Name: ______________________________

GEOL1551 - Primary Production Lab

Primary Productivity is the rate at which inorganic carbon is utilized by organisms to produce organic compounds. In the surface ocean, this is driven by photosynthesis. The general formula for this is:

$6CO_2 + 6H_2O$ + sunlight (energy) → $C_6H_{12}O_6 + 6O_2$

Or, more simply: $CO_2 + H_2O$ + sunlight → $CH_2O + O_2$

Where $C_6H_{12}O_6$ or CH_2O represent organic matter.

Photosynthesis consumes CO_2 and produces O_2 and the organic compounds (e.g., sugars) that can be used to fuel the metabolism of an autotroph. To grow and reproduce, the sugars are broken down via respiration (the opposite reaction from above) to produce energy. So, respiration consumes O_2 and produces CO_2 (both autotrophs and heterotrophs respire).

In the oceans, phytoplankton (algae; dominated by diatoms and coccolithophorids – see your textbook for images of these) are responsible for much of the primary productivity, and produce chlorophyll giving them their green color. As you would suspect, they grow where the sunlight occurs (the euphotic zone in the upper 100 to 200 m of the ocean). Diatoms have a skeleton (frustule) made of hydrated silica ($SiO_2 \cdot nH_2O$). Thus silicon (Si) is an important nutrient for them. Additionally, primary productivity is dependent on the nutrients phosphate (PO_4^{-3}) and nitrate (NO_3^-). Every 106 atoms of carbon that are incorporated into organic matter requires 16 atoms of nitrogen and 1 atom of phosphorus (C:N:P = 106:16:1). This is called the Redfield ratio. It is important because if the supply of one of the nutrients is exhausted, then primary productivity stops.

When algae grow, they consume the nutrients as well as CO_2, and produce O_2. When algae die and sink through the water column, the organic matter is consumed by bacteria which release the nutrients and CO_2 back to the water. This is called the Biological Pump (moving CO_2 into the deeper water via biological means; for more information see http://earthguide.ucsd.edu/virtualmuseum/climatechange1/06_2.shtml). So, you should be able to predict what the concentration of nutrients and CO_2 and O_2 should be in the water due to these processes.

The amount of primary productivity can be determined by looking at the amount of chlorophyll in the surface water of the oceans by means of satellite imagery or by direct measurements of the water. Likewise, the nutrients and dissolved gases can be analyzed from water samples taken at different depths through the water column during oceanographic cruises.

With these facts in your knowledge tool belt, answer the following questions.

Part I.

Visit: https://earthobservatory.nasa.gov/global-maps/MY1DMM_CHLORA

4 points each

1. What does this map show (give the units).

2. In general, where does low chlorophyll occur and what does that mean for the concentration of phytoplankton?

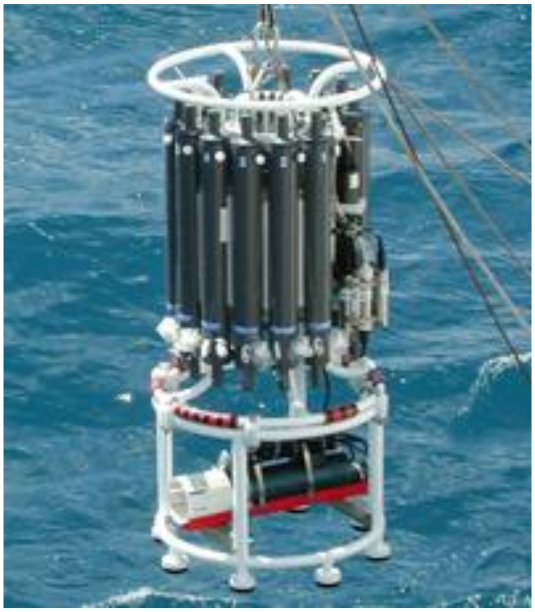
3. What is the relationship between the distribution chlorophyll and surface water temperature (see Select and Compare on the right side of the webpage)?

4. Why does this relationship exist?

5. Why is there high chlorophyll near the coasts?

Part II. Photosynthesis Exercise

The data below, in Table 1, are the kind of data that would be derived by lowering water sampling bottles (Nisken bottles) through the water column, and remotely triggering their closure at certain depths. These bottles are typically mounted on a “rosette” (https://www.mbari.org/ctd-rosette/), and a CTD is also used to measure the conductivity (salinity), temperature and depth. The samples are then brought back to the ship and analyzed for the constituents shown, which are important for understanding biological productivity.



A rosette consisting of Nisken bottles and a CTD.

1. (20 pts.) On the graph paper provided to you plot the data from Table 1 (below):

(a) O_2 versus depth (**use open circles**),

(b) PO_4^{3-} versus depth (**use X's**),

(c) SiO_2 versus depth (**use open triangles**).

Note that when you have plotted (a) it is easy to plot (b) and (c) by matching depths.

Connect the oxygen points with a solid line, the phosphate points with a dashed line, and the silica points with a dotted line.

Plot depth on the vertical axis (increasing from top to bottom) and the concentrations on the horizontal axis (increasing from left to right).

You will use 3 different scales for the three different concentrations. The phosphate curve that you will get shows what oceanographers call a **nutrient** **profile**.

Table 1. Measurements of dissolved gases and nutrients in seawater as a function of depth.

Depth	**Oxygen**	**Phosphate**	**Silica**	**TCO_2**
meters	**mmoles/kg**	**micromoles/kg**	**micromoles/kg**	**mmoles/kg**
20	0.203	0.18	1.8	NA
49	0.204	0.18	1.8	1.946
99	0.209	0.18	1.6	1.973
149	0.205	0.21	1.8	2.041
248	0.169	0.85	10.3	2.093
544	0.053	2.61	71.7	2.303
742	0.044	2.83	86.8	2.299
988	0.05	2.88	107.8	2.331
1185	0.058	2.9	121.6	2.357
1534	0.073	2.9	139.2	2.365
2126	0.102	2.78	156.4	2.353
2530	0.117	2.7	162.2	2.366
3130	0.135	2.61	164.4	2.375
3735	0.148	2.48	162.5	2.341
4385	0.157	2.44	152.8	2.323
4953	0.182	2.33	136.9	2.411

2. Using your plot and the following simplified representation of the photosynthesis reaction (top line shows raw materials and bottom line shows products) answer the questions below. Remember that **<u>the reverse of the photosynthesis reaction is respiration</u>** or decay (top line shows reactants and bottom line shows products). Note that phosphorous (P) in the form of phosphate (PO_4^{-3}), and nitrogen in the form of nitrate (NO_3^-) are very important nutrients for photosynthesis.

$$106\ CO_2\ (g) + 122\ H_2O\ (l) + 16\ NO_3^-\ (aq) + PO_4^{3-}(aq) + 19\ H^+(aq) =$$

$$(CH_2O)_{106}(NH_3)_{16}H_3PO_4(s) + 138\ O_2(g)$$

Or more simply:

Photosynthesis reaction: $6CO_2 + 6H_2O$ + sunlight (energy) + nutrients $\rightarrow$ $C_6H_{12}O_6 + 6O_2$

Plant decay (or respiration) is the reverse: $C_6H_{12}O_6 + 6O_2$ $\rightarrow$ $6CO_2 + 6H_2O$ + nutrients

a. (6 pts.) Starting at the sea surface (0 meters depth) and working down into deeper water, at what depth do you see the concentrations of oxygen, phosphate and silica **start** to change?

b. (6 pts.) Using the above reactions as guides, which process (either photosynthesis or respiration) could cause phosphate and silica in the water column to **increase** and oxygen to **decrease**?

c. (6 pts.) Based on your answers to “a” and “b” and your nutrient chart, in what portion of the ocean (give the range of depths) is photosynthesis the dominant process in the water column?

d.(6 pts.) In what portion of the ocean (give range of depths) is respiration and decay the dominant processes in the water column?

e. (6 pts.) Study the reaction for photosynthesis above and note the position of CO_2 – meaning, is it a product of photosynthesis or is it consumed by photosynthesis?) What effect should the downward variation from photosynthesis-dominated to respiration-dominated environments have on the CO_2 concentrations as you go deeper in the water column?

f. (6 pts.) Now look at the column of CO_2 concentrations given in Table 1. Is your predicted effect on CO_2 concentration observed in the **table** of concentrations? Explain what happens to CO2 concentrations from shallow water to deeper water.

g. (8 pts.) Based on the depth to which photosynthesis dominates (given in answer c above), to what depth in the ocean do you think significant amounts of sunlight penetrate? [Remember, sunlight is necessary for photosynthesis to occur!]

h. (8 pts.) Study the photosynthesis reaction and explain why phosphate concentrations are so low in the surface waters?

i. (8 pts.) Look at your nutrient chart. Does silica show a nutrient profile? (Does it follow a similar pattern as phosphorus, for example?) If so, **why** do you think this is the case? What organisms might be using silica as a nutrient?