Big Idea 4: Biological systems interact, and these systems and their interactions possess complex properties.

Enduring understanding 4.A: Interactions within biological systems lead to complex properties.

Essential knowledge 4.A.5: Communities are composed of populations of organisms that interact in complex ways.

a. The structure of a community is measured and described in terms of species composition and species diversity.

Community Ecology

Main Idea: Diversity is important for healthy communities.

Main Idea: Each community has unique feeding relationships.

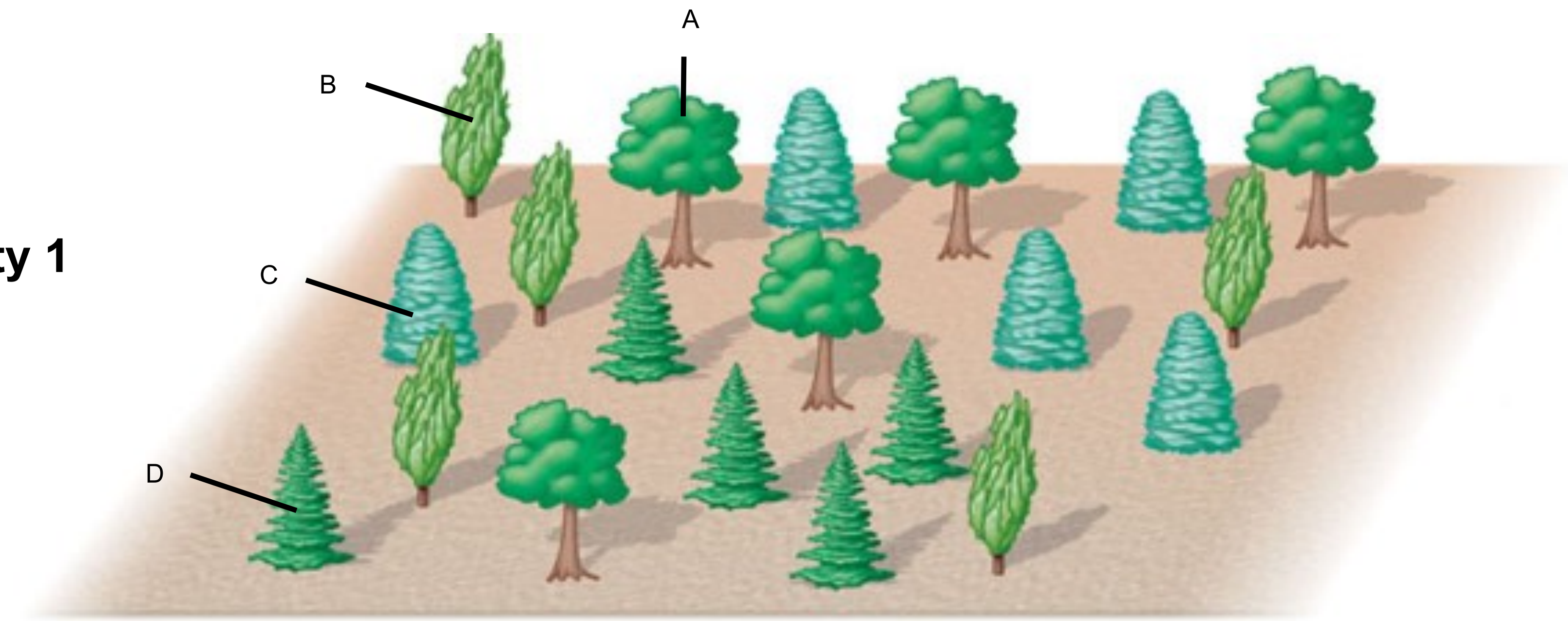
DIVERSITY & TROPHIC STRUCTURE

A. Species Diversity

- Diversity has two components
  - 1. **Richness** = number of different species
  - 2. **Relative Abundance** = the proportion that each species represents of all individuals in the community
- *Shannon Diversity (H)* is a widely used index used to calculate both richness and abundance
  - $H = -(pA \ln pA + pB \ln pB + pC \ln pC + \ldots)$
  - where: A,B,C are species, *p* is abundance, ln is natural logarithm
  - The higher the "H" the more diverse the community
  - Often times finding number and abundance can be difficult.

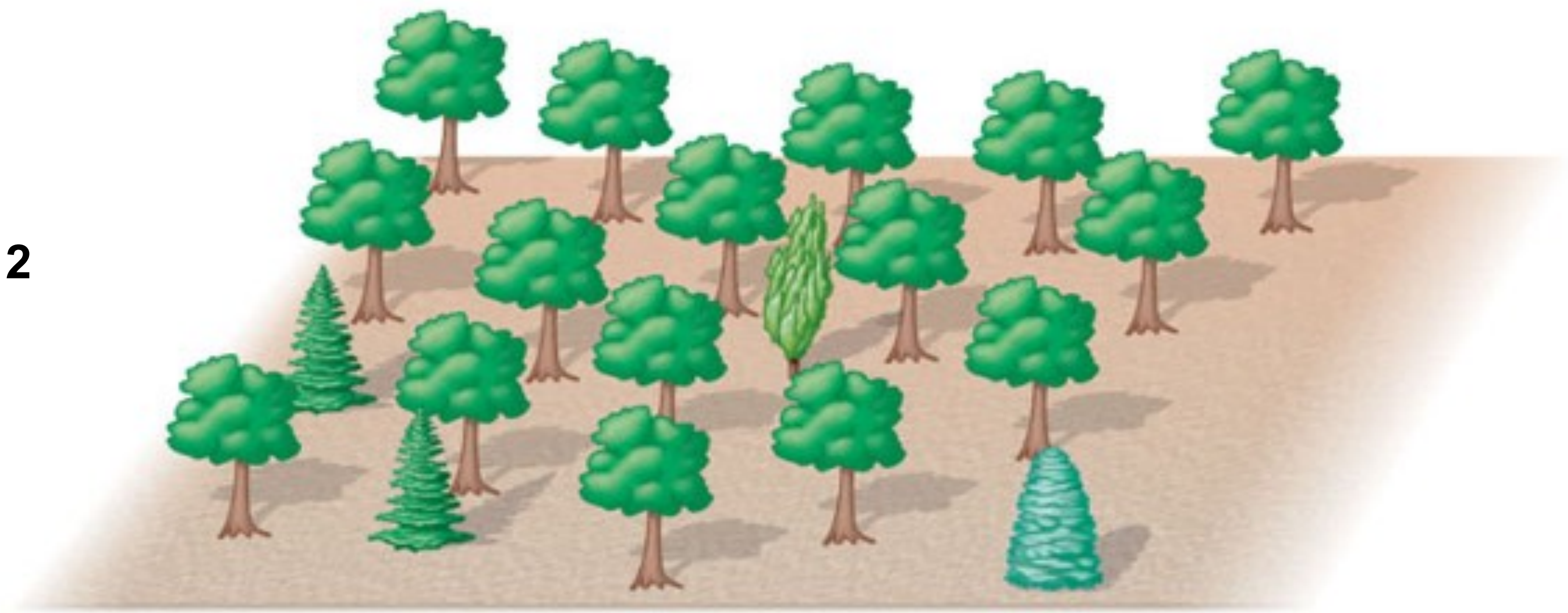
Which community below is more diverse? Use your gut.

Community 1



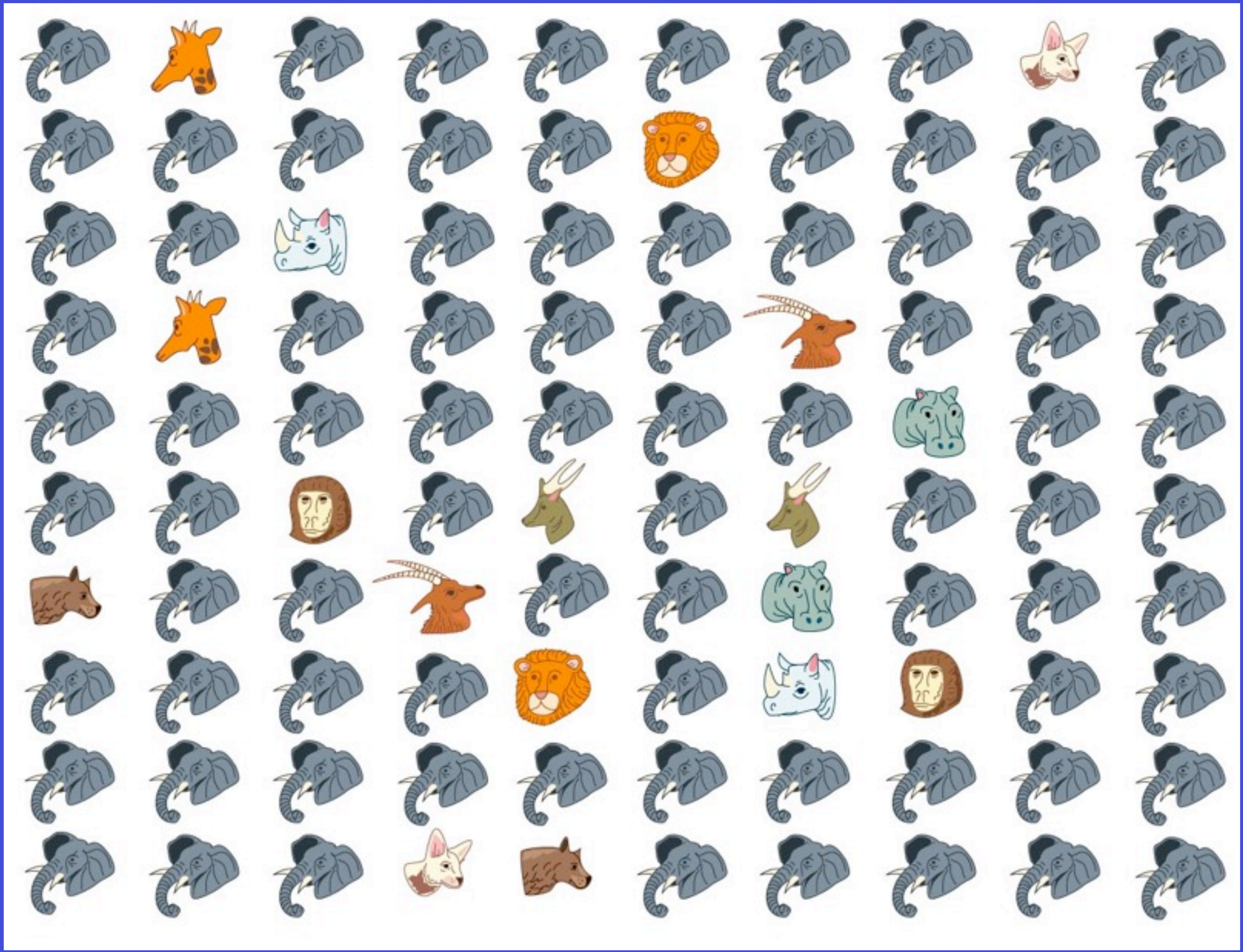
A: 25% B: 25% C: 25% D: 25%

Community 2



A: 80% B: 5% C: 5% D: 10%

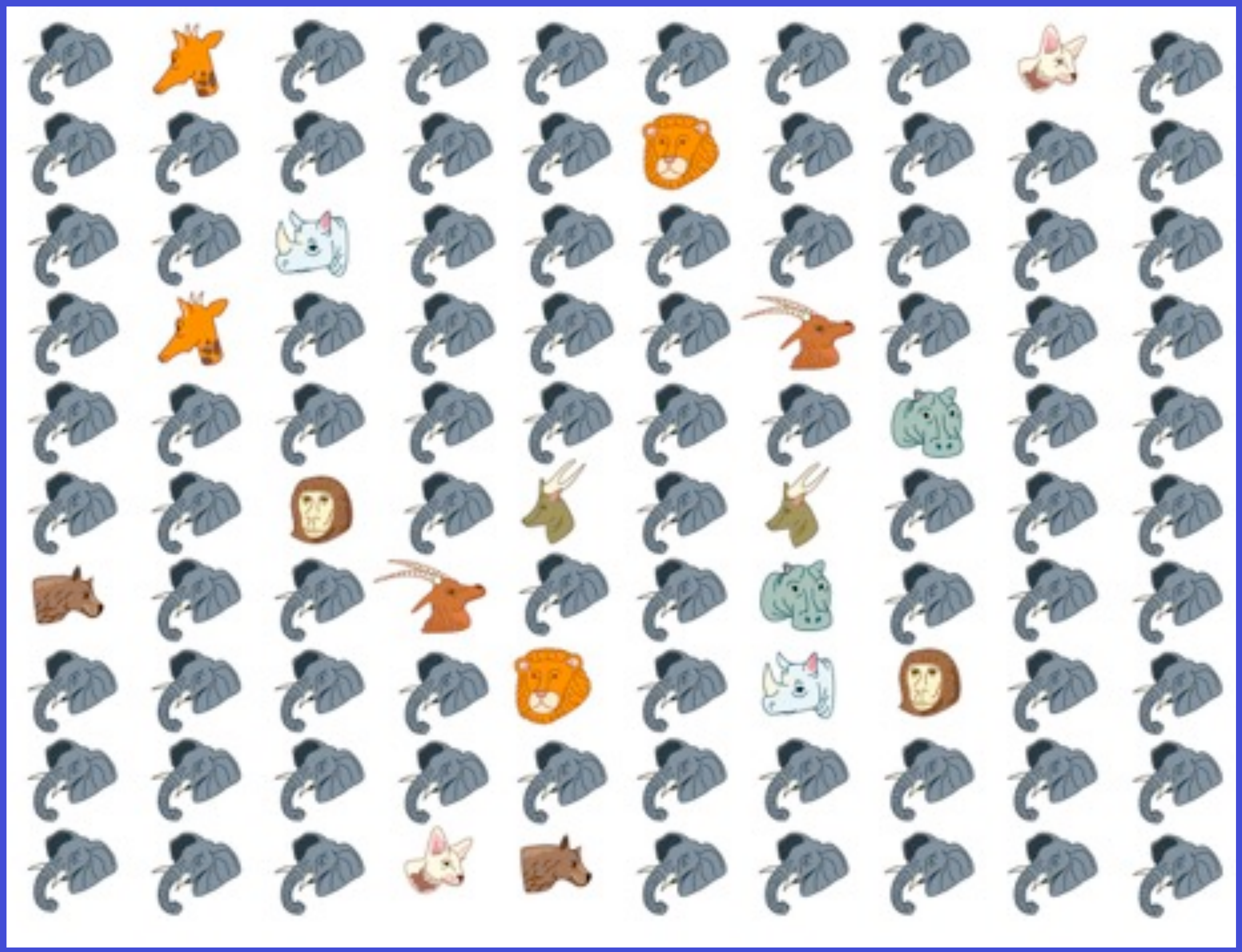
Now check your gut... Calculate the Shannon diversity.



10 species; 100 ind, 87 elephants, 9 sp w/ 2 ind each

10 species; 100 ind, 10 ind each species

Species Diversity



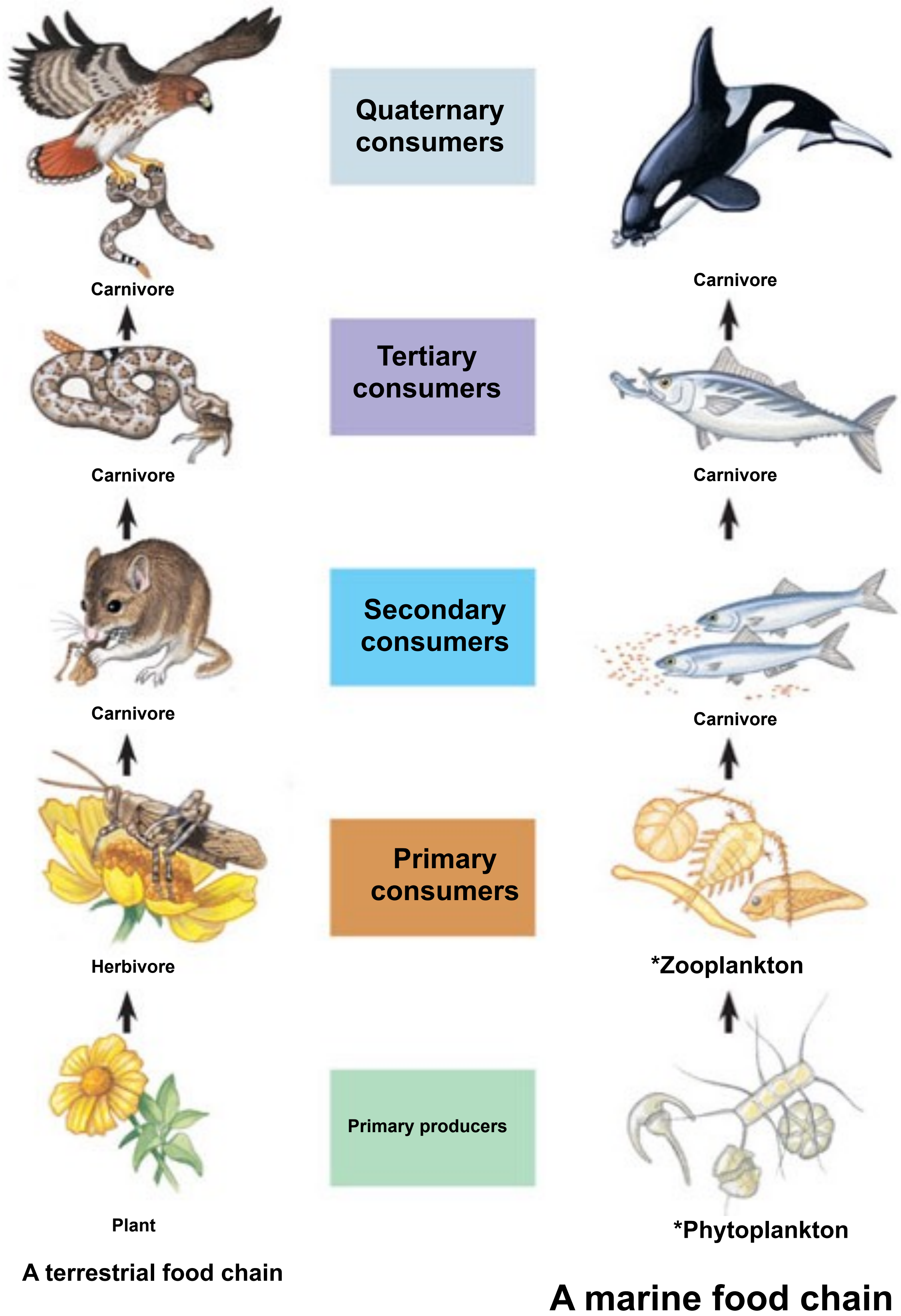
Merely counting the number of species is not enough to describe biological diversity.

B. Diversity & Stability

- Diversity has its benefits
  - 1. **Productive**, higher diversity communities are more productive
  - 2. **Resilient**, higher diversity communities are more stable during times of environmental stress
  - 3. **Stable**, higher diversity communities are more stable (consistent) year to year in their productivity
  - 4. **Resistant**, higher diversity communities are more resistant against *invasive species*.

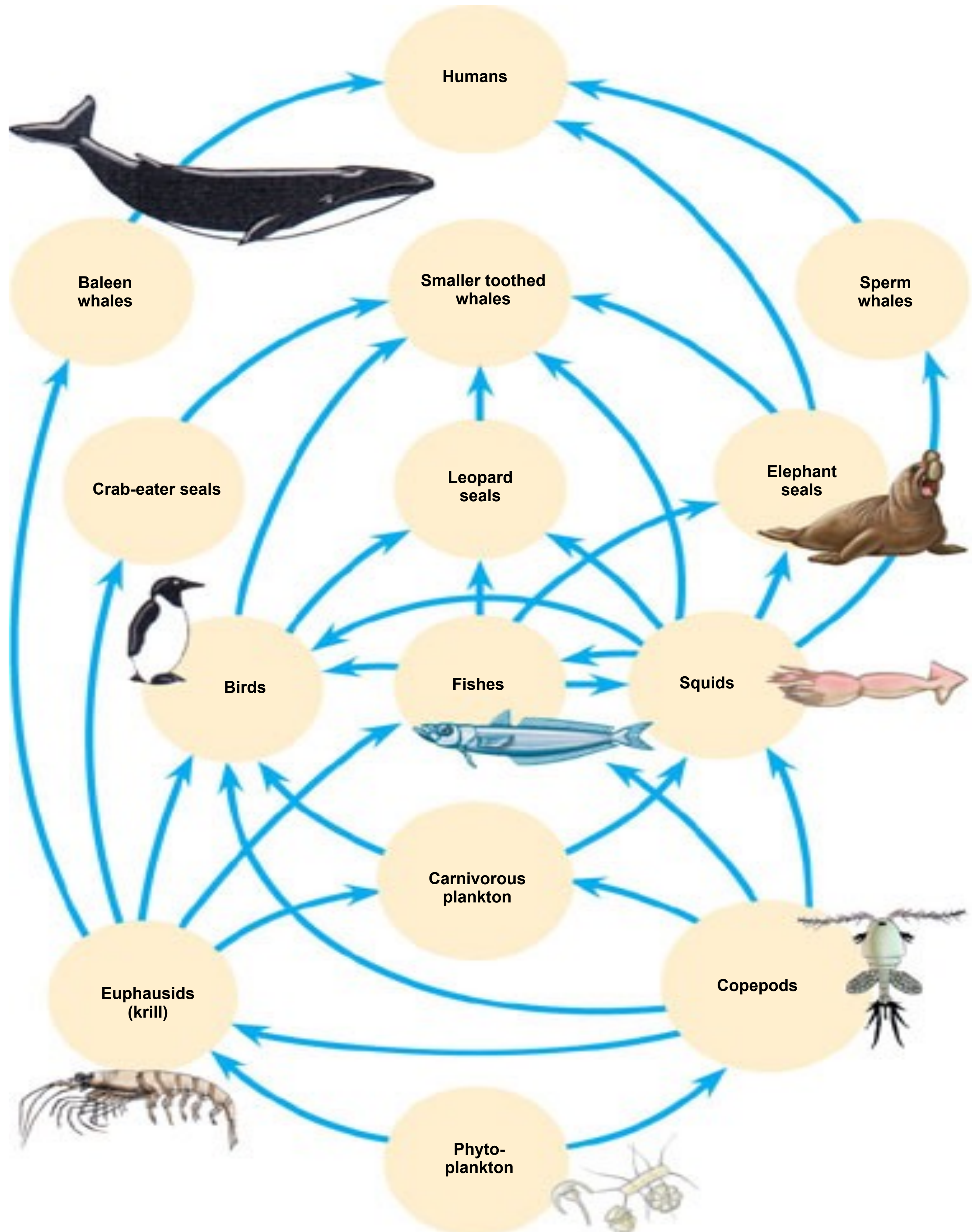
C. Trophic Structure

- **Trophic Structure**...feeding relationships within the community.
- The movement of food energy from autotrophs through and up to the largest consumers...**food chains**.



1. Food Webs

- Interconnected and linked food chains make up **food webs**.
- The arrow points in the direction of foods movement. In other words A⟶ B indicates that B is eating A. Many students reverse this so be careful



Could you interpret these feeding relationships IF...
1.the pics were removed?
2. the pics and names were removed?
3.What if I removed all pics, names and turned in upside down?

1. Food Chain Lengths

- Food chains are limited in their lengths.
- The two common hypotheses..
  - The *Energetic Hypothesis* states that the energy transfer one one trophic level to another is inefficient (about 10-20%) and after 3 - 5 transfers there is not enough energy to support another level.
  - The *Stability Hypothesis* states long chains are unstable, that fluctuations in lower trophic levels are magnified in the higher levels.
    - The most current data supports the *energetic hypothesis*.

Essential knowledge 4.A.5: Communities are composed of populations of organisms that interact in complex ways.

b. Mathematical or computer models are used to illustrate and investigate population interactions within and environmental impacts on a community. [See also 3.E.1]

To foster student understanding of this concept, instructors can choose an illustrative example such as:

-Predator/prey relationships spreadsheet model

-Introduction of species

-Symbiotic relationship

-Graphical representation of field data

-Global climate change models

BIOGEOGRAPHIC FACTORS AFFECT COMMUNITY DIVERSITY

- Here we consider larger scale factors that affect biodiversity.

A. Latitude

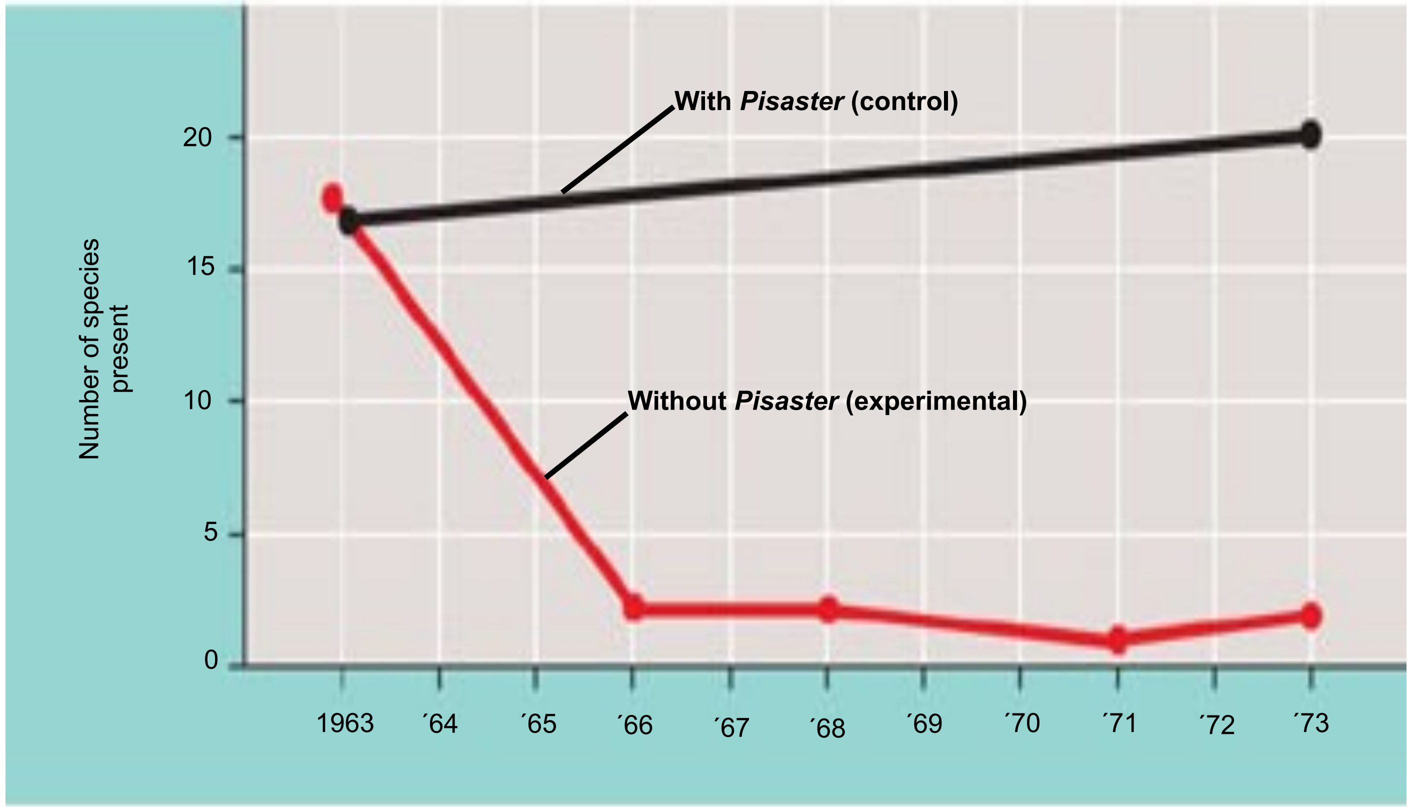
- *Biodiversity is generally greater at the equator and decreases as you move towards the poles.*
- Two factors contribute to this pattern
  - **Evolutionary History**: Tropical communities are *older* than polar communities this allows more time for speciation to occur AND the *growing season* is 5X as long in tropical communities.
  - **Climate**: Tropical climates receive more *solar energy* and *water* than polar communities

Introduction or Removal of Species

D. Dominant & Keystone Species

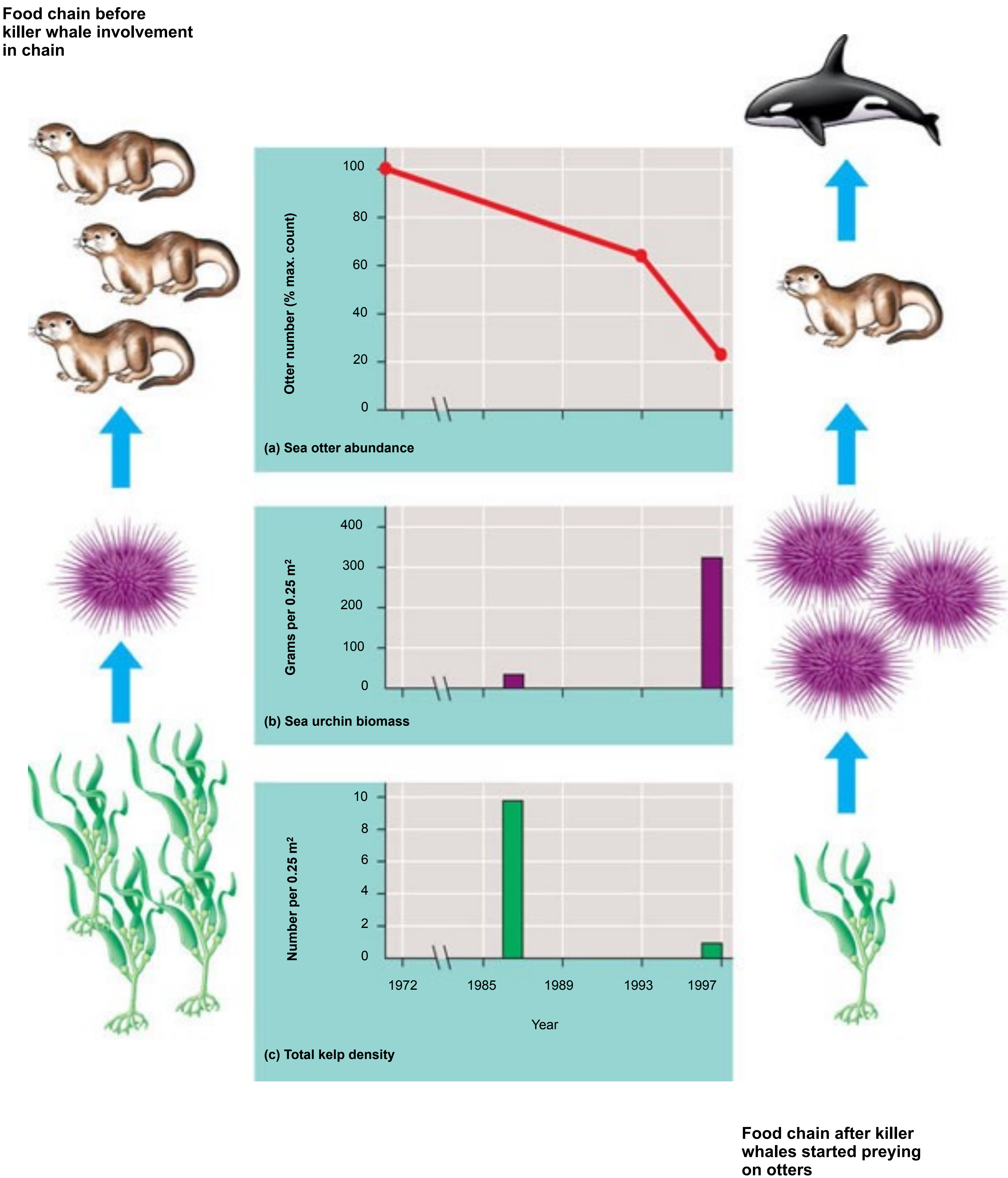
- 2. **Keystone Species**; are not the most abundant but they exert strong control on community dynamics due their unique role or niche.

(a) The sea star *Pisaster ochraceous* feeds preferentially on mussels but will consume other invertebrates.



(b) When *Pisaster* was removed from an intertidal zone, mussels eventually took over the rock face and eliminated most other invertebrates and algae. In a control area from which *Pisaster* was not removed, there was little change in species diversity.

What is a "keystone"?

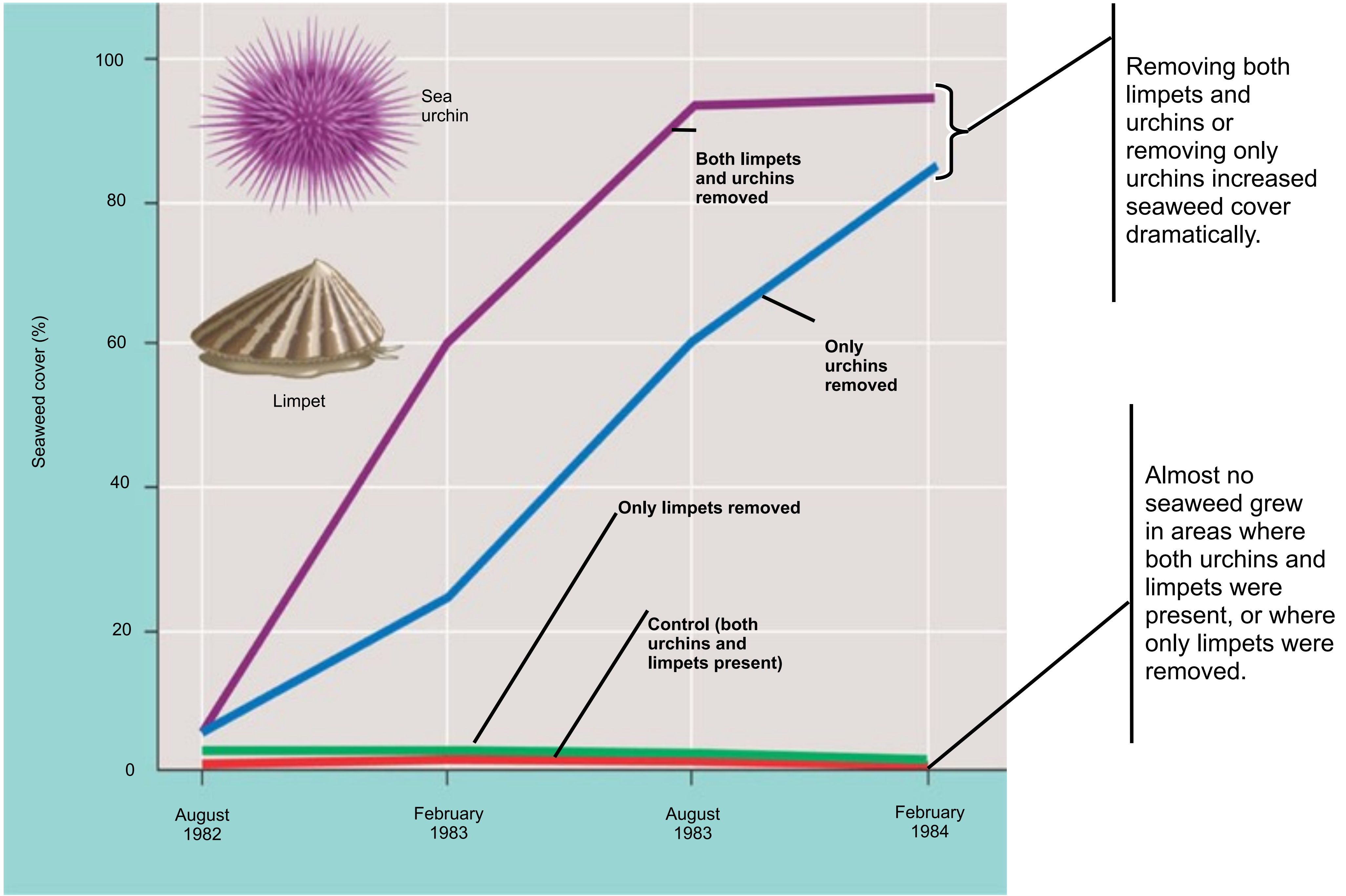


<u>Note:</u>

- **Engineer Species**; exert strong control on community by changing the physical environment.

EXPERIMENT W. J. Flecher tested the effects of two algae-eating animals, sea urchins and limpets, on seaweed abundance near Sydney, Australia. In areas adjacent to a control site, either the urchins, the limpets, or both were removed.

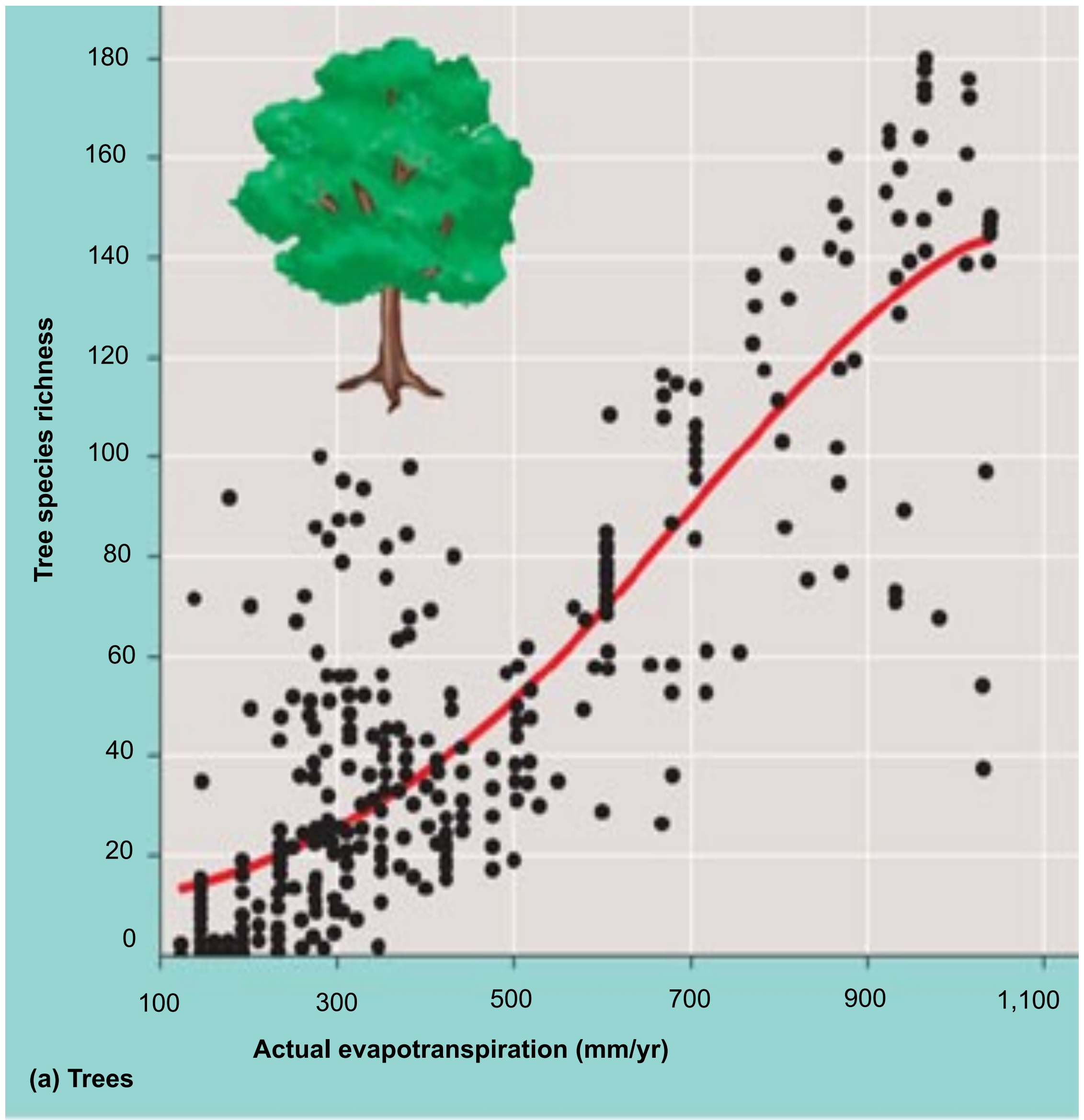
RESULTS Fletcher observed a large difference in seaweed growth between areas with and without sea urchins.

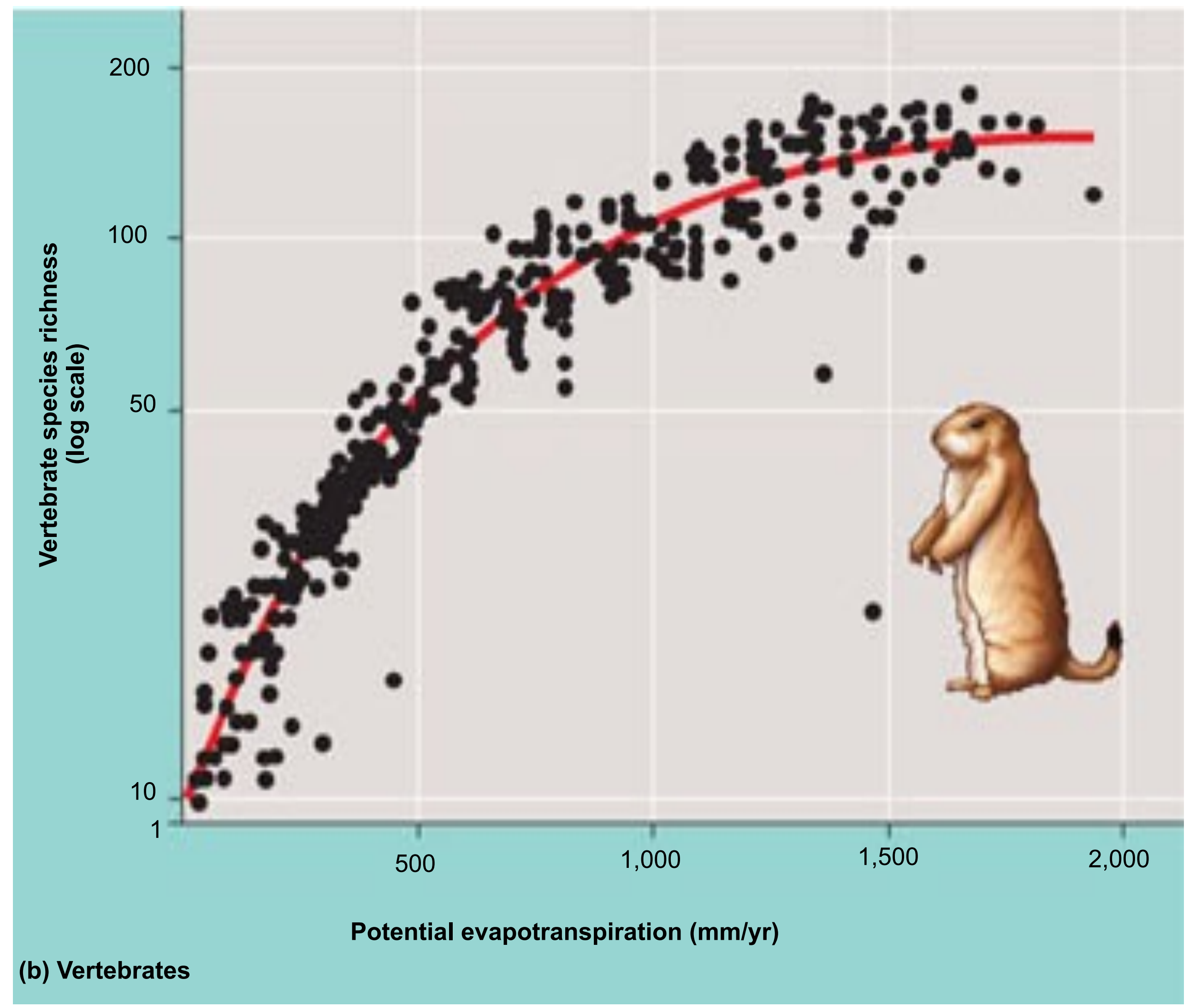


CONCLUSION Removing both limpets and urchins resulted in the greatest increase of seaweed cover, indicating that both species have some influence on seaweed distribution. But since removing only urchins greatly increased seaweed growth while removing only limpets had little effect, Fletcher concluded that sea urchins have a much greater effect than limpets in limiting seaweed distribution.

Graphical Field Data

Essentially you can measure evapotranspiration (evaporation form soil & plants) and get a good estimate of biodiversity in an area. This makes sense since evapotranspiration is a function of solar

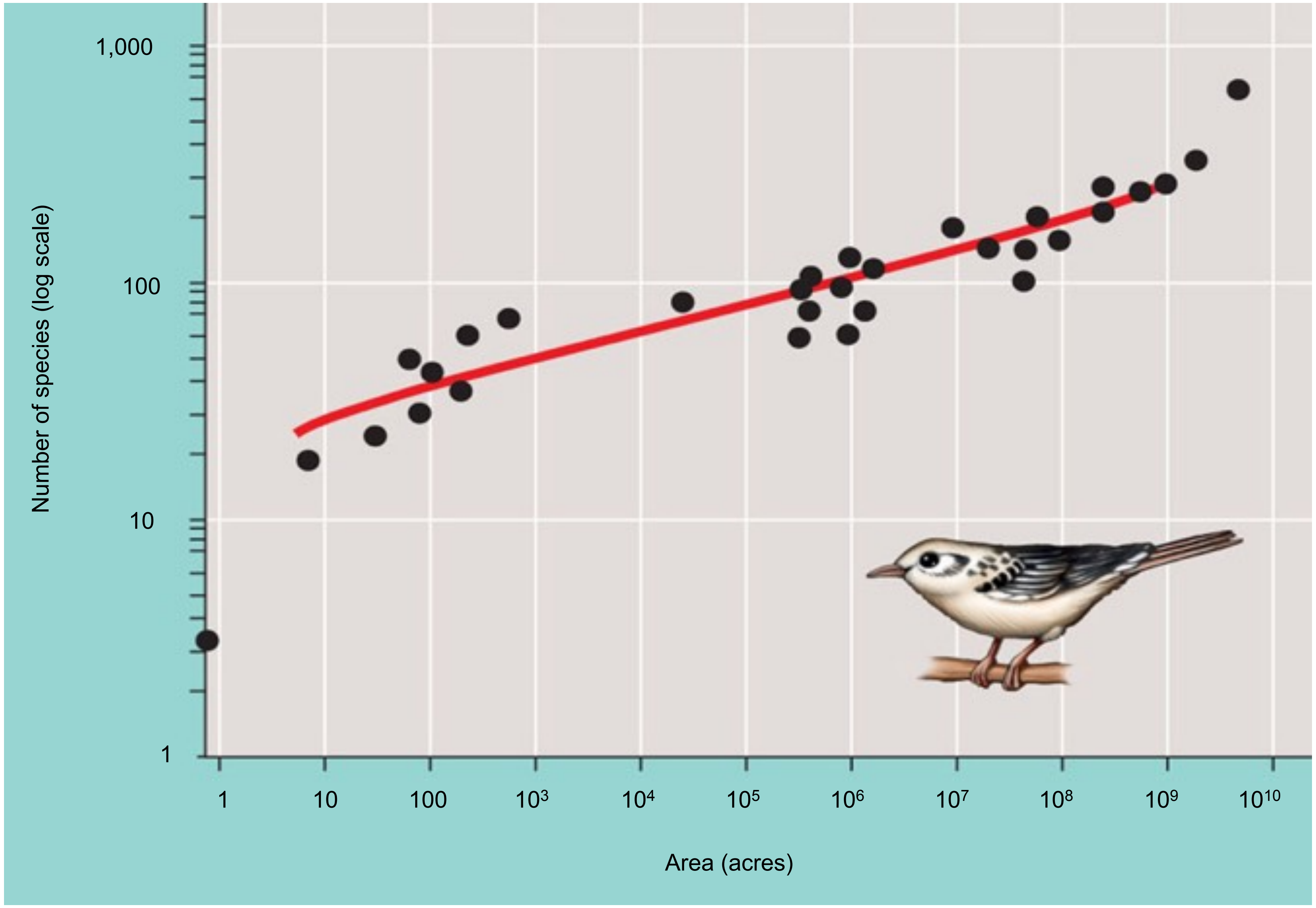




What happens to the size of mammals as you move towards the poles? Why?

B. Area

- *All factors equal the greater the geographical area, the greater the biodiversity.*
    - more area = more habitats and niches

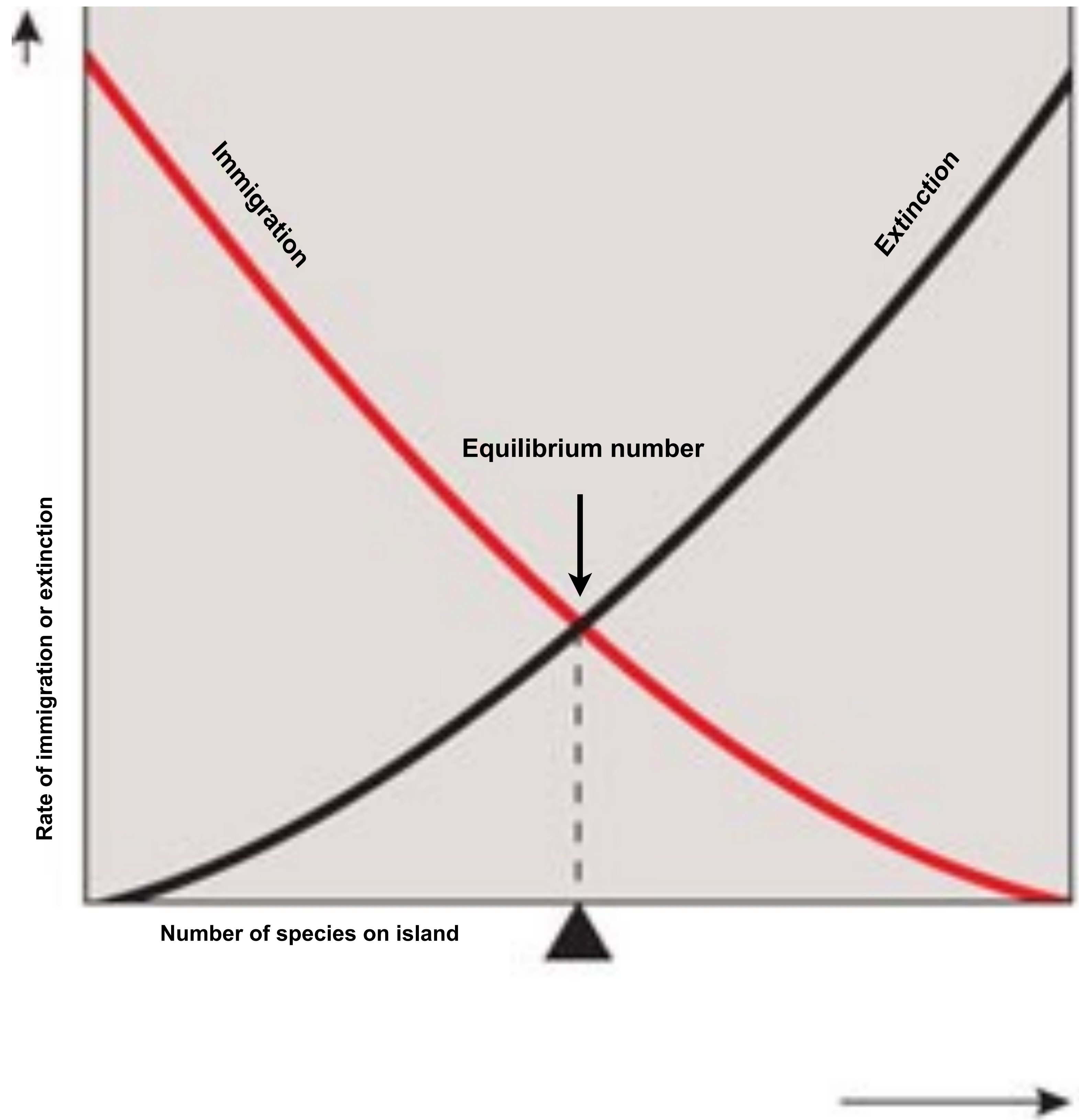


C. *Island* Equilibrium Model

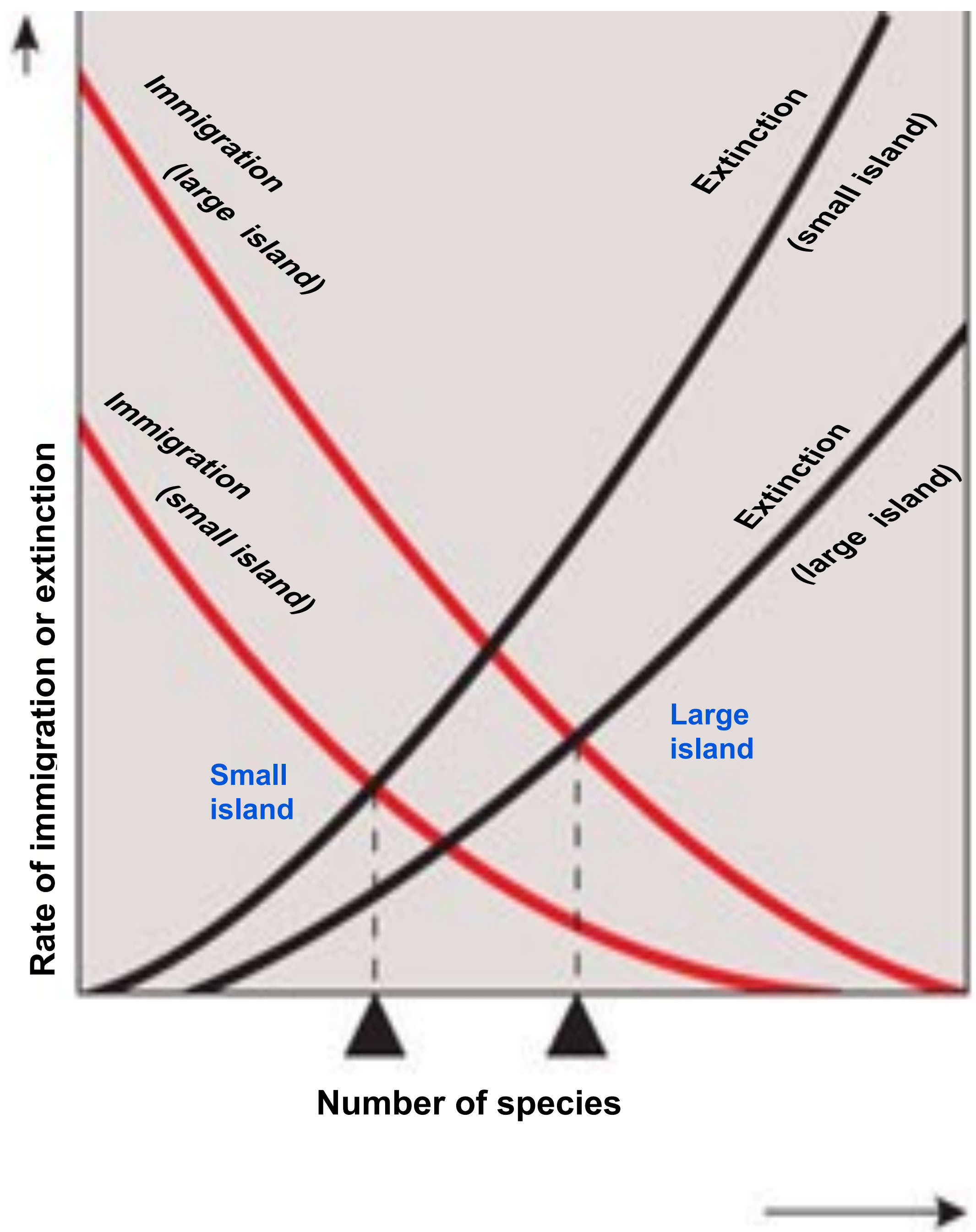
- This includes all "*island habitats*" not just oceanic islands. An "*island*" can be any patch of suitable habitat surrounded by unsuitable habitats.
  - Two factors determine the number of species on an island.
    - Immigration & Extinction
  - Two physical features affect immigration and extinction.
    - Size & Distance (from mainland or suitable habitat)

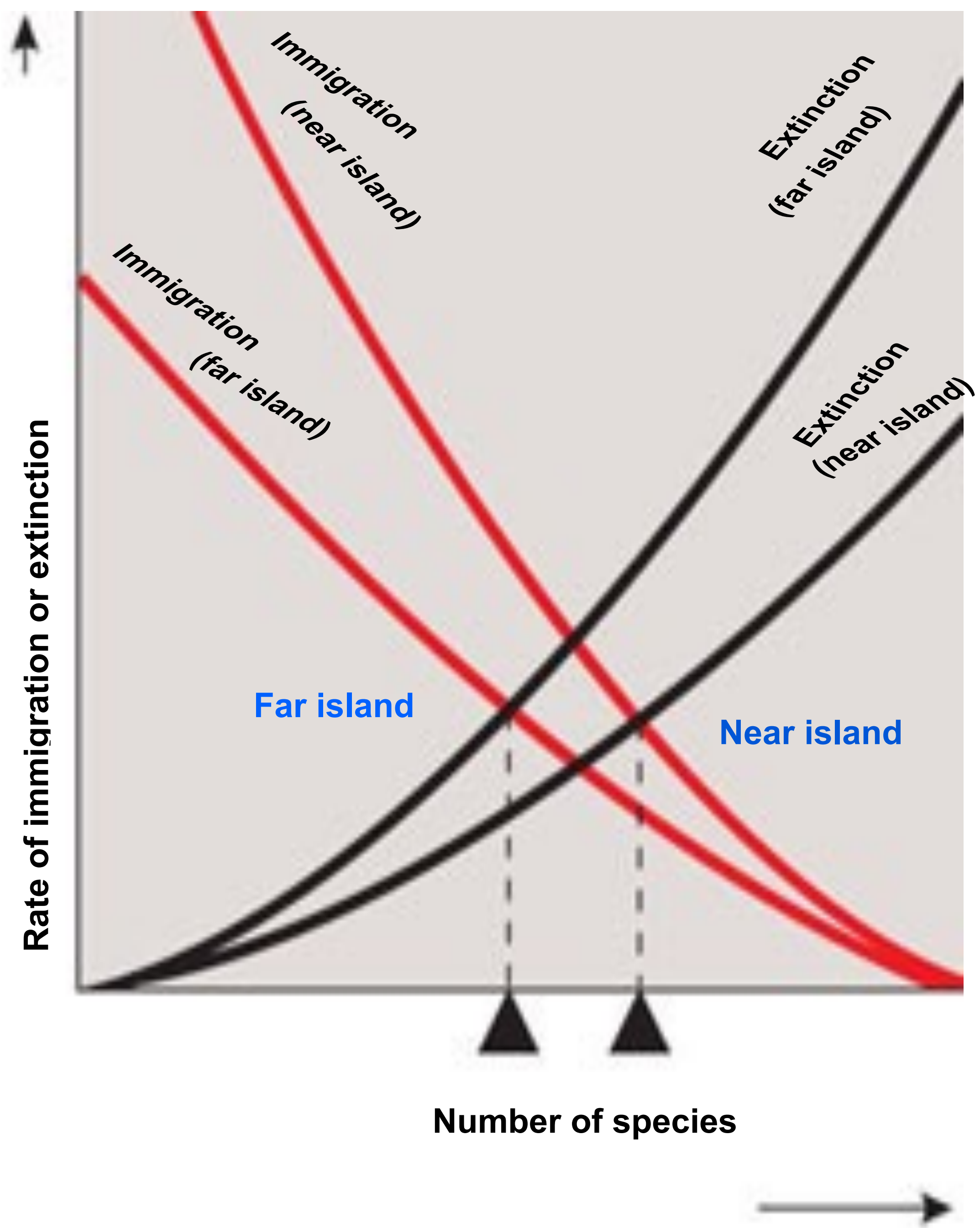
These factors determine the number of species on an island

Immigration and extinction rates. The equilibrium number of species on an island represents a balance between the immigration of new species and the extinction of species already there.



These physical features affect immigration and extinction.



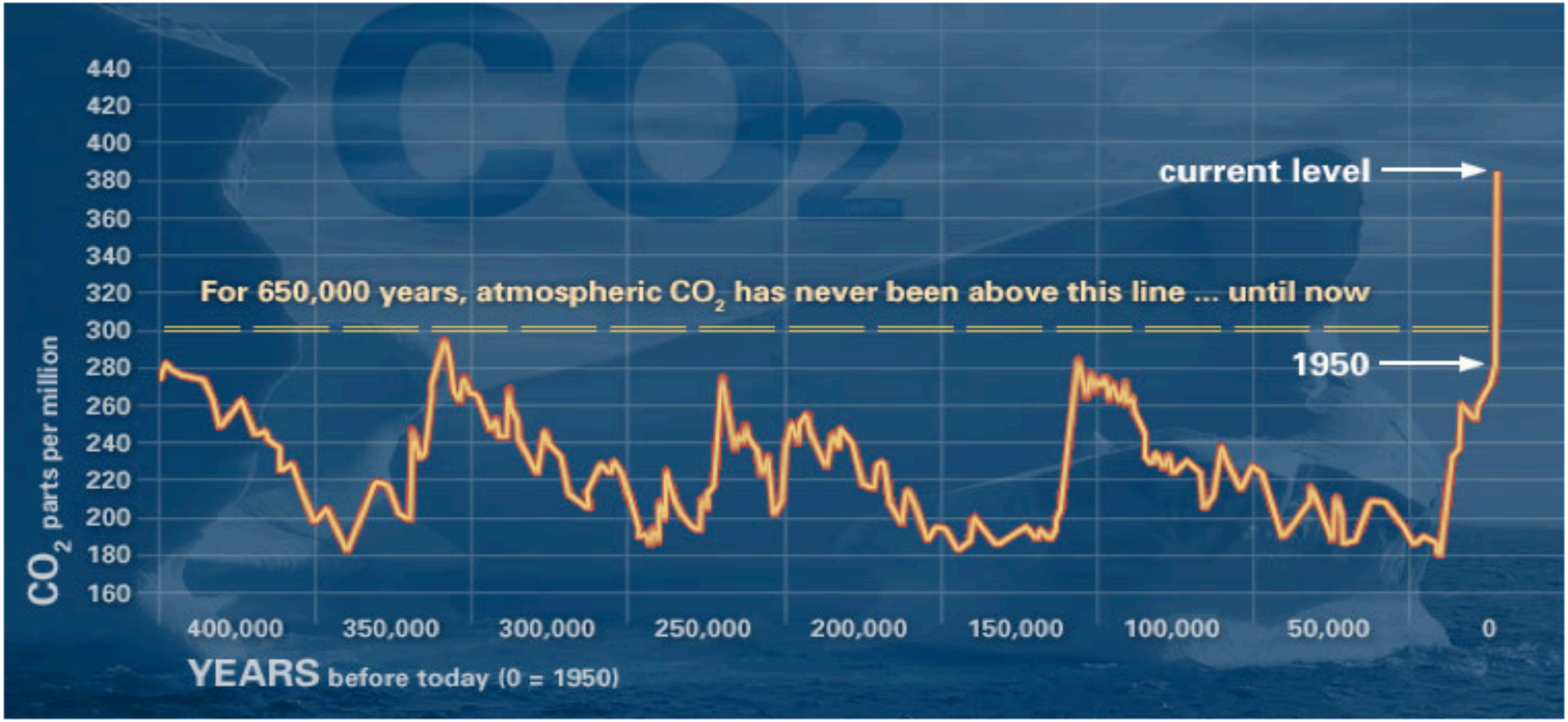


Effect of island size. Large islands may ultimately have a larger equilibrium number of species than small islands because immigration rates tend to be higher and extinction rates lower on large islands.

Effect of distance from mainland. Near islands tend to have larger equilibrium numbers of species than far islands because immigration rates to near islands are higher and extinction

Climate Change Data

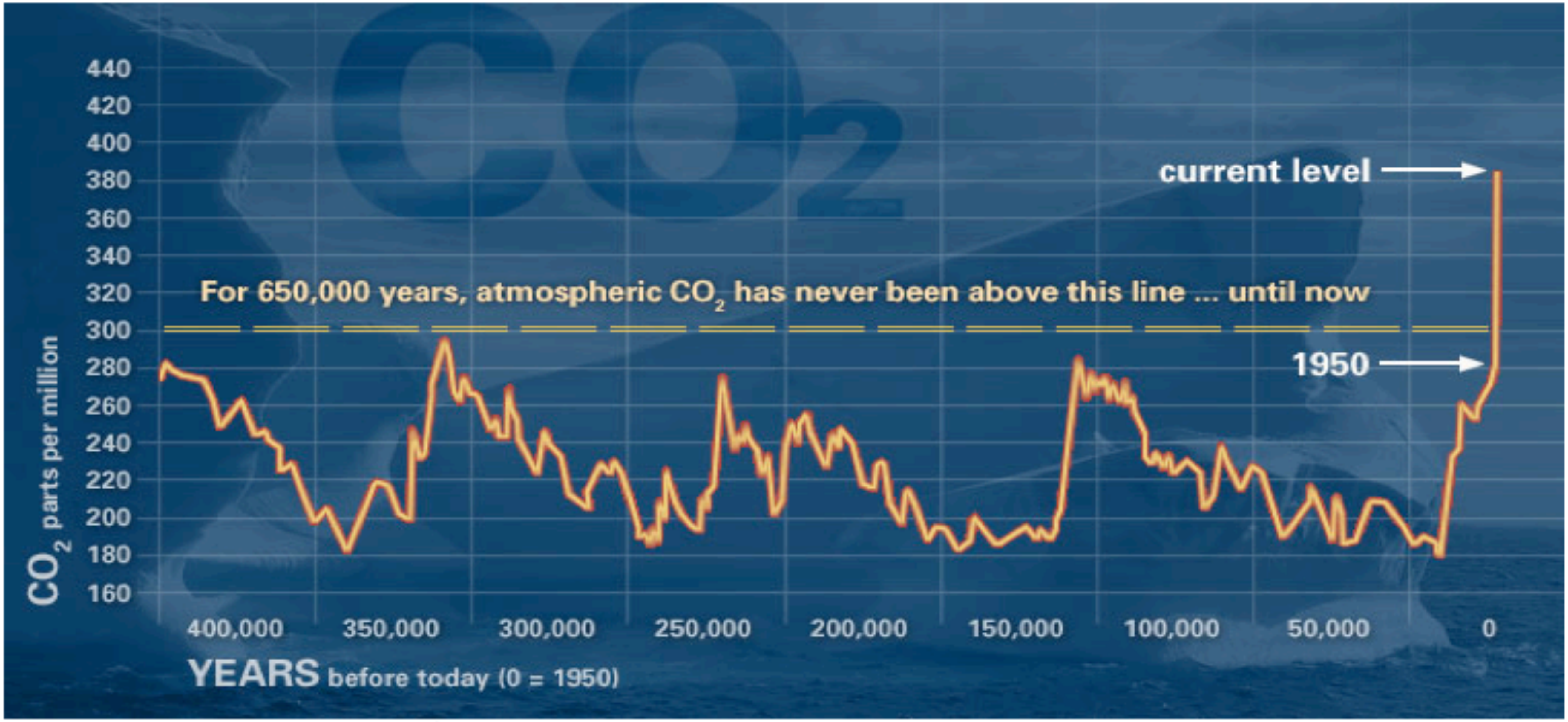
Climate change: How do we know?



This graph, based on the comparison of atmospheric samples contained in ice cores and more recent direct measurements, provides evidence that atmospheric CO_2 has increased since the Industrial Revolution. (Source: NOAA)

What do the skeptics say about the rising CO_2 levels in the atmosphere?

Climate change: How do we know?



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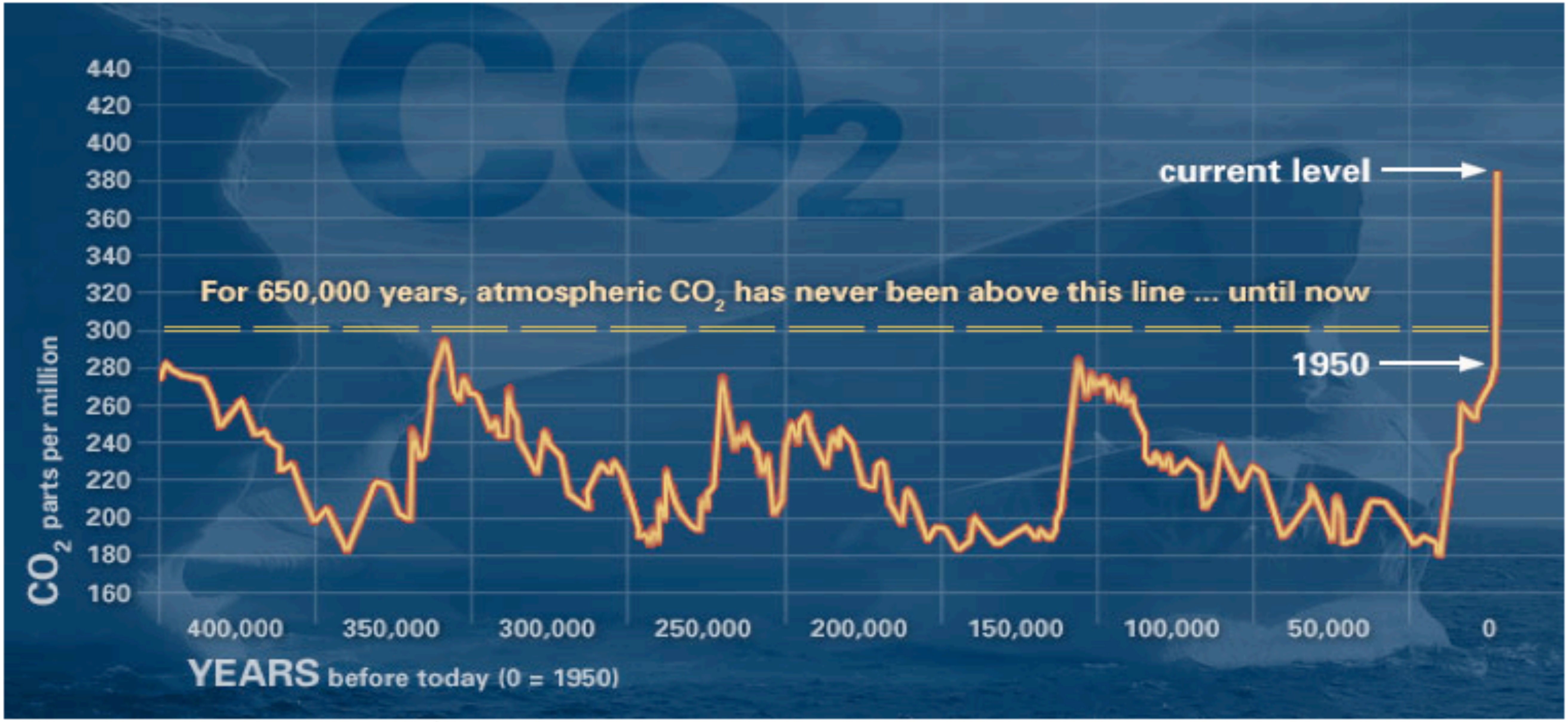


This graph, based on the comparison of atmospheric samples contained in ice cores and more recent direct measurements, provides evidence that atmospheric CO_2 has increased since the Industrial Revolution. (Source: NOAA)

What do the skeptics say about the rising CO_2 levels in the atmosphere?

"Yes, our climates change. They've been changing ever since the earth was formed."

17 August 2011 (Source)

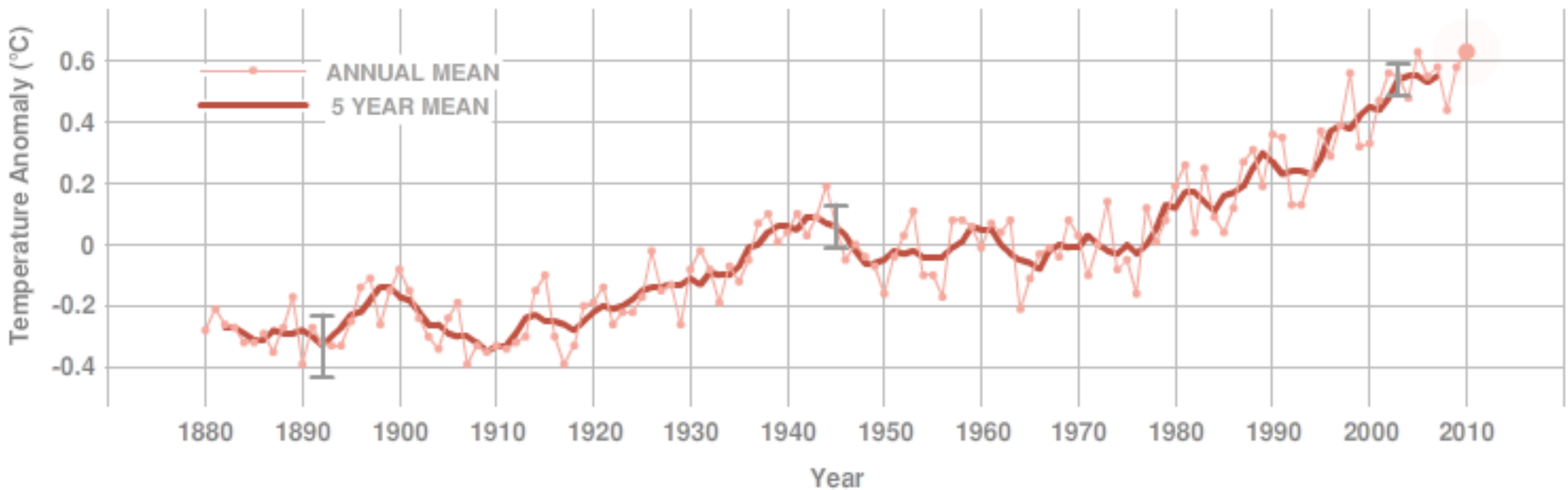
Global Surface Temperature

download data

Data updated 4.18.11

GLOBAL LAND-OCEAN TEMPERATURE INDEX

Source: NASA/GISS. This research is broadly consistent with similar constructions prepared by the Climatic Research Unit and the National Atmospheric and Oceanic Administration. Credit: NASA/GISS



Politician	Objective Data	Politician
"the last 4 or 5 years, have they been cooler or warmer?" 31 March 2011 (Source)	Global temperature is still rising and 2010 was the hottest recorded.	"we've actually had global cooling in the last ten years" 7 December 2009 (Source)
"would it be fair to say then that there has been a cooling of global temperatures at least over the last 13 years compared to 1998?" 31 March 2011 (Source)	The last decade 2000-2009 was the hottest on record.	"What the science says is that temperatures peaked out globally in 1998. So we've gone for 10 plus years where the temperatures have gone down." 14 April 2009 (Source)

Sea Level

Data updated 8.5.11

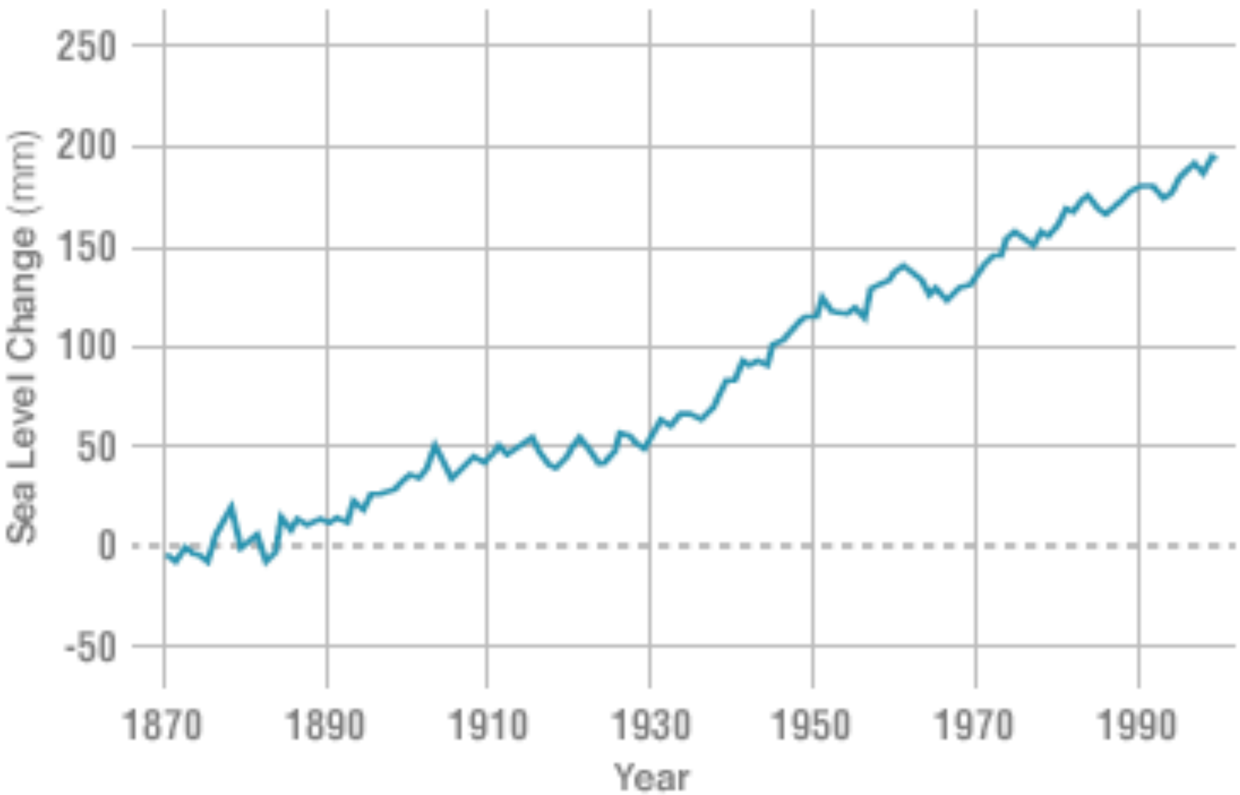
download data

GROUND DATA: 1870-2000

RATE OF CHANGE

Data source: Coastal tide gauge records.
Credit: CSIRO

↑ 1.70 mm per yr*



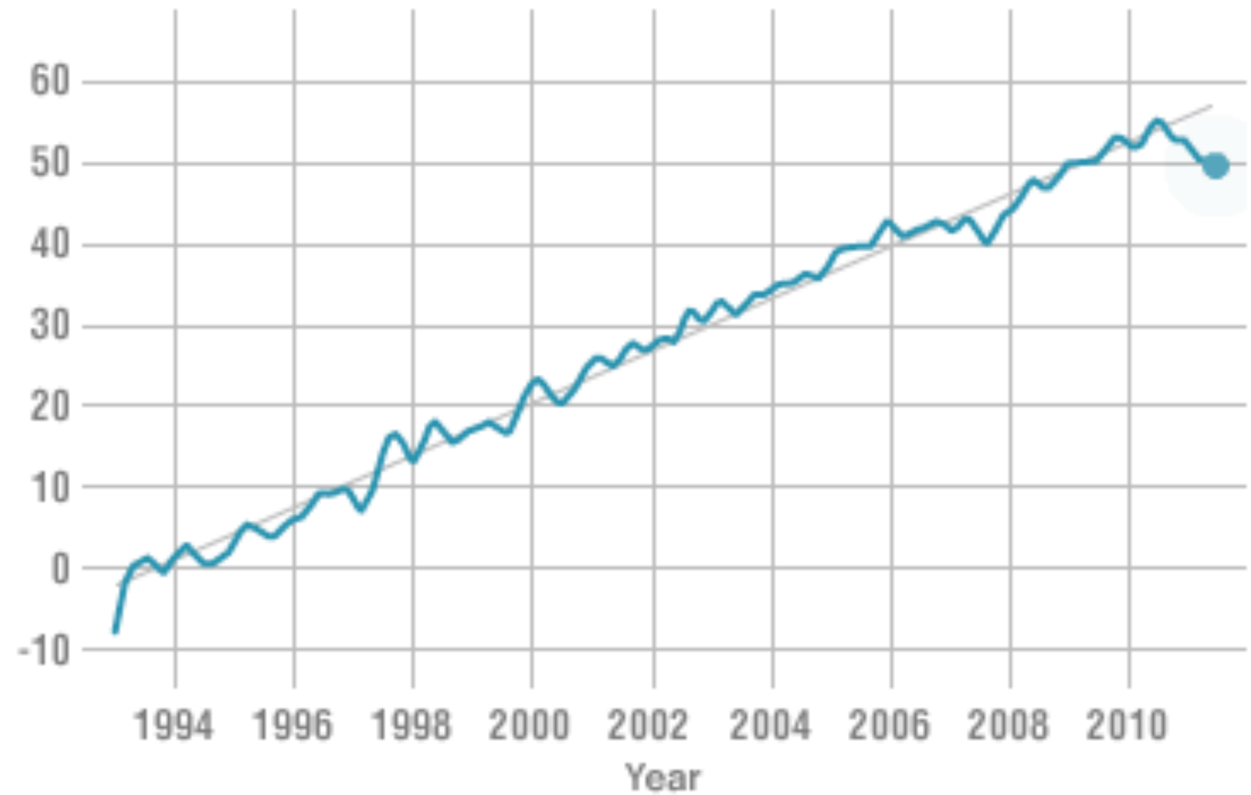
*estimate for 20th century

SATELLITE DATA: 1993-PRESENT

RATE OF CHANGE

Data source: Satellite sea level observations.
Credit: CLS/Cnes/Legos

↑ 3.27 mm per yr*



Inverse barometer applied and seasonal signals removed.
*estimate for 1993-2010

Arctic Sea Ice

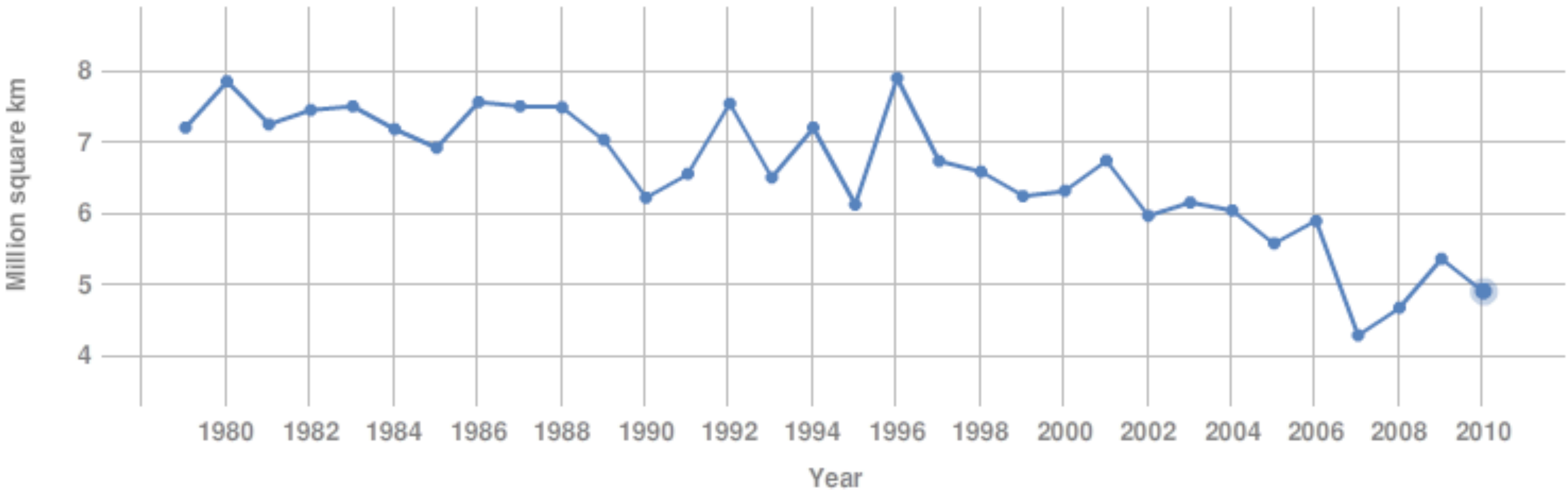
Data updated 2.23.11

download data

AVERAGE SEPTEMBER EXTENT

Data source: Satellite observations

Credit: NSIDC



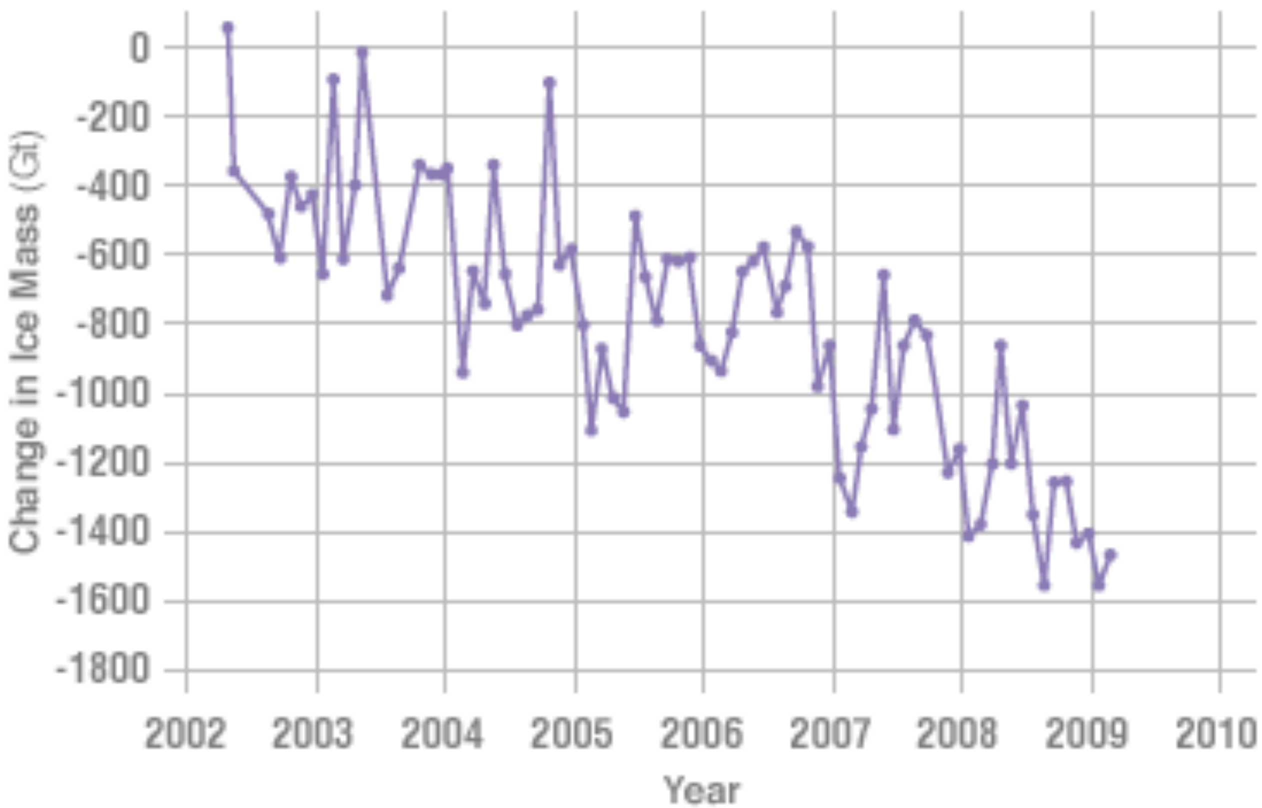
Land Ice

Data updated 2.23.11

download data

ANTARCTICA MASS VARIATION SINCE 2002

Data source: Ice mass measurement by NASA's Grace satellites.
Credit: NASA/University of California, Irvine



GREENLAND MASS VARIATION SINCE 2002

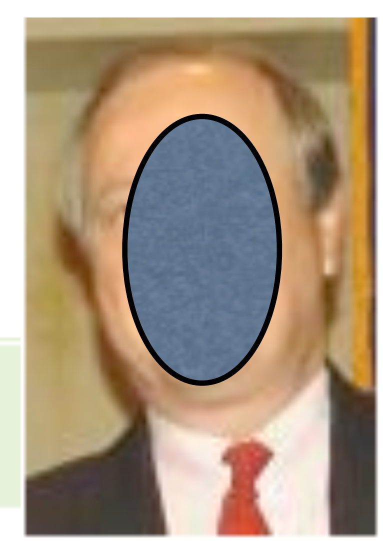
Data source: Ice mass measurement by NASA's Grace satellites.
Credit: NASA/University of California, Irvine

Note: In the above charts, negative numbers indicate mass loss; positive numbers indicate mass gain. (Reference)

Really?

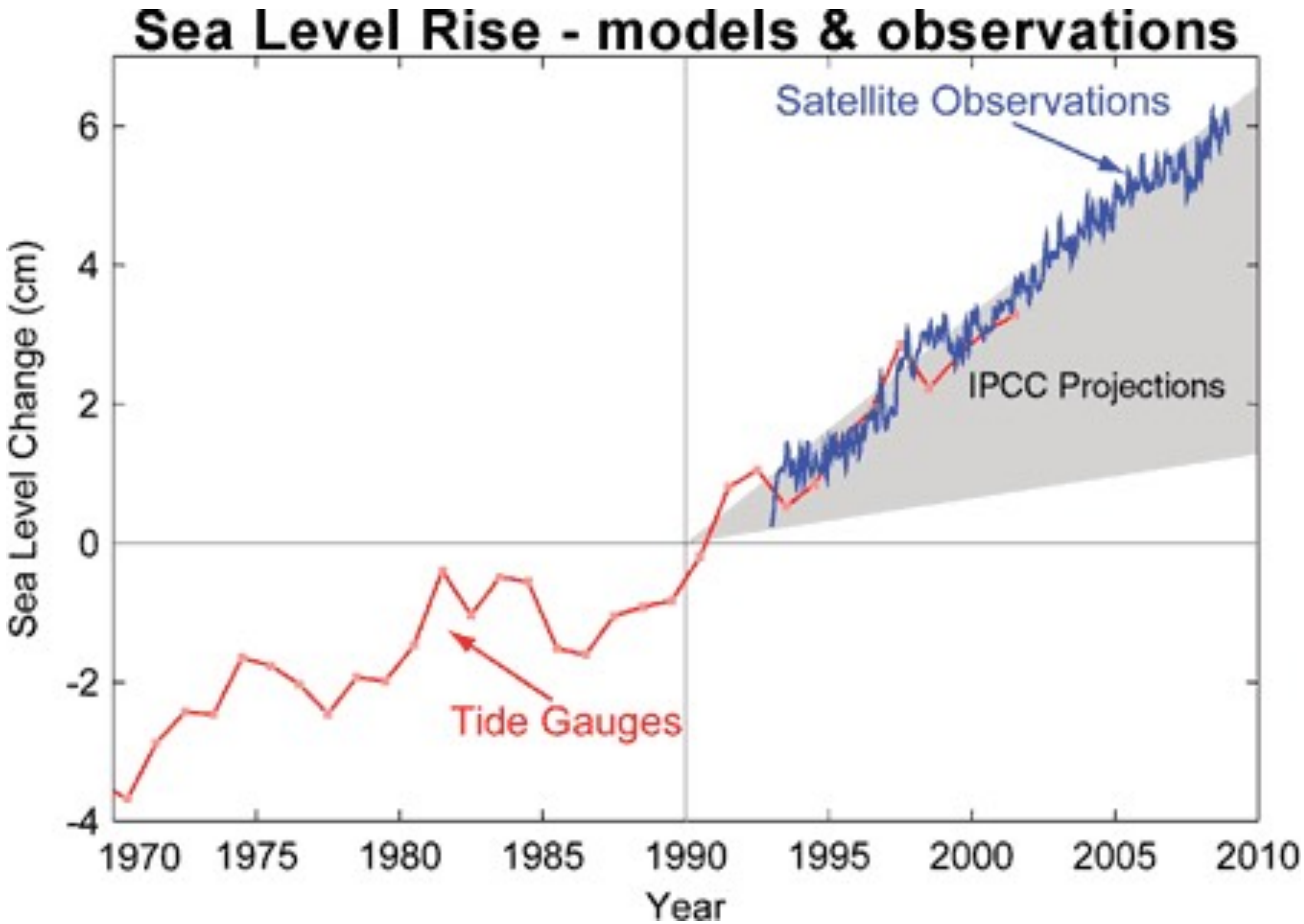
"in the Antarctic, where the penguins are, there is a buildup of ice."
18 March 2009 (Source)

"the ice in the Antarctic is growing"
8 March 2011 (Source)



Climate Change Models

Climate models are mathematical representations of the interactions between the atmosphere, oceans, land surface, ice, and the sun. ... The **models** used to predict future global warming can accurately map past **climate** changes.



Observed sea level rise since 1970 from tide gauge data (red) and satellite measurements (blue) compared to model projections for 1990-2010 from the IPCC Third Assessment Report (grey band). (Source: [The Copenhagen Diagnosis, 2009])

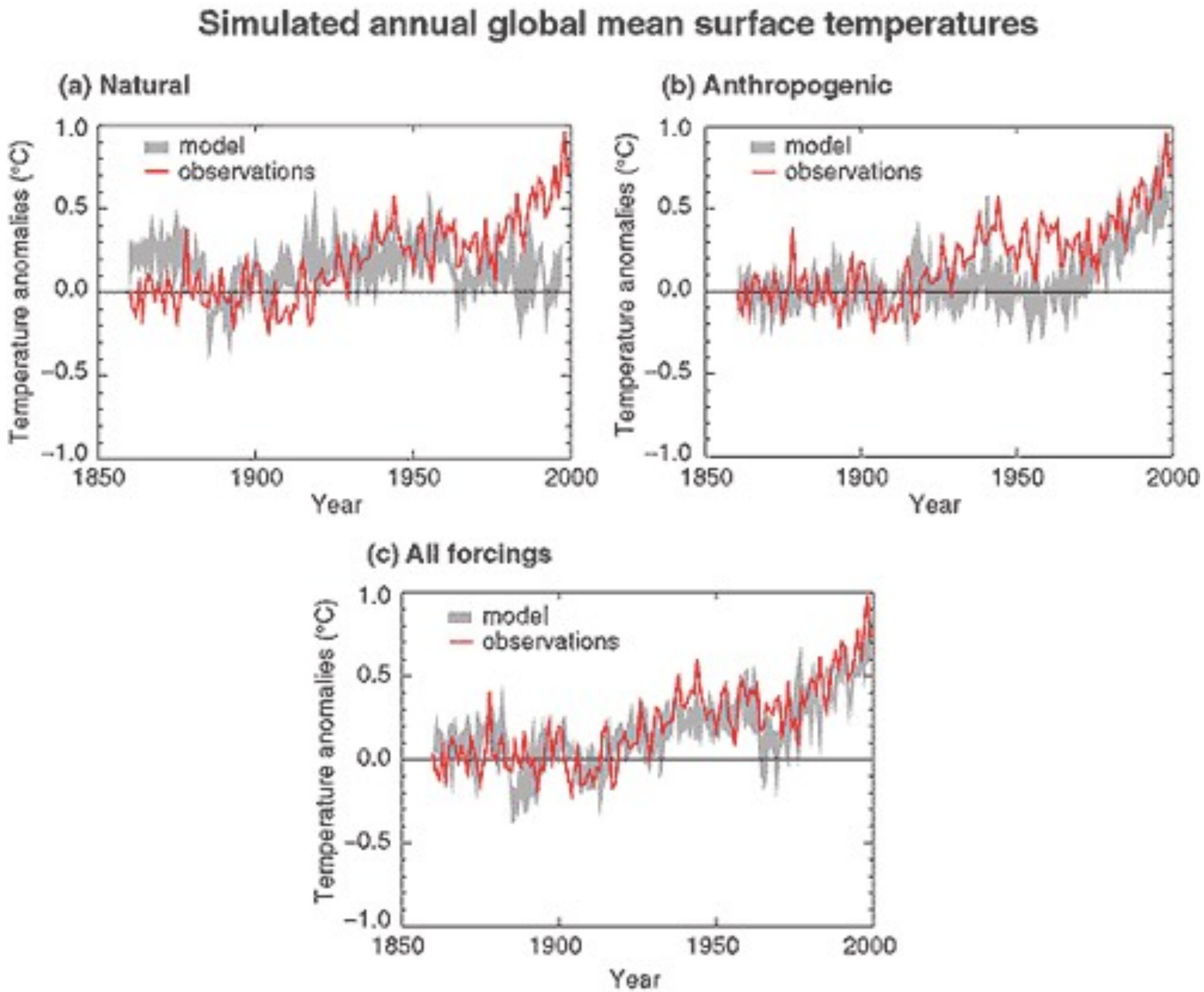


Figure 1: Comparison of climate results with observations. (a) represents simulations done with only natural forcings: solar variation and volcanic activity. (b) represents simulations done with anthropogenic forcings: greenhouse gases and sulphate aerosols. (c) was done with both natural and anthropogenic forcings (IPCC).

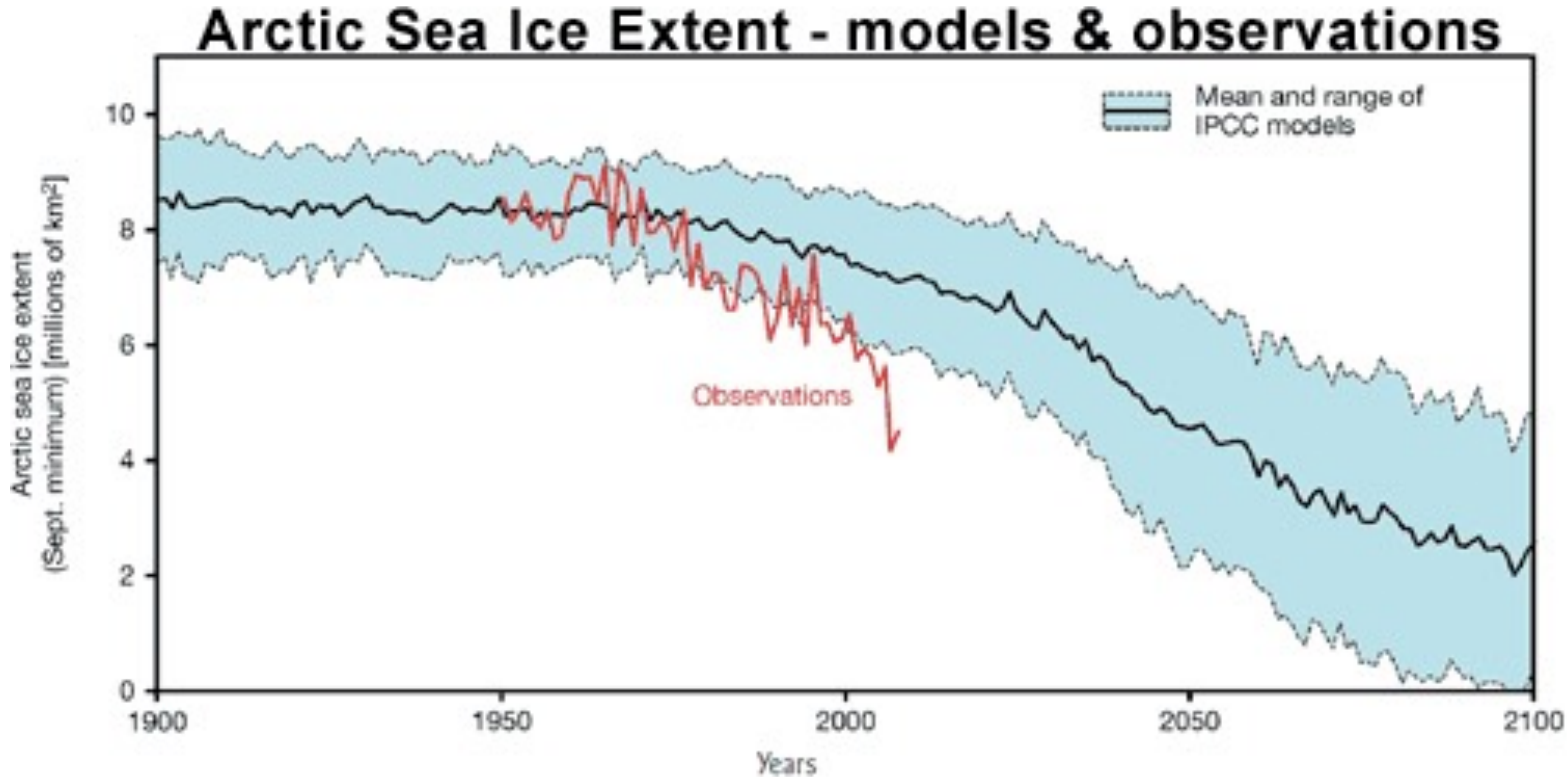


Figure 5: Comparison of observed September minimum Arctic sea ice extent through 2008 (red line) with IPCC AR4 model projections. The solid black line shows the mean of the 13 models, and dashed black lines show the range of the model results. The 2009 minimum was calculated at 5.10 million km2, the third lowest year on record and still well below the IPCC worst case scenario. (Source: Copenhagen Diagnosis, 2009)

Essential knowledge 4.A.5: Communities are composed of populations of organisms that interact in complex ways.

c. Mathematical models and graphical representations are used to illustrate population growth patterns and interactions.

Evidence of student learning is a demonstrated understanding of each of the following:

1. Reproduction without constraints results in the exponential growth of a population.
2. A population can produce a density of individuals that exceeds the system's resource availability.
3. As limits to growth due to density-dependent and density-independent factors are imposed, a logistic growth model generally ensues.
4. Demographics data with respect to age distributions and fecundity can be used to study human populations.

Population Ecology

Main Idea: All species have the potential to increase their population size greatly under ideal conditions.

Main Idea: Exponential growth describes a population growing at its maximum potential under ideal conditions

What type of factors do you think constitute "ideal conditions"?

EXPONENTIAL MODEL

- *Bacteria have a fast rate of intrinsic growth*
- *A population of bacteria doubles every 20 minutes.*
  - *1 becomes 2 in 20 minutes, 2 become 4 in another 20 minutes*
  - *at this rate bacteria would cover the earth's surface at a depth of 30 cm in just 36 hours*
- *Elephants have a slow rate of intrinsic growth*
- *An elephant may produce only 6 offspring in a 100 years time*
  - *still in 750 years, a pair of elephants could give rise to a population that exceeds 19 million*

Per Capita Rate of Increase

- Change in population size
  - *pop. change = births + immigration - deaths + emigration*
    - (we will simplify and ignore immigration and emigration)
    - *per capita birth rate = offspring produced per unit time by an average member of the population (same goes for per capita death rate)*

For Example: 68 births per year in a population of 1000 equals a per capita birth rate of 0.068

What is the expected number of births in a population of 750 with a birth rate of 0.068?

Per Capita Rate of Increase

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For Example: 68 births per year in a population of 1000 equals a per capita birth rate of 0.068

What is the expected number of births in a population of 750 with a birth rate of 0.068?

Answer: B=bN, (births) = (birth rate)(population size) so (0.068)(750) = 51

- Difference between birth rate and death rate is $r = b - m$
- *Thus $r > 0$ indicates a growing population*
- *$r < 0$ indicates a declining population*
- *and $r = 0$ indicates zero population growth*
- *Change in Population size over time is described by the equation below (* for a discrete or fixed time)*
  - *where N is population size, t is time, r is difference in birth and death rates*

$$^{*}\ \frac{\Delta N}{\Delta t} = rN$$

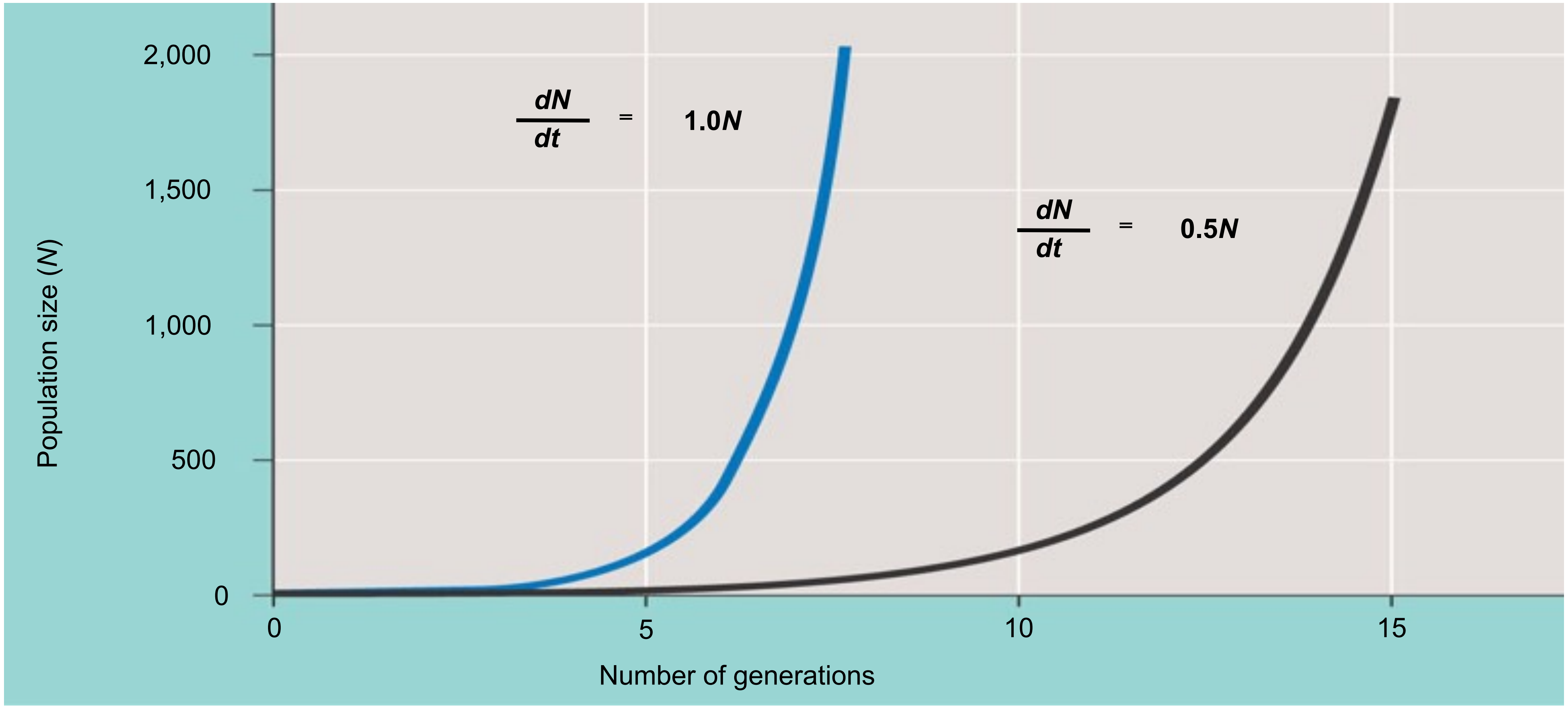
$$\frac{dN}{dt} = rN$$

Instantaneous Growth, at a particular instant in time

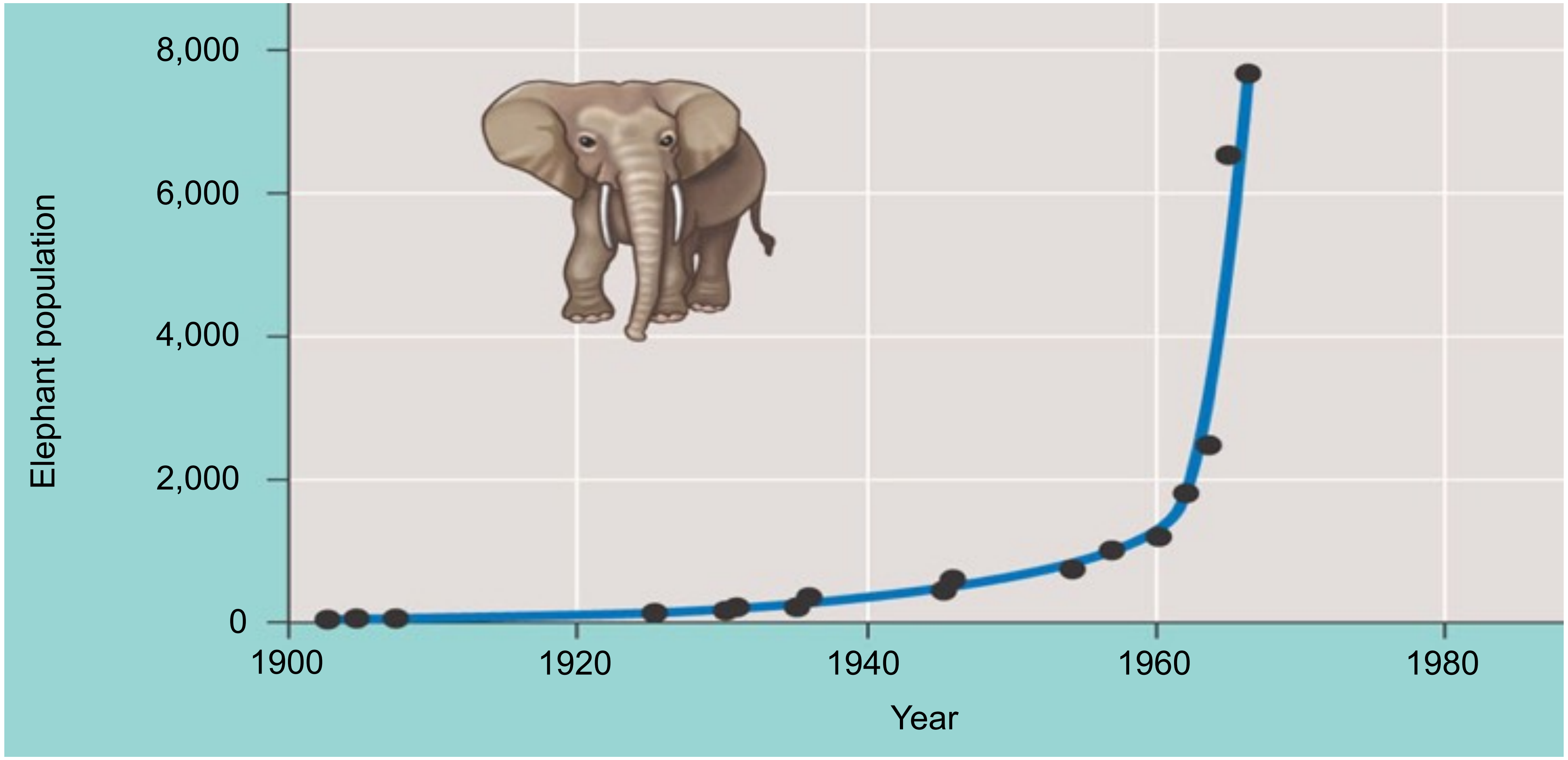
The derived equation(s) can be found in your text!

Exponential Growth

- Reproduction at the physiological capacity (maximum)
  - *denoted as r_{max}*
    - "graphed" **exponential growth** takes on a "**J**" shaped curve
    - this type of growth is rare in the real world
      - it does/can occur where populations are rebounding or have been recently introduced into a new environment
    - a population with a higher rate of increase (dN/dt = 1.0N) will grow faster than a population with lower rate of increase (dN/dt = 0.5N)



2,000
1,500
1,000
500
0
Population size (N)
0
5
10
15
Number of generations
$\frac{dN}{dt} = 1.0N$
$\frac{dN}{dt} = 0.5N$



8,000
6,000
4,000
2,000
0
Elephant population
1900
1920
1940
1960
1980
Year

Population Ecology

Main Idea: Conditions are rarely ideal and as such the environment can support a limited number of individuals

Main Idea: The maximum number of individuals that the environment can sustain is its carrying capacity.

Main Idea: Population growth rate decreases as a population approaches its carrying capacity.

Can you think of any limiting factors?

“REAL” POPULATION GROWTH

- Start with exponential growth and add an expression that reduces the per capita rate of increase as N increases.
  - *K = carrying capacity*
  - *so (K-N)/K is the fraction of K that is still available for population growth*
    - when N is small relative to K, the (K-N)/K approaches 1.0 (maximum growth rate)
    - when N is large relative to K, the (K-N)/K approaches 0 (slow growth rate)
    - when N = K, population growth stops!
      - *population growth decreases dramatically as N approaches K*

Logistic Growth Model

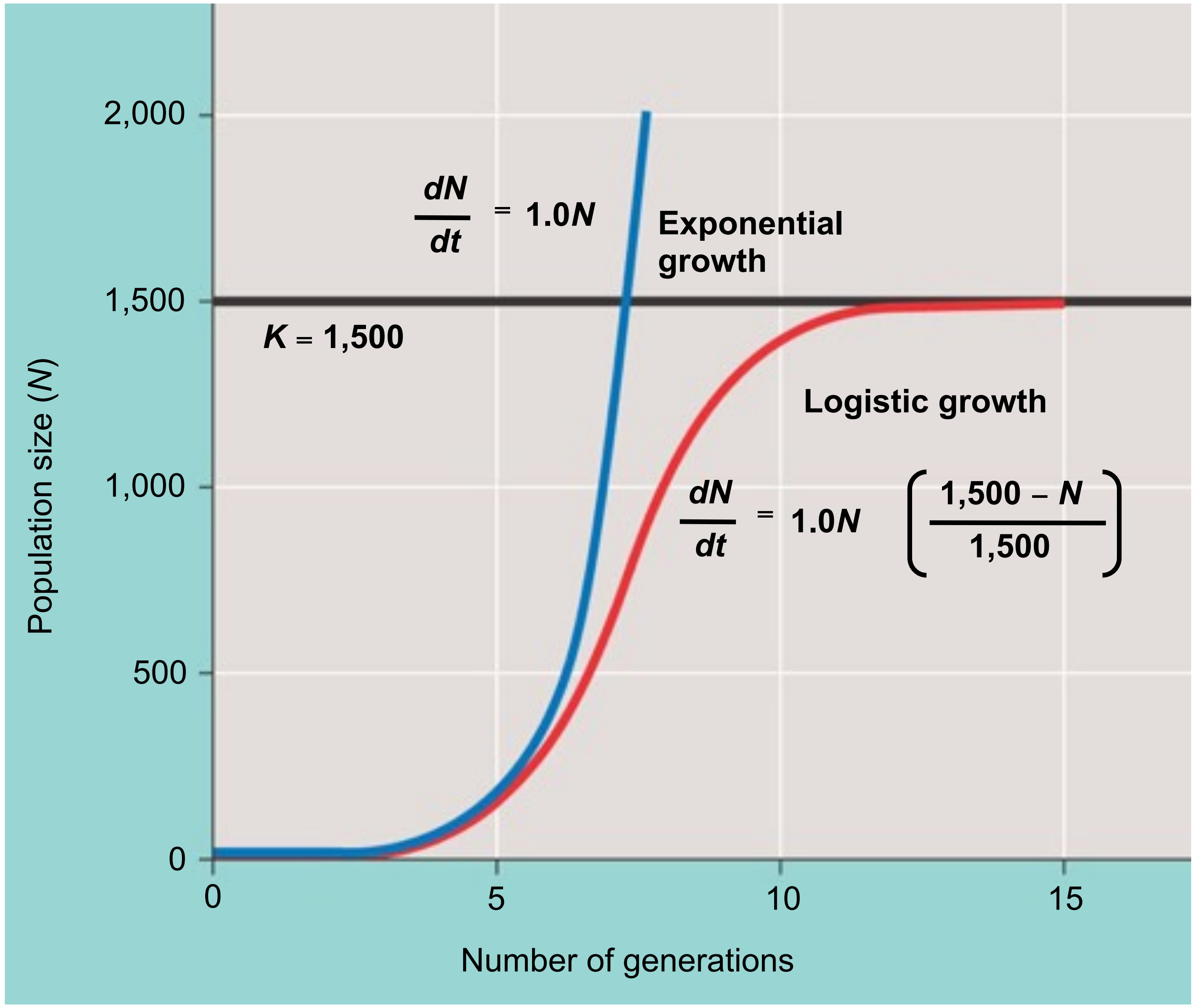
- "graphed" **logistic growth** takes on a "**S**" shaped curve
- the equation for logistic growth is seen below

$$\frac{dN}{dt} = r_{max}N\frac{(K-N)}{K}$$

Table 52.3 A Hypothetical Example of Logistic Population Growth, Where K = 1,000 and r_{max} = 0.05 per Individual per Year

Population Size: N	Intrinsic Rate of Increase: r_{max}	$\left(\frac{K-N}{K}\right)$	Per Capita Growth Rate: $r_{max}\left(\frac{K-N}{K}\right)$	Population Growth Rate:* $r_{max}N\left(\frac{K-N}{K}\right)$
20	0.05	0.98	0.049	+1
100	0.05	0.90	0.045	+5
250	0.05	0.75	0.038	+9
500	0.05	0.50	0.025	+13
750	0.05	0.25	0.013	+9
1,000	0.05	0.00	0.000	0

*Rounded to the nearest whole number.



Logistic Growth in Real Populations

- Logistic Model Assumptions
  - 1. that populations adjust instantly and smoothly as it approaches the carrying capacity (K)
    - However there is often a delay involved causing the population to overshoot the carrying capacity
  - 2. that each individual added has the same negative effect on growth rate
    - However some have a more difficult time surviving/reproducing if the population is too small...*Allee Effect*
  - Furthermore many populations fluctuate greatly, making it difficult to establish an accurate carrying capacity
  - This model is a starting point for more complex ones!

REGULATION OF POPULATION GROWTH

- As it turns many factors that regulate population size are in fact *density dependent*.
- Understanding these factors can have practical applications
  - preventing extinctions, managing endangered species, managing pests

Population Change Over Time

- *Once again will simplify matters by ignoring immigration and emigration or assume they cancel each other out!*
- A factor that does not effect birth rates and death rates as the population becomes more dense is said to be *density independent.*
- Should birth rates and death rates change as population size change then those factors are said to be *density dependent.*

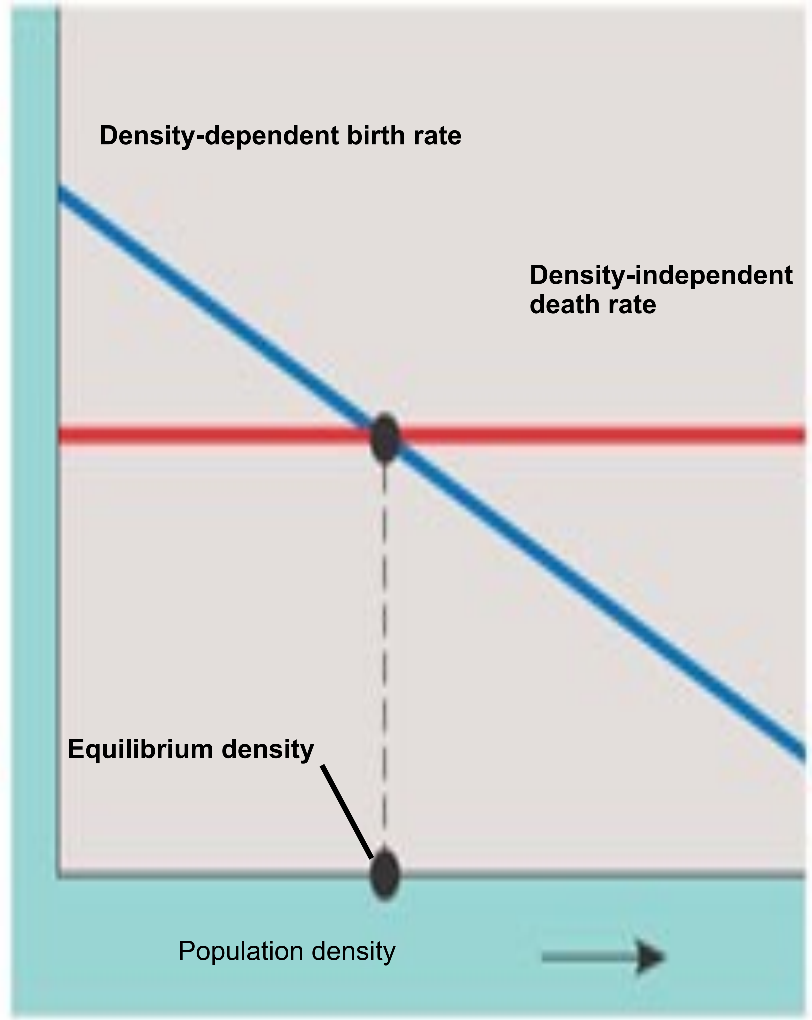
Density Dependent Population Regulation

**Negative Feedback regulates population growth. Without this mechanism populations would continually grow, exceed their carrying capacity and crash. (*negative feedback is a common and important theme in biology, you must understand it completely)*

- ***Density Dependent Factors.***
  - Competition
  - Predation
  - Disease
  - Territoriality
  - Toxic Waste
  - Intrinsic Factors

Propose how each of these might regulate population growth as density increases. Can you provide examples?

Determining Equilibrium for Population Density



(b) Birth rate changes with population density while death rate is constant.

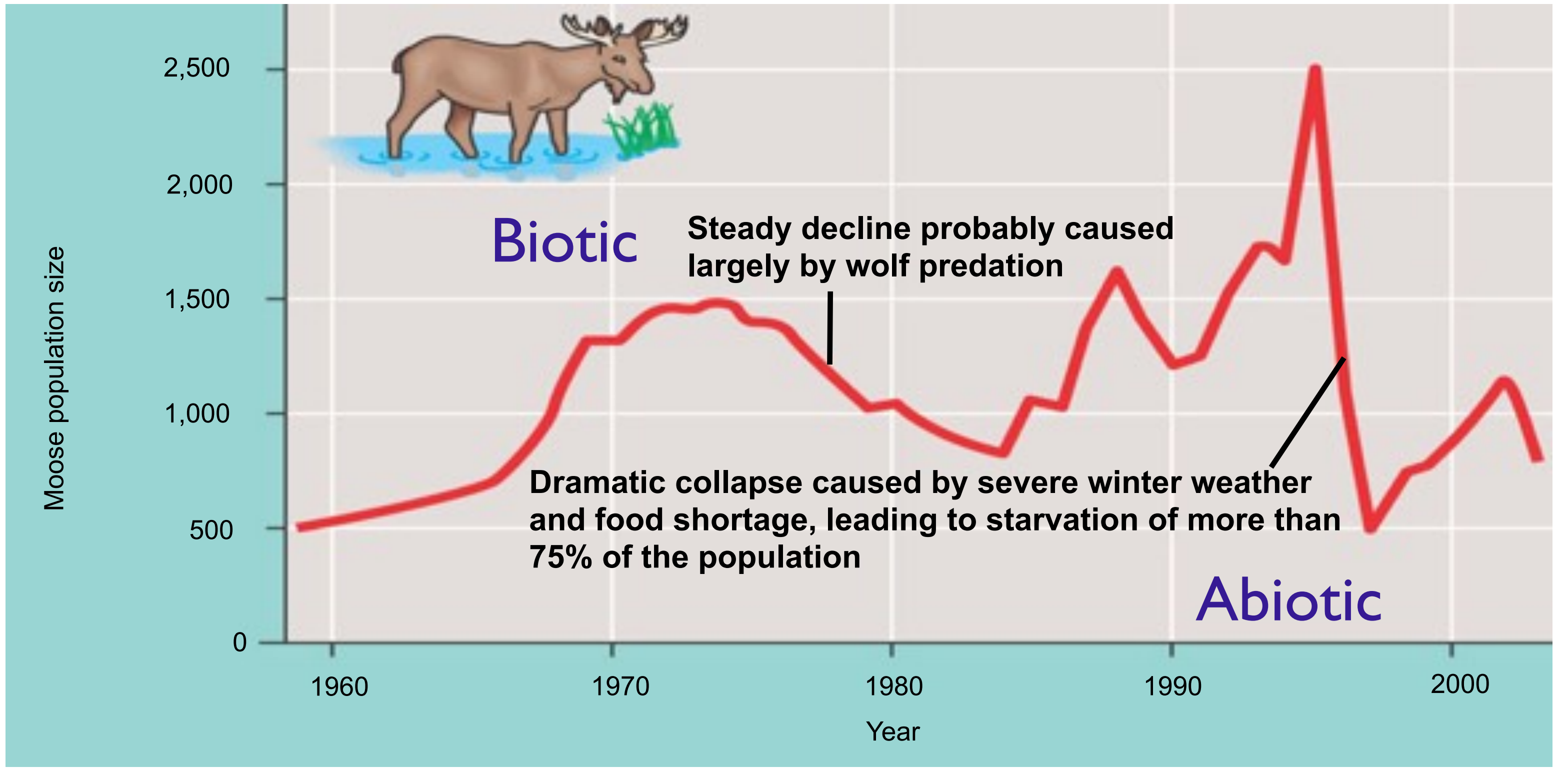
Redraw this figure where both birth rates and death rates are density dependent.

Population Dynamics

Regardless the mechanism most populations fluctuate to some extent or another. The reasons may be complex and often involve both biotic and abiotic factors.

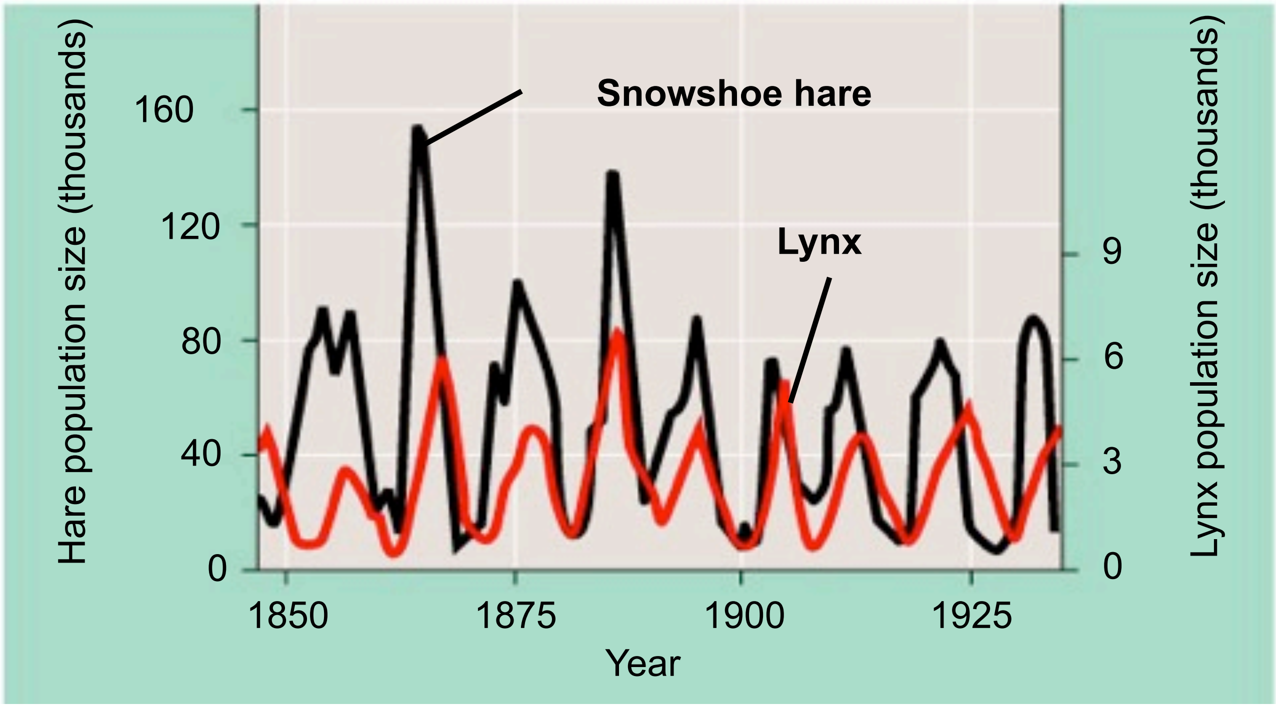
Stability and Fluctuation

- Biotic & Abiotic Factors.
  - ↓harsh weather, ↓parasites, ↓↑ food availability, etc.



Population Cycles

- 10 year cycling pattern in snowshoe hares...Why?
- 3 Hypotheses
  - *if* food shortages...
  - *if* predation...
  - *if* sunspot activity...
  - *and...*_______________
  - *then...*_______________
  - *and or but...*_____________
  - *therefore...*_________________



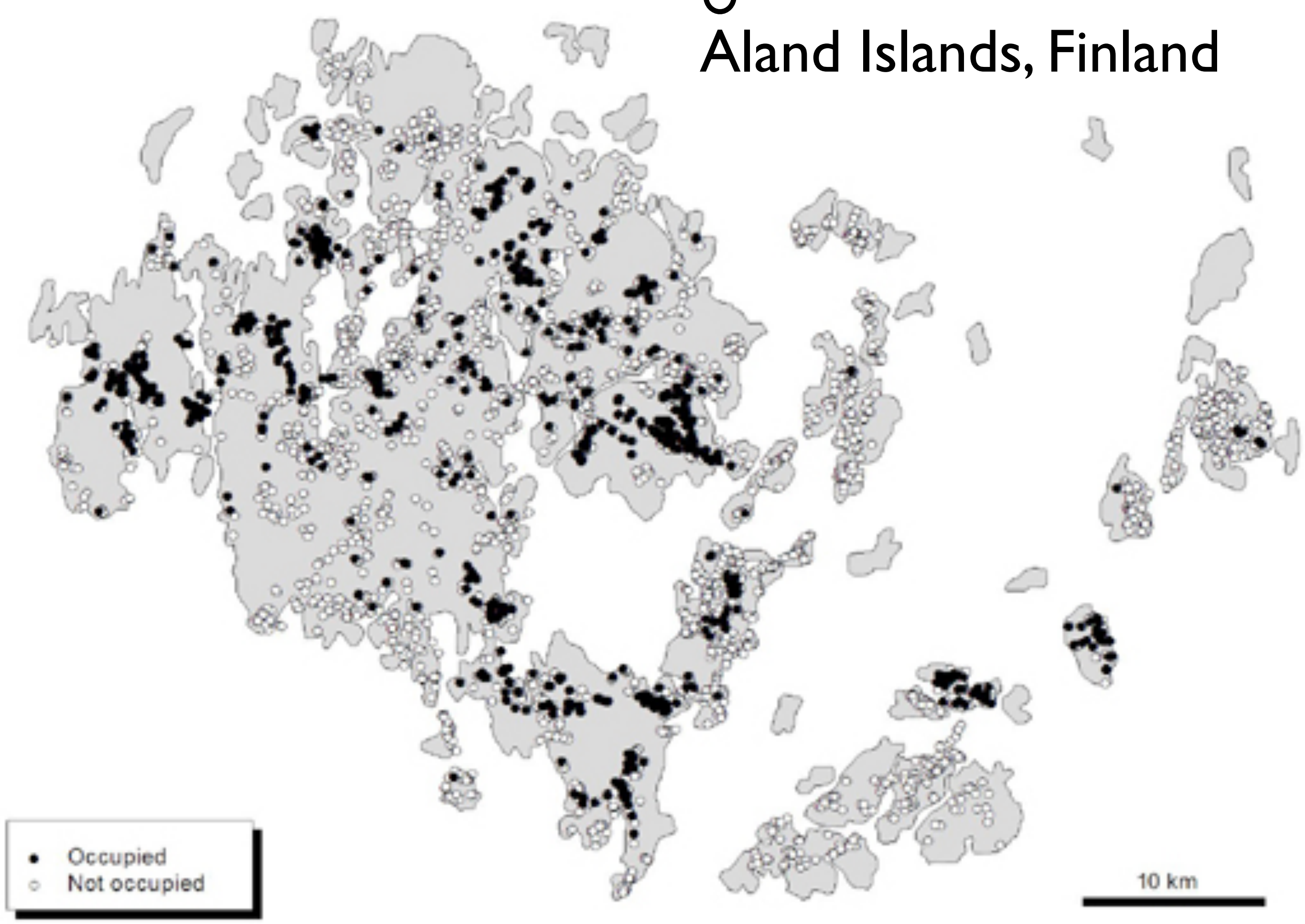
Can you fill in the blanks?

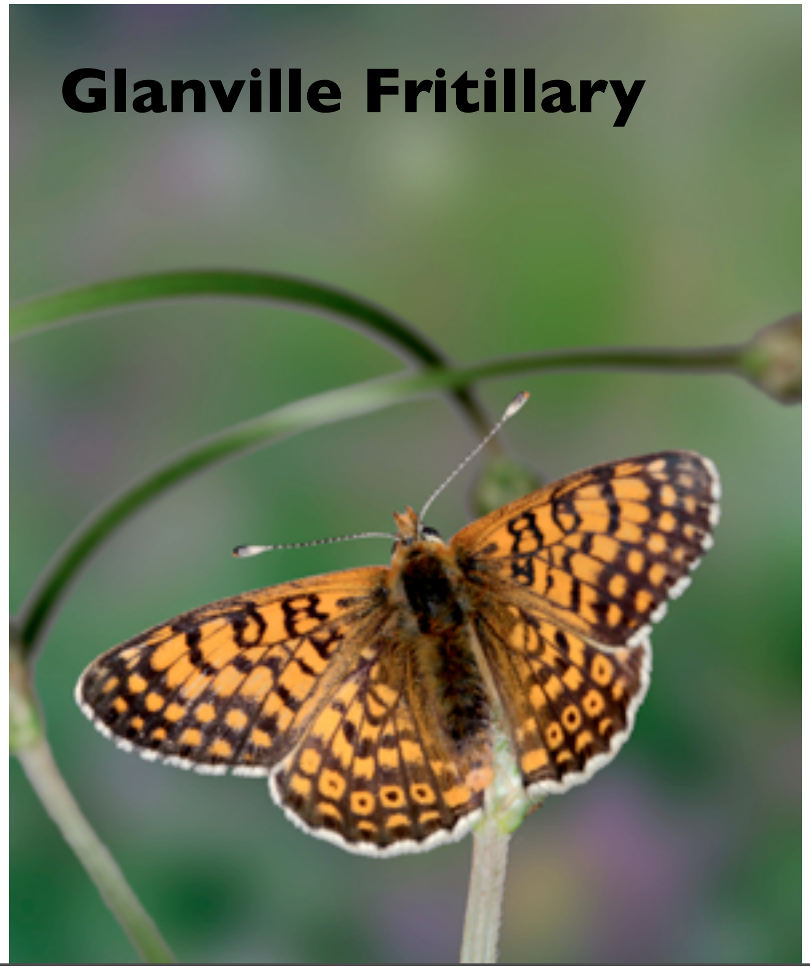
- The sunspot hypothesis is an interesting and remarkable idea.
- Apparently when sunspot activity is low...
- slightly less atmospheric ozone is produced...
- less ozone means more UV radiation reaches the earth (plants)..
- plants respond by making more UV blocking chemicals...
- this results in less secondary compounds being made...
- less secondary compounds to deter herbivores...
- means the quality of food is higher for hares...
- higher quality food can support more hares
- COOL... *this reminds us how sensitive life can be to abiotic factors and further that our actions even if they slightly alter the environment may have larger consequences.*

Immigration & Emigration (metapopulations)

- Immigration & Emigration are especially important in metapopultaions
- Metapopulations are local populations linked together, they occupy discrete suitable habitats in a sea of unsuitable habitats
- Essentially when resources become limited the population can emigrate from that one and immigrate to another

o
Aland Islands, Finland





THE HUMAN POPULATION

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- Human population has exploded over the last few centuries

Human Population

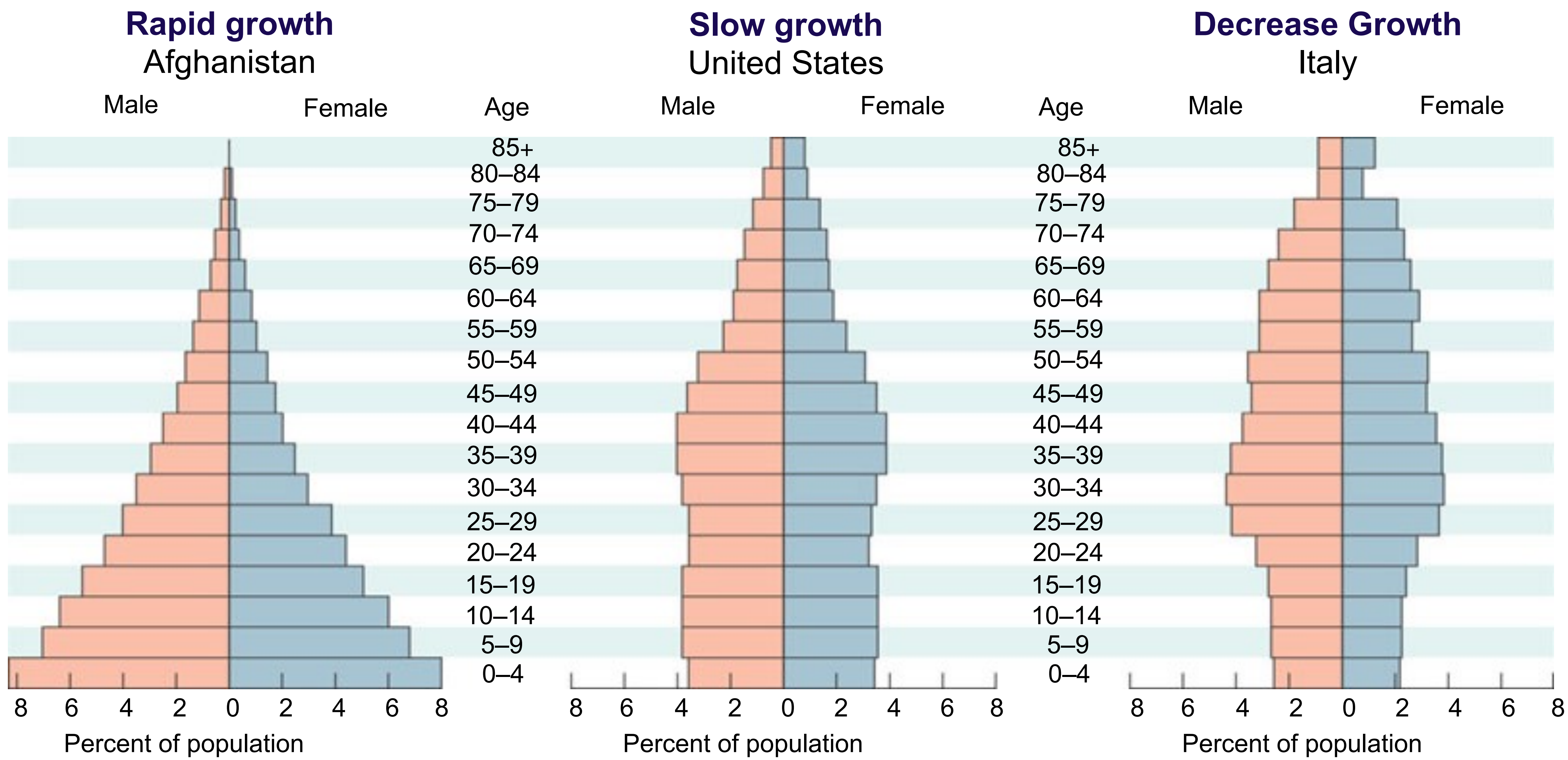
- **Year Population 1 200 million** 1000 275 million **1650 500 million** 1750 700 million **1804 1 billion** 1900 1.6 billion **1927 2 billion** 1950 2.55 billion **1960 3 billion** 1970 3.7 billion **1975 4 billion** 1990 5.3 billion **1999 6 billion** 2005 6.45 billion **2006 6.5 billion** 2010 6.8 billion **projections:** 2020 7.6 billion 2030 8.2 billion 2040 8.8 billion 2050 9.2 billion
- Nearly 80 million people are added to the earth each year at the current rate
- 200,000 are added each day this equivalent to the city of Richmond, Virginia
- Growth rate has decreased over the last few decades, it has departed from true exponential growth
- Likely this change is a result of voluntary population control (China) and diseases (AIDS)
- http://www.poodwaddle.com/clocks/worldclock/

Regional Patterns of Population Change

- Stable (zero) population growth has 2 configurations
- *#1. high birth rate - high death rate = zero growth*
  - seen in less developed countries
- *#2. low birth rate - low death rate = zero growth*
  - seen in developed countries
- The Transition from #1 to #2 is called the ***demographic transition***
  - it associated with improved sanitation, health care and education (especially for women)
  - 80% of the world's population lives in less developed countries

Age Structure

- ...the relative number of individuals of each age in a population
- this data can help us to understand present and future social issues



Infant Mortality / Life Expectancy

- *Infant mortality*- number of infant deaths per 1000 live births
- *Life Expectancy*- predicted average length of life from birth
  - Both vary widely
  - Both reflect differences in "quality of life"
  - Over all Life Expectancy is increasing world wide
    - Afghanistan (IM) is 15.5%, Japan (IM) only 0.3%
    - Angola (LE) is 38 years, Sweden (LE) 76 years

Global Human Carrying Capacity

- Are we approaching it? Have we already surpassed it?

Estimates of Human Carrying Capacity

- Average estimates between 10-15 billion
- Range from less than 1 billion to more than 1 trillion
  - 3 Methods of estimation
    - 1. *math/computer*: models from logistic curve principles
    - 2. *land*: amount of habitable land vs population density
    - 3. *single limiting factors*: food, water, farmland

Global Human Carrying Capacity

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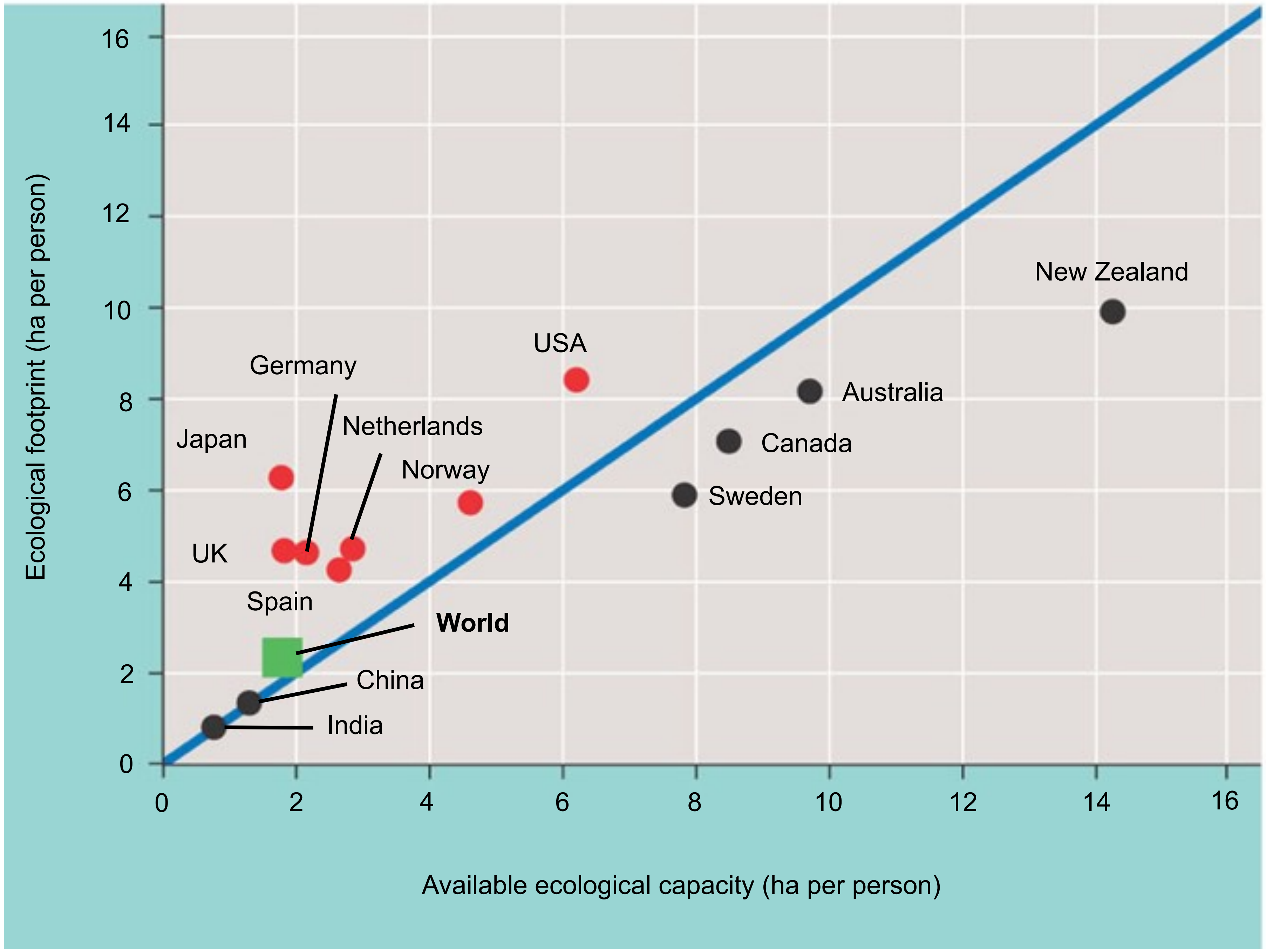
Limits on Human Population Size

Ecological Footprints- *the aggregate land and water area required by each person, city or nation to produce all the resources it consumes and to absorb all the waste it generates.*

- Calculations suggest 1.7-2 hectares per person or roughly 2-4 acres
- Anyone with a footprint above 2 hectares is using an unsustainable share of earth's resources
  - The average american has a footprint of 10 hectares!
  - An american use 30X more energy than the a typical person from central Africa



Ultimately the combination of resource use per person and population density will determine our global ecological footprint.

- **Bottom Line... we can only speculate on the earth's carrying capacity!**
- Perhaps ***food*** will be our limiting factor, perhaps ***space***, perhaps ***freshwater***, perhaps ***nonrenewable resources*** or maybe the environments ability to ***absorb waste***.

This Much is True- *1. no population can grow indefinitely, 2. quality of life we choose to enjoy will effect the earth's carrying capacity.*

Unlike any other species we have the choice to achieve zero population growth through social change or allow nature to do it through plagues, limited resources, war and environmental degradation.

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"Nothing in nature takes more than it needs"
unknown

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"Nothing in nature takes more than it needs"
unknown
" ...Except Humans" Morone Jr.

Learning Objectives:

LO 4.11 The student is able to justify the selection of the kind of data needed to answer scientific questions about the interaction of populations within communities. [See **SP 1.4, 4.1**]

LO 4.12 The student is able to apply mathematical routines to quantities that describe communities composed of populations of organisms that interact in complex ways. [See **SP 2.2**]

LO 4.13 The student is able to predict the effects of a change in the community's populations on the community. [See **SP 6.4**]