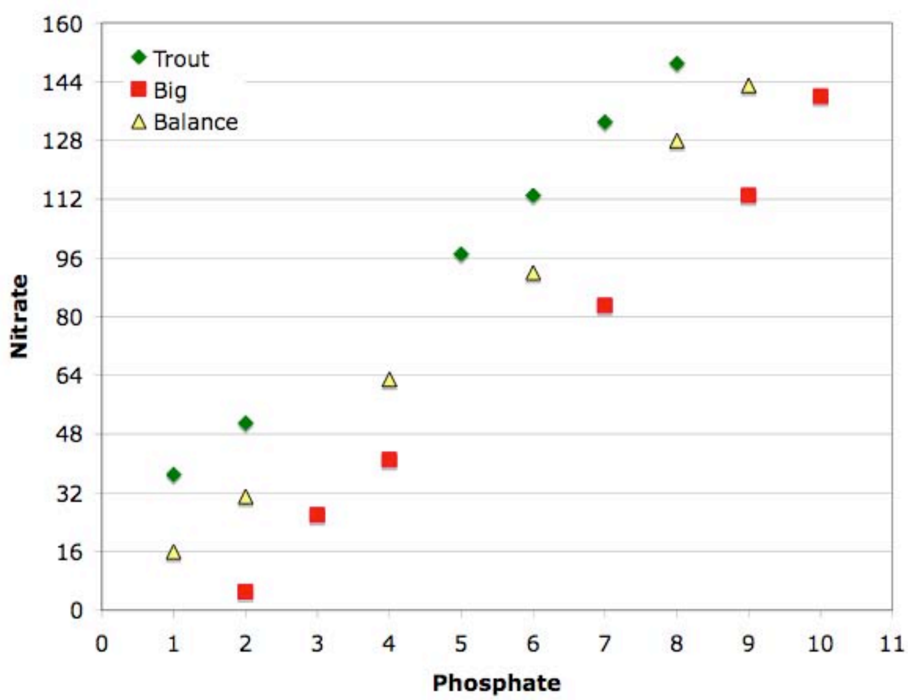
1. You are a limnologist studying several lakes in northern Ontario. The lakes have little input of nutrients from streams. You measure the concentrations of nitrate and phosphate every two months, and generate the following data. All units are in mg/L concentration. Using the graph paper provided below may help you answer the question.

	Trout Lake		Big Lake		Lake Balance	
	NO_3^-	PO_4^{3-}	NO_3^-	PO_4^{3-}	NO_3^-	PO_4^{3-}
January	149	8	140	10	143	9
March	113	6	113	9	128	8
May	97	5	41	4	63	4
July	37	1	5	2	31	2
September	51	2	26	3	16	1
November	133	7	83	7	92	6



a) Which lake is limited by the availability of P? By the availability of N? Explain your answer.
P-limited: Trout Lake – because the intercept is on the y axis, indicating that when P runs out, there is still N in the lake. Alternatively, you can just calculate the N:P ratios for a few points
N-limited: Big Lake – because the intercept is the P axis. Alternatively, you can just calculate the N:P ratios for a few points
The Redfield Ratio for N:P is 16:1. Whenever the ratio exceeds 16 (as in Trout Lake), phosphorous is limiting. When the ratio is less than 16, nitrogen is limiting.

b) A resort-house development is proposed to be built around Lake Balance leading to the use of large numbers of septic systems around the lake. (Septic systems leach nitrogenous compounds into the groundwater, and the groundwater ultimately carries them to the lake). Would Lake Balance start to look more like Trout Lake or Big Lake over time?
Lake Balance would start to look more like Trout Lake because Trout Lake is P-limited. The septic systems are leaching nitrogen-bearing compounds into the water, making Lake Balance enriched in nitrogen with respect to phosphorous.

c) The development goes ahead, and the concentrations of NO_3 in Lake Balance skyrocket. At the same time, the housing developments around the lake began to leach sewage into the lake, increasing its P supply. What might happen to the oxygen concentrations in the deep waters of Lake Balance over time and why? What is this process called?
Oxygen concentrations will decline, especially in the deep waters of the lake. The added nutrients cause blooms of algae, which increase the primary productivity of the lake. When the algae die, they sink towards the bottom and are decomposed by heterotrophs, which consume oxygen as they decompose the organic carbon produced by the algae. This is Cultural Eutrophication,

Bonus: To mitigate the effects of the added nitrate from sewage coming from the new homes surrounding Lake Balance, the local wastewater treatment authority proposes an innovative solution. Rather than trying to install a sewer system across the entire, remote area, they propose using denitrifying bacteria to convert the nitrate in groundwater to nitrogen gas. They set up an anaerobic ground system and test it. Initially they find that there are fast rates of denitrification, but these rates soon slow down. There is still a lot of nitrate to be reduced and the environment is still anaerobic. What would you recommend adding to the system to help spur further denitrification?
Organic carbon

2. With respect to the carbon cycle, please answer each of the following questions in a sentence or two:

a) Which 'compartment', terrestrial or marine, has the slowest biological carbon turnover? Why do these compartments differ in terms of organic carbon turnovers?
The terrestrial compartment has the slowest biological carbon turnover because the primary producers on land (trees, etc.) have longer lifespans than primary producers in the ocean (phytoplankton). Thus, once fixed, carbon stays in the biomass for longer. Note: although the biological pump may sequester a small amount of carbon by sinking of phytoplankton, this amount is so small that it doesn't change the mean residence time of carbon substantially.

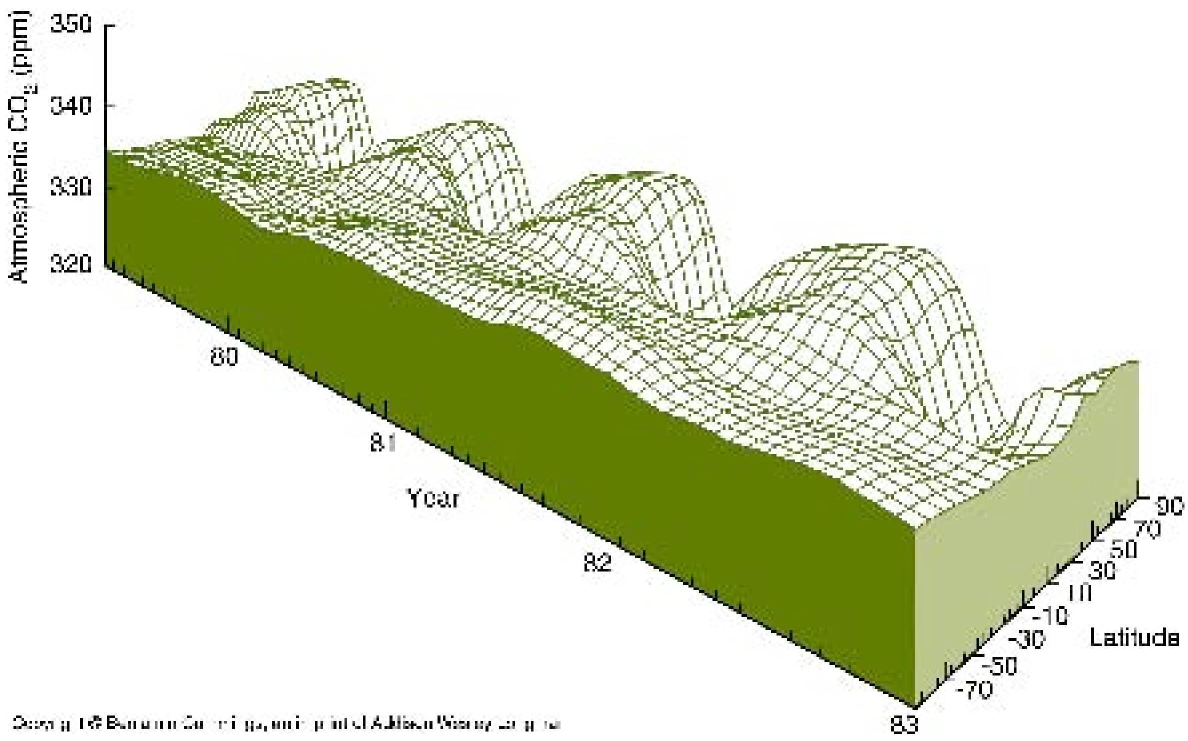
b) Which has the longest mean residence time for CO2, the deep-sea, or ocean surface waters? Why ?
The deep-sea. Downwelling at the poles brings cold water (in which dissolved gases are more soluble) deep into the ocean basins. Here, the water cannot undergo air-sea exchange since it

is sealed off from contact with the atmosphere. This is the so-called “physical pump” of carbon dioxide.

c) Fossil fuel burning and deforestation release about 9.1 petagrams of CO_2 per year. In which compartments (atmosphere, ocean, etc) does the manmade CO_2 end up in, and in approximately what proportions?
About 4.1 Pg remains in the atmosphere, 2.2 Pg is absorbed into the ocean, 0.7 is absorbed by land and 2.1 Pg is unaccounted for – and may wind up in the sediments or terrestrial biomass.

d) What explains the trends shown in annual CO_2 variation in the plot below? (Explain the trend in both the spatial, and the temporal variation).
Spatial variation: The Northern hemisphere has more land mass (and therefore, greater primary productivity) and this land mass is concentrated at higher latitudes, where it experiences greater seasonal variation.

Temporal variation: In summer (May-September in the Northern hemisphere; the opposite in the Southern hemisphere), carbon dioxide is sequestered through photosynthesis so there is a “valley” in CO_2 concentrations. In fall and winter, CO_2 is released by decomposition and anthropogenic activity, so CO_2 concentrations increase.



3. In class and in your readings, you learned about the long-term ecological experimentation done at the Hubbard Brook Experimental Forest in New Hampshire.

a) Explain the biogeochemical mechanisms by which clear-cutting leads to increased NO_3^- leaching from forest soils.
Clear cutting contributes to the buildup of ammonium in soils that are warm and moist. This stimulates nitrification by microbes, creating a much larger nitrate pool in the soil. The nitrate is negatively charged (compared to ammonium which is positively charged) and thus is not held by

the negatively charged soil particles. Increased runoff of water from the system leaches this increased nitrate out.

b) Explain biogeochemically why there is more Ca^{2+} ion leaching from clear-cut forests.
The process of nitrification also acidifies, which creates more hyrdrogen ions that replace Ca^{2+} cations and leach it from the system with increased runoff.

c) Over the last fifty years, even in intact forests ,Ca^{2+}has been depleted from the soils. Explain what was the ultimate cause of this depletion, and how it caused it.
Acid rain from sulfur dioxide emissions in industry. The hydrogen ions replace calcium cations at ion exchange sites in the soil, creating calcium leaching.

d) What is wollastonite (exact chemical formula), what were they doing with it at Hubbard Brook and why?
$CaSiO_3$. It is a calcium mineral they were fertilizing forests from helicopter with in order to measure the effect of replacing the leached calcium on productivity (thereby determining how the leached calcium from the soil due to acid rain was affecting the forest). The graphs presented in class showed both that calcium concentrations had increased after fertilization and that it had become incorporated into biomass.

4. Below is a table of the annual fish catch from an ocean basin that is a self-contained ecosystem. It has roughly yielded this catch for over a decade. A local ecology class has estimated the primary productivity of the basin to be around 2×10^7 metric tons of carbon. You do a quick check to see if their measurements are in the right ballpark. Do you think their estimate is correct? Why or why not? Explain your answer in detail, and what assumptions you have made to arrive at your answer.

Fish Species	**Trophic Level Occupied**	**Amount Harvested Annually (tons carbon x 10^3)**
Cod	3	100
Flounder	2	50
Catfish	2	30
Bluefish	4	10

No, it is not a reasonable estimate. By calculation:

Flounder and catfish TL=2:
$50\text{x}10^3$ tons / (0.10) = $500\text{x}10^3$ tons
$30\text{x}10^3$ /(0.10) = $300\text{x}10^3$ tons

Cod TL=3:
$100\text{x}10^3$/(0.10x0.10) = $10{,}000\text{x}10^3$ tons

Bluefish TL=4
$10\text{x}10^3$/(0.10x0.10x0.10) = $10{,}000\text{x}10^3$ tons

Total this is $20{,}800\text{x}10^3$ tons or $2.08\text{x}10^7$ tons of carbon harvested. This is equal (approximately) to the estimate for the total primary production in the system. ($2\text{x}10^7$ tons carbon). However, if all of the primary productivity is harvested each year through the fish catch, there would be no stock of fish to replace them the next year. We are harvesting the entire system and removing it from the system leaving no biomass left to spawn, etc. This should be straightforward from the Beddington and Pauly readings: estimates range from 2% in open ocean to an alarming 24-35% of PP required to support coastal fisheries. If the fishery represents 100% of the PP, this is a disaster. 8% PP required is the global estimate.

5. True or False
__T__ Phytoplankton draw down more CO_2 per mass than terrestrial photosynthetic organisms.
__T__ The concentration of carbon dioxide in the atmosphere is positively correlated with ambient temperature of the planet.
__F__ If humans did not emit huge amounts of carbon dioxide, the carbon cycle and its fluxes would be constant and balanced.
__F__ The eutrophication of lakes and rivers due to increased phosphorus concentrations will cause an increase in photosynthesis that will offset a substantial amount of carbon.
__F__ Coral reefs will probably be able to adapt to the new changes in ocean pH, as they have in the past.

6. A population of 100 ferrets is introduced to a large island in the beginning of 1990. Ferrets have an intrinsic growth rate, r_{max} of 1.3 yr^{-1}.

a. Assuming unlimited resources—i.e., there are enough resources on this island to last the ferrets for hundreds of years—how many ferrets will there be on the island in the year 2000 and what is the doubling time of the population? (Show your work!)

N_o = 100 (in 1990)
N = ? (in 2000)
t = 10 yr
r = 1.3 yr^{-1}
$N = N_o e^{rt} = 100 * e^{(1.3/yr)(10\ yr)} = 4.4 \times 10^7$ Ferrets

$t_d = (\ln(2))/r = 0.693/(1.3\ yr^{-1}) = 0.53$ years

b. A small population ferrets is introduced to an island where resource limitation is a significant problem. The population is growing according to the Logistic equation. When the population reaches 300 ferrets, you measure its growth rate, and find it to be 1.0 $year^{-1}$ What is the carrying capacity, K, of this island for this species of ferrets? Show your work. [Hint: the measured growth rate has the units ferret per ferret per year, and it is not r_{max}. You know from question I that r_{max} is 1.3 $year^{-1}$]

$1/N\ dN/dt = r_{max}(1-N/K)$
$1.0\ year^{-1} = 1.3\ year^{-1}(1-300/K)$
$1/1.3 = 1 – 300/K$
$1/1.3 – 1 = - 300/K$
$K = -300/((1/1.3) – 1))$
K = 1300 ferrets

c. You have decided to go into the ferret meat business on the small island described above. At what density should you maintain the ferrets in order to have the maximum output of ferrets? Explain your answer.

You should maintain the ferrets at a density of 1300/2 or 650 ferrets because this is the point where production (dN/dt) is maximal (from second derivative).

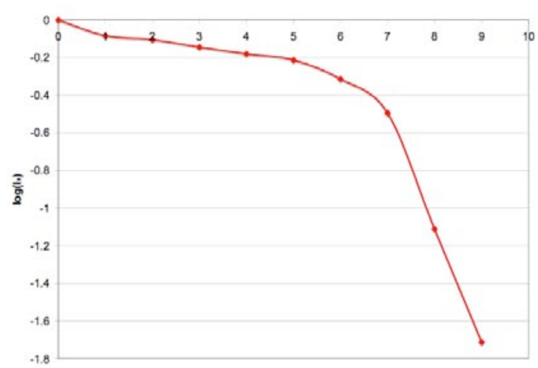
7. A recent collection of fossil skulls of *Unicornia imaginarus* showed the following age of death distribution:

Age	# of skulls
0-1 yr	36
1-2 yr	8
2-3 yr	14
3-4 yr	12
4-5 yr	10
5-6 yr	26
6-7 yr	34
7-8 yr	50
8-9 yr	12
9-10 yr	4

a) Tabulate the complete life table for this species

x	n_x	l_x	d_x	q_x	L_x	T_x	e_x	$\log(l_x)$
0	206	1.000	36	0.175	188.000	1031.000	5.005	0.000
1	170	0.825	8	0.047	166.000	843.000	4.959	-0.083
2	162	0.786	14	0.086	155.000	677.000	4.179	-0.104
3	148	0.718	12	0.081	142.000	522.000	3.527	-0.144
4	136	0.660	10	0.074	131.000	380.000	2.794	-0.180
5	126	0.612	26	0.206	113.000	249.000	1.976	-0.213
6	100	0.485	34	0.340	83.000	136.000	1.360	-0.314
7	66	0.320	50	0.758	41.000	53.000	0.803	-0.494
8	16	0.078	12	0.750	10.000	12.000	0.750	-1.110
9	4	0.019	4	1.000	2.000	2.000	0.500	-1.712
10	0	0.000						

b) Plot the survivorship curve for this species. What can you infer from this concerning the nature of the species?



This is a Type I population, suggesting that the low infant mortality is brought about by increased parental care of fewer young.

c) Discuss the assumptions involved in drawing conclusions from such a table.
We assume that we are not missing significant numbers of skulls (through poor searching or consumption) and that there has been no year-to-year variation prior to this sampling in total number of births or age-specific survival rates.

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