Lecture 9:

a) methods of determining interactions: stable isotopes

b) single population dynamics review

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Stable Isotope Analysis

– used to track elemental cycling and energy flow pathways

– useful in food web studies for tracking the flow of energy from primary producers to consumers

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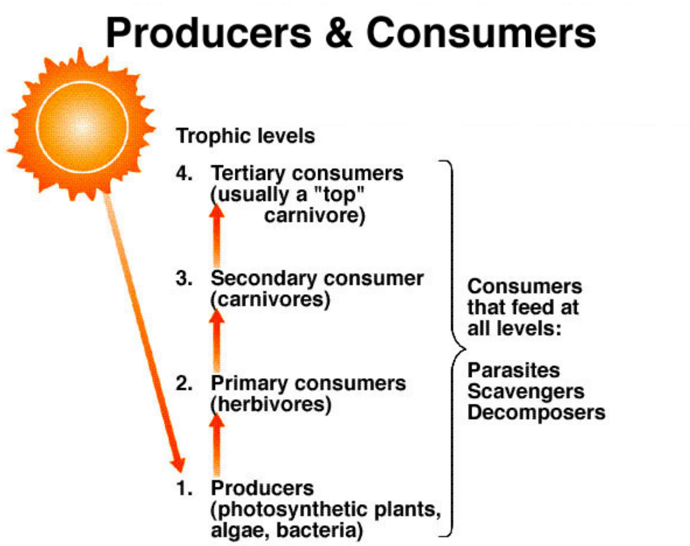
The Flow of Energy
(*trophic levels, food chains*)



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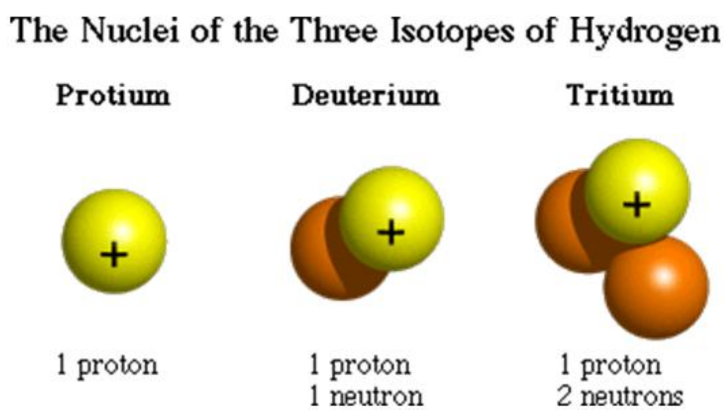

^{1}H (99.98%) ^{2}H(~0.002)% ^{3}H(radioactive)

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Element	Stable isotopes*	Avg Abundance (%)
Carbon	^{12}C ^{13}C	98.89 1.11
Nitrogen	^{14}N ^{15}N	99.64 0.36
Oxygen	^{16}O ^{18}O	99.763 0.1995
Hydrogen	^{1}H ^{2}H	99.9844 0.0156
Sulfur	^{32}S ^{34}S	95.02 4.21

*O has 1 additional stable isotope; S has 2 more

Stable isotopic fractionation

- Alteration of the distribution of stable isotopes as a result of a chemical or physical process

- Environment: 10% heavy 90% light
- Organism: 30% heavy 70% light

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(Fry, 2006 Fig.1.6)

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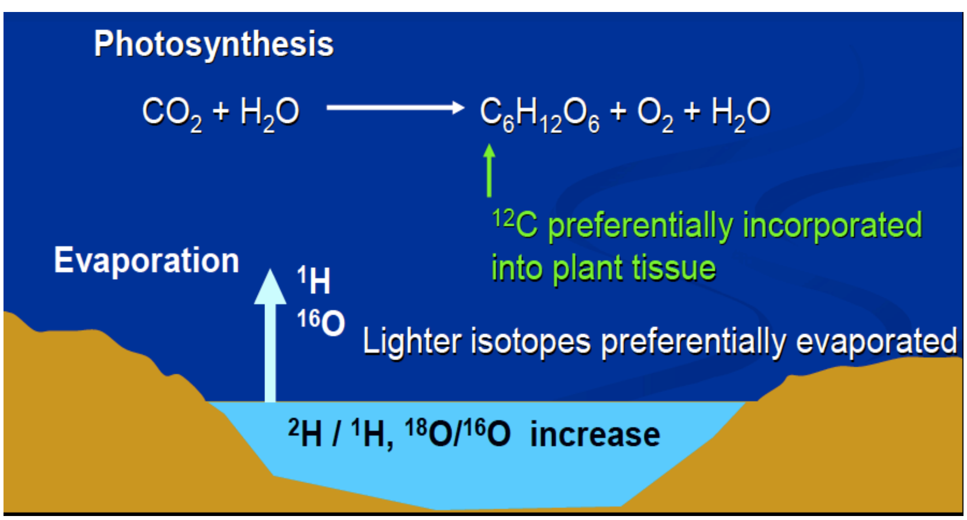
Examples of stable isotopic fractionation



Fractionation and food webs

- More *light* isotopes are used in chemical reactions within the body
- These *lighter* isotopes are then excreted as waste
- More *heavy* isotopes become incorporated into muscle tissues (think: “not used up”)

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Sample Prep

- Isotope Ratio Mass Spectrometers can only directly analyze simple gas molecules like:
  - H_2 ,CO_2 , SO_2 , N_2 , CO

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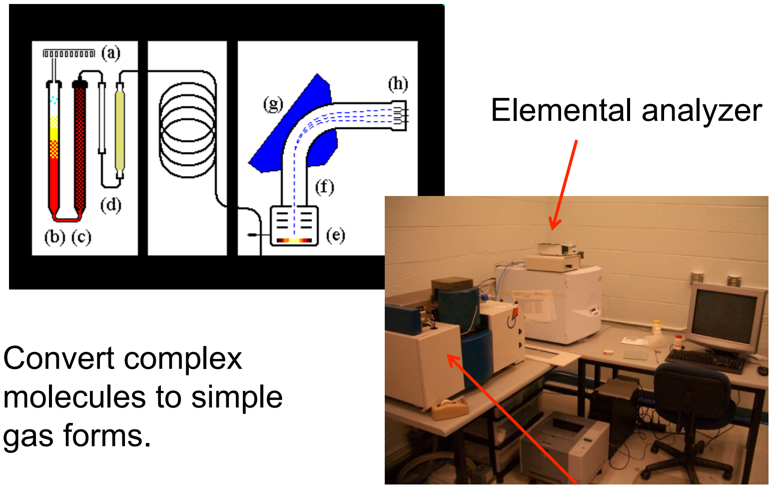
Elemental Analyzer



Elemental analyzer

Convert complex molecules to simple gas forms.

Mass Spectrometer

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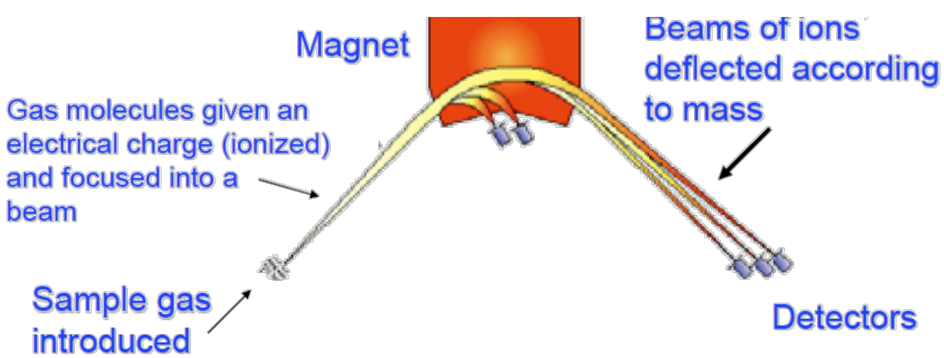
Measuring stable isotope ratios in the mass spec



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Measure sample $\delta^{15}N$

- $\delta^{15}N=$

Measurement

$$\delta^{xx}I = \left(\frac{I^*/I_{sample}}{I^*/I_{standard}} - 1 \right) 1000$$

Where I^* is the heavier isotope, I is the lighter isotope (the ratio I^*/I is usually abbreviated as R) and xx is the atomic weight of the heavier isotope.

$$\delta^{13}C = \left(\frac{{}^{13}C/{}^{12}C_{sample}}{{}^{13}C/{}^{12}C_{standard}} - 1 \right) 1000$$

HOW DO WE EXPRESS THE QUANTITY OF ISOTOPE IN A SAMPLE?

Samples are always analyzed in conjunction with standard gases calibrated to an accepted global standard of isotope abundance.

•Carbon: PDB (Pee Dee Formation of South Carolina).
•a belemnite formation
•CO_2 liberated by reaction with acid
• $^{13}C/^{12}C$ = 0.01124.

•Oxygen and Hydrogen:
•SMOW (standard mean ocean water)
•$^{18}O/^{16}O$=0.0020052 and D/H=0.00015576

•Nitrogen:
•atmospheric
•$^{15}N/^{14}N$=.0036765

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- For example: If a fish tissue sample had an isotopic ratio of 0.003696

δ^{15}N=?

•Nitrogen:
•atmospheric
•$^{15}N/^{14}N$=.0036765

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- For example: If a fish tissue sample had an isotopic ratio of 0.003696

$\delta^{15}N$=?

- Relative to the isotopic ratio of air, the fish tissue is enriched with ^{15}N

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Nitrogen isotopic concentration indicates trophic position

- Trophic position =

$$((\delta^{15}N_{consumer} - \delta^{15}N_{baseline})/3.4)$$

Carbon isotopic concentration indicates food source

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Measured isotope ratios and trophic level

- "You are what you eat" … or more
- The isotope ratio of predator tissues becomes *heavier* than the prey items.
- $\delta^{13}C$ is enriched by 1‰ per trophic level
- $\delta^{15}N$ is enriched by 3‰ per trophic level

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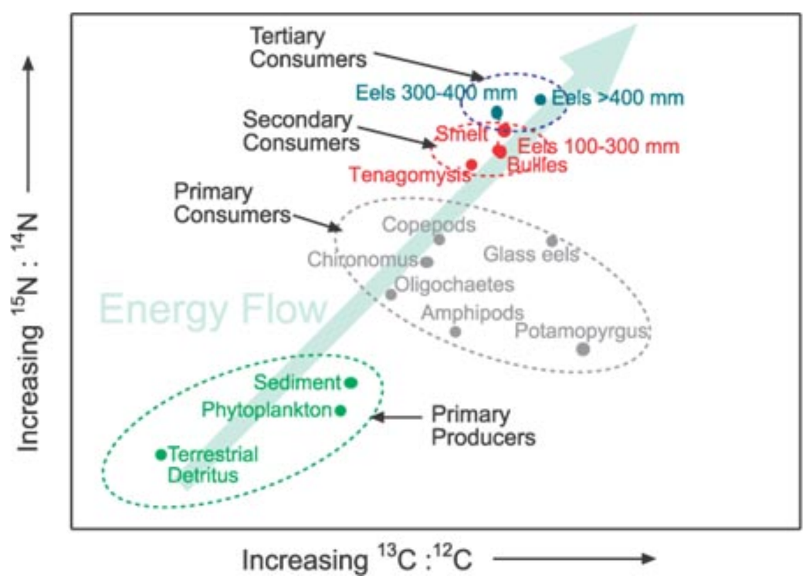

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Some commonly observed differences in stable isotope ratios among primary producers

- C3 vs. C4 plants (different photosynthetic pathways – corn vs. soybeans example)
- Stream algae/phytoplankton vs. terrestrial vegetation
- Benthic algae vs. phytoplankton in lakes

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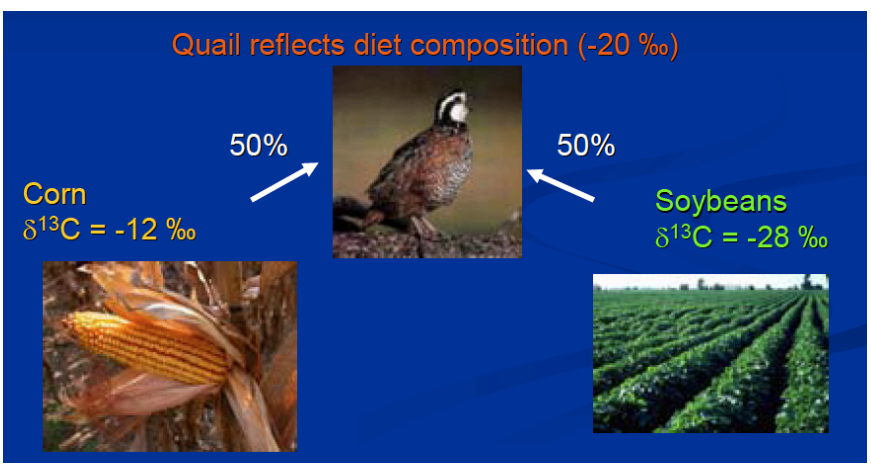
Stable isotope mixing models



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Stable isotope evidence for the food web consequences of species invasions in lakes

M. Jake Vander Zanden*‡, John M. Casselman† & Joseph B. Rasmussen*

* *Department of Biology, McGill University, 1205 Ave. Dr. Penfield, Montreal, PQ, H3A 1B1, Canada*
† *Science Development Transfer Branch, Ontario Ministry of Natural Resources, Glenora Fisheries Station, RR4, Picton, ON, K0K 2T0, Canada*

Species invasions pose a serious threat to biodiversity and native ecosystems[1,2]; however, predicting and quantifying the impacts of invasive species has proven problematic[3–6]. Here we use stable isotope ratios to document the food-web consequences of the invasion of two non-native predators, smallmouth bass and rock bass, into Canadian lakes. Invaded lakes had lower littoral prey-fish diversity and abundance than uninvaded reference lakes. Consistent with this difference, lake trout from invaded lakes had more negative $\delta^{13}C$ values (−29.2‰ versus −27.4‰) and reduced trophic positions (3.3 versus 3.9) than those from reference lakes, indicating differences in food-web structure. Furthermore, a comparison of the pre- and post-invasion food webs of

‡ Present address: Department of Environmental Science and Policy, One Shields Avenue, University of California-Davis, Davis, California 95616, USA.

quently, both species have greatly expanded their geographical range over the last century.

These two bass species are presently invading a number of relatively pristine lakes in North America's Northern Hardwood–Boreal Forest transition zone, many of which contain lake trout

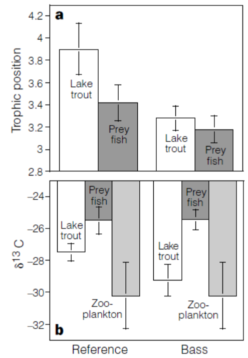

Figure 1 Trophic position and δ^{13}C values. **a**, Comparison of mean trophic position of lake trout and pelagic forage fish from invaded and reference lakes. **b**, Comparison of mean δ^{13}C values of lake trout, littoral prey-fish and zooplankton from invaded and reference lakes. Error bars represent 1 s.e.m. using lake-specific averages.

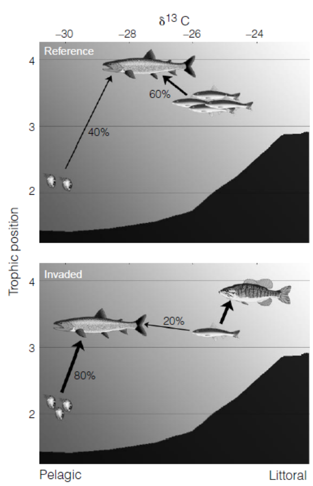

Figure 2 The pathways of energy flow through food webs of reference lakes (lakes in which bass have not become established) and lakes invaded by smallmouth bass and rock bass, based on δ^{15}N and δ^{13}C information.

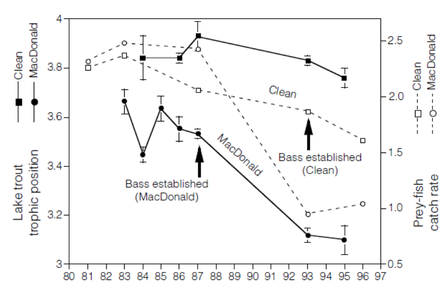

Figure 3 Temporal changes in the trophic position of lake trout (left axis) and log-transformed littoral prey-fish catch rate from quantitative electrofishing transects (right axis) in MacDonald Lake (circles) and Clean Lake (squares) for the period 1981–1996. Arrows indicate the year in which both smallmouth bass and rock bass were fully established in MacDonald and Clean lakes.

Stable Isotope Analysis

PRO
- Relatively fast and easy processing
- Can use smaller sample sizes
- Gives a long-term view of assimilated diet

CON
- $20-$100/sample if using outside lab
- Only gives δ values, no species identification
- Gives a long-term view of assimilated diet

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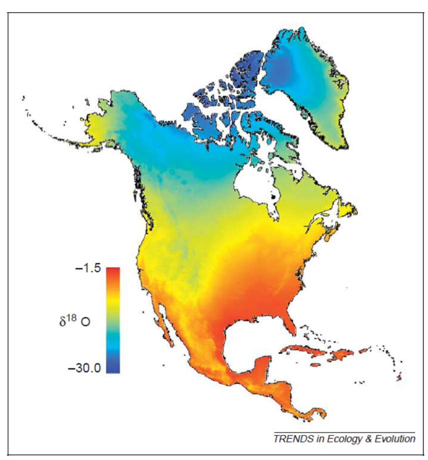
Connection through other material flows

- Evapotranspiration, rainfall etc (^{18}O)



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Read

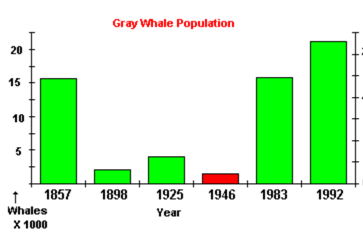
- Fry, B. (2006). Stable Isotope Ecology. New York, Springer Science + Business Media, LLC. 308 pp.
- West et al. 2006. Stable isotopes as one of nature's ecological recorders. TRENDS 21:408-414

Review: population ecology

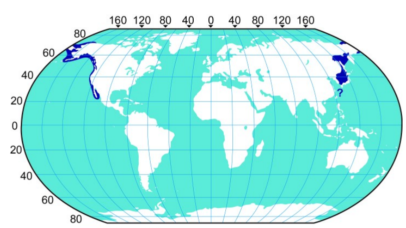
All the fish in Lake Superior ______ a population, but all the grey whales in the eastern Pacific _______ a population

1) are not; are
2) are; are not

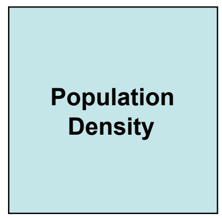
Pacific Gray whale



Current estimate for the Western Pacific population = 100 individuals



Population prediction
(in the absence of species interactions)



Population prediction
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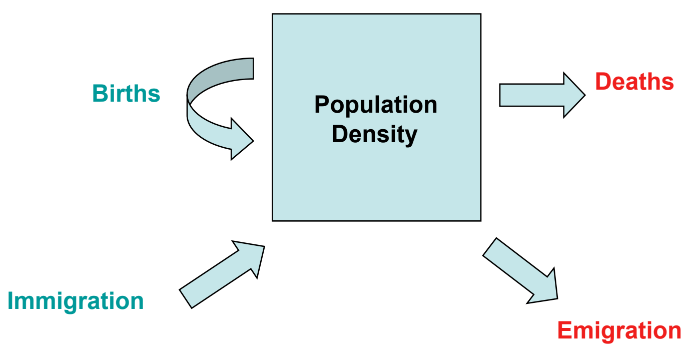


Population Growth

- Individual reproduction, individual survival and individual movement determine population increase or decrease

Birth

Death

Immigration

Emigration

$$N_{future} = N_{now} + B - D + I - E$$

A simple (discrete) population model

$$N_{t+1} = N_t + B - D + I - E$$

pop next time period

pop. this time period

births deaths immigrants emigrants

Change in abundance

$$N_{t+1} - N_t = B - D + I - E$$

$$\Delta N = B - D + I - E$$

Basic closed population model

Simplifying assumption:
no movement between populations

- Abundance
  $N_{t+1} = N_t + B - D$
- Change in abundance
  $\Delta N = B - D$

if $B > D$ then population increases
if $B < D$ then population decreases
if $B = D$ then stable population

Basic discrete model

Let number of births and deaths depend on population size:
i.e. $B = bN$
$D = dN$
Hence

$$N_{t+1} = N_t + (b - d)\, N_t$$
$$N_{t+1} = (1 + b - d)\, N_t$$

Let $\lambda = 1 + b - d$

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

λ is the finite rate of increase

$$N_t = N_0\lambda^t$$

Number at some initial time *0* times λ raised to the power *t*

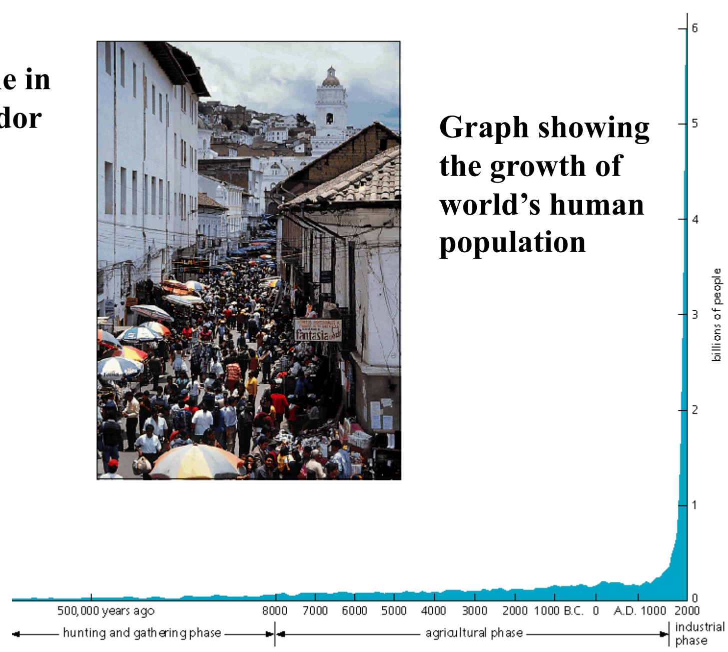
Number of time intervals, in hours, days, years, etc.

Number at some time *t*

Average number of offspring left by an individual during one time interval

A street scene in Quito, Ecuador

Graph showing the growth of world's human population



When reproduction is continuous

- The time interval between one reproductive event and the next shrinks to zero!
- We need INSTANEOUS rates of change to predict population size in the future
- Instantaneous rate of population change

$$dN/dt = B - D$$

Exponential growth

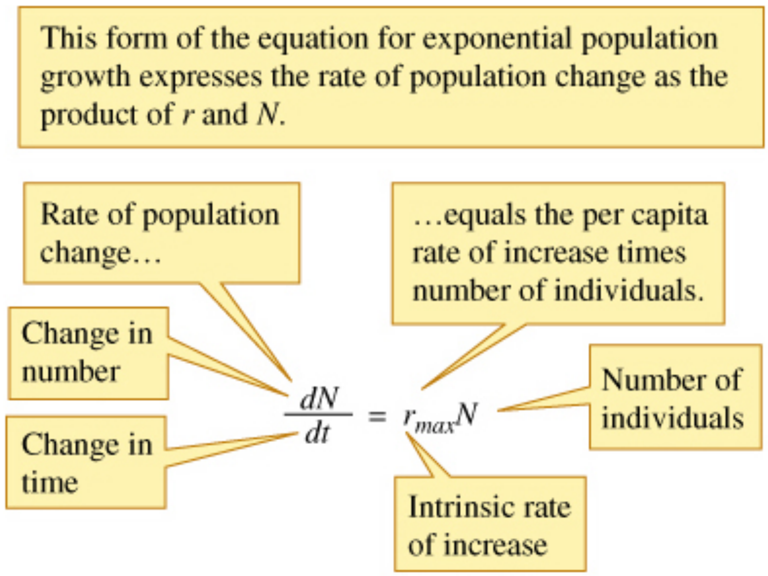
- In exponential growth, new individuals added continuously to population
- Using per capita rates we have

$$dN/dt = B - D = bN - dN = (b-d)N$$

- b = instantaneous per capita birth rate
- d = instantaneous per capita death rate

$$dN/dt =(b-d)N = rN$$

- r = intrinsic rate of increase



Can we use this equation for rate of change to predict population size at some time in the future?

You bet!

I'll do the integration for you

$$N_t = N_0 e^{rt}$$

NOTE

$$\frac{dN}{N} = r \cdot dt$$

$$\int \frac{dN}{N} = \int r \cdot dt$$

$$\ln N = rt + c;$$

when $t = 0$, $N = N_0$, therefore, $c = \ln N_0$

$$\ln N = rt + \ln N_0$$

$$\ln N - \ln N_0 = rt$$

$$\mathbf{\ln N - \ln N_0 = \frac{\ln N}{\ln N_0}}$$

$$\frac{\ln N}{\ln N_0} = rt$$

$$\frac{N}{N_0} = e^{rt}$$

$$N = N_0 e^{rt}$$

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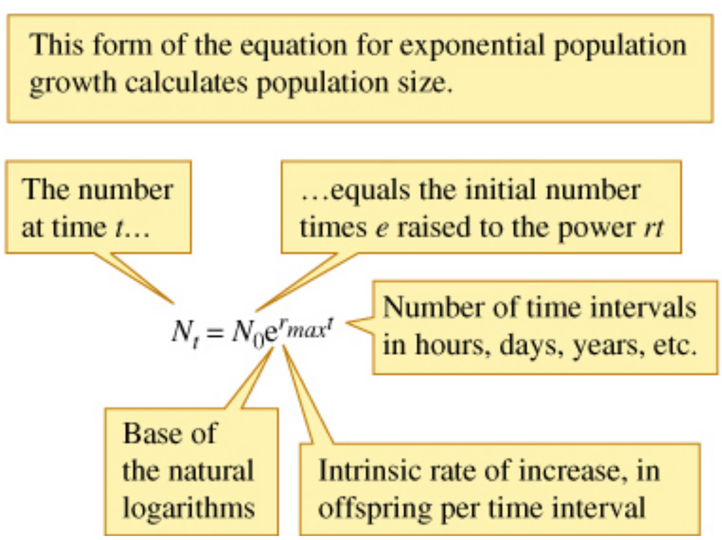

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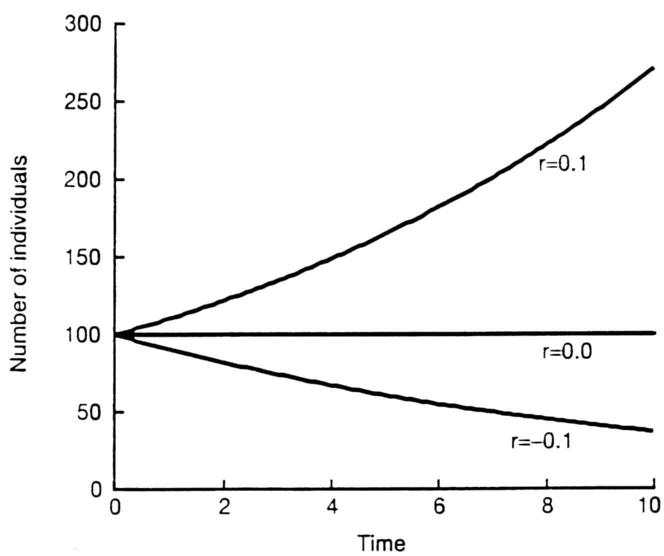
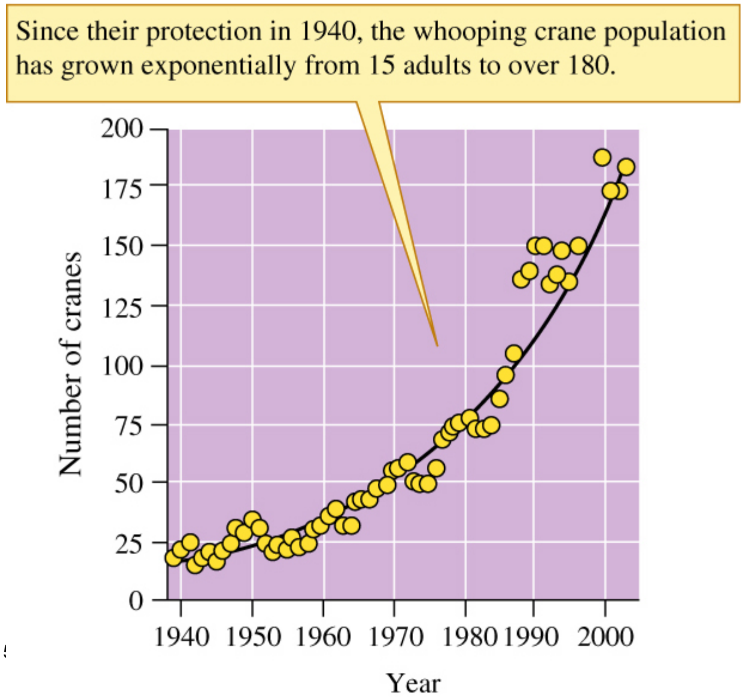
If r is = 0, the population will ________

1) increase
2) decrease
3) stay the same

Exponential population growth: three possible outcomes





Exponential growth: summary

While environmental resources are constant, AND resources are not limiting population may grow exponentially

rate of growth is determined by the intrinsic rate of population increase, r = b-d, which is a CONSTANT per capita rate

No predation, parasitism, or competition. No immigration or emigration.

Limits on exponential growth

•r is a constant, that is we are assuming density-independent growth

•So, for exponential growth, we have to assume that even if there are 30 billion people instead of 7 billion our per capita birth and death rates are the same???

•How likely is this?

Read

- Mittelbach ch 4
- Begon et al. ch 5