

Solutions to 7.014 Problem Set 5

Question 1

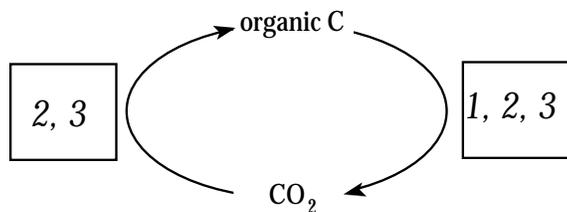
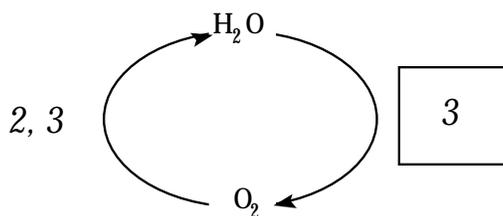
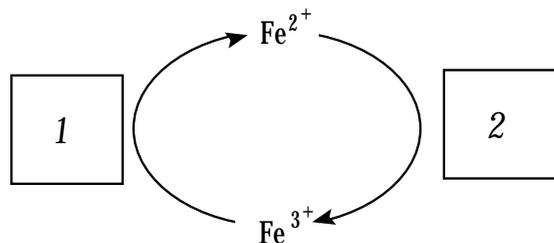
a) Fill in the following table:

Process:	Energy Source:	Carbon Source:
Anaerobic Photosynthesis	Sunlight	CO ₂
Aerobic Photosynthesis	Sunlight	CO ₂
Chemosynthesis	Reduced chemical compounds	CO ₂
Aerobic Respiration	Organic carbon compounds like glucose	Organic carbon compounds like glucose
Lactic Acid Fermentation	Organic carbon compounds like glucose	Organic carbon compounds like glucose

b) You've been stranded on a deserted island with the following:

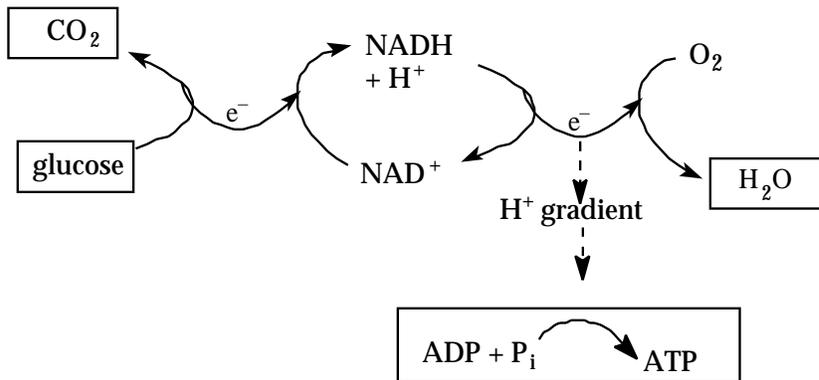
- 1) a heterotroph that carries out anaerobic respiration
- 2) an autotroph that carries out chemosynthesis
- 3) an autotroph that carries out oxygenic photosynthesis

For each of the transformations below, indicate which organism(s) would be responsible for the conversion.



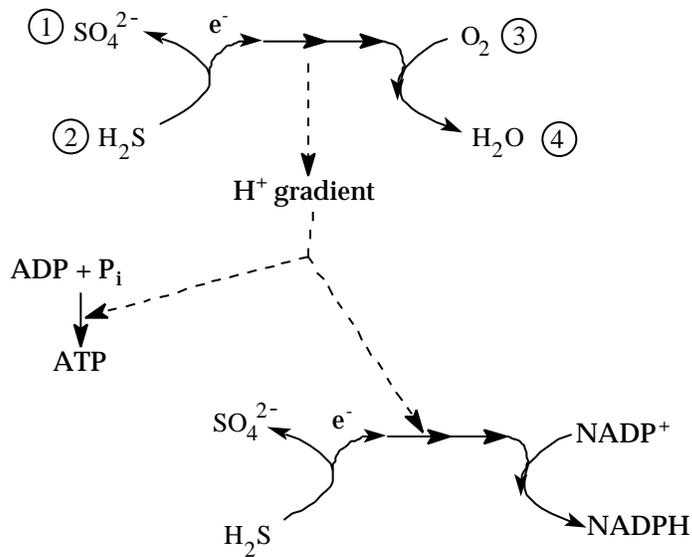
Question 1, continued

c) Fill in the blanks on the following graph and indicate which type of metabolism this organism is using.



Metabolism = aerobic respiration

d) Consider the metabolism diagrammed below:



i) This type of metabolism is an example of chemosynthesis. It is most commonly carried out by prokaryotic organisms. These organisms are autotrophs.

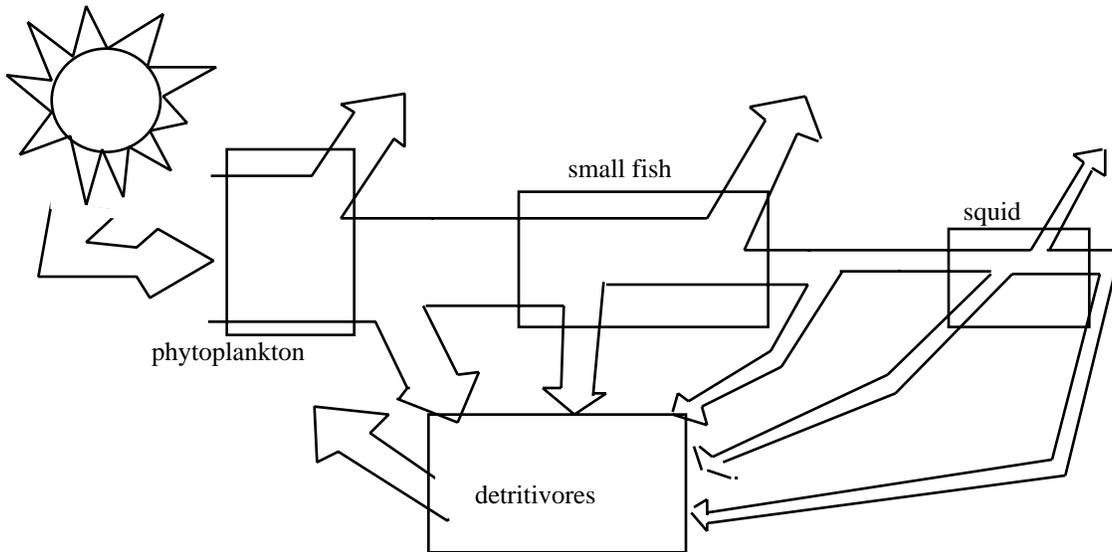
ii) What is the energy stored in the ATP and the NADPH produced in the metabolism above used for?

To fuel the Calvin cycle, fix CO₂ into glucose.

Question 2

Your ongoing interest in bioluminescent organisms has led you to study the Hawaiian squid, *Euprymna scolopes*. Most nocturnal creatures cast shadows under the bright Hawaiian moonlight, and are easy prey to predatory fish. This type of squid can shine light downwards to match the moonlight and avoid casting a shadow thereby decreasing predation.

To provide squid for your studies, you maintain a large, self-supporting squid tank. The food web of the tank is shown below.



When your tank is at steady state, you can harvest 10 kg of squid carbon/week and all the other biomasses (phytoplankton, fish, squid, and detritivores) remain constant.

Given the following values:

- NPP of phytoplankton = 2.0 kilograms of organic carbon per gram of phytoplankton per day
- plant production efficiency = 60%
- fish exploitation efficiency = 50%
- fish assimilation efficiency = 20%
- fish net production efficiency = 5%
- squid exploitation efficiency = 50%
- squid assimilation efficiency = 80%
- squid net production efficiency = 40%

a) What NPP (in kilograms of carbon) is required to support a harvest of 10 kg of squid carbon per week at steady state? Show your work.

$$10\text{kg} / (.4)(.8)(.5)(.05)(.2)(.5) = 12,500 \text{ kg/week}$$

Question 2, continued

b) Month after month, your squid harvest is 10 kg/week and all the biomasses remain constant. One month, you find that you can only harvest 5 kg of squid carbon/week and maintain steady state.

You suspect that something has contaminated your tank and reduced your yield. You propose two models to account for the reduction in yield. To test these models, you measure the respiration rate of the detritivores in the tank. You find that detritivore respiration has increased by 5 kg of carbon per week.

Model 1: Phytoplankton photosynthesis is inhibited so that they now only produce 1.0 kilogram of organic carbon per gram of phytoplankton per day, but at this new steady state, all other efficiencies remain constant.

i) Is this model consistent with your measurement? Explain.

This model would predict that 1/2 as much carbon would be fixed by the phytoplankton. Since all efficiencies remain the same, this would cause all flows to decrease to 50% of their non-poisoned levels. This would therefore reduce the detritivore respiration by 50%. This is not consistent with the observed increase.

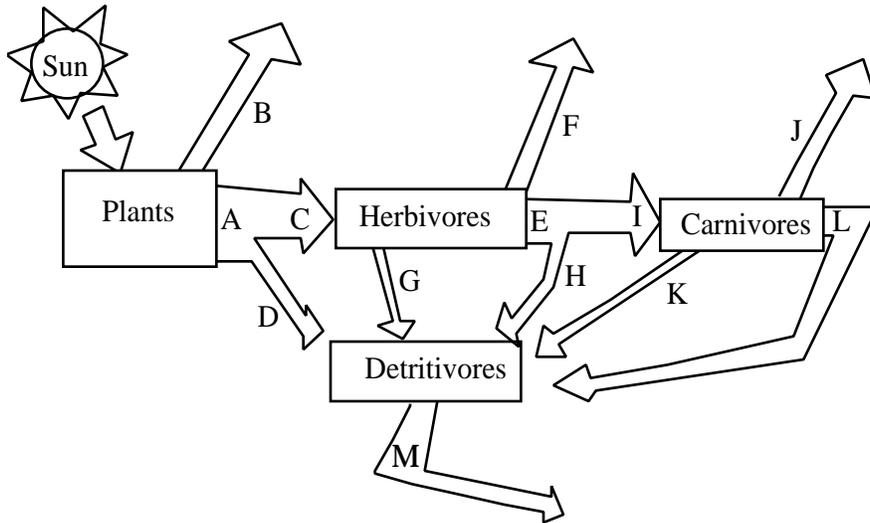
Model 2: 5 kg of fish per week are dying with all other efficiencies remaining constant.

ii) Is this model consistent with your measurement? Explain.

This model would predict that 5 kg carbon per week of fish are dying and therefore becoming detritus. Since all efficiencies are the same and the tank remains at steady state, this additional input to the detritus must be made up for by an equal increase in output from detritus. Since the only output from detritus is respiration (refractory carbon cannot increase at steady state), detritivore respiration must increase by 5 kg carbon per day. This is consistent with your measurement.

Question 3

a) You have just won the lottery and you and 10 friends decide to sail around the world in your new yacht. Unfortunately, due to stormy seas in the Pacific, you find yourselves shipwrecked on a remote island near Micronesia. On the island there are trees and edible plants, plant-eating boars, and lions.



i) In one sentence, describe what each of the following flows represents.

A: *NPP = net primary production, all plant matter available to herbivores*

C: *Herbivore ingestion = the plant matter actually consumed by herbivores*

D: *Plant detritus = plant material not consumed by herbivores*

F: *Herbivore respiration = the energy lost by herbivores*

b) In terms of the flows given on the energy flow diagram:

i) What is the production efficiency of the carnivores? $PE_C = L/L + J$

ii) What is the exploitation efficiency of the herbivores? $EE_H = C/A$

iii) If the NPP is 1×10^6 grams C, what is the respiration of herbivores if the $EE_H = 0.5$, $AE_H = 0.2$, $PE_H = 0.6$? $R_H = (1 \times 10^6)(0.5)(0.2)(1 - 0.6) = 40,000$ grams carbon

iv) Using the letters given on the above diagram, write the equation for NEP, net ecosystem production (also call NCP, net community production). The NEP is the organic carbon produced through photosynthesis and not lost through respiration. (M is the respiration of the detritivores.)

$$NEP = A - (F + J + M)$$

Question 3, continued

c) As vegetarians, your introduction into the ecosystem changes the energy flow of the system. In the table below indicate if the flow would increase, decrease, or stay the same as a consequence of your introduction into the ecosystem. Assume the gross primary production (GPP) does not change. There may be more than one correct answer, so choose only one and explain your answer.

	increase or decrease	explain
C	increase	more herbivores therefore more ingested plant matter
D	decrease	more plants are eaten, so less die.
F	increase	more herbivores therefore more herbivore respiration
I	increase	more herbivores therefore more food for carnivores
	OR same	people will not be eaten by the lions because the boars are easier prey.
	OR decrease	people hunt the lions, less lions less flow into the carnivore trophic level.

d) Some time after your introduction to the island, the ecosystem reaches a new steady state. Unfortunately, a tribe of cannibals visits the island, captures you, your friends, and all the plant-eating boars and returns to their homeland. (You are later rescued and return to MIT to finish your studies). Once the terrestrial ecosystem reaches a new equilibrium, how has the number of trophic levels changed? Explain your answer.

The number of trophic levels has decrease by two. The entire herbivore trophic level has been captured and removed, therefore the carnivore trophic level will also be lost.

Question 4

Biogeochemical cycles are necessary for life to exist. Three of the most important cycles are the Nitrogen, Carbon, and Hydrological Cycles.

a) After reading the article, “Human domination of Earth’s Ecosystems,” describe the impact that humans have had on each of these cycles.

Humanity adds CO₂ to the atmosphere via mining and fossil fuels, also by converting forests and grasslands to low-biomass ecosystems. The levels of CO₂ have thus increased. This will directly affect the climate and will cause increased temperature levels due to the phenomena of global warming. Also, increased levels of CO₂ cause abnormal growth in plants to a degree where the tissue chemistry of plants change, decreasing food quality for animals and microbes.

Humans deplete waterways that are important because of their influence in many ecosystems, their ability to aid in flood control and dilution of chemical wastes. Our irrigation increases atmospheric humidity in semiarid areas – which increases precipitation and thunderstorm frequency. We are also draining large quantities of ground water which is not being replaced.

Nitrogen cycle has dramatically changed due to human activities. Nearly all nitrogen fixation prior to industrialization was carried out by bacteria. We now have the ability to have been fix vast quantities of N₂ into organic nitrogen that is used as fertilizer. Much of this nitrogen flows into the waterways and into the oceans. We are adding nearly twice as much fixed N to the terrestrial exosystems – this increases the concentration of the greenhouse gas NO.

b) Explain why the Biosphere2 project suffered from a critical decrease in O₂ levels. Sketch the carbon cycle as it would have been in the Biosphere2 dome.

Biosphere 2 suffered because they added too much organic matter in the soil. This caused a feeding frenzy for the microorganisms that fed off the organic matter, causing increased respiration, thereby increasing the amount of O₂ in the air.

c) The productivity (the g C m⁻² year⁻¹) of an acre of farmland in California looks to be much greater than the productivity of that same land prior to agricultural advances. Give three reasons why this increase in productivity is overestimated.

Today, farmland is prepared using large equipment, and much carbon in the form of fossil fuel was used to produce this machinery. This machinery requires fossil fuel to function. Irrigation also requires fossil fuel, as does the production of the fertilizers used to increase crop production. To assess whether productivity per acre of farmland has increased, this fuel cost need to be subtracted from the total g C m⁻² year⁻¹.

Question 4, continued

d) When considering how well life will thrive in an aquatic environment, two major factors are usually considered: the ability of light to penetrate to an appropriate depth and the availability of various nutrients in the water. Many organisms thrive near the surface of the water because of the accessibility to sunlight, but eventually the nutrients in the surface water are insufficient to sustain life. Much of the dead biomass floats to the bottom where it decomposes and creates a nutrient-rich environment. However, light cannot penetrate to this depth and so very little can grow. Moreover, a steep temperature gradient called a thermocline prevents mixing of the upper and lower waters.

Explain the following phenomena in term of limiting factors and thermoclines:

i) **Plankton thrive in the wake of a hurricane.** *The hurricane mixes the ocean to a greater depth than does normal wind. This disturbs the thermocline and brings nutrient rich water to the surface allowing the plankton to thrive.*

ii) **Algae bloom in lakes in the spring.**

Cooling of lakes in the winter destroys the thermocline present in warmer temperatures. In the spring, nutrient rich water is at the surface allowing the algae to thrive.

iii) **An increase the primary productivity along the coast.**

The thermoclines are eroded along the coast due to coastal upwelling.

d) In New England the soil has a higher percent of nitrogen and phosphorus than does the living biomass. In a tropical forest, the reverse is true. In an experiment, you fertilize soil from the rain forest with phosphorus and nitrogen containing compounds and find an increase in plant growth.

i) **If you repeated the experiment in a New England forest, would you expect the same result? Explain your answer.**

The fertilization of New England forests would have less effect because the soil has a higher proportion of these nutrients.

ii) **What two major factors influence the density of biomass in an environment?**

The two major factors are temperature and water availability.