}\,d_N - P\,a_{PR}\,d_P\right)$$

$$\frac{dN}{dt} = N(R\,a_{NR}b_{NR}d_N - P\,a_{PN} - m_N)$$

$$\frac{dP}{dt} = P(R\,a_{PR}\,b_{PR}\,d_P + N\,a_{PN}\,b_{PN} - m_P)$$

$$d_i = 1 - e_i\,f_j\,\varphi$$

d_i is the effect of defense on the *i*th predator's realized attack rate and is proportional to the level of effort (e_i) and relative defense efficiency ($f_j\,\varphi$).

$$\frac{de_i}{dt} = ve_i\left\{\frac{\partial W}{\partial e_i} - \left(\sum_{x=N,P} e_x\frac{\partial W}{\partial e_x}\right)\right\}$$

e_i is the level of effort towards defense against the *i*th predator and is itself a dynamic variable that is adjusted based on the changes to the prey's fitness, *W*, for a given change in predator-specific defense effort.

$$c = 1 - \sum_{i=N,P} c_i e_i$$

c_i is the total cost of defensive efforts on the prey's growth rate.

$$W = r\,c - \frac{R}{k} - a_{NR}\,d_N - a_{PR}\,d_P$$

W is the fitness of the resource *R*, defined as the prey's per capita growth rate.

Modeling novel predators

1. φ controls the **relative efficiency** of defense against the introduced predator for both introduction scenarios: a novel top predator *P* or a novel intermediate consumer *N*. Thus, φ = 1 reflects optimal defense toward the invader while φ = 0 renders defense completely ineffective.
2. ρ modifies the **perceived predation threat** of the introduced predator in the fitness equation and hence alters the prey's adaptive response to changing predator density. Thus, ρ = 1 reflects perfect perception, while ρ = 0 reflects complete naïveté toward the introduced predator.

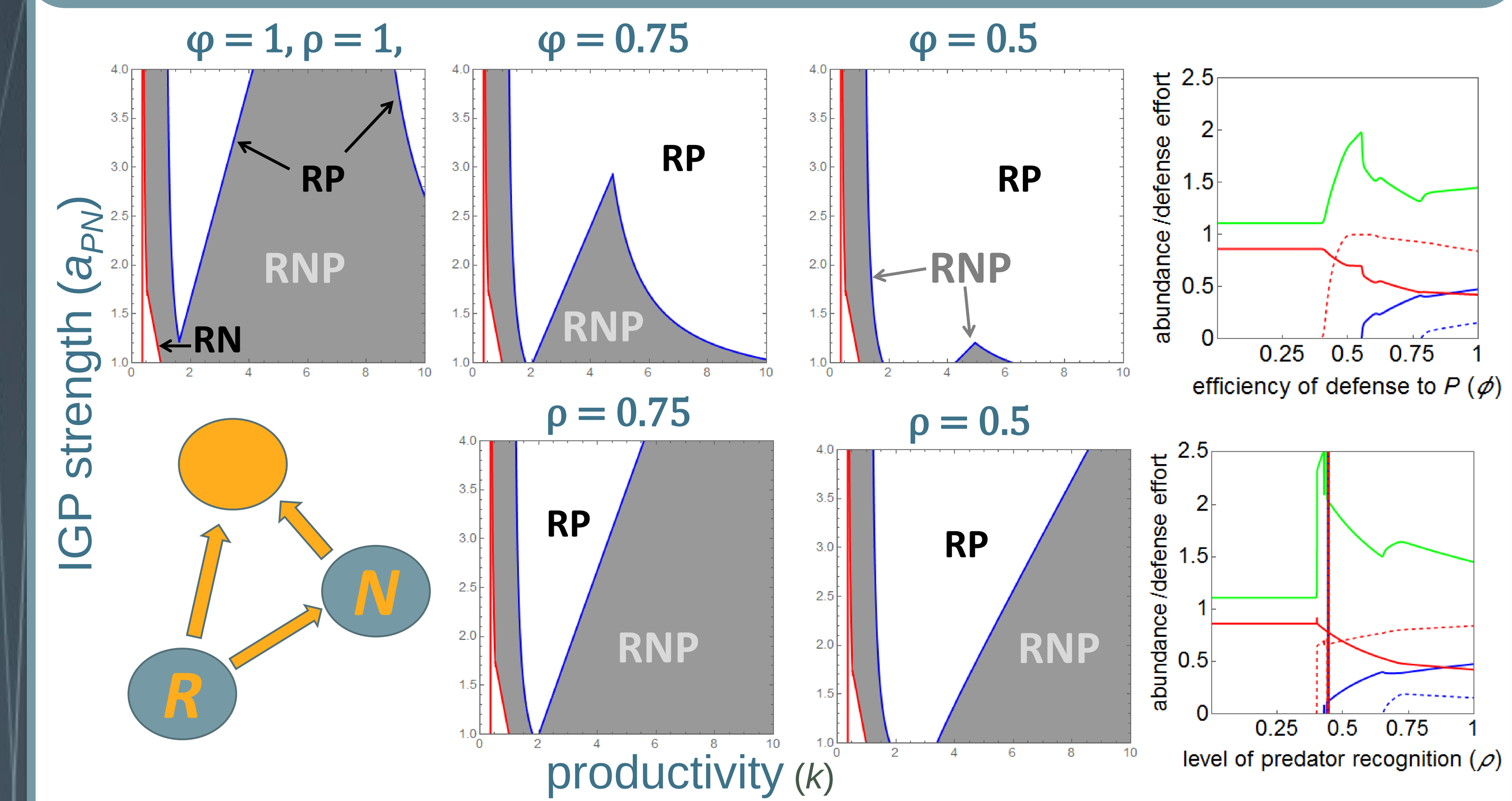
Analysis

We examined predator coexistence across gradients of naïveté and suboptimal defense and evaluated the local stability of coexistence equilibria by determining the characteristic equation of the appropriate Jacobian matrix.

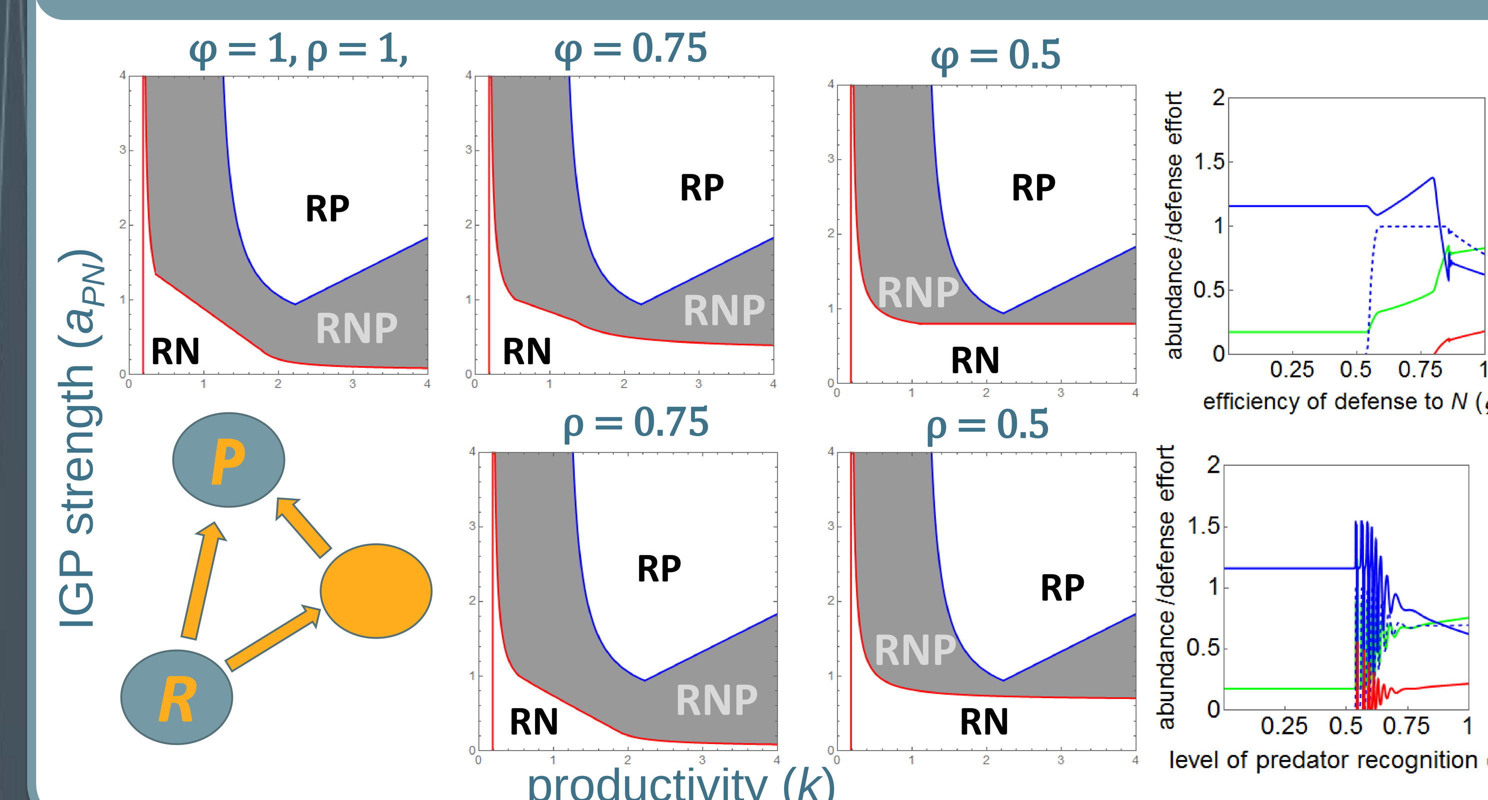
Key Assumptions

— Prey maximize per capita growth rate through adaptive effort allocation
— Effort towards defense reduces energy available for prey reproduction
— Adaptation rates of defense toward each predator are equal
— Coefficients of cost for defense toward each predator are equal
— Defense effectiveness is linearly related to defense effort

Results: Novel Top Predator



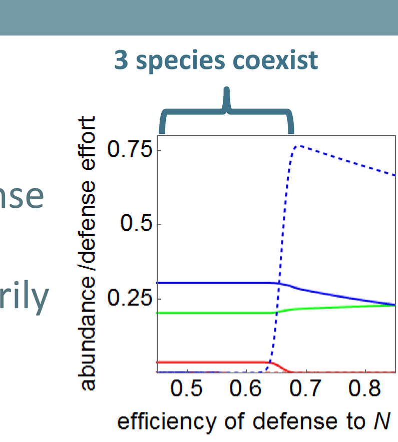
Novel Intermediate Consumer



Key Finding

Novelty can facilitate coexistence

Increasing novelty of an introduced intermediate consumer can facilitate coexistence under certain conditions. As defense toward *N* becomes less efficient, *P* can invade the system, subsidized by increasing abundance of *N*. This occurs primarily at low productivity (*k*) and IGP strength (a_{PN}), such that the majority of energy flux is via the indirect route (***R*→ *N* → *P***).



Conclusions

1. Increasing novelty of an invader can result in exclusion of the native predator.
2. Novel top predators have a greater affect on the likelihood of coexistence than novel intermediate consumers.
3. Coexistence is more sensitive to changes in defense effectiveness (φ) than to the perception of predation risk (ρ) because a suboptimal response carries the non-consumptive fitness cost of anti-predator defense.
4. Under restricted conditions, a novel intermediate consumer (but not top predator) can actually increase the region of coexistence.