Mathematically Modeling the Evolution of Fear Acquisition Strategies in Predator-Prey Encounters

Megan E. Bishop[1], Brian A. Lerch[1]. Dr. Maria Servedio[1]

[1]*University of North Carolina at Chapel Hill, Chapel Hill, NC, USA*

BACKGROUND

- Fear is a survival necessity with evolutionary origins in predation[1]
- Fear has evolved via **two mechanisms**[2]:

Innate	Learned
Individuals are predispositioned to fear what threatened primate ancestors[3,4]	Fear is learned via experience and observation[2]

- There is a **trade off** between the two strategies. Innate fear acquisition may be too general yet allows for greater avoidance during early encounters[2,3,4].
- We **hypothesize** that **innate fear** evolution is **driven** by high predator **threat levels** while **learned fear** is **driven** by high predator **density**

METHODS

Model Framework

- Theoretical models allow us to test existing theories via simulations over evolutionary time[5,6]
- We assume a **one locus, haploid population genetic model** with two allele options (A_1 or A_2), each with a different proportion of innate fear ($\boldsymbol{\alpha}_x$)
- Allele frequencies update over a series of generation. When **allele frequencies get larger**, they are said to **evolve**

Model Assumptions

- An infinite population where **prey individually encounter predators** during a generation at a rate of $\boldsymbol{\lambda}$
- The danger of an encounter is determined by the probability of death
- Learned fear is a function of the **sum of danger** experienced

Model Parameters

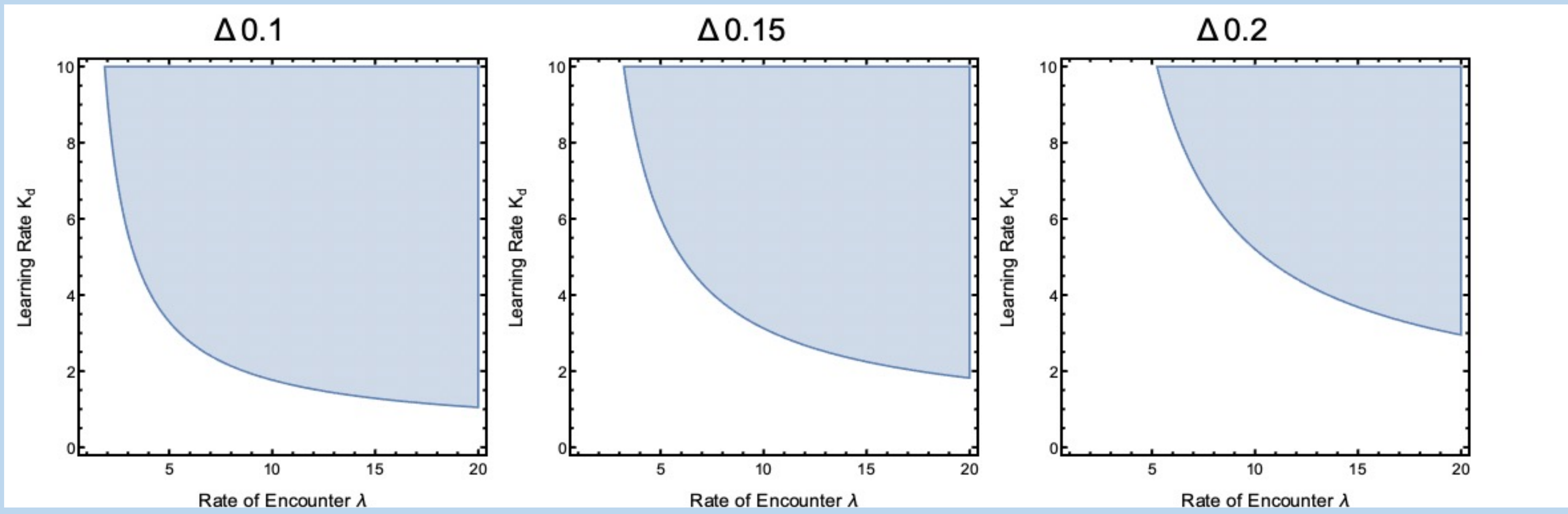
*** Note $\Delta = d_i - d_o$**

Parameters	
λ	Encounter rate
k_f	Amount of danger needed to learn fear
k_d	Speed in which danger is encoded into learned fear (learning rate)
d_i	Level of danger before the first encounter for the innate strategy
d_0	Level of danger before the first encounter for the learning strategy
c_L	Cognitive cost of learning
c_f	Reproductive cost of fear

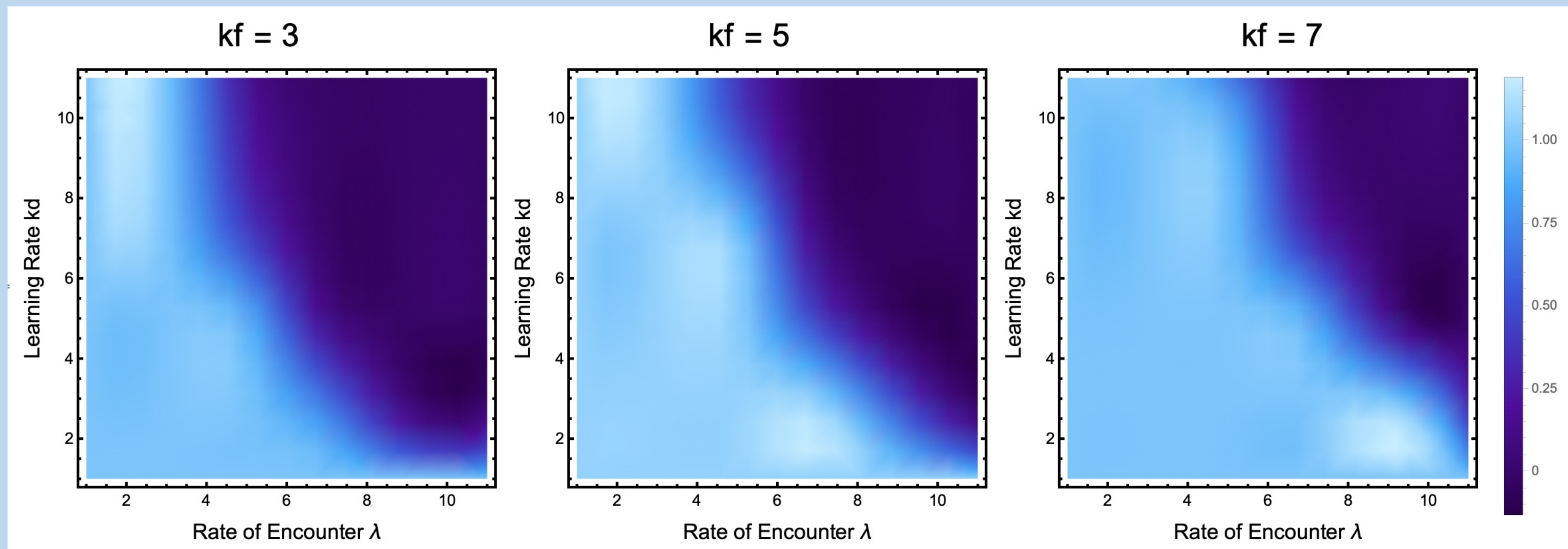
RESEARCH QUESTION

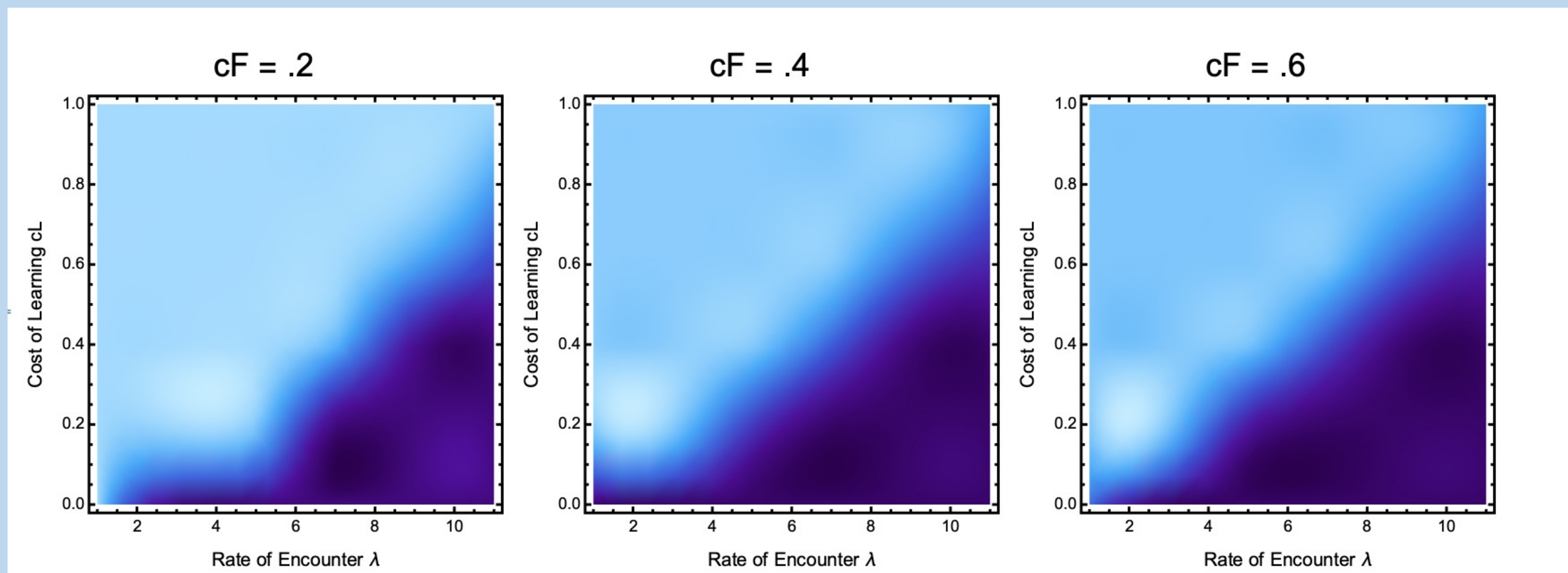
How does predator threat level, learning rate, and predator density influence the evolution of each fear-acquisition strategy?

We **compete extreme strategies**, where $\boldsymbol{\alpha}_x = 0$ (only learning) or 1 (only innate). The **shaded region are conditions where learning "wins"**

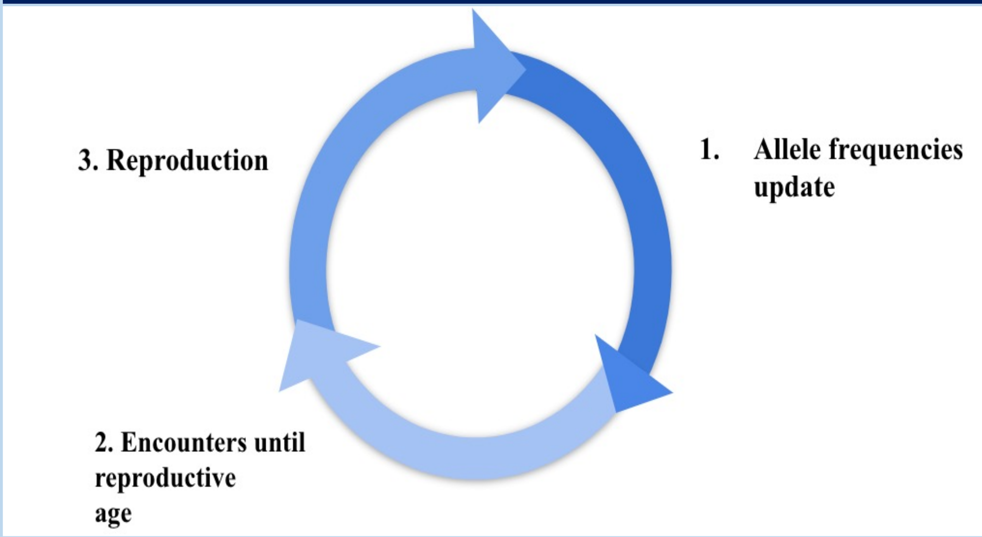


To evaluate **mixed strategy evolution**, we analyze the proportion of $\boldsymbol{\alpha}_1$ **at maximum fitness.** Darker blues indicate where higher frequencies of innate fear evolve





Model Simulation



FINDINGS

- High encounter rates favor greater frequencies of learning
  - Predator density
- Greater relative danger favors innate fear acquisition
  - Predator threat level
- Costs allow for intermediate strategies to evolve
- Greater costs to learning favor greater frequencies of innate fear acquisition
- Greater reproductive costs don't explicitly favor learning
  - But seemingly allow for intermediate strategy emersion

DISCUSSION

Discussion

- For the most part, we confirmed our hypothesis
- Surprisingly, the reproductive cost of fear seems to equally effect both strategies
- Costs to learning and reproduction are responsible for intermediate strategy emersion

Limitations

- Social learning via observation or signaling is not considered
- Only learning by experience (direct learning)
- No variation in predator type
- We don't consider epigenetics
- Innate learning is constant

Future Directions

- A neural network approach for learning
- Isolate costs to observe their primary influences
- Include a capacity for social learning

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