

1.018/7.30J
Fundamentals of Ecology

Quiz 1: Energy, Primary Productivity, and Limiting Factors

September 30, 2003

1. Suppose that you have graduated and with your new-found ecological expertise, have landed a job as a researcher for the state Department of Environmental Protection. You've been asked to evaluate a report about a nearby lake, Lake Yucco, which is highly eutrophic and covered in scum most of the year.

(a). What kind of organisms are likely to be in the scum? Why are they considered such a nuisance? (6 pts)

Cyanobacteria aka blue-green algae (3 pts) (partial credit for saying it's algae, phytoplankton)

Cyanobacteria tend to be filamentous and are hard for zooplankton to eat (1 pt)

Since they don't tend to get consumed, cyanobacteria die and are broken down by bacteria.

The bacteria degradation of the cyanobacteria depletes oxygen, which is critical for aerobic heterotrophs such as fish. (2 pts)

In addition, decay of cyanobacterial blooms is often associated with bad smells and decreased water clarity.

The report goes on to cite a scientist who says that because eutrophication is caused by high concentrations of nutrients and that because nitrogen is a major nutrient, nitrogen should be removed from the lake in order to take care of the problem. The scientist proposed using denitrifying bacteria to accomplish this removal.

(b). What reaction involving nitrogen is carried out by denitrifying bacteria? Is this oxidation or reduction? What kind of organism are they (*i.e.*, heterotroph or autotroph, and which sub-group)? Would they be effective for removing nitrogen from the lake? Explain. (6 pts)

$\text{NO}_3^- \rightarrow \text{N}_2$ (1.5 pts) This is reduction carried out by heterotrophic anaerobic respirers (1.5 pts)

Maybe. While the denitrification would remove nitrogen from the lake by turning it into a gaseous form, these denitrifying bacteria can only live in anaerobic conditions, so the lake would need to be stratified. In any case, since these bacteria do not exist in the same location as the cyanobacteria, it is not clear that they would reduce the amount of N the cyanobacteria have access to. (3 pts for a cogent argument along one of these lines)

(c). Do you agree with the scientist's conclusion that reducing the amount of nitrogen in the lake will alleviate the algae problem? Why or why not? What kind of analysis would you do to support your statement? (6 pts)

No. Most lakes are P-limited, rather than N-limited. (2 pts) The presence of cyanobacteria suggests that the N:P ratio is already too low for eukaryotic algae to thrive. Lowering the N:P ratio even further would probably not affect the productivity of the cyanobacteria, since they can fix their own nitrogen (2 pts). Measuring the N:P ratio in the lake would support this case, or doing a nutrient enrichment experiment (adding N and P to separate bottles to see which caused more growth), or verifying the identity of the autotrophs as cyanobacteria (2 pts for describing one of these).

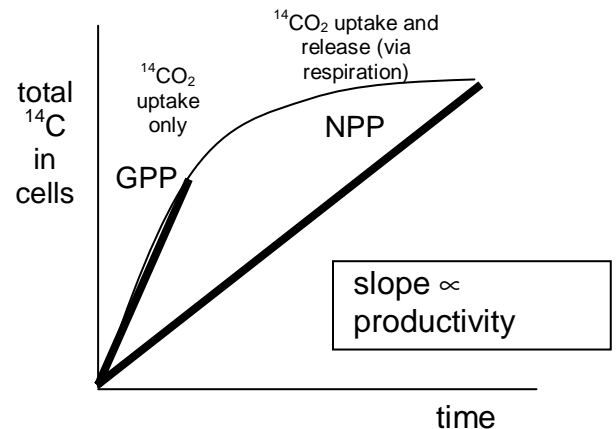
2. Now your agency has been asked to establish baseline conditions in Lake Yucco before improvement efforts are put in place. You have been put in charge of a team of scientists to measure NPP in the lake's waters. To verify the accuracy of the measurements, you split your team in half and instruct one team to measure productivity using $^{14}\text{CO}_2$ uptake and the other team to measure O_2 production. For samples taken near the surface and incubated during the day in the surface of the lake, the following data are obtained, expressed in units of $\text{g C m}^{-2} \text{ hr}^{-1}$, and averaged over either 2 or 6 hours.

<u>time (hrs)</u>	<u>$^{14}\text{CO}_2$ method</u>	<u>O_2 method</u>
2	1.3 ± 0.1	1.0 ± 0.1
6	0.8 ± 0.1	1.1 ± 0.1

(a). How might you explain why the productivity as estimated by $^{14}\text{CO}_2$ uptake data decreases over time? (Sketching a graph may help). (6 pts)

Early in the experiment, the phytoplankton will be incorporating $^{14}\text{CO}_2$ into sugar and respiring sugars that do not contain ^{14}C (produced before the exposure). There is a time lag between the production of $^{14}\text{CH}_2\text{O}$ in the chloroplasts and the respiration of these radiolabelled sugars by the mitochondria.

Hence, the first time point could represent just GPP, and the second time point could represent NPP (or NCP). Or the first time point could be NPP and the second one NCP.



The slope of this curve (C uptake per time) represents the productivity. Since at the first time point, you're just measuring $^{14}\text{CO}_2$ uptake, and at the second time point you're measuring uptake and release (via respiration), the average $^{14}\text{CO}_2$ uptake rate will decrease over time.

(b). Which method do you think is a better way to measure NPP in this case and why? For the method you select, name one major source of error in your measurements. (6 pts)

The O_2 method, since the productivity measured does not change over time. You don't need to figure out where you are along the curve. (Other answers possible). (3 pts)

Sources of error: (3 pts)

- the presence of heterotrophs would mean you're really measuring NCP not NPP
- unrepresentative sample
- effects of no mixing, or of O_2 accumulation, or of CO_2 depletion from the water

3. Having selected a method for measuring NPP, your team goes out on a warm sunny summer day and collects a profile of NPP with depth:

(a). Given the NPP data shown here, calculate the absorption coefficient of this lake. State your assumptions and be clear with your units. (6 pts)

Assume $NPP=0$ at the compensation point, z_c , where $I_c = 0.01 \cdot I_0$ (3 pts)

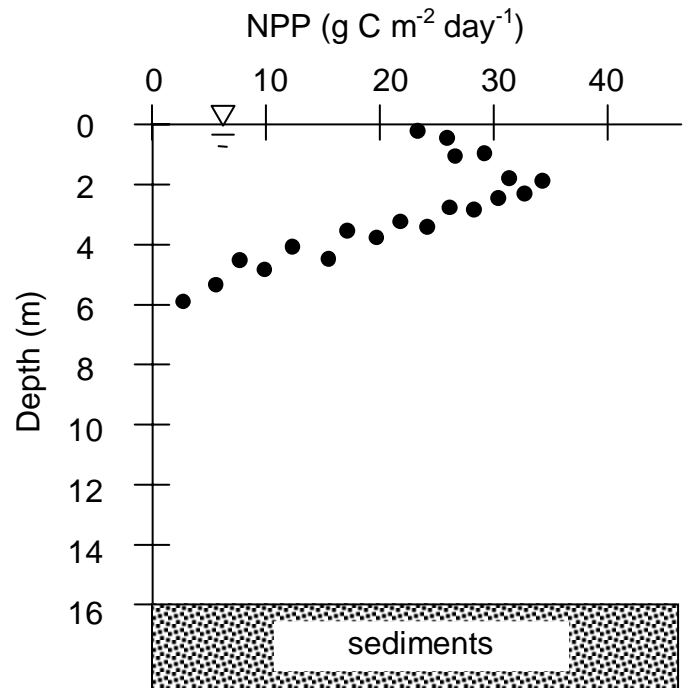
From the graph, $NPP = 0$ at 6 m (z_c)

$I = I_0 e^{-kz}$, or $I_c = I_0 e^{-kz_c}$ (2 pts)

$0.01 \cdot I_0 = I_0 \cdot e^{-(k \cdot 6m)}$

$\ln(0.01) = -k \cdot (6 \text{ m})$

$k = 0.76 \text{ m}^{-1}$ (1 pt, full credit only if you have the right units)



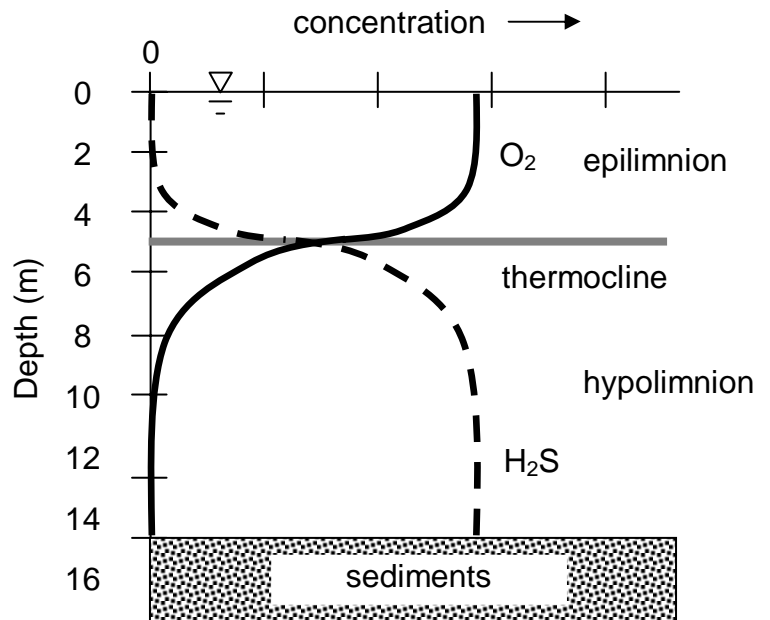
(b). Provide an explanation for why the NPP maximum does not occur at the surface of the lake. (6 pts)

Photoinhibition caused by high light intensities at the surface.

(c). Temperature measurements of the lake show that the lake is thermally stratified and that the thermocline occurs at 5 m. Sketch the concentration depth profiles of O_2 and H_2S in the lake. (Don't worry about the relative magnitude of O_2 versus H_2S , just the shape of the curves). (6 pts)

O_2 higher in the mixed layer at the surface (in equilibrium with atm) than in deeper layer, where O_2 is depleted by bacteria. H_2S is only produced in anaerobic conditions, and hence is only present in the deeper layer.

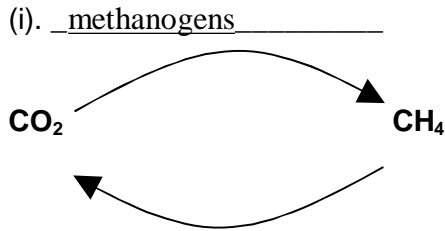
H_2S should be 0 in oxic water. By "relative magnitude of O_2 versus H_2S ", we meant not to worry about $[O_2]$ in the epilimnion versus $[H_2S]$ in the hypolimnion. But, the question was perhaps confusing, so if you got -2 for not having H_2S go through 0, come see us.



4. As part of your establishment of the baseline condition of the lake, you also want to establish the other kinds of microorganisms living in the lake.

(a). For each blank (i)-(v), fill in the name of the organism (e.g. nitrogen fixing bacteria, not the Latin name) that carries out the transformation. (5 pts)

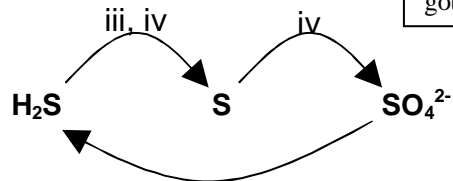
1 pt each; -0.5 if you got just the general type (e.g. chemoautotroph)



(ii). methanotrophs

(iii). purple (or green)sulfur bacteria

(iv). sulfur oxidizing bacteria



(v). sulfate reducing bacteria

no pts off if you reversed these, or put purple sulfur for one and green sulfur for the other. but, if you wrote the same thing twice, you only got 1 of 2 pts

(b). For each reaction, indicate

- the type of organism (oxygenic or anoxygenic photosynthesizer, chemolithoautotroph, aerobic or anaerobic respirer, or fermenter)
- where in the lake you generally would expect to find them (think about your Winogradsky columns)

(5 pts)	<u>Type</u>	<u>Location</u>
(i)	anaerobic respirer	sediments/hypolimnion
(ii)	chemolithoautotroph	sediments/hypolimnion, or near thermocline
(iii)	anoxygenic photosynthesizer	thermocline
(iv)	chemolithoautotroph	sediments/hypolimnion
(v)	anaerobic respirer	sediments/hypolimnion, or near thermocline

you got points if you gave the right location for the type of organism you wrote, or if you got the right location but the wrong type

5. (a). Having done your part to improve the conditions of Lake Yucco, you decide to move on to bigger topics. You decide to become an oceanographer and study the productivity of open oceans because they are so important on a global scale. When you tell your roommate your intended career switch, your roommate (who took 1.018 last year and only remembers some things) looks puzzled and says, "But don't oceans have the same productivity as deserts? How could they possibly be important on a global scale?" Explain how you are both correct. (6 pts)

While it is true that open oceans have low productivity on a per area basis, because they occupy such a large percentage ($\cong 2/3$) of the Earth's surface area, they contribute nearly half of global NPP.

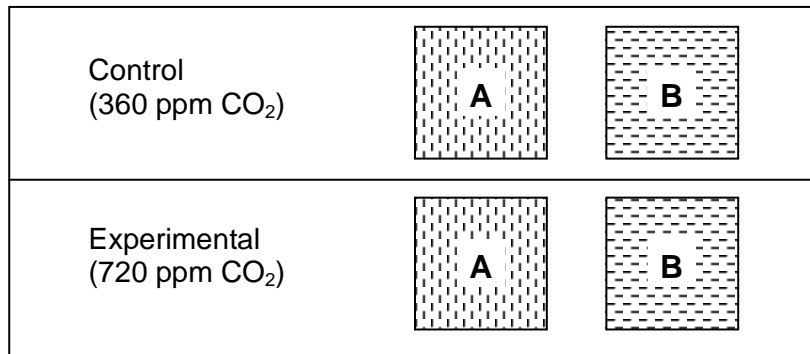
(A lot of people talked about turnover rates here, or P:B ratios (sometimes making incorrect statements!). Turnover rate has to do with how long a C atom stays in the system, not how much C enters the system. And while the oceans do have much higher P:B ratios than terrestrial ecosystems, there is so little biomass in the oceans that this fact alone does not explain why the oceans contribute so much to global productivity).

(b). Throughout the semester, we have discussed a number of ways that organisms have, through their individual metabolic processes, significantly altered their environment on a global scale. In the 1930s, Redfield observed something interesting about the connection between marine life and relative concentrations of major nutrients in oceans around the world. Explain what he observed and what major conclusion he drew. (6 pts)

Redfield observed a certain ratio of C:N:P in life (2 pts) and observed the same ratio of C:N:P in the surface and deep waters of oceans around the world (2 pts). (If you didn't explicitly say that he found life to have that ratio but it was implied in what you said you got full credit). He also found that the amount of oxygen depleted in deep waters (compared to surface water) also closely correlated with the concentrations of the major elements.

Thus, through the processes of photosynthesis and degradation of organic compounds, the relative concentrations of major elements in the world's oceans have come to reflect the requirements of life. In the absence of life, the chemical composition of the oceans would most likely look very different. (2 pts)

6. Having been out on a few oceanographic cruises and suffered severe seasickness, you decide to switch careers again and become a terrestrial ecologist. Since you are still interested in global issues, you decide to study the effects of increased CO₂ levels on the productivity of two species of grass: a C₃ plant (Species A) and a C₄ plant (Species B). You have plots of soil in your greenhouse containing one of the two species, at either ambient CO₂ concentration (360 ppm) in the air, or at doubled CO₂ concentration (720 ppm). You sow the grass seeds in the spring time, water the soil periodically, harvest the grass in the fall, dry the grass and record the weights.



(a). Are you measuring GPP, NPP or NCP? Why? (6 pts)

NPP. (3 pts)

The physical biomass produced represents the amount of carbon (or energy) fixed by the plants, minus the amount of carbon (or energy) that the plants respired. (3 pts)

NCP was also an acceptable answer if you mentioned that there would be heterotrophic respiration as well.

(b). How might your answer change if your grass was growing outside in a field? (6 pts)

In a field outside, you would have to consider the loss of biomass from herbivore consumption (3 pts), and thus you might really be measuring NCP (3 pts).

(c). In comparing experimental versus control plants for each species, you observe that both species exhibit increased growth at the elevated CO₂ concentrations, but that one species exhibits a much greater increase. Which one and why? (6 pts)

Species A. C₄ plants (Species B) have a mechanism to concentrate CO₂ in their cells, so they are more efficient at using CO₂ and tend to be less limited by CO₂ than are C₃ plants. Hence, we would expect C₃ plants (Species A in this case) to benefit from having higher CO₂ because they can keep their stomata more closed and have higher water use efficiency. See Chap 28 in your textbook.

(n.b. this doesn't say anything about the relative growth of Species A vs. Species B)

(Some people mentioned light intensity, and the fact that C₃ plants can get saturated with respect to light (at 25-33% full sunlight intensity), while C₄ plants continue to show increased

growth as light intensity increases. In partial sunlight, C₃ plants will be saturated with respect to light, meaning that adding more sunlight won't increase their growth. This doesn't mean that you can't add something else to make them grow more, it just means that they can't make use of extra sunlight coming in. So C₃ plants are likely to be primarily limited by some other factor, and given their poor water use efficiency, they're likely limited by water or CO₂. By contrast, C₄ plants are at least partially limited by light intensity, and are likely to be less limited by CO₂ than the C₃ plants. Therefore at full light intensity, where C₃ are saturated with respect to light and C₄ plants are not, it is more likely that the C₃ plants would exhibit greater growth when given additional CO₂).

(d). The following year, you decide to continue the experiment. Using the same experimental setup as the previous year, you once again sow seeds in the spring, water the soil periodically, and harvest the grass in the fall to measure productivity. This time, you don't see any increases in productivity between the two treatments. Explain these observed results. (6 pts)

Most likely, the soils have become depleted of nutrients (most likely nitrogen) when last year's crop was harvested and removed, so that the additional CO₂ won't increase growth anymore because both species of plant are nutrient-limited.

(e). Global change scientists predict that in addition to continuing increases in atmospheric CO₂ concentrations, that in certain regions temperatures will increase and rainfall will decrease. Briefly discuss how these two changes would affect the relative distributions of C₃ versus C₄ plants. (6 pts)

Higher temperature and lower rainfall will have the same effect. C₄ plants outcompete C₃ plants under conditions of high temperature and low rainfall (3 pts), so a trend towards more hot arid areas will mean that C₄ plants will become more predominant (3 pts). (This is already being observed, that areas of C₃ dominance are being pushed further north in the Northern Hemisphere and further south in the Southern Hemisphere).