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Module 1 Origins and Earth Systems
Problem set_01 “Prokaryotes: The unseen majority”

Learning objectives:

- Describe the numerical abundance of microbial life in relation to the ecology and biogeochemistry of Earth systems.

Specific Questions:

• *What are the primary prokaryotic habitats on Earth and how do they vary with respect to their capacity to support life? Provide a breakdown of total cell abundance for each primary habitat from the tables provided in the text.*

The primary prokaryotic habitats on earth are the oceans (referring specifically to bodies of water), mountains and the subterranian layers of land, forests (majority on leaves), underwater sediment layers.

• *What is the estimated prokaryotic cell abundance in the upper 200 m of the ocean and what fraction of this biomass is represented by marine cyanobacterium including Prochlorococcus? What is the significance of this ratio with respect to carbon cycling in the ocean and the atmospheric composition of the Earth?*

The number of prokaryotic cells in the upper 200m of ocean are 10^18 cells, with prochlorococcus making up the majority of prokaryotic life in this layer. There is not as dense a mass of cells below the first 200m but the volume of this layer is larger than that of the top 200m of ocean

Upper 200m of the ocean: 360x10^26
Fraction represented by cyanobacterium including Prochlorococcus: 8%

Marine cyanobacterium such as Prochlorococcus produce their own energy from sunlight via photosynthesis, which in the process produces oxygen while fixing carbon. Despite only being 8% of the prokaryotic cell abundance in the upper 200m, they are responsible for approximately 50% of the oxygen in the atmosphere and contribute greatly to carbon cycling as demonstrated by their quick turnover time and resulting 8.2 x 10^29 cells/year

3.6 X 10^28 cells
5 X 10^5 cells/mL

Cyanobacteria
4 X 10^4 cells/mL/
5 X 10^5 cells x 100 = 8%

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• *What is the difference between an autotroph, heterotroph, and a lithotroph based on information provided in the text?*

Autotrophs in this text are bacteria that produce their own food, primarily using energy from the sun. As a result, these are prokaryotes that are often found on surface environments that are able to recieve some amount of sunlight. They are <10% of upper layer marine prokaryotes. However, they form the majority of prokaryotes in soil and subsurface. Thus, they are defined as primarily land-dwelling organisms.
Heterotrophs make up the majority of prokaryotic organisms with the majority of those found below 200m. They are defined as the most abundant sea-dwelling organisms.
Lithotrophs are subsurface prokaryotes that use a different method of energy generation. They are defined as mysterious, primarily found in subsurface environments, and are scarcer than other types of prokaryotes.

Autotroph- "self nourishing", fix inorganic carbon into biomass
Heterotroph - Assimilate organic carbon
Lithotroph - use inorganic substrates

• *Based on information provided in the text and your knowledge of geography what is the deepest habitat capable of supporting prokaryotic life? What is the primary limiting factor at this depth?*

The Mariana Trench is the deepest part of the ocean, and we know that it is an environment that supports prokaryotic life, although at this depth, there is nearly no light reaching it as well. Therefore, it is the deepest habitat known to support life. Because the paper has deduced that subsurface sediments below the water layer also contains prokaryotes, we could make the argument that the deepest habitat to host prokaryotic life would be the subsurface sediment layer of the Trench.

Subsurface environments on land may contain prokaryotes further below that of the Mariana Trench. However, not much is currently known about life existing below these depths, due to challenges in retrieving uncontaminated samples from these areas. The text talks about how in subsurface environements, the limited carbon nutrition available to these organisms means that the majority are metabolically inactive or non-viable. However, evidence shows that metabolic activity is on par with that of surface prokaryotes. Because most of the carbon nutrient availability is gained from the surface, the primary limiting factor would be the transfer of carbon nutrients from surface to deeper subsurface environments, which logically decreases the deeper you go.

Deep habitats supporting life
Subsurface- terrestrial + marine
Temperature is 125 degrees About 4km to 6km for both environments

• *Based on information provided in the text your knowledge of geography what is the highest habitat capable of supporting prokaryotic life? What is the primary limiting factor at this height?*

Prokaryotes have been found in in the atmosphere at altitudes as high as 57-77 km. Mount Everest (8,848 meters) is the highest geographical location on Earth, and therefore would technically be the highest habitat capable of supporting prokaryotic life. Is it capable of supporting prokaryotic life?
Primary limiting factors at this height include temperature. Some prokaryotes, psychrophiles, have adapted to such low temperatures.
Nutrients are also limited at high altitude. Less atoms are found in the upper atmosphere and thus less material is available to compose the building blocks of life. This would result in slower growth. UV radiation as well as pressure are limiting to life at high altitudes because they can damage cells.

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• *Based on estimates of prokaryotic habitat limitation, what is the vertical distance of the Earth's biosphere measured in km?*

Taking the lowest point and highest point, there is 24km. The "skin" of the world. The biosphere of the earth is a relatively narrow band.

Lower range:
Mariana Trench is 10,994 meter deep, but the lower limit is much deeper since it includes subsurface sediments, which is about 4.5km deeper.

Upper limit:
Mount Everest 8,848 m high, but the upper limit is much higher if it includes atmosphere as an "habitat".

Vertical distance of the Earth's biosphere: 19.84 km + 4.5km = 24km (+ potential atmosphere)

• *How was annual cellular production of prokaryotes described in Table 7 column four determined? (Provide an example of the calculation)*

Marine heterotrophs

Annual cellular production, in cells/year X 10^29 was calculated with the following formula:
Cells/year = Population Size * (365 / (turnover time [days]))

[3.6 x 10^28 cells x 365 days]/16 turnovers = 8.2 x 10^29 cells

Or (same thing below)

Cells/year = Population Size * (turnover/year)

• *What is the relationship between carbon content, carbon assimilation efficiency and turnover rates in the upper 200m of the ocean? Why does this vary with depth in the ocean and between terrestrial and marine habitats?*

Carbon content along with carbon assimilation efficiency determine the upperbound limit on the turnover rates seen in the upper 200m of the ocean.
This varies with depth in the ocean, and between terrestrial and marine habitats because the abundance of carbon in each habitat is different.

Carbon efficiency = 20% (this is an assumption that the authors make) - somehow get a multiplier of 4 from this to use to multiply total carbon later; not sure why
Total carbon = average carbon per cell * number of cells
4 * total carbon = 2.88 Py/year

Carbon efficiency: 20%
20 fg of C on avg in prokaryotic cell (20 fg/cell)
~20 = 20?*10^-30 Pg/cell
(3.6 X 10^28 cells) x (10^-30 Pg/cell) = 0.72 Pg C in marine heterotrophs

51 Pg cell/year 85% consumed = 43 Pg C
(43 Pg cell/year)/2.88 Pg/year = 14.9 turnovers/year, 1 turnover every 24.1 days
[365 days /14.9 turnovers = ~24 days / turnover]

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• *How were the frequency numbers for four simultaneous mutations in shared genes determined for marine heterotrophs and marine autotrophs given an average mutation rate of 4 x 10^{-7} per DNA replication? (Provide an example of the calculation with units. Hint: cell and generation cancel out)*

((365d/y)*(24h/d)/(((4*10^-7)^4 mutations/cell))*(8.2*10^29 cells/y)=(h/4 simultaneous mutations)

= 4x10^-7 mutations/generation
For 4 mutations to happen at once:
(4x10^-7)^4 = 2.56x10^-26 mutations/generation
(3.1x 10^28 cells) x 22.8 = 8.2 X 10^29 cells/yr
365 / 16 = 22.8 turnover/yr
(8.2 x 10^ 29 cells/ yr) x 2.56 x 10^26 mutations/yr = 2.1 X 10^4 mutations/ yr

• *Given the large population size and high mutation rate of prokaryotic cells, what are the implications with respect to genetic diversity and adaptive potential? Are point mutations the only way in which microbial genomes diversify and adapt?*

A large mutation rate means that there is a great potential for multiple point mutations in a single replication.
This allows for quick adaptation by creating a more diverse pool of mutants to be selected from.
Genetic diversity will be extremely high when small scale changes to sequence are considered and long term "species" level biodiversity will mostly be determined by competition and environmental pressures. Horizontal gene transfer can allow new genes to proliferate in a microbial community assuming the gene is successful in the organism is "born" in.

• *What relationships can be inferred between prokaryotic abundance, diversity, and metabolic potential based on the information provided in the text?*

High abundance allows for high diversity by increasing the potential for mutations and simultaneous mutations.
Metabolic potential is dependent on both abundance and diversity. Diversity determines the pool of available genes to be used in metabolic pathways and abundance determines the magnitude of the effect of these pathways.