Fundamentals of Ecology

Week 7, Ecology Lecture 4

Cara Brook

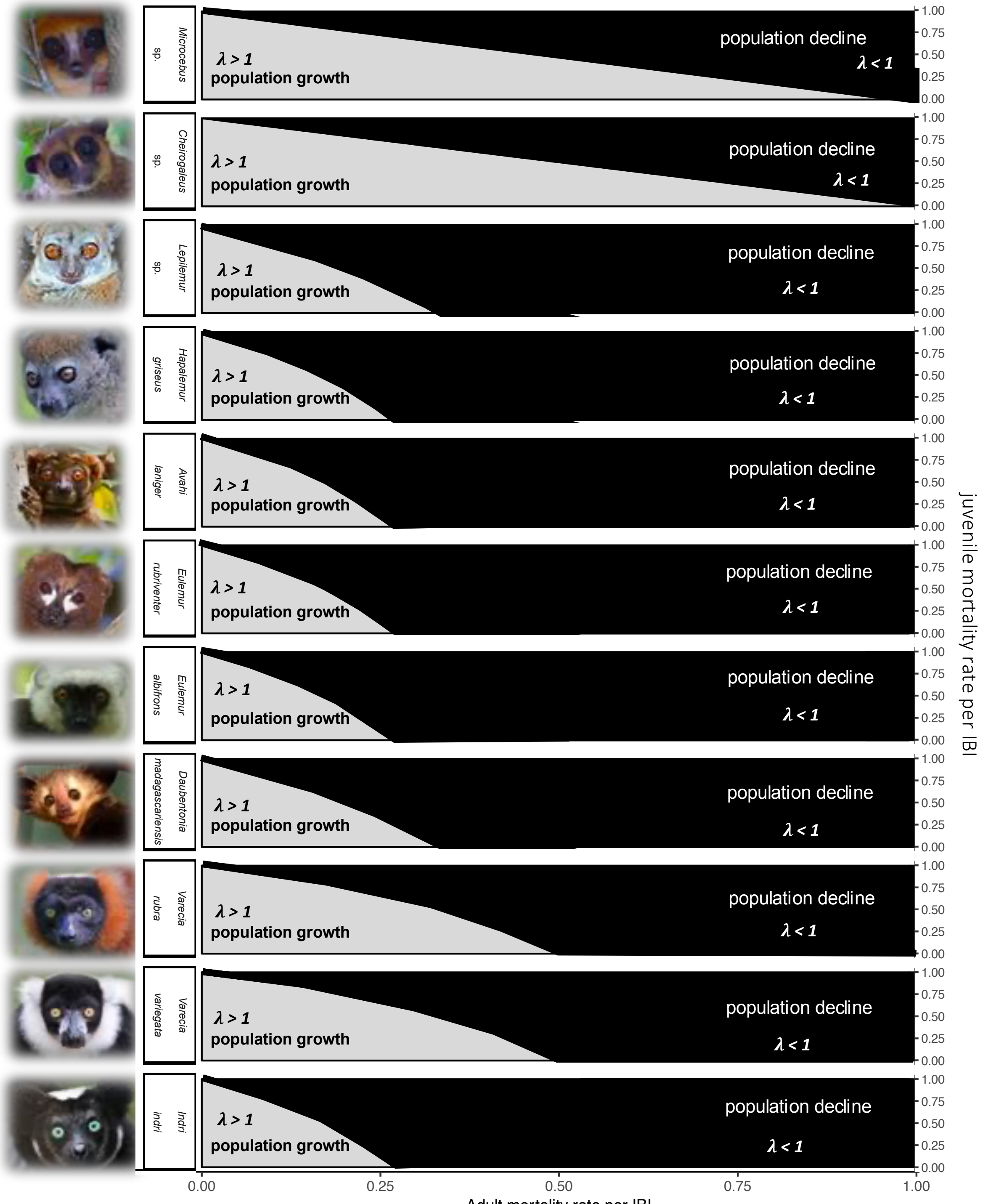
February 18, 2025

Office hours: On ZOOM
Friday, Feb 21, 2025
4-5pm
I will email out a link!

Learning objectives from Lecture 3

You should be able to:

- Know why/when a structured population model is needed
- From lab: know what elements of the transition matrix correspond to survival and fecundity for N^{th} age class and be able to identify the equation predicting the size of an age class in the next time interval
- Sketch graph of a demographic transition and corresponding population birth and death rates at different stages
- Predict the trajectory of a population (growing, shrinking, constant) by looking at its age pyramid
- Understand what a metapopulation is and why it matters
- Recognize and be able to apply Levins' metapopulation model equation
- Name and describe the 'metapopulation rescue effect'



We plotted **zero-growth lines** to evaluate lemur population trajectories across different **mortality rates**.

Smaller lemurs with **faster life histories** are resilient to **mortality**.

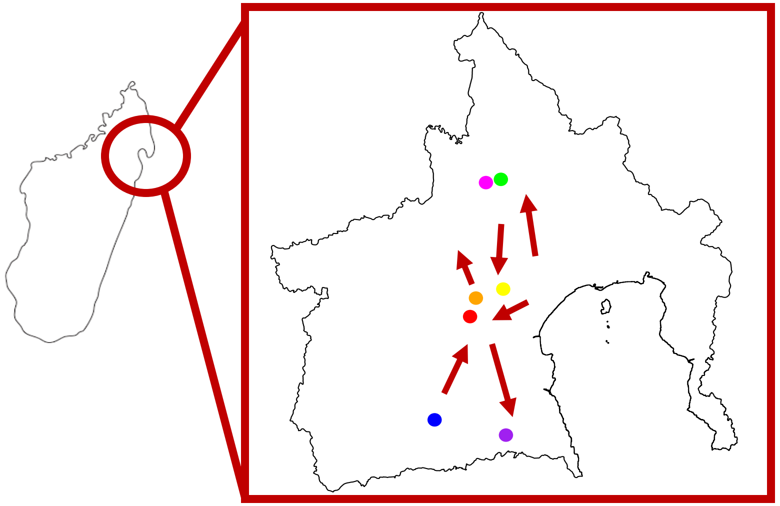
Bigger lemurs with **slower life histories** are particularly **vulnerable**.

Brook et al. 2018. *Conservation Biology.*

We built a regional **metapopulation model** to simulate population dynamics into the future for a subset of species.

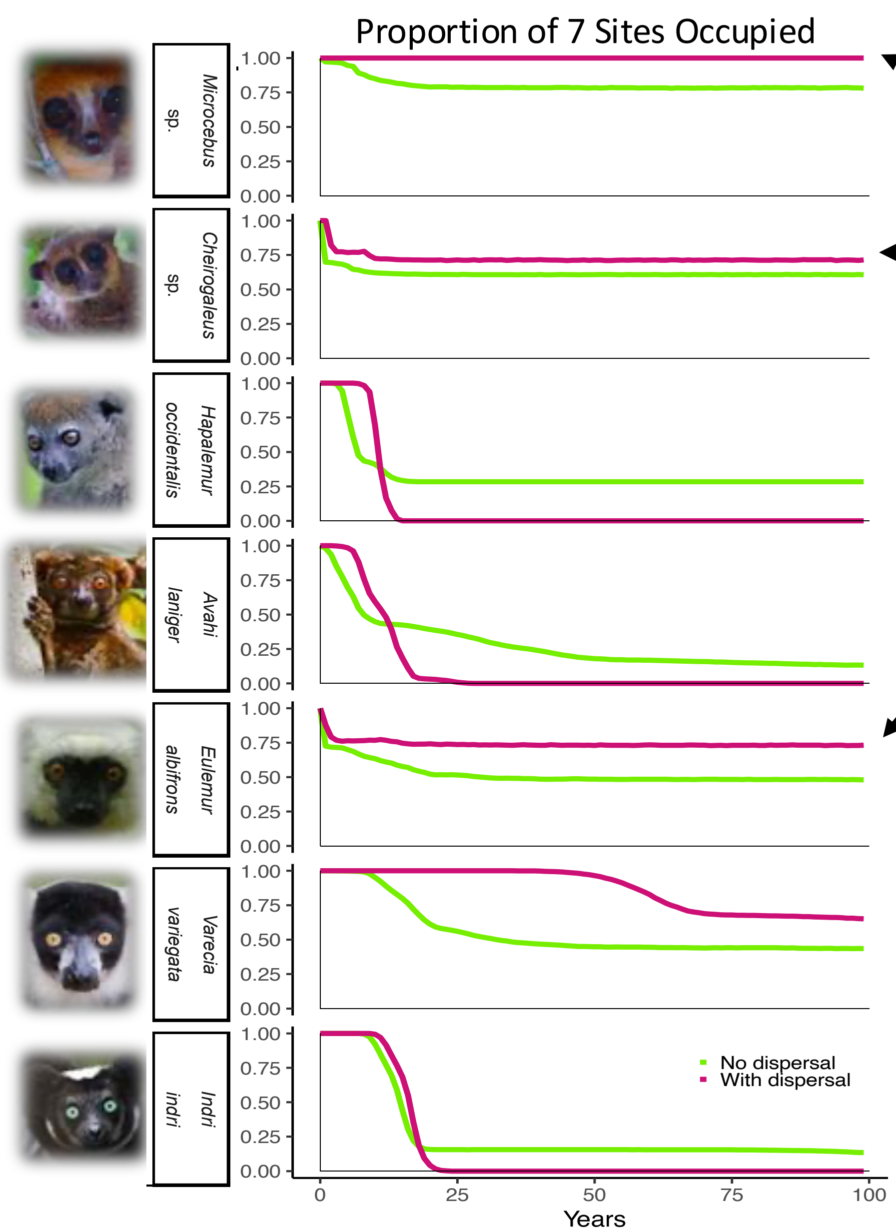
Assumptions:

- Starting population of 200 lemurs per site
- Site-specific mortality rates derived from field studies
- Density dependent effects on fecundity
- Compared **no dispersal scenarios** vs. scenarios allowing for **stochastic dispersal** mediated by geographic distance

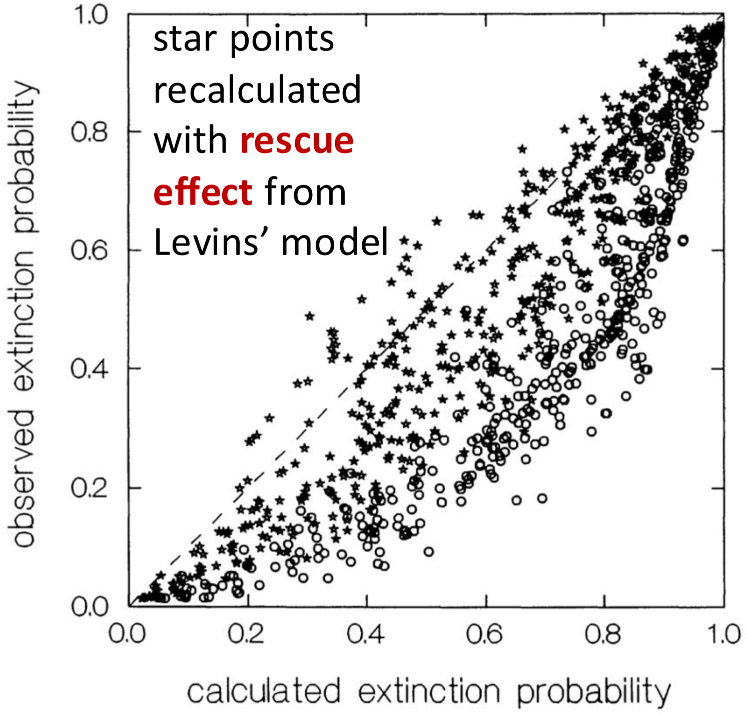


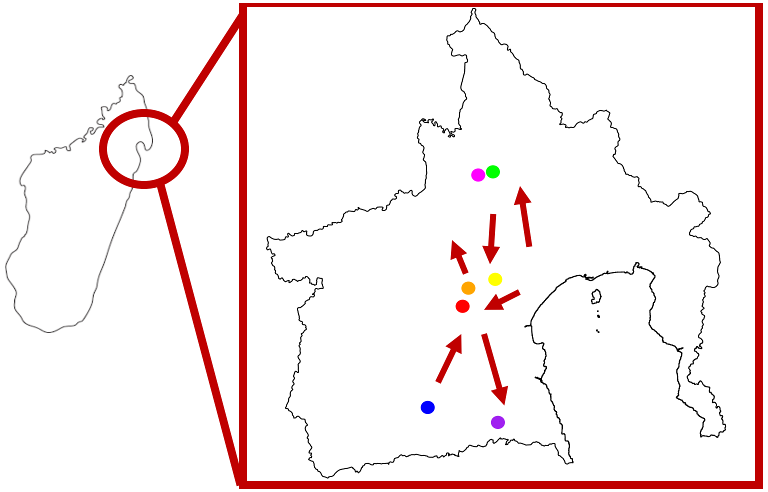
Brook et al. 2018. *Conservation Biology.*

Dispersal sometimes promoted rescue effects as seen in Hanksi's work.



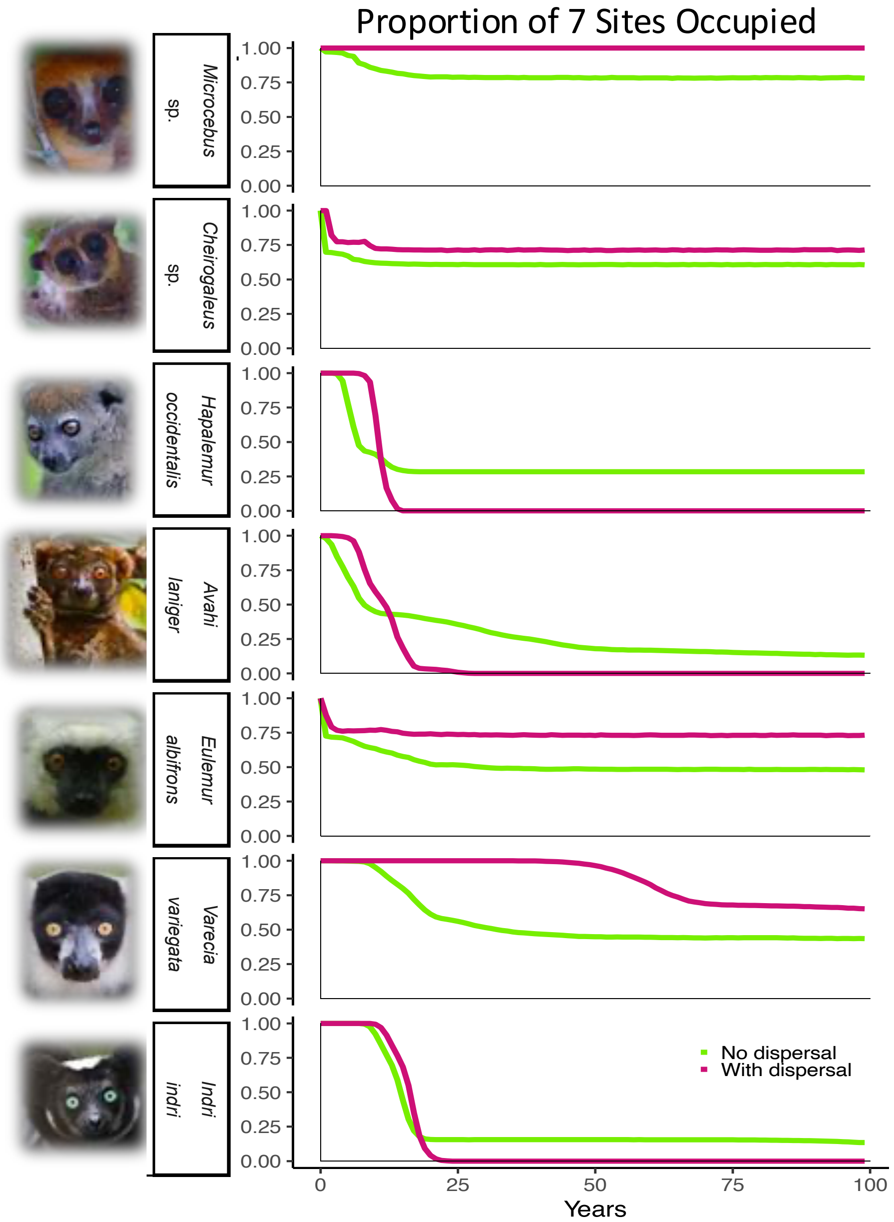
Metapopulation dynamics can promote more lemurs at more sites across the landscape!





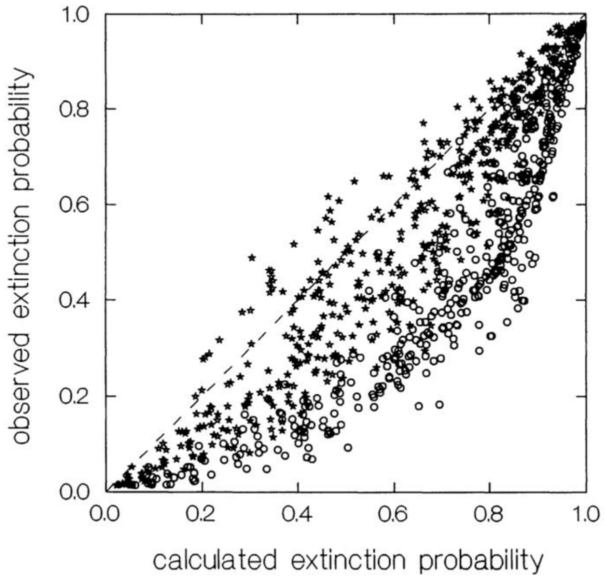
Brook et al. 2018. *Conservation Biology.*

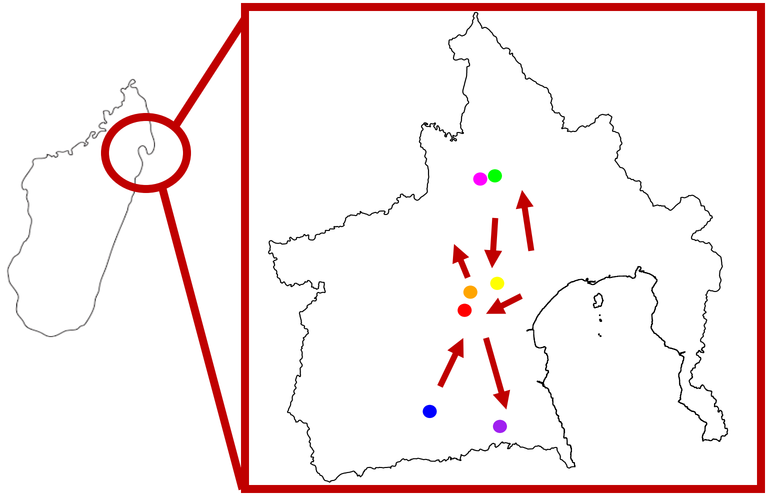
Dispersal can drive **regional extirpation** if the majority of local sites function as **population sinks**.



Metapopulation dynamics can drive regional declines in other cases!

In contrast to the **rescue effect** observed in Hanski!

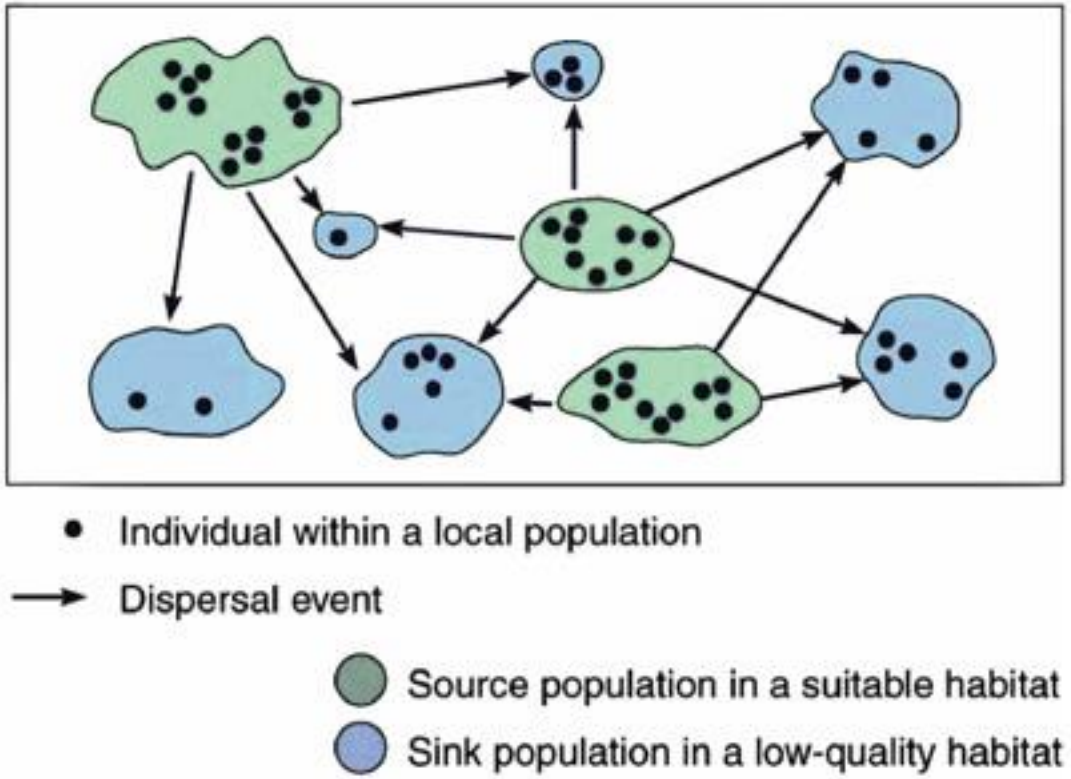




Brook et al. 2018. *Conservation Biology.*

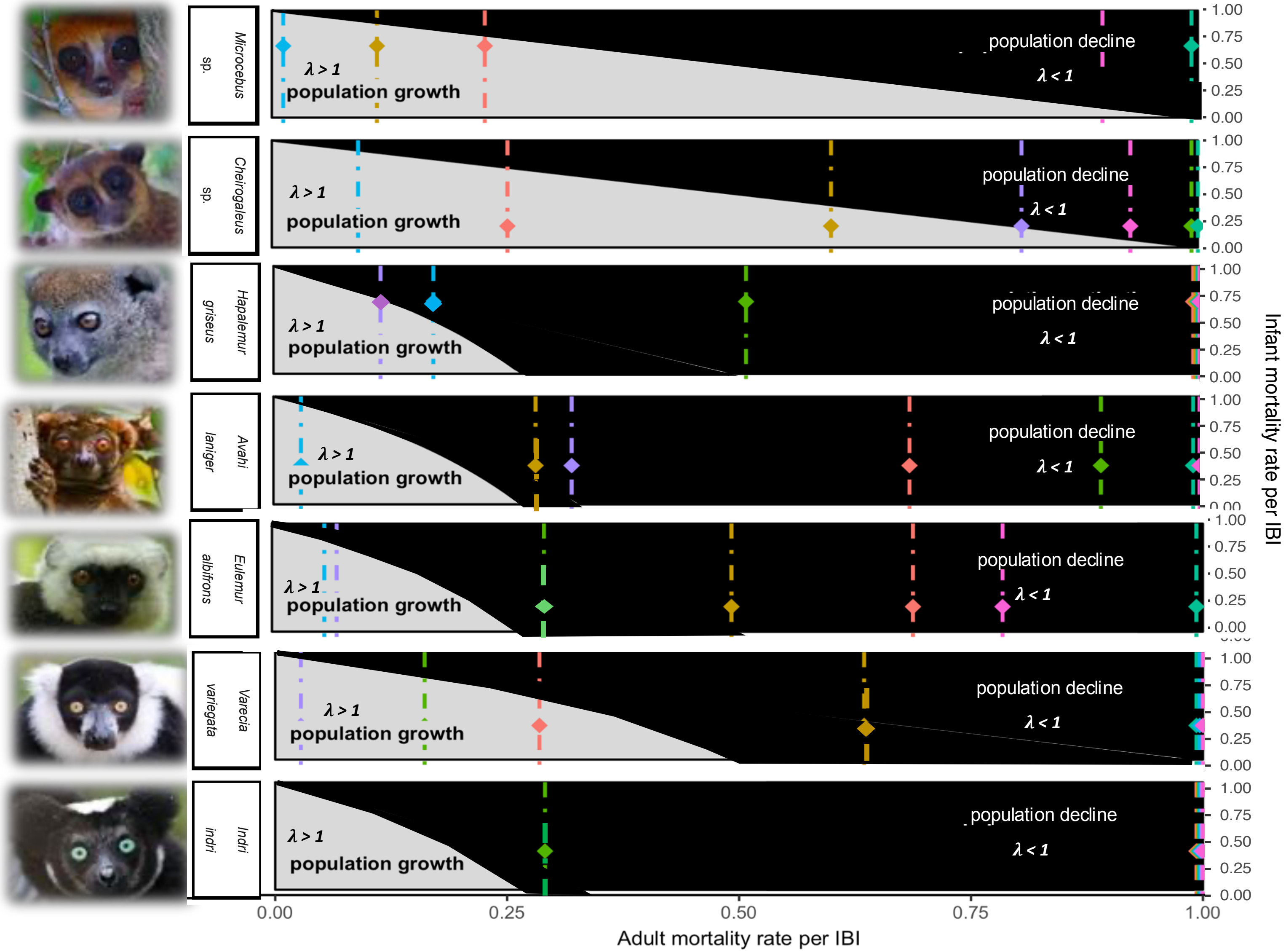
Source-sink theory describes how variation in habitat may affect population dynamics.

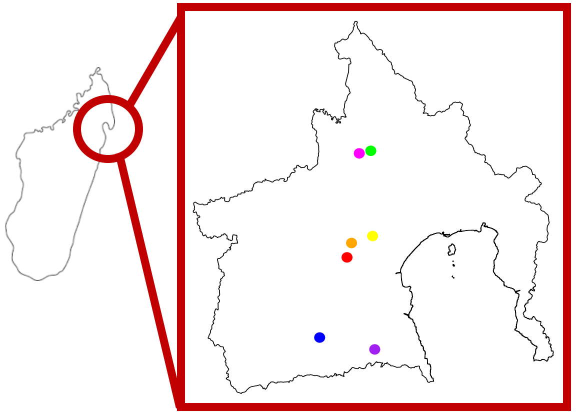
- Dispersal can drive **extinction** if the majority of sites function as **population sinks**.
- An **ecological trap** is an organism's preference for poor quality habitat
  - Ex: polarized light pollution & insect ovipositing



Pulliam 1988. *The American Naturalist.*

We also evaluated **excess mortality due to human hunting** to assess **harvest sustainability**.



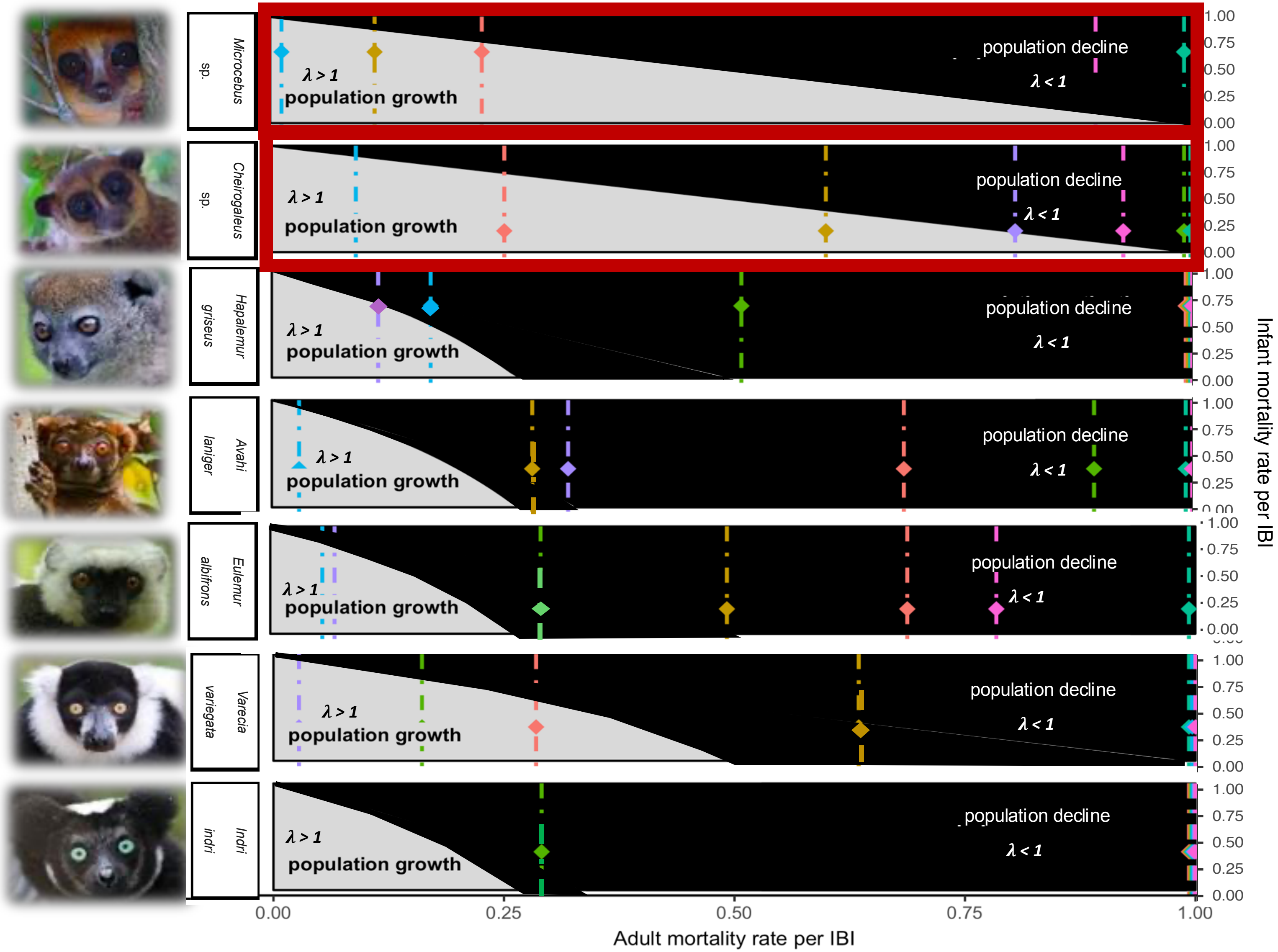


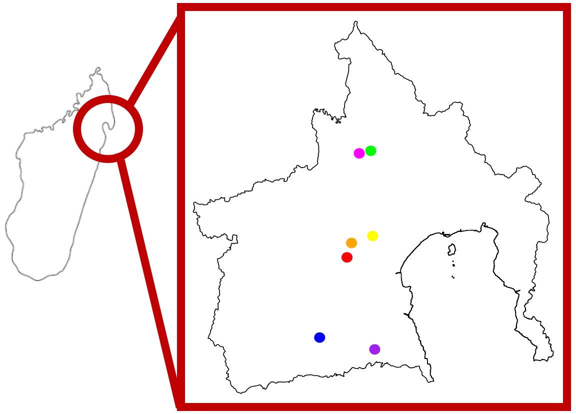
Colored vertical lines give **site-specific hunting rates** for adult lemurs.

Diamonds correspond to the intersection of that hunt rate with estimated juvenile mortality.

Brook et al. 2018. *Conservation Biology.*

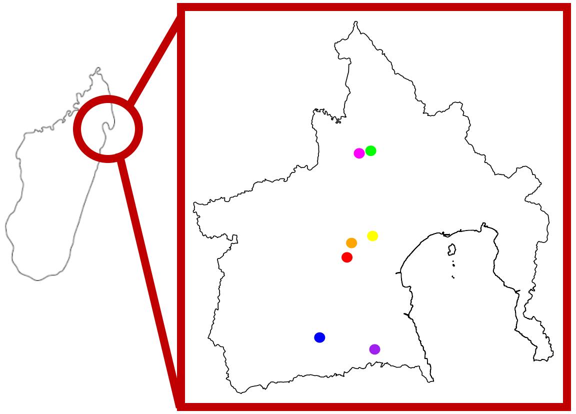
Small-bodied lemurs are largely **harvested at sustainable rates** on the Makira-Masoala peninsula.

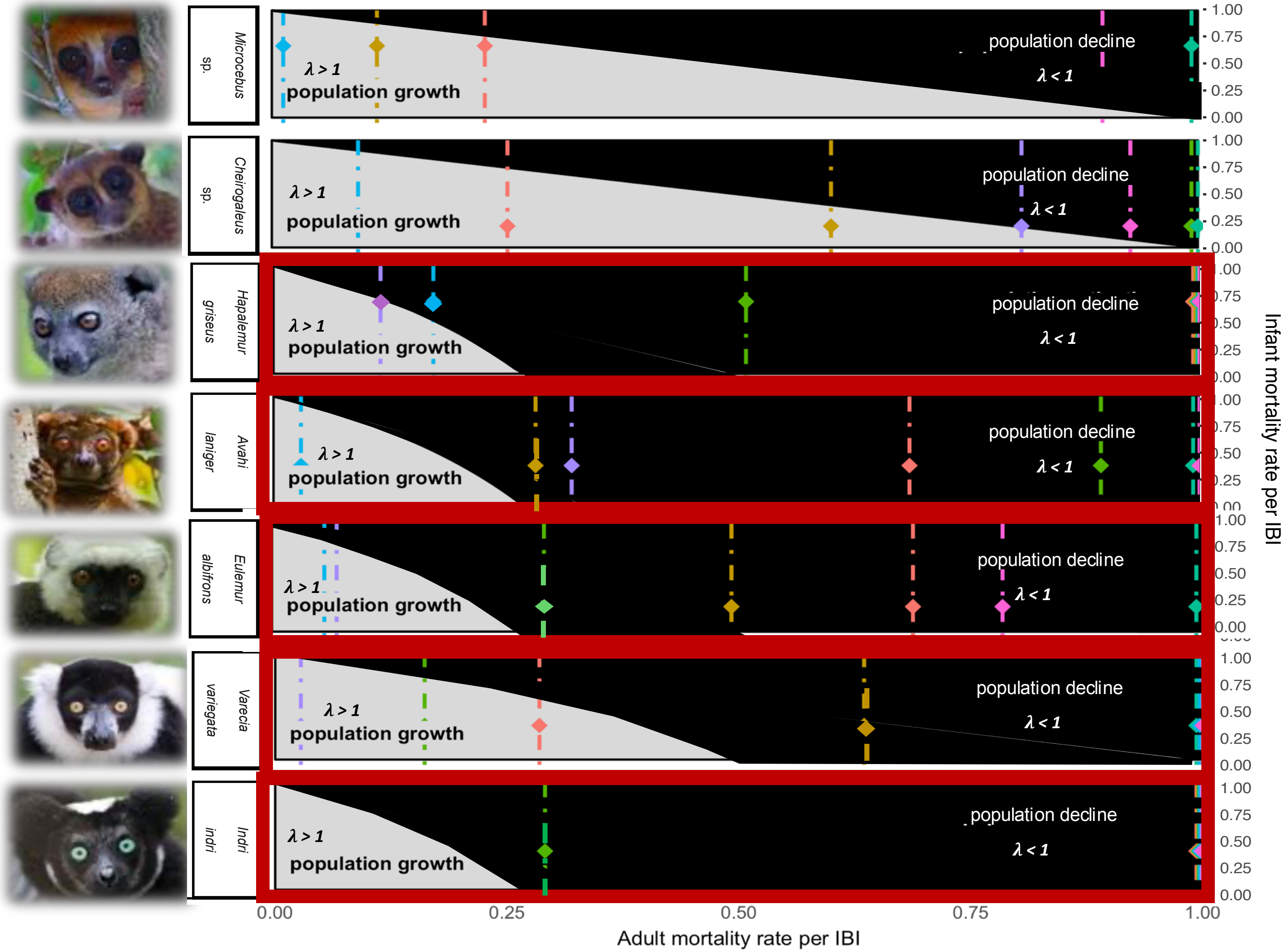




Brook et al. 2018. *Conservation Biology.*

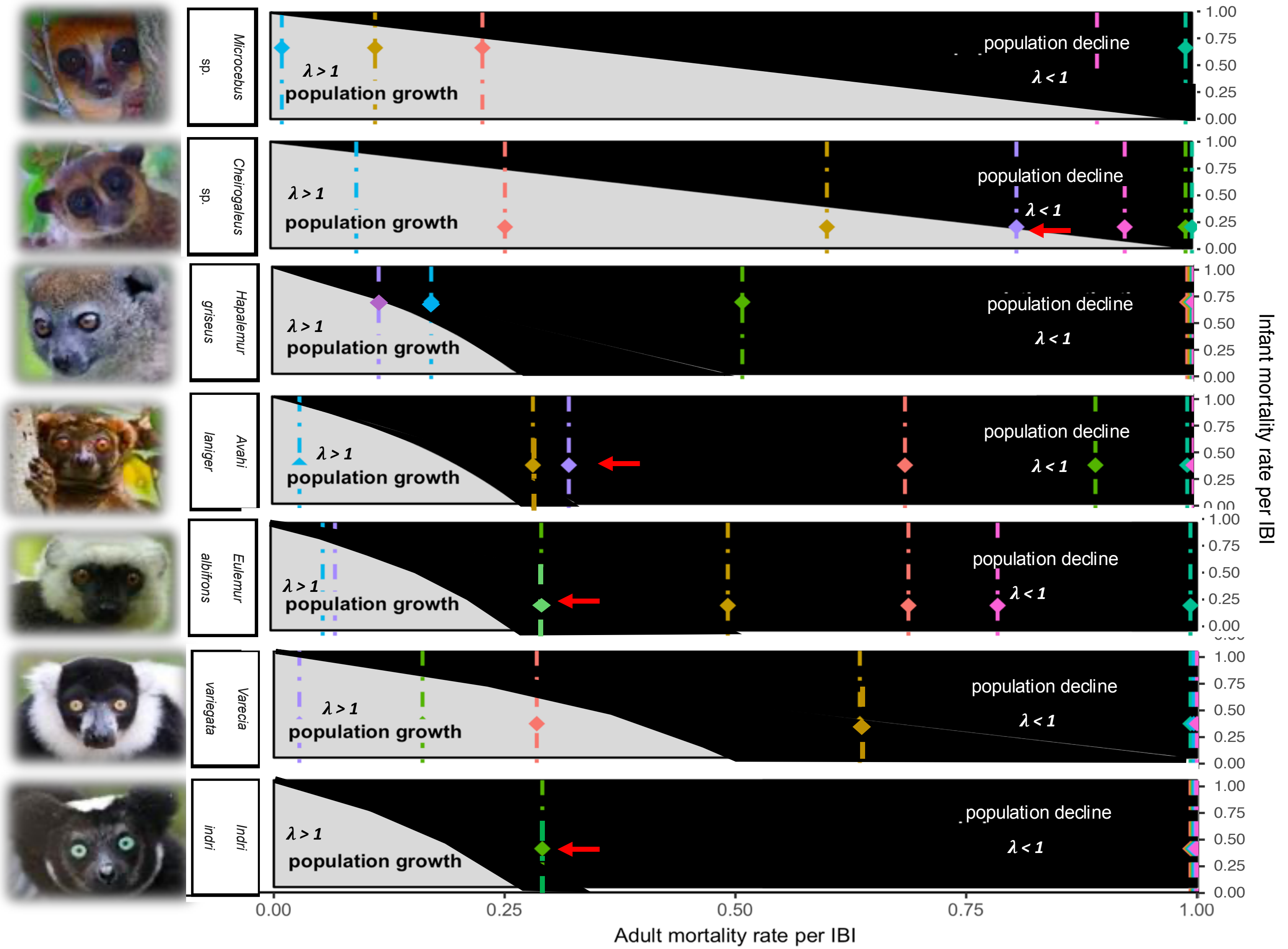
By contrast, **larger-bodied lemurs** are severely **threatened**.

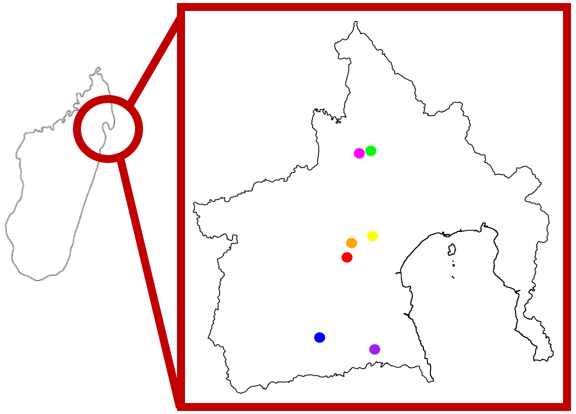




Brook et al. 2018. *Conservation Biology.*

Harvesting near the zero-growth curve highlights the problems inherent with MSY!



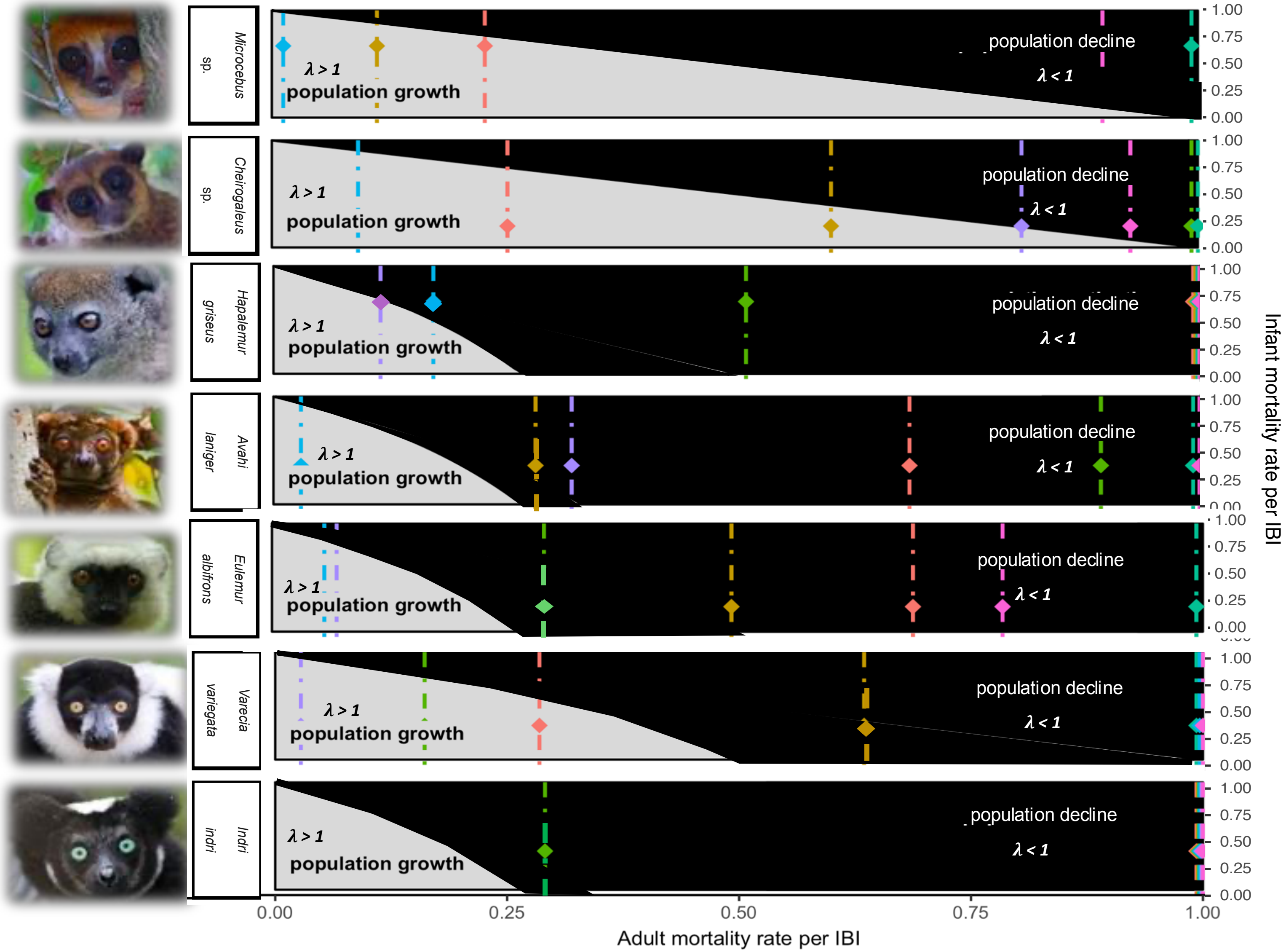


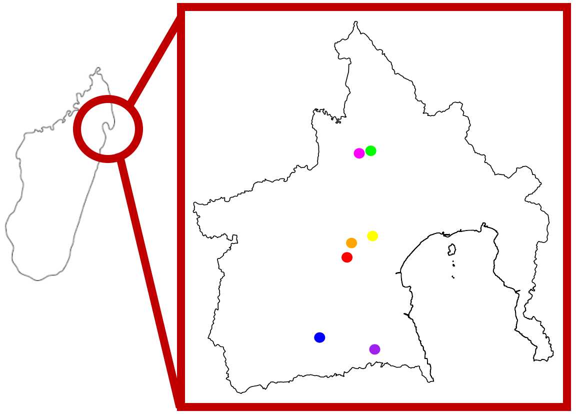
Because of the **semi-stable equilibrium** at MSY, small (natural) decreases in N can be devastating:

- environmental **stochasticity**
- demographic **stochasticity**

Brook et al. 2018. *Conservation Biology.*

Harvesting near the zero-growth curve highlights the problems inherent with **MSY**!



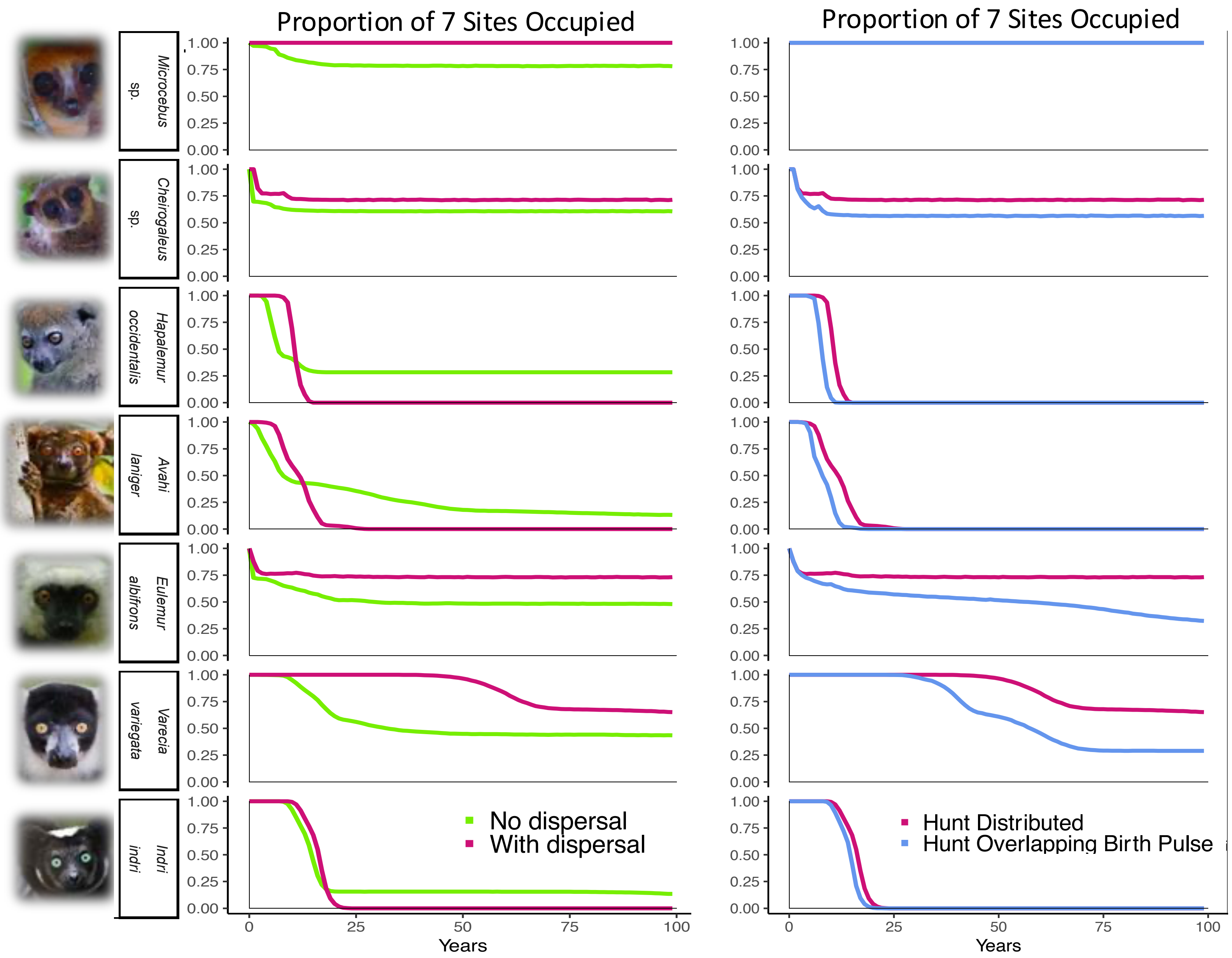


The **'Allee effect'** describes the correlation between population size and population 'fitness', often measured by the population rate of increase, λ.

Large animals tend to have **smaller population sizes**, which are often associated with **lower λ**.

Brook et al. 2018. *Conservation Biology.*

Species are even **further threatened** when **hunt seasonality** overlaps the **annual birth pulse**.



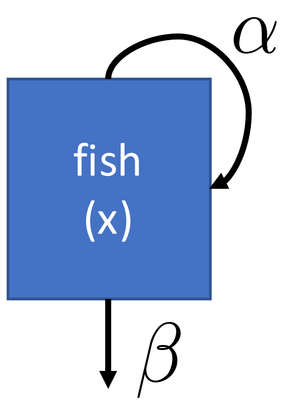
Our lemur model highlights some of the earlier challenges discussed with modeling '**maximum sustainable yield**' in fisheries!

Simplest representations of MSY:

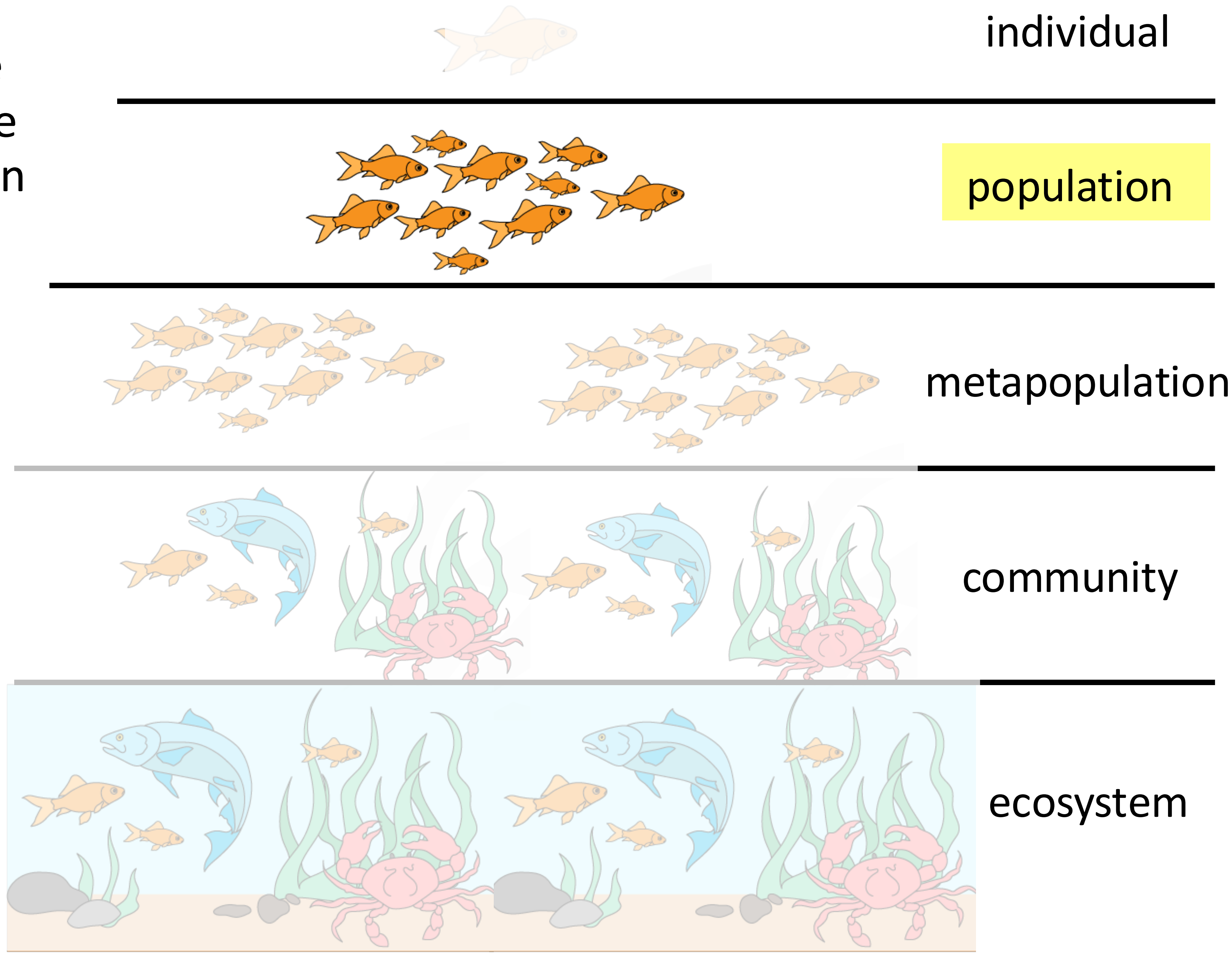
- Neglect population structure.
- Assume constant harvest.
- Ignore environmental and demographic stochasticity

Brook et al. 2018. *Conservation Biology.*

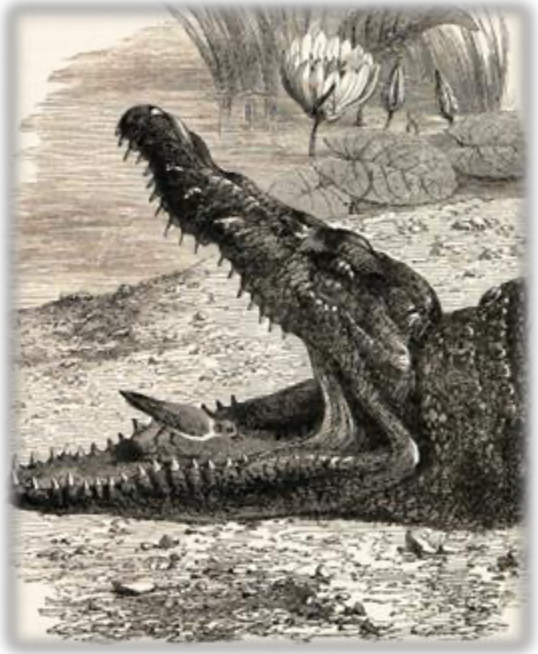
Population = multiple individuals of the same species (**conspecifics**) in the same habitat



*How does the abundance of fish **change** through time?*

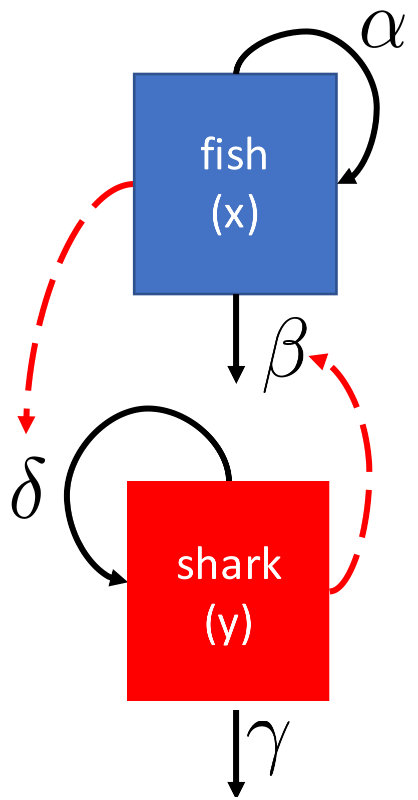


The logistic growth equation offers an explanation for population self-regulation, an example of **intraspecific competition**.

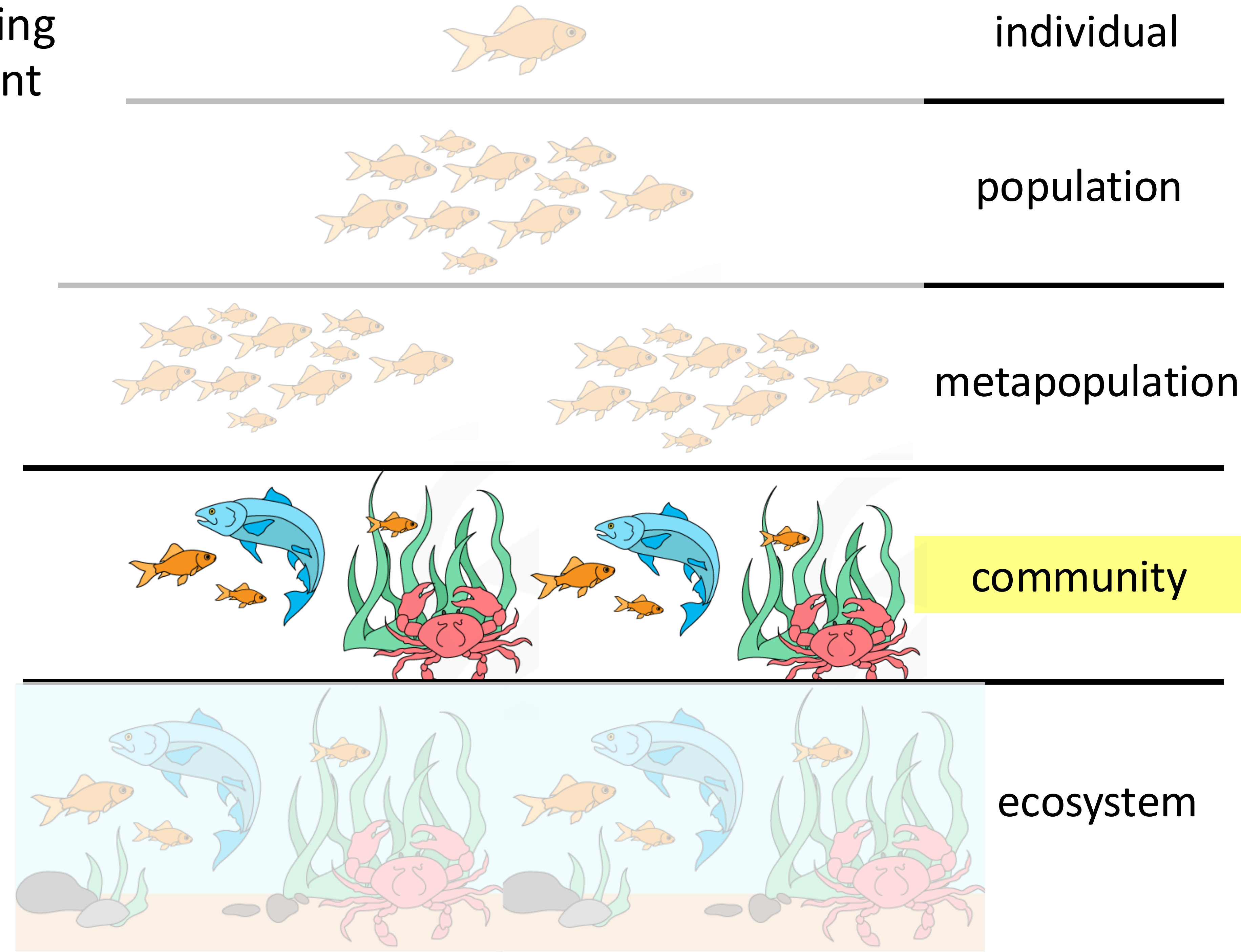


But ecology is the study of the **interactions** of organisms with each other and their environment, and in some cases, **interspecific interactions** are essential to understanding ecological systems.

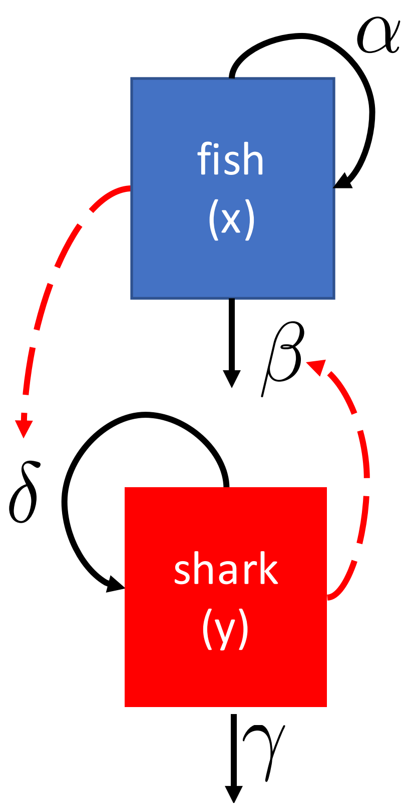
Community = interacting populations of different species



*How does fish abundance **vary** with **changes** in shark abundance?*



The Lotka-Volterra predator-prey model



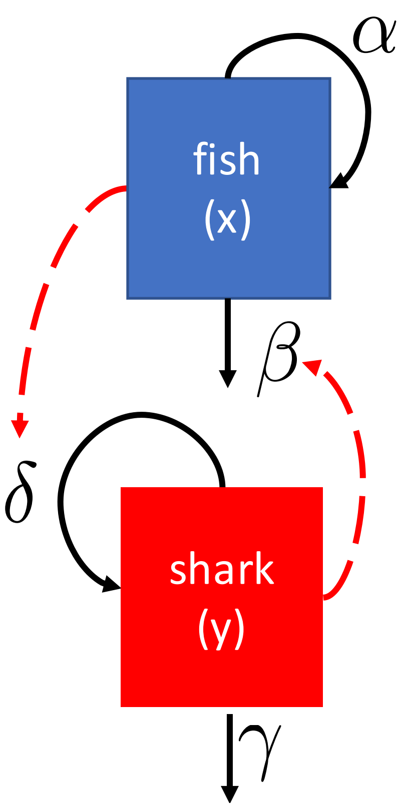
*How does **fish** abundance **vary** with **changes** in **shark** abundance?*

$$\frac{dx}{dt} = \alpha x - \beta xy$$

$$\frac{dy}{dt} = \delta xy - \gamma y$$

- First proposed by Polish-born American mathematician & chemist, Alfred J. Lotka, in 1920 to explain autocatalytic chemical reactions.
- Lotka worked with Soviet mathematician Andrey Kolmogorov to extend the model to “organic systems”, originally studying plant-herbivore interactions.
- In 1926, Italian mathematician Vito Volterra independently developed the same model to explain the dynamics of predatory fish catches which increased immediately following WWI after years of low fishing.
- Idea that **interspecies interactions** regulate populations

The Lotka-Volterra predator-prey model



*How does **fish** abundance **vary** with **changes** in **shark** abundance?*

growth rate of prey, independent of predator

$$\frac{dx}{dt} = \alpha x - \beta xy$$

death rate of prey, depends on abundance of predator

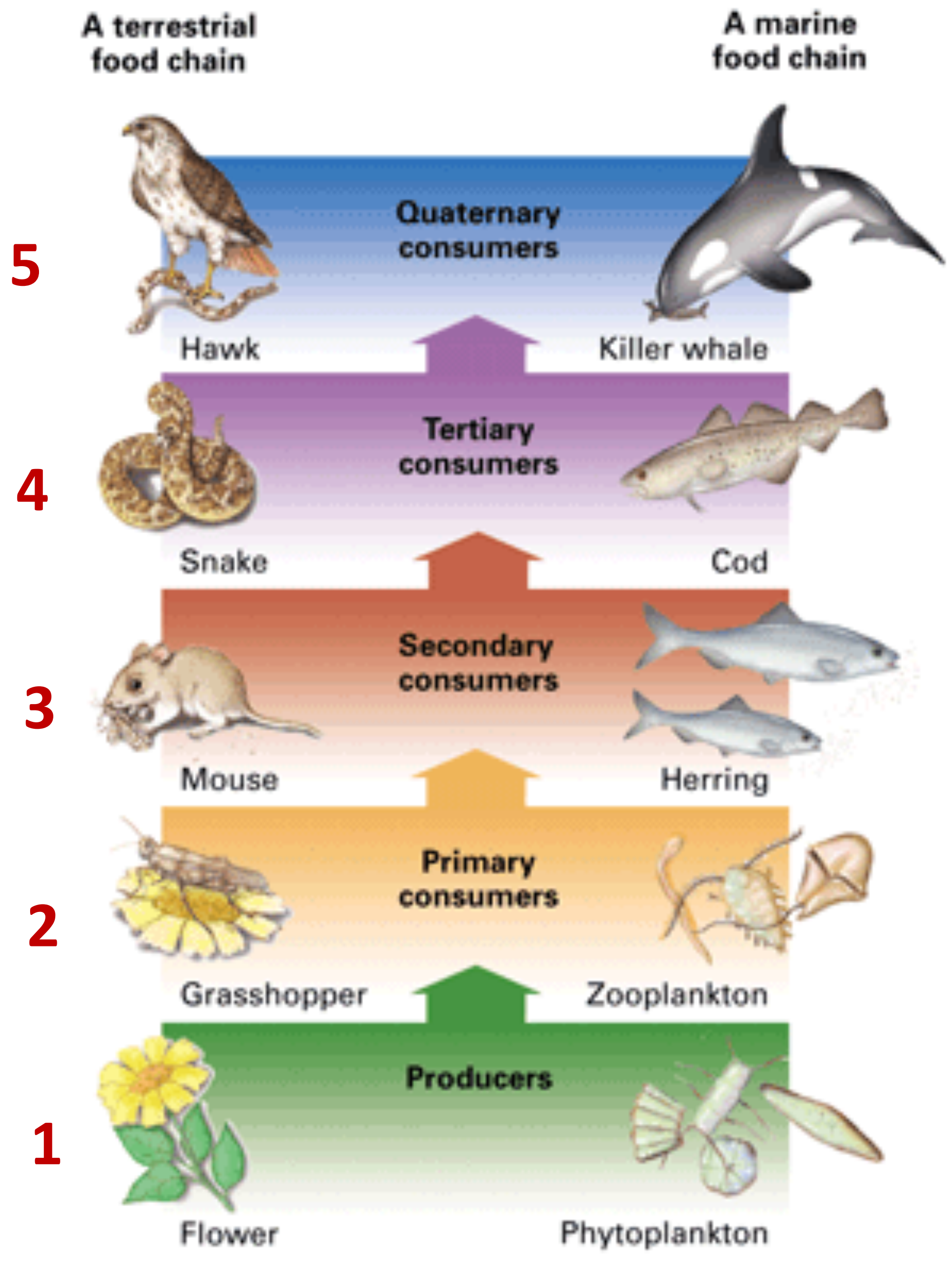
$$\frac{dy}{dt} = \delta xy - \gamma y$$

death rate of predator, independent of prey

growth rate of predator, depends on abundance of prey (and efficiency of consumption)

Trophic levels are levels in the food chain, grouped by energy transfer.

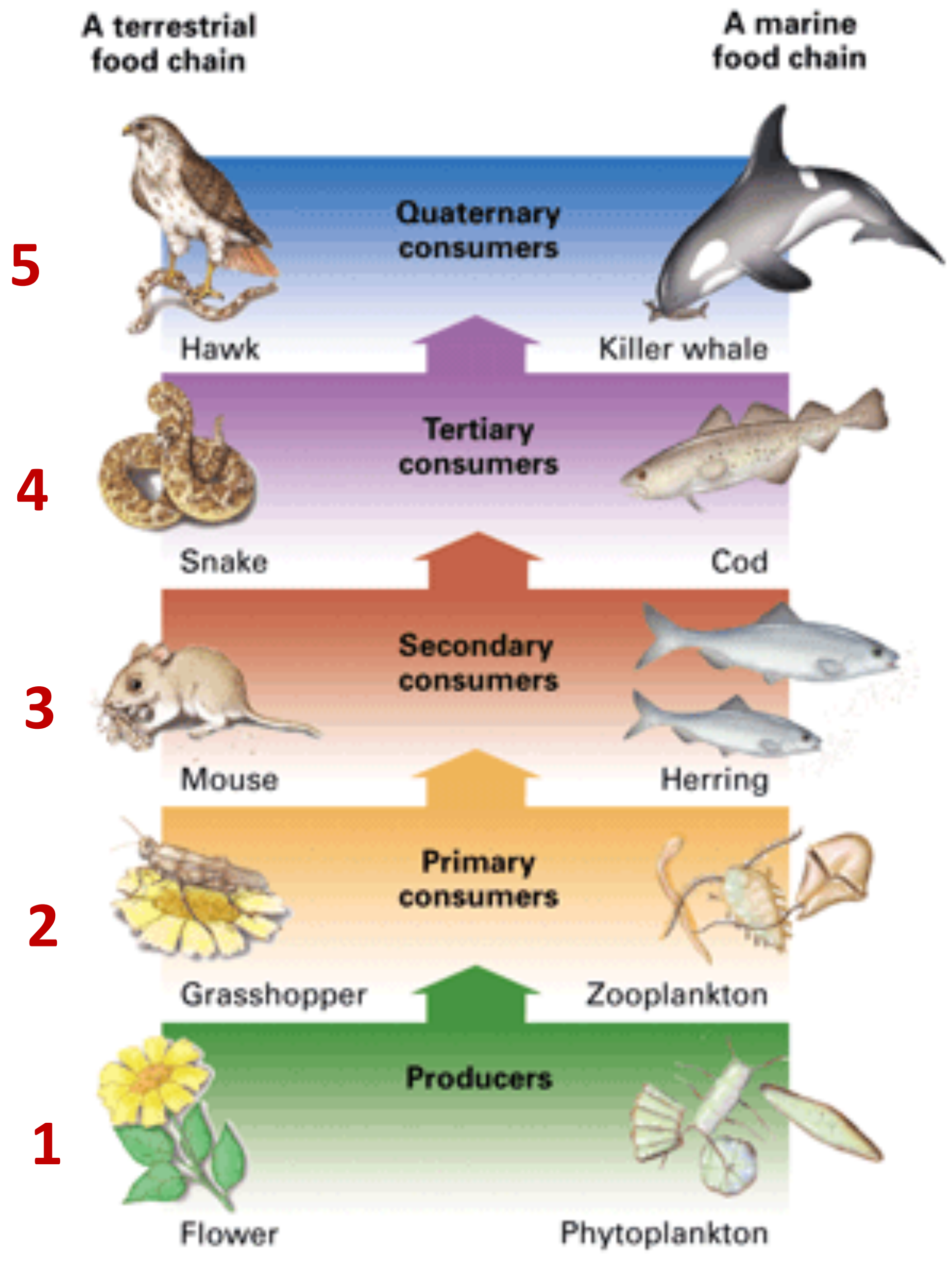
Each trophic level is given a number corresponding to **how many steps it is away from the start of the chain**.



Trophic levels are levels in the food chain, grouped by energy transfer.

Each trophic level is given a number corresponding to **how many steps it is away from the start of the chain**.

Energy efficiency is the term used to describe the transfer of energy moving up a trophic level.



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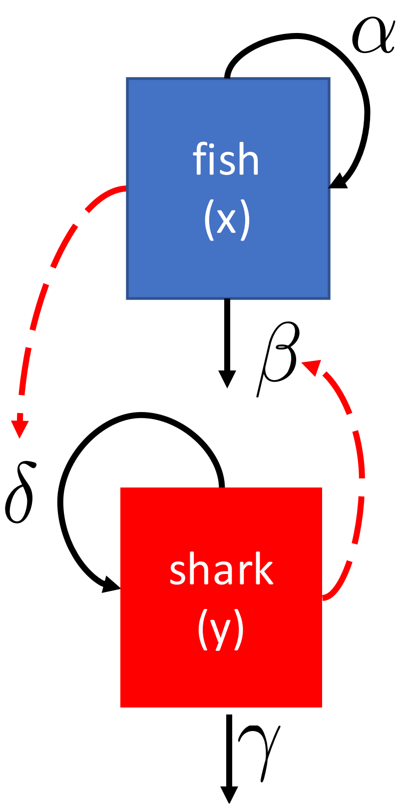


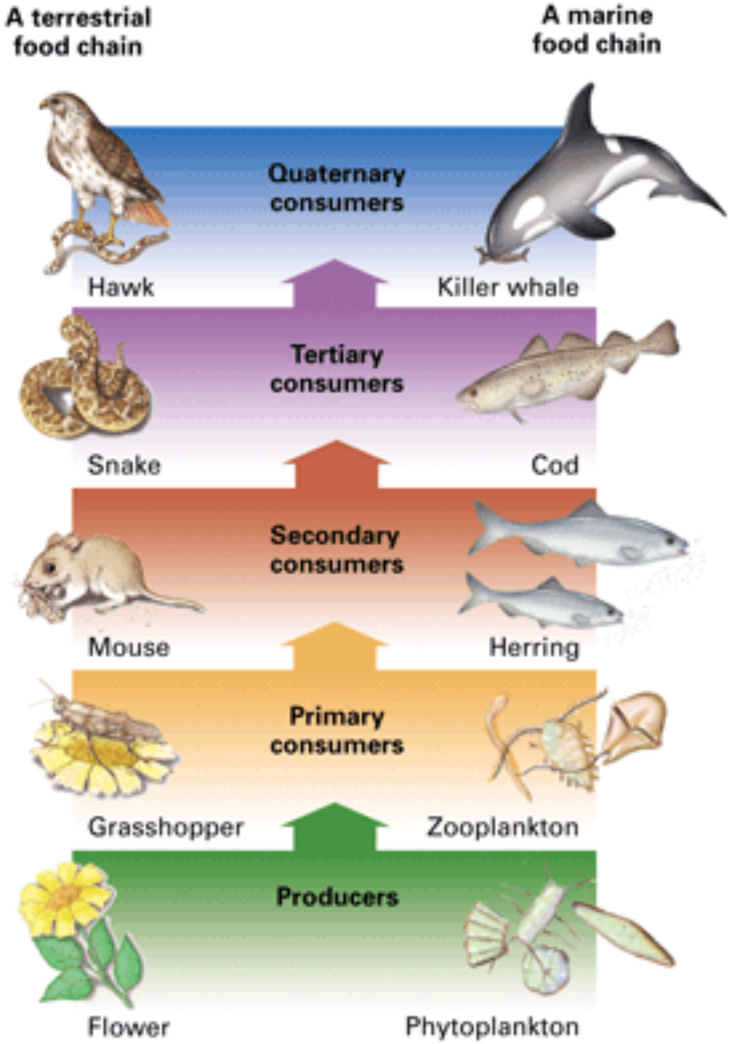
*How does **fish** abundance **vary** with **changes** in **shark** abundance?*

$$\frac{dx}{dt} = \alpha x - \beta xy$$

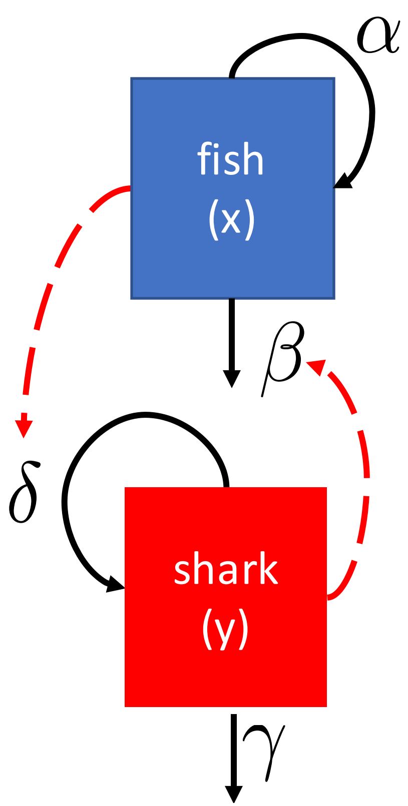
$$\frac{dy}{dt} = \delta xy - \gamma y$$

Bottom-up processes describe ecosystems regulated via production from lower trophic levels.

Top-down processes describe ecosystems regulated via consumption from higher trophic levels.



The Lotka-Volterra predator-prey model



$$\frac{dx}{dt} = \alpha x - \boxed{\beta xy}$$

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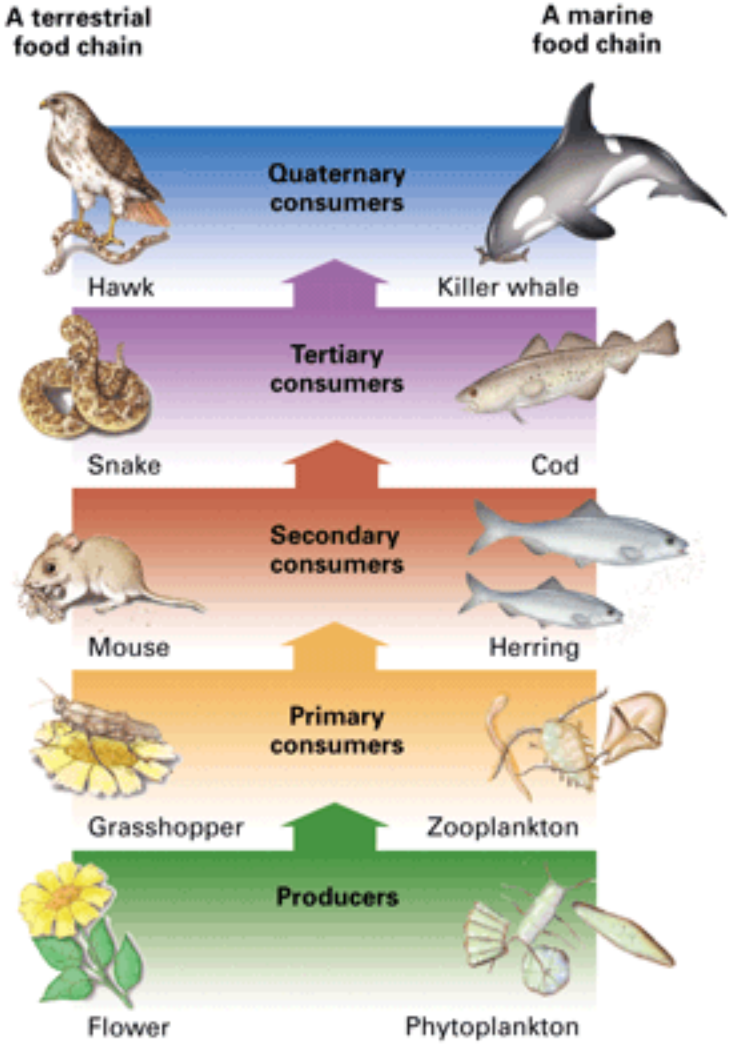
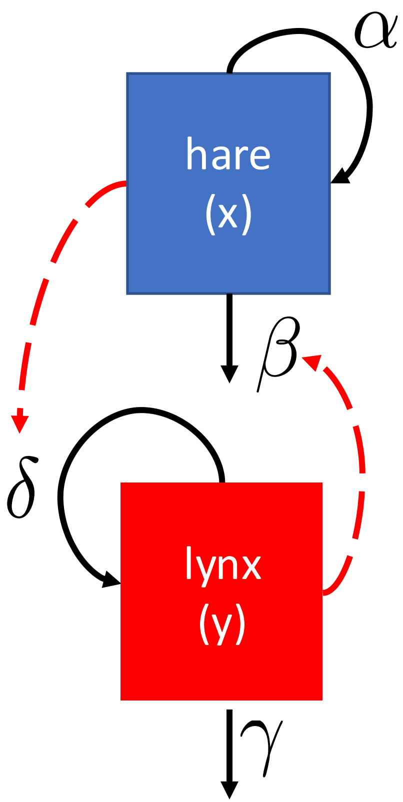


*How does **fish** abundance **vary** with **changes** in **shark** abundance?*

Bottom-up processes describe ecosystems regulated via production from lower trophic levels.

Top-down processes describe ecosystems regulated via consumption from higher trophic levels.

Lotka-Volterra predator-prey models with data



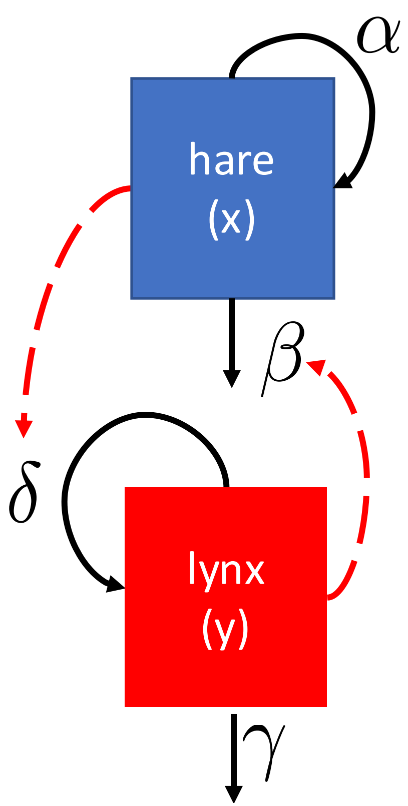
*How does **hare** abundance **vary** with **changes** in **lynx** abundance?*

PRO PELLE CUTEM

HUDSON'S BAY

INCORPORATED 2 MAY 1670

Lotka-Volterra predator-prey models with data



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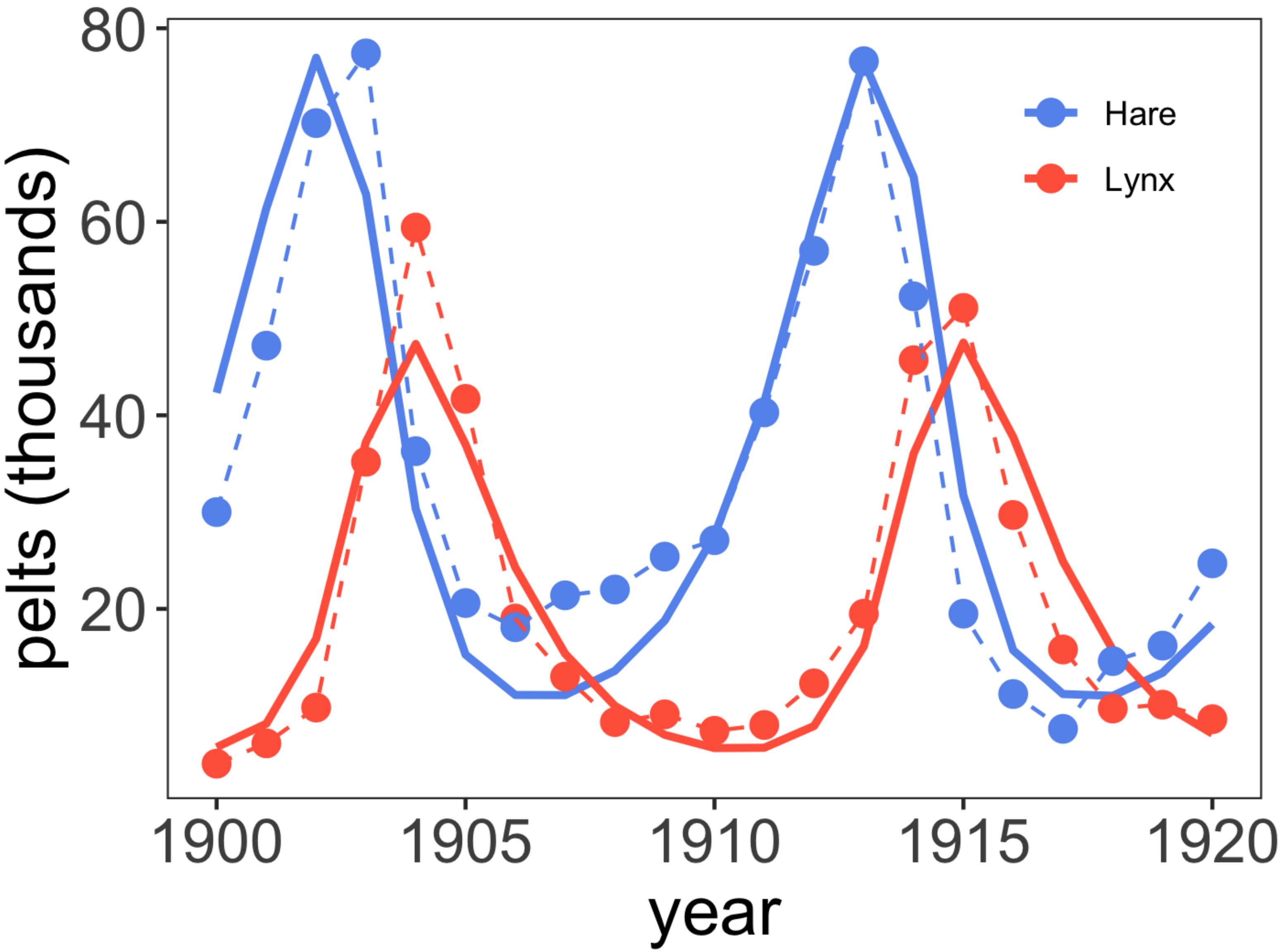
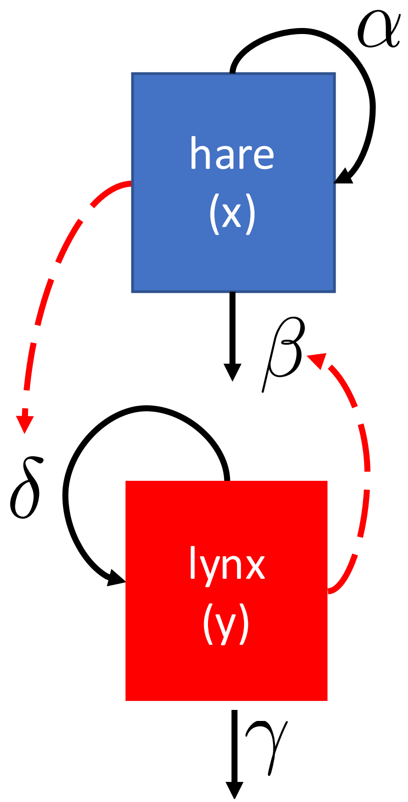
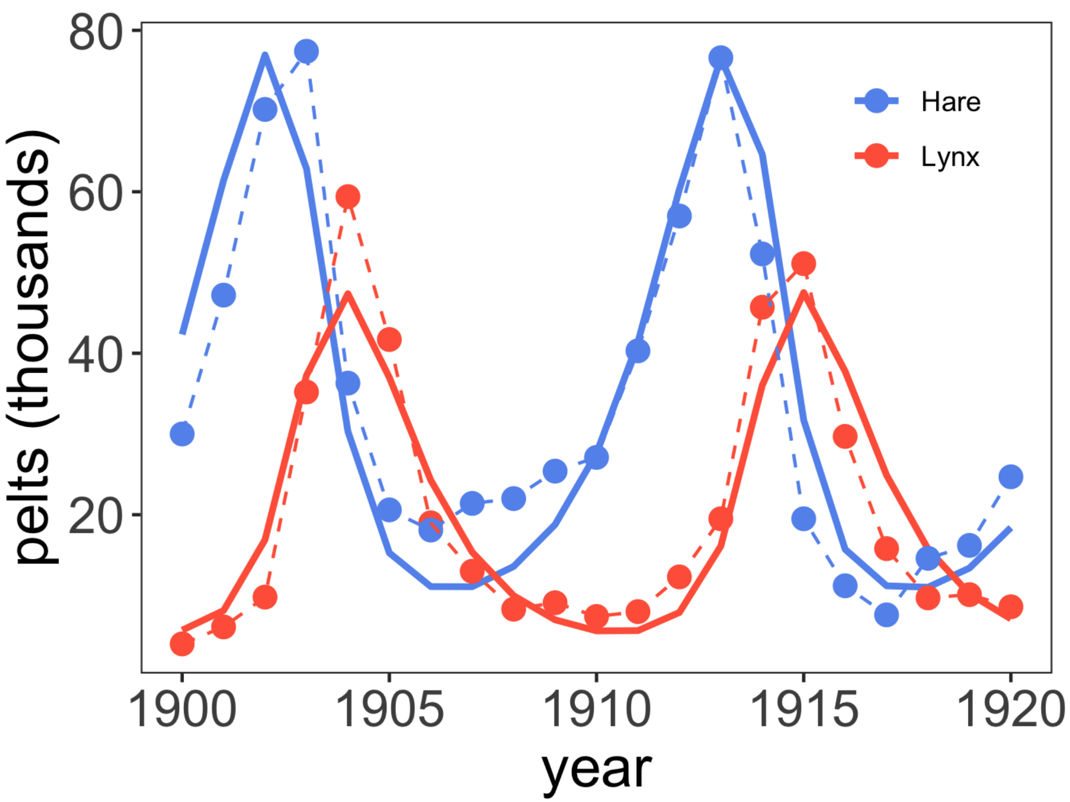


Lotka-Volterra predator-prey models with data





- Fitting a model to data allows us to estimate parameters – remember those growth rates from the human population models!
- Here, we can explore the growth rate of the prey under exponential growth (α), the efficiency of kill (β) and digestion (δ) by the predator, and the natural death rate of the predator (γ).

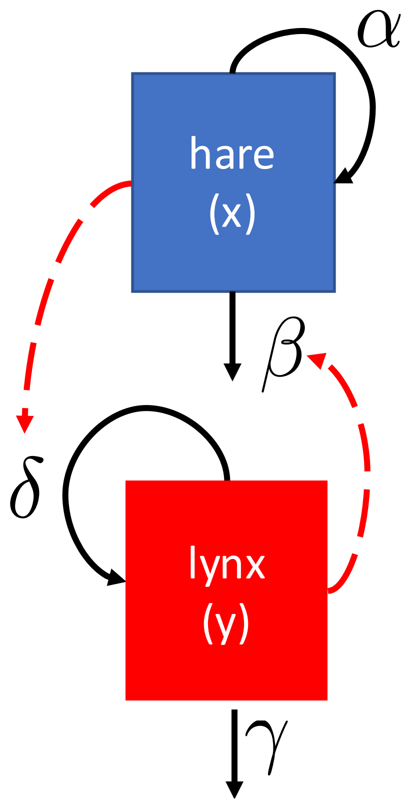
*How does **hare** abundance **vary** with **changes** in **lynx** abundance?*

$$\frac{dx}{dt} = \alpha x \ - \beta xy$$

$$\frac{dy}{dt} = \delta xy \ - \gamma y$$

- α = .0897 hare/year
- β = .0000157 hare/lynx/year
- δ = .0250 lynx/hare/year
- γ = .0174 lynx /year

Lotka-Volterra predator-prey **isoclines**



$$\frac{dx}{dt} = \alpha x - \beta xy$$

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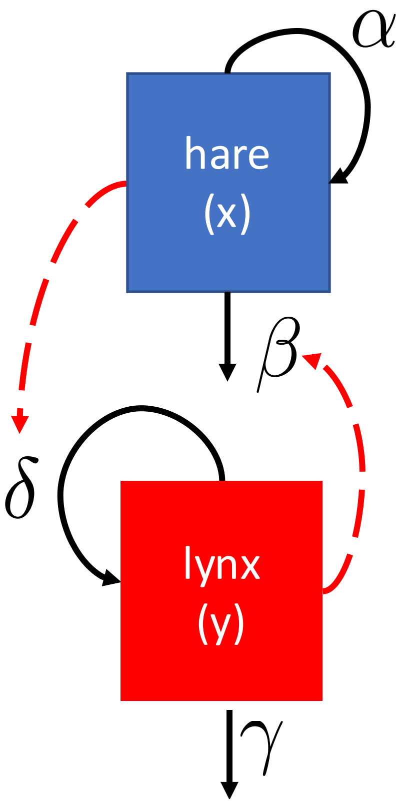
*How does **hare** abundance **vary** with **changes** in **lynx** abundance?*

The **zero-growth isocline** (or **nullcline**) refers to the line at which the rate of change for **one population in a two-population interaction model is not changing**.

(e.g. one of the differential equations is set equal to zero)

Lotka-Volterra predator-prey **isoclines**



$$\frac{dx}{dt} = \alpha x - \beta xy$$

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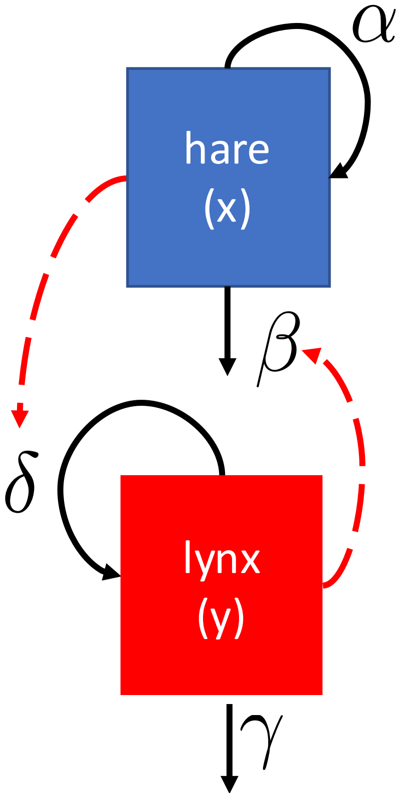
*What are the **prey** isoclines?*

(hint: this means the prey population is not changing!)

*How does **hare** abundance **vary** with **changes** in **lynx** abundance?*

Lotka-Volterra predator-prey **isoclines**



How does ***hare*** *abundance* ***vary*** *with* ***changes*** *in* ***lynx*** *abundance?*

$$\frac{dx}{dt} = \alpha x - \beta xy$$

$$\frac{dy}{dt} = \delta xy - \gamma y$$

What are the ***prey*** *isoclines?*

$$0 = \alpha x - \beta xy$$

$$0 = x(\alpha - \beta y)$$

$$isoclines\ at:$$

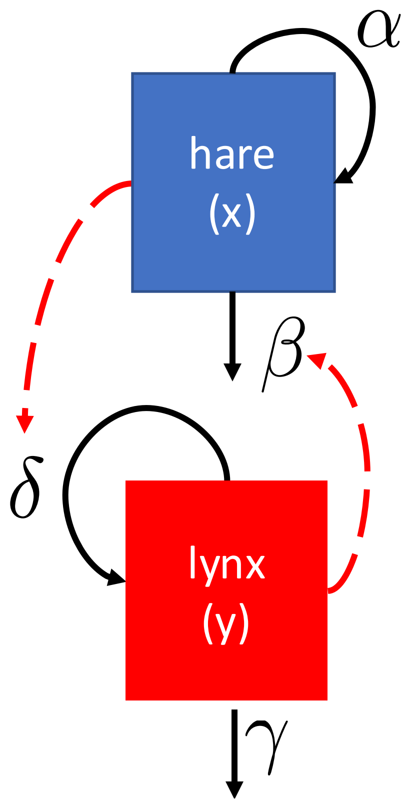
$$x = 0$$

$$y = \frac{\alpha}{\beta}$$

This is the predator number that results in no change in the prey population!

(because prey are top-down regulated)

Lotka-Volterra predator-prey **isoclines**



$$\frac{dx}{dt} = \alpha x \; - \beta xy$$

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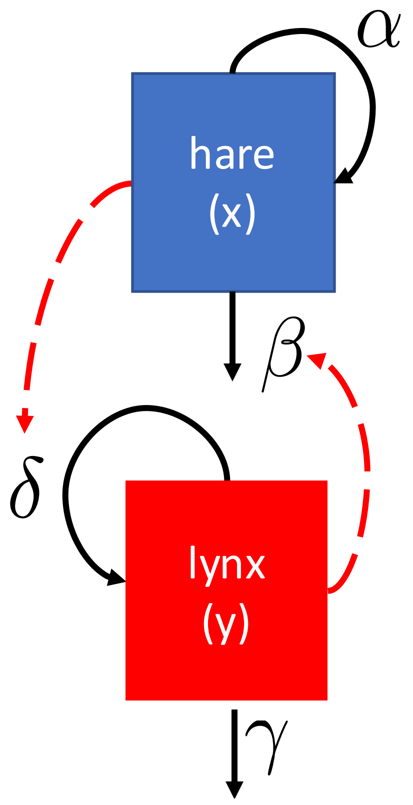
*What are the **predator** isoclines?*

(hint: this means the predator population is not changing!)

*How does **hare** abundance **vary** with **changes** in **lynx** abundance?*

Lotka-Volterra predator-prey **isoclines**



$$\frac{dx}{dt} = \alpha x - \beta xy$$

$$\frac{dy}{dt} = \delta xy - \gamma y$$

*What are the **predator** isoclines?*

$$0 = \delta xy - \gamma y$$

$$0 = y(\delta x - \gamma)$$

$$isoclines\ at:$$

$$y = 0$$

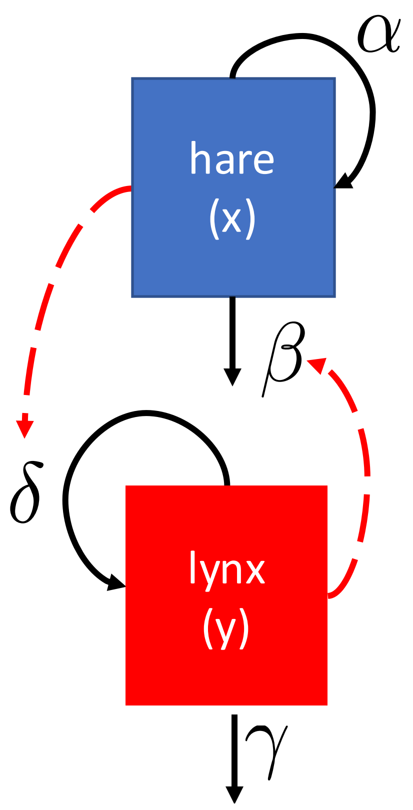
$$x = \frac{\gamma}{\delta}$$

This is the prey number that results in no change in the predator population!

(because predators are bottom-up regulated)

*How does **hare** abundance **vary** with **changes** in **lynx** abundance?*

Lotka-Volterra predator-prey **isoclines**



$$\frac{dx}{dt} = \alpha x \; - \beta x y$$
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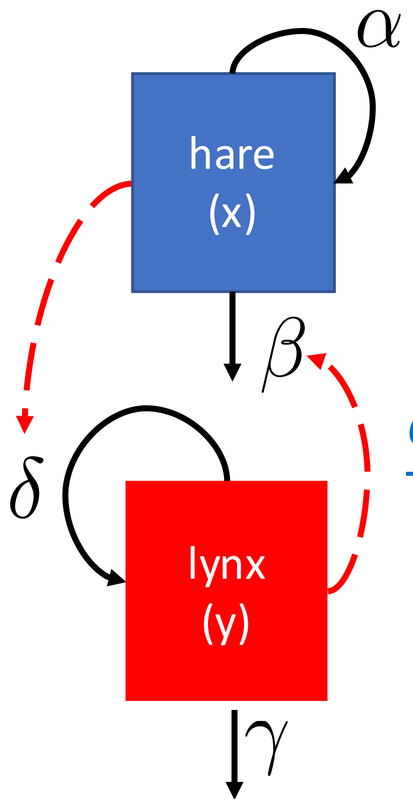
$prey\ isoclines$:
$$x = 0$$
$$y = \frac{\alpha}{\beta}$$

$predator\ isoclines$:
$$y = 0$$
$$x = \frac{\gamma}{\delta}$$

*How does **hare** abundance **vary** with **changes** in **lynx** abundance?*

Lotka-Volterra predator-prey isoclines



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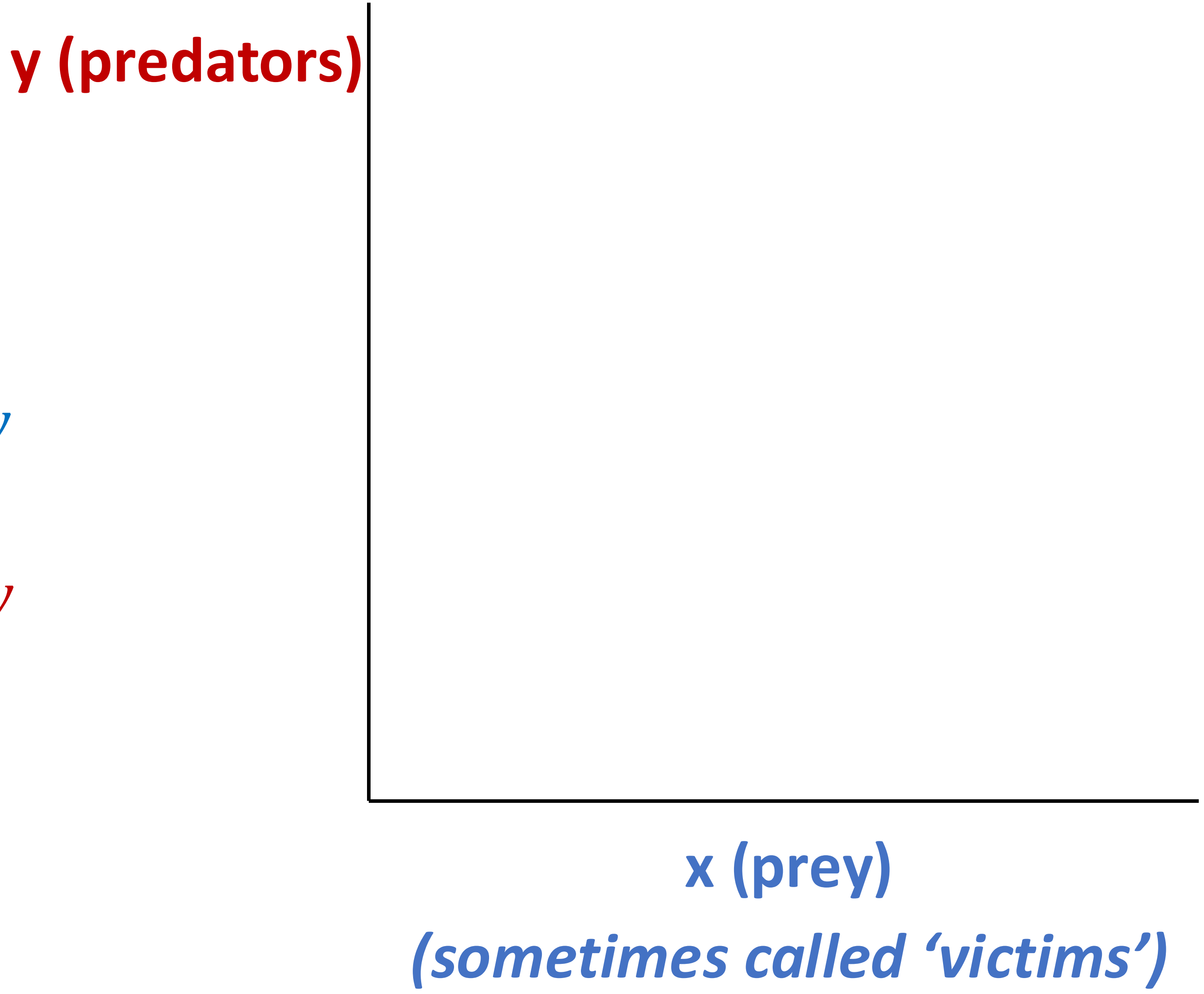
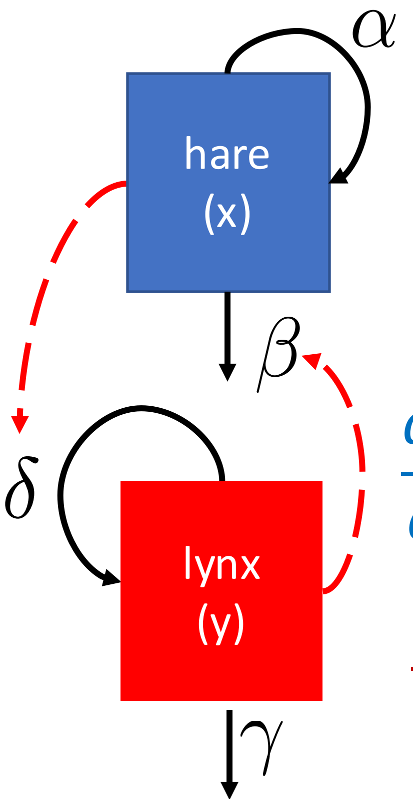


Lotka-Volterra predator-prey **isoclines**



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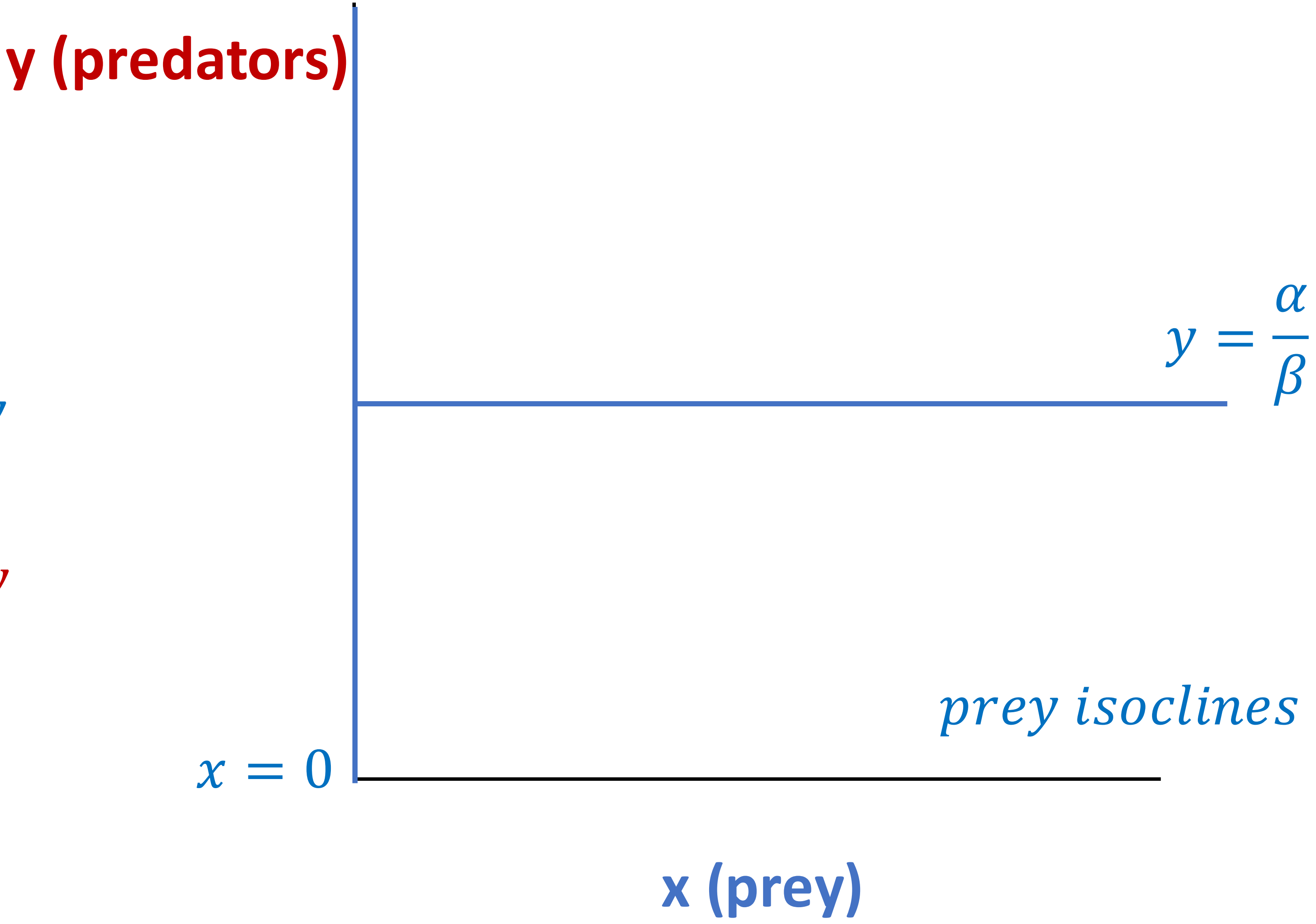
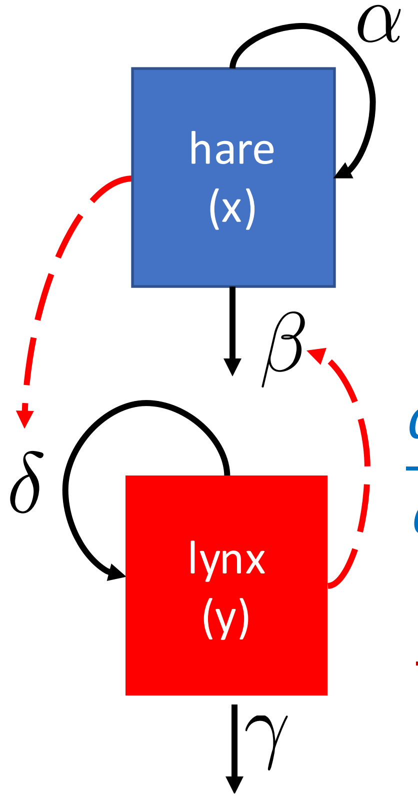


Lotka-Volterra predator-prey isoclines



$$\frac{dx}{dt} = \alpha x \ - \beta xy$$

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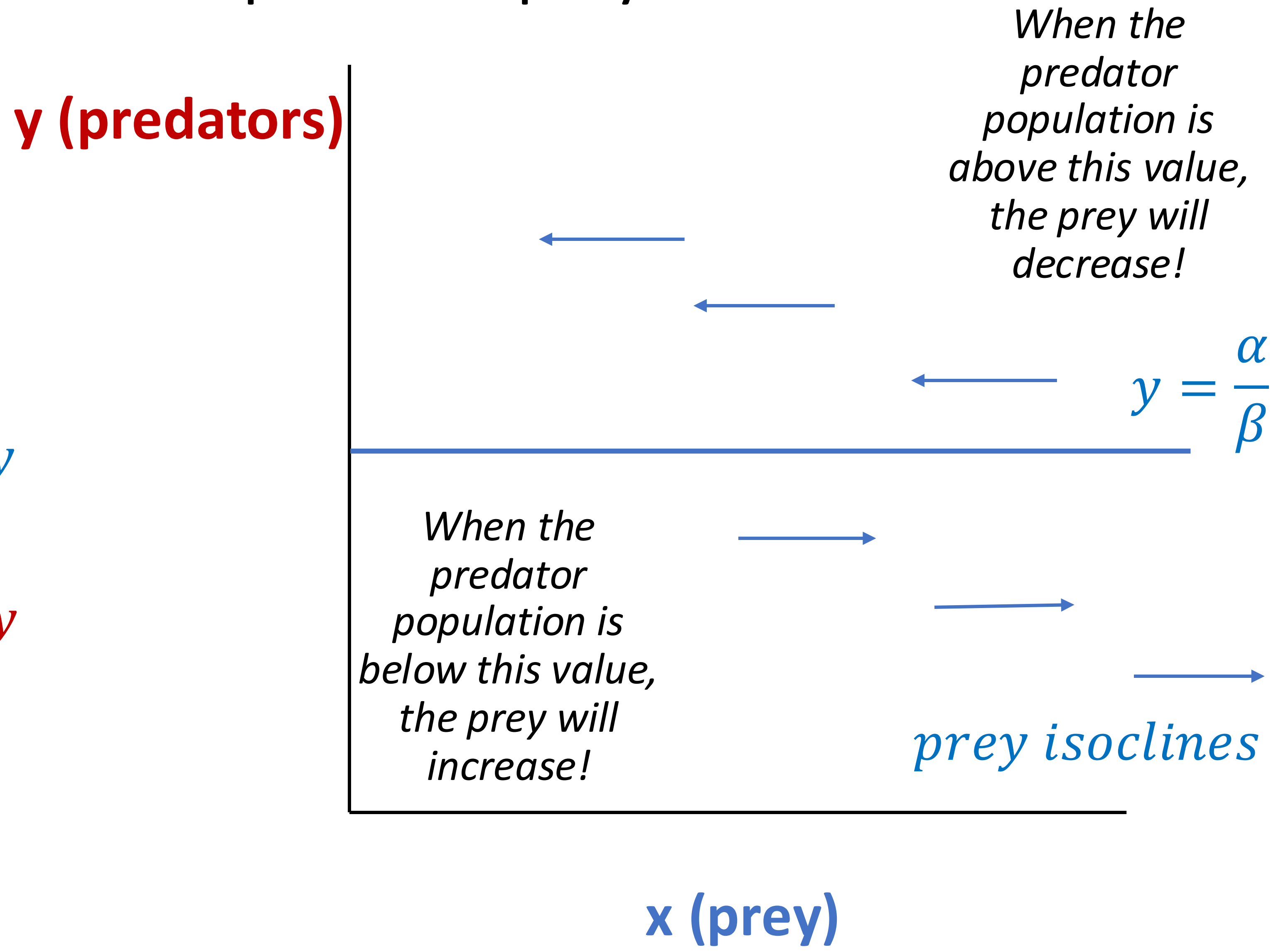

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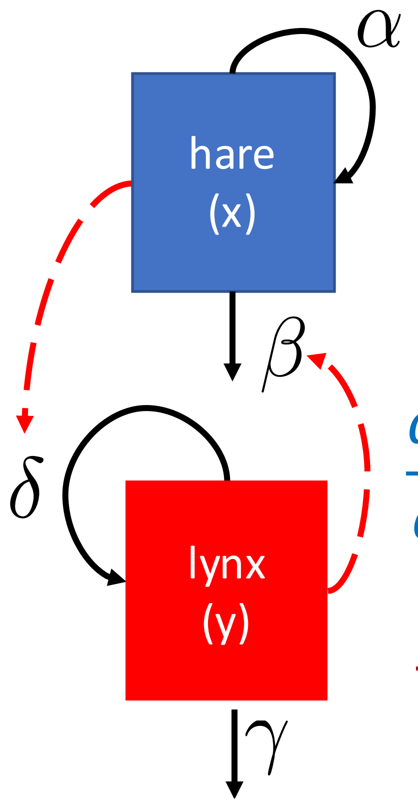

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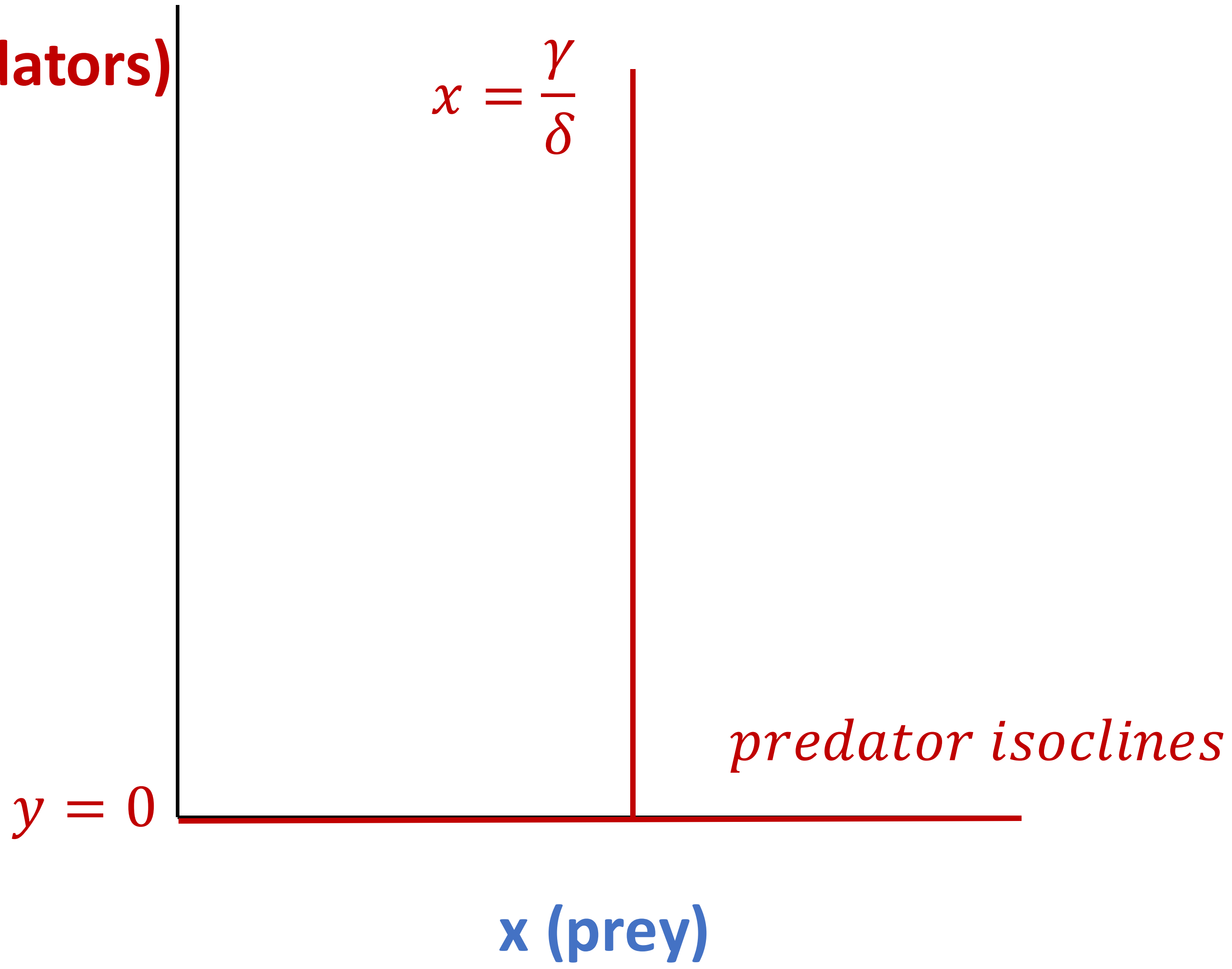

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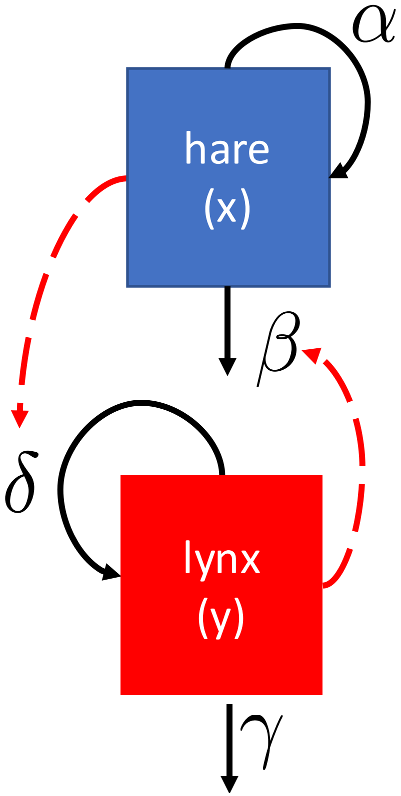

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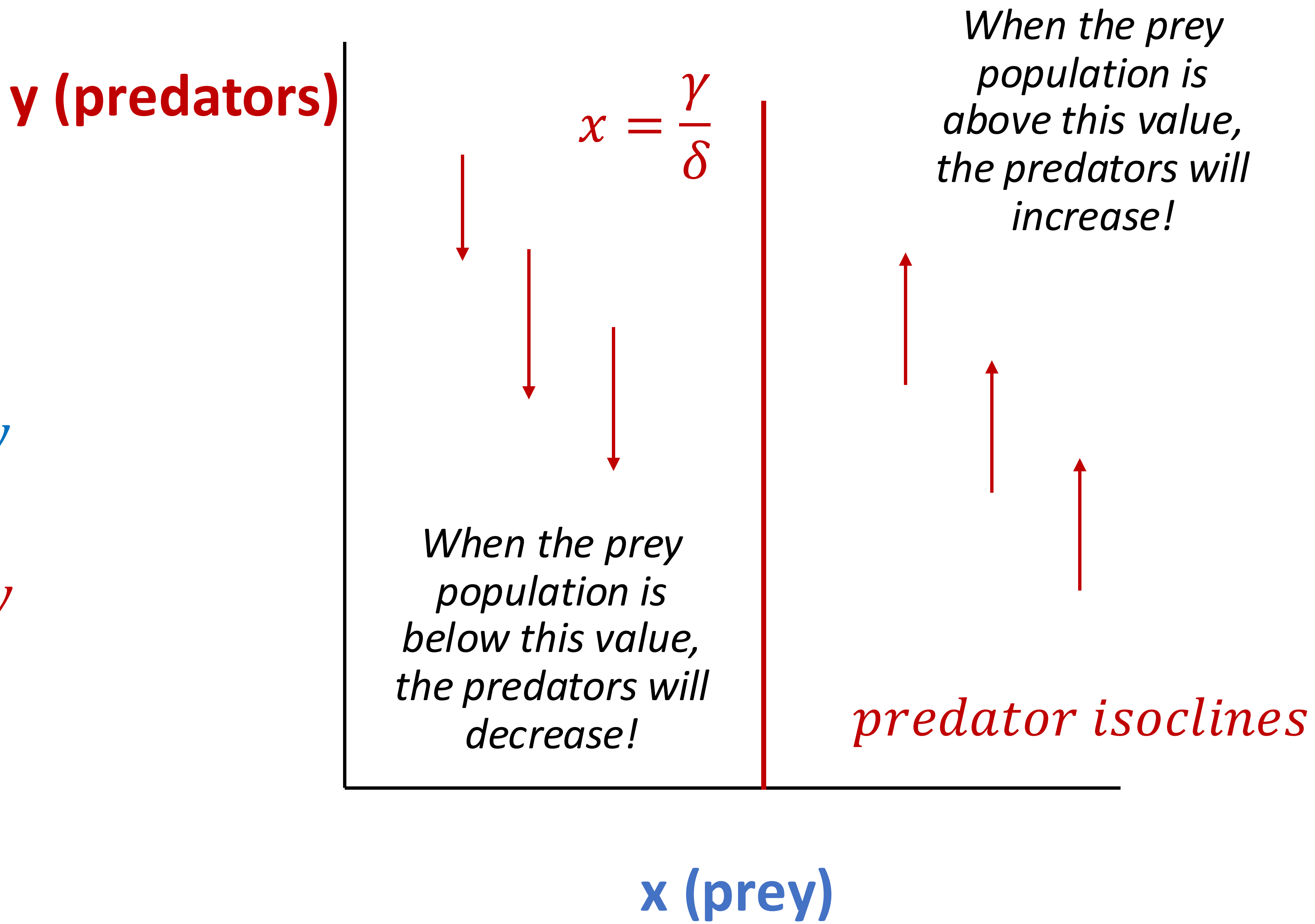

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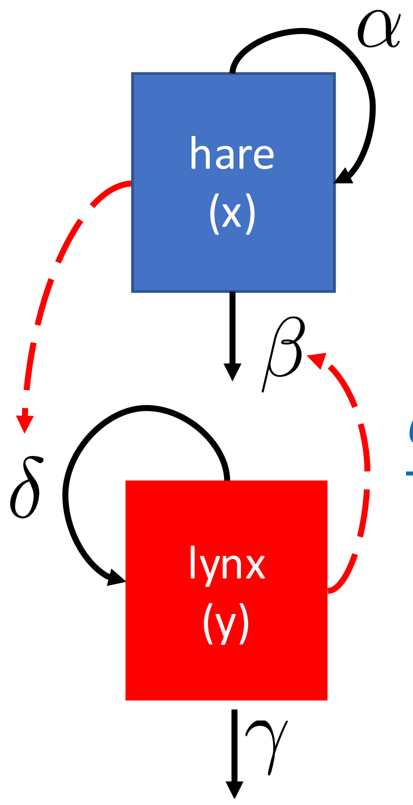

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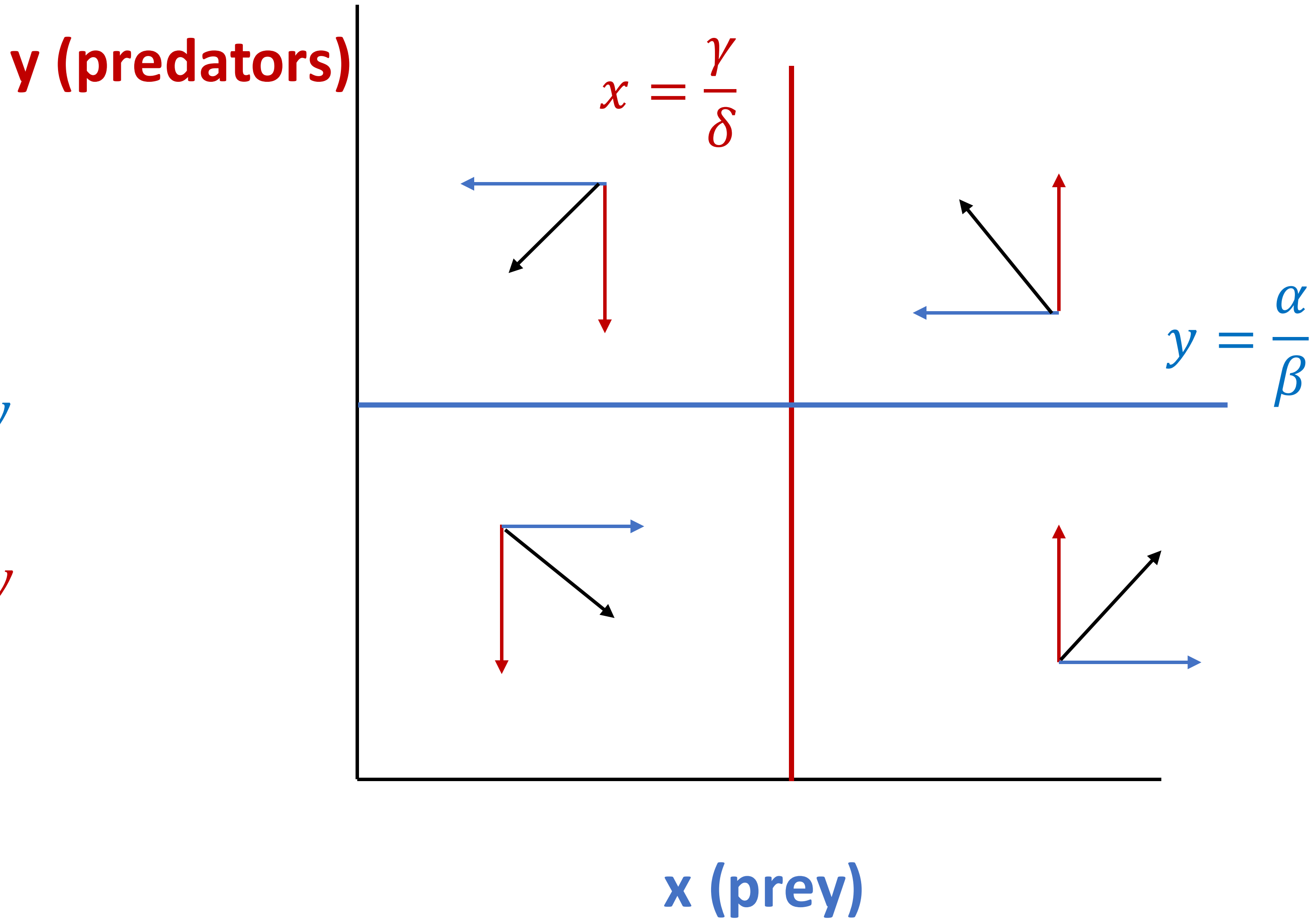

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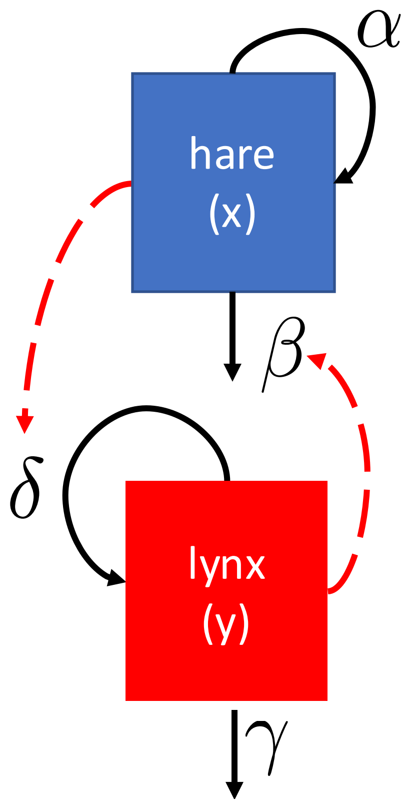

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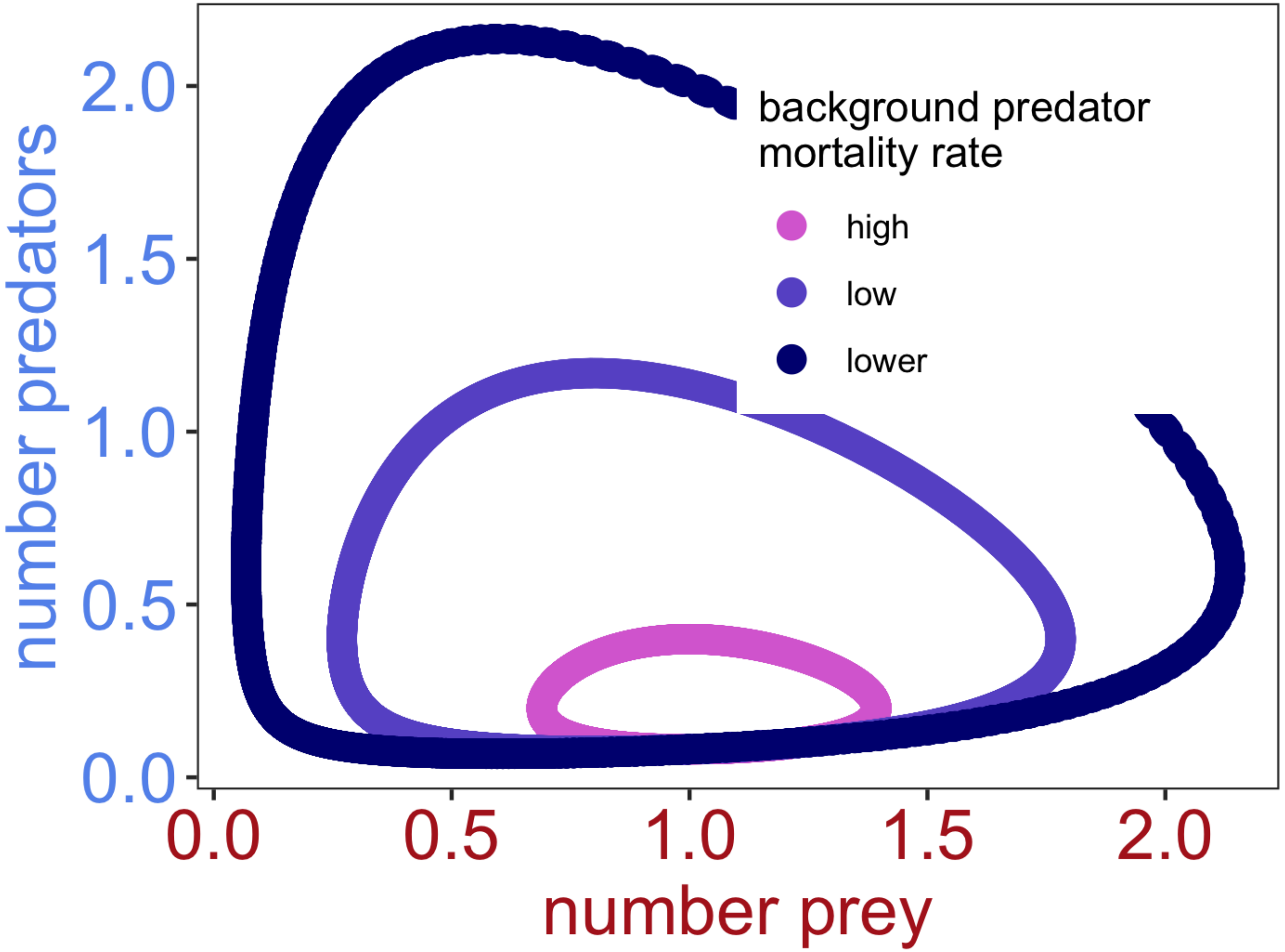
*How does **hare** abundance **vary** with **changes** in **lynx** abundance?*

Predator-prey cycles can be visualized as oscillations.



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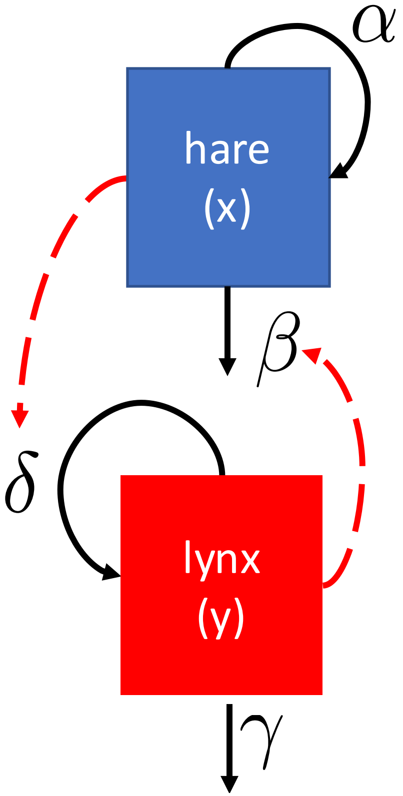

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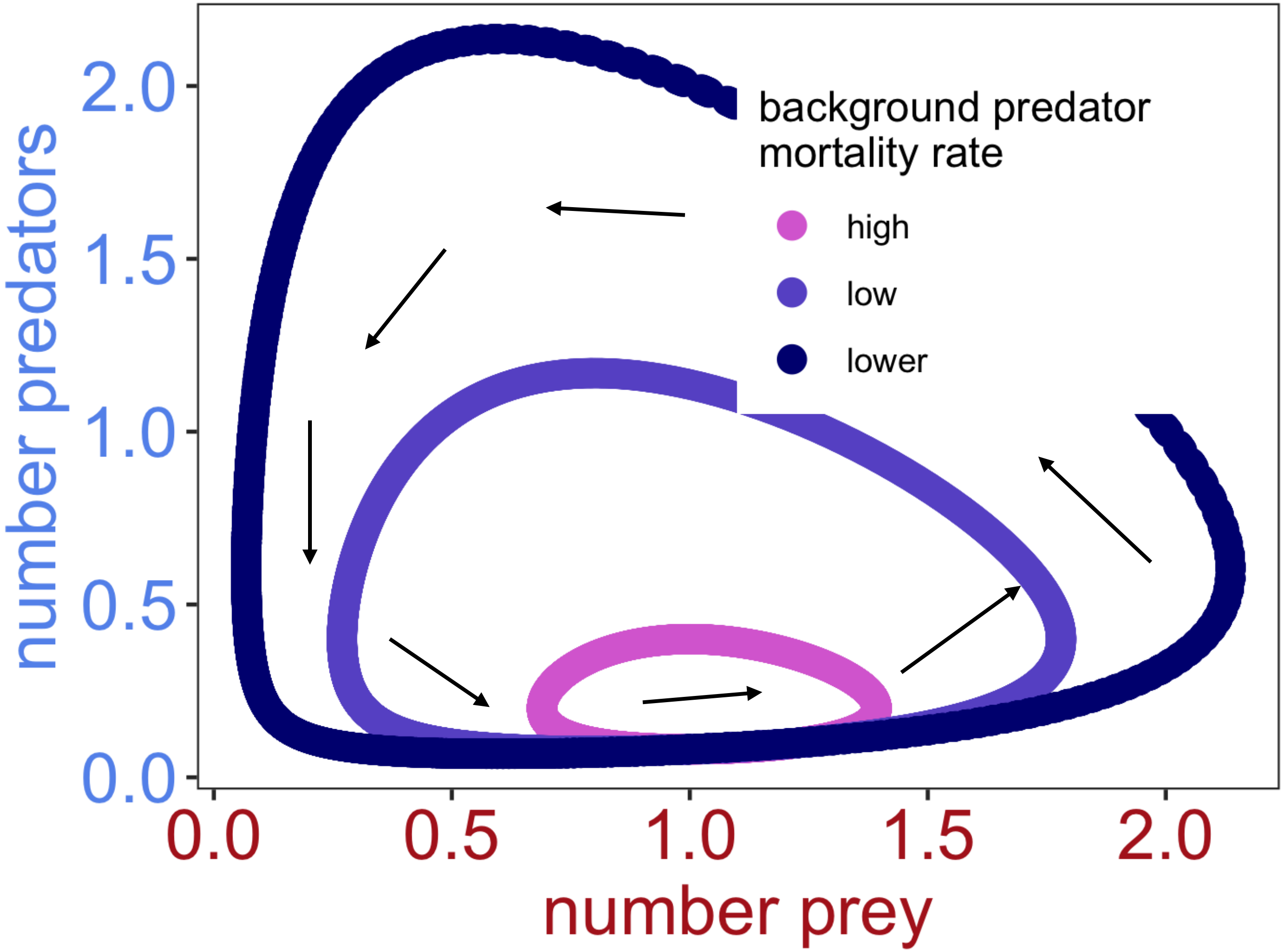
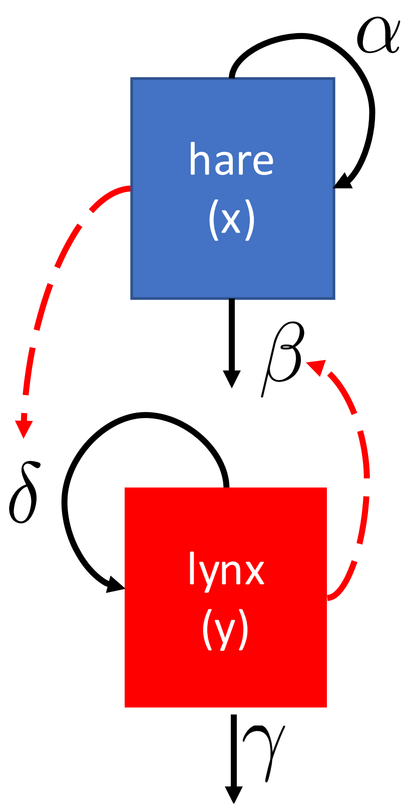


These oscillations are just another way of visualizing the time series!



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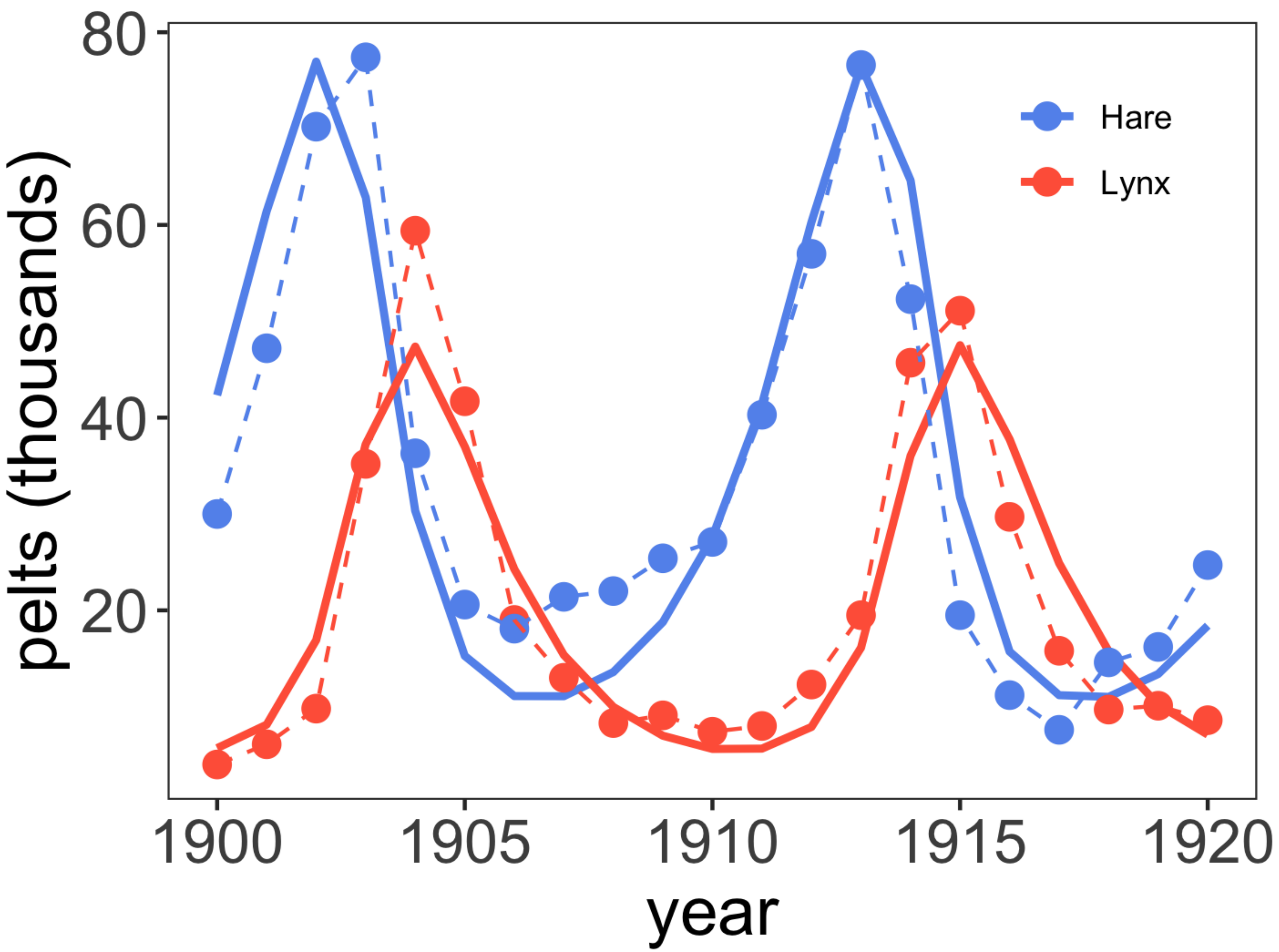
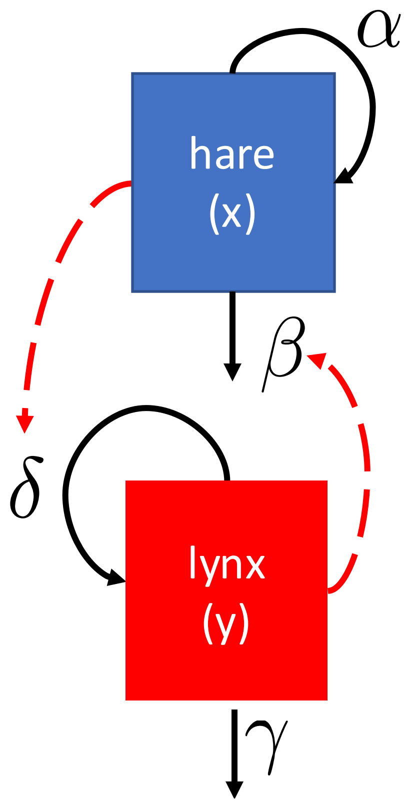


Lotka-Volterra predator-prey isoclines with data



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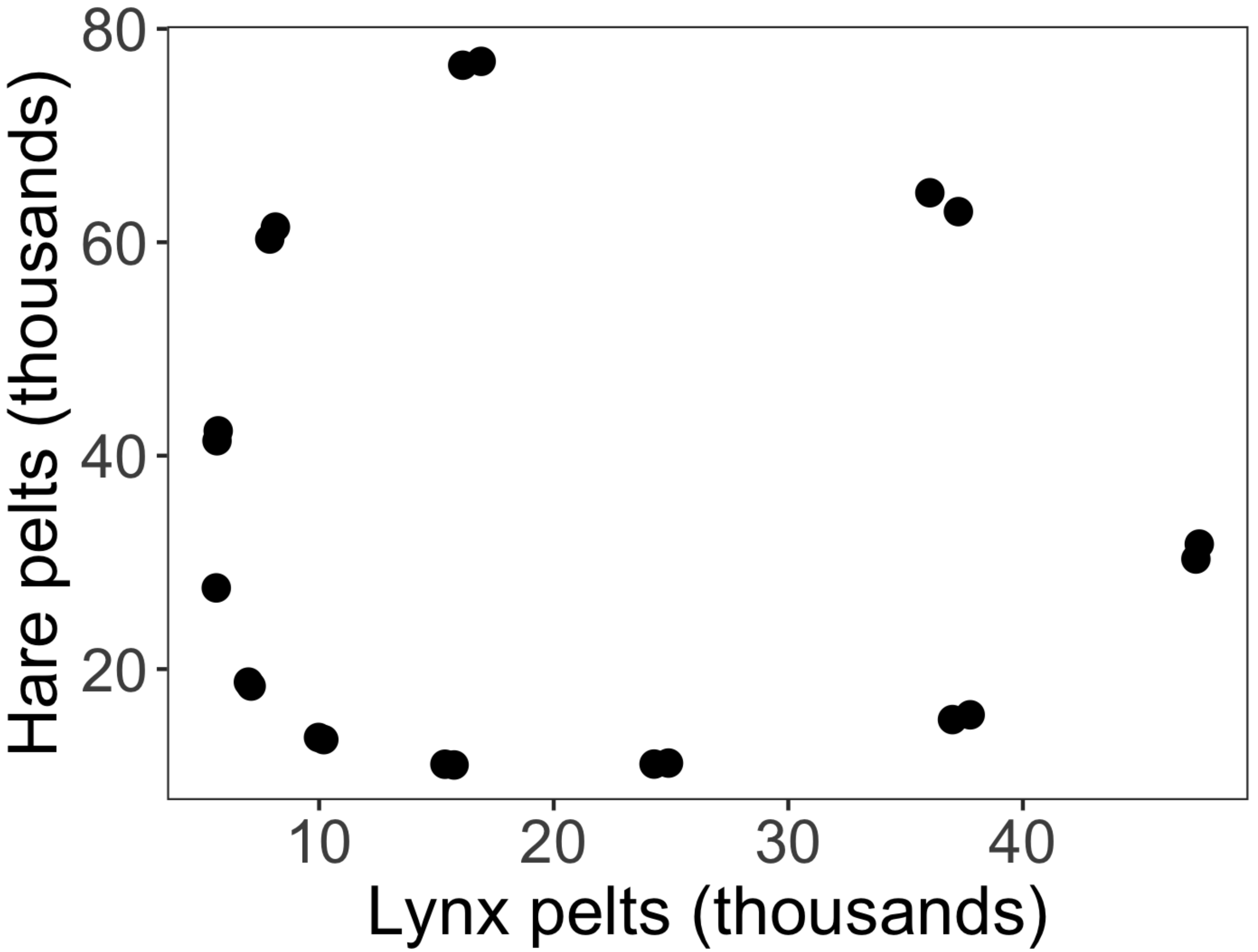

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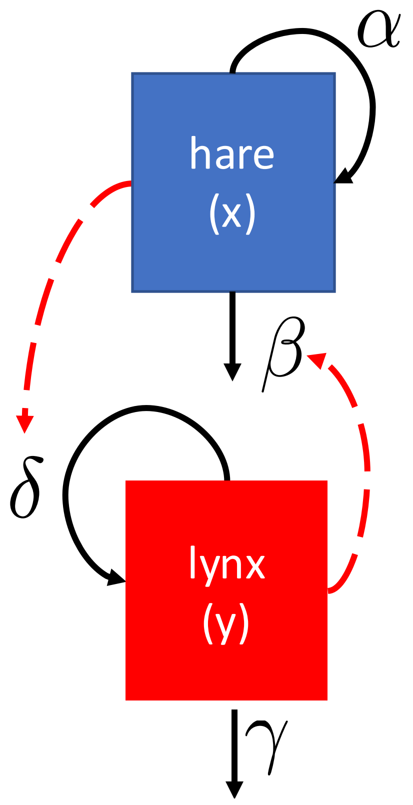

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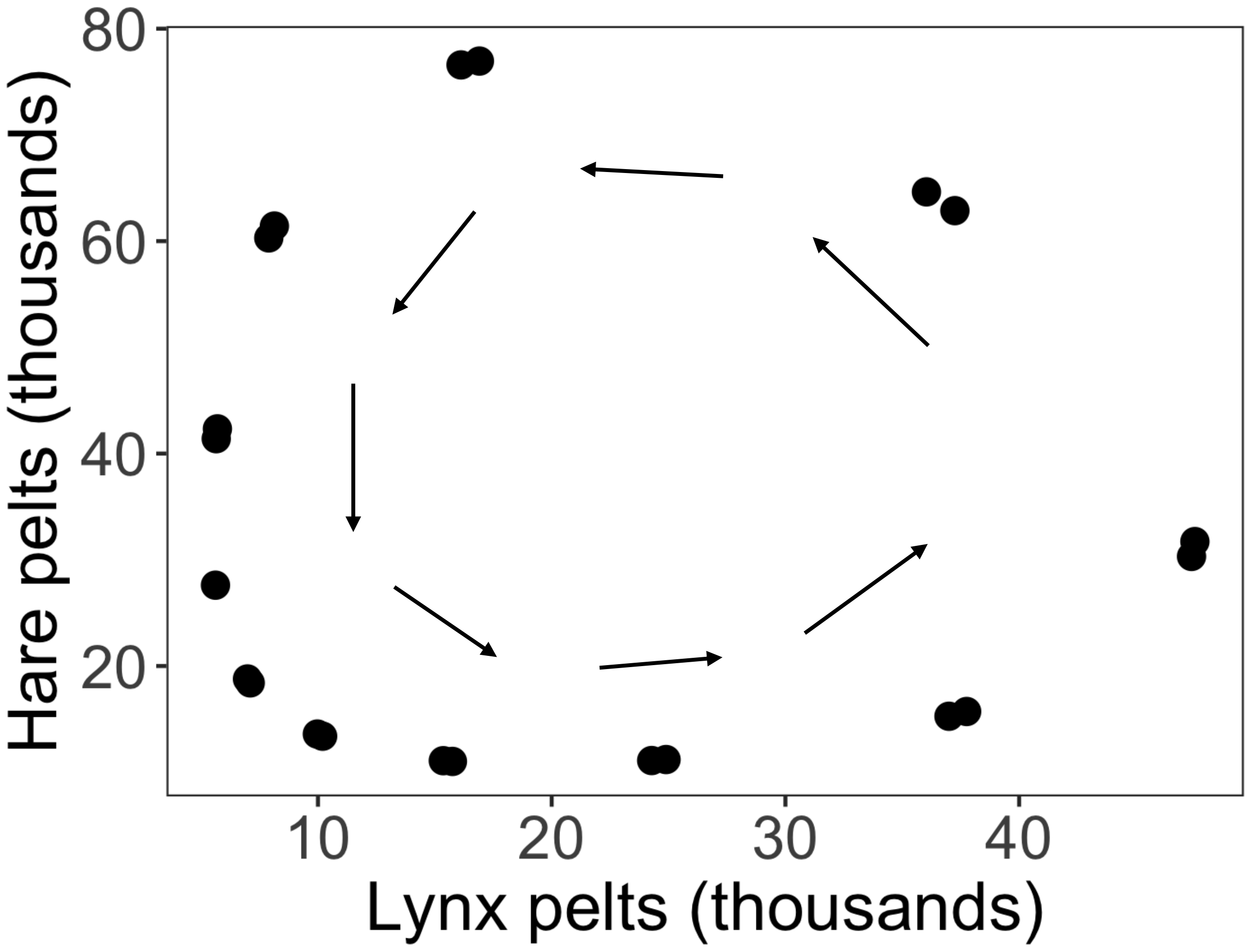
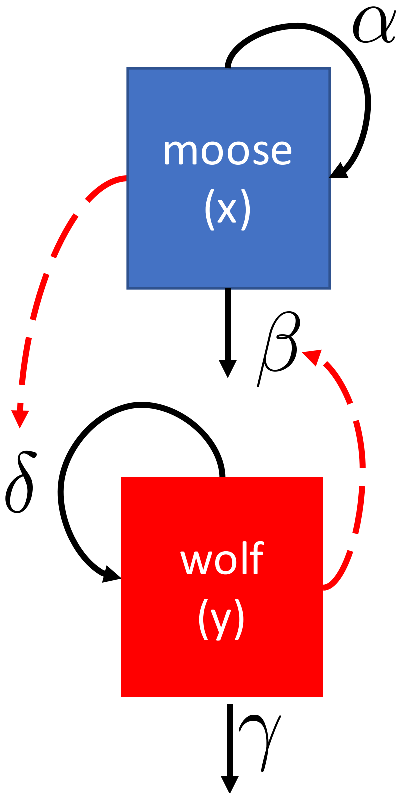


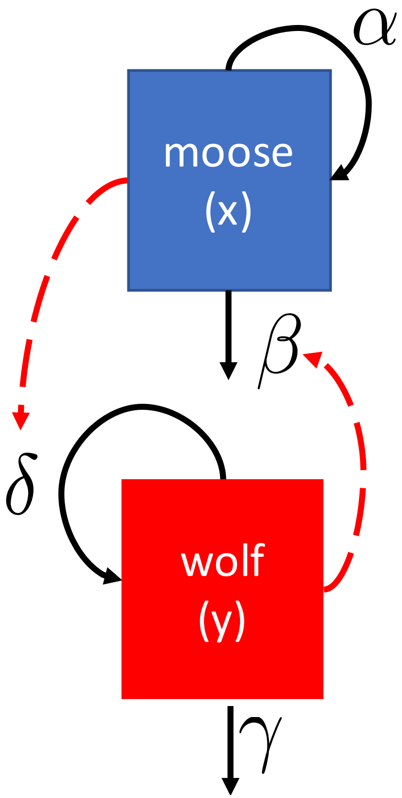
Another famous example: Wolf-Moose on Isle Royale



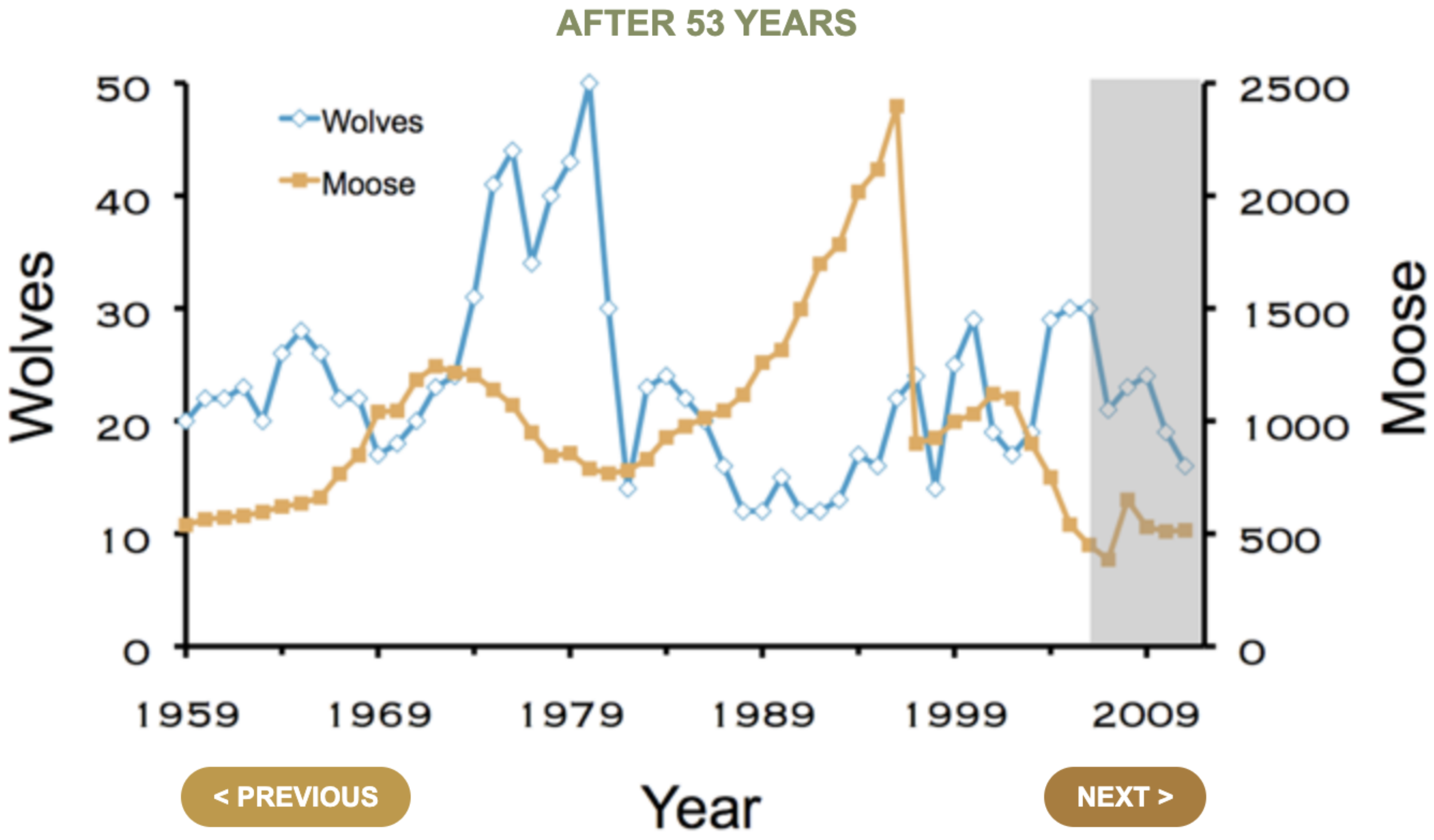
How does ***moose*** *abundance* ***vary*** *with* ***changes*** *in* ***wolf*** *abundance?*

isleroyalewolf.org

Another famous example: Wolf-Moose on Isle Royale



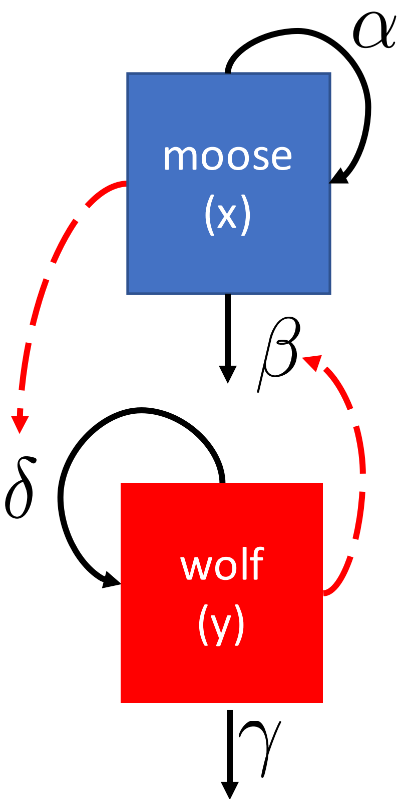
*How does **moose** abundance **vary** with **changes** in **wolf** abundance?*



The wolf population eventually stumbles as the moose continue to be kept low by high rates of predation, ticks, and hot summers.

isleroyalewolf.org

Another famous example: Wolf-Moose on Isle Royale



*How does **moose** abundance **vary** with **changes** in **wolf** abundance?*

Field Work Opportunity for College Students

This could be you!

FIELD WORK OPPORTUNITY FOR COLLEGE STUDENTS FOR MAY/JUNE 2023

We are seeking volunteers to assist with data collection for the 2023 summer field season. This is a great opportunity to gain valuable field experience while working in the remote and beautiful Isle Royale National Park.

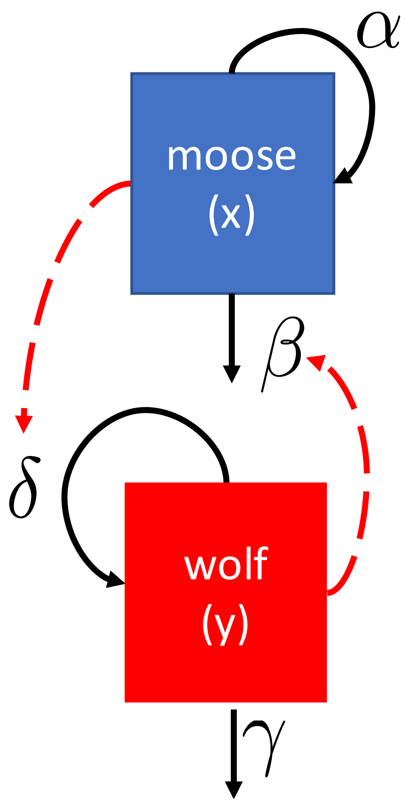
Duration: Approximately 4-5 weeks between early-May and mid-June.

Work Environment: Work is conducted on-trail and off-trail throughout Isle Royale. This is a physically demanding position; the climate, insects (mosquitoes and black flies), and terrain are often difficult. Volunteers may be required to carry up to 60 lbs. for varying distances (up to 10 miles per day) over trail and cross-country conditions. The primary mode of living is backpacking. Most travel is by foot.

Work Schedule: Typically spend 6-8 days in the field followed by 1-2 days at base camp. Work schedule varies depending upon conditions, project needs and logistics.

isleroyalewolf.org

Another famous example: Wolf-Moose on Isle Royale



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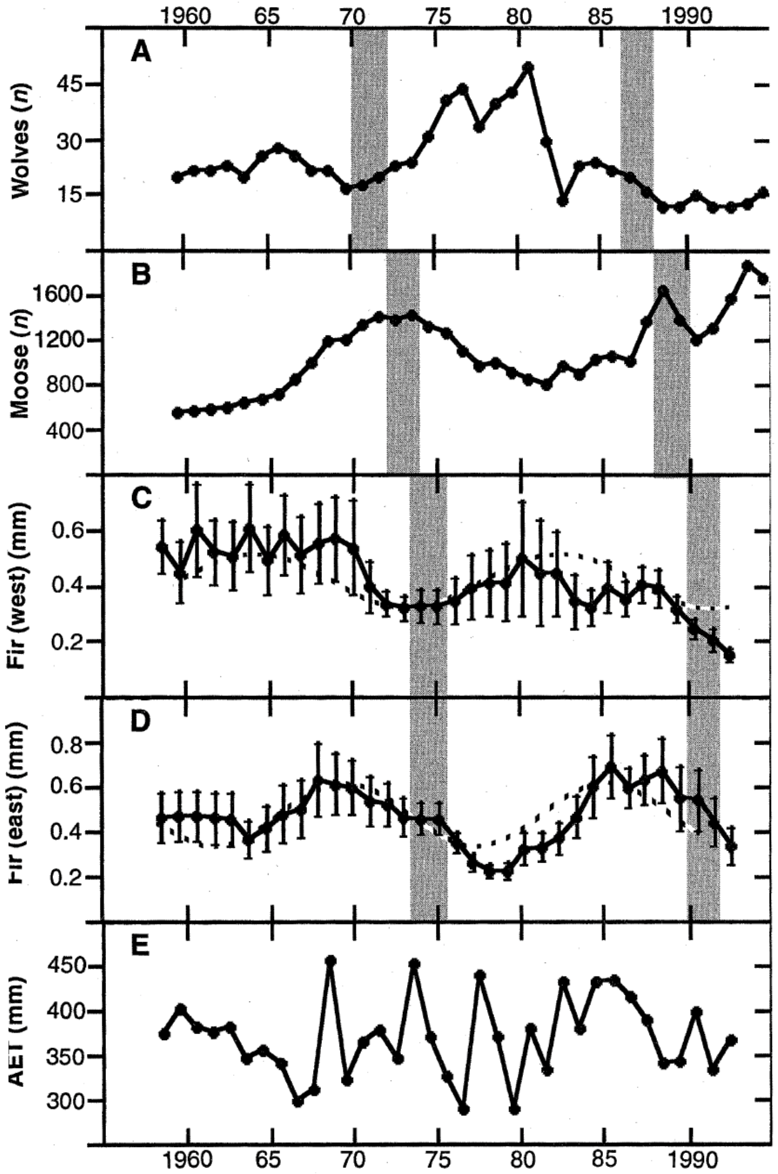


Wolf-moose dynamics on Isle Royale are **more complex than simple predator-prey**.

This 3-way interaction is an example of a **trophic cascade**.

By, definition, **trophic cascades span at least 3 trophic levels**, highlighting the process of **top-down** ecosystem control.

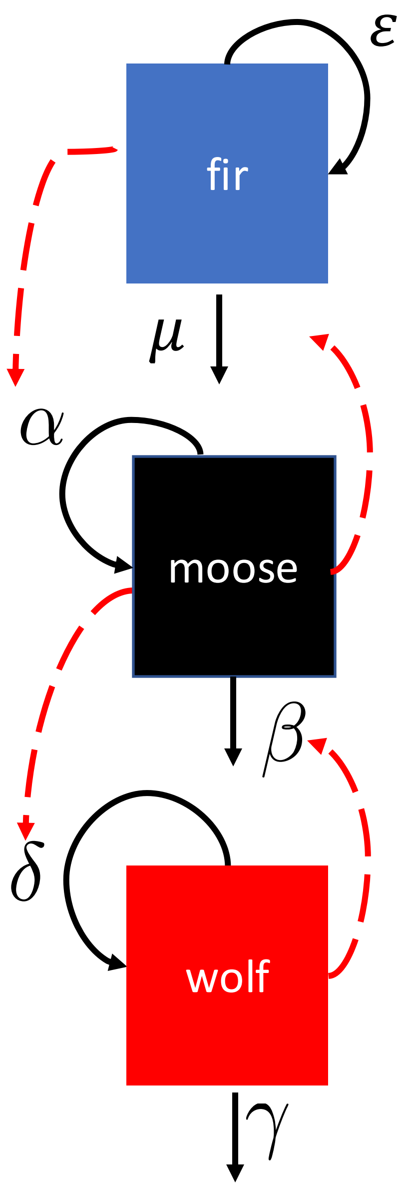
Wolves, Moose, and Tree Rings on Isle Royale

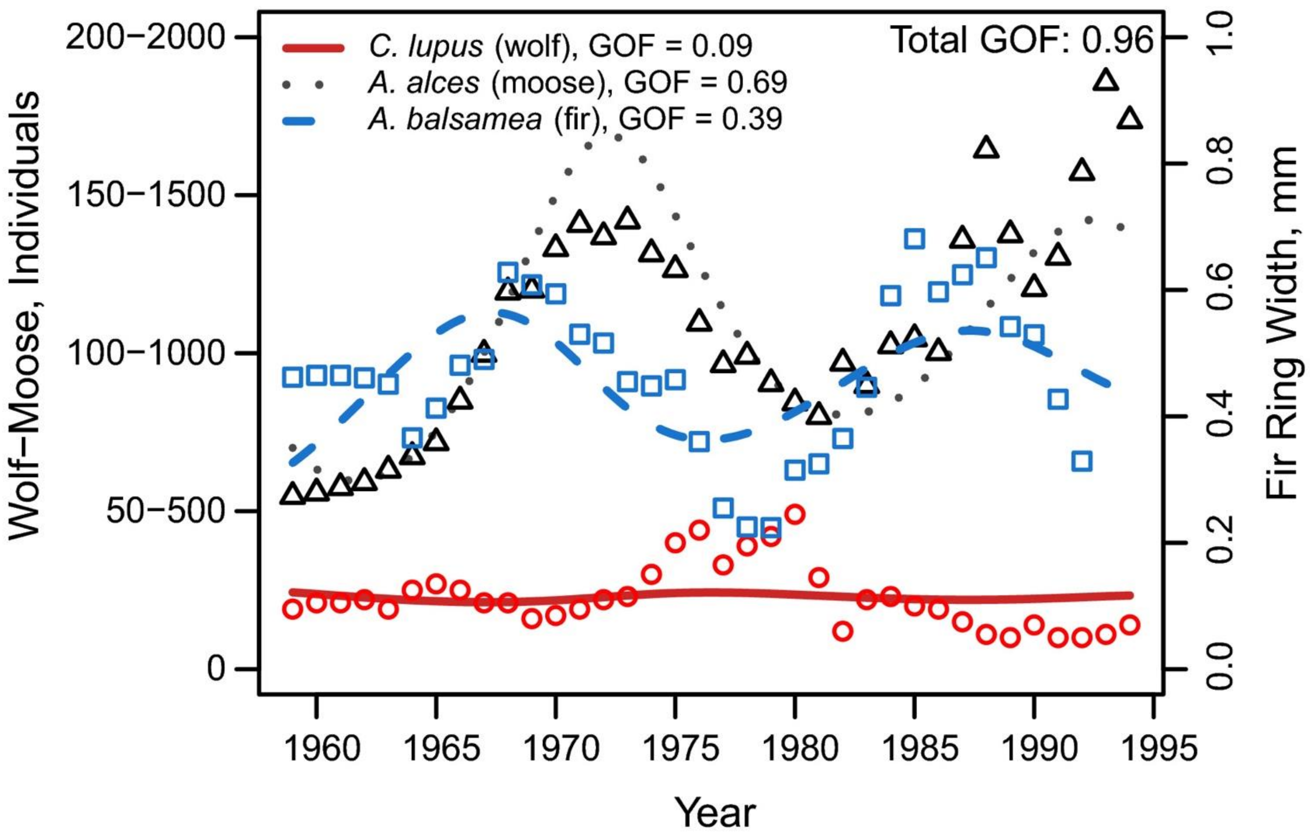
B. E. McLaren* and R. O. Peterson

Investigation of tree growth in Isle Royale National Park in Michigan revealed the influence of herbivores and carnivores on plants in an intimately linked food chain. Plant growth rates were regulated by cycles in animal density and responded to annual changes in primary productivity only when released from herbivory by wolf predation. Isle Royale's dendrochronology complements a rich literature on food chain control in aquatic systems, which often supports a trophic cascade model. This study provides evidence of top-down control in a forested ecosystem.

SCIENCE • VOL. 266 • 2 DECEMBER 1994

Another famous example: Wolf-Moose on Isle Royale





Models incorporating >2 trophic levels can be challenging, but ecologists do sometimes attempt them!

*How does **fir growth** vary with **moose** abundance, which varies with changes in **wolf** abundance?*

Mülhbauer et al. 2020. *Ecology & Evolution.*

HSS: The first theory of **top-down regulation** of trophic levels

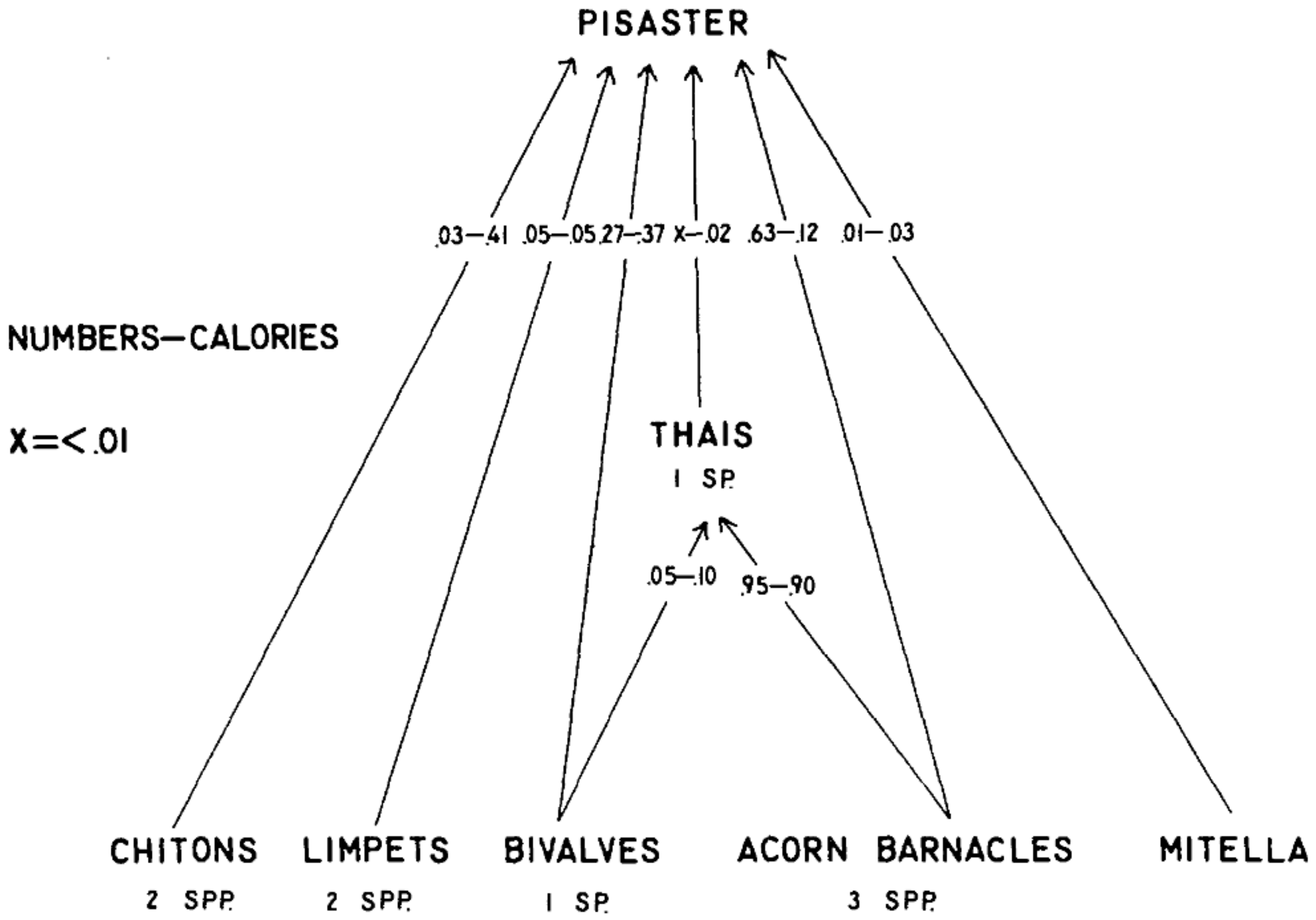
Vol. XCIV, No. 879 The American Naturalist November–December, 1960

COMMUNITY STRUCTURE, POPULATION CONTROL, AND COMPETITION

NELSON G. HAIRSTON, FREDERICK E. SMITH, AND LAWRENCE B. SLOBODKIN

1. Producers, decomposers, and carnivores are **bottom-up controlled** in a density-dependent fashion
2. **Interspecific competition** mediates these interactions
3. Herbivores are **top-down controlled** (and, as a result, ‘the world is green’)

This work inspired empirical studies on **trophic cascades**: *Pisaster* removal on Tatoosh Island



Paine 1966. *The American Naturalist.*