Are you ready for ecology?

yes please!	0%
I need to evolve some more	0%

Fundamentals of Ecology

Week 5, Ecology Lecture 1

Cara Brook

February 1, 2024

Where are we headed?

Week	Mon/Tues Lab	Tues Lecture	Thurs Lecture
1	--	--	Jan 4: Evolution History
2	1: Intro R	Jan 9: Mutation and Variation	Jan 11: Hardy-Weinberg
3	2: Hardy-Weinberg	Jan 16: Migration and Drift	Jan 18: Natural Selection
4	3: Microevolution	Jan 23: Phylogenetics	Jan 25: Molecular Evolution & Sexual Selection
5	4: Phylogenetics	Jan 30: Kin Selection, Speciation	Feb 1: Ecology & Population Growth
6	5: Evolution paper	Feb 6: Single Species Population Growth & Regulation	Feb 8: Midterm
7	6: Population Growth	Feb 13: Species Interactions 1	Feb 15: Species Interactions 2
8	7: Population Regulation	Feb 20: Disease Dynamics as Population Biology 1	Feb 22: Disease Dynamics as Population Biology 2
9	8: Disease Dynamics	Feb 27: Community Assembly & Island Biogeography	Feb 29: Critical Transitions & Conservation Interventions

Where are we headed?

Week	Mon/Tues Lab	Tues Lecture	Thurs Lecture
1	--	--	Jan 4: Evolution History
2	1: Intro R	Jan 9: Mutation and Variation	Jan 11: Hardy-Weinberg
3	2: Hardy-Weinberg	Jan 16: Migration and Drift	Jan 18: Natural Selection
4	3: Microevolution	Jan 23: Phylogenetics	Jan 25: Molecular Evolution & Sexual Selection
5	4: Phylogenetics	Jan 30: Kin Selection, Speciation	Feb 1: Ecology & Population Growth
6	5: Evolution paper	Feb 6: Single Species Population Growth & Regulation	Feb 8: Midterm
7	6: Population Growth	Feb 13: Species Interactions 1	Feb 15: Species Interactions 2
8	7: Population Regulation	Feb 20: Disease Dynamics as Population Biology 1	Feb 22: Disease Dynamics as Population Biology 2
9	8: Disease Dynamics	Feb 27: Community Assembly & Island Biogeography	Feb 29: Critical Transitions & Conservation Interventions

Where are we headed?

Week	Mon/Tues Lab	Tues Lecture	Thurs Lecture
1	--	--	Jan 4: Evolution History
2	1: Intro R	Jan 9: Mutation and Variation	Jan 11: Hardy-Weinberg
3	2: Hardy-Weinberg	Jan 16: Migration and Drift	Jan 18: Natural Selection
4	3: Microevolution	Jan 23: Phylogenetics	Jan 25: Molecular Evolution & Sexual Selection
5	4: Phylogenetics	Jan 30: Kin Selection, Speciation	Feb 1: Ecology & Population Growth
6	5: Evolution paper	Feb 6: Single Species Population Growth & Regulation	Feb 8: Midterm
7	6: Population Growth	Feb 13: Species Interactions 1	Feb 15: Species Interactions 2
8	7: Population Regulation	Feb 20: Disease Dynamics as Population Biology 1	Feb 22: Disease Dynamics as Population Biology 2
9	8: Disease Dynamics	Feb 27: Community Assembly & Island Biogeography	Feb 29: Critical Transitions & Conservation Interventions

Where are we headed?

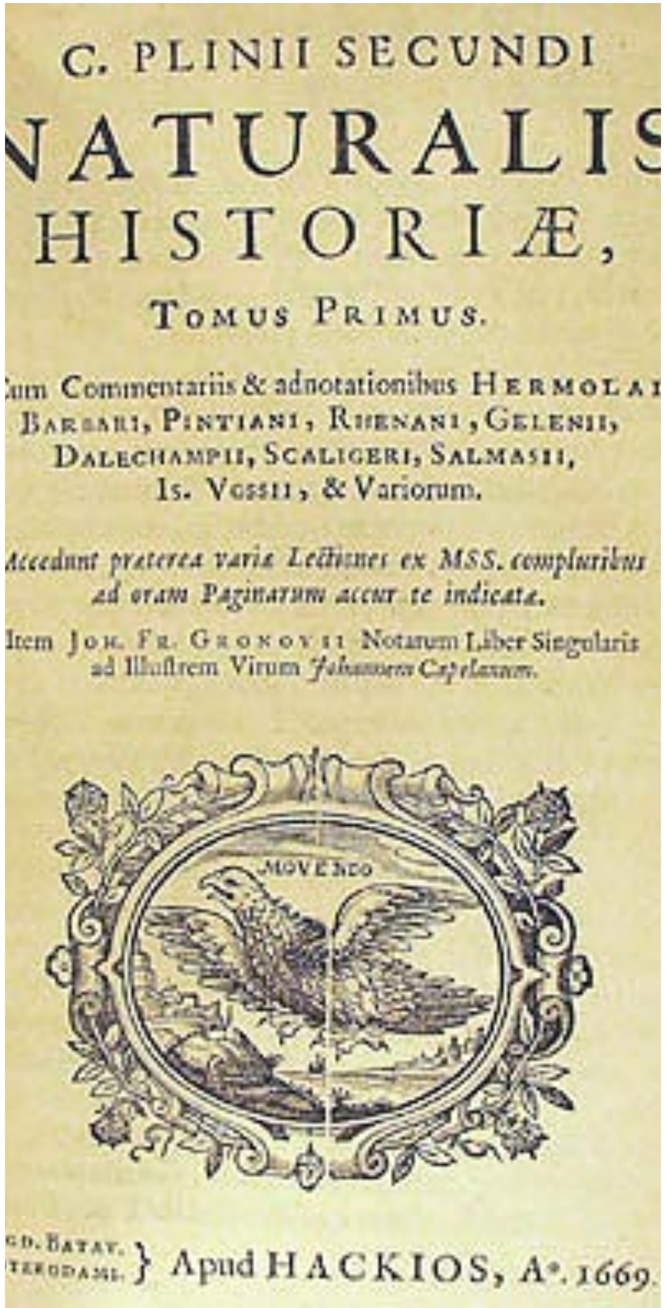
Week	Mon/Tues Lab	Tues Lecture	Thurs Lecture
1	--	--	Jan 4: Evolution History
2	1: Intro R	Jan 9: Mutation and Variation	Jan 11: Hardy-Weinberg
3	2: Hardy-Weinberg	Jan 16: Migration and Drift	Jan 18: Natural Selection
4	3: Microevolution	Jan 23: Phylogenetics	Jan 25: Molecular Evolution & Sexual Selection
5	4: Phylogenetics	Jan 30: Kin Selection, Speciation	Feb 1: Ecology & Population Growth
6	5: Evolution paper	Feb 6: Single Species Population Growth & Regulation	Feb 8: Midterm
7	6: Population Growth	Feb 13: Species Interactions 1	Feb 15: Species Interactions 2
8	7: Population Regulation	Feb 20: Disease Dynamics as Population Biology 1	Feb 22: Disease Dynamics as Population Biology 2
9	8: Disease Dynamics	Feb 27: Community Assembly & Island Biogeography	Feb 29: Critical Transitions & Conservation Interventions

Where are we headed?

Week	Mon/Tues Lab	Tues Lecture	Thurs Lecture
1	--	--	Jan 4: Evolution History
2	1: Intro R	Jan 9: Mutation and Variation	Jan 11: Hardy-Weinberg
3	2: Hardy-Weinberg	Jan 16: Migration and Drift	Jan 18: Natural Selection
4	3: Microevolution	Jan 23: Phylogenetics	Jan 25: Molecular Evolution & Sexual Selection
5	4: Phylogenetics	Jan 30: Kin Selection, Speciation	Feb 1: Ecology & Population Growth
6	5: Evolution paper	Feb 6: Single Species Population Growth & Regulation	Feb 8: Midterm
7	6: Population Growth	Feb 13: Species Interactions 1	Feb 15: Species Interactions 2
8	7: Population Regulation	Feb 20: Disease Dynamics as Population Biology 1	Feb 22: Disease Dynamics as Population Biology 2
9	8: Disease Dynamics	Feb 27: Community Assembly & Island Biogeography	Feb 29: Critical Transitions & Conservation Interventions

Where are we headed?

Week	Mon/Tues Lab	Tues Lecture	Thurs Lecture
1	--	--	Jan 4: Evolution History
2	1: Intro R	Jan 9: Mutation and Variation	Jan 11: Hardy-Weinberg
3	2: Hardy-Weinberg	Jan 16: Migration and Drift	Jan 18: Natural Selection
4	3: Microevolution	Jan 23: Phylogenetics	Jan 25: Molecular Evolution & Sexual Selection
5	4: Phylogenetics	Jan 30: Kin Selection, Speciation	Feb 1: Ecology & Population Growth
6	5: Evolution paper	Feb 6: Single Species Population Growth & Regulation	Feb 8: Midterm
7	6: Population Growth	Feb 13: Species Interactions 1	Feb 15: Species Interactions 2
8	7: Population Regulation	Feb 20: Disease Dynamics as Population Biology 1	Feb 22: Disease Dynamics as Population Biology 2
9	8: Disease Dynamics	Feb 27: Community Assembly & Island Biogeography	Feb 29: Critical Transitions & Conservation Interventions


C. PLINII SECUNDI

NATURALIS

HISTORIÆ,

TOMUS PRIMUS.

Cum Commentariis & adnotationibus HERMOLAI BARBARI, PINTIANI, RHENANI, GELENII, DALECHAMPII, SCALIGERI, SALMASII, IS. VOSSII, & Variorum.

Accedunt praeterea variae Lectiones ex MSS. compluribus ad oram Paginarum accurate indicatae.

Item JOH. FR. GRONOVII Notarum Liber Singularis ad Illustrem Virum *Johannem Capellanum.*

MOVENDO

GD. BATAV. TERODAMI. } Apud HACKIOS, Aº. 1669.

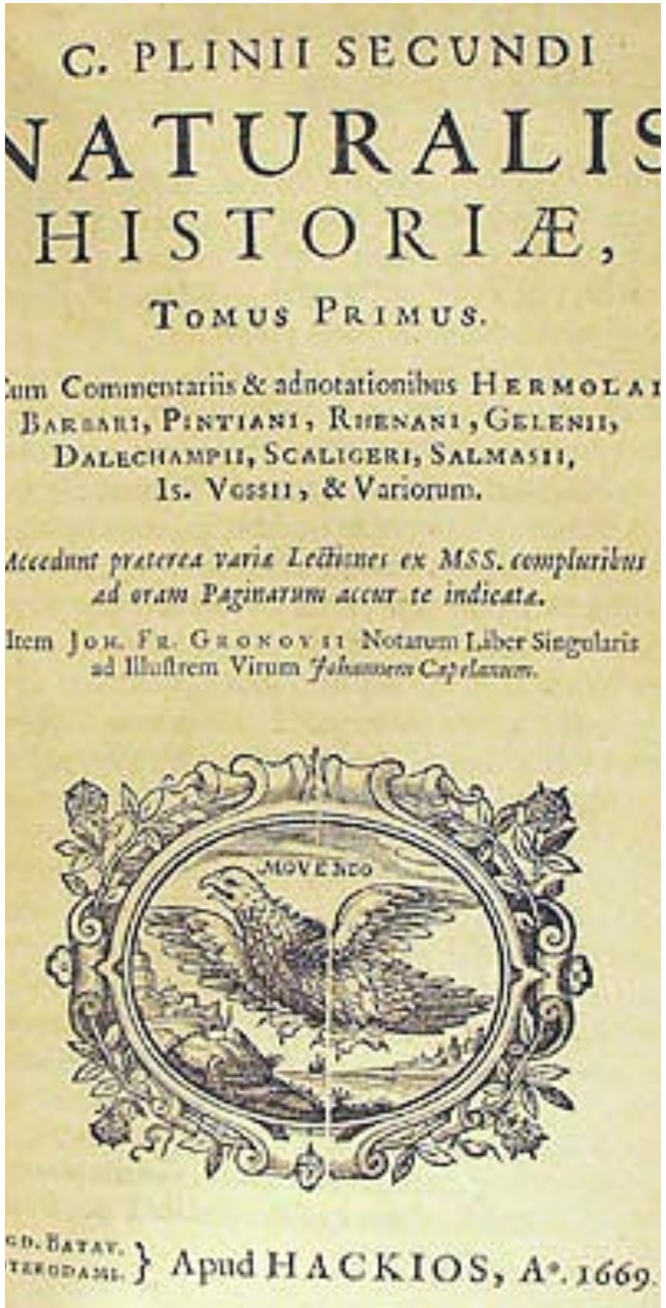
Natural history is the observational study of the living things on planet Earth.

Is natural history science?

Is natural history science?

Science: the **systematic observation** of natural events and conditions in order to discover facts about them and to **formulate laws and principles** based on these facts.

– *Academic Press Dictionary of Science & Technology*


C. PLINII SECUNDI

NATURALIS

HISTORIÆ,

TOMUS PRIMUS.

Cum Commentariis & adnotationibus HERMOLAI BARBARI, PINTIANI, RHENANI, GELENII, DALECHAMPII, SCALIGERI, SALMASII, Is. VOSSII, & Variorum.

Accedunt præterea variæ Lectiones ex MSS. compluribus ad oram Paginarum accur te indicatæ.

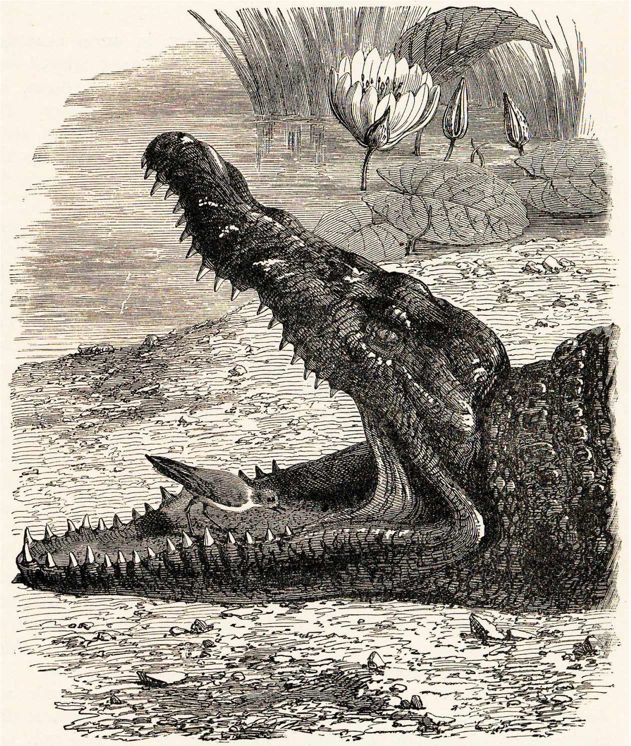
Item JOH. FR. GRONOVII Notarum Liber Singularis ad Illustrem Virum *Johannem Capelanum.*

MOVENDO

D. BATAV. TERODAMI. } Apud HACKIOS, A°. 1669.

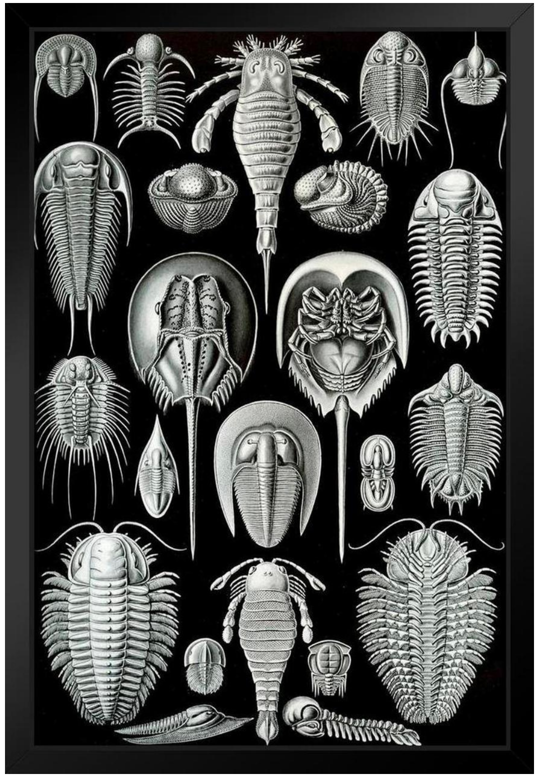
Natural history gave way to the **natural sciences** when those observations became **systematic** and were used to support **general laws and principles** describing the natural world.

Ecology is the study of the **interactions** of **organisms** with each other and their **environment.**



THE CROCODILE'S FRIEND.

Ecology is the study of the **interactions** of **organisms** with each other and their **environment.**



oikos = 'house’

+ *logia* = ‘study of'

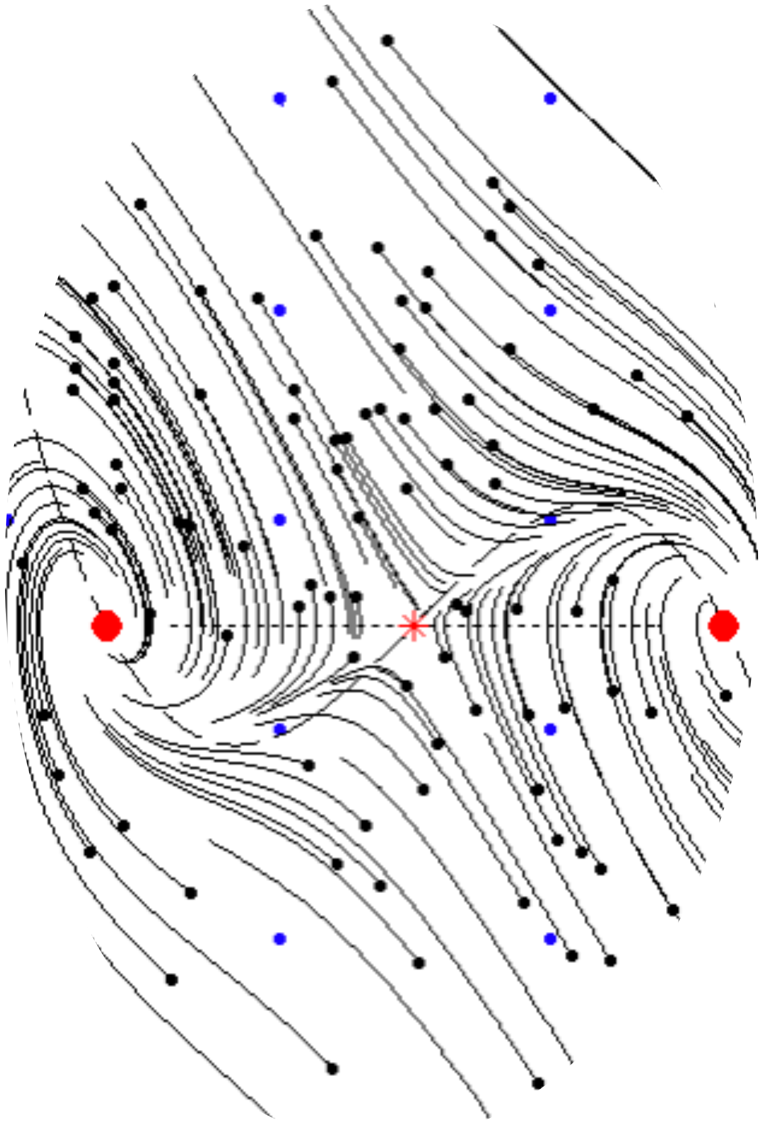
ecology

- 1866 Ernst Haeckel

“**Ecology** has a synonym which is **ALL**.”

-John Steinbeck

The Log from the Sea of Cortez (1941)



Ecology is the study of the **interactions** of **organisms** with each other and their **environment.**

As a science, ecology uses **models** to formalize general **laws and principles** describing the natural world.

What is a model?

What is a model?

an abstract representation of a phenomenon

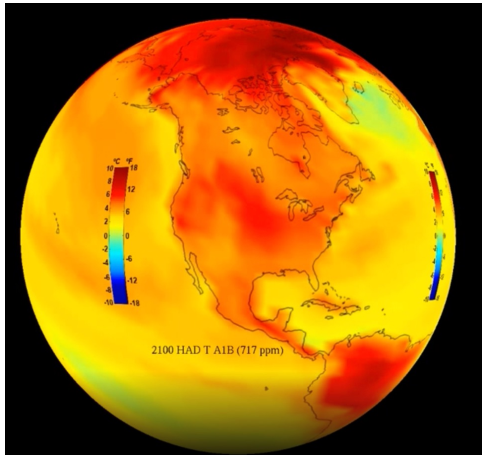
What is a model?

an abstract representation of a phenomenon

Human

Solar System

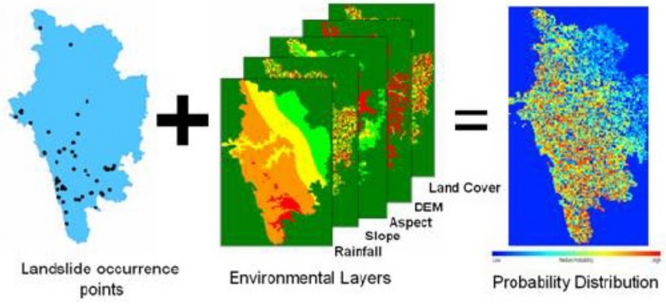
Climate



Human Genetics

Human Disease

Species Distribution



Why build models?

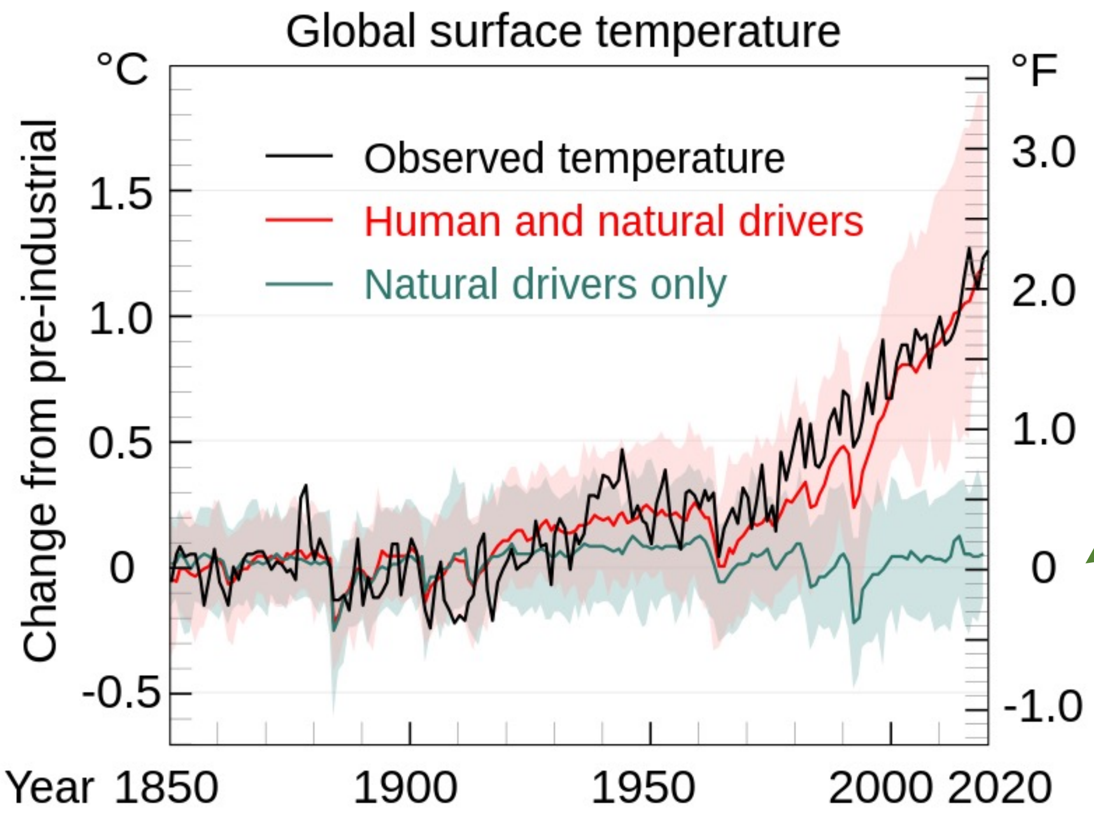
Why build models?

to <u>explain</u> and <u>predict</u>

(IPCC 2007)

Why build models?

to explain and predict



explain

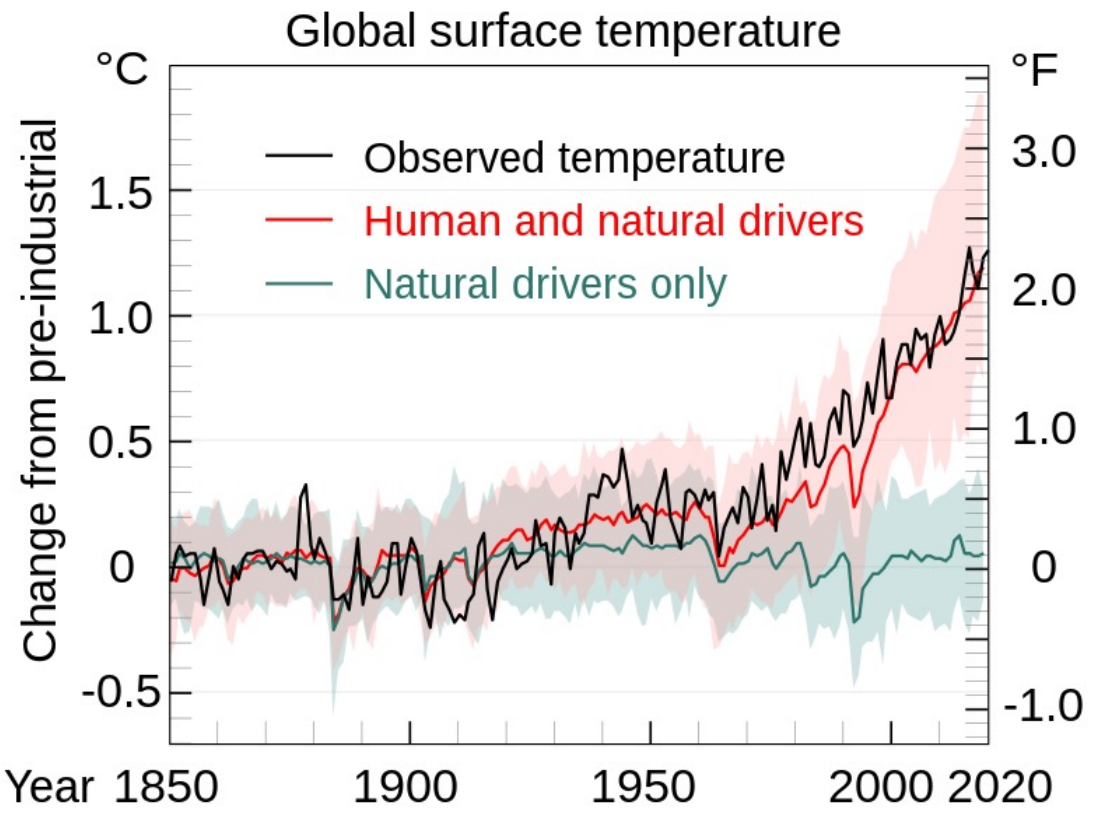
Models produce 'simulated data' that is compared against the observed data.

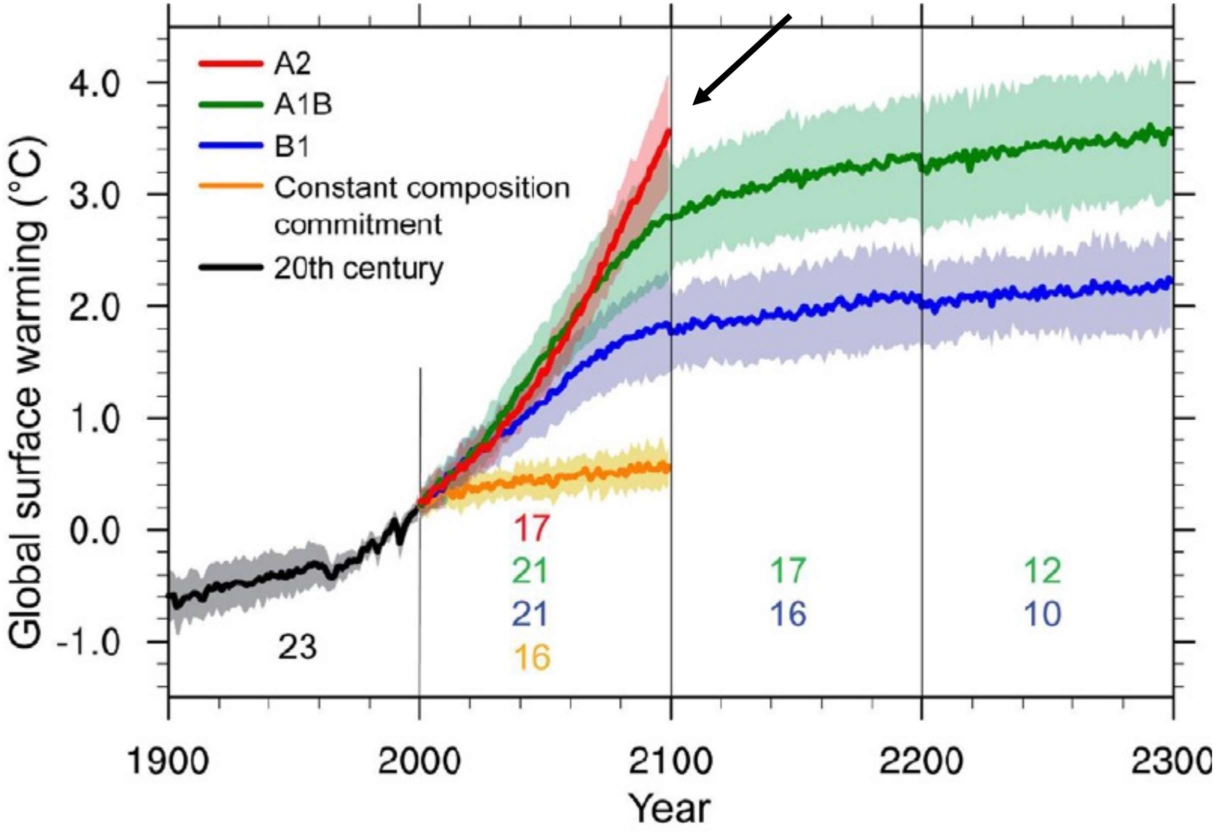
The process of adjusting the model to more closely match the data is called 'model fitting.'

Why build models?

to explain and predict

Fitted models can then be used to "predict" the future, under different conditions.





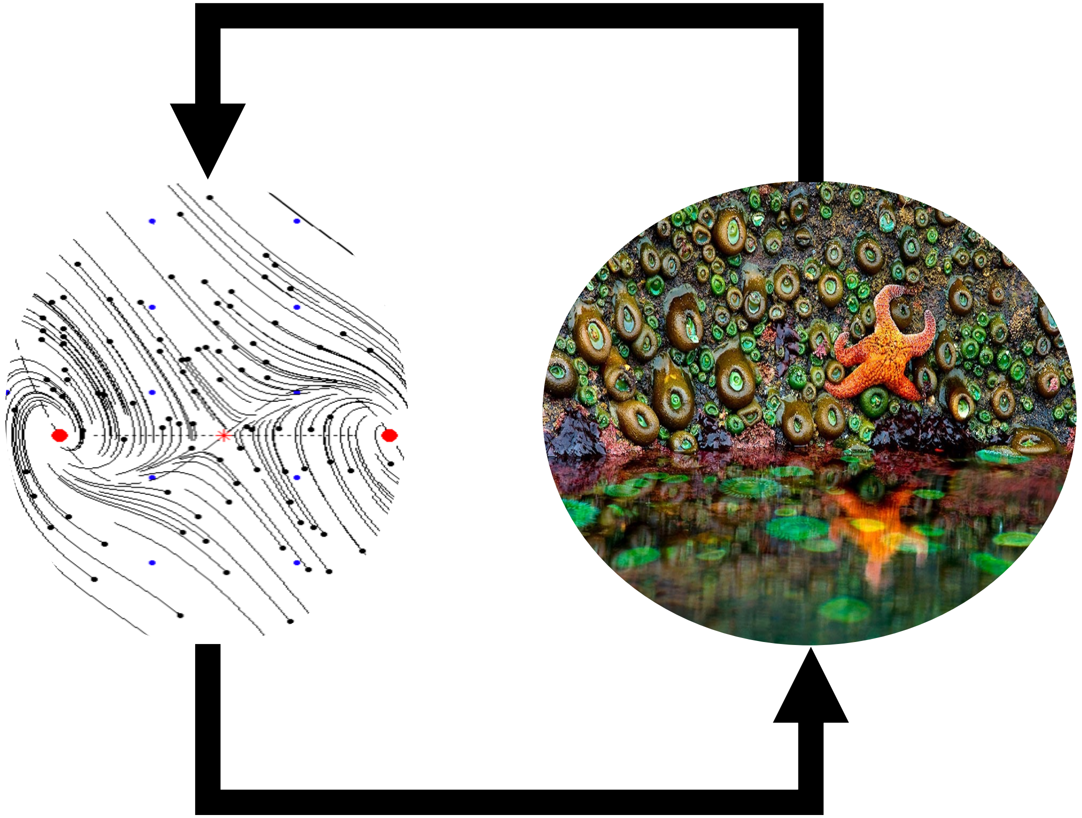
explain

predict

(IPCC 2007)

Two kinds of ecological models

Statistical Model
Pattern

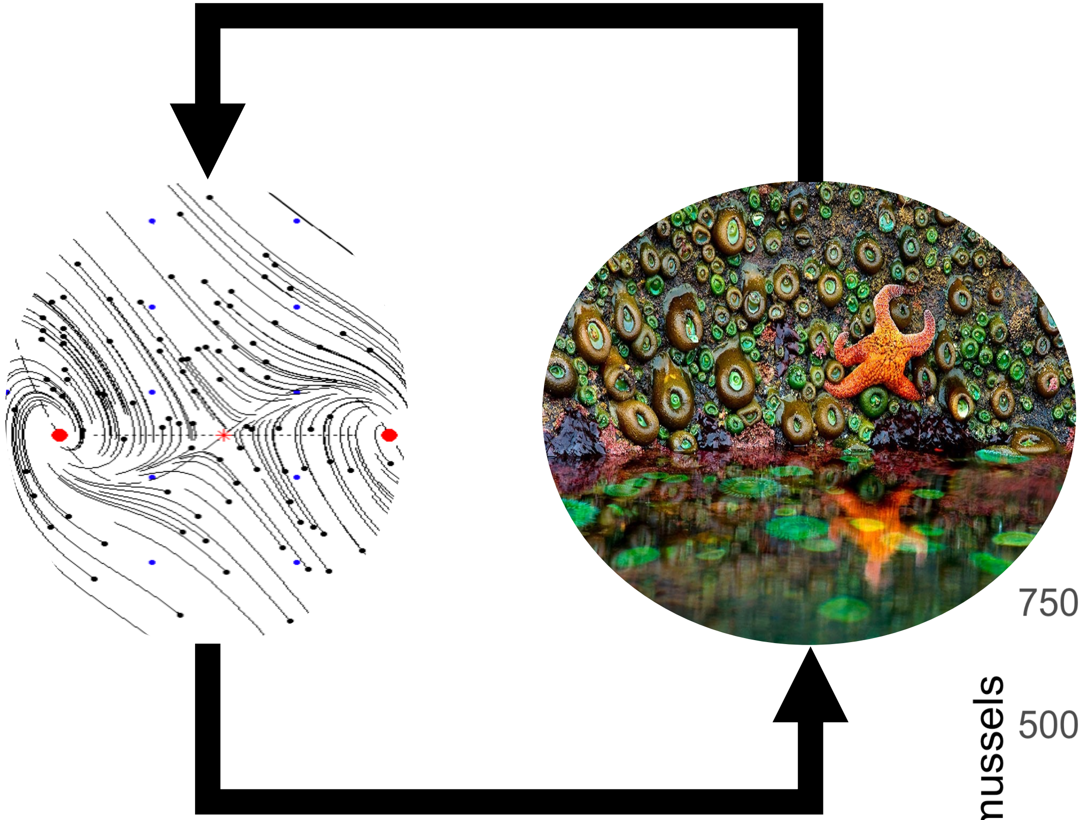


Population Model
Process

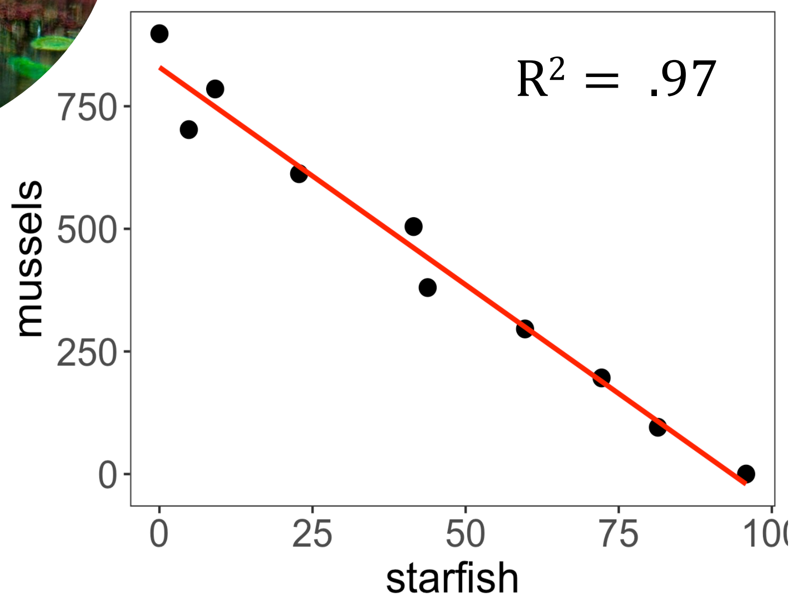
Two kinds of ecological models

Statistical Model

Pattern



$y = mx + b$



Population Model

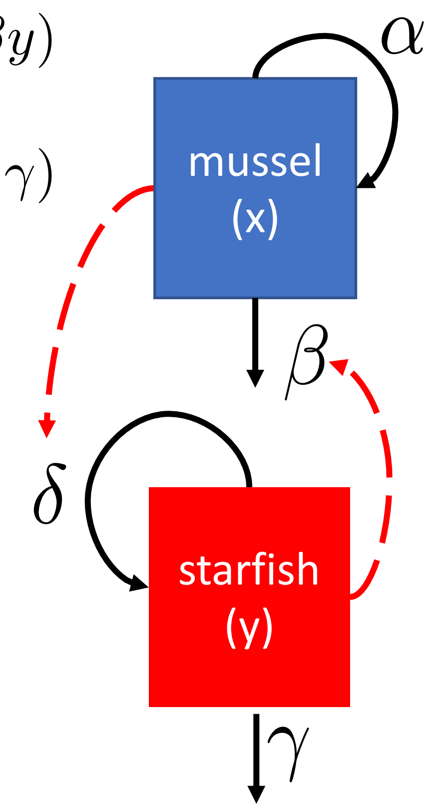
Process

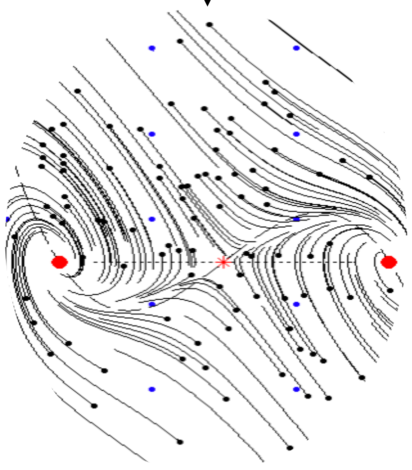
Two kinds of ecological models

Statistical Model

Pattern

$$\frac{dx}{dt} = x(\alpha - \beta y)$$
$$\frac{dy}{dt} = y(\delta x - \gamma)$$





Population Model

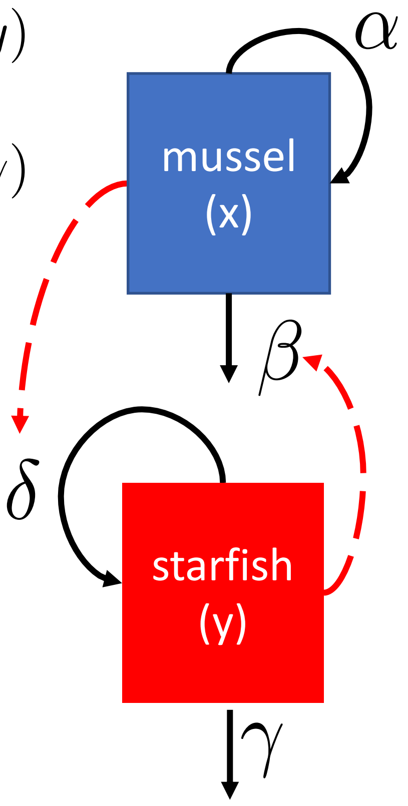
Process

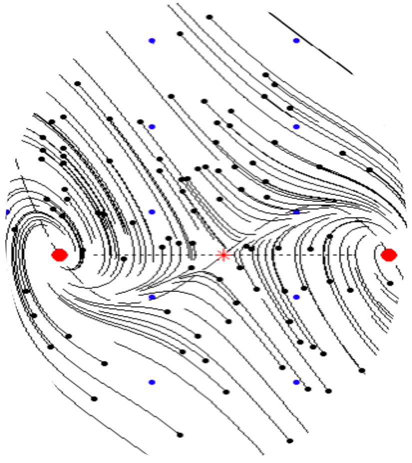
Two kinds of ecological models

Statistical Model

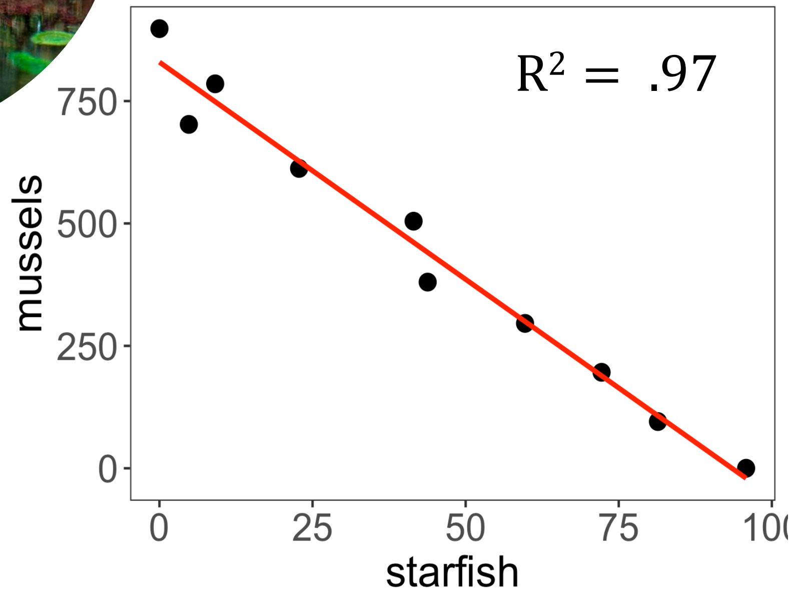
Pattern

$$\frac{dx}{dt} = x(\alpha - \beta y)$$
$$\frac{dy}{dt} = y(\delta x - \gamma)$$





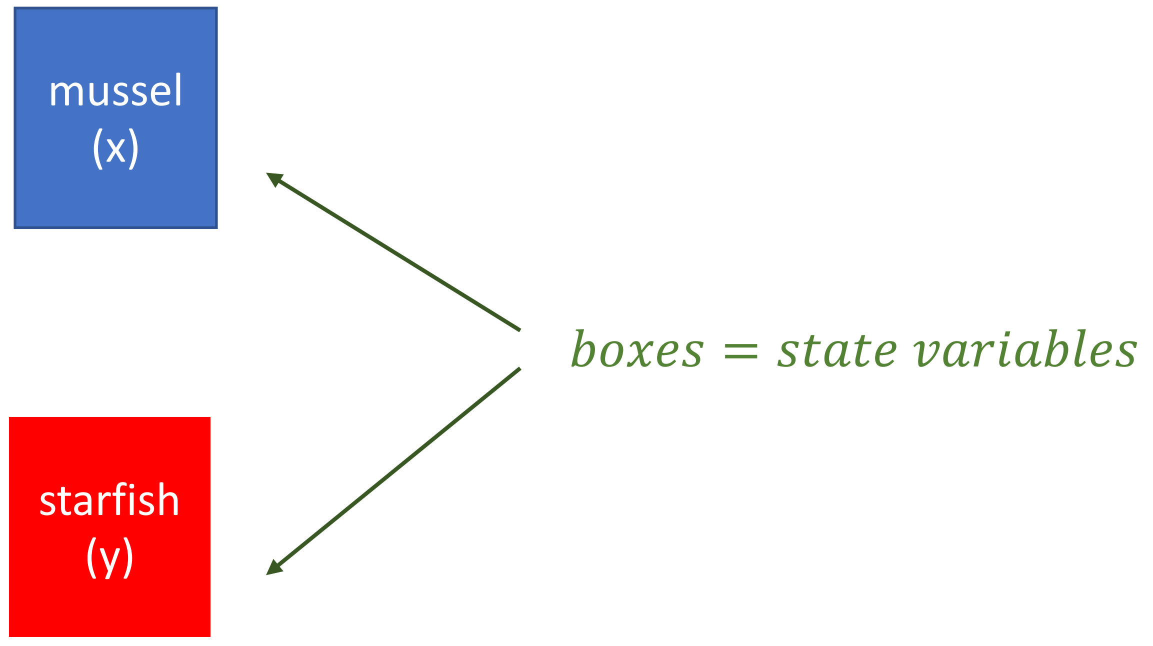
$$y = mx + b$$



Population Model

Process

How to construct a population model



How to construct a population model

$$\frac{dx}{dt}$$

state variables

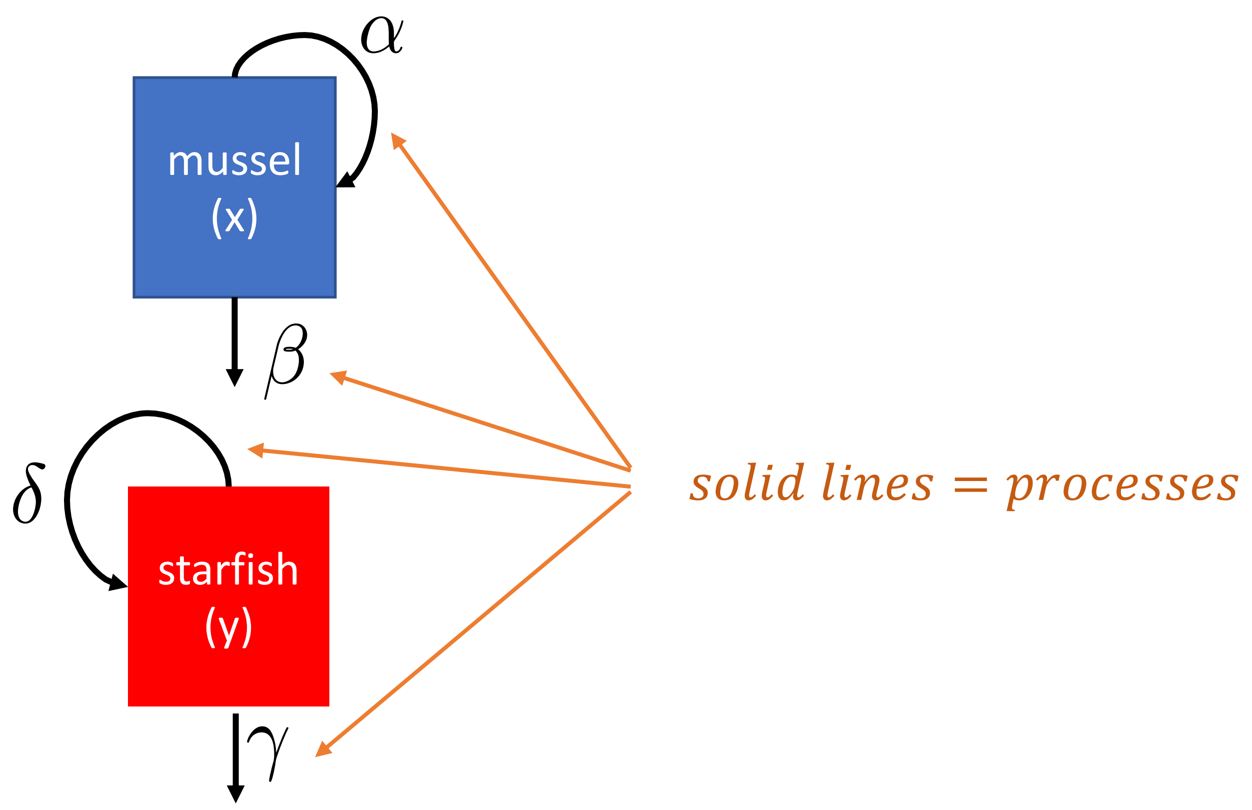
$$\frac{dy}{dt}$$

mussel
(x)

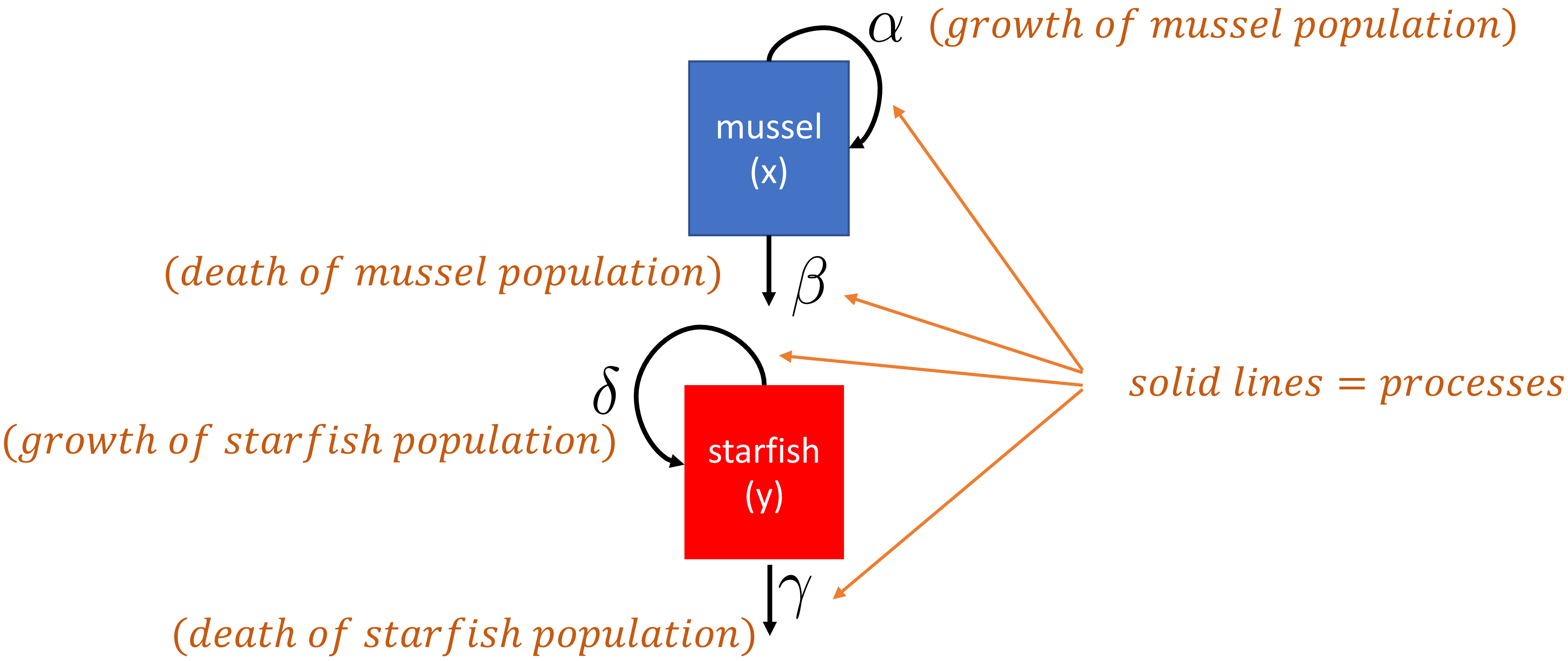
starfish
(y)

boxes = state variables

How to construct a population model



How to construct a population model

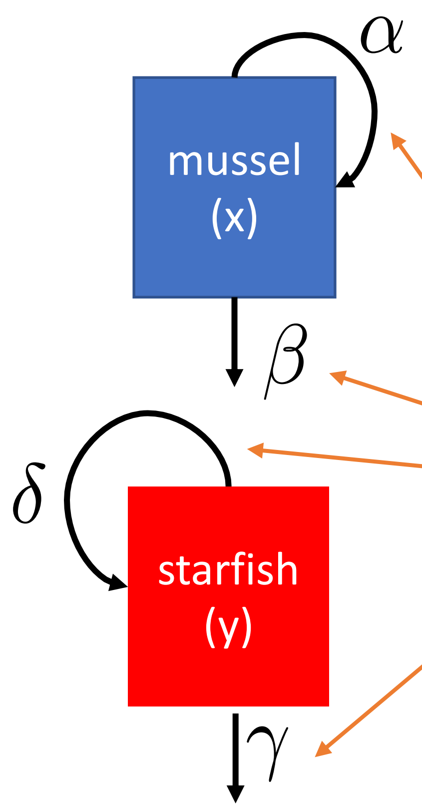


How to construct a population model

$$\frac{dx}{dt} = x(\alpha - \beta y)$$

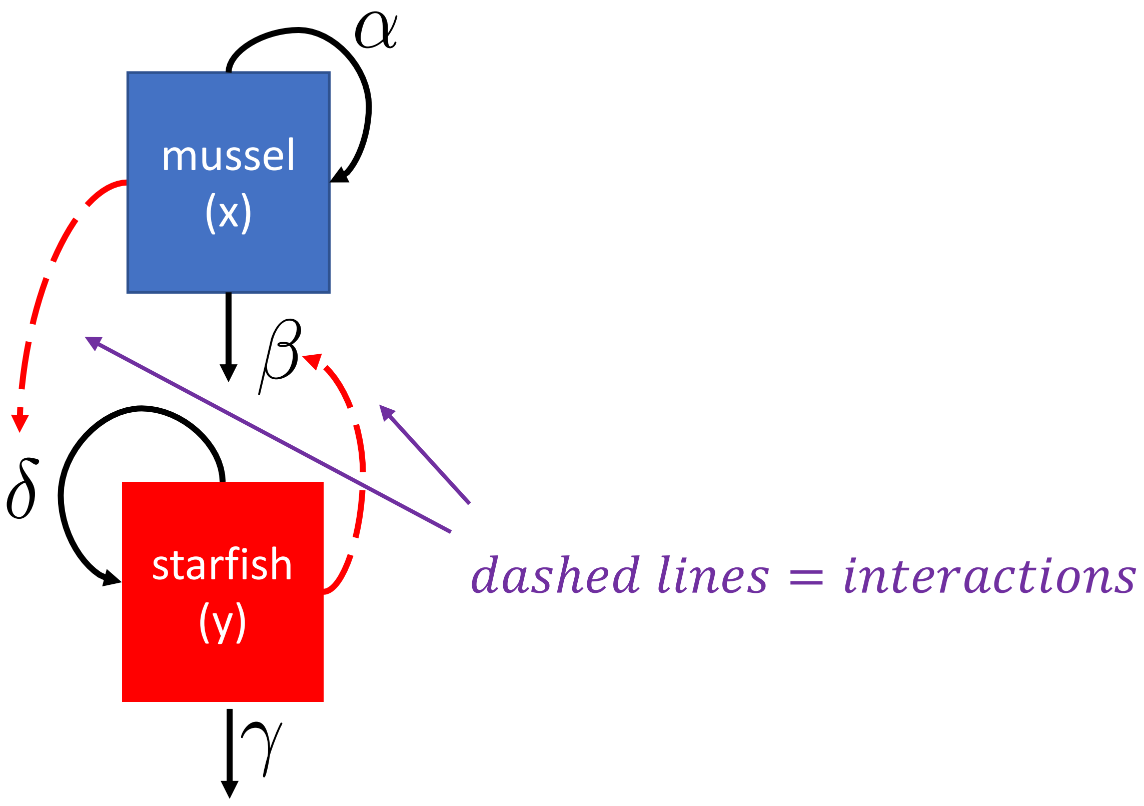
processes

$$\frac{dy}{dt} = y(\delta x - \gamma)$$



solid lines = processes

How to construct a population model



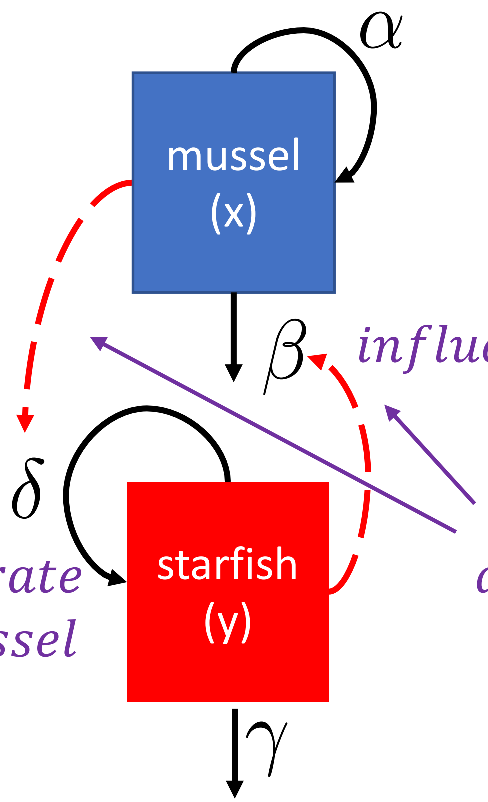
How to construct a population model

$$\frac{dx}{dt} = x(\alpha - \beta y)$$

interactions

$$\frac{dy}{dt} = y(\delta x - \gamma)$$

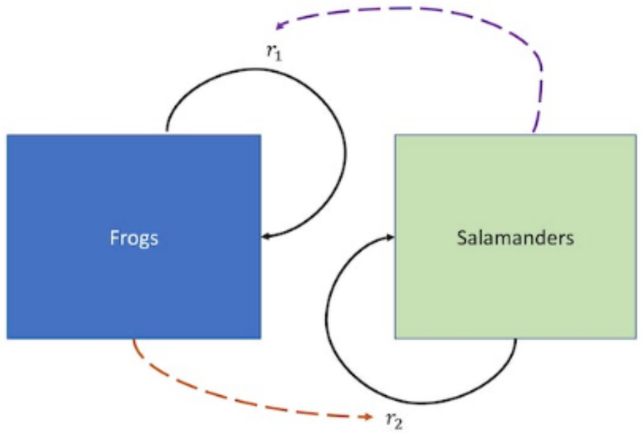
(starfish growth rate influenced by mussel abundance)



(mussel death rate influenced by starfish abundance)

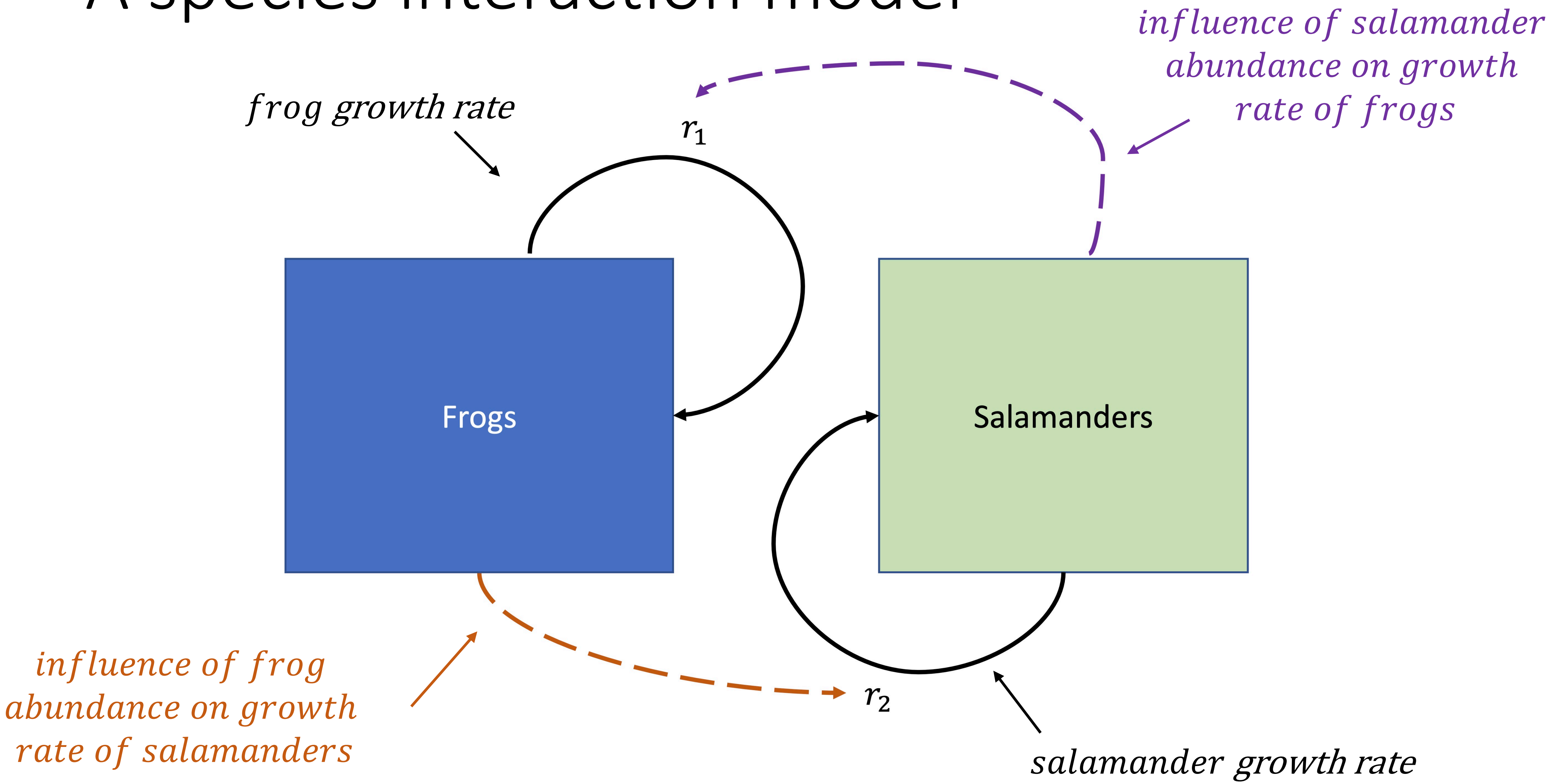
dashed lines = interactions

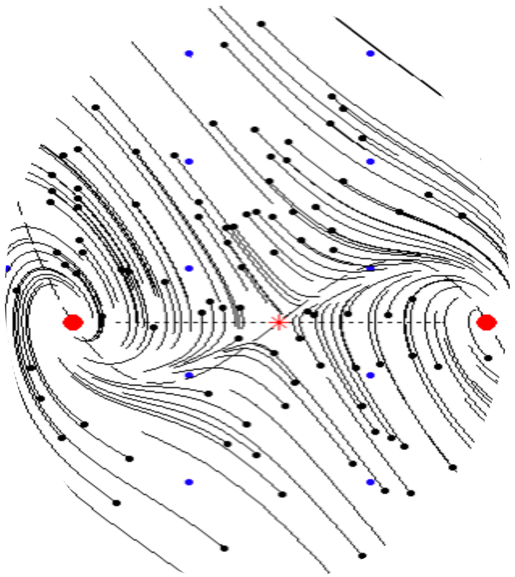
What does the dashed purple line in this model diagram indicate?



The growth rate of the salamanders	0%
The growth rate of the frogs	0%
The influence of salamander abundance on the growth rate of the frogs	0%
The influence of the frog abundance on the growth rate of the salamanders	0%
The population size of the frogs	0%

A species interaction model





Ecology is the study of the **interactions** of **organisms** with each other and their **environment**.

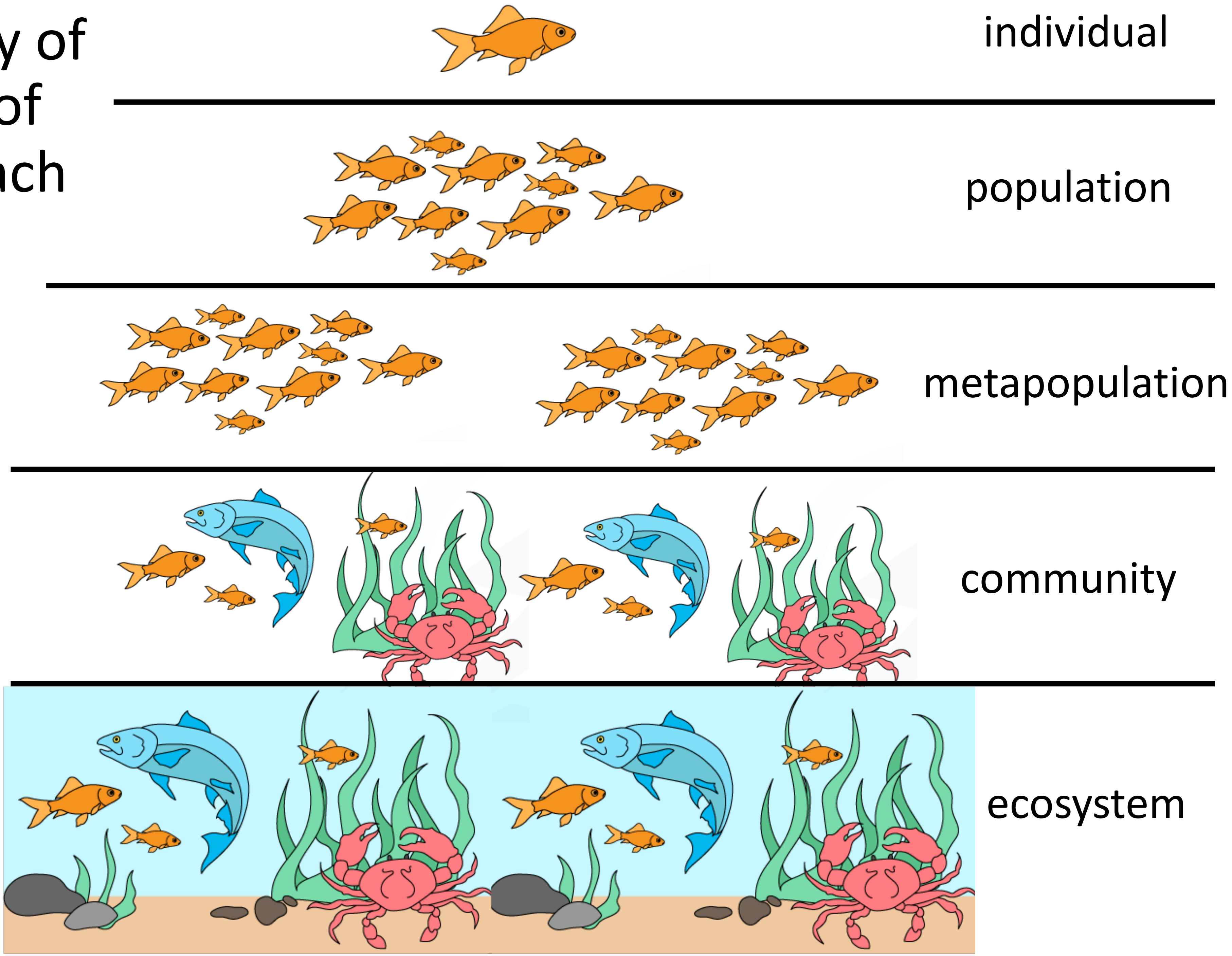
dynamic

frequently changing

complex

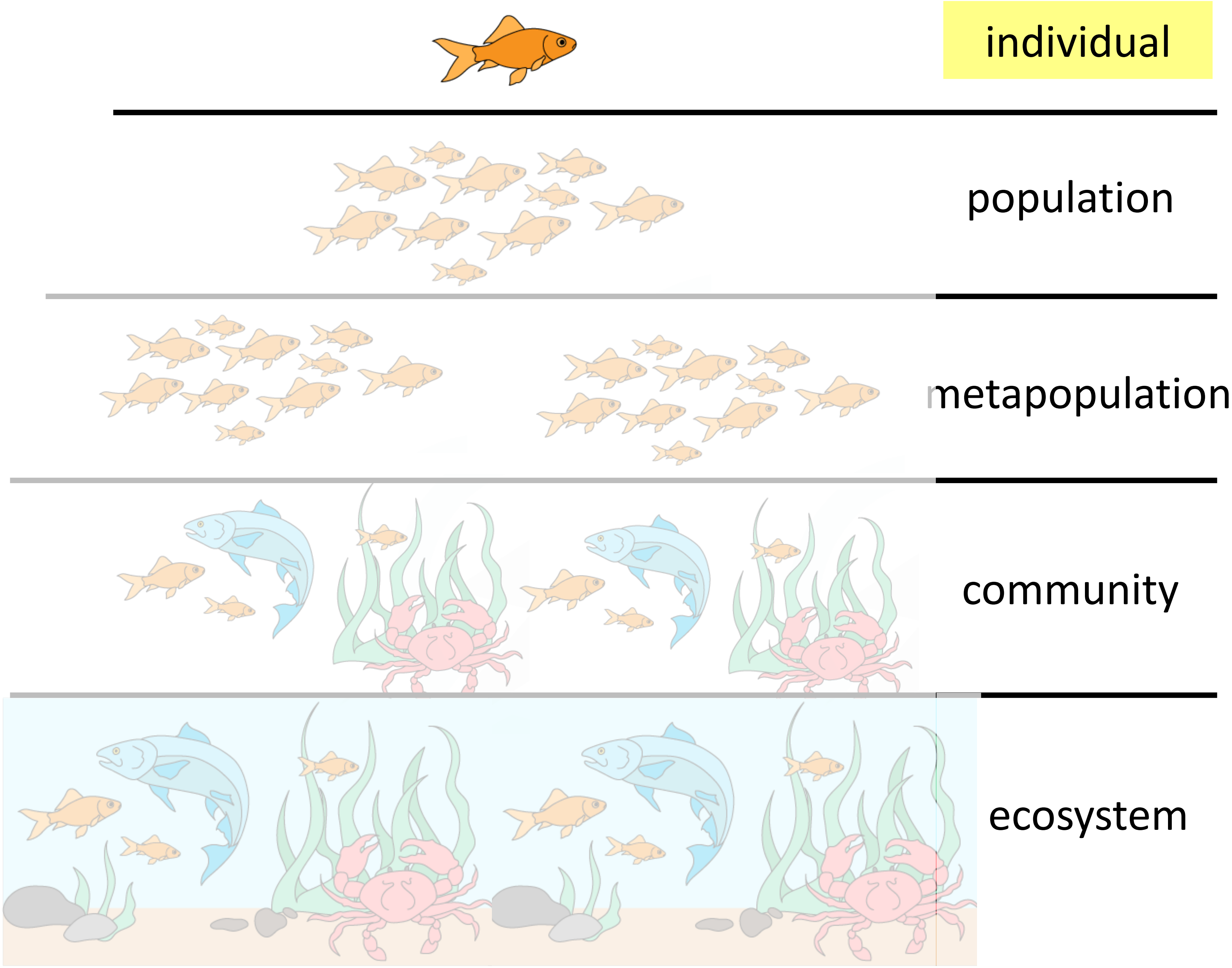
many interacting parties

Ecology is the study of the **interactions** of **organisms** with each other and their **environment.**



Individual:
metabolism, behavior, life history.

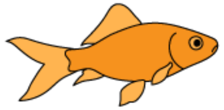
interactions of an individual with the environment



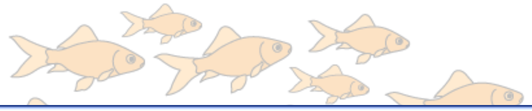
Individual: metabolism, behavior, life history.

Dynamic Energy Budget (DEB) Model

*How does a fish's metabolism **change** with temperature?*



individual

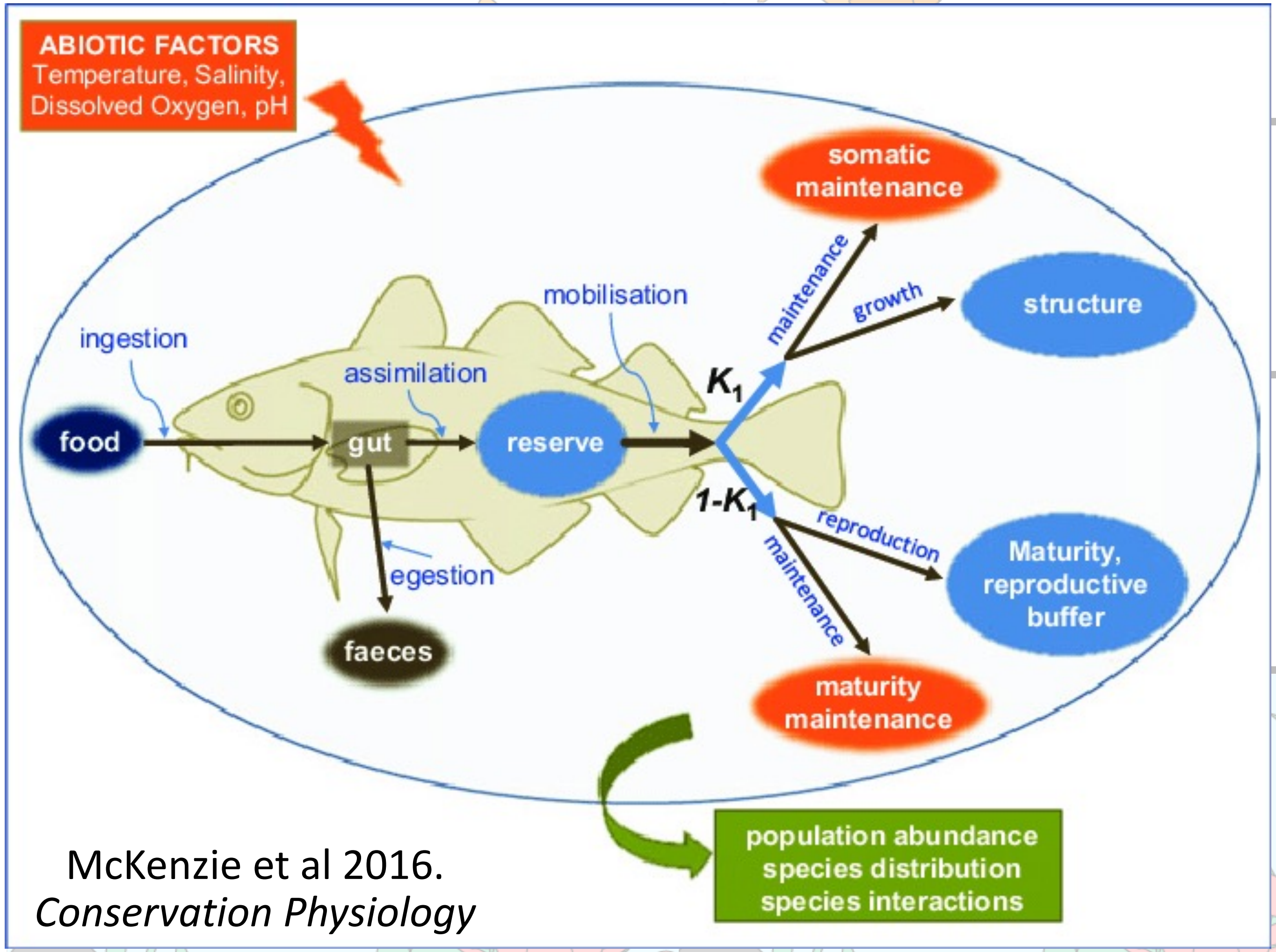


population

metapopulation

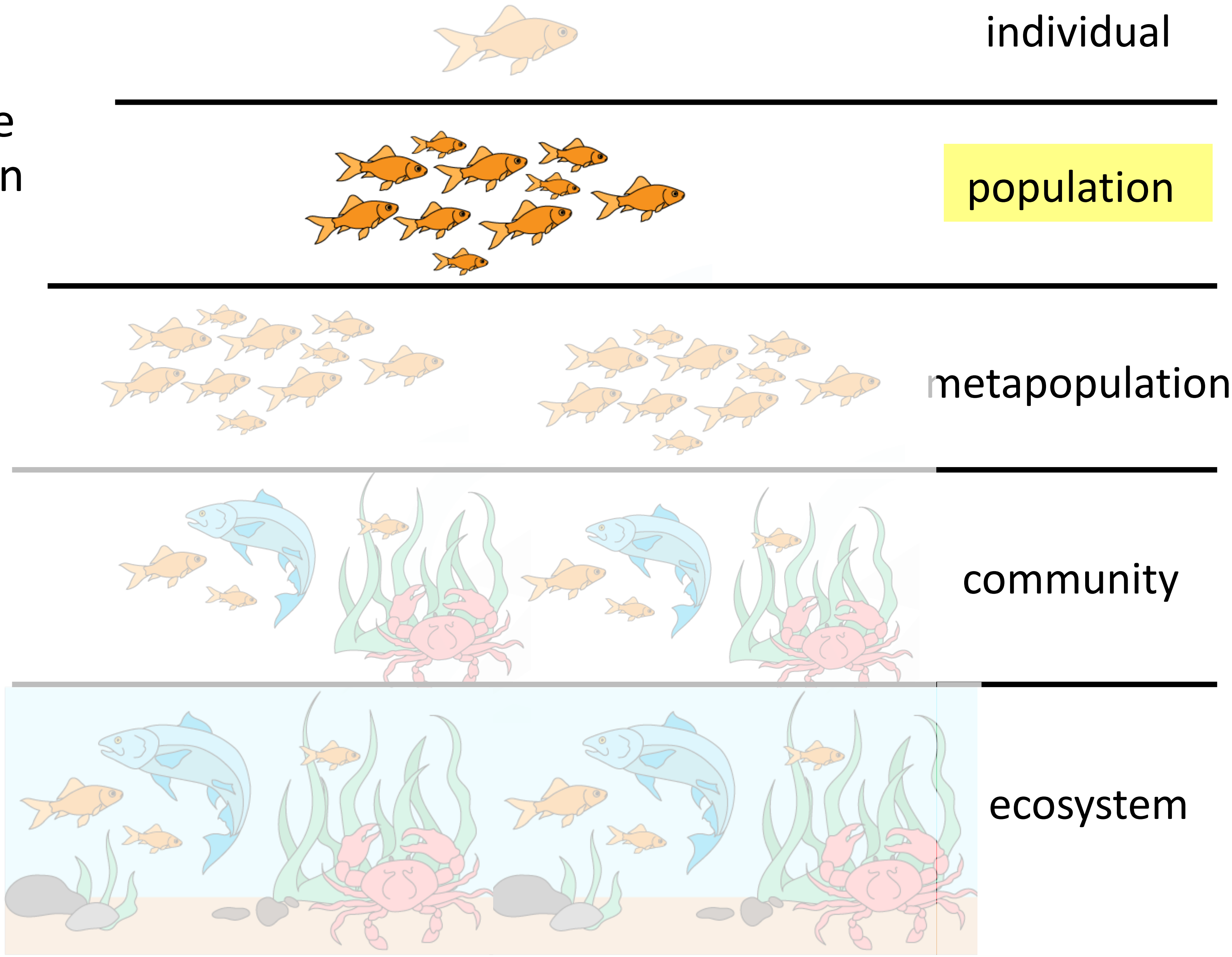
community

ecosystem

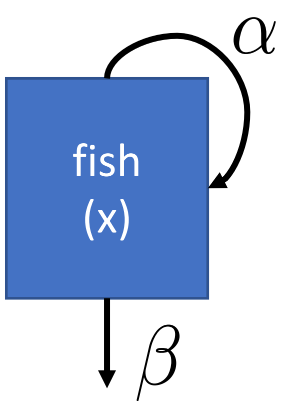


McKenzie et al 2016. *Conservation Physiology*

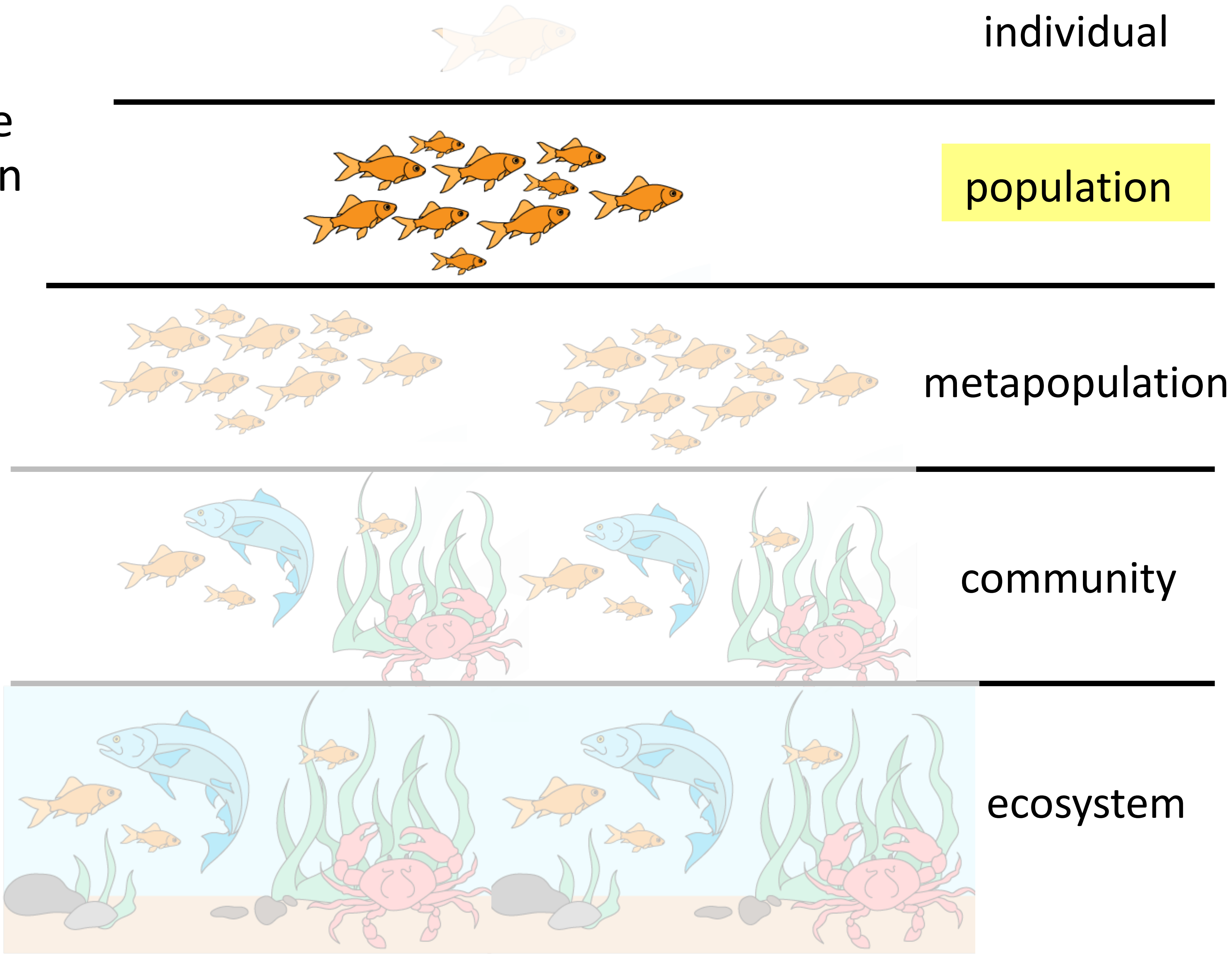
Population = multiple individuals of the same species (**conspecifics**) in the same habitat



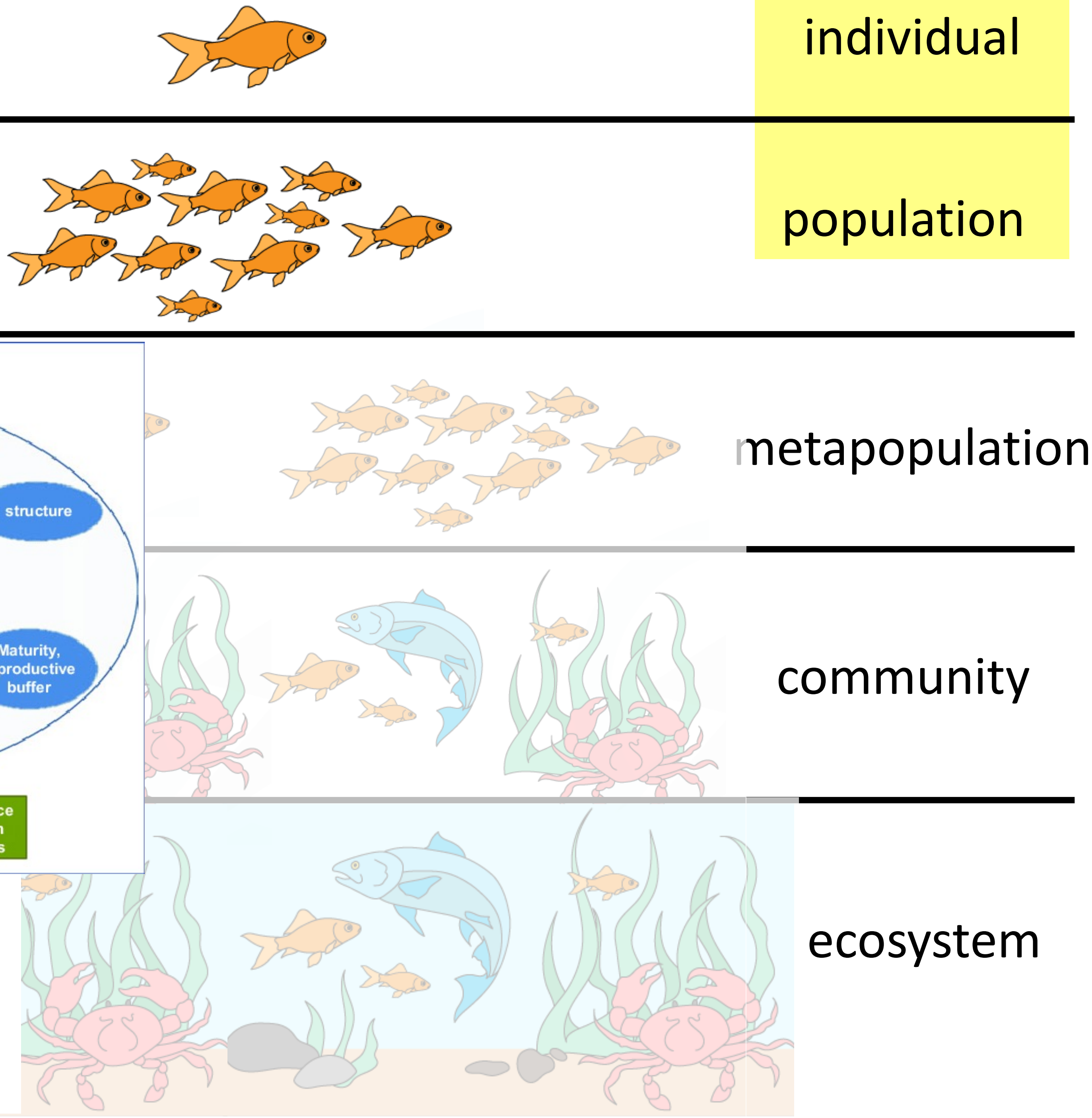
Population = multiple individuals of the same species (**conspecifics**) in the same habitat

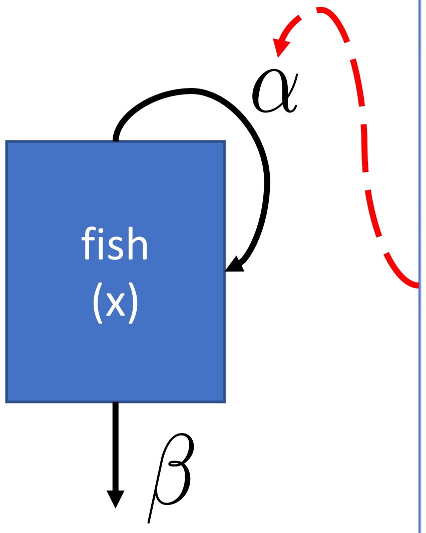


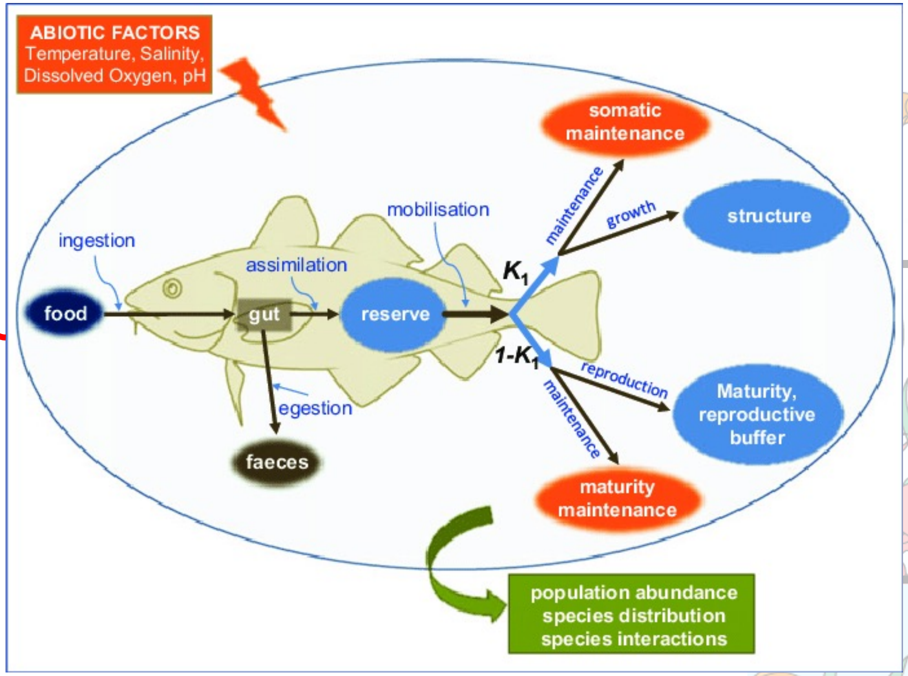
*How does the abundance of fish **change** through time?*



Nested Models, including a class of model known as **Integral Projection Models** (IPMs), link individual- and population-level processes

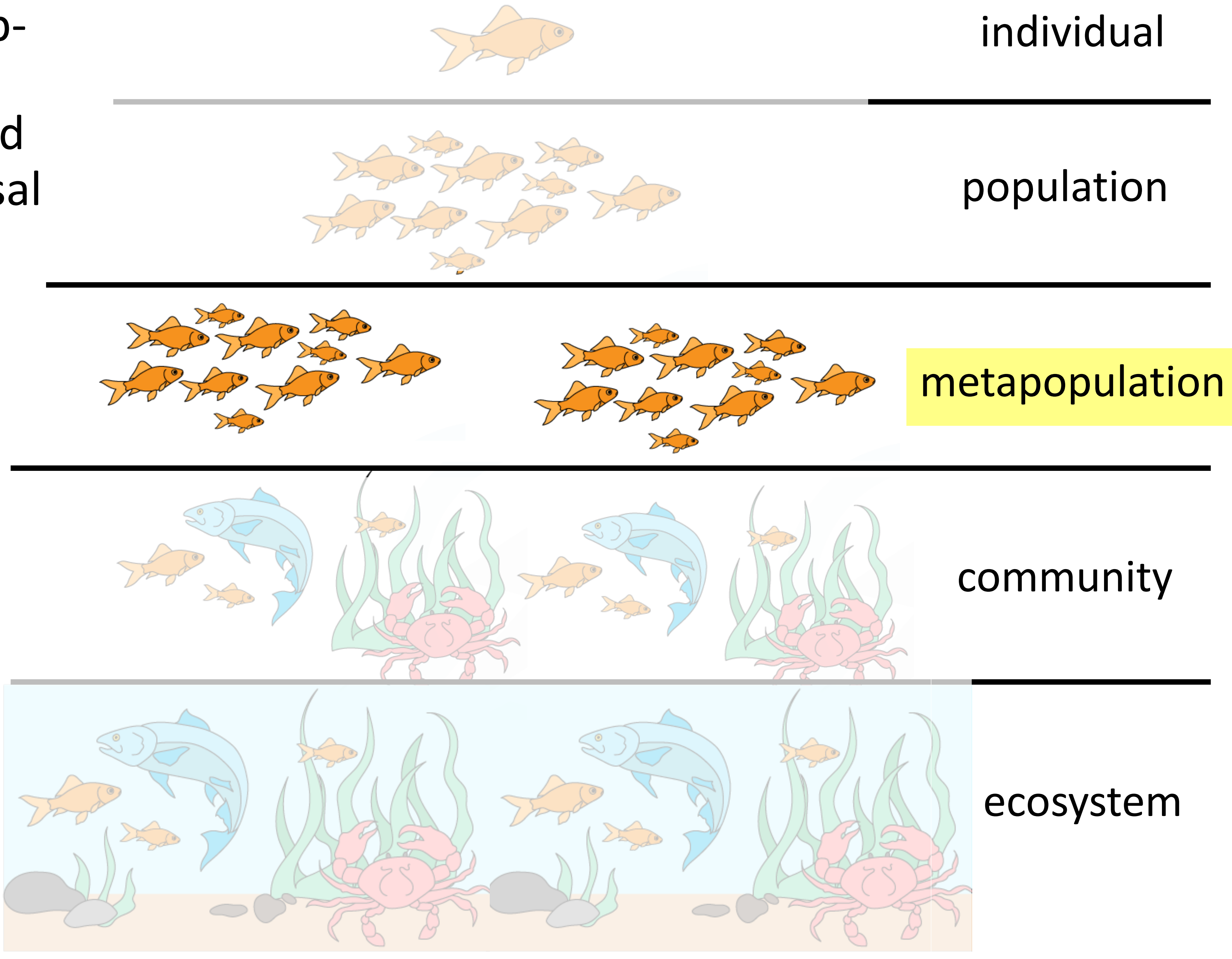




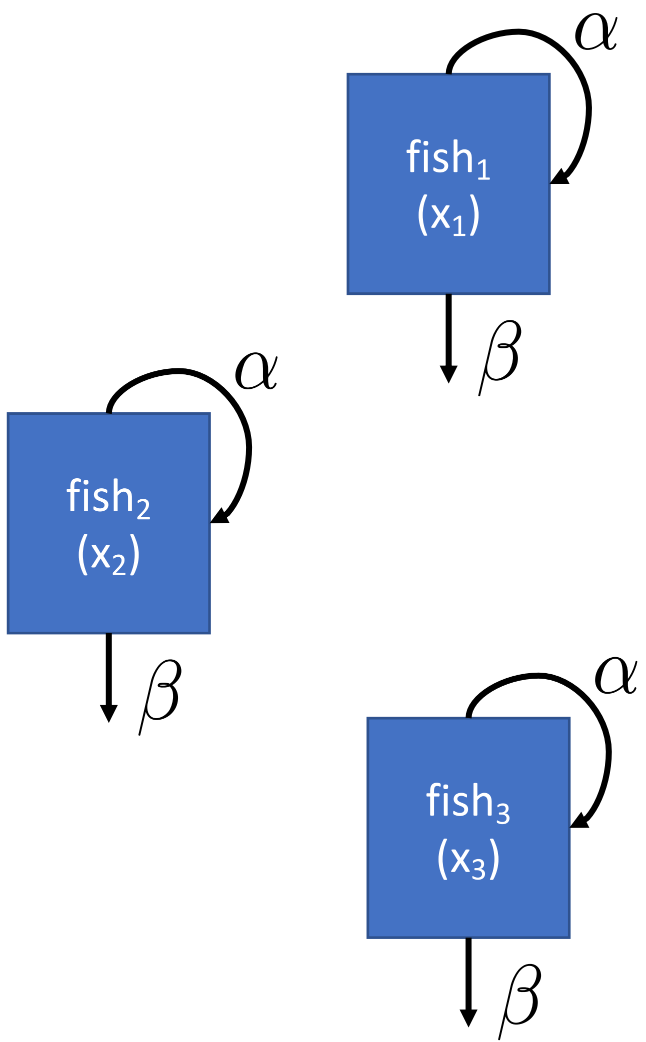


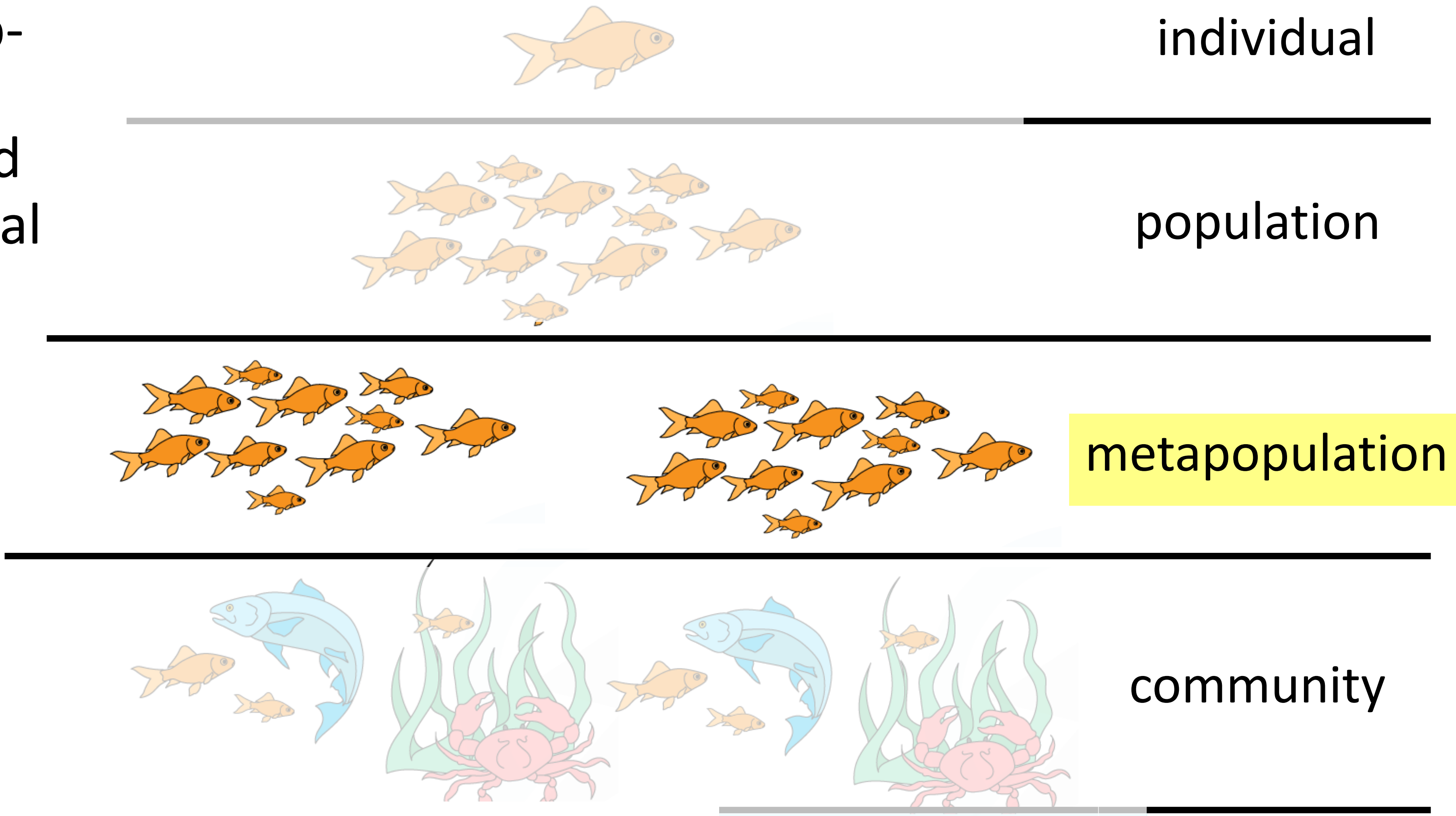
How does the abundance of fish ***change*** *through time as temperature* ***changes*** *metabolism?*

Metapopulation = sub-populations of conspecifics connected by migration or dispersal

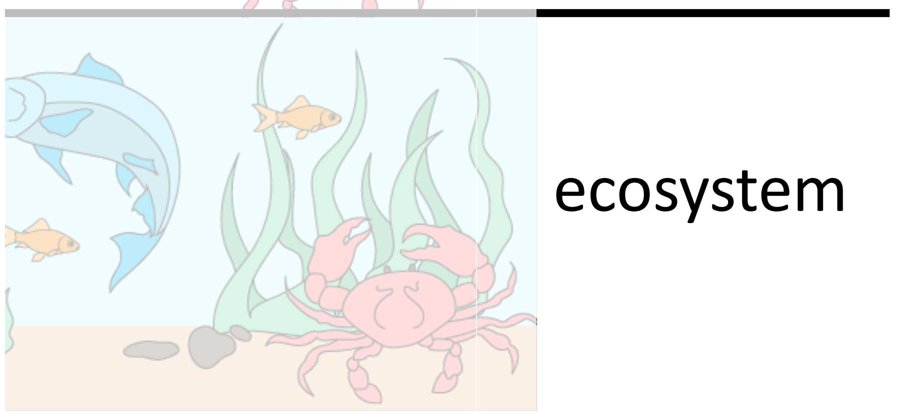


Metapopulation = sub-populations of conspecifics connected by migration or dispersal

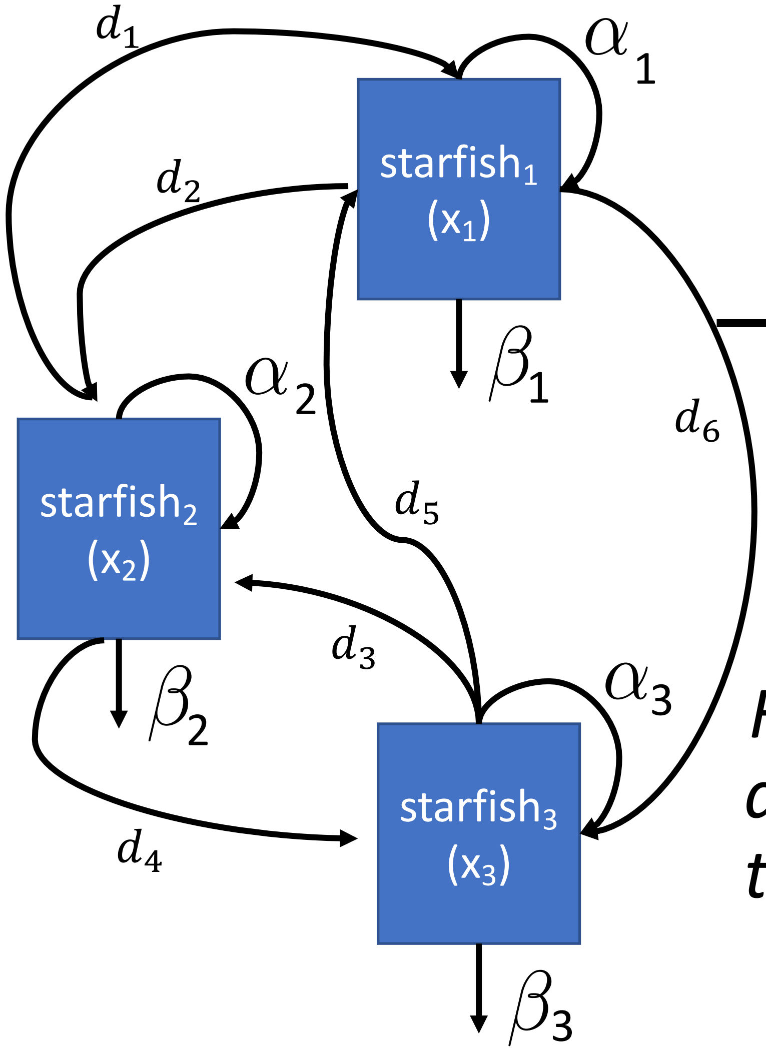


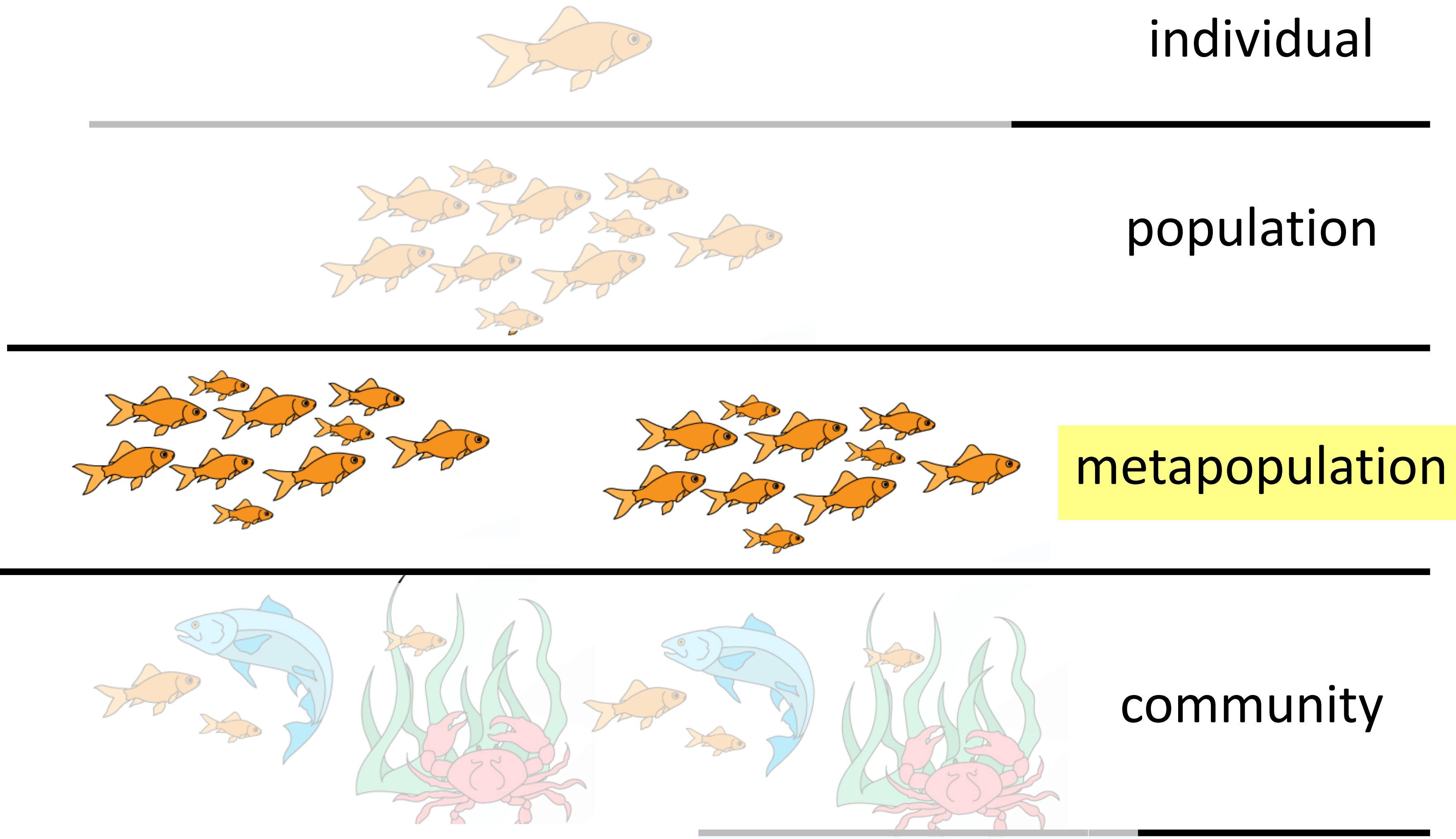


*How do the abundances of different subpopulations of the same fish **vary** in space [and time]?*

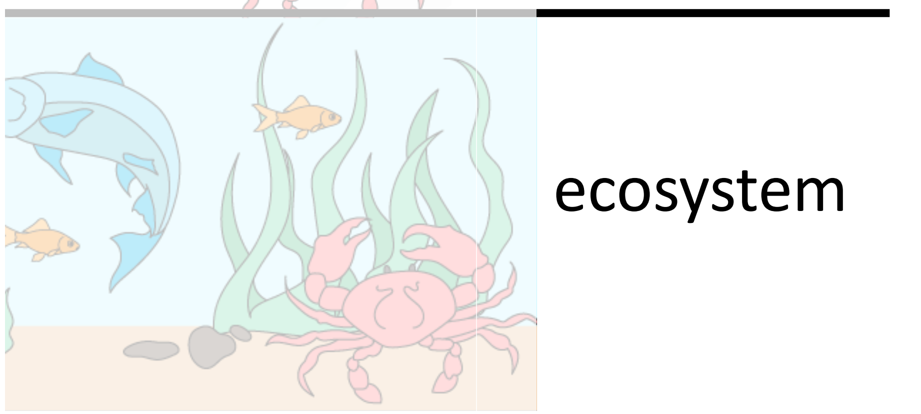


Metapopulation = sub-populations of conspecifics connected by migration or dispersal

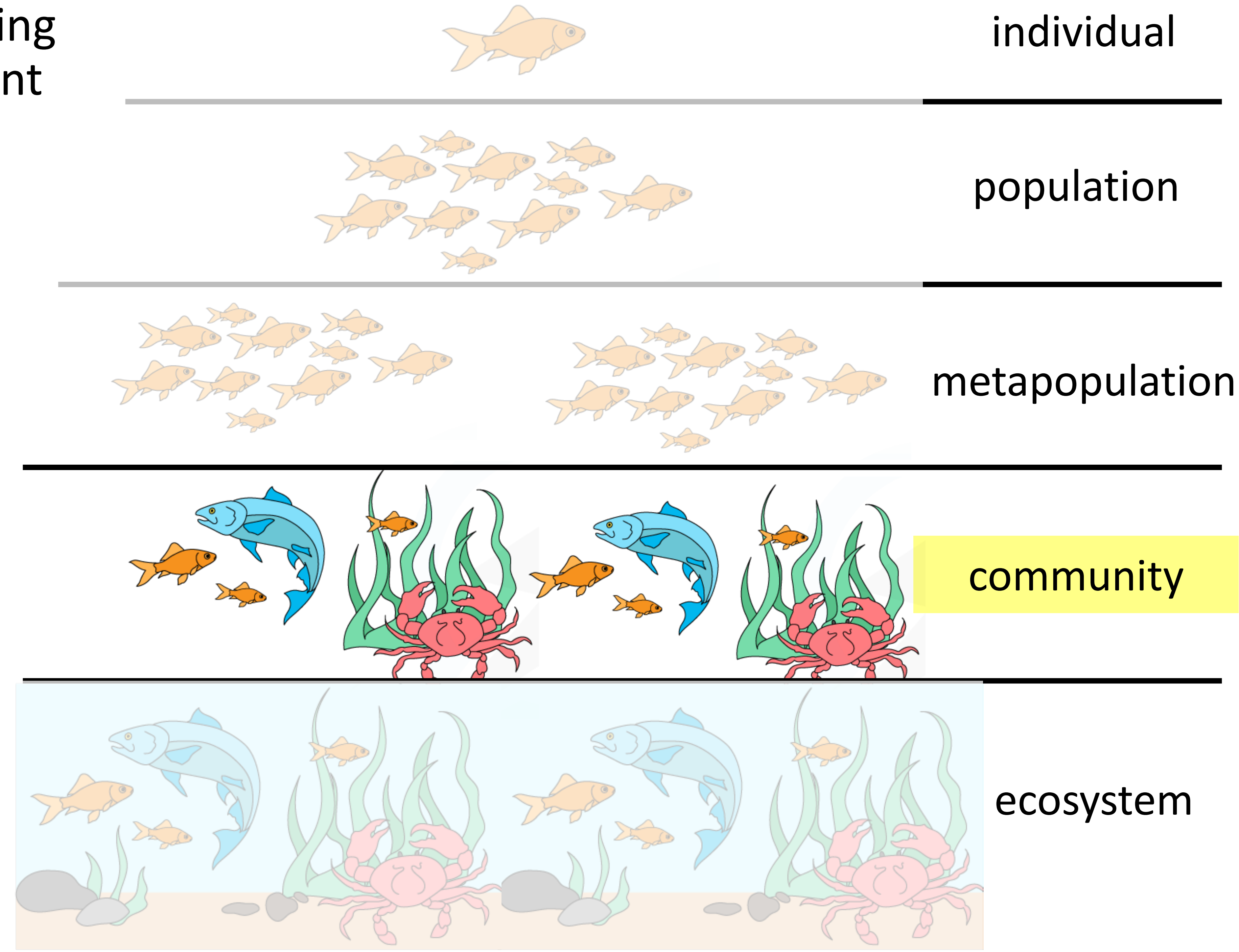




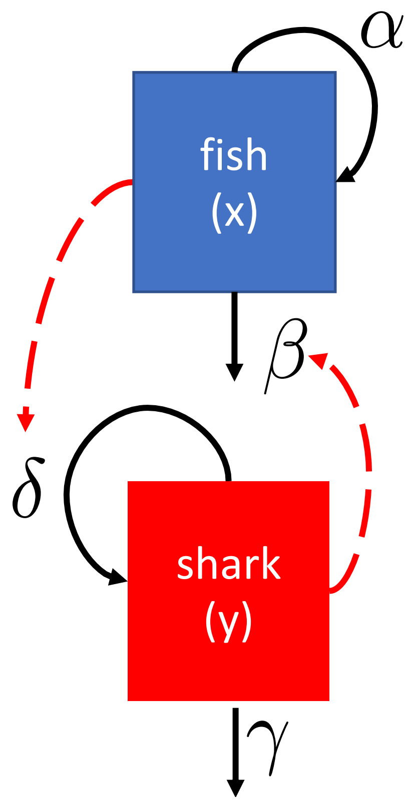
*How do the abundances of different subpopulations of the same fish **vary** in space [and time]?*



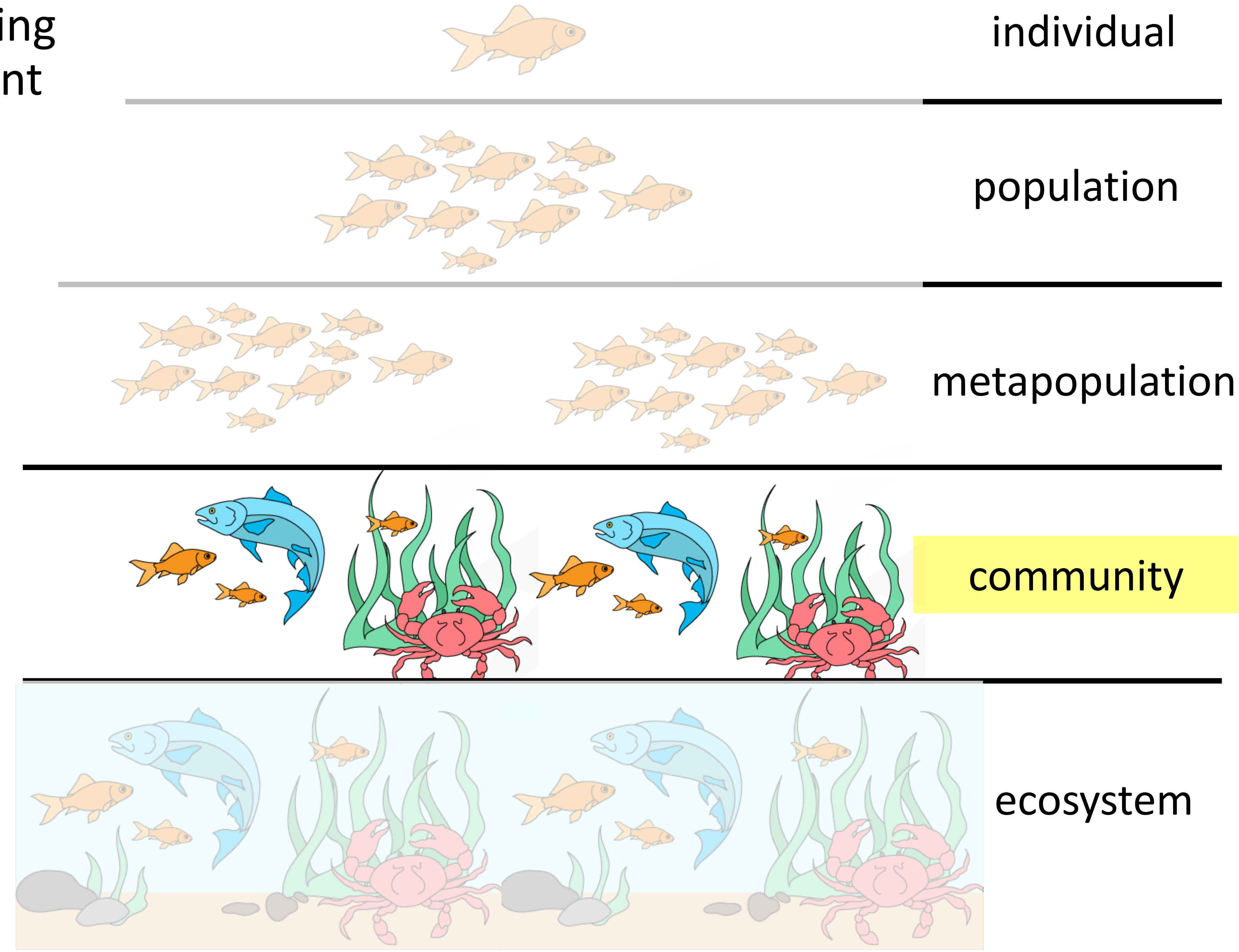
Community = interacting populations of different species



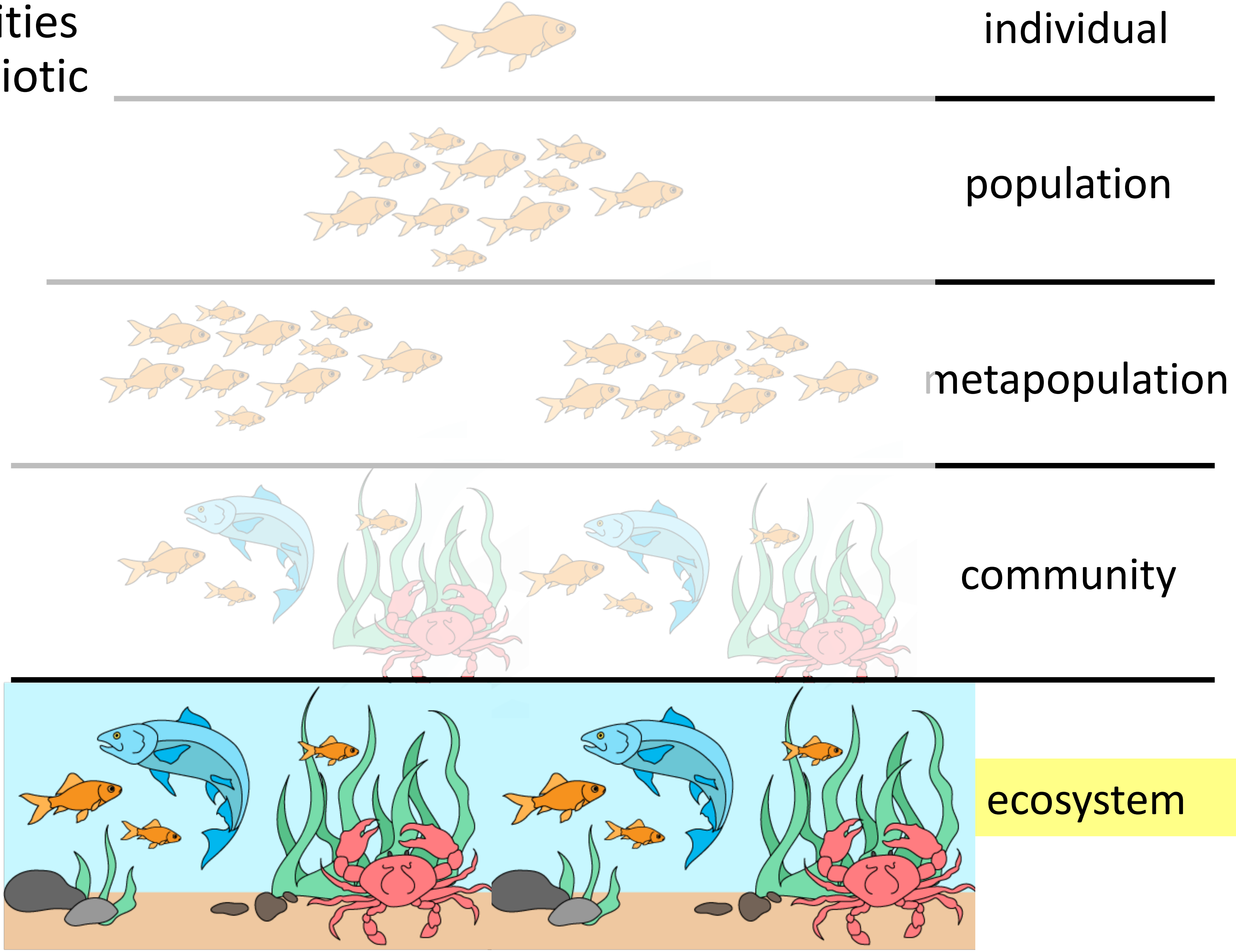
Community = interacting populations of different species



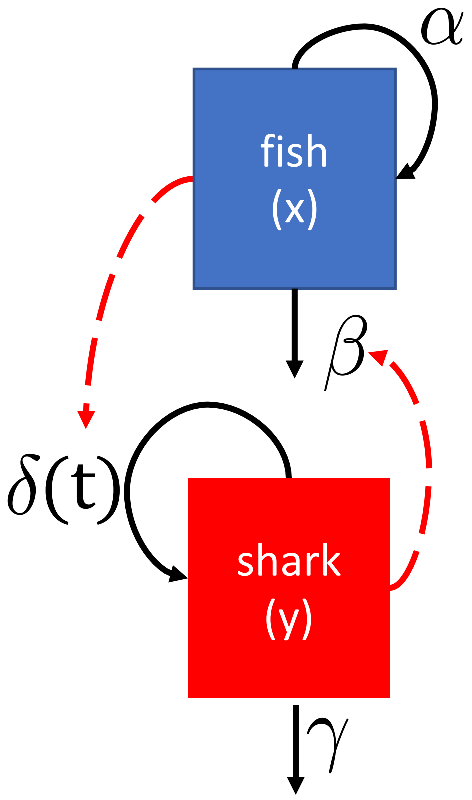
*How does fish abundance **vary** with **changes** in shark abundance?*



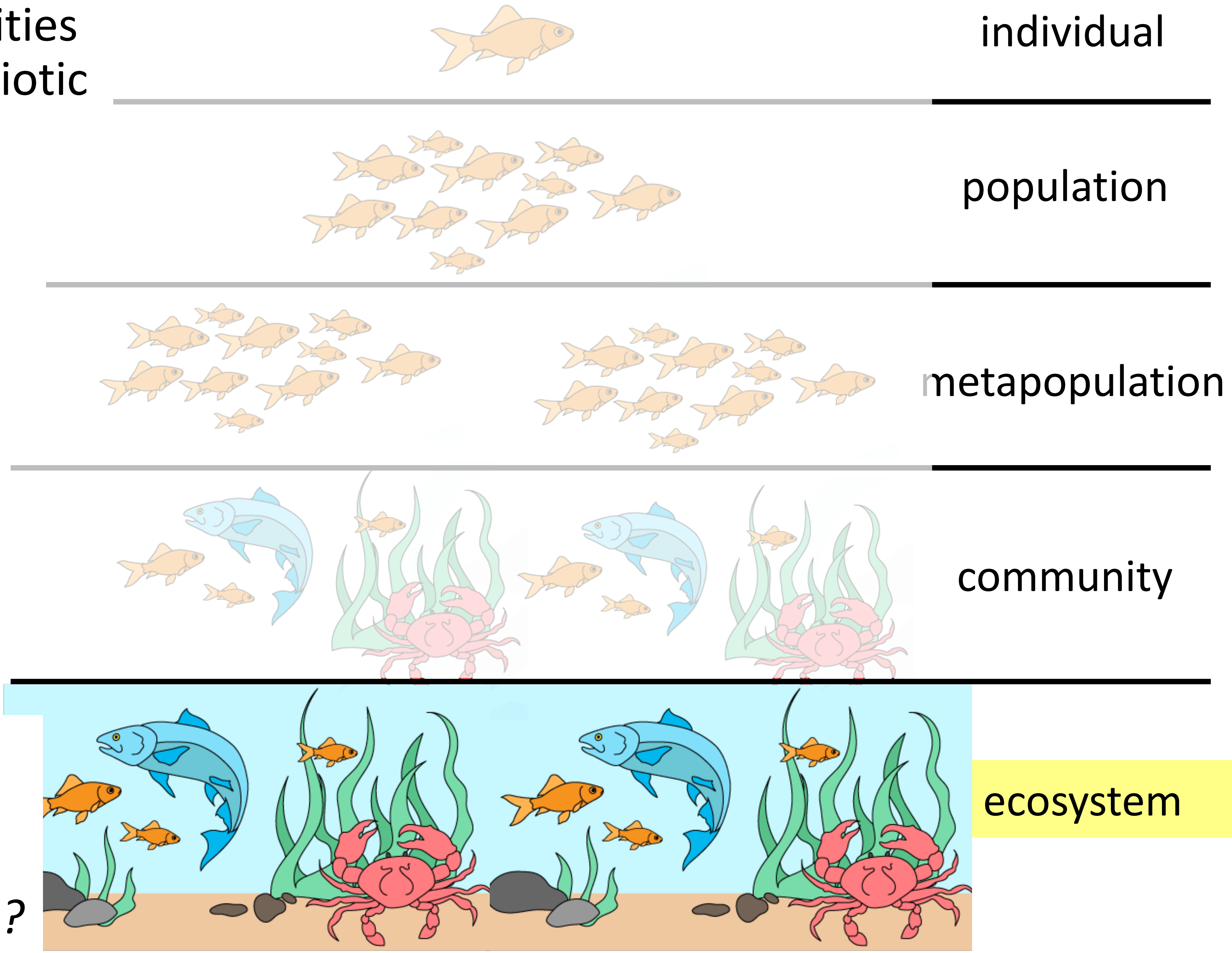
Ecosystem = communities interacting with the abiotic environment



Ecosystem = communities interacting with the abiotic environment

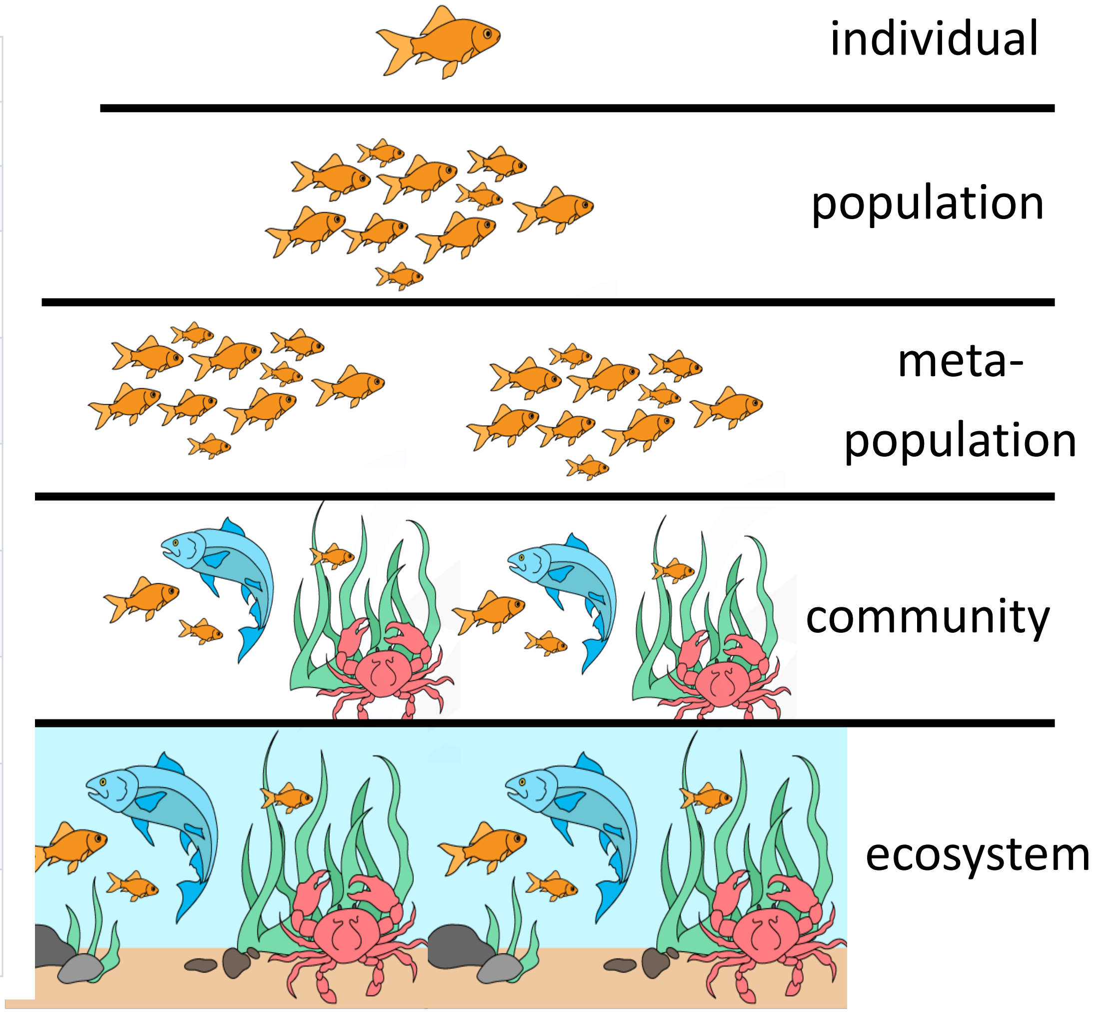


*How does fish abundance **vary** with **changes** in shark birth rates with **temperature**?*



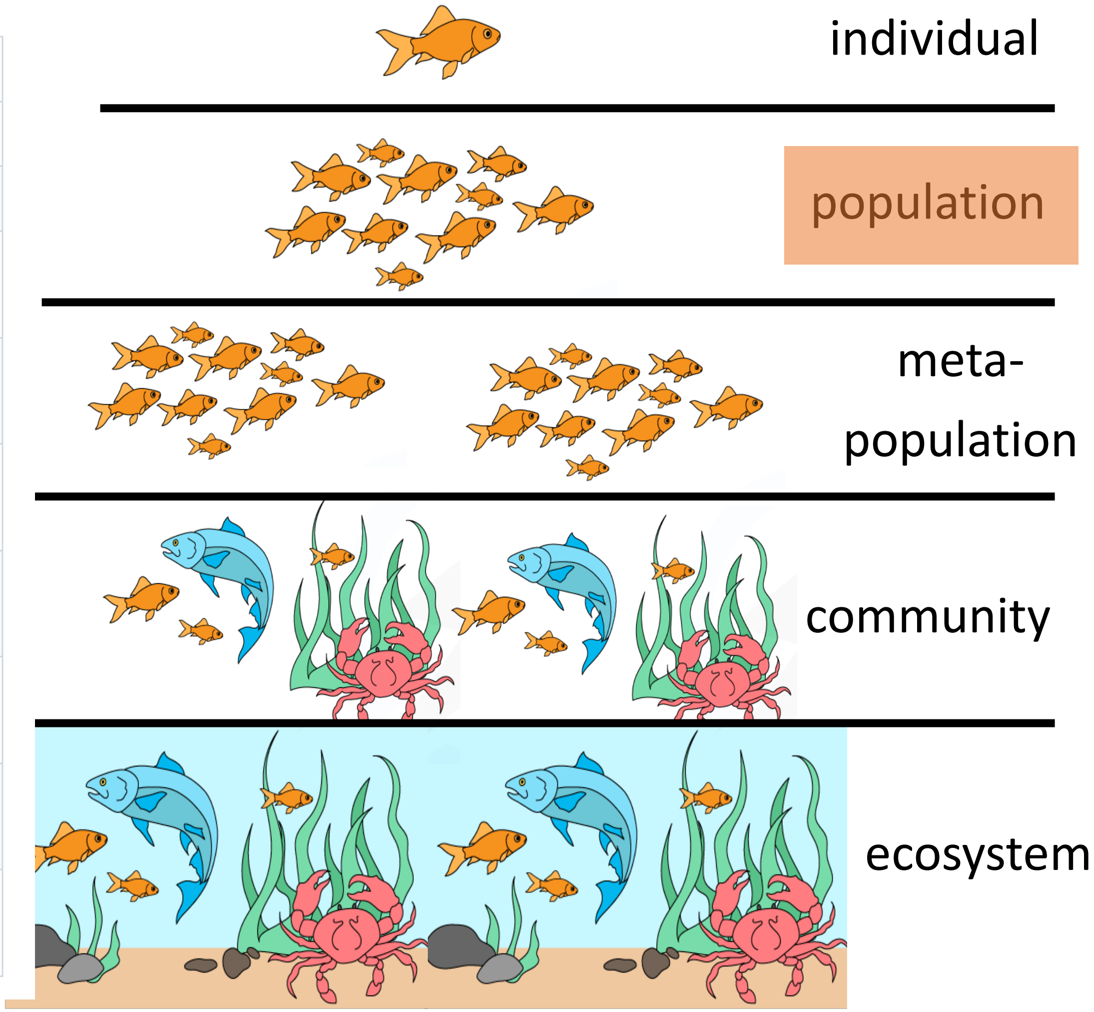
Where are we headed?

Week	Mon/Tues Lab	Tues Lecture	Thurs Lecture
1	--	--	Jan 4: Evolution History
2	1: Intro R	Jan 9: Mutation and Variation	Jan 11: Hardy-Weinberg
3	2: Hardy-Weinberg	Jan 16: Migration and Drift	Jan 18: Natural Selection
4	3: Microevolution	Jan 23: Phylogenetics	Jan 25: Molecular Evolution & Sexual Selection
5	4: Phylogenetics	Jan 30: Kin Selection, Speciation	Feb 1: Ecology & Population Growth
6	5: Evolution paper	Feb 6: Single Species Population Growth & Regulation	Feb 8: Midterm
7	6: Population Growth	Feb 13: Species Interactions 1	Feb 15: Species Interactions 2
8	7: Population Regulation	Feb 20: Disease Dynamics as Population Biology 1	Feb 22: Disease Dynamics as Population Biology 2
9	8: Disease Dynamics	Feb 27: Community Assembly & Island Biogeography	Feb 29: Critical Transitions & Conservation Interventions



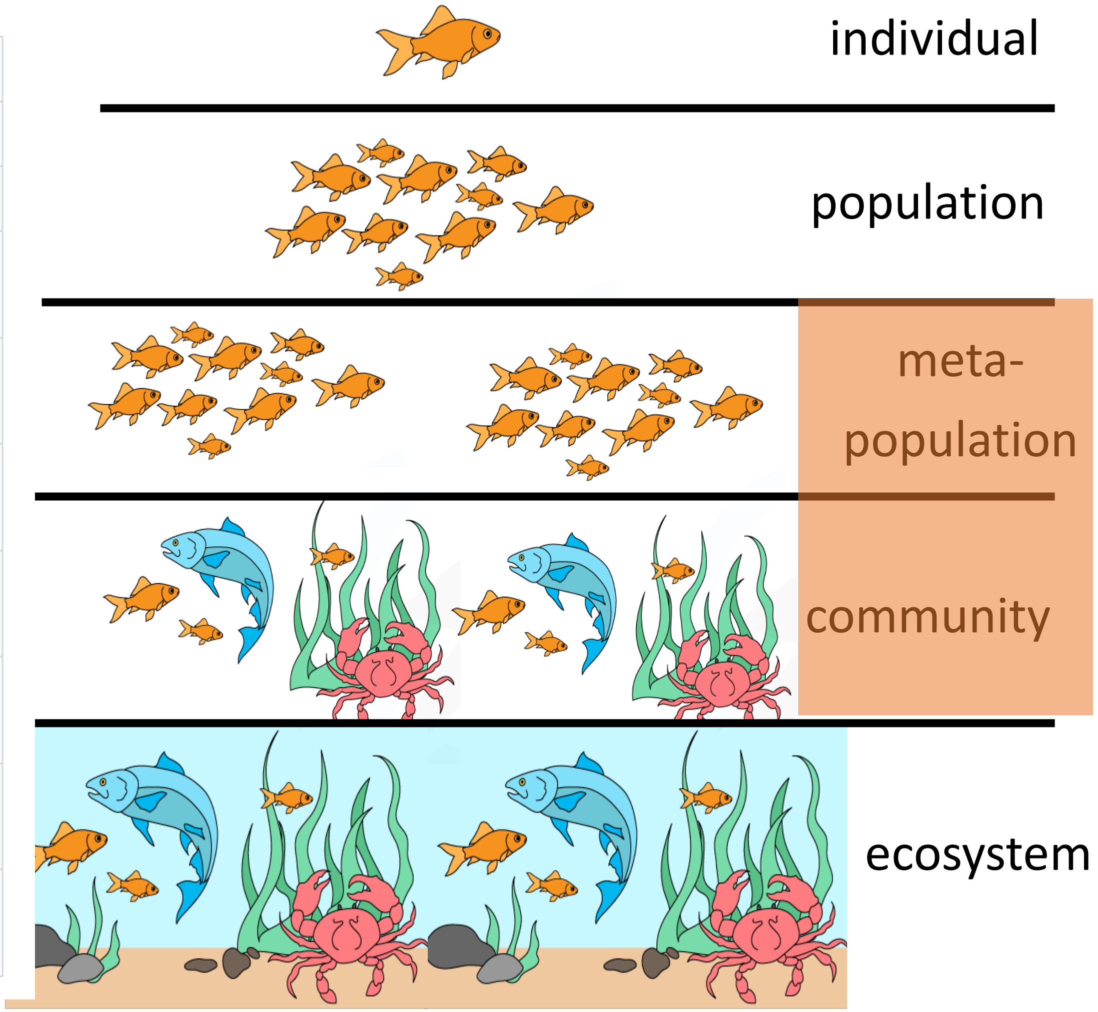
Where are we headed?

Week	Mon/Tues Lab	Tues Lecture	Thurs Lecture
1	--	--	Jan 4: Evolution History
2	1: Intro R	Jan 9: Mutation and Variation	Jan 11: Hardy-Weinberg
3	2: Hardy-Weinberg	Jan 16: Migration and Drift	Jan 18: Natural Selection
4	3: Microevolution	Jan 23: Phylogenetics	Jan 25: Molecular Evolution & Sexual Selection
5	4: Phylogenetics	Jan 30: Kin Selection, Speciation	Feb 1: Ecology & Population Growth
6	5: Evolution paper	Feb 6: Single Species Population Growth & Regulation	Feb 8: Midterm
7	6: Population Growth	Feb 13: Species Interactions 1	Feb 15: Species Interactions 2
8	7: Population Regulation	Feb 20: Disease Dynamics as Population Biology 1	Feb 22: Disease Dynamics as Population Biology 2
9	8: Disease Dynamics	Feb 27: Community Assembly & Island Biogeography	Feb 29: Critical Transitions & Conservation Interventions



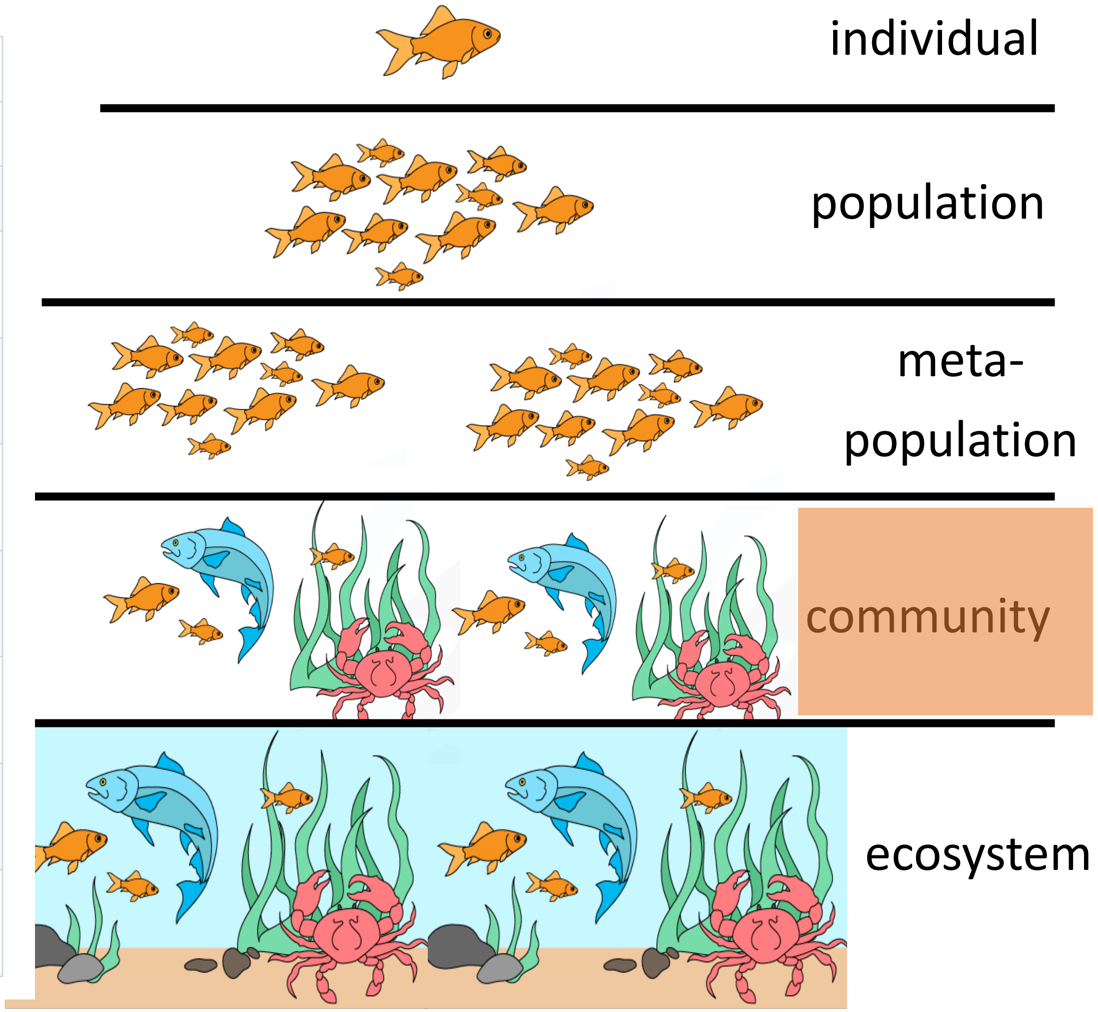
Where are we headed?

Week	Mon/Tues Lab	Tues Lecture	Thurs Lecture
1	--	--	Jan 4: Evolution History
2	1: Intro R	Jan 9: Mutation and Variation	Jan 11: Hardy-Weinberg
3	2: Hardy-Weinberg	Jan 16: Migration and Drift	Jan 18: Natural Selection
4	3: Microevolution	Jan 23: Phylogenetics	Jan 25: Molecular Evolution & Sexual Selection
5	4: Phylogenetics	Jan 30: Kin Selection, Speciation	Feb 1: Ecology & Population Growth
6	5: Evolution paper	Feb 6: Single Species Population Growth & Regulation	Feb 8: Midterm
7	6: Population Growth	Feb 13: Species Interactions 1	Feb 15: Species Interactions 2
8	7: Population Regulation	Feb 20: Disease Dynamics as Population Biology 1	Feb 22: Disease Dynamics as Population Biology 2
9	8: Disease Dynamics	Feb 27: Community Assembly & Island Biogeography	Feb 29: Critical Transitions & Conservation Interventions



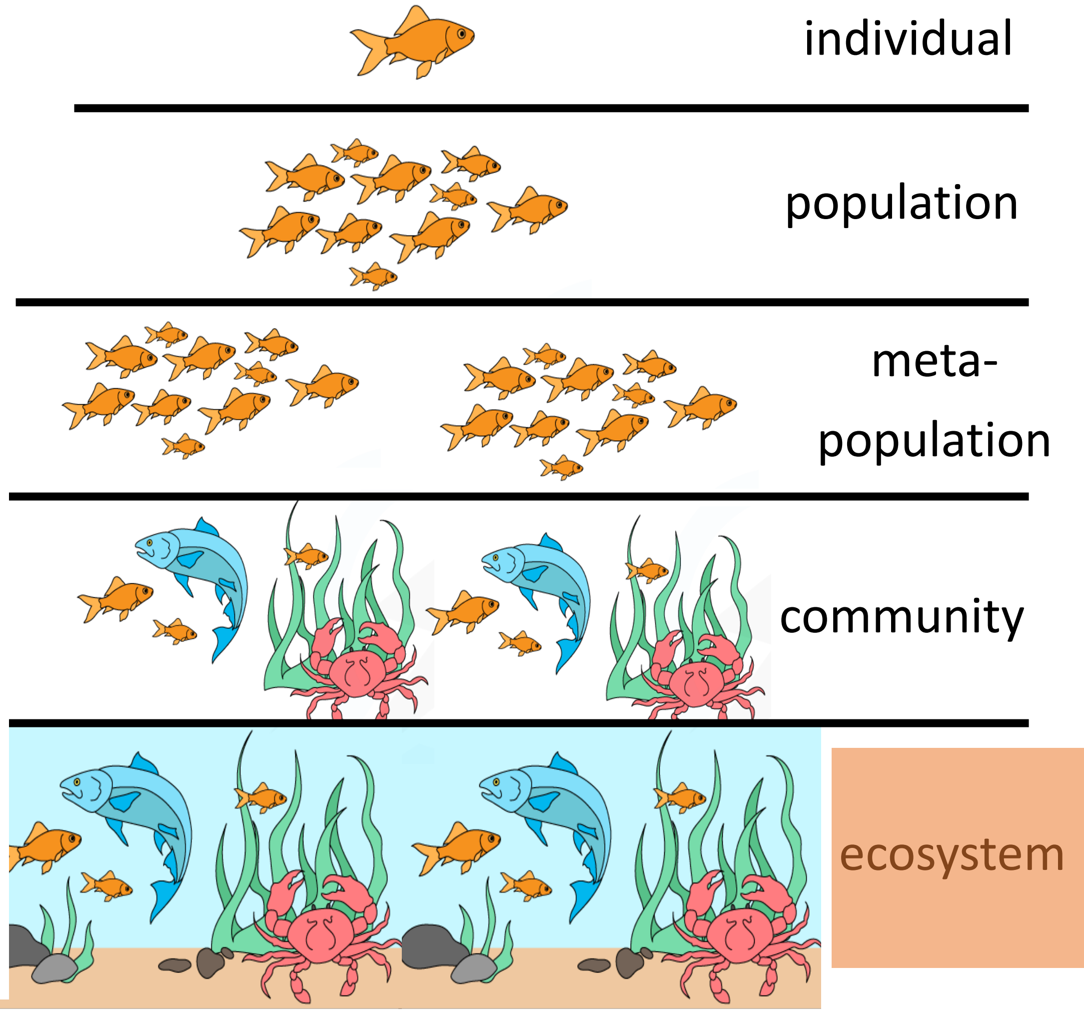
Where are we headed?

Week	Mon/Tues Lab	Tues Lecture	Thurs Lecture
1	--	--	Jan 4: Evolution History
2	1: Intro R	Jan 9: Mutation and Variation	Jan 11: Hardy-Weinberg
3	2: Hardy-Weinberg	Jan 16: Migration and Drift	Jan 18: Natural Selection
4	3: Microevolution	Jan 23: Phylogenetics	Jan 25: Molecular Evolution & Sexual Selection
5	4: Phylogenetics	Jan 30: Kin Selection, Speciation	Feb 1: Ecology & Population Growth
6	5: Evolution paper	Feb 6: Single Species Population Growth & Regulation	Feb 8: Midterm
7	6: Population Growth	Feb 13: Species Interactions 1	Feb 15: Species Interactions 2
8	7: Population Regulation	Feb 20: Disease Dynamics as Population Biology 1	Feb 22: Disease Dynamics as Population Biology 2
9	8: Disease Dynamics	Feb 27: Community Assembly & Island Biogeography	Feb 29: Critical Transitions & Conservation Interventions



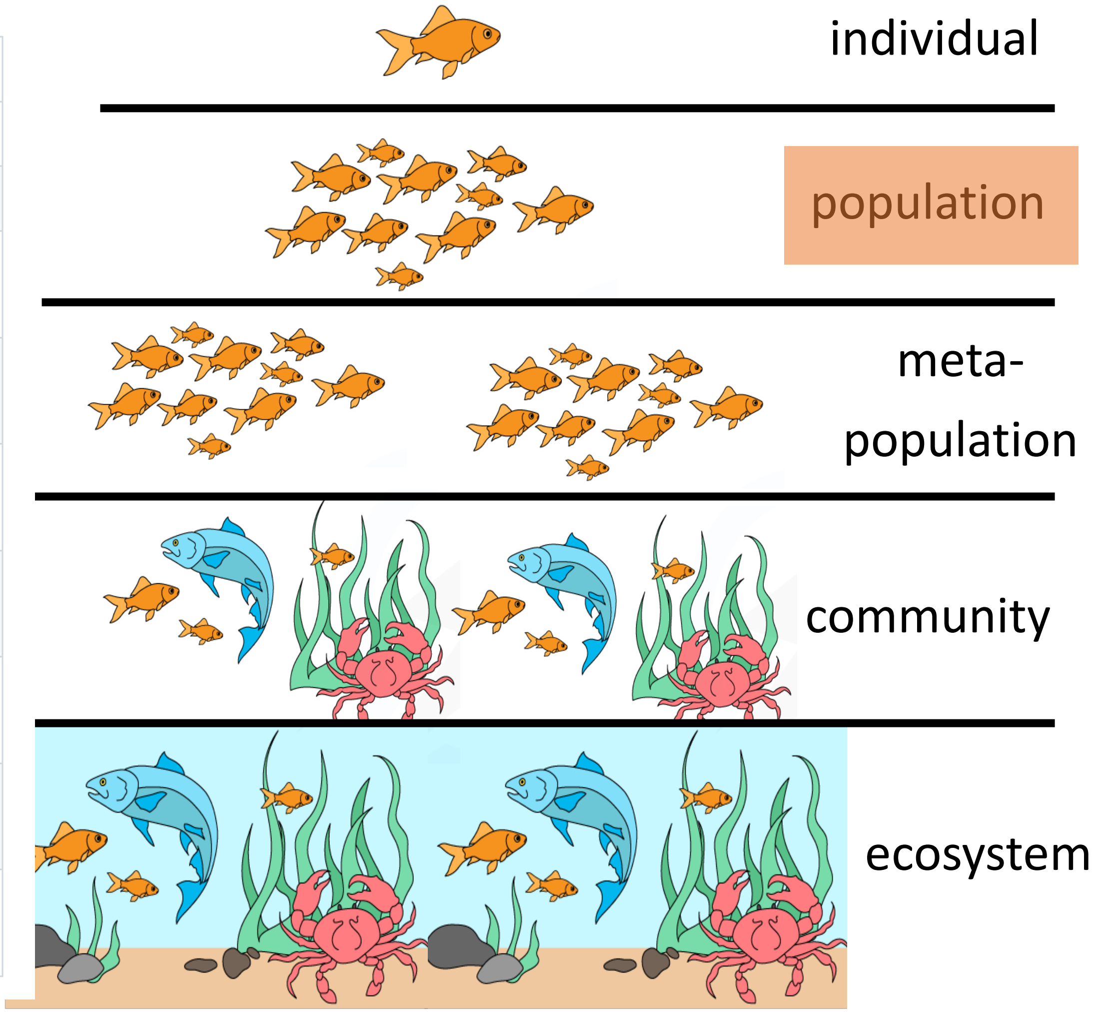
Where are we headed?

Week	Mon/Tues Lab	Tues Lecture	Thurs Lecture
1	--	--	Jan 4: Evolution History
2	1: Intro R	Jan 9: Mutation and Variation	Jan 11: Hardy-Weinberg
3	2: Hardy-Weinberg	Jan 16: Migration and Drift	Jan 18: Natural Selection
4	3: Microevolution	Jan 23: Phylogenetics	Jan 25: Molecular Evolution & Sexual Selection
5	4: Phylogenetics	Jan 30: Kin Selection, Speciation	Feb 1: Ecology & Population Growth
6	5: Evolution paper	Feb 6: Single Species Population Growth & Regulation	Feb 8: Midterm
7	6: Population Growth	Feb 13: Species Interactions 1	Feb 15: Species Interactions 2
8	7: Population Regulation	Feb 20: Disease Dynamics as Population Biology 1	Feb 22: Disease Dynamics as Population Biology 2
9	8: Disease Dynamics	Feb 27: Community Assembly & Island Biogeography	Feb 29: Critical Transitions & Conservation Interventions



Population Growth and Regulation

Week	Mon/Tues Lab	Tues Lecture	Thurs Lecture
1	--	--	Jan 4: Evolution History
2	1: Intro R	Jan 9: Mutation and Variation	Jan 11: Hardy-Weinberg
3	2: Hardy-Weinberg	Jan 16: Migration and Drift	Jan 18: Natural Selection
4	3: Microevolution	Jan 23: Phylogenetics	Jan 25: Molecular Evolution & Sexual Selection
5	4: Phylogenetics	Jan 30: Kin Selection, Speciation	Feb 1: Ecology & Population Growth
6	5: Evolution paper	Feb 6: Single Species Population Growth & Regulation	Feb 8: Midterm
7	6: Population Growth	Feb 13: Species Interactions 1	Feb 15: Species Interactions 2
8	7: Population Regulation	Feb 20: Disease Dynamics as Population Biology 1	Feb 22: Disease Dynamics as Population Biology 2
9	8: Disease Dynamics	Feb 27: Community Assembly & Island Biogeography	Feb 29: Critical Transitions & Conservation Interventions



Why do we care how populations grow?

Why do we care how populations grow?

(Shafer 1980)

DETERMINING MINIMUM VIABLE POPULATION SIZES FOR THE GRIZZLY BEAR[1]

MARK L. SHAFFER,[2] School of Forestry and Environmental Studies, Duke University, Durham, NC 27706

Abstract: A stochastic computer simulation is presented for use in determining the relationship of population size to extinction probabilities for populations of grizzly bears (*Ursus arctos*). Published data on numbers, age, sex, reproduction, and mortality for the grizzly bear population of Yellowstone National Park were used to develop and test several simulation models. The results indicate that, for the Yellowstone grizzlies, 35 to 70 bears constitute a minimum viable population (the smallest population with a 95% probability of surviving at least 100 years). Minimum area requirements for populations of this size range from 700 to 10,000 $km.^2$

Int. Conf. Bear Res. and Manage. 5:133 – 139

Why do we care how populations grow?

(Shafer 1980)

DETERMINING MINIMUM VIABLE POPULATION SIZES FOR THE GRIZZLY BEAR[1]

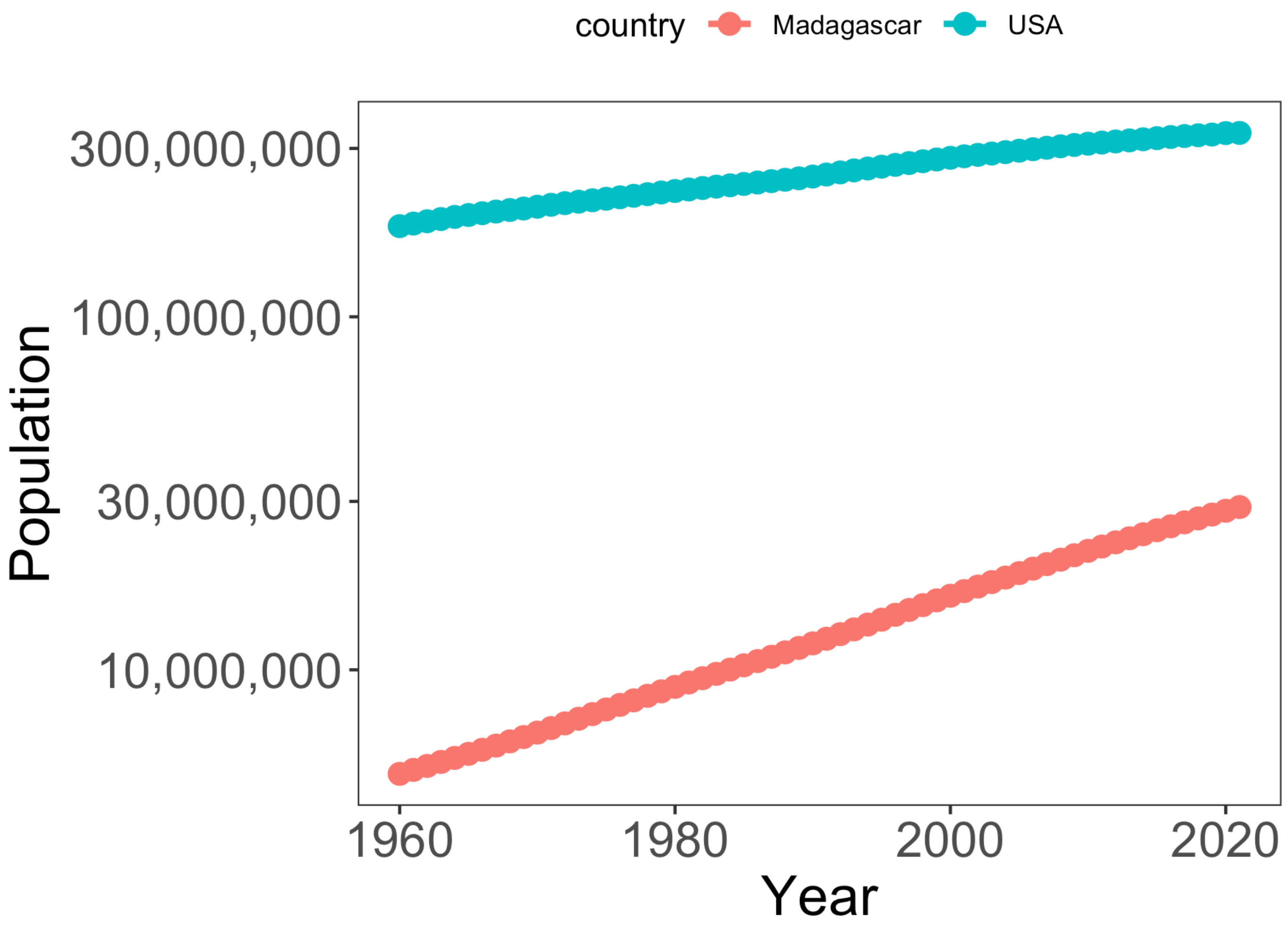
MARK L. SHAFFER,[2] School of Forestry and Environmental Studies, Duke University, Durham, NC 27706

Abstract: A stochastic computer simulation is presented for use in determining the relationship of population size to extinction probabilities for populations of grizzly bears (*Ursus arctos*). Published data on numbers, age, sex, reproduction, and mortality for the grizzly bear population of Yellowstone National Park were used to develop and test several simulation models. The results indicate that, for the Yellowstone grizzlies, 35 to 70 bears constitute a minimum viable population (the smallest population with a 95% probability of surviving at least 100 years). Minimum area requirements for populations of this size range from 700 to 10,000 km.^{2}

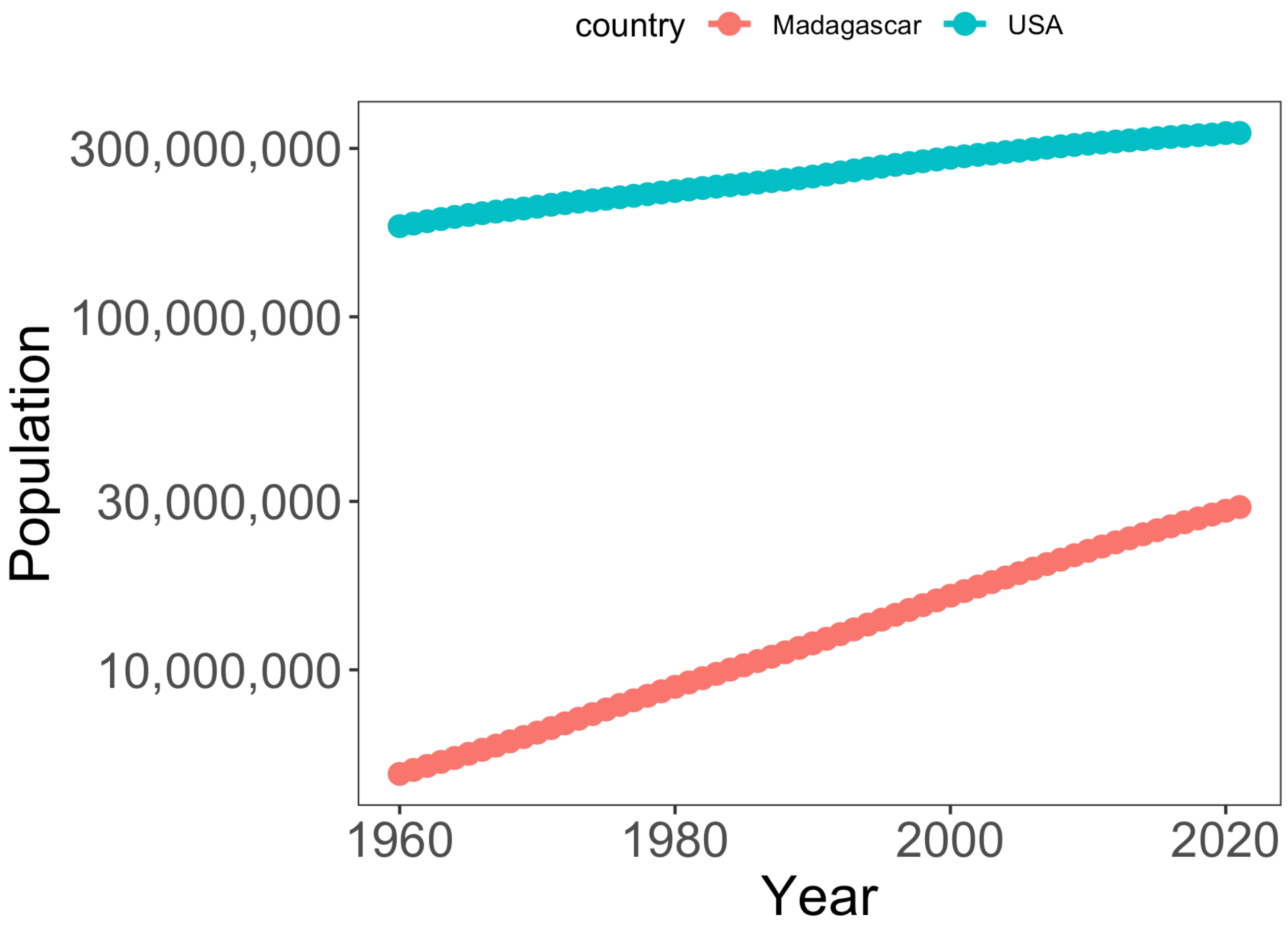
Int. Conf. Bear Res. and Manage. 5:133 – 139

to protect populations from extinction

Why do we care how populations grow?



Why do we care how populations grow?



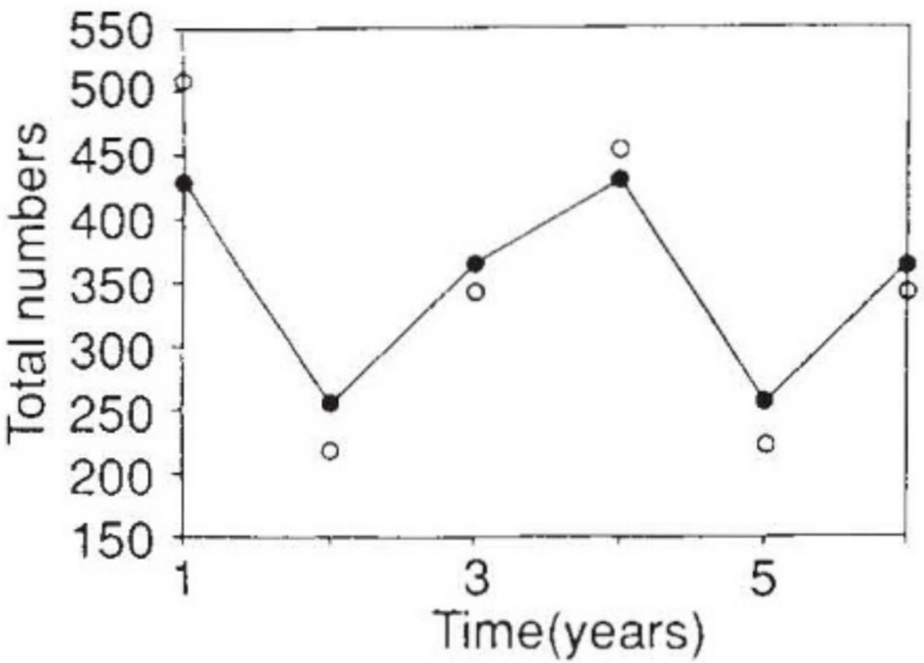
to forecast resource use

Why do we care how populations grow?

Soay Sheep of St. Kilda, Scotland

Why do we care how populations grow?

to understand past phenomena



Overcompensation and population cycles in an ungulate

B. T. Grenfell, O. F. Price, S. D. Albon & T. H. Glutton-Brock

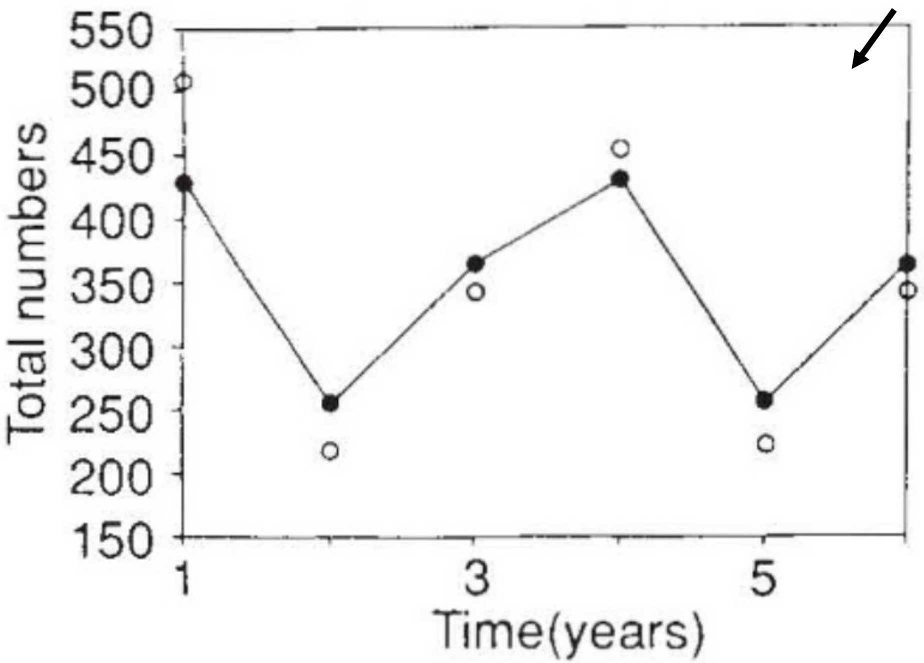
Nature **355**, 823–826 (1992) | Cite this article

589 Accesses | **107** Citations | Metrics

Why do we care how populations grow?

Model compared against data

to understand past phenomena



Overcompensation and population cycles in an ungulate

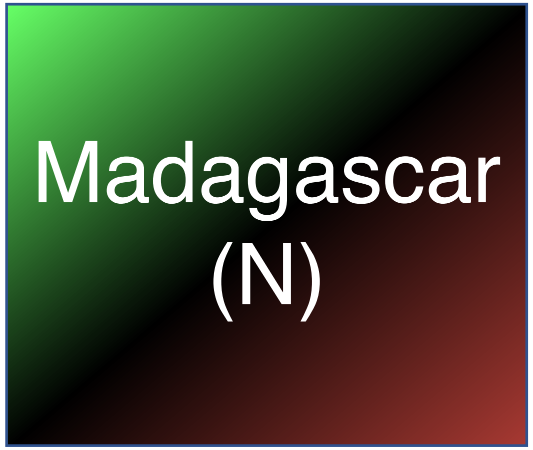
B. T. Grenfell, O. F. Price, S. D. Albon & T. H. Glutton-Brock

Nature **355**, 823–826 (1992) | Cite this article

589 Accesses | **107** Citations | Metrics

The simplest population model

1. Populations are divided into compartments
2. Individuals within a compartment are homogenously mixed
3. Compartments and transition rates are determined by biological systems
4. Rates of transferring between compartments are expressed mathematically



The simplest population model

1. Populations are divided into compartments
2. Individuals within a compartment are homogenously mixed
3. Compartments and transition rates are determined by biological systems
4. Rates of transferring between compartments are expressed mathematically

Madagascar
(N)

The simplest population model

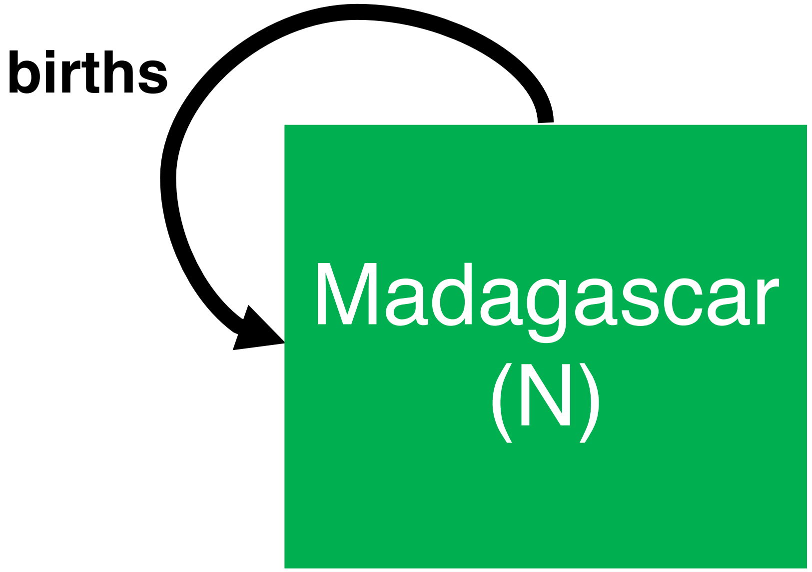
1. Populations are divided into compartments
2. Individuals within a compartment are homogenously mixed
3. Compartments and transition rates are determined by biological systems
4. Rates of transferring between compartments are expressed mathematically

Madagascar
(N)

How does the population grow?

The simplest population model

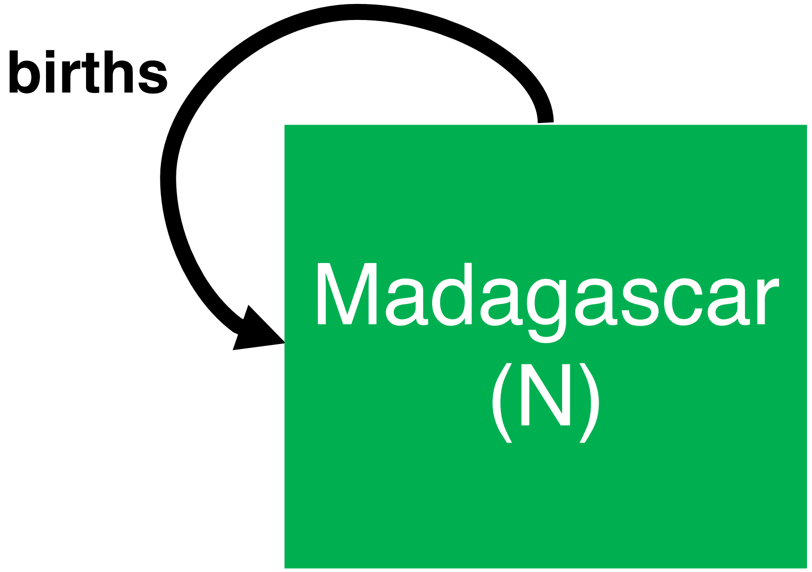
1. Populations are divided into compartments
2. Individuals within a compartment are homogenously mixed
3. Compartments and transition rates are determined by biological systems
4. Rates of transferring between compartments are expressed mathematically



How does the population grow?

The simplest population model

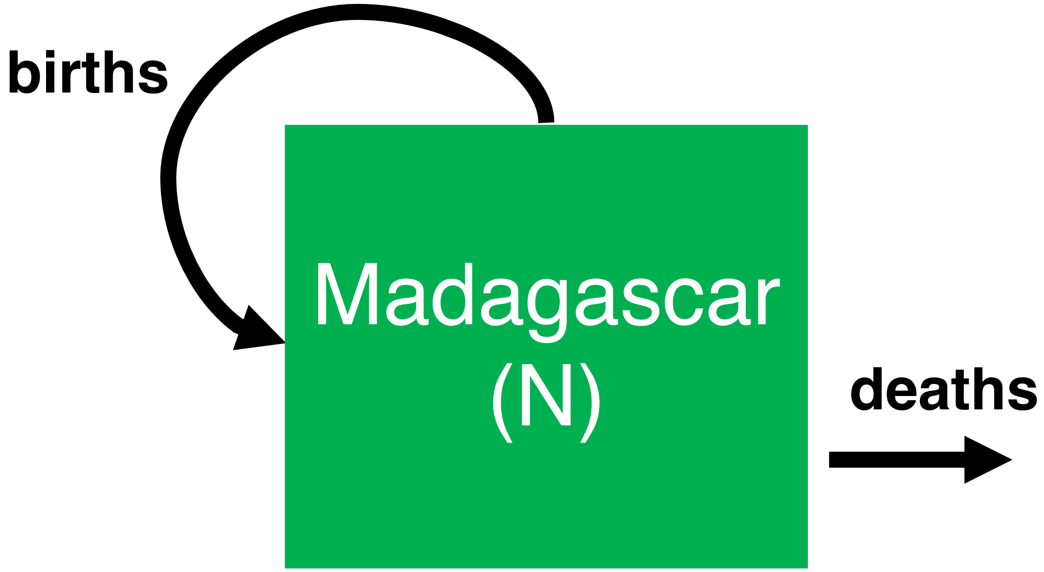
1. Populations are divided into compartments
2. Individuals within a compartment are homogenously mixed
3. Compartments and transition rates are determined by biological systems
4. Rates of transferring between compartments are expressed mathematically



How does the population decrease?

The simplest population model

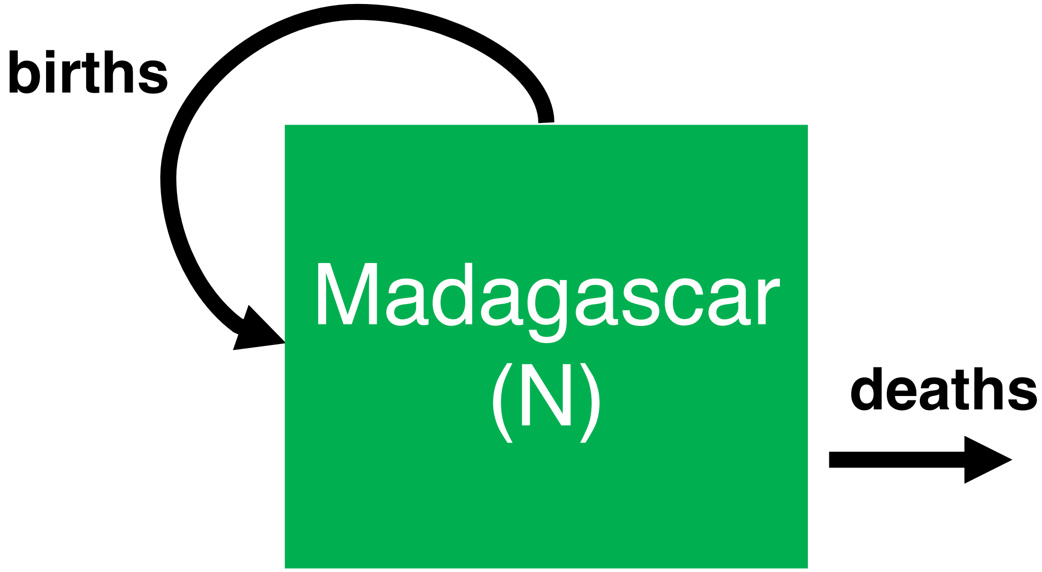
1. Populations are divided into compartments
2. Individuals within a compartment are homogenously mixed
3. Compartments and transition rates are determined by biological systems
4. Rates of transferring between compartments are expressed mathematically



How does the population decrease?

The simplest population model

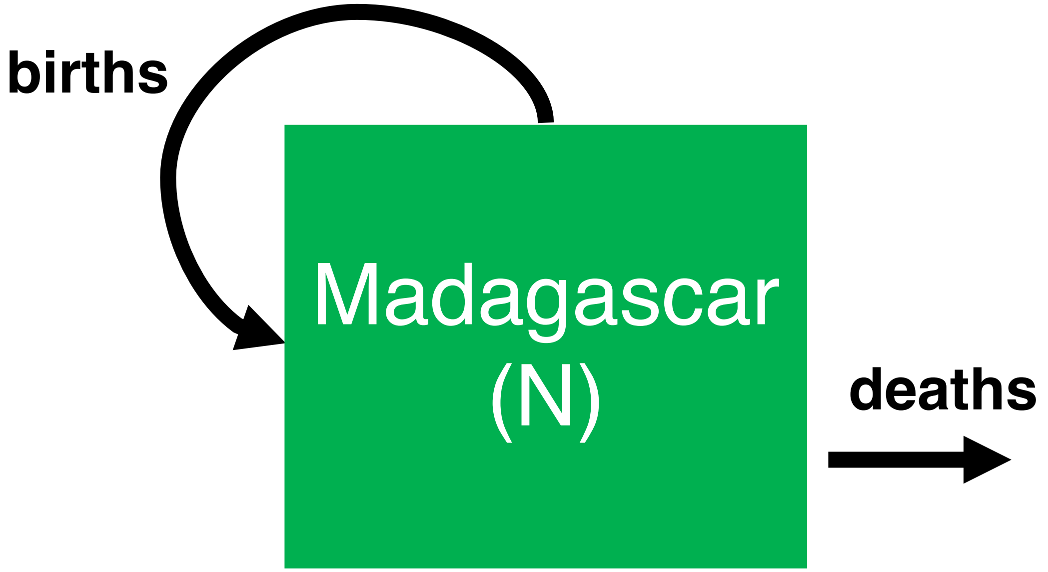
1. Populations are divided into compartments
2. Individuals within a compartment are homogenously mixed
3. Compartments and transition rates are determined by biological systems
4. Rates of transferring between compartments are expressed mathematically



$$N_{t+1} = N_t + \text{births}*N_t - \text{deaths}*N_t$$

The simplest population model

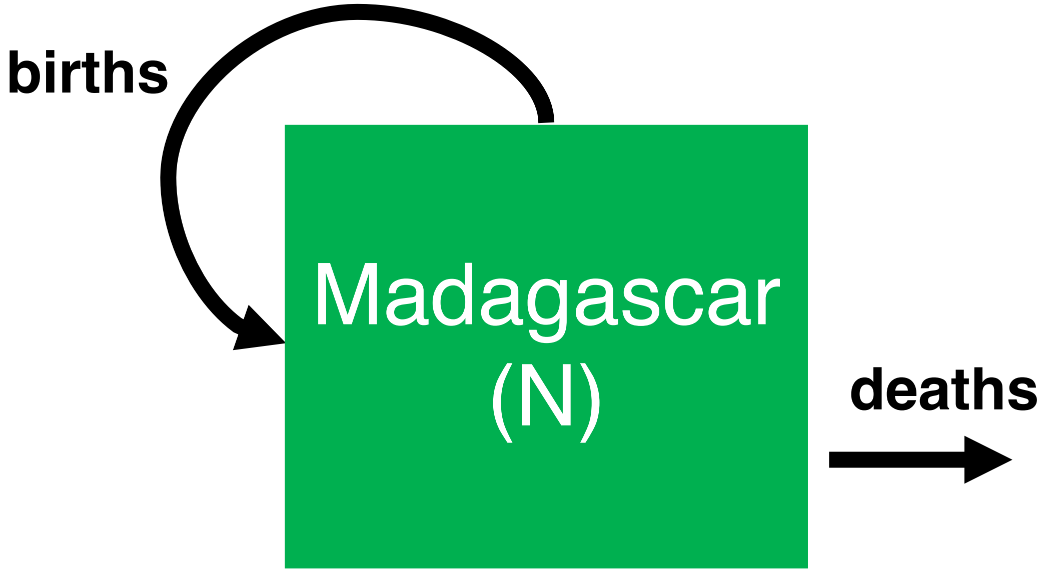
1. Populations are divided into compartments
2. Individuals within a compartment are homogenously mixed
3. Compartments and transition rates are determined by biological systems
4. Rates of transferring between compartments are expressed mathematically



$$N_{t+1} = N_t + \text{births}^*N_t - \text{deaths}^*N_t$$
$$N_{t+1} = N_t + (\text{births}-\text{deaths})^*N_t$$

The simplest population model

1. Populations are divided into compartments
2. Individuals within a compartment are homogenously mixed
3. Compartments and transition rates are determined by biological systems
4. Rates of transferring between compartments are expressed mathematically



$$N_{t+1} = N_t + \text{births}*N_t - \text{deaths}*N_t$$
$$N_{t+1} = N_t + (\text{births}-\text{deaths})*N_t$$
$$N_{t+1} = N_t + R*N_t$$

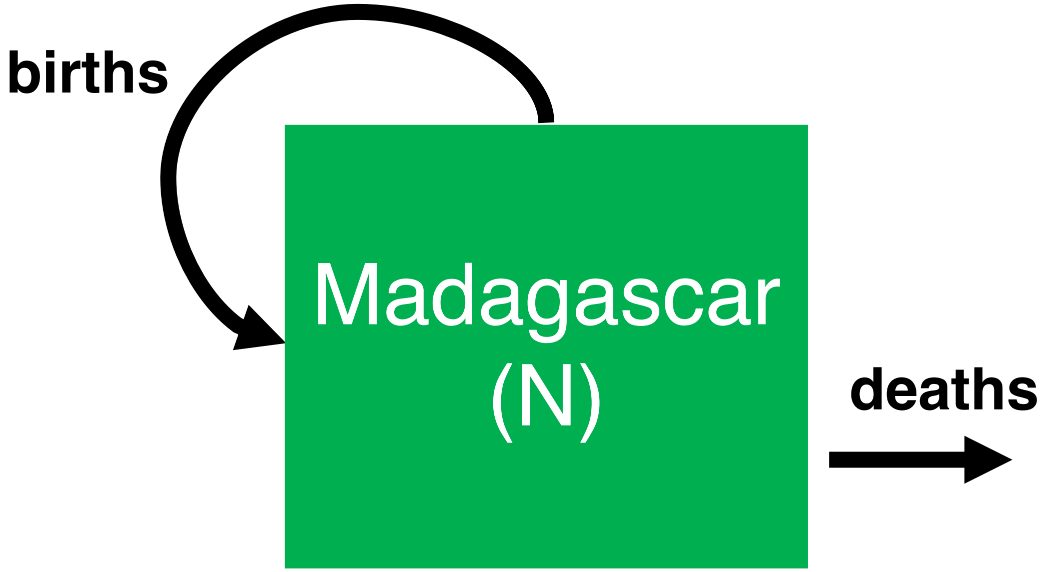
R=geometric rate of increase

R = (births – deaths)

(pop grows @ R > 0 & declines @ R < 0)

The simplest population model

1. Populations are divided into compartments
2. Individuals within a compartment are homogenously mixed
3. Compartments and transition rates are determined by biological systems
4. Rates of transferring between compartments are expressed mathematically



$$N_{t+1} = N_t + \text{births}*N_t - \text{deaths}*N_t$$

$$N_{t+1} = N_t + R*N_t$$

$$N_{t+1} = (1 + R)*N_t$$

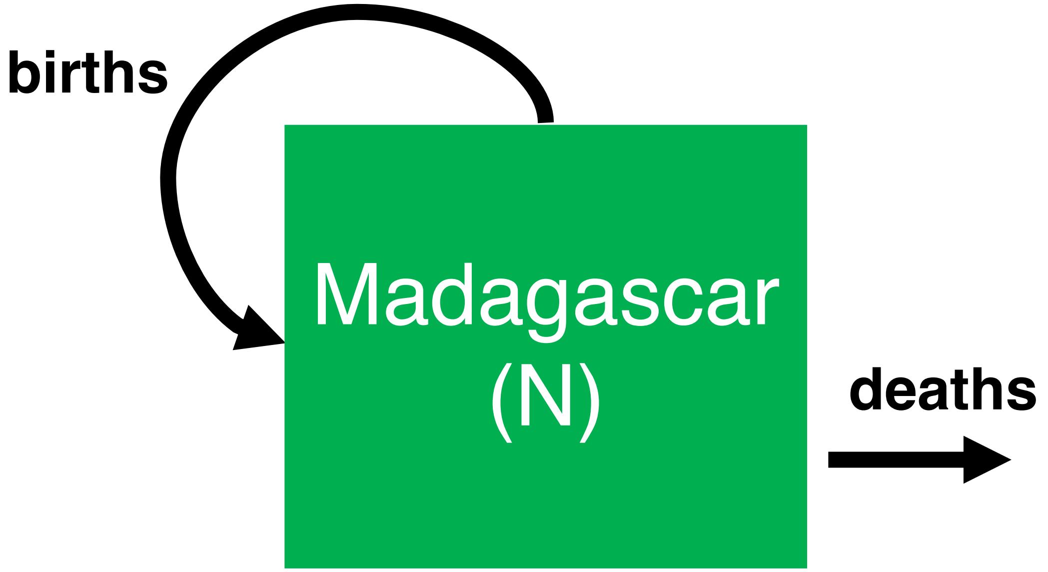
$$N_{t+1} = \lambda * N_t$$

λ= population rate of increase (finite growth rate)

λ=1+R

The simplest population model

1. Populations are divided into compartments
2. Individuals within a compartment are homogenously mixed
3. Compartments and transition rates are determined by biological systems
4. Rates of transferring between compartments are expressed mathematically



$$N_{t+1} = N_t + \text{births}*N_t - \text{deaths}*N_t$$

$$N_{t+1} = N_t + R*N_t$$

$$N_{t+1} = (1 + R)*N_t$$

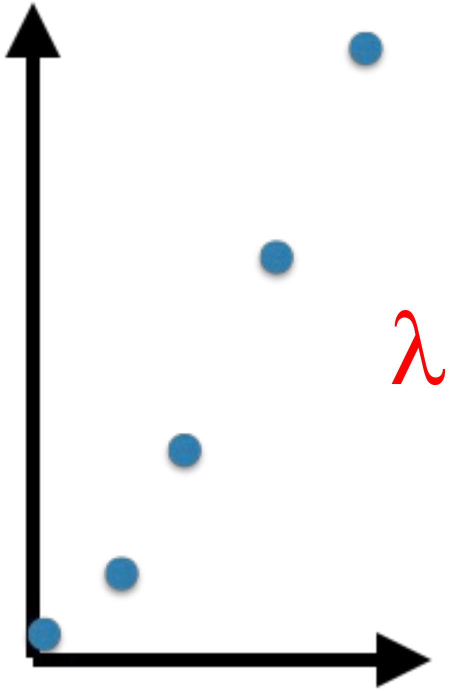
$$N_{t+1} = \lambda*N_t$$

λ= population rate of increase (finite growth rate)

(pop grows @ $\lambda > 1$ & declines @ $\lambda < 1$)

Geometric growth

Geometric growth is measured in <u>discrete</u> time



$$\lambda = N_{t+1}/N_t$$

$N_1 = \lambda N_0$

$N_2 = \lambda[\lambda N_0] = \lambda^2 N_0$

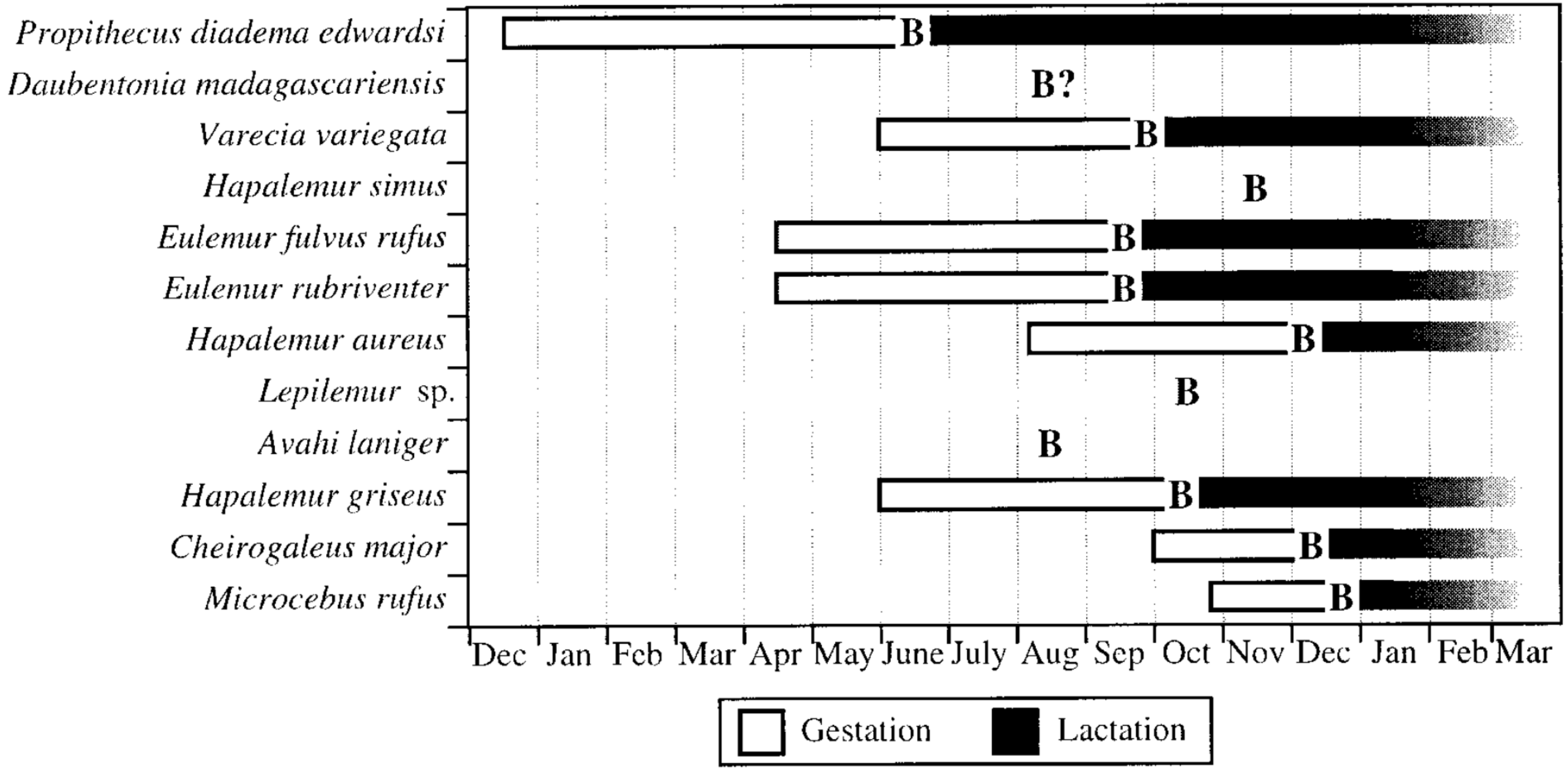
$N_3 = \lambda^3 N_0$

$N_t = \lambda^t N_0$

λ=population rate of increase

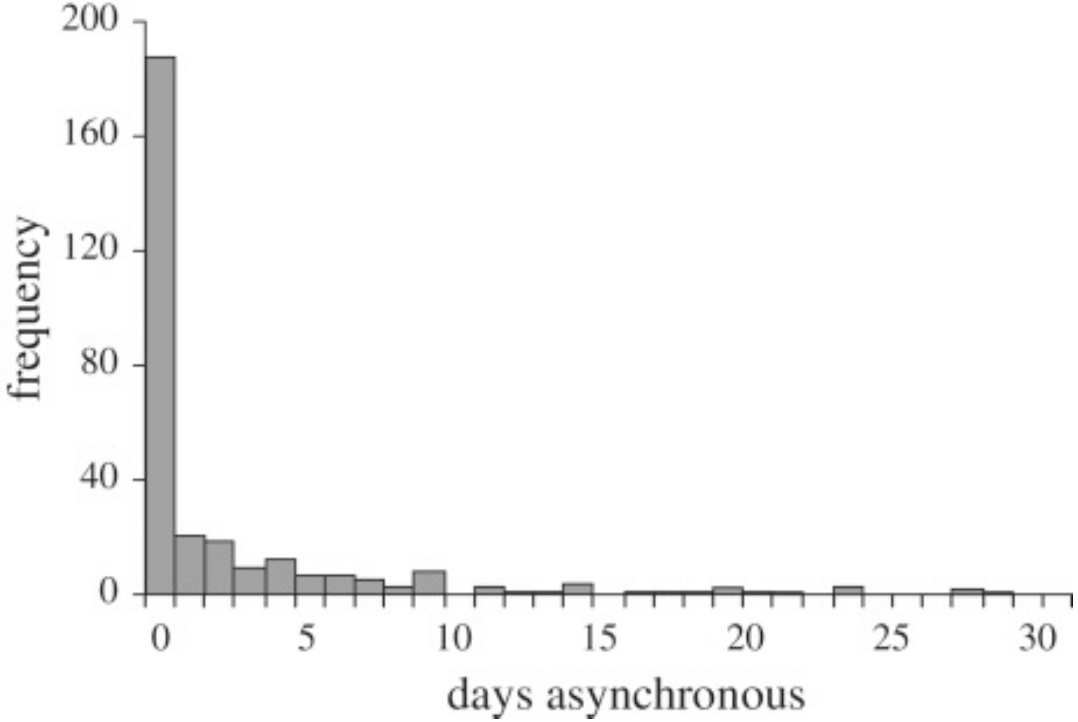
Is discrete time realistic for population growth?

Is discrete time realistic for population growth?



Wright 1999. *Am J of Phys Anthr.*

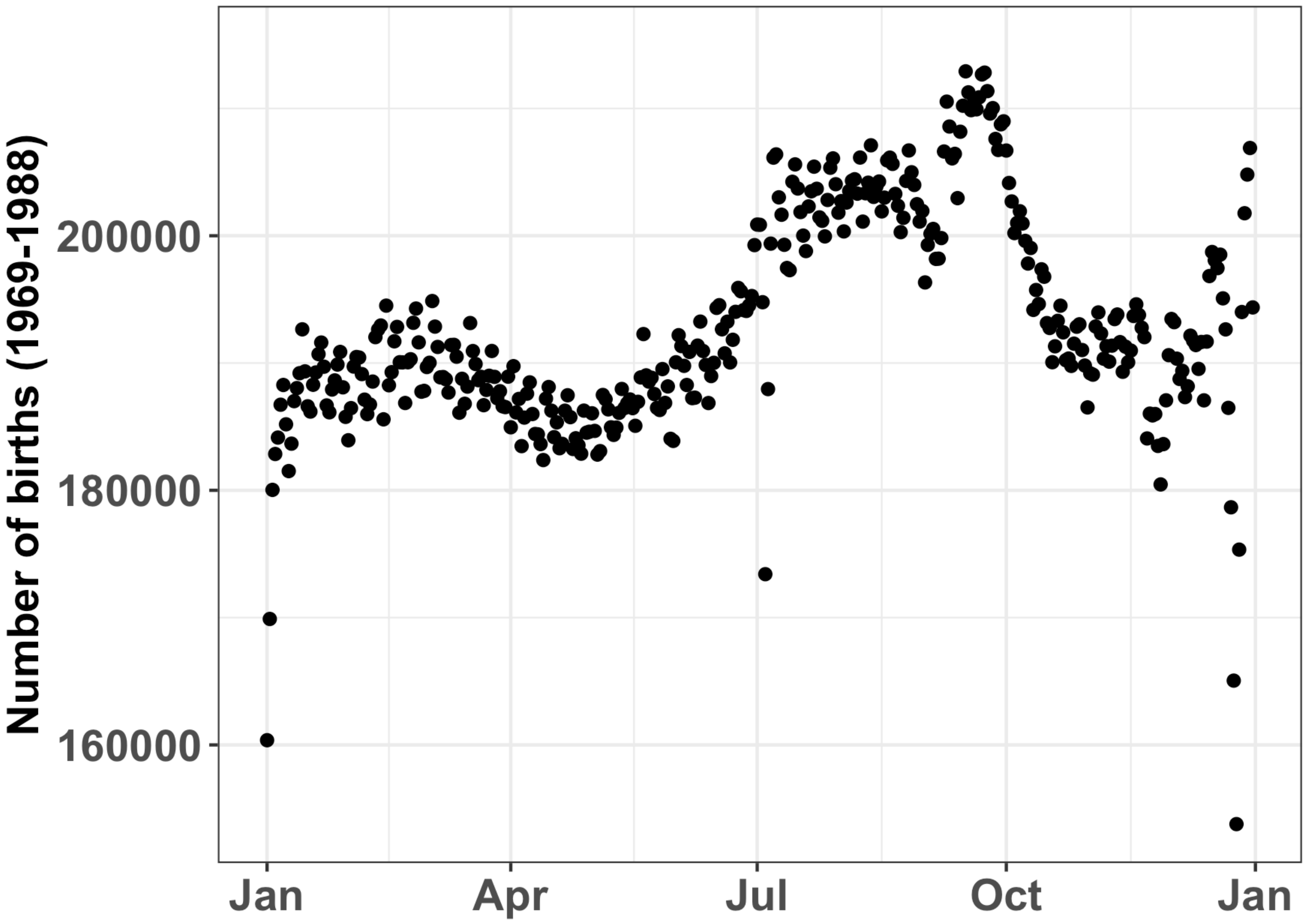
Is discrete time realistic for population growth?



64% of banded mongoose pups are born on the same day.

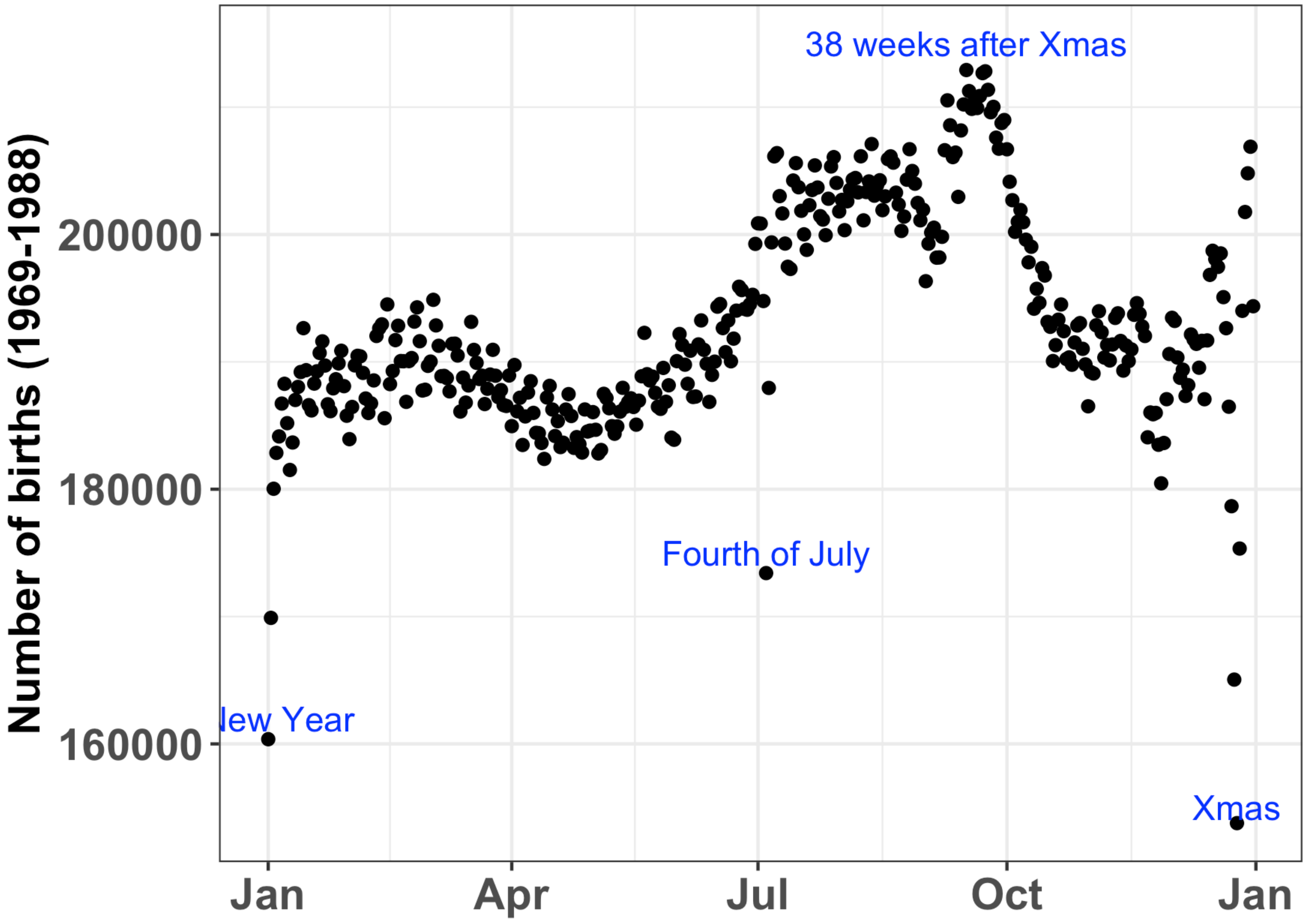
Hodge et al. 2011. *Biology Letters.*

Is discrete time realistic for population growth?



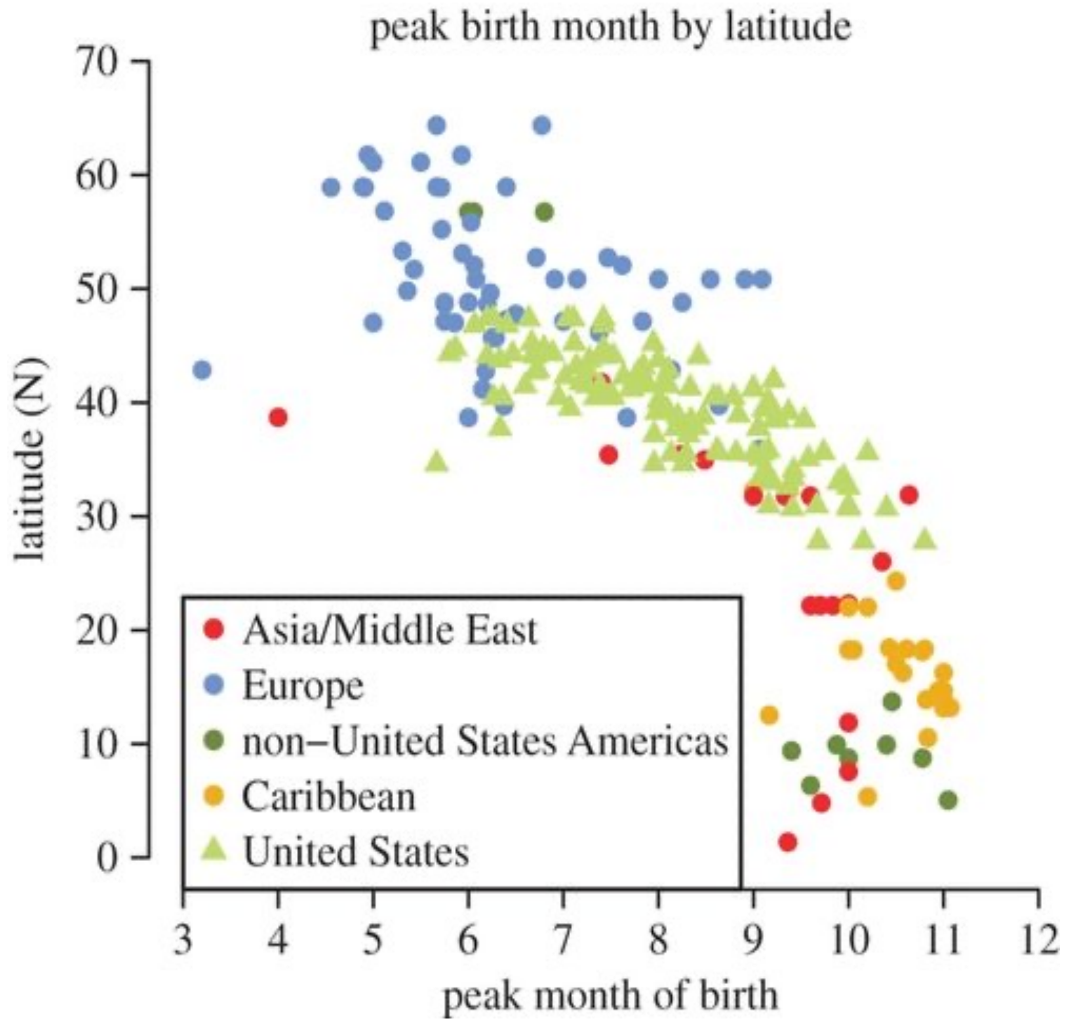
Human births by day in the US (1969-1988)

Is discrete time realistic for population growth?



Human births by day in the US (1969-1988)

Is discrete time realistic for population growth?

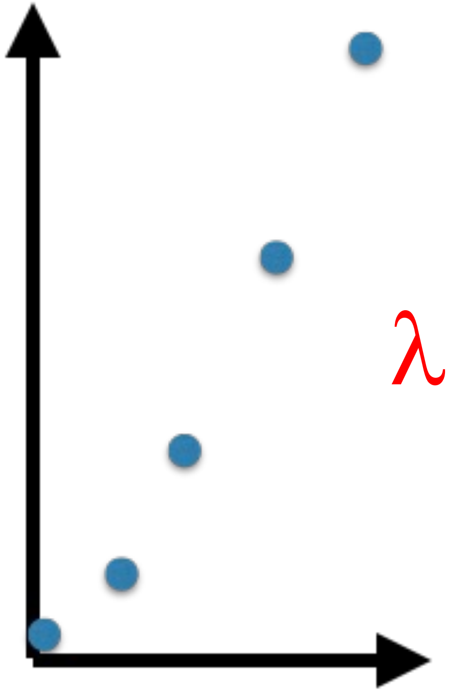


Many populations (including human) are better approximated by an assumption of a continuous birth rate

Martinez-Bakker et al. 2014. *Proc Roy Soc B.*

Geometric vs. exponential growth

Geometric growth

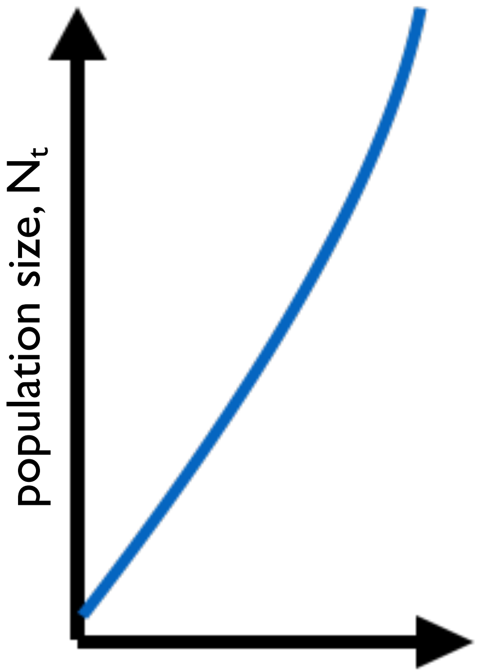


$\lambda = N_{t+1}/N_t$

$N_1 = \lambda N_0$
$N_2 = \lambda[\lambda N_0] = \lambda^2 N_0$
$N_3 = \lambda^3 N_0$
$N_t = \lambda^t N_0$

λ=population rate of increase

Exponential growth is measured in <u>continuous</u> time



!as $t \rightarrow 0$

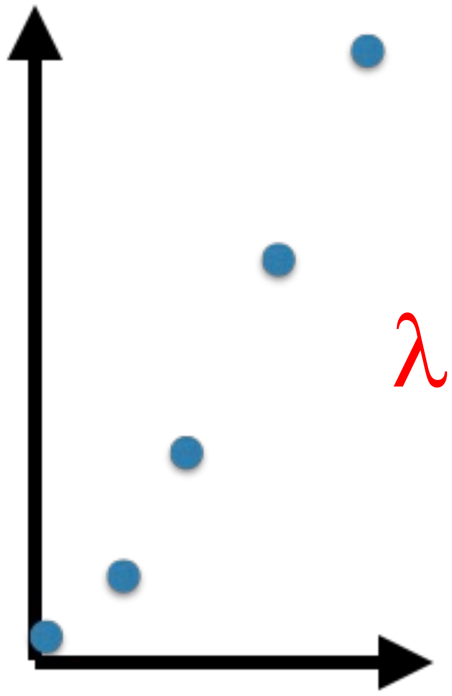
$$r = \frac{\ln\left(\frac{N_t}{N_0}\right)}{t}$$

$dN(t)/dt = rN(t)$

r=intrinsic (instantaneous) rate of increase

Geometric vs. exponential growth

Discrete time



$$\lambda = N_{t+1}/N_t$$

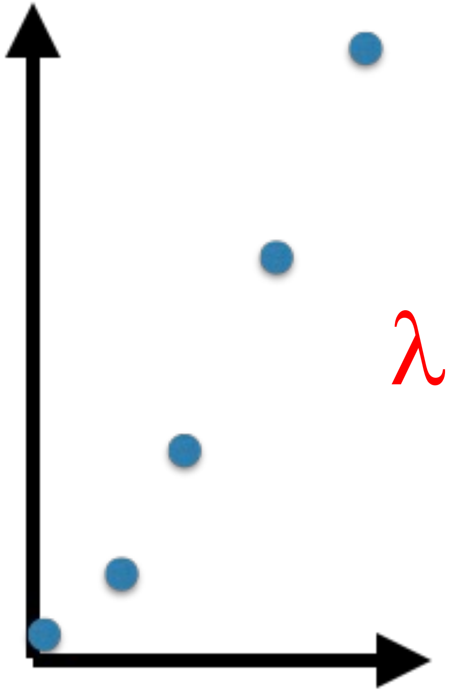
$N_1 = \lambda N_0$
$N_2 = \lambda[\lambda N_0] = \lambda^2 N_0$
$N_3 = \lambda^3 N_0$
$N_t = \lambda^t N_0$

Continuous time

$dN(t)/dt = rN(t)$

Geometric vs. exponential growth

Discrete time



$\color{red}{\lambda}=N_{t+1}/N_t$

$N_1= \lambda N_0$
$N_2= \lambda[\lambda N_0]=\lambda^2 N_0$
$N_3= \lambda^3 N_0$
$\color{red}{N_t= \lambda^t N_0}$

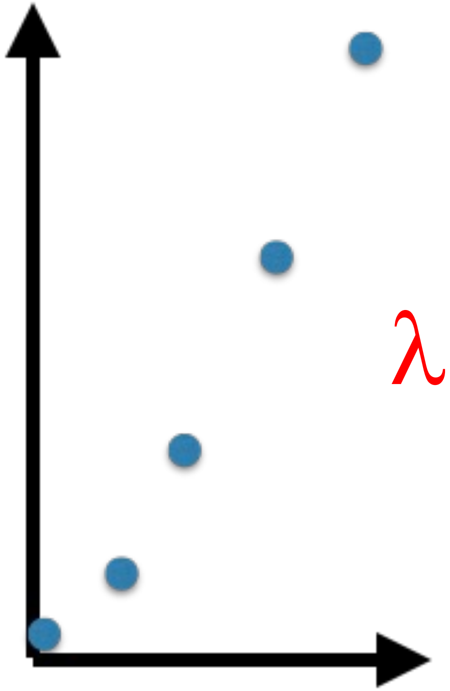
Continuous time

$dN(t)/dt = rN(t)$

Separation of variables:
$dN(t)/N(t) = r\, dt$

Geometric vs. exponential growth

Discrete time



$\color{red}{\lambda}=N_{t+1}/N_t$

$N_1 = \lambda N_0$
$N_2 = \lambda[\lambda N_0] = \lambda^2 N_0$
$N_3 = \lambda^3 N_0$
$\color{red}{N_t = \lambda^t N_0}$

Continuous time

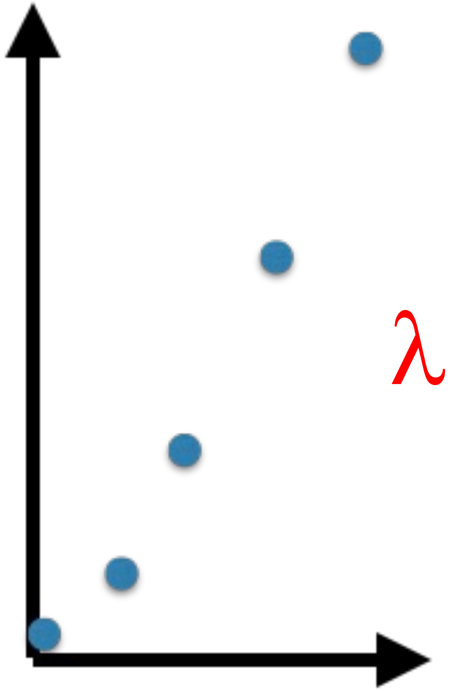
$dN(t)/dt = rN(t)$

Separation of variables:
$dN(t)/N(t) = r\, dt$

Integrate both sides:
$\int dN(t)/N(t) = \int r\, dt$

Geometric vs. exponential growth

Discrete time



$\color{red}{\lambda}=N_{t+1}/N_t$

$N_1= \lambda N_0$
$N_2= \lambda[\lambda N_0]=\lambda^2 N_0$
$N_3= \lambda^3 N_0$
$\color{red}{N_t= \lambda^t N_0}$

Continuous time

$dN(t)/dt = rN(t)$

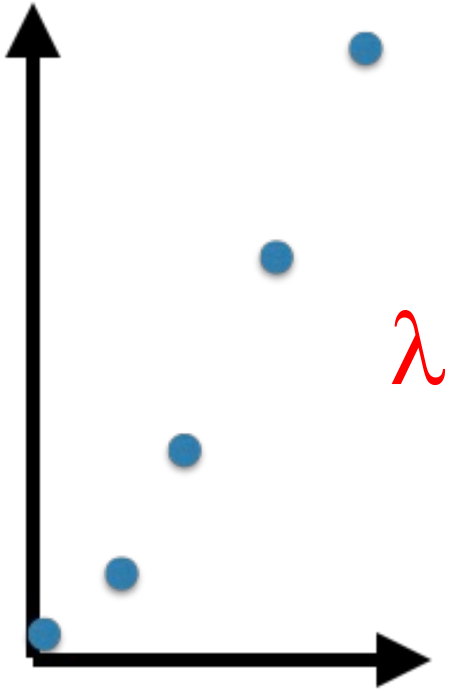
Separation of variables:
$dN(t)/N(t) = r\ dt$

Integrate both sides:
$\int dN(t)/N(t) = \int r\ dt$

By definition:
$\log(N(t)) = rt + c$

Geometric vs. exponential growth

Discrete time



$\color{red}{\lambda}=N_{t+1}/N_t$

$N_1= \lambda N_0$
$N_2= \lambda[\lambda N_0]=\lambda^2 N_0$
$N_3= \lambda^3 N_0$
$\color{red}{N_t= \lambda^t N_0}$

Continuous time

$dN(t)/dt = rN(t)$

Separation of variables:
$dN(t)/N(t) = r\ dt$

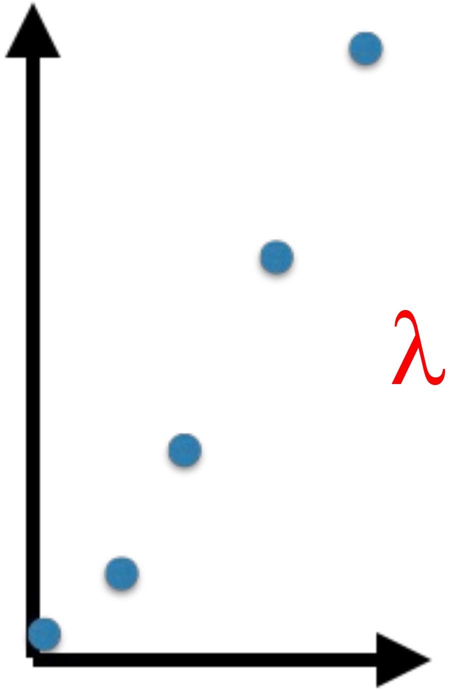
Integrate both sides:
$\int dN(t)/N(t) = \int r\ dt$

By definition:
$\log(N(t)) = rt + c$

Take exponentials:
$N(t) = e^{rt + c} = Ce^{rt}$
$\color{red}{N(t) = N(0)e^{rt}}$

Geometric vs. exponential growth

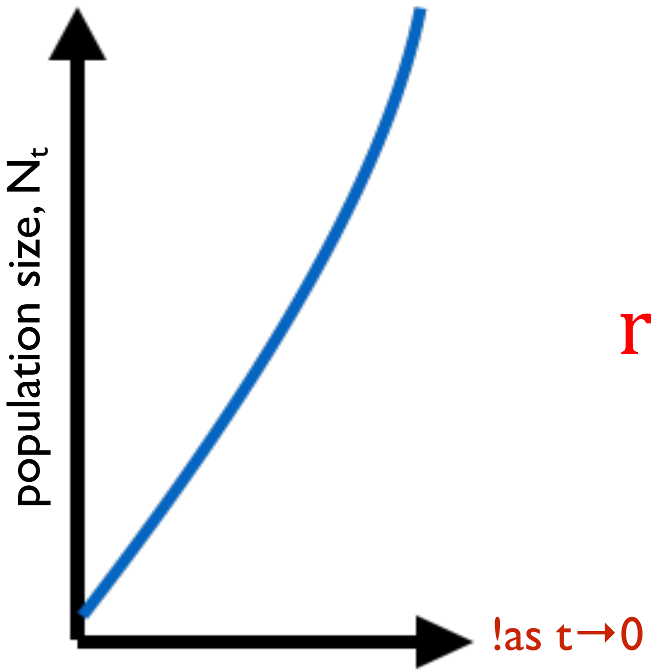
Discrete time



$\lambda = N_{t+1}/N_t$

$N_1 = \lambda N_0$
$N_2 = \lambda[\lambda N_0] = \lambda^2 N_0$
$N_3 = \lambda^3 N_0$
$N_t = \lambda^t N_0$

Continuous time



$$r = \frac{\ln\left(\frac{N_t}{N_0}\right)}{t}$$

$N_t = N_0 e^{rt}$

λ=population rate of increase

(pop grows @ λ >1 & declines @ λ < 1)

r=intrinsic (instantaneous) rate of increase

(pop grows @ $r > 0$ & declines @ $r < 0$)

Geometric vs. exponential growth

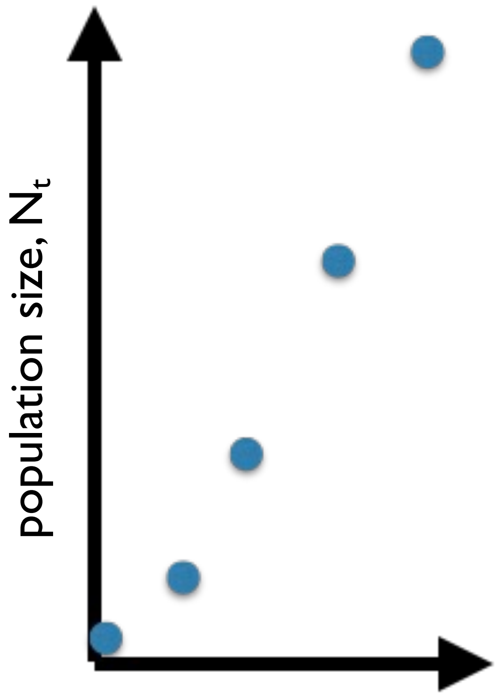
geometric

$N_t = \lambda^t N_0$

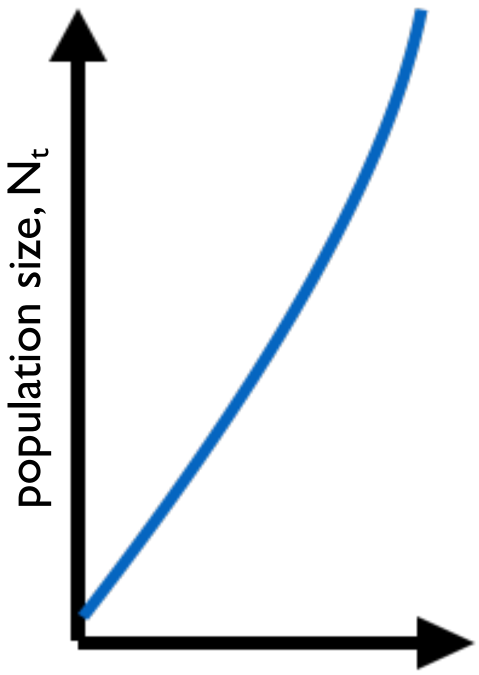
exponential

$N_t = N_0 e^{rt}$

Discrete time



Continuous time

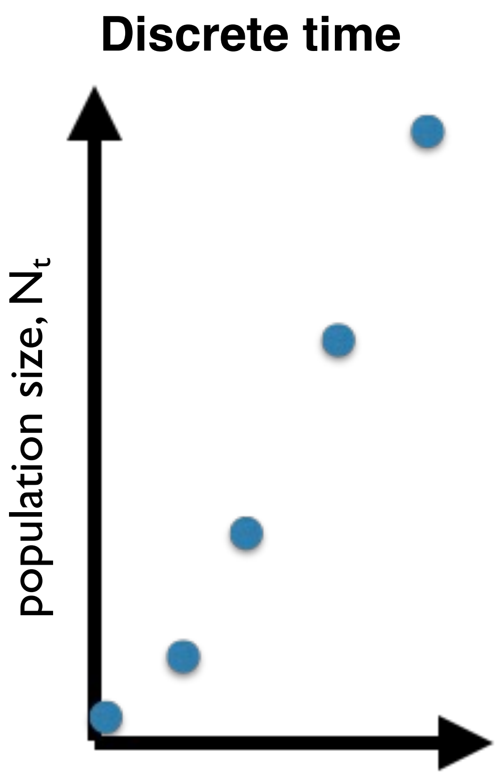


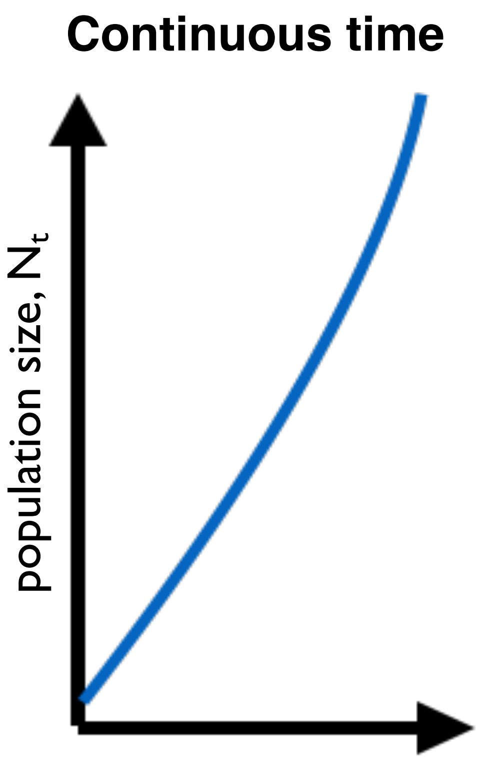
Geometric vs. exponential growth

geometric
$N_t = \lambda^t N_0$

exponential
$N_t = N_0 e^{rt}$

$\lambda^t N_0 = N_0 e^{rt}$



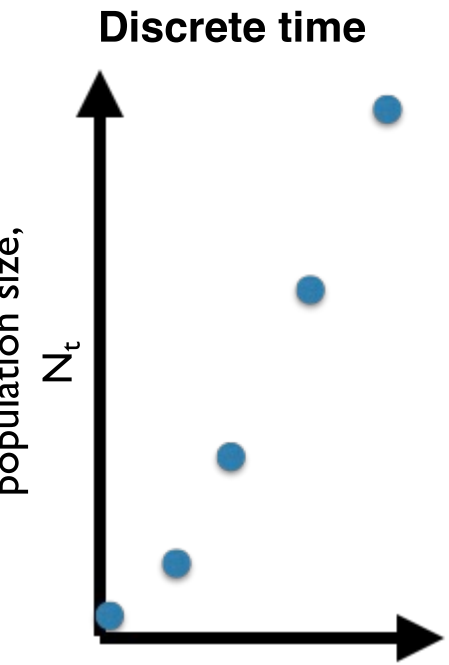


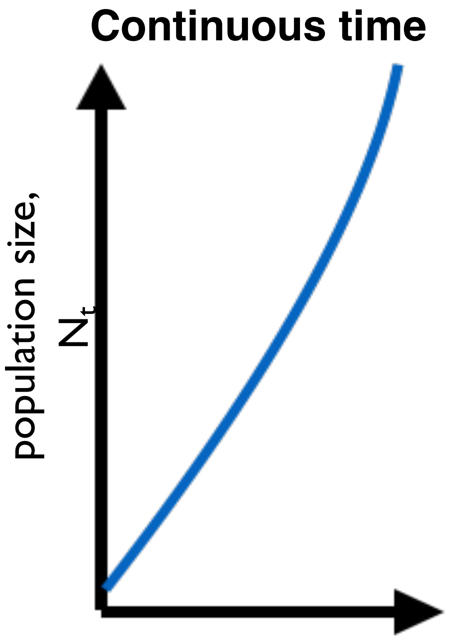
Geometric vs. exponential growth

geometric
$N_t = \lambda^t N_0$

exponential
$N_t = N_0 e^{rt}$

$\lambda^t N_0 = N_0 e^{rt}$
$\lambda^t = e^{rt}$



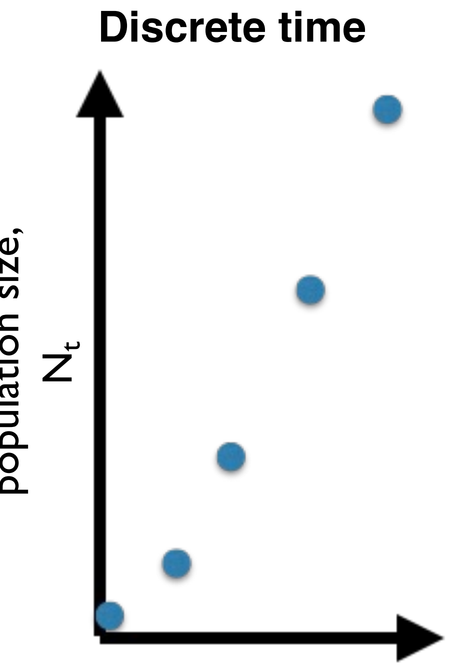


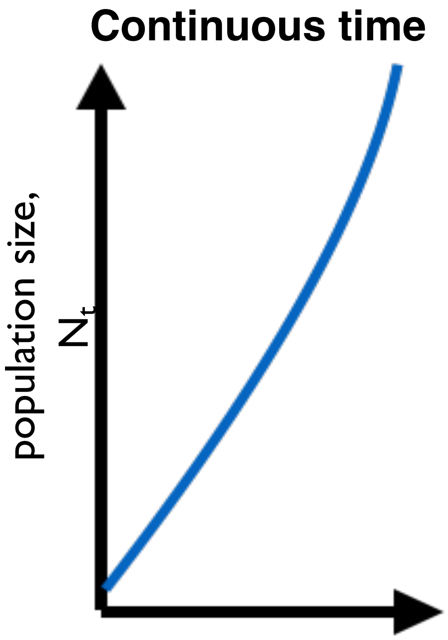
Geometric vs. exponential growth

geometric
$N_t = \lambda^t N_0$

exponential
$N_t = N_0 e^{rt}$

$\lambda^t N_0 = N_0 e^{rt}$
$\lambda^t = e^{rt}$
$\lambda = e^r$





Geometric vs. exponential growth

geometric

$N_t = \lambda^t N_0$

exponential

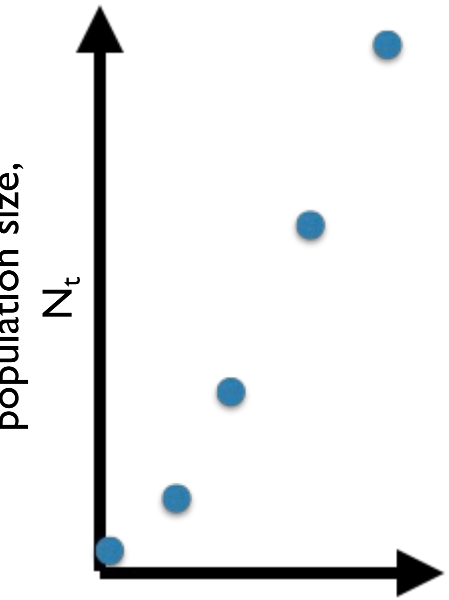
$N_t = N_0 e^{rt}$

$\lambda^t N_0 = N_0 e^{rt}$

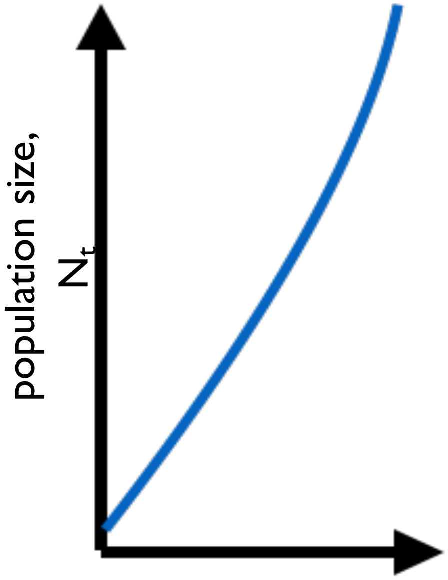
$\lambda^t = e^{rt}$

$\lambda = e^r$

Discrete time



Continuous time



Continuous models can be discretized.

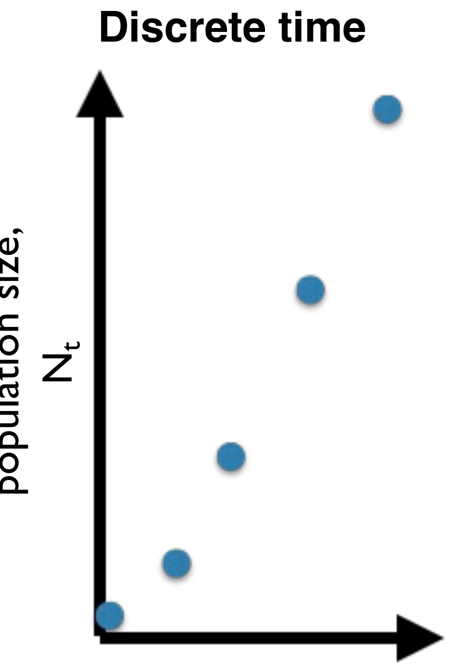
Discrete models can be approximated in continuous time.

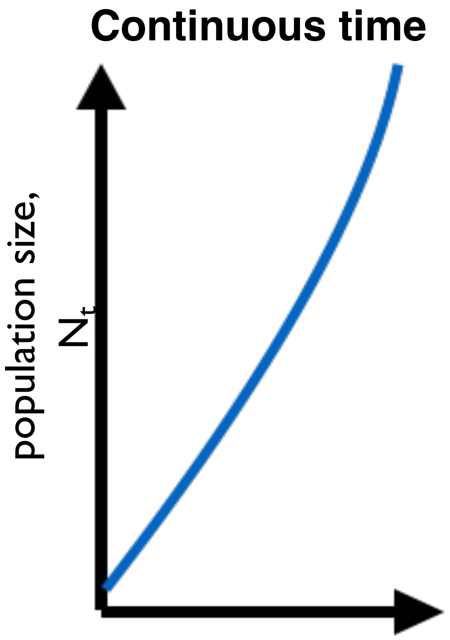
Geometric vs. exponential growth

geometric
$N_t = \lambda^t N_0$

exponential
$N_t = N_0 e^{rt}$

$\lambda^t N_0 = N_0 e^{rt}$
$\lambda^t = e^{rt}$
$\lambda = e^r$





Continuous models can be discretized.

Discrete models can be approximated in continuous time.

How to choose what to do?

Geometric vs. exponential growth

geometric

$N_t = \lambda^t N_0$

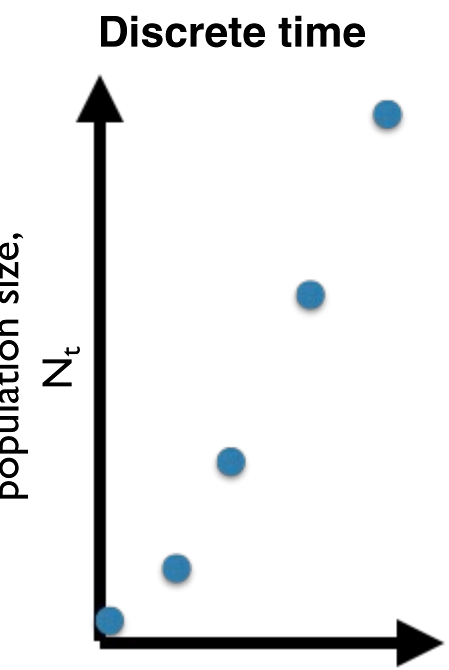
exponential

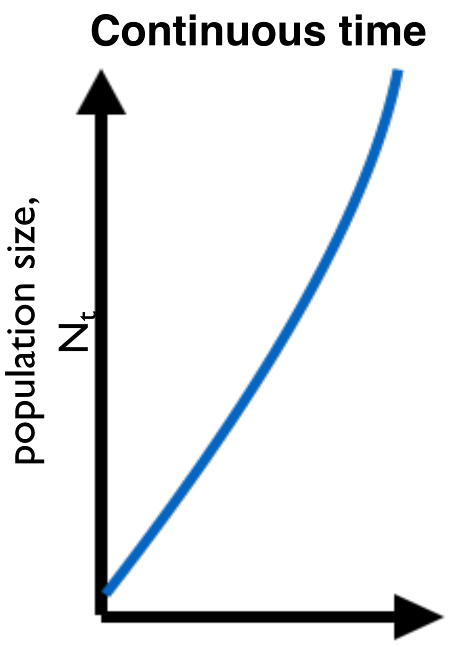
$N_t = N_0 e^{rt}$

$\lambda^t N_0 = N_0 e^{rt}$

$\lambda^t = e^{rt}$

$\lambda = e^r$





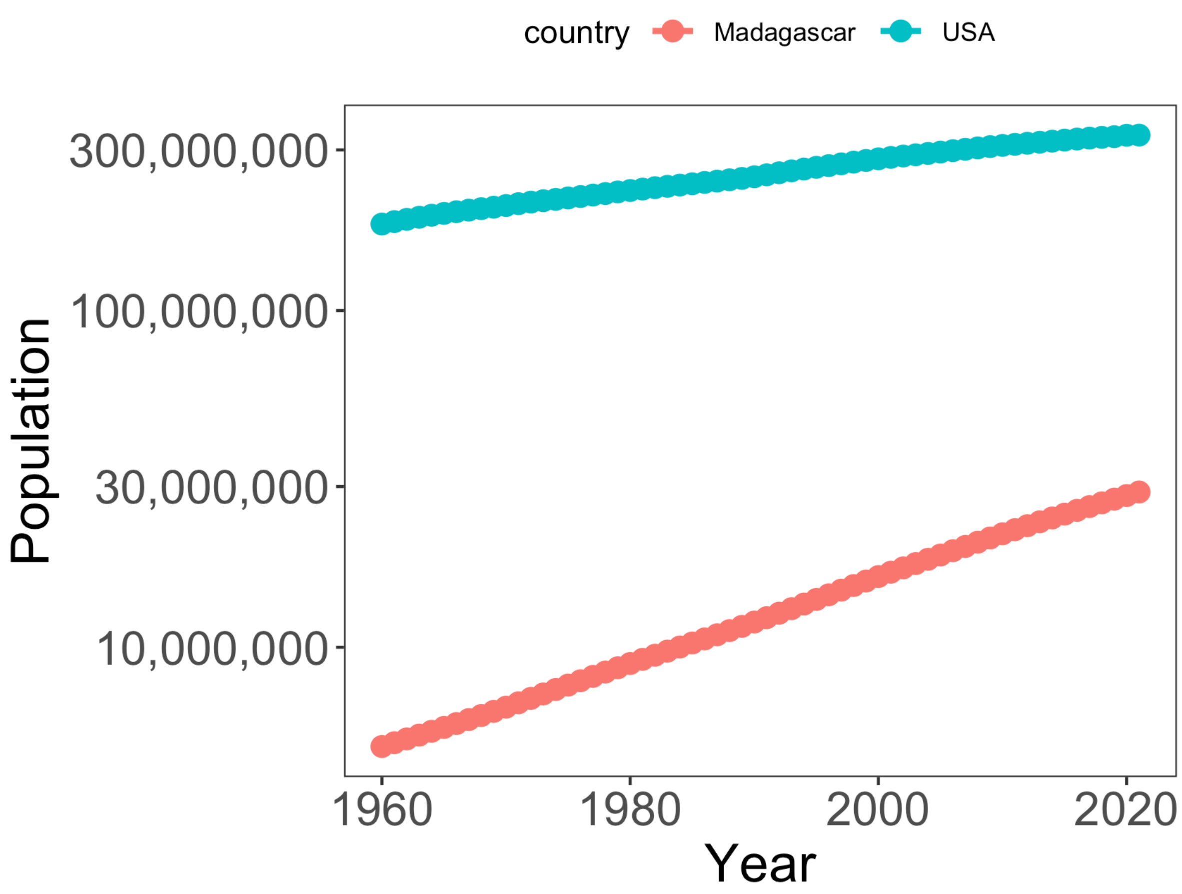
Continuous models can be discretized.

Discrete models can be approximated in continuous time.

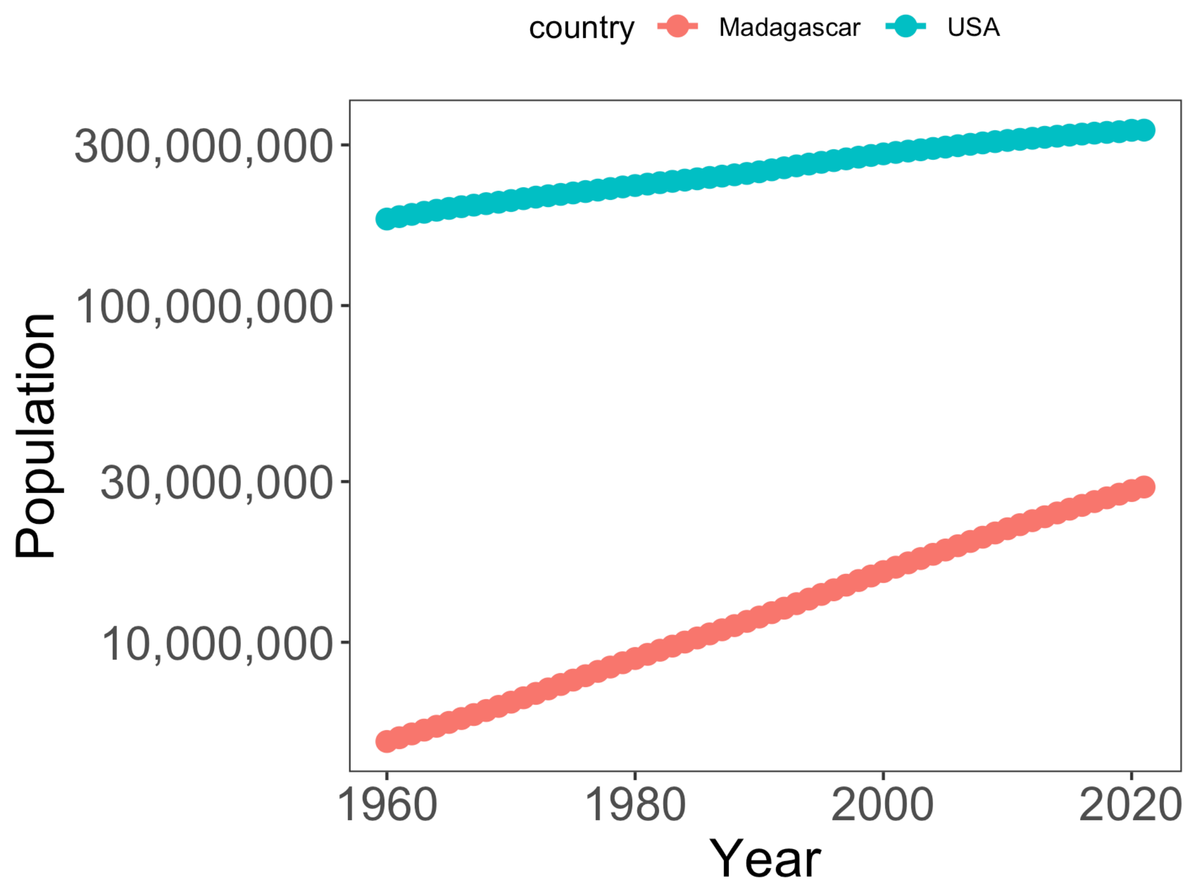
How to choose what to do?

The answer depends on the data and the question at hand!

Geometric vs. exponential growth



Geometric vs. exponential growth



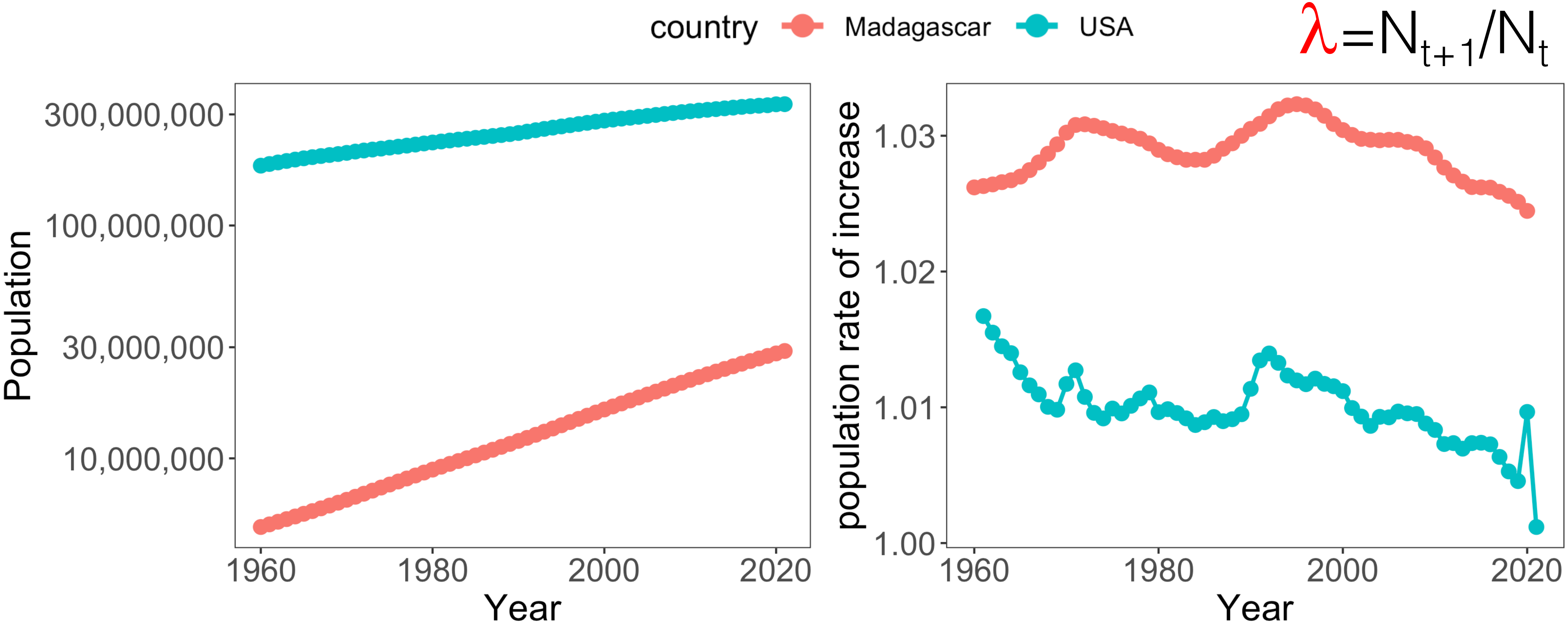
$\lambda = N_{t+1}/N_t$

where t = 1 year

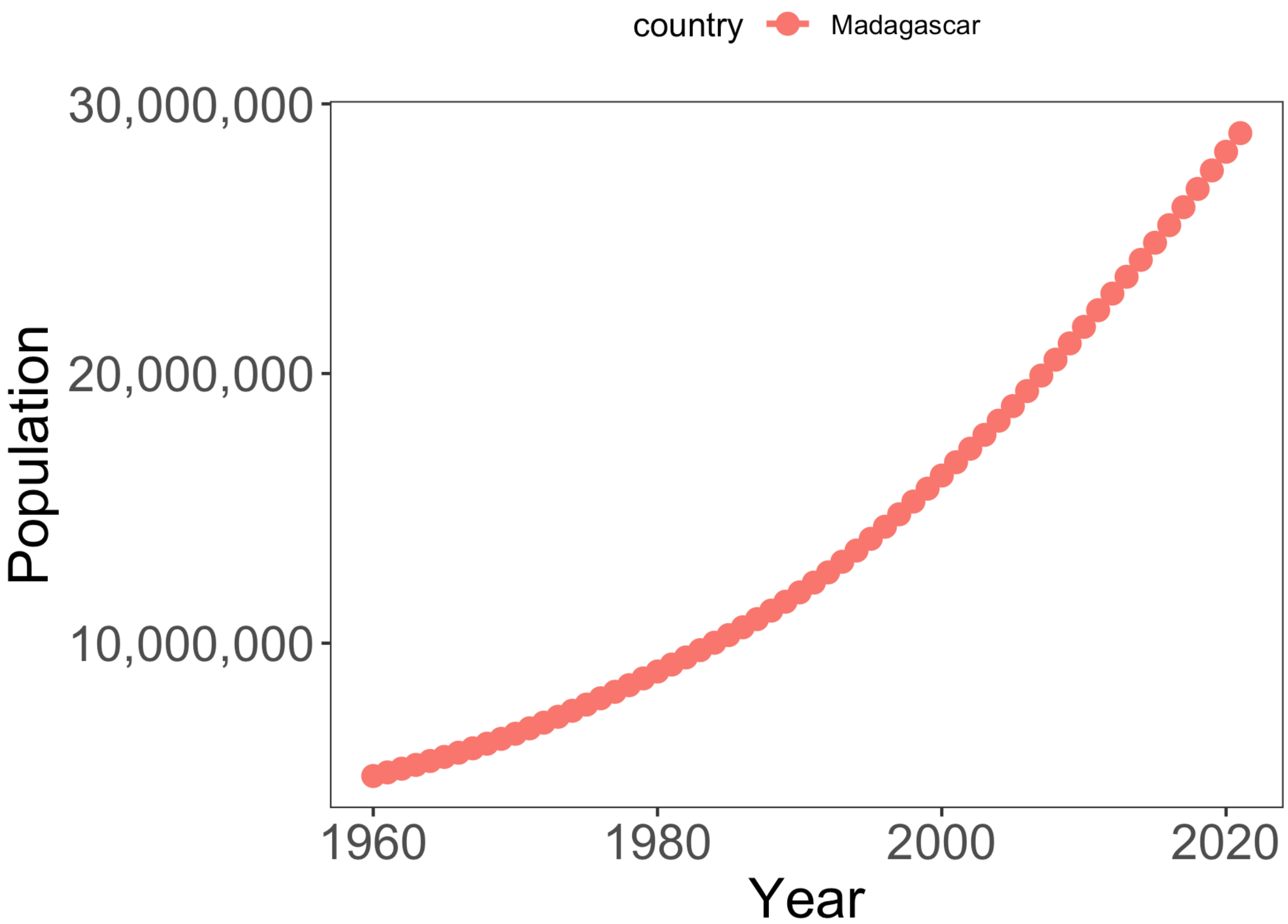
Which country has the higher growth rate?

Geometric vs. exponential growth

$\lambda = N_{t+1}/N_t$



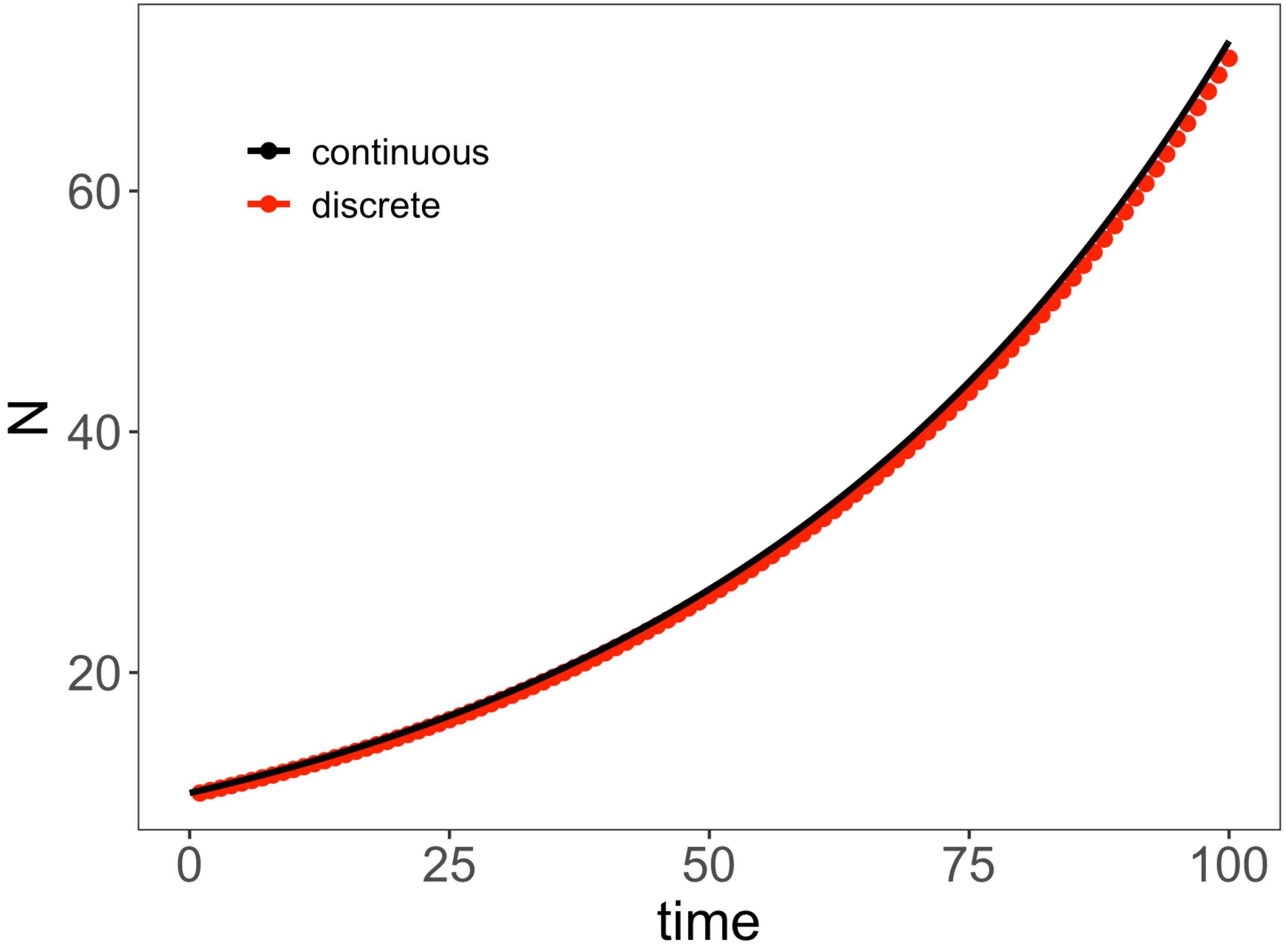
Geometric growth approximation of Madagascar's population



$\lambda = N_{t+1}/N_t$

mean λ = 1.02

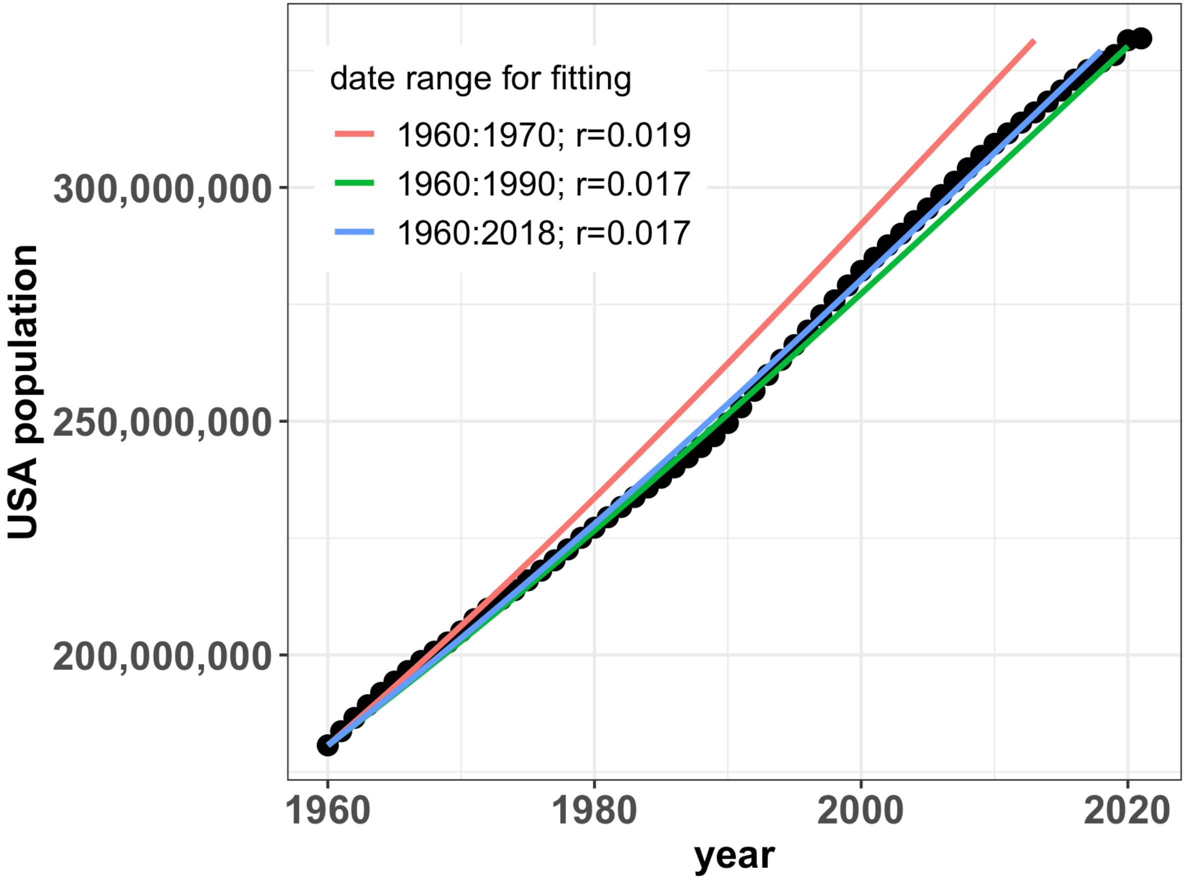
Projecting population under geometric vs. exponential growth



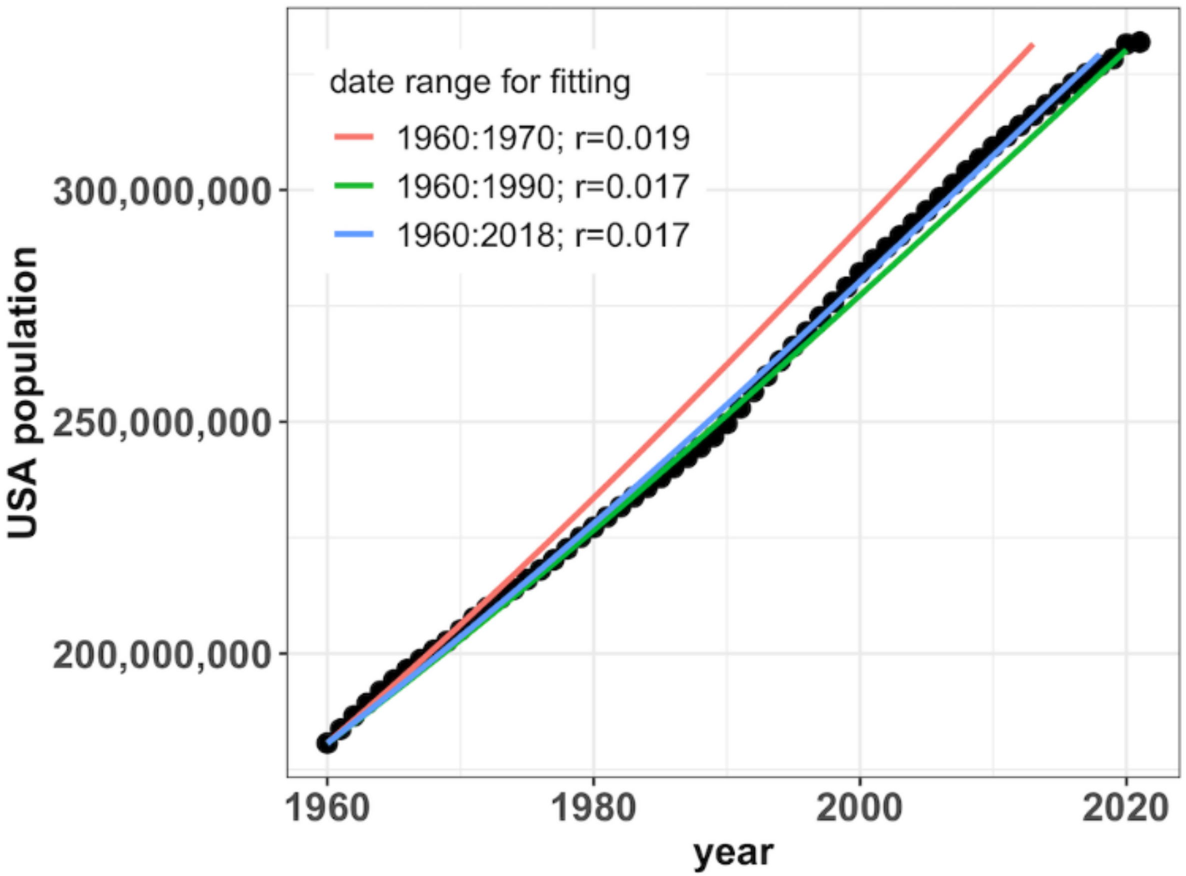
Geometric: λ = 1.02
Exponential: r = log(1.02) = 0.02

Models are similar over short time horizons and/or when discrete timesteps are small!

We can estimate growth rates by ‘fitting’ a model to data

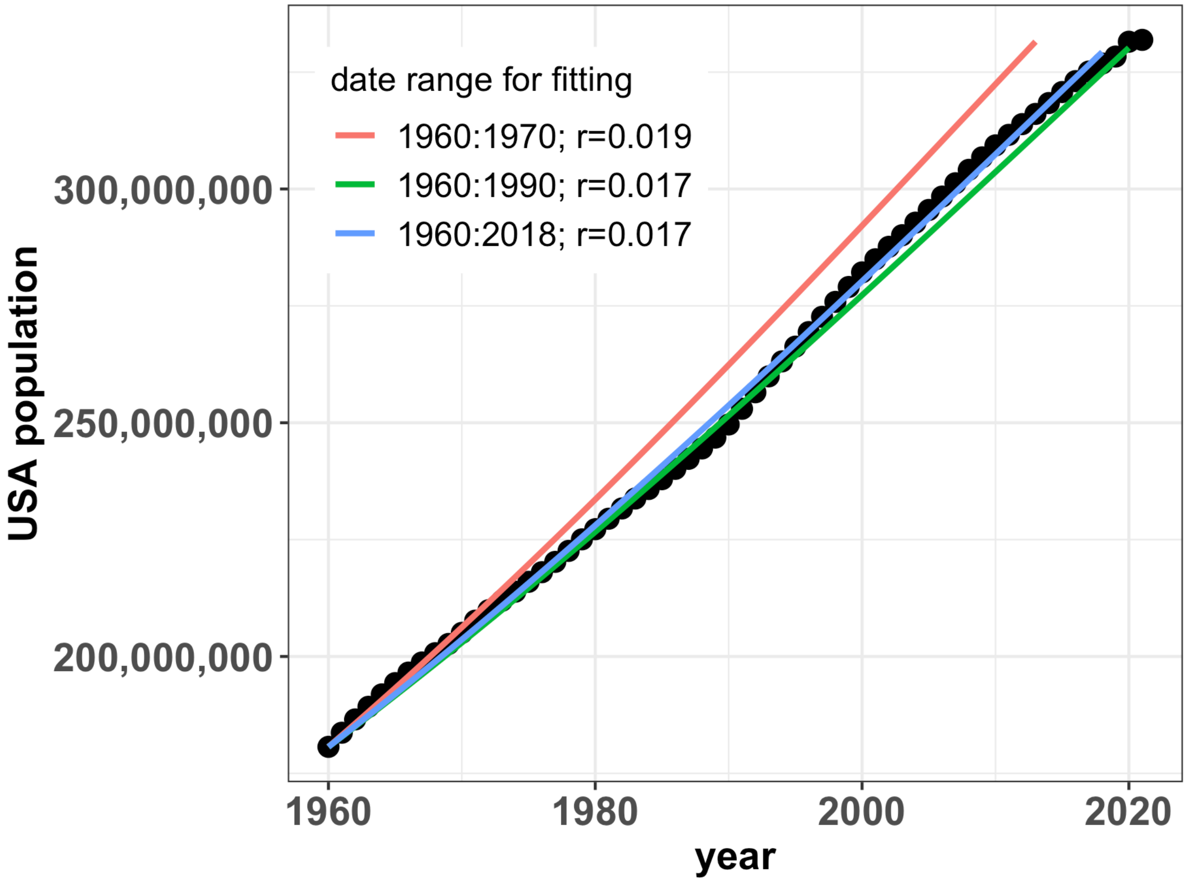


What does this plot suggest about the growth rate of the US population with time?



US growth rates slowed over time	0%
US growth rates increased over time	0%
US growth rates stayed stable over time	0%
Many people immigrated to the US in the 1980s	0%

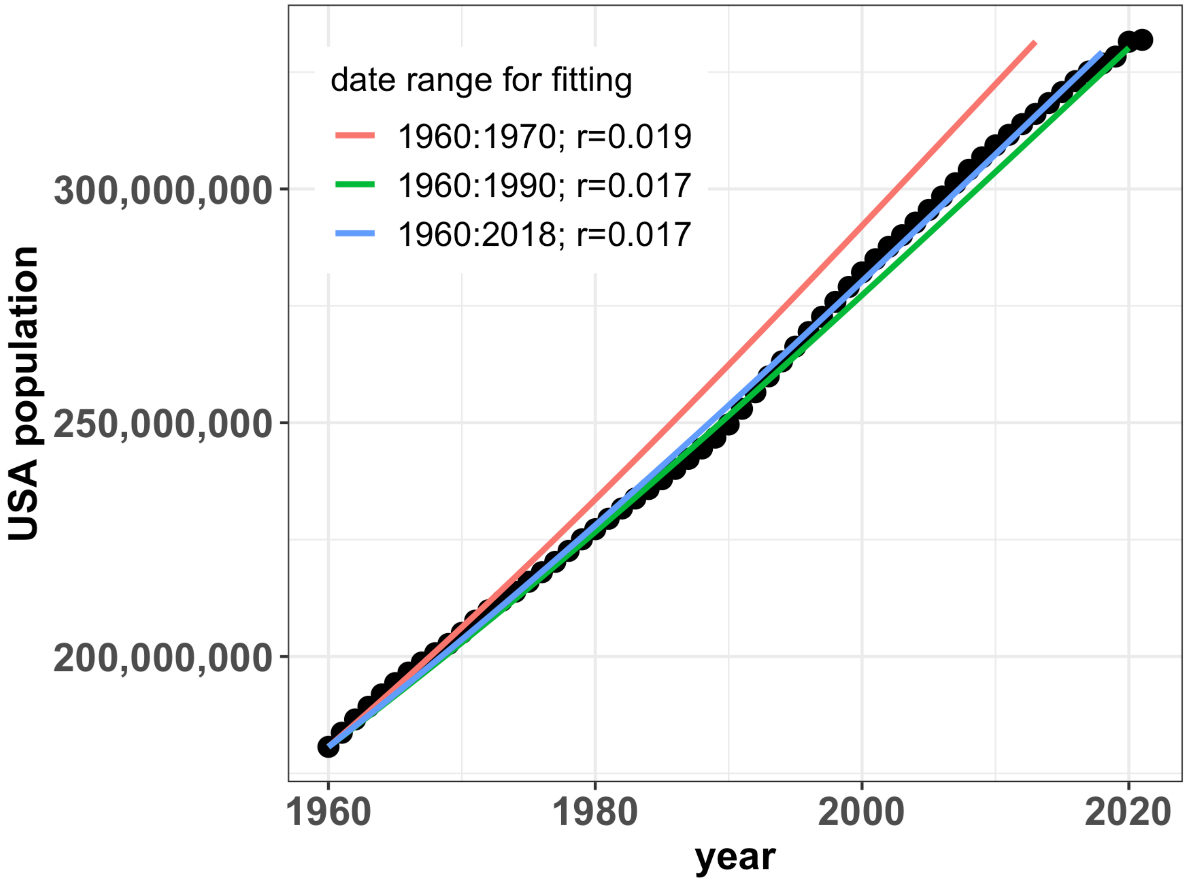
We can estimate growth rates by ‘fitting’ a model to data

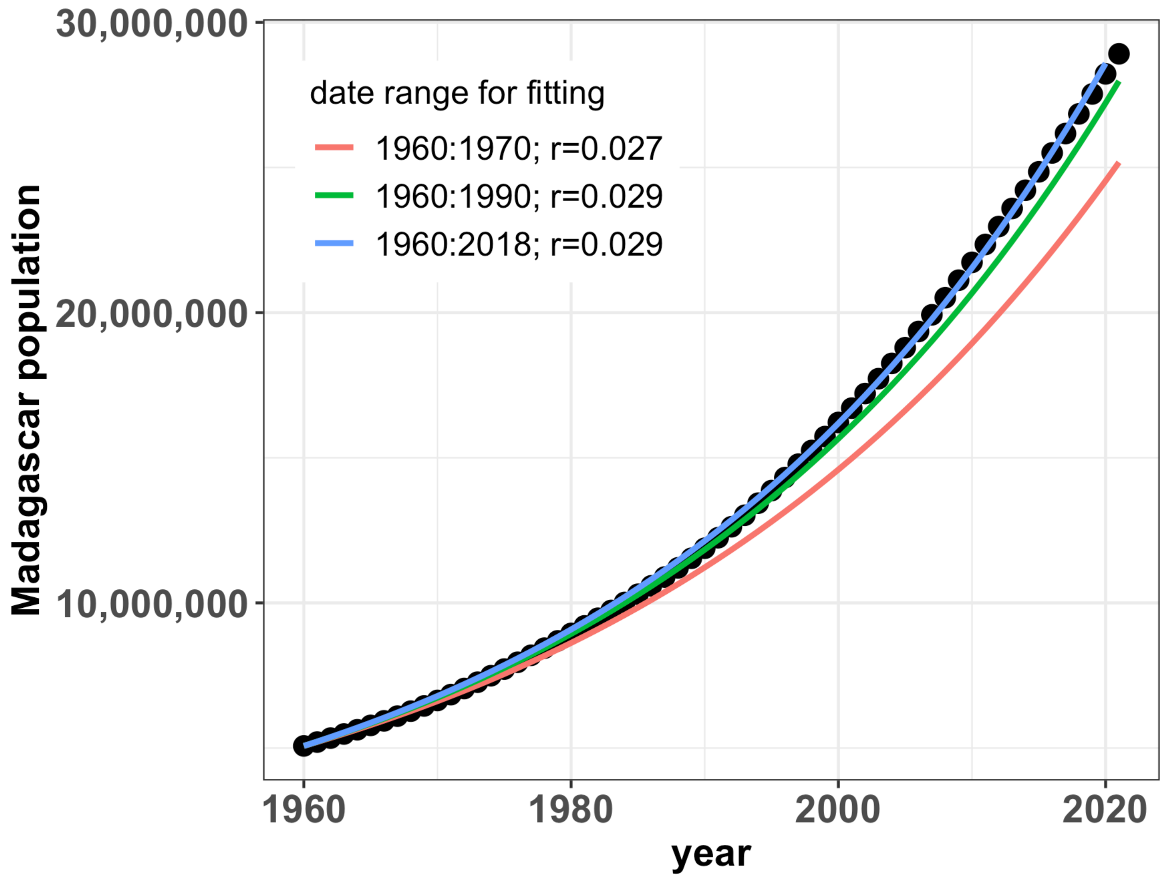


US growth rates slowed over the time period!

Model fits to data from earlier years **overestimate** current population growth rates

We can estimate growth rates by ‘fitting’ a model to data

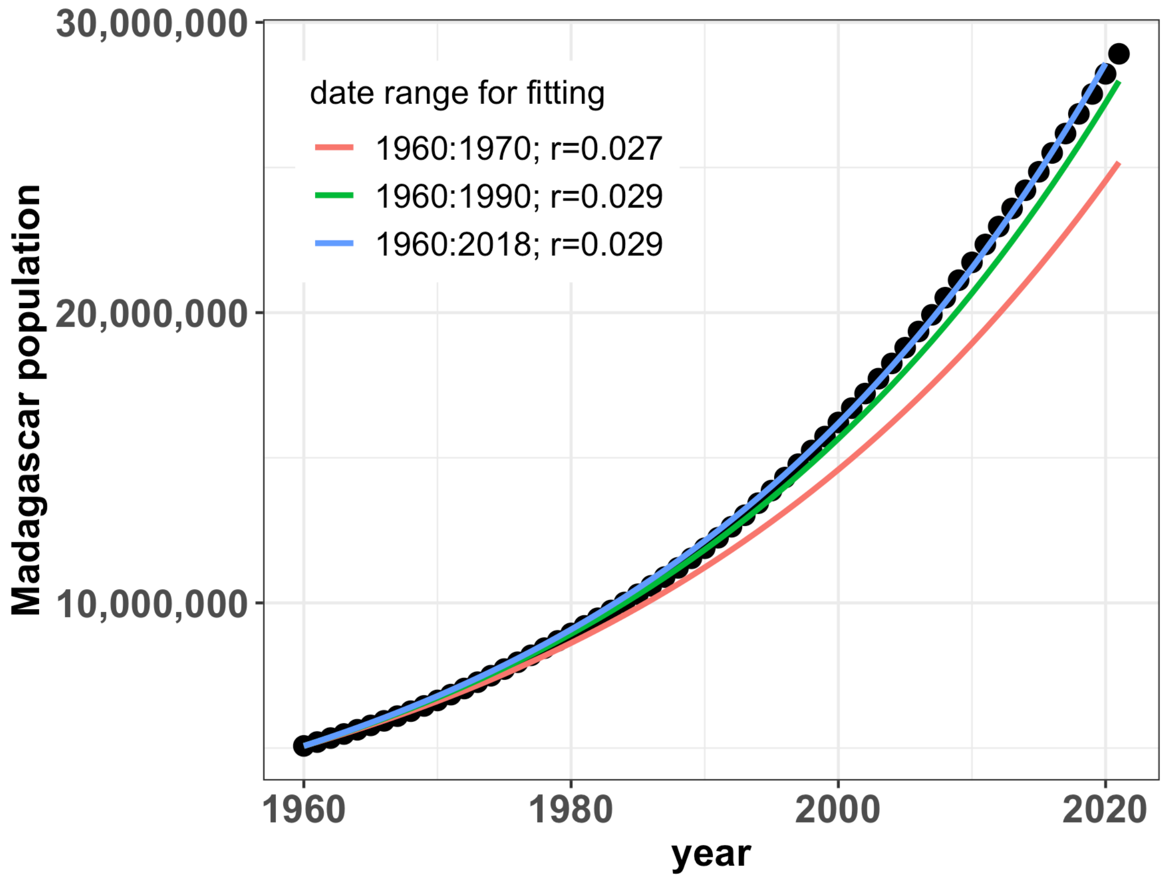




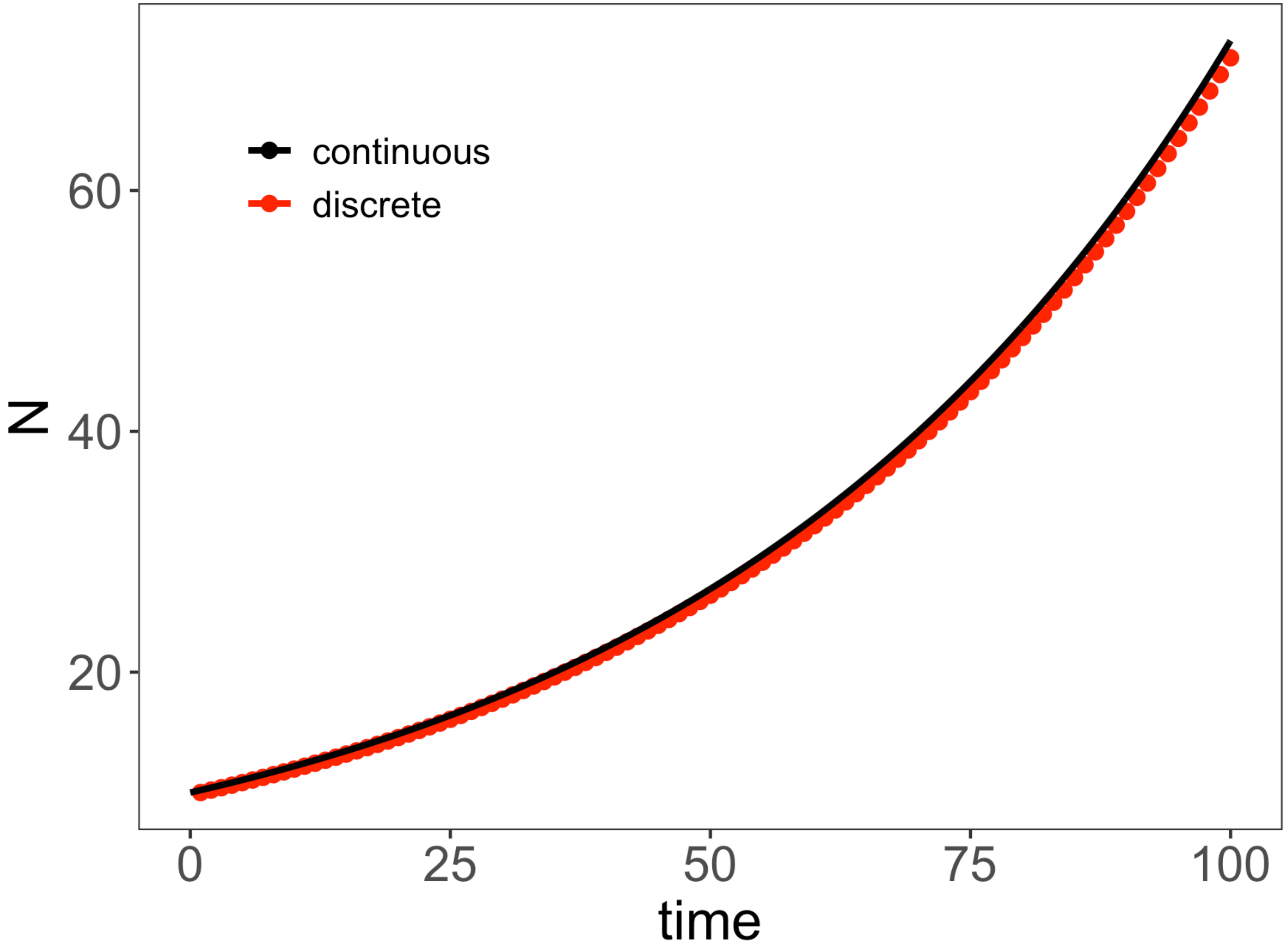
We can estimate growth rates by ‘fitting’ a model to data

Madagascar growth rates accelerated over the time period!

Model fits to data from earlier years **underestimate** current population growth rates



Both geometric and exponential growth are unchecked.

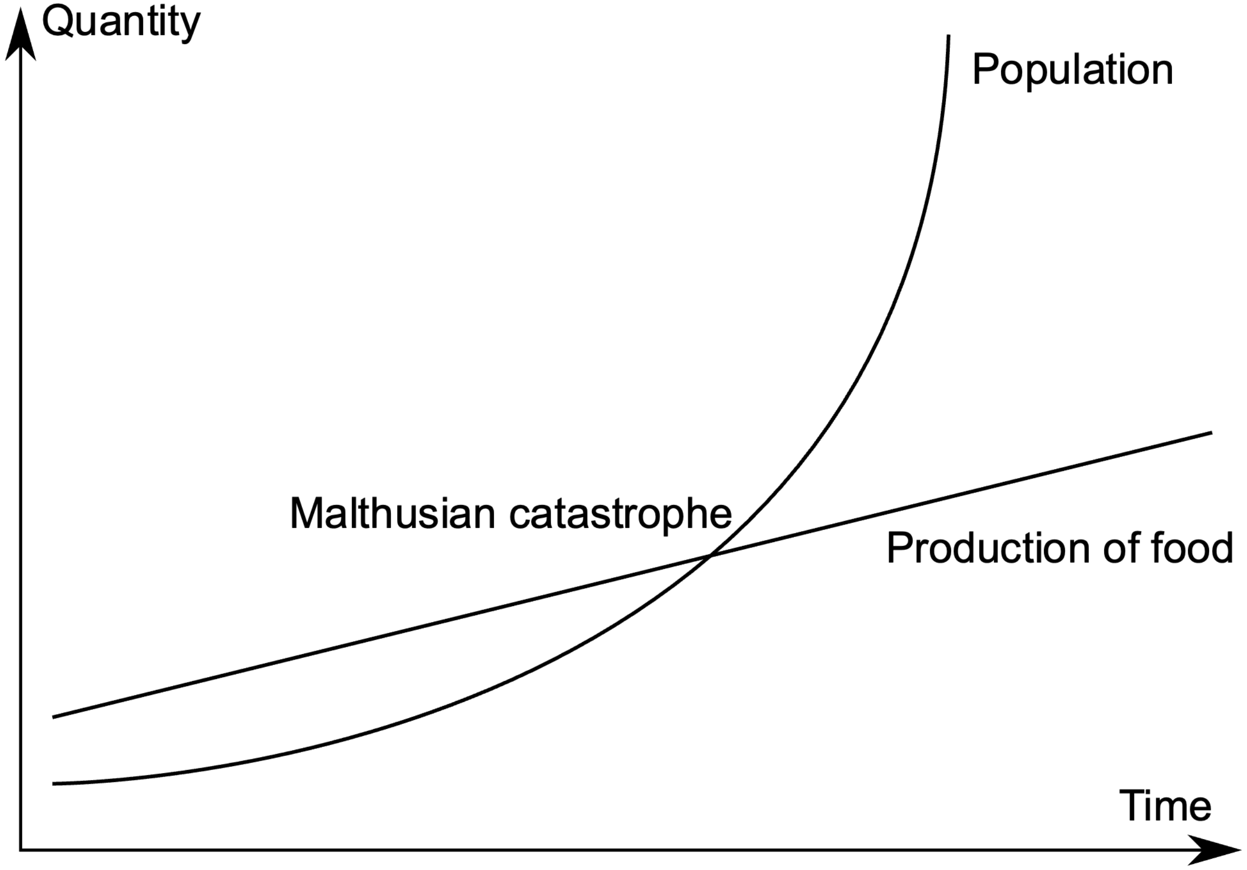


Malthus proposed some limits to population growth

“[. . .] the power of population is indefinitely greater than the power in the earth to produce subsistence for man. Population, when unchecked, increases in a geometrical ratio. Subsistence increases only in an arithmetical ratio. A slight acquaintance with numbers will shew the immensity of the first power in comparison of the second. By that law of our nature which makes food necessary to the life of man, the effects of these two unequal powers must be kept equal. This implies a strong and constantly operating check on population from the difficulty of subsistence. This difficulty must fall somewhere; and must necessarily be severely felt by a large portion of mankind.”

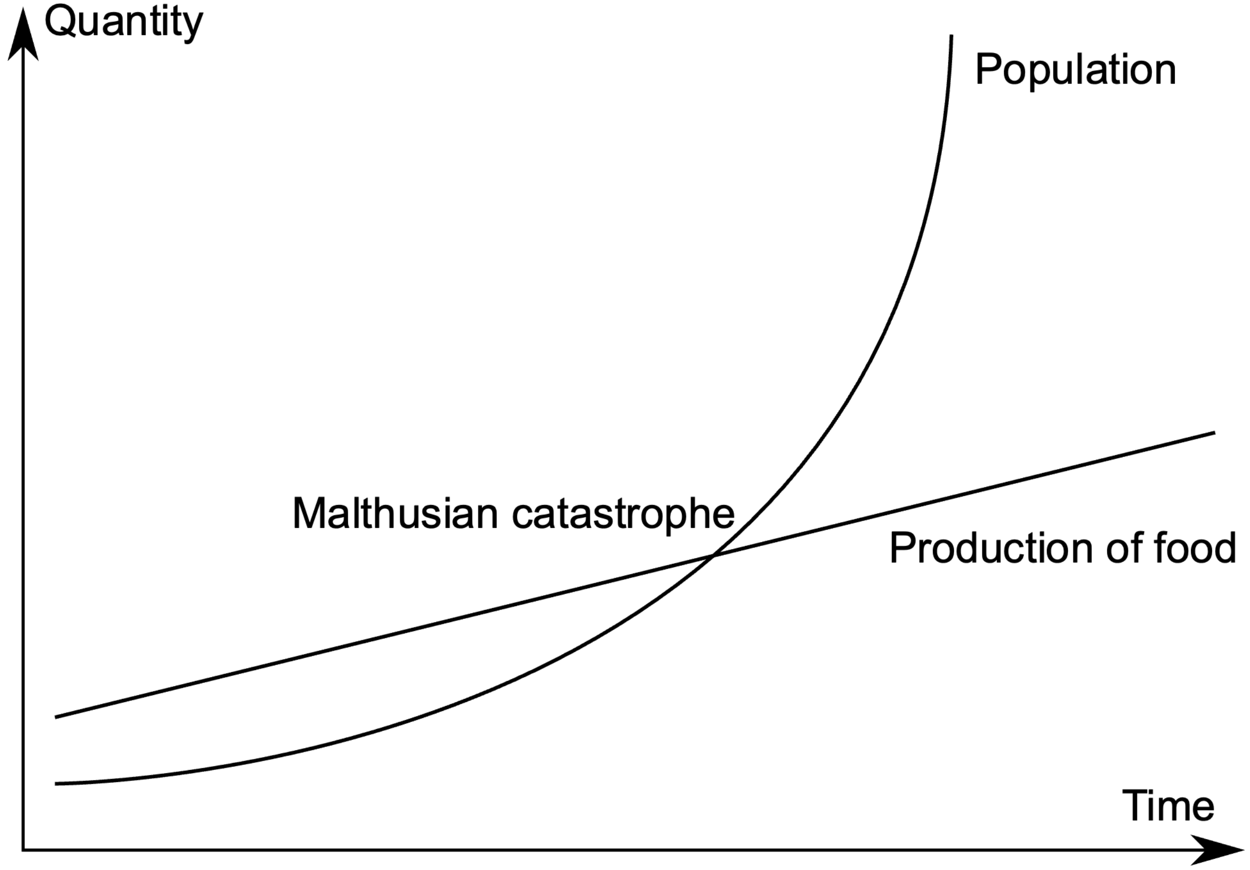
- Thomas Malthus (1798)
An Essay on the Principle of Population as it Effects the Future Improvement of Society, With Remarks on the Speculations of Mr Godwin, Mr. Condorcet and Other Writers

Malthus proposed some limits to population growth



- Thomas Malthus (1798)
An Essay on the Principle of Population as it Effects the Future Improvement of Society, With Remarks on the Speculations of Mr. Godwin, Mr. Condorcet and Other Writers

Malthus proposed some limits to population growth



Problem!
No basis for assumption of arithmetical ratio for food.

- Thomas Malthus (1798)
An Essay on the Principle of Population as it Effects the Future Improvement of Society, With Remarks on the Speculations of Mr. Godwin, Mr. Condorcet and Other Writers

Logistic growth equation

$$\frac{dN}{dt} = rN\left(1 - \frac{N}{K}\right)$$

"We shall not insist on the hypothesis of geometric progression, given that it can hold only in very special circumstances; for example, when a fertile territory of almost unlimited size happens to be inhabited by people…"

- Pierre-Francois Verhulst (1838)

Logistic growth equation

$$\frac{dN}{dt} = rN\left(1 - \frac{N}{\boxed{K}}\right)$$

← population size

intrinsic growth rate

carrying capacity

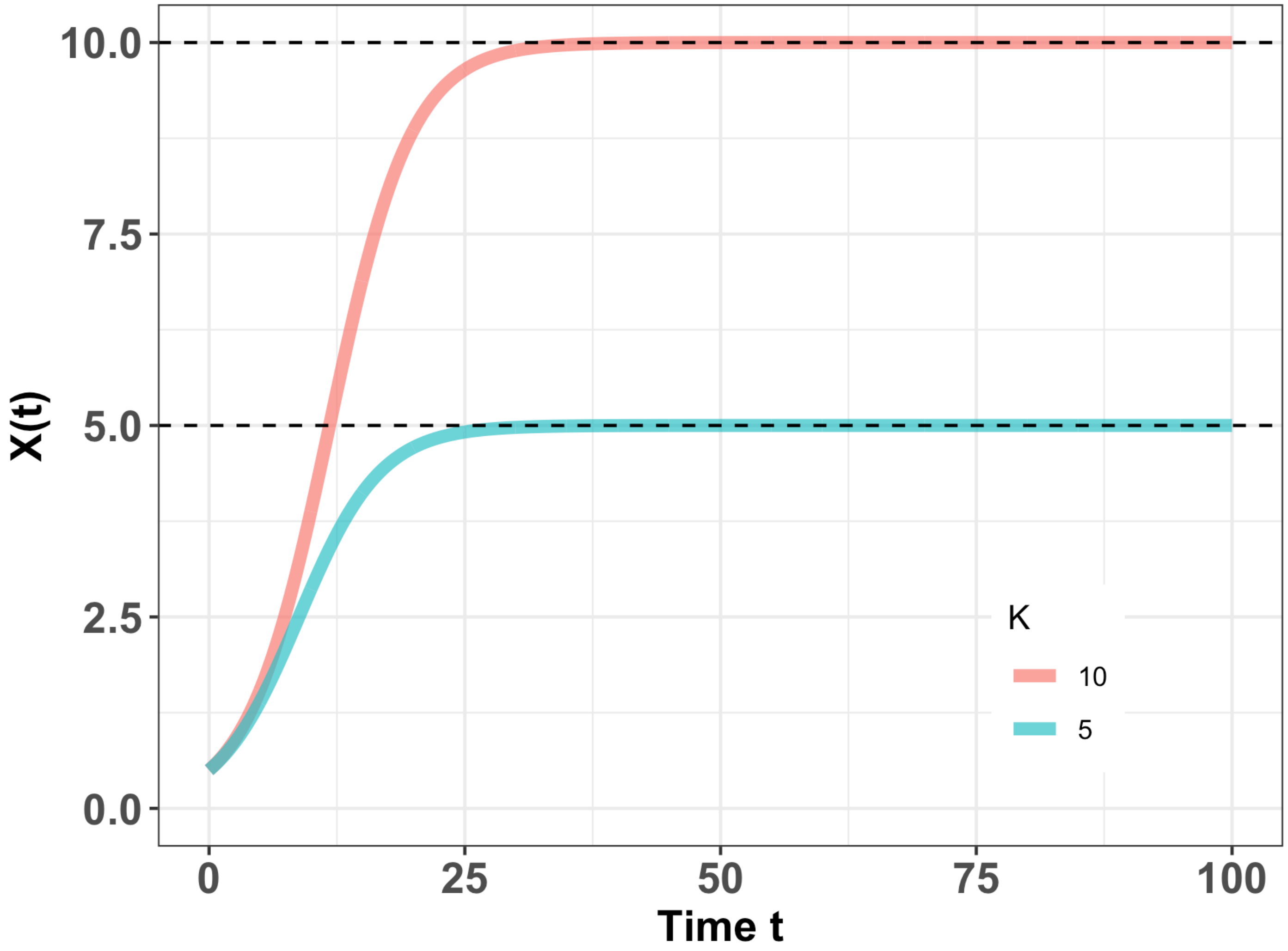
"We shall not insist on the hypothesis of geometric progression, given that it can hold only in very special circumstances; for example, when a fertile territory of almost unlimited size happens to be inhabited by people…"

- Pierre-Francois Verhulst (1838)

Population growth slows as abundance approaches **carrying capacity**.
Population growth is **density-dependent**.

Logistic growth equation

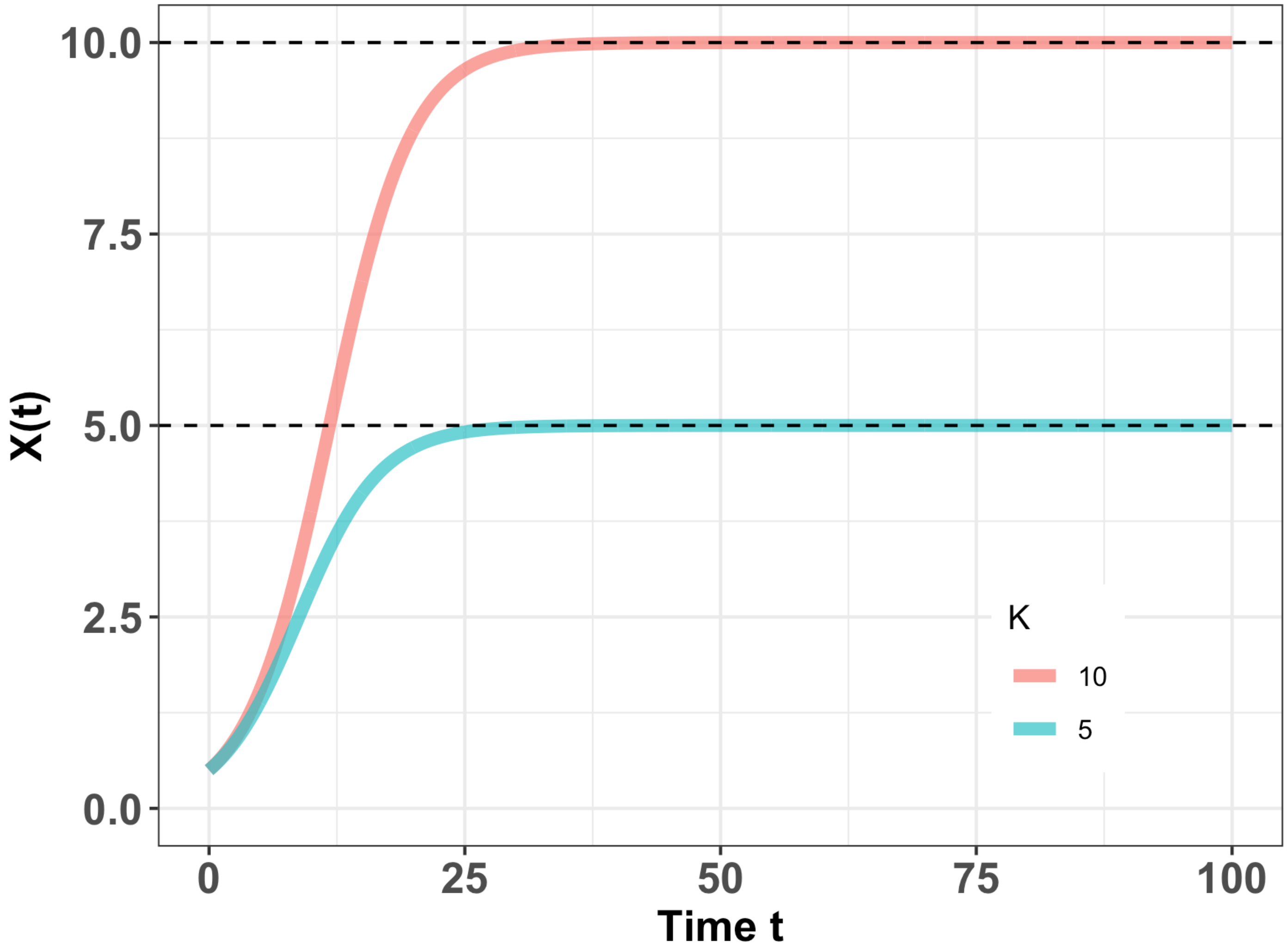
$$\frac{dN}{dt} = rN\left(1 - \frac{N}{K}\right)$$



Population growth slows to 0 as N approaches **K**, or – in other words – as the total population size approaches **carrying capacity**.

Logistic growth equation

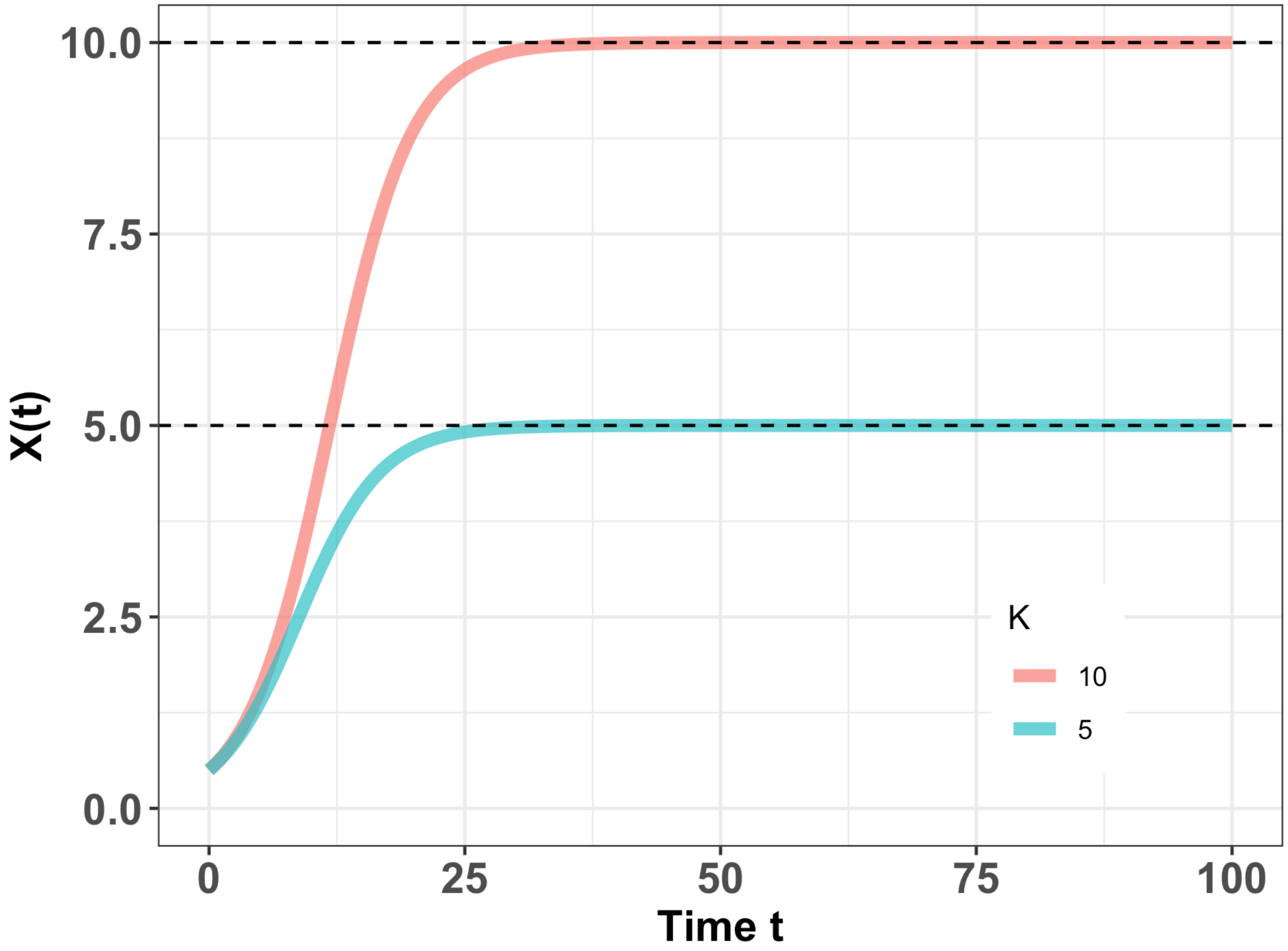
$$\frac{dN}{dt} = rN\left(1 - \frac{N}{K}\right)$$



Carrying capacity= maximum population size an environment can sustain indefinitely.

Logistic growth equation

$$\frac{dN}{dt} = rN\left(1 - \frac{N}{K}\right)$$

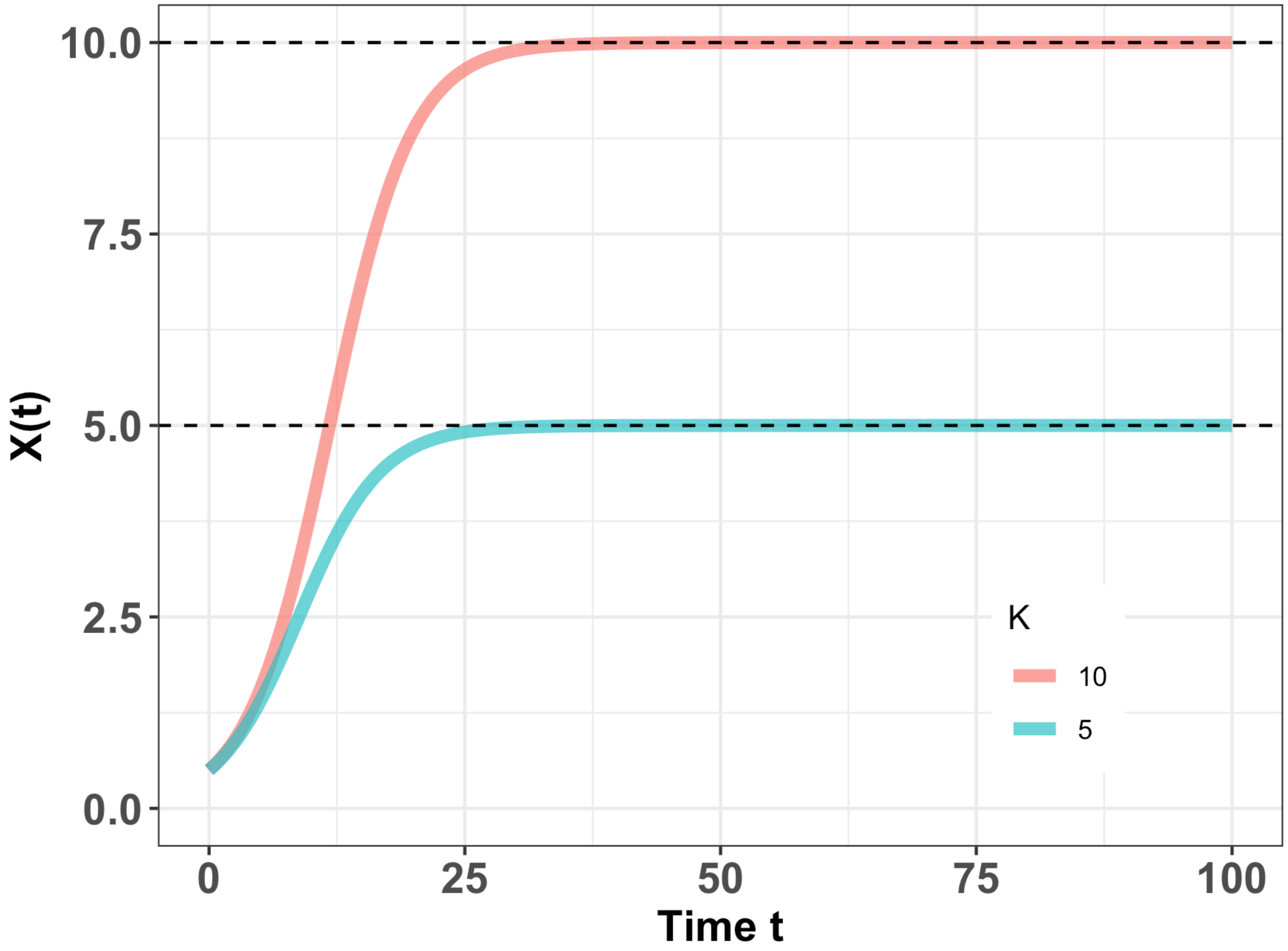


Carrying capacity= maximum population size an environment can sustain indefinitely.

Ecology = organisms interacting with each other and the **environment**

Logistic growth equation

$$\frac{dN}{dt} = rN\left(1 - \frac{N}{K}\right)$$



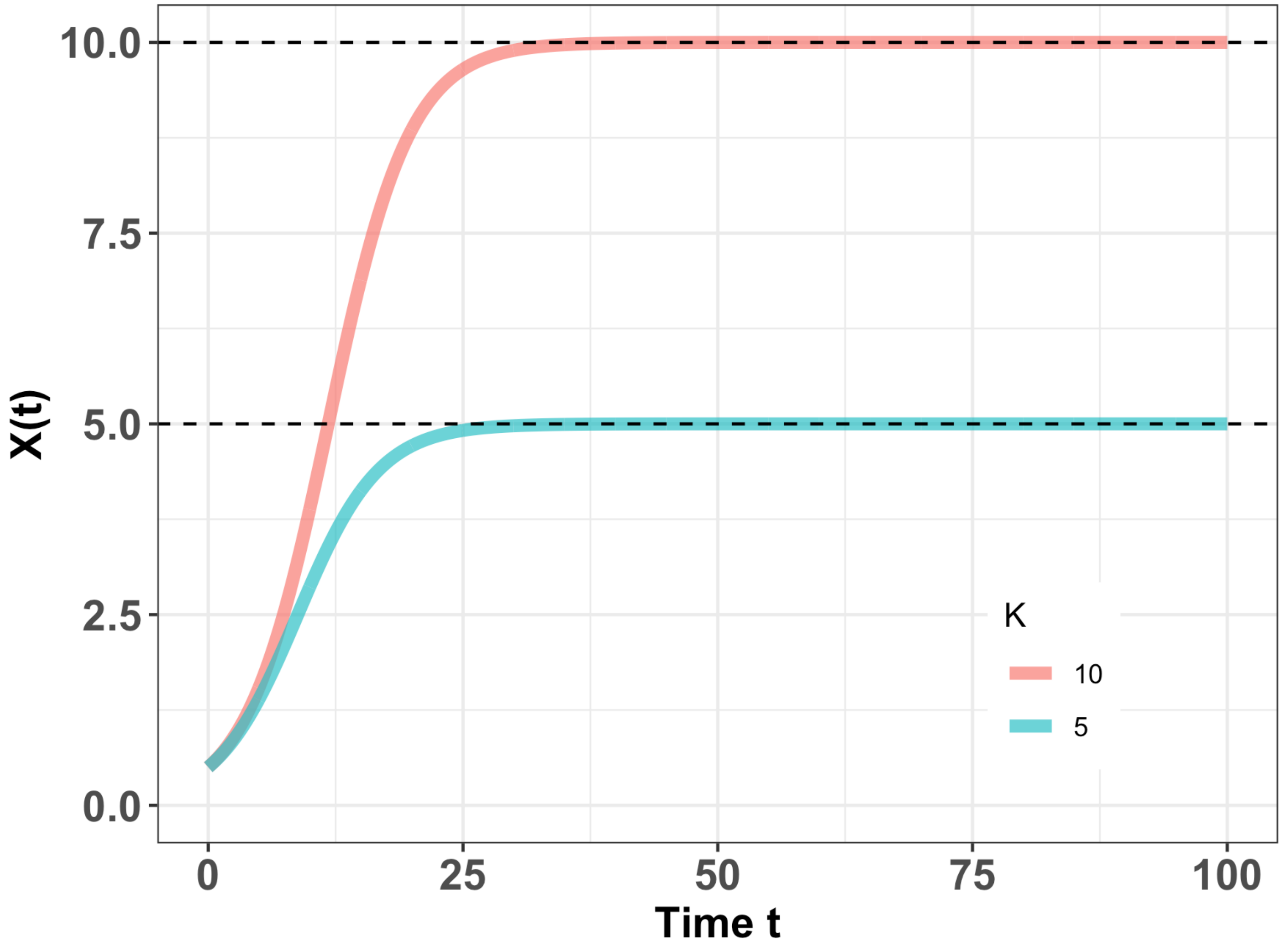
Carrying capacity= maximum population size an environment can sustain indefinitely.

Ecology = organisms interacting with each other and the **environment**

K can change!

Logistic growth equation

$$\frac{dN}{dt} = rN\left(1 - \frac{N}{K}\right)$$



Carrying capacity= maximum population size an environment can sustain indefinitely.

Ecology = organisms interacting with each other and the **environment**

K can change!

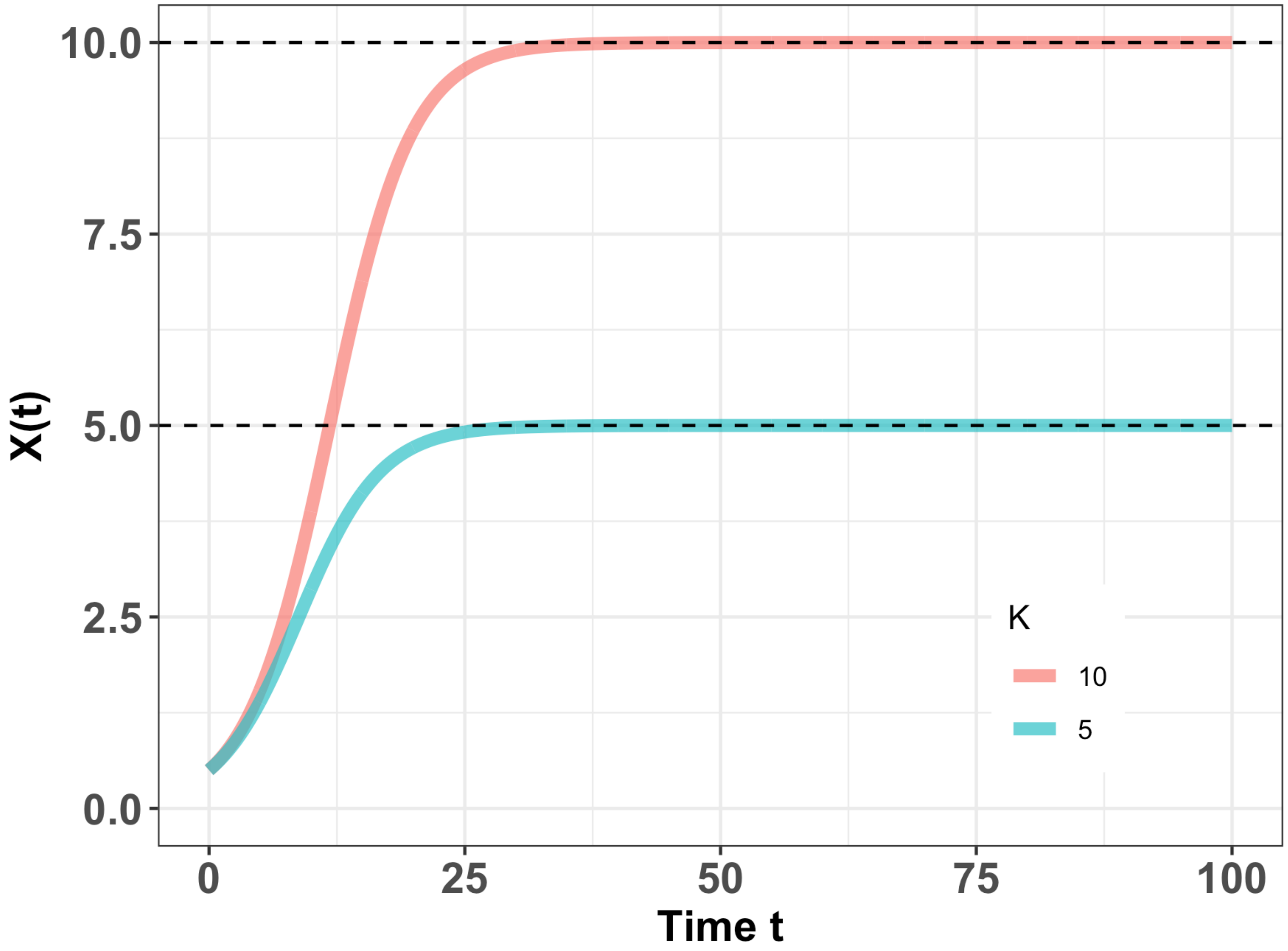
'**r**' vs. '**K**'-selected species

Logistic growth and equilibrium

$$\frac{dN}{dt} = rN\left(1 - \frac{N}{K}\right)$$

$$\frac{dN}{dt} = 0$$

When population size is not changing, the population is said to be at **equilibrium**.



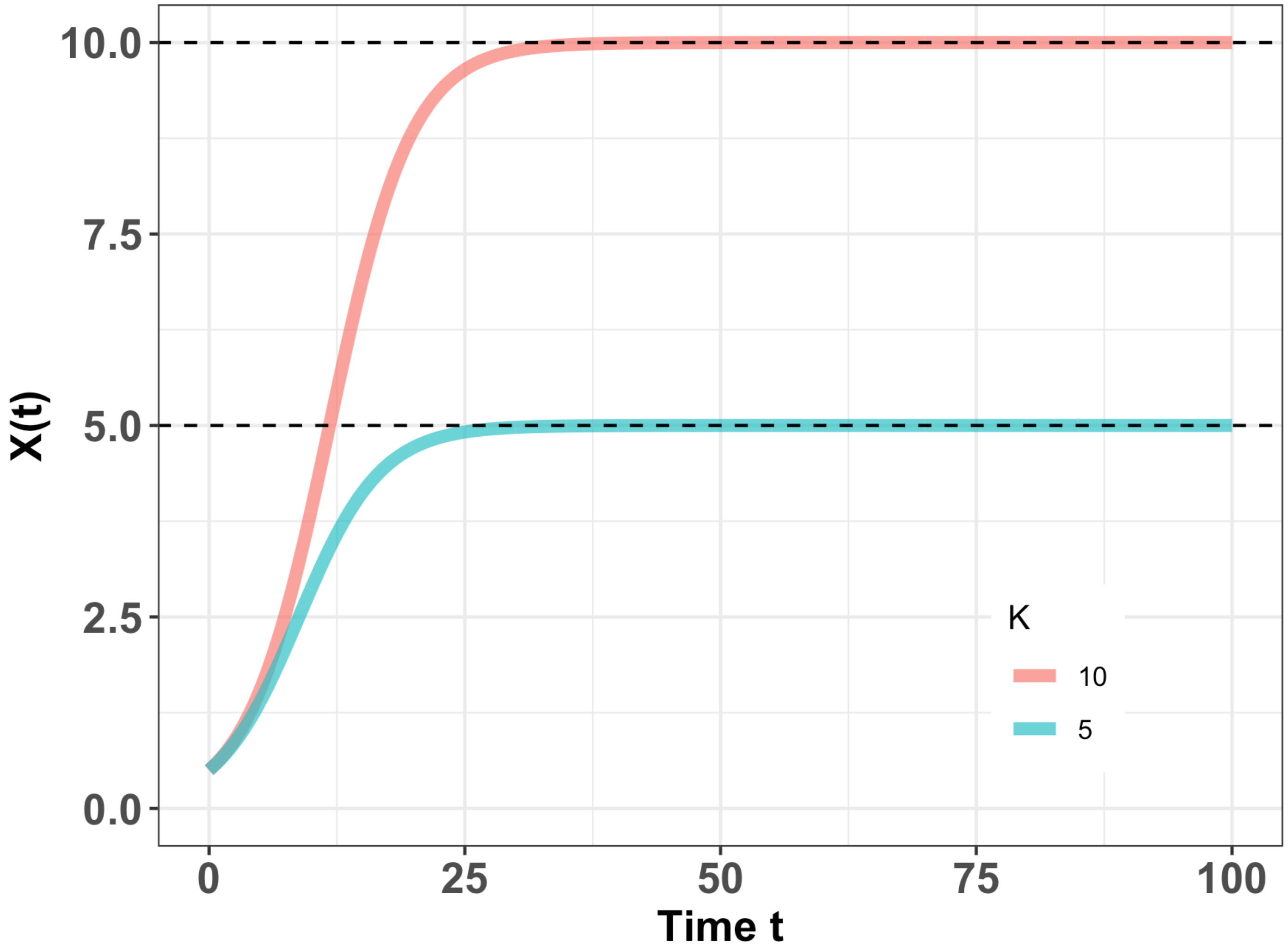
Logistic growth and equilibrium

$$\frac{dN}{dt} = rN\left(1 - \frac{N}{K}\right)$$

$$\frac{dN}{dt} = 0$$

$$0 = rN\left(1 - \frac{N}{K}\right)$$

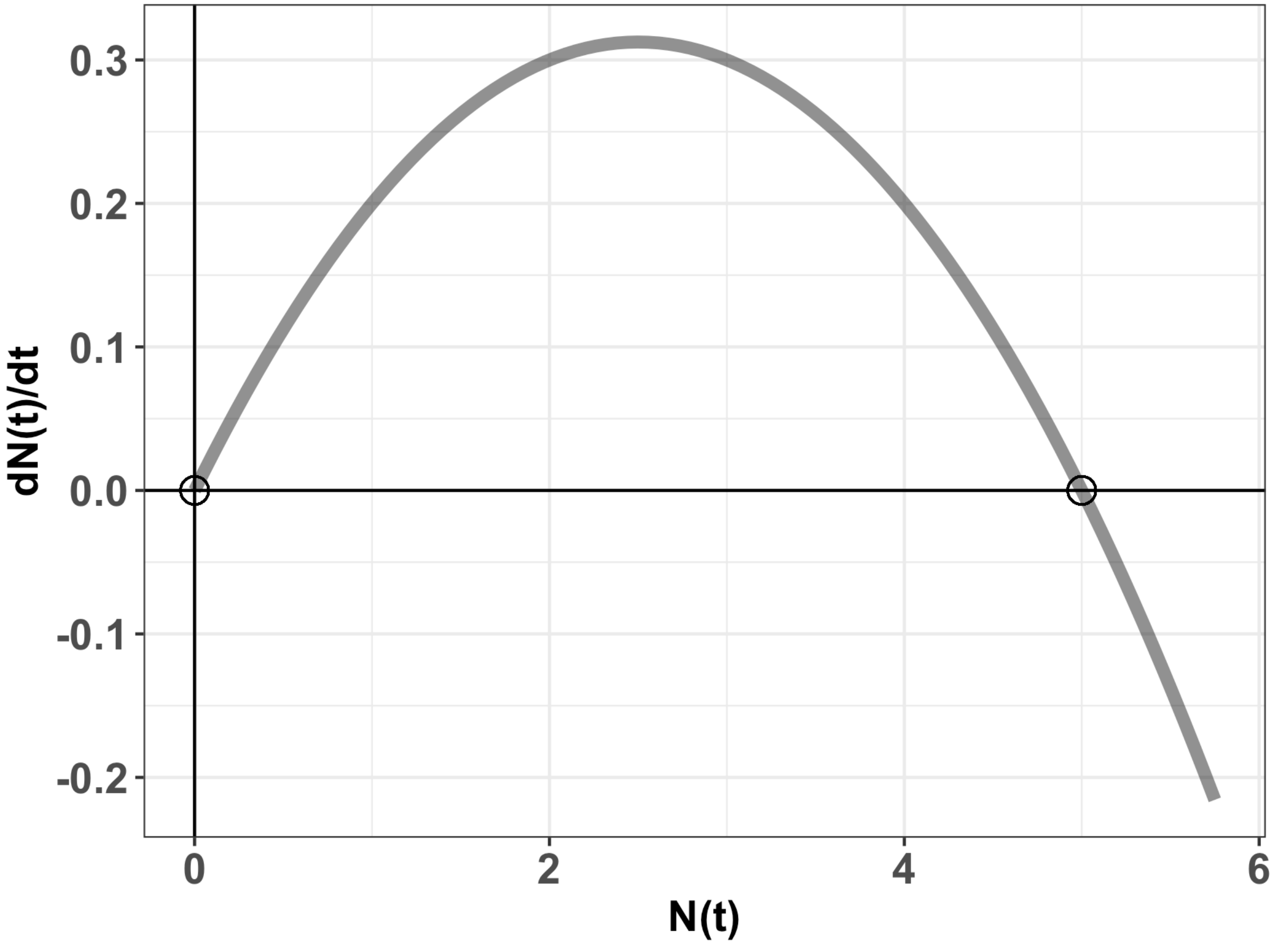
$$N = K$$



A little algebra shows that the population at carrying capacity is at **equilibrium**.

Logistic growth and equilibrium

$$\frac{dN}{dt} = rN\left(1 - \frac{N}{K}\right)$$



$$\frac{dN}{dt} = 0$$

$$0 = rN\left(1 - \frac{N}{K}\right)$$

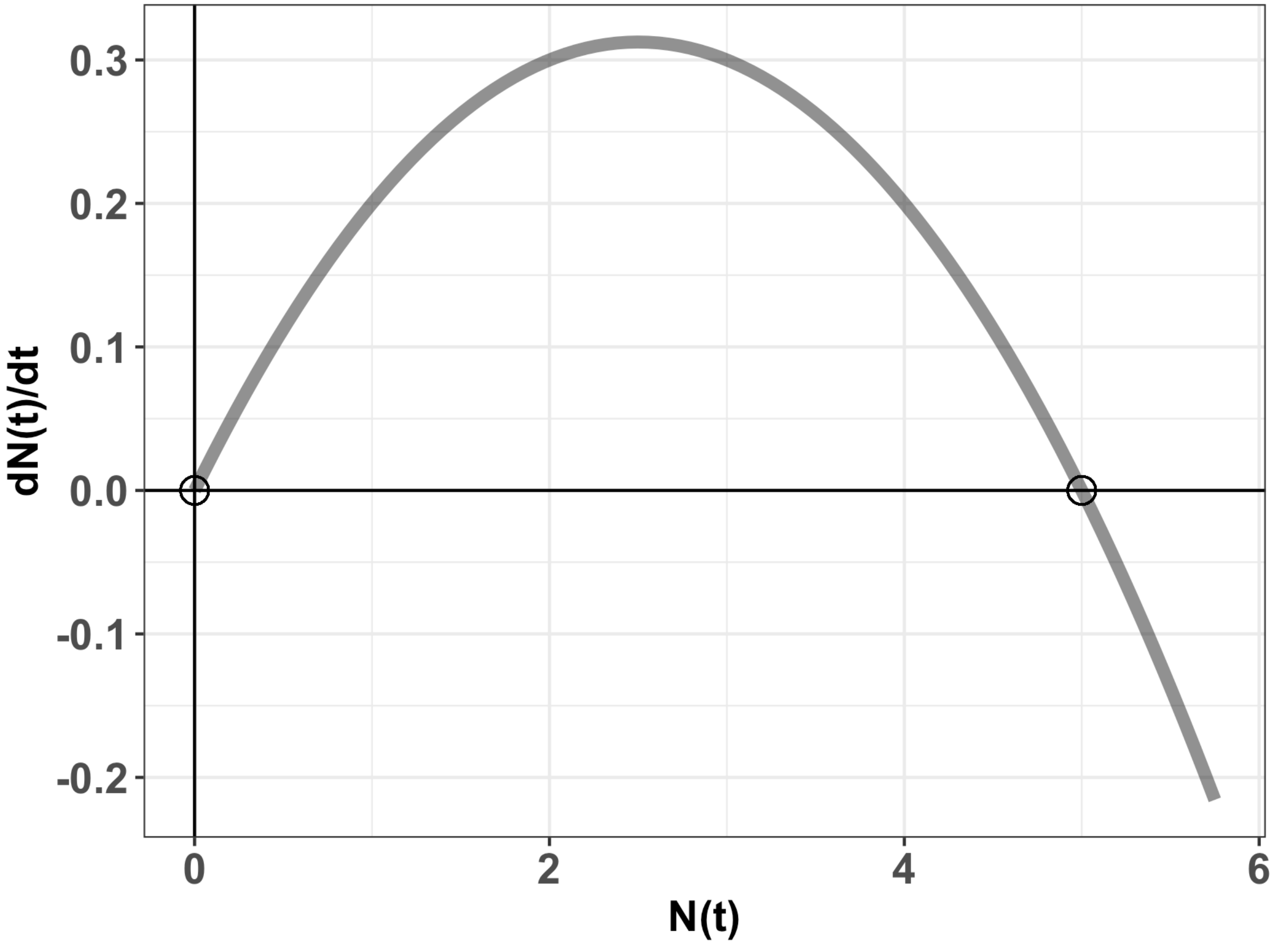
$$\left.\begin{array}{l} N = K \text{ or} \\ N = 0 \end{array}\right\}$$ logistic growth **equilibria**

Logistic growth and equilibrium

$$\frac{dN}{dt} = rN\left(1 - \frac{N}{K}\right)$$

$$\frac{dN}{dt} = 0$$

$$0 = rN\left(1 - \frac{N}{K}\right)$$



$$\left.\begin{aligned} N &= K \text{ or} \\ N &= 0 \end{aligned}\right\}$$ logistic growth **equilibria**

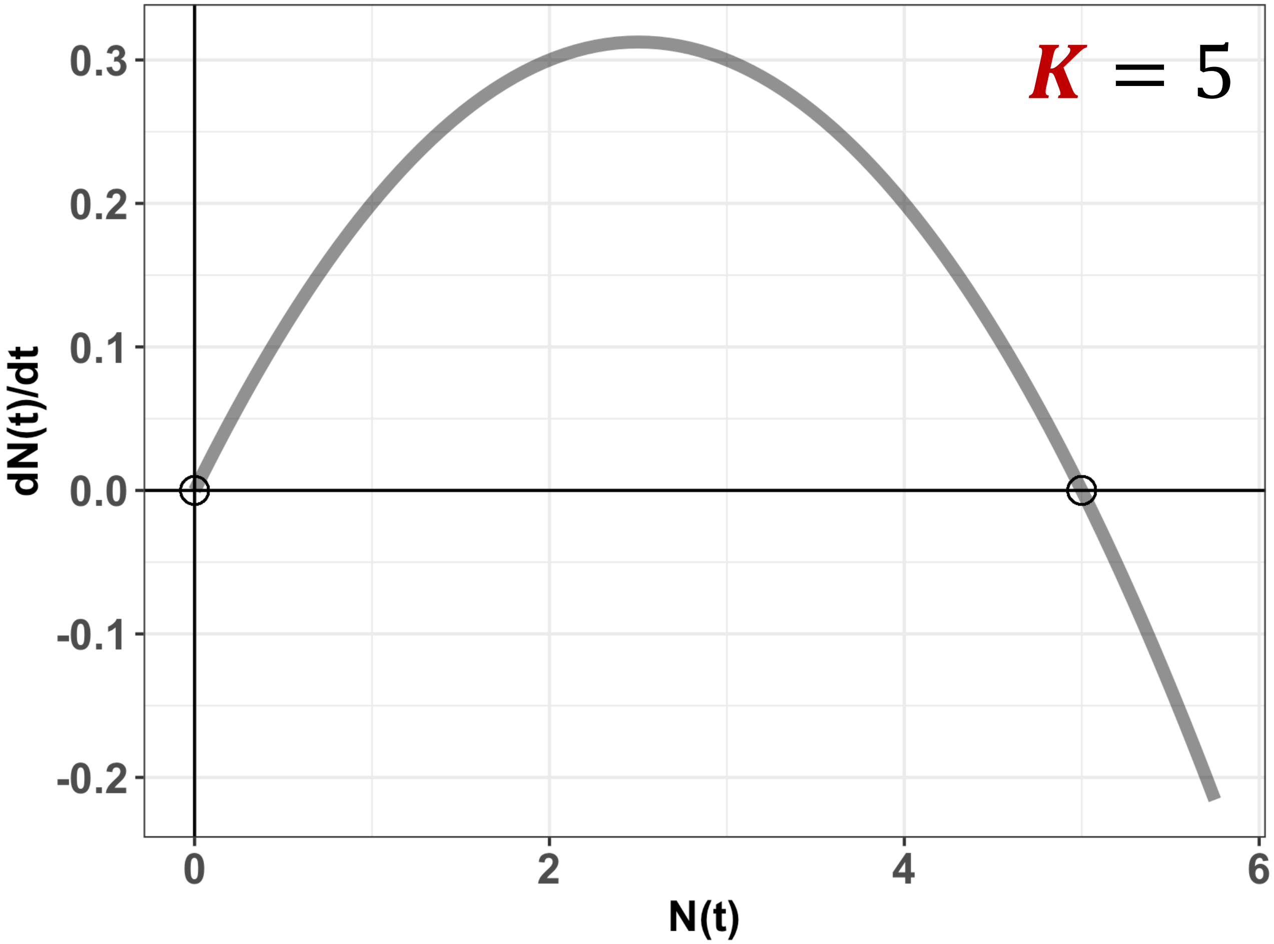
What is **K**?

Logistic growth and equilibrium

$$\frac{dN}{dt} = rN\left(1 - \frac{N}{K}\right)$$

$$\frac{dN}{dt} = 0$$

$$0 = rN\left(1 - \frac{N}{K}\right)$$

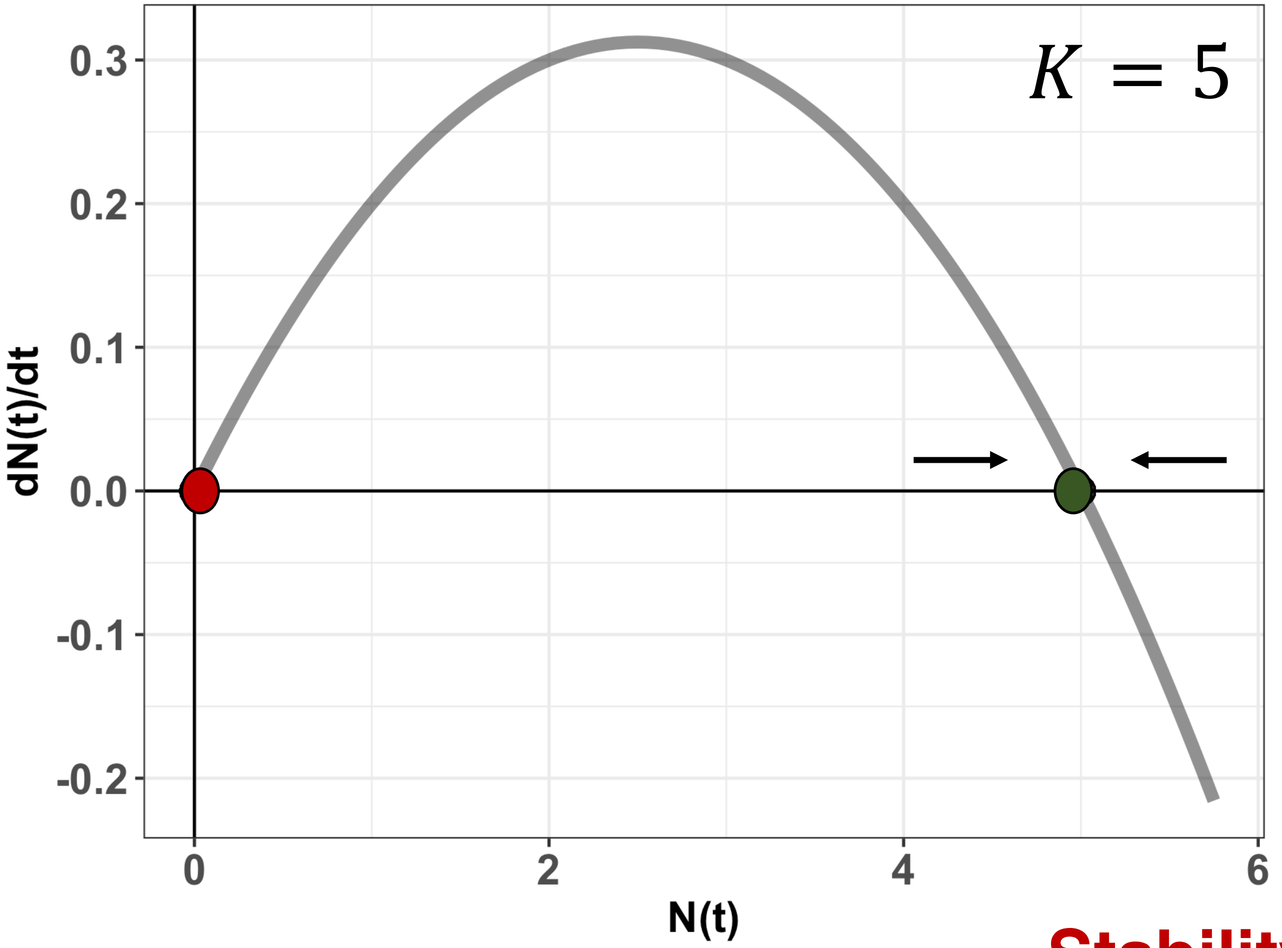


$$\left.\begin{aligned} N &= K \text{ or} \\ N &= 0 \end{aligned}\right\}$$ logistic growth **equilibria**

What is **K**?

Logistic growth and equilibrium

$$\frac{dN}{dt} = rN\left(1 - \frac{N}{K}\right)$$



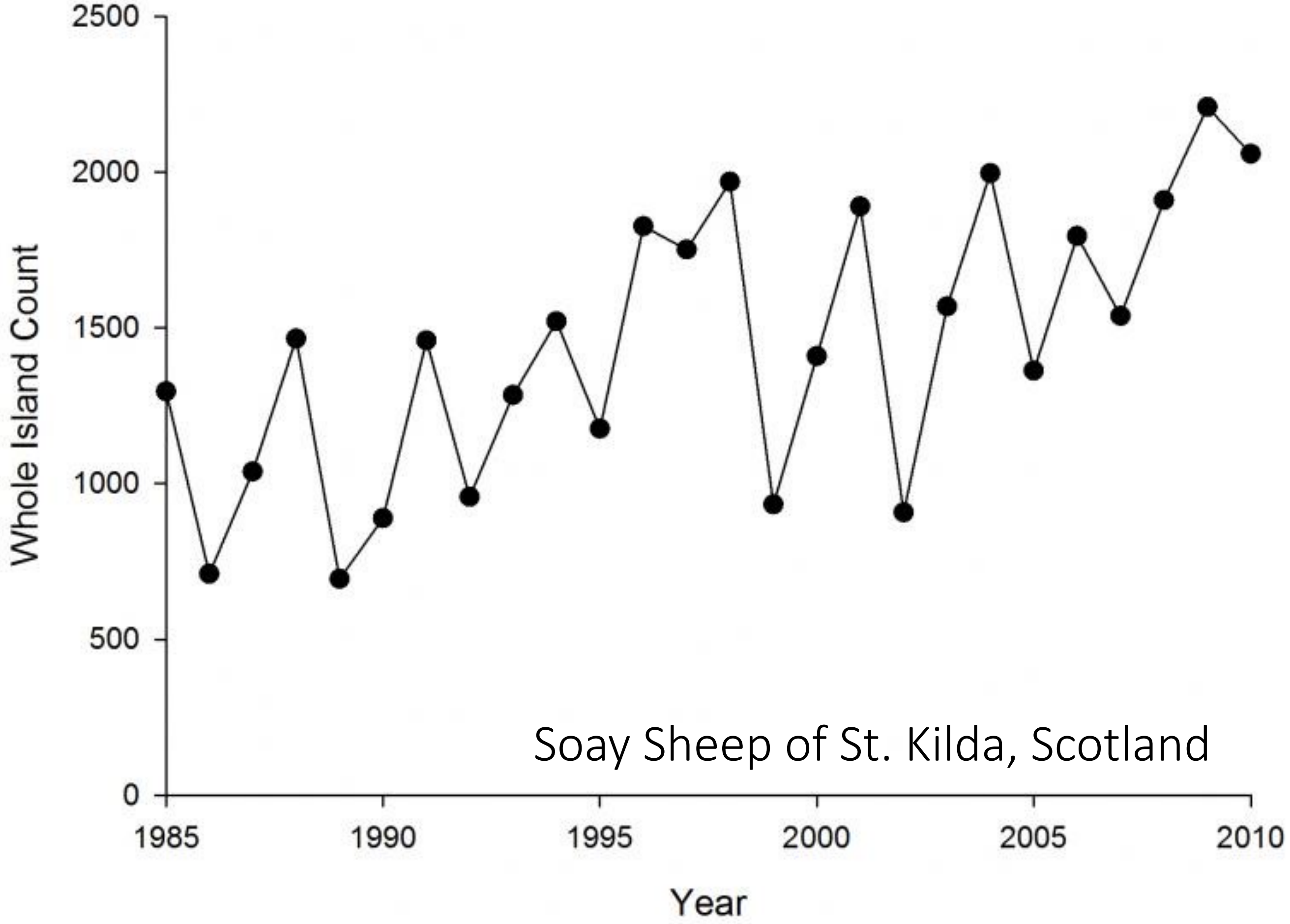
$$\frac{dN}{dt} = 0$$

$$0 = rN\left(1 - \frac{N}{K}\right)$$

$$\left.\begin{array}{l} N = K \text{ or} \\ N = 0 \end{array}\right\} \text{logistic growth } \textbf{equilibria}$$

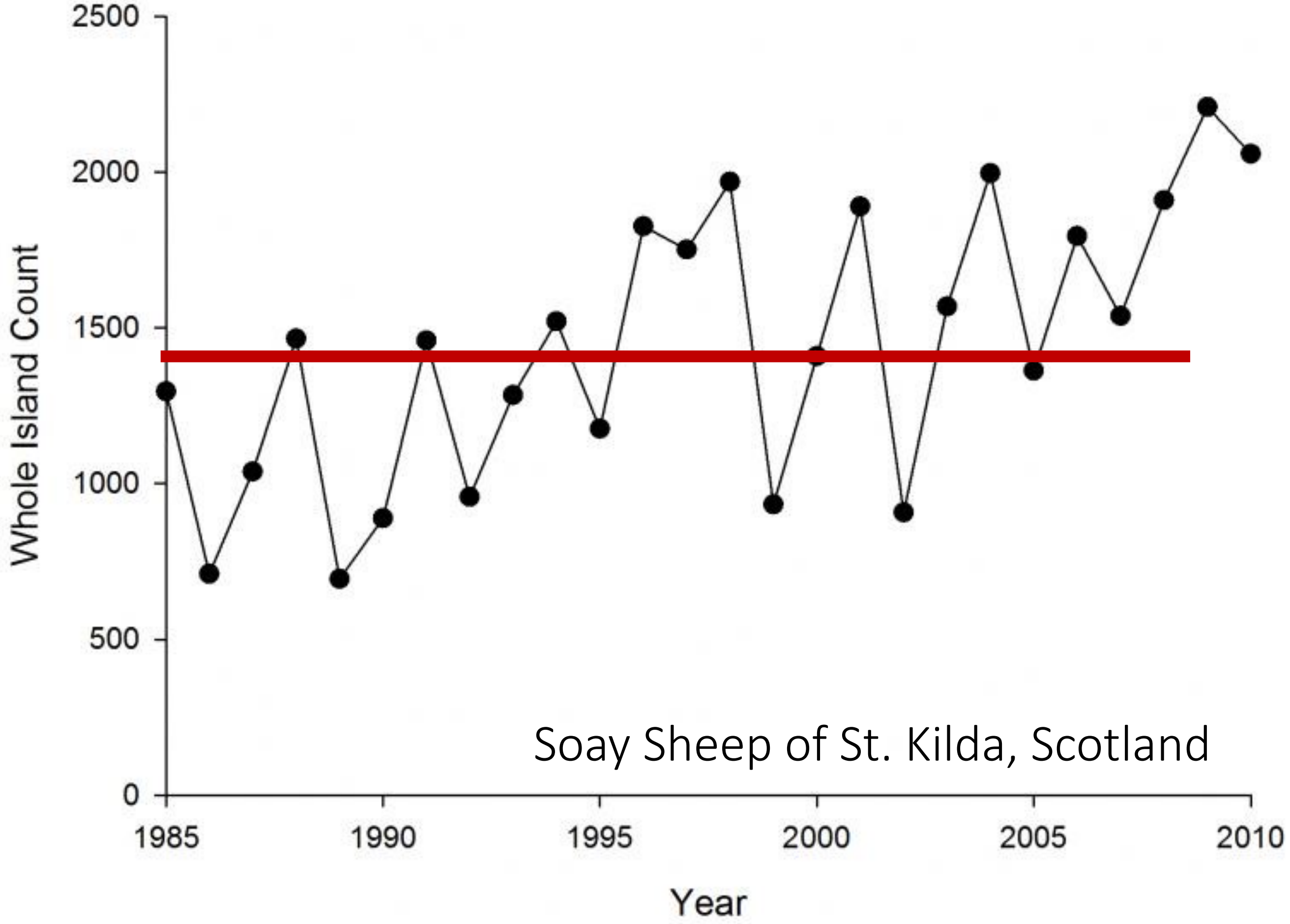
Stability: If the population is perturbed, will it return to equilibrium?

Many populations will fluctuate above or below carrying capacity.



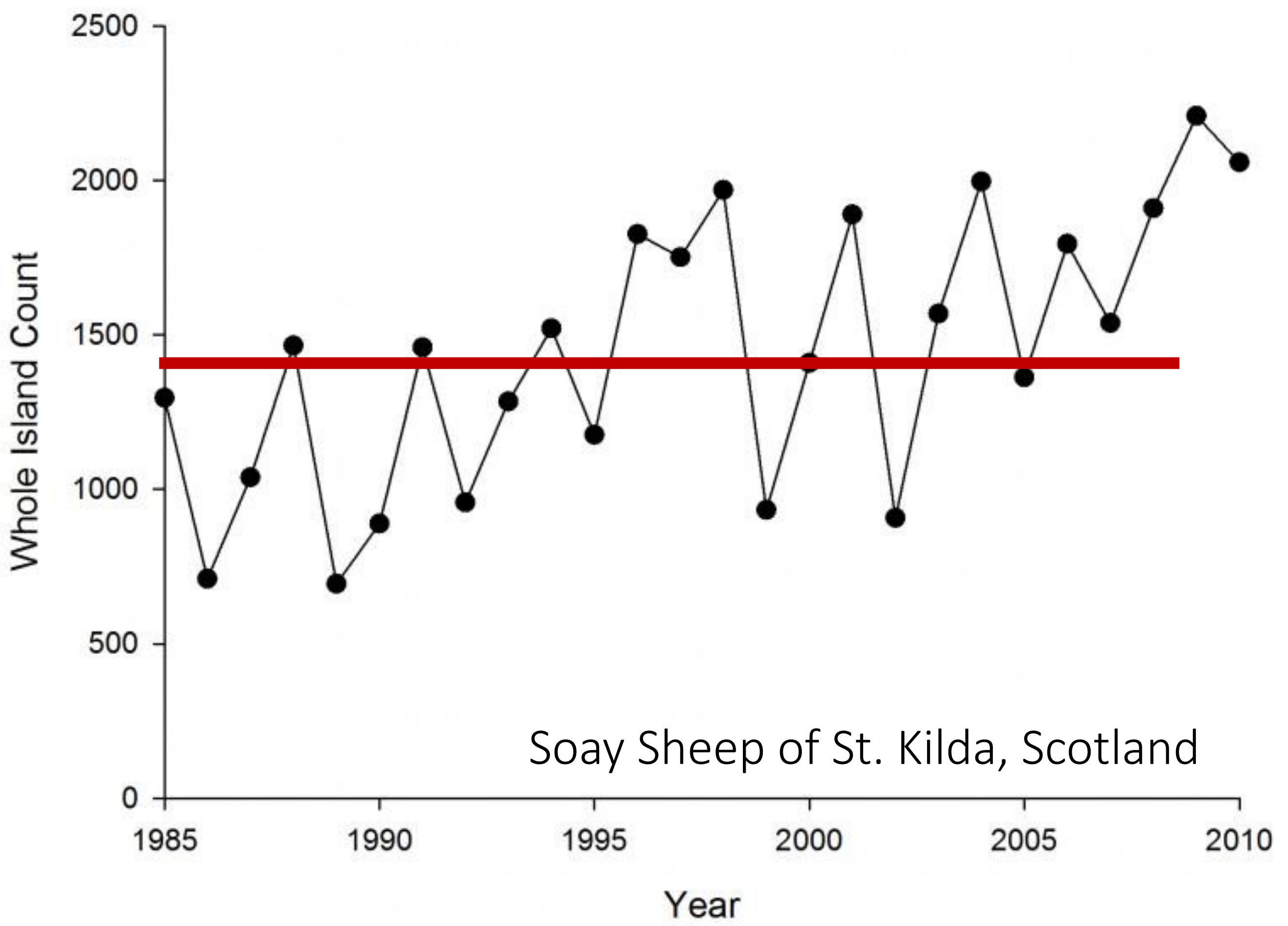
Soay Sheep of St. Kilda, Scotland

Many populations will fluctuate above or below carrying capacity.



But they can still be stable populations if they return to **equilibrium**.

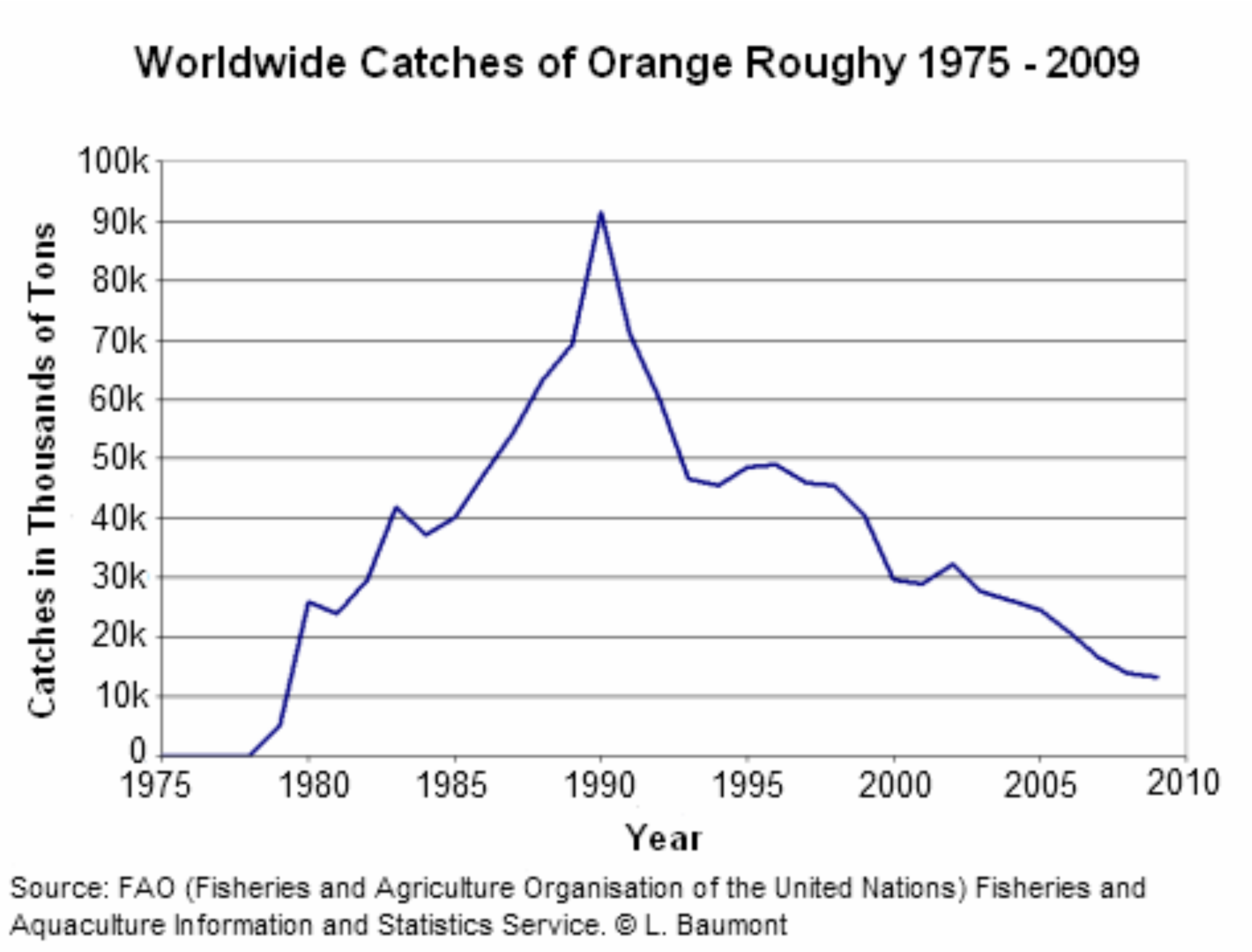
Many populations will fluctuate above or below carrying capacity.



But they can still be stable populations if they return to **equilibrium**.

In some cases, it is not possible to recover.

Many populations will fluctuate above or below carrying capacity.



But they can still be stable populations if they return to **equilibrium**.

In some cases, it is not possible to recover.

Logistic growth still does not describe human populations well.