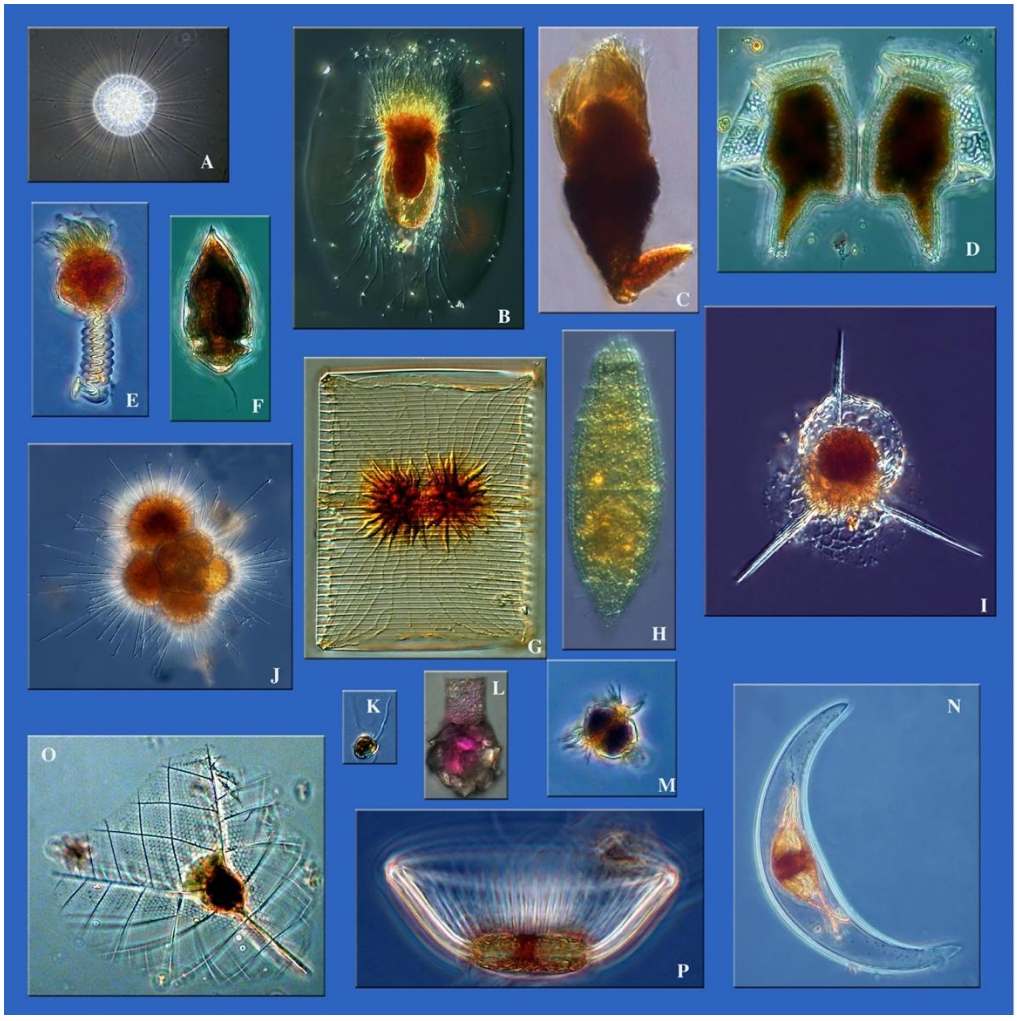
A child-centric microbiology education framework

Protists

Are there microscopic animals?



Protists have diverse shapes and sizes that do not always give clues about how they make a living or survive. Among those in this panel that use photosynthesis, as plants do, are G (Striatella), K (an unidentified haptophyte alga), P (Planktoniella) and N (Pyrocystis). Those here that feed on bacteria and small algae are F (Oxytoxum), A (Actinophrys), B (Cystidium), E (a Vorticella), H (Tiarina), I (Lophophaeana), L (Codonellopsis) and O (Callimitra). Some protistes use photosynthesis and can also eat other organisms, just like carnivorous plants. Examples of these are C (Tontonnia), D (Dinophysis) and M (Mesodinium) - and possibly even K (some haptophytes can eat and others do not). Images from John Dolan (U. Paris, Villefranche).

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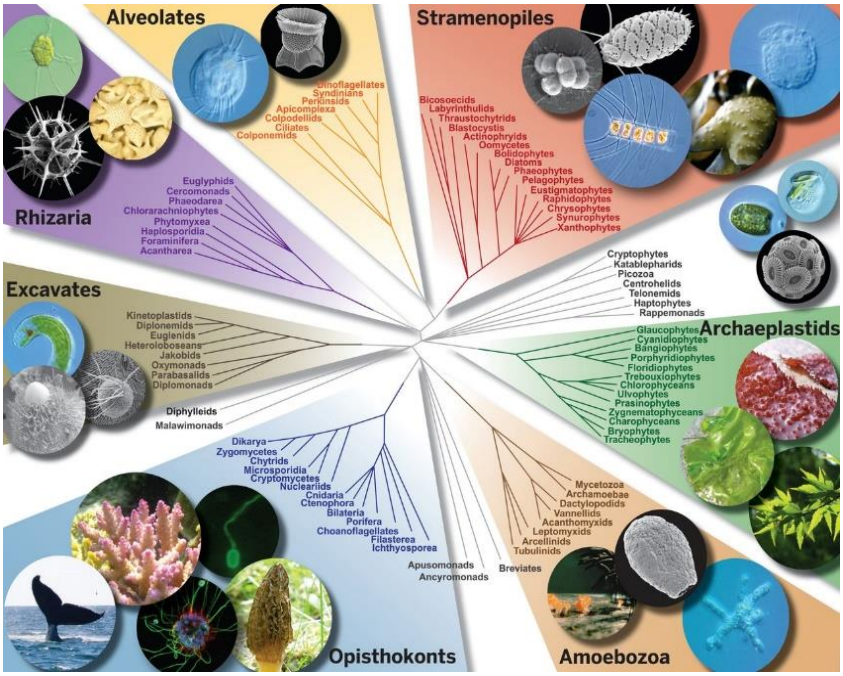
A child-centric microbiology education framework

Storyline

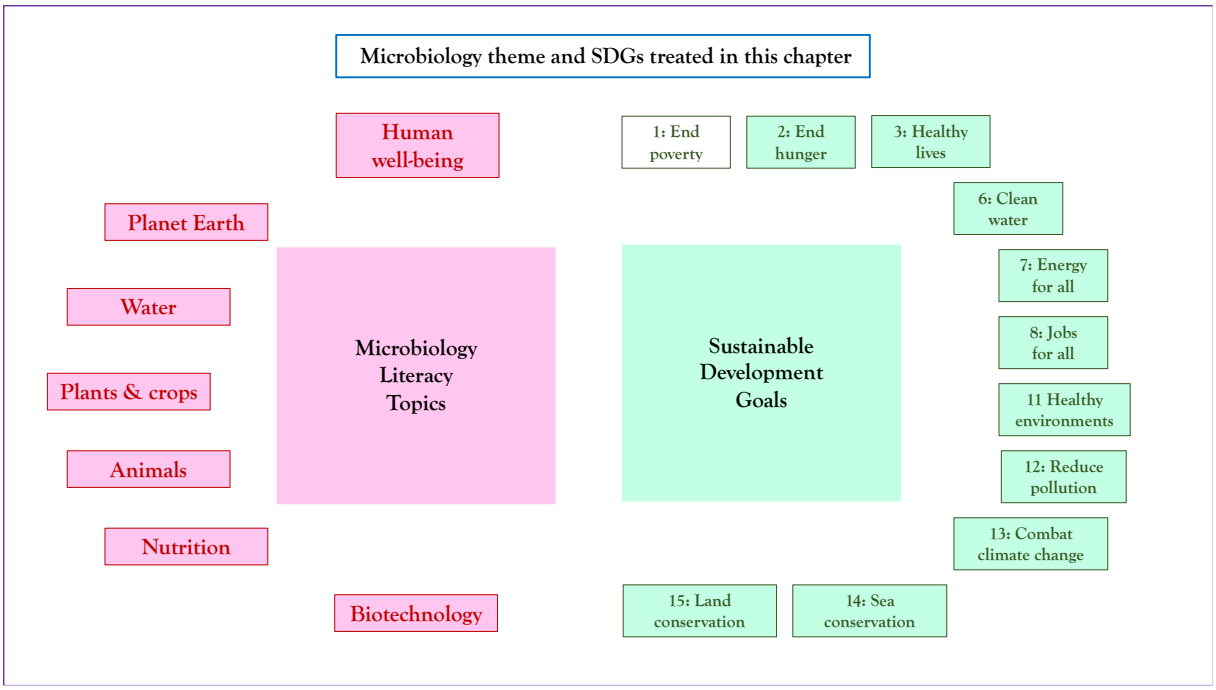
Animals are multicellular **eukaryotes** that form their own group, Animalia. There are some microscopic multicellular animals, such as Tardigrades that are ~1.5 mm long, dust mites, spider mites, some small copepods and small crustaceans. But there is also a huge diversity of microscopic single-celled organisms that are also eukaryotes, that we call **protists**. Protists display both plant- and animal-like characteristics as well as a mixture of both…and even other characteristics that are not common to plants or animals. Protists come in diverse shapes and many are beautiful to look at. Protists are found in soils, freshwaters, **brackish**, and marine environments, and even in air. The diversity of protists is really amazing! Most protists are single cells, but there are a few unusual exceptions, such as the multicellular red algae (plant-like) and choanoflagellates (animal-like). Protists constitute the majority of lineages within the eukaryotic tree of life.



Schematic of the major lineages of eukaryotes based on phylogenetic analyses of several genes, morphology, and phylogenomic analyses. Colored wedges show seven "supergroups," all of which contain multiple protistan lineages. From Worden et al. 2015.

The Microbial and Societal Context

The microbiology: contributions to global photosynthesis and carbon and other nutrient cycling in aquatic and terrestrial ecosystems, food web connection between other microorganisms and Metazoa, participants in beneficial symbioses and causative agents in human (and other animal) diseases) as well as plant diseases, and even diseases of other protists! *Sustainability issues*: health; food and energy source; clean water; healthy environment and pollution cleanup; help combat climate change; economy; and employment.

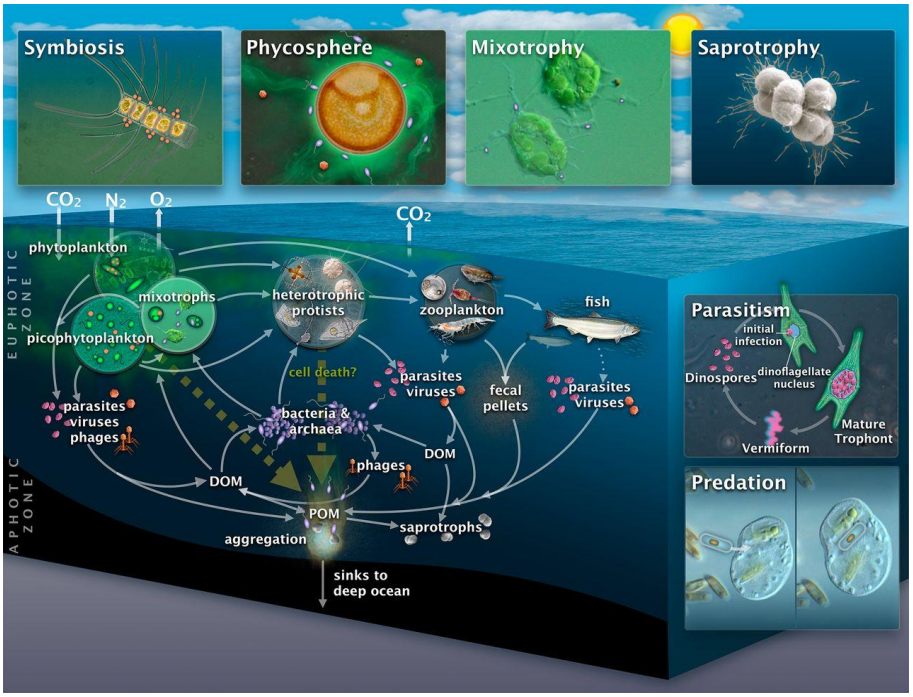


Protists: the Microbiology

1. ***Protists are important to aquatic and terrestrial food webs on planet Earth.*** **Heterotrophic** protists consume Bacteria, Archaea and other microbial eukaryotes, and in turn, they and autotrophic (photosynthetic) protists are food for larger protists and **Metazoa**, which includes tiny multicellular, and progressively larger animals. They perform diverse roles in ecosystems (see Box). Some protists consume small bits of organic material for food, some absorb nutrients from dead organisms, some have chloroplasts and can make their own food using **photosynthesis**, and some are **parasites** of other microorganisms or of plants or animals, including juvenile fish and humans! Some protists can even contribute to the breakdown of toxic chemicals in the environment.

2. ***Protists help influence our atmosphere, and are affected by climate change.*** Photosynthetic protists, are comprised of a diverse set of different lineages with very different evolutionary histories – but all of them consume carbon dioxide and contribute oxygen to our atmosphere. **Respiration** by protists (mostly by heterotrophic protists, but photosynthetic protists also respire a small amount) produces carbon dioxide and other greenhouse gases. As climate change increases average water temperatures it changes different marine ecosystems in different ways. For example, warming can cause regions of oxygen-depletion in aquatic systems to expand, changing the composition of microbial communities toward microorganisms (including protists) that can live in the absence of oxygen. These altered communities carry out different metabolic processes, and this can have major impacts on biogeochemical **nutrient cycles**. Some protists are causative agents in toxic algal blooms. When water temperatures rise and when excess nutrients are present, protists can reproduce quickly, coloring the water with their abundant cells. In some cases, these bloom protists produce toxins that poison other organisms, including fish and shellfish. If humans eat those fish, they can become sick. In some open ocean regions, the

warming of the surface ocean is predicted to make nutrients less available and organisms to be trapped in surface sunlight levels for longer. This will also change the types of protists and bacteria that can grow in these environments. Healthy ecosystems that support an oxygenated atmosphere depend on protecting diverse microbial (including protists) communities.



Diverse roles played by protists in the marine environment as an example. Similar roles are played in other ecosystems. From Worden et al. 2015.

3. ***Protists are important to plant, human, and other animal health***. Some protists are **pathogens** of plants and animals. For example, even clean-looking water has microorganisms in it unless it has been filtered or chemically treated to remove them. Drinking untreated, or unfiltered water from a lake, stream or pond or spring that may appear clean, but has been contaminated by feces of animals can transmit pathogens including protist parasites such as *Giardia lamblia* that can cause disease in humans and other animals. In the summer, when water temperatures are higher, microorganisms (including the not-so-nice ones) can multiply quickly. This is why communities regularly test the water quality at public swimming locations to make sure you are safe. On the more positive side, many are beneficial partners in **symbioses** with other organisms, for example some microorganisms that live in the guts of animals help them digest their food. There are protists that control the growth of some pathogens, including controlling some toxic algae.

4. ***Protists provide nutrition***. Protists and other microorganisms are at the base of all food webs. In all habitats they provide an important food source for small Metazoa, such as, copepods (small crustaceans that live in almost all aquatic habitats, e.g., *Calanus*) and nematodes (roundworms), as well as juvenile fish, molluscs (e.g., clams and snails), and even whales, some of the largest creatures on Earth, for whom protist **phytoplankton** are a major food source! Humans

consume various algae as a source of protein, vitamins and fiber, such as red algae and green algae. Some protists are involved in symbioses within the guts of animals and help digest plant material consumed by their host, thus providing critical nutritional benefits. On a less positive note, protist parasites can be detrimental to fish and other animal food species important to humans.

5. ***Protists have biotechnological uses***. Despite the significance of protists for understanding evolution of life on Earth and their diverse roles in food webs and biogeochemical cycles, little is known about their cell biology. New tools to genetically modify diverse protist species have just been developed and will help us to understand the vast portions of their genomes with unknown function. Some protists are useful because they produce **secondary metabolites** of medical or industrial importance. For instance, the metabolite euplotin C, with anticancer activity, is extracted from the ciliated protist *Euplotes crassus*. There are many other drugs of protist origin approved by the FDA, including Cytarabine, Vidarabine, Ziconitide, ethyl extracts of various omega-3 fatty acids, Trabectedin, etc.

Relevance for Sustainable Development Goals (SDGs)and Grand Challenges

Protists are relevant to several SDGs (microbial aspects in italics), including

- **Goal 2. End hunger through increased food security and use of sustainable harvesting and agriculture** *(provide food security and improved nutrition and promote sustainable food resource management)* Red algal protists (predominantly marine species) include species that are important food crops for humans (e.g., Nori in Japanese cuisine). Efforts to farm these algae as a food crop are increasing worldwide because they are valuable source of protein, vitamins and fiber that can be sustainably cultured and harvested. The gelling agent agar/carrageenan used in various popular foods and car (e.g., puddings and ice cream) also comes from red algae. Protists parasites of plants and animals can have negative impacts on food crops and so care must be taken to grow plant and animal foods in ways that protect them from these pathogens. This often means growing food in a more sustainable, less intensive fashion. For example, protist parasites of plants such as oomycetes can destroy food crops. Farmers must practice good land management to avoid problems, by rotating crops, to avoid having to use chemicals to control them and other pests.
- **Goal 3: Ensure healthy lives** *(improve health of humans through a healthier environment, reduce preventable diseases, fundamentally important members of microbiomes)* Protists are important members of the soil microbiome, and of the microbiomes of many organisms. Beneficial protists are increasingly recognized within the microbiomes of many species. Examples include the human gut and the gut of other non-human primates, insects, nematodes, and ruminants. Photosynthetic protists contribute almost 50% of the oxygen in our atmosphere. They are critical to the healthy function of all food webs (including all the fish we eat!) of importance to humans. Medicines used in treatments of ulcers, high blood pressure and digestive problems come from protists. Red algal protists are an important nutritional source protein, fiber, and vitamins. Protist parasites of animals grown for

human consumption such as, *Toxoplasma, Cryptosporidium, Giardia*, and *Entamoeba* can cause health problems for those animals and for the humans who eat the meat, if it is improperly cooked. Animal wastes that contaminate drinking water can contain parasitic protists that can sicken humans.

- **Goal 6: Ensure the availability and sustainable management of clean water for drinking, bathing, and recreation** *(reduce pollution that causes unwanted, and sometimes toxic blooms of microorganisms, reduce contamination of drinking water from animal feces, improve water sanitation management)* Water with excess nutrients from sources such as fertilizers, septic systems, and fossil fuel burning can cause blooms of photosynthetic protists that lead to **eutrophication**, causing waters to smell and to be unappealing to swim in. The use of fertilizers and burning of fossil fuels needs to be reduced, especially close to water bodies where they contribute too much nitrogen and carbon. Inadequate septic systems in coastal areas and around lakes and ponds need updating or replacement with sewers. Clean drinking water is a precious resource. Drinking water must be filtered or chemically treated to remove/kill microorganisms that make humans and other animals sick. Protist parasites that live in animal guts, such as *Giardia lamblia*, are excreted with animal feces. If animal feces are not disposed of properly, or in the case of large feedlots where cows and other animals are held prior to slaughter, these parasites can contaminate groundwater and drinking water, sickening those who drink it. If humans reduced their consumption of meat by growing more plant protein sources, contamination of freshwater sources from animal wastes would be reduced.
- **Goal 7: Ensure access to affordable and sustainable energy for all** *(increase our use of sustainably-harvested biofuels)* Protists are sources of **biofuels**. Diverse algal and other photosynthetic protists grow in a wide range of aquatic environments, including freshwater and saline are sources of fatty acids (lipids) being explored as sources of biofuels. This includes microbial green algae that grow quickly, and produce energy rich lipids. *(note that cyanobacteria are also common sources of biofuels, but cyanobacteria are not eukaryotic algae, they are a class of photosynthetic bacteria).* Other photosynthetic protist species such as *Euglena gracilis* are also being explored as potential sources of lipid-rich biofuels.
- **Goal 8: Promote sustained, inclusive economies that provide decent jobs for all** *(promote healthy economies while developing sustainable industries and creating jobs)* Increased interest in aquaculture of algae (currently primarily the red algae, e.g., *Palmaria palmata*) for food, as well as investigations of diverse algae for sources of biofuels is creating jobs.
- **Goal 11: Restore damaged environments and protect healthy environments** *(biodiversity and clean habitats are the foundation of healthy environments)* Human health depends on clean waters, clean air, and healthy food produced without the use of excessive chemicals. The beauty of our natural world depends on preservation of the diversity of life found in different habitats. This **biodiversity** includes macrofauna that people are familiar with (deer, coyotes, squirrels, birds, insects, trees, flowers, etc.) and also critical microbial communities that include protist populations. All animal life on Earth depends on healthy microbial communities for survival.
- **Goal 12: Eliminate pollution by promoting sustainable consumption, recycling, and waste disposal** *(achieve sustainable production and consumption practices, reduce waste*

production and release of pollutants into the environment) Protists have diverse metabolic capabilities, and they are important for helping to restore ecosystems that have been damaged by pollution. Examples include the demonstration of enhanced degradation of **hydrocarbons** in marine sediments and increased degradation of toxic trichloroethylene (TCE) in contaminated aquifer environments, when protists are present. The use of living organisms to reduce or eliminate pollutants is called bioremediation. Protists are also important components of microbial consortia used to bioremediate slaughterhouse and sewage wastewater. Algal turfs (mats of algae) have been used to successfully remove most nitrogen and phosphorus from manure runoff and sewage treatment plants. There is lots we can do to reduce pollution – including reducing the use of plastics, which are made from fossil fuels and are making their way into every part of the environment and food chain. Compounds in plastics can even mimic hormones in animals and shift their biochemistry and sexual developments.

Red tide in San Diego, CA, USA. The phytoplankton cells that cause red tides capture sunlight needed for their growth and reproduction using pigments that look red to the human eye (like here), or from brown to bright red, and even yellow, depending on the species. Photo by Kai Schumann, California Department of Public Health.

- **Goal 13: Understand and combat climate change** *(understand the impacts of climate change on food webs, understand sources and sinks of greenhouse gases, particularly* CO_2*)* Emissions of carbon dioxide into Earth's atmosphere is enhancing the "**greenhouse effect**" which leads to higher average water and air temperatures. Reducing our carbon dioxide and other greenhouse gas emissions is essential for protection of Earth's diverse habitats for future generations. A major source of carbon dioxide and other harmful gasses is burning of

fossil fuels (like gasoline, oil) for energy (e.g., industry, power generation, automobiles). While photosynthetic organisms including aquatic protists take up significant amounts of carbon dioxide, they cannot keep pace with emissions.

- **Goals 14 and 15: Conserve and sustainably use sea and land resources** *(reduce pollution, habitat destruction, and release of toxic chemicals and wastes into the environment, understand bioremediation and its potential for helping to clean up toxic releases)* Conservation of ocean and terrestrial (including freshwater) ecosystems is critical for a healthy environment and for sustaining food webs of major importance to humans as well as the beautiful habitats that we and other creatures enjoy. Protecting sensitive ecosystems is so important because all organisms, even protists, have their role in the food web, and polluted or destructed ecosystems lose diversity and therefore their resilience or ability to meet future challenges.

Potential Implications for Decisions

1. ***Individual***
   - ***a.*** Should I drink this stream water without filtering it or not? (do the potential negative personal health effects outweigh the benefits of drinking this cool clear water?)
   - ***b.*** Can my personal behavior (amount and type of consumables purchased, waste disposal habits, household waste treatment practices) impact water, soil, and air quality/health?
2. ***Community policies***
   - a. What are the local environmental consequences of polluting public water bodies with fertilizers, hazardous wastes, improperly functioning septic systems?
   - b. What are the health costs for communities without access to clean drinking water who may be exposed to microbial pathogens including protist parasites?
   - c. How could my community get engaged in aquaculture (farming) of beneficial algae for food?
3. ***National policies relating to water and air quality, hazardous waste disposal***
   - a. What kinds of laws should be enacted to control how household and industrial waste is disposed?
   - b. What polices can be established to protect rivers and streams from contamination from farm animal wastes?
   - c. What changes can be made to reduce inputs of nutrients into water bodies (rivers, streams, lakes, ponds, coastal areas that cause eutrophication?
   - d. What can be changed to reduce production of greenhouse gases that contribute to global climate change?
   - e. What types of lessons can be added to science courses to help people understand the importance of tiny microscopic organisms at the base of food webs in every ecosystem on Earth?

Pupil Participation

1. ***Class discussion about drinking water and possible sources of contamination***

2. ***Student awareness about protists***
    a. There are beneficial protists and protist pathogens. Give examples of both and where they would be found
    b. Can you think of things that can be done to improve water quality and therefore ecosystem health of lakes, streams, the ocean?
    c. Can you think of things that you can do to reduce the waste that you produce, including releases of greenhouse gases like carbon dioxide?

The Evidence Base, Further Reading and Teaching Aids

1. Algal biofuels: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3152439/
2. Margulis, L., Sagan, D. *Microcosmos Coloring Book,* ISBN-13: 978-0156594301, ISBN-10: 0156594307
3. Chapman, R.L. 2010. Algae: the world's most important "plants" – an introduction. *Mitig Adapt Strateg Glob Change* 2013 18:5-12 DOI: 10.1007/s11027-010-9255-9, available with free access at https://link.springer.com/article/10.1007/s11027-010-9255-9
4. New York Times 2019: Climate Change: The biggest climate stories you might have missed – but still have time to read. Many links to stories of interest to students. https://www.nytimes.com/interactive/2019/12/13/climate/year-in-review.html
5. Worden, A.Z., Follows, M.J., Giovannoni, S.J., Wilken, S., Zimmerman, A.E. 2015. Rethinking the marine carbon cycle: Factoring in the multifarious lifestyles of microbes. Science 347:1257594, DOI:10.1126/science.1257594
6. Carpi, S., Polini, B., Poli, G., Barata, G.A., Fogli, S., Romanini, A., Tuccinardi, T., Guella, G., Frontini, F.P., Nieri, P., Di Giuseppe, G. 2018. Anticancer activity of Euplotin C, isolated from the marine ciliate *Euplotes crassus*, against human melanoma cells. *Mar Drugs* **16**:166, DOI:10.3390/md16050166
7. "Introduction to the Rhodophyta, The red "algae"" https://ucmp.berkeley.edu/protista/rhodophyta.html
8. Wells, M.L., Potin, P., Craigie, J.S., Raven, J.A., Merchant, S.S., Helliwell, K.E., Smith, A.G., Camire, M.E., Brawley, S.H. 2018. Algae as nutritional and functional food sources: revisiting our understanding. *J Appl Phycol* **29**:949-982, DOI:10.1007/s10811-016-094-5
9. "Pathogenic Protists" Lumen Biology for Majors II, https://courses.lumenlearning.com/wm-biology2/chapter/pathogenic-protists/
10. "Parasitic Protists" Tree of Life Web Project, http://tolweb.org/accessory/Parasitic_Protists?acc_id=53
11. Stensvold, C.R. 2019. Pinning down the role of common luminal intestinal parasitic protists in human health and disease – status and challenges. Parasitology 146:695-701, http://tolweb.org/accessory/Parasitic_Protists?acc_id=53

Glossary

Biofuels: Renewable energy sources made from organic matter or wastes.
Biodiversity: The number of different species living in an ecosystem
Biosynthesis: production of complex molecules within living organisms or cells
Brackish: water that has some salt in it but less than seawater
Eukaryotes: Organisms consisting of a cell or cells with DNA contained in a nucleus, and having other membrane-bound organelles
Eutrophication: A process where excess nutrients in a water body cause dense growth of plants or algae, and as this growth dies and sinks, its degradation by microorganisms removes oxygen from the water, killing many animals and plants.
Genetic tools: methods developed to manipulate the genetic content of an organism. These tools can include moving new DNA into a cell, knocking out (removing), or replacing one stretch of DNA sequence with a different sequence.
Greenhouse effect: the trapping of the sun's heat in the planet's lower atmosphere due to the greater transparency of the atmosphere to incoming visible radiation from the sun than to reflected (outgoing) infrared (heat) radiation emitted from the planet's surface. Increased CO_2, water vapor, methane, and other gases in Earth's lower atmosphere trap this heat
Heterotrophic: an organism that cannot make its own food by fixation of carbon dioxide, and gets its nutrition from other sources of carbon
Hydrocarbons: compounds consisting of carbon and hydrogen, such as any of the components of petroleum and natural gas
Metazoa: a major division of the animal kingdom comprised of multicellular animals with differentiated tissues
Nutrient cycles: cycles of movement and exchange of organic and inorganic matter between organisms and the environment involving metabolic pathways within organisms
Parasites: organisms that live on or inside of other species (their host) and benefit by deriving nutrients at the expense of the host
Pathogen: an organism that causes disease
Photosynthesis: process by which some organisms use sunlight for energy to synthesize food from carbon dioxide and water
Phytoplankton: Microorganisms in aquatic food webs that provide food for a wide range of other taxa, contain chlorophyll or other photosynthetic pigments, and require sunlight to live and grow.
Protists: eukaryotes that are not animals, land plants, or true fungi
Respiration: a process in living organisms whereby one molecule is used as an electron donor (such as glucose for humans) and another as an electron acceptor (such as oxygen for humans) in a pathway that produces energy (ATP). Note: respiration does not have to involve the use of oxygen!
Secondary metabolites: organic compounds produced by bacteria, fungi, or plants that are not directly involved in the organism's growth, development, or reproduction, but can include molecules used as chemical weapons against other organisms, transporters, agents of symbiosis, sexual hormones, chemical signals, and differentiation effectors.

Symbiosis: an interaction between two different species living in close physical association with one another.