

Productivity & Plankton - Tutorial Script

What autotrophs support the largest food web in the world? Single-celled planktonic marine autotrophs, such as diatoms, dinoflagellates, coccolithophores, and bacteria. These organisms provide 90-96% of the ocean's photosynthetic sugar production. And the ocean food web is the largest food web in the world. That means these organisms support the majority of the world's ecosystems.

Let's review what all photosynthesizing autotrophs on our planet have in common: **chlorophyll**. Chlorophyll is a green pigment - which means it absorbs all light colors except green, which it reflects. There are a number of different types of chlorophyll pigment, but all photosynthesizing autotrophs have at least one of them. This is a problem for organisms that live in the deeper coastal ocean environment where only green light is available. Since chlorophyll will not capture this green light, another pigment is needed to do so. We call these extra pigments, **accessory pigments**, and we use the color of these pigments, as well as other differences, to classify the multicelled seaweeds that live in the coastal environment. Brown algae includes kelp, such as in this picture, and they contain brown accessory pigments. Red algae contain red accessory pigments, and green algae contain only chlorophyll, but a number of different types. Net result? Green algae cannot survive in the deeper coastal ecosystems, because they require light other than green. They are typically found in the highest levels of the intertidal environment. Red algae dominate the middle intertidal zone, and brown algae, the lower zone. Plants also have only chlorophyll, but because they have the added challenge of roots and need to get their nutrients and water through these roots, they are relegated to the upper intertidal zone and consist only of grasses and mangrove trees.

These multicelled marine autotrophs - plants and seaweeds - account for only 4% to 10% of the marine photosynthesis - remember most of it comes from the single-celled organisms. Let's review some of those important organisms, starting with bacteria.

Marine bacteria are single-celled prokaryotes with no nucleus and the simplest cell structures. However, they play a number of important roles in the ocean. In addition to photosynthesis, they also act as decomposers and nitrogen fixers. The dominant form of nitrogen in the ocean is nitrogen gas - a form that is unusable by most marine organisms. That gas has to be converted first into nitrate ions, before it can diffuse into an autotroph and be used for growth. It is a limited, but very important nutrient.

Of the remaining single-celled photosynthesizing autotrophs, three important ones are diatoms, coccolithophores, and dinoflagellates.

Diatoms are single-celled Protista with a siliceous shell made of SiO_2 . They come in a number of different shapes and sizes, including centric and pennate forms as well as pillows and chains. Chains are made up of centric diatoms that connect together into larger units. These larger units can be ramrod straight, curved, or completely balled up. The protrusions you see in these pictures of diatoms from San Francisco Bay are glass spines they use, among other things, to increase their surface area and help themselves stay afloat, as most diatoms are planktonic. Shells of dead diatoms that have collected on the seafloor contribute greatly to siliceous oozes.

Coccolithophores are single-celled Protista with a calcium carbonate shell made of many donut-shaped plates. They have two flagella they use to move around and a haptoneme they use to capture nutrient molecules. They, too, are planktonic, and their shells contribute to calcareous oozes on the seafloor.

Dinoflagellates are single-celled Protista with no shells. Most dinoflagellate species are autotrophs, but there are also some that are heterotrophs. They have a thick cellulose outer cell wall and two flagella that they use to change their direction in the water. As they cannot swim faster than currents, they are also referred to as plankton. Because they have no shells, they do not contribute to seafloor oozes or sediment.

Pause now.

Plankton can be subdivided into autotrophic plankton, referred to as **phytoplankton**, and heterotrophic plankton, referred to as **zooplankton**. Diatoms, Coccolithophores, and Dinoflagellates are three important phytoplankton organisms found across the world's oceans.

Let's talk more now about photosynthesis. We can measure the amount of carbon produced daily by photosynthesizing organisms in a given area. We call the total amount produced **gross primary productivity**. If you subtract the amount of sugar that gets consumed, through respiration, by those same organisms to supply their own metabolic needs, including growth and reproduction, the result is called **net primary productivity**. Very similar to gross salaries and net salaries, which have had all the taxes and benefit contributions removed.

Is the amount of photosynthesis the same everywhere in the oceans? No. Why not? There are certain factors necessary for photosynthesis that are absent in many parts of the oceans. These factors limit photosynthesis in those areas, thus we call them **limiting factors**. The two largest limiting factors to marine productivity are sunlight and nutrients. Sunlight is present only in the photic zone, which can be significantly reduced by suspended sediment or high amounts of plankton in the water. Sunlight availability also decreases significantly in the poles during their winter months when some areas receive absolutely no sun. During summer in those same areas, there can be 24 hours of sun. What about nutrients? Nutrients are trapped at depth in areas where there are well-developed pycnoclines. Nutrients can return to the surface only when there is upwelling or river runoff. The pycnoclines form when surface waters warm so much they separate from deeper cold waters. That happens in the equatorial and tropical oceans all year round. It happens in the temperate latitudes in the summer. There is never a pycnocline at the poles because there's never enough sunlight there to produce one.

The **compensation depth** is the depth at which net primary productivity equals zero. It is also the base of the photic zone. It represents the lower limit of where autotrophs can survive in the oceans. Though photosynthesis can still happen below this depth, there's not enough light to produce enough sugar to provide the autotroph's own daily needs. The compensation depth increases in summer as the amount of direct sunlight hitting the surface increases. It decreases in winter when the sun appears for less time each day and at a shallower angle. Deepest photic zones and compensation depths happen when the pycnocline is most developed. Maximum sunlight, but minimal nutrients. In winter, we have the opposite, no pycnocline. Maximum nutrients, minimal sunlight.

Based on the availability of Sunlight and Nutrients, where would you expect productivity in the oceans to be high?

Productivity should be high in the Poles during the summer. Plenty of sunlight and nutrients. No pycnocline. The sudden presence of both limiting factors to an area often will precipitate a **bloom** or rapid growth of plankton, and high biological productivity. The summer plankton blooms at the poles are the largest in the world's oceans.

In the temperate oceans, productivity is highest in spring and fall. The pycnocline that develops in summer traps the nutrients at depth. The limited sunlight in winter diminishes productivity then. So only just before the pycnocline develops or just after it disappears, will both sunlight and nutrients be available in abundance. In temperate regions we get a large spring bloom and smaller fall bloom .

In equatorial and tropical oceans, where there is always a pycnocline, there will be no productivity in the waters. Unless... as previously mentioned, in areas of upwelling or river runoff, as long as sunlight is sufficient as well, biological productivity can be quite high.

We can use chlorophyll abundance to get an idea of general productivities. You'll see red and yellow, as the highest productivity, showing up along coasts near deltas and in the polar oceans during summer. Green, the next highest productivity, appears in areas of upwelling, such as where the North Atlantic Deep Water wells up north of Antarctica and in the eastern equatorial zones where the trade winds pull the surface waters offshore, such as off California and Peru and the west coasts of Africa. Productivity is low in the equatorial and tropical oceans. This image shows the chlorophyll concentration over a smaller area - just off of southwestern Africa. It demonstrates the high productivity that results from high nutrient runoff along the coasts.

Pause now.

Sometimes the blooms that are triggered by an influx of nutrients contain organisms that emit toxins that can kill other organisms. We used to call these “red tides,” but as they have nothing to do with the tide, now they are referred to as **HABs or Harmful Algal Blooms**. The primary culprits are some species of dinoflagellates and diatoms. Typically these organisms have a dark brown or reddish pigment, so they will cause the water’s surface color to change when they are present in high amount. Some of the toxins emitted by these organisms are neurotoxins that can cause paralysis or respiratory failure and can enter the animals through ingestion or inhalation of sea spray. It is for this reason that during an HAB, you should stay out of the water and close the shellfish industries in the area until the HAB has disappeared and the filter feeders have had time to eliminate the toxins from their system.

Natural and human-dumped toxins in the marine environment, such as pesticides and heavy metals, can be absorbed by autotrophs and then transferred up the food web to different trophic or feeding levels, accumulating in each level in increasingly greater and greater amounts. We call this **biomagnification**. These toxins accumulate in an organism because they are ingested faster than they can be expelled by the body’s natural waste processes.

In open ocean food webs, roughly 10% of the energy available in one organism is transferred to its consumer. The rest is lost in heat energy or waste material. There’s a lot of energy loss in this process AND a lot of accumulation and magnification of toxins.

We call the first level of this pyramid **trophic level 1** – the second – trophic level 2 – and so on. Coastal regions have a slightly higher energy transfer efficiency – 15%. Areas of upwelling are even higher – 20%. The lowest efficiency of transfer happens between sunlight and autotrophs at trophic level one. Only 2% of the energy available in the sunlight absorbed by chlorophyll is transferred to sugar production. 98% is lost. As this picture demonstrates, to support 1 average human body mass eating salmon, you’d need 10 times your body mass in salmon, which would mean 100 times your body mass in herring, which means 1,000 times your body mass in zooplankton and 10,000 times your body mass in autotrophs like diatoms. This image of a food web shows a more realistic view of eating habits where each organism eats meals from various trophic levels.

Pause now.

Much of the zooplankton includes larval organisms present only until they grow big enough to swim or sink and attach to the bottom or crawl away. These larval organisms include fish, crabs, clams, and sea cucumbers. We call organisms that live as plankton for only part of their lifecycle meroplankton. If an organism is planktonic through its entire life cycle we call it holoplankton – it spends its **whole** life as plankton.

Let’s highlight some examples of both, starting with some examples of meroplankton. This image shows the lifecycle of jellyfish. The adult form is planktonic and releases egg and sperm into the water column to reproduce. These get together in the planktonic environment and develop into a larval form that sinks to the bottom of the seafloor and attaches – now a benthic polyp. As the larvae evolve in this polyp form, they generate many buds that eventually release themselves and swim away back into the plankton world. Other examples of meroplankton include larval barnacles, such as this one, which when full grown will also sink to the seafloor, attach and become sessile benthic barnacles. And once a year coral reefs emit egg and sperm into the water column where they develop into larvae that sink to the bottom of the seafloor, and if the environment is right to develop a coral, a new coral reef community will form.

As for holoplankton, again, there are many different varieties. We’ve already discussed the diatoms, dinoflagellates, and coccolithophores of the phytoplankton variety. Now let’s explore four examples of zooplankton that spend their entire lives as plankton, starting with two single-celled protista – radiolaria and foraminifera. Both of these organisms contribute to oozes on the bottom of the seafloor – radiolaria with silica shells and foraminifera with calcareous shells. The shells, as you see in these images, can be quite spectacular with ornate designs, spines, and holes. The cell wall of these organisms can be extruded through these holes, like

bubbles, to engulf and trap prey, much like an amoeba. This picture shows a single-celled foraminiferan eating a multicelled copepod trapped on its spines.

Copepods are an important animal in the holoplankton community. They are arthropods, very similar to crabs, but spending their whole lives in small planktonic form. Like all arthropods copepods have an exoskeleton they must shed in order to grow. We call this process molting, and you can imagine that much of the detritus that falls to the seafloor will be composed of copepod molts. These organisms create currents that move water along their bodies and they use their cilia-covered appendages to filter food out of the water.

A complete list of heterotrophic holoplankton should also include nautiloids, ostracods, krill, arrow worms, tintinnids, and rotifers.

What about jellyfish? How do they fit in? Jellyfish are multicelled meroplankton. These cnidarians have tentacles that surround a single opening. Tentacles all have stinging cells, and the body creates a hollow pouch in which all food and waste are processed. Jellyfish are plankton because while they can move vertically through the water column, they cannot swim horizontally faster than currents, so they are at the whim of currents. There are many types of jellyfish in the oceans including common varieties like sea nettles and moon jellies. Some, like this variety shown here – By-The-Wind-Sailors – are made of communities of individuals that all grow together to create a single organism. These are part of a regular beaching event that can happen when large groups of these jellyfish get caught up in strong currents or winds and blown or pushed onto the beach.

Pause now.

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Produced by Katryn Wiese
City College of San Francisco

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*Coccolithophore morphology – P. Bown (Ed.), 1998, *Calcareous Nannofossil Biostratigraphy*. Chapman and Hall.

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