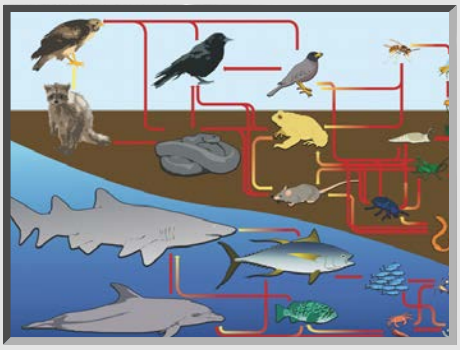
The Diving Environment

Dimensions & Cycles



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The Diving Environment
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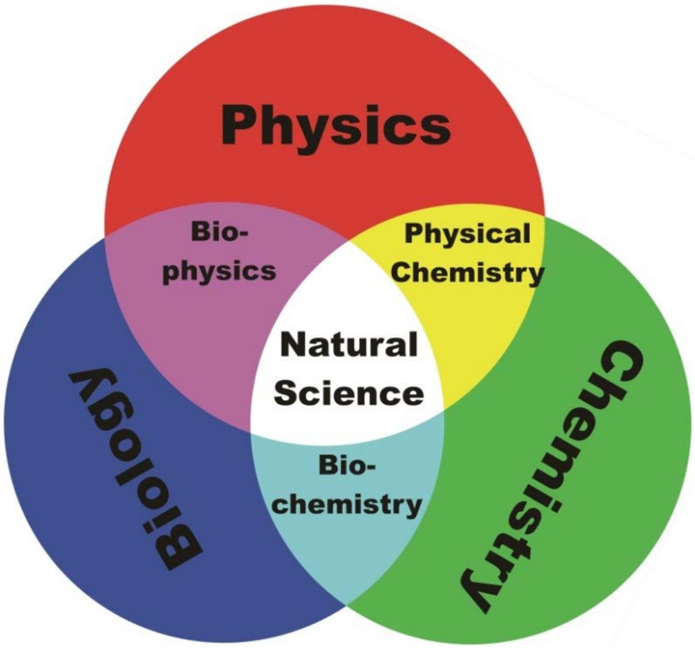
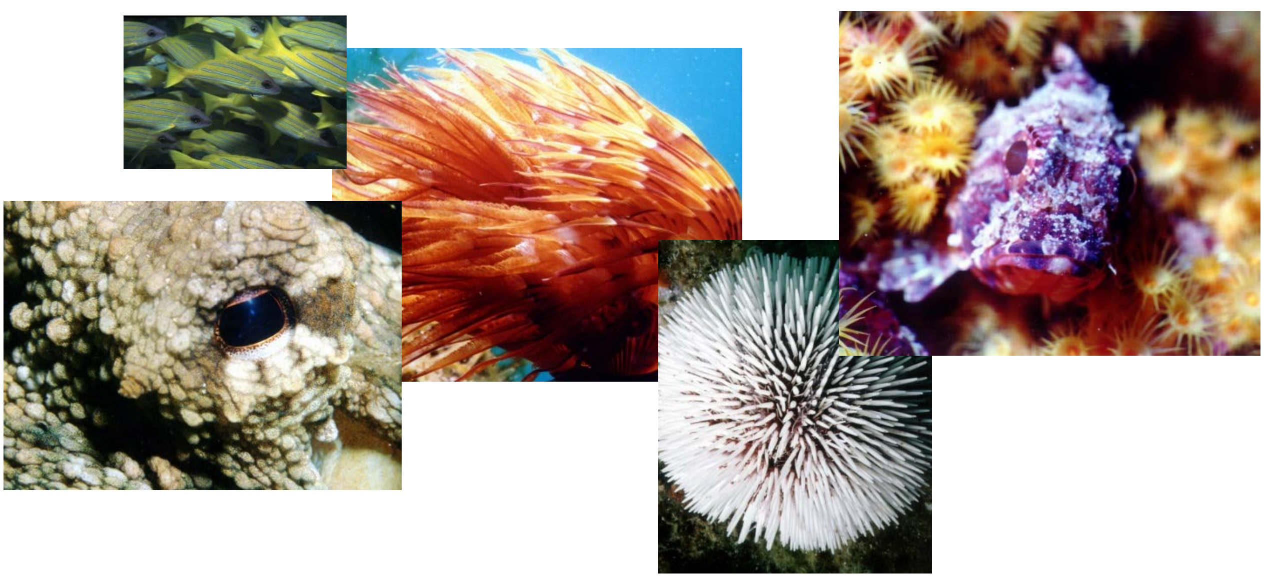


Enjoying the underwater environment is the most listed reason when people are asked why they dive. Since you cannot really enjoy what you see when you do not understand what you are looking at, diving becomes more interesting with every detail you learn with respect to the underwater world. Biology is the eye-catcher. Organisms varying in size, colour, body-shape and other features can be found in enormous diversity. They all look very different from the organisms found in a terrestrial ecosystem. To explain such differences we have to draw on notions from physics and chemistry. Understanding of the diving environment requires us to combine information from different disciplines of natural (or environmental) sciences. Such combination of disciplines has guided the writing of this book.

This book is used for three different courses. For participants in a naturalist course, the first two chapters are needed (Dimensions & Cycles and Naturalist). The naturalist course covers the different classes of organisms found in the aquatic environment and the relationships they have. For the Scuba Eco course, the first and third chapters (Dimensions & Cycles and Chemistry) are relevant. The Scuba Eco programme covers (invisible) challenges for the underwater environment, such as eutrophication and acidification. It addresses the impact the growing human population has on the aquatic environment. Participants in a research course need the last chapter (Research). Depending on the project they choose for the practical part of the course, they may need to draw on information from previous chapters.

Of course this book can also be used to improve your understanding of the underwater environment without participating in any of the above mentioned courses. As a diver you are an ambassador for the aquatic realm. The more you know, the better you can fulfil that role.

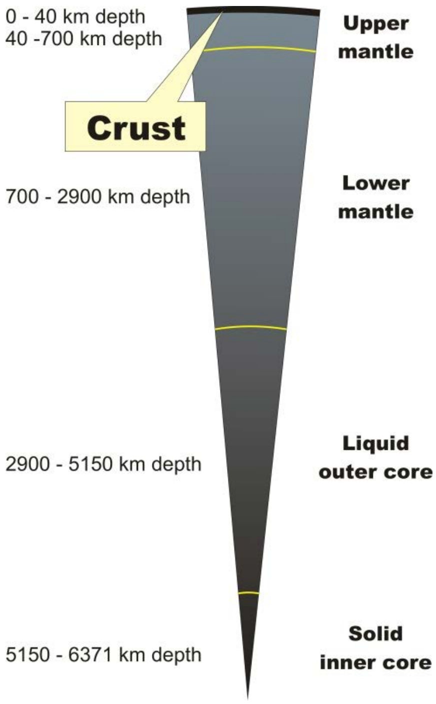


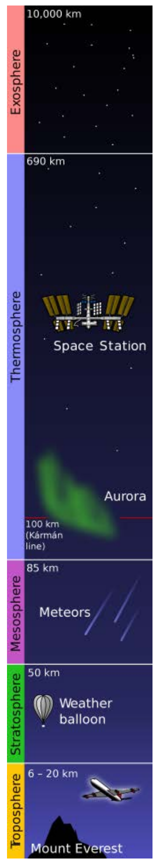
Dimensions & Cycles

For an understanding of the physical, chemical and biological characteristic of the underwater environment, it is often necessary to place your observations into “a bigger picture”. Processes taking place in nature are often influenced by factors or conditions that originate from great distance or from another “sphere”. Acid can end up in a lake because of industrial activity thousands of kilometres away. Plankton can bloom because of activities far up-river. In the same style, a storm in the desert on a continent can cause a plankton bloom in a faraway ocean.

Of course there are plenty of local interactions and processes that are more or less isolated, but before learning about the underwater environment in more detail, it makes sense to first cover the mentioned “bigger picture”. To do that, first the dimensions of the worlds “spheres” are covered, followed by some examples of environmental cycles. Specifically these are the energy cycle, the carbon cycle and a short introduction to the nitrogen cycle. Of course there are more than just these three. They are chosen as examples, because they can be well used to illustrate the need for balance.

Planet Earth and its Spheres



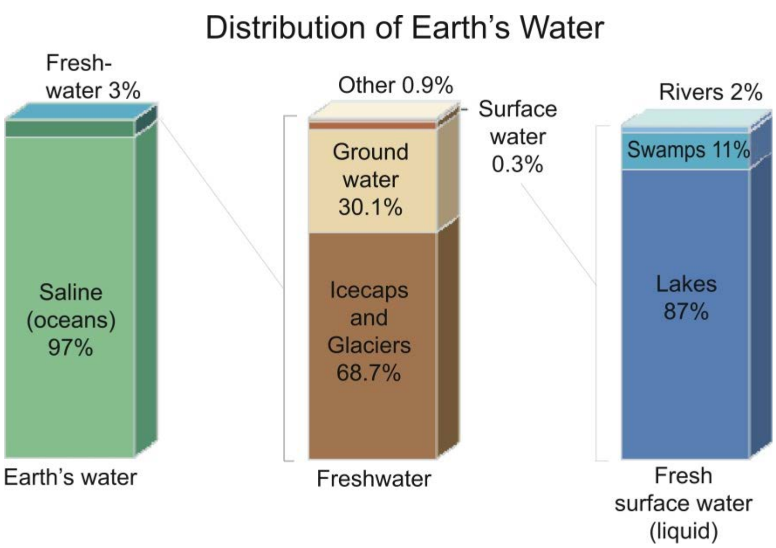


The biggest influences on the diving environment originate from the earth's crust and the atmosphere. The diving environment itself is part of the hydrosphere (the combined bodies of water). All three, the mantle, the atmosphere and the hydrosphere originate from release of material from within the upper mantle of the early earth. The name lithosphere is used to address the crust and the uppermost part of the upper mantle.

Interaction with the diving environment must be taken into account from the upper layer of the earth (the crust) and the lower layer of the atmosphere (the troposphere). The conditions in this region have been favourable for living organisms to develop. All living organisms together are referred to as the biosphere.

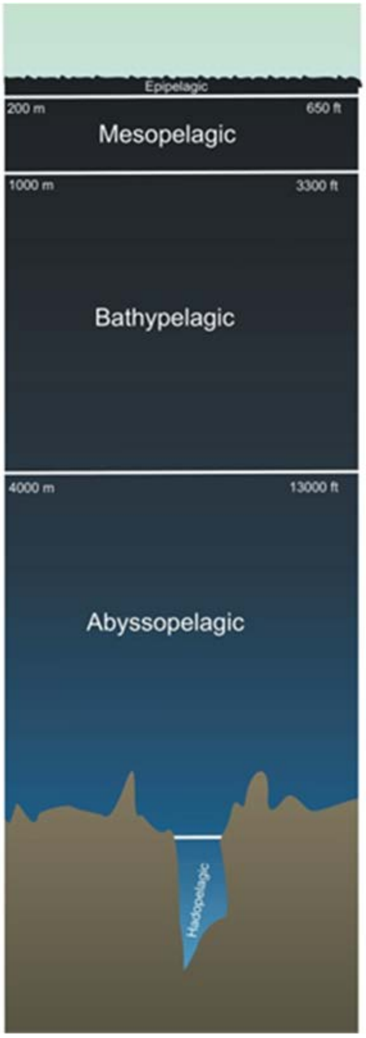
Interaction takes place at locations where the biosphere, the troposphere, the lithosphere and/or the hydrosphere are within the range of each other's influence. This zone of interaction is often referred to as the pedosphere. It is the sum of all organisms, soils, water and air. The pedosphere is the skin of the Earth and only develops when there is a dynamic interaction between the air (in and above the soil), living organisms, soils (and consolidated rock) and water in, on and below the soil. The pedosphere is the foundation of life on earth.

The Hydrosphere



Water covers 71% of the Earth's surface, and is vital for all known forms of life. 97% of the planet's water is found in oceans, 1% in groundwater, 2% in glaciers and the ice caps. A small fraction if stored in other large water bodies. 0.001% found in the air as humidity, clouds and precipitation. Only 3% is freshwater. 99.1% of this freshwater is stored in ice and groundwater. Less than 0.3% of all freshwater is found in rivers, lakes, and swamps. An even smaller amount (0.003%) is contained within biological bodies and manufactured products.

The ocean is deep. The deepest point is found in the Mariana Trench and is recorded to be around 10,950 metres. With a water column that big, it is logical to divide it in different zones. The simplest approach is to split the ocean (form surface to bottom) into two zones. Those are the photic zone, which



is exposed to sufficient sunlight to allow photosynthesis and the aphotic zone, where the quantity of light is not sufficient for primary production (or where there is no light at all).

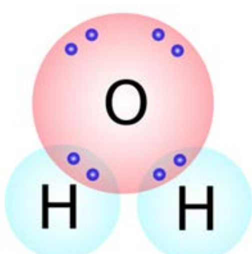
The photic zone largely corresponds with the epipelagic zone. This zone starts at the surface up to a depth of 200 metres. The mesopelagic zone (200 to 1,000 metres depth) would still allow some light to penetrate (this is why it is also called the twilight zone). It is not enough for photo synthesis at a sufficient rate to support an ecosystem, but the light would still be enough to allow some animals to be fluorescent.

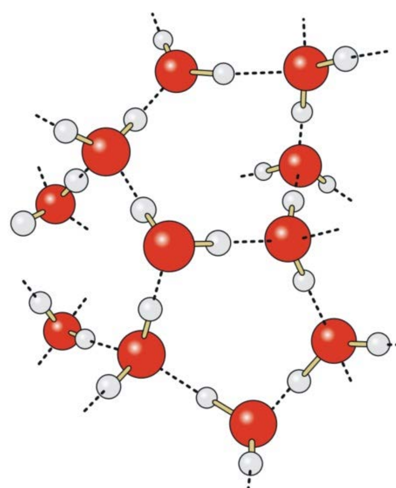
The bathypelagic zone (or midnight zone) is completely dark. It ranges from 1,000 to 4,000 metres depth. There is life, but far less than in the water layers above this zone. Some of the biggest whales descend to this depth to feed. No predators live in the zone, because they could not see their prey. In most of the ocean, the bathypelagic zone extends to the bottom (the benthic zone).

In deeper parts of the ocean, there is an abyssal zone. The name stands for "bottomless". Beyond the abyss, there is the hadal zone (or hadopelagic). Only the deepest trenches in the world belong to this designation.

The bottom, regardless on which depth it is, is the benthic zone. Organisms living in or on the bottom are called benthos. The benthic boundary layer – the zone where solid material meets the water column – has a big influence on biological activity. The boundary layer can be coral or rock, but can just as well be a sandy bottom or mud. The layer of water that is close enough to the bottom to be influenced by it is called the demersal zone. Fish living in the demersal zone are called demersal fish. Fish that live near the surface or in the middle of the water column are called pelagic fish.

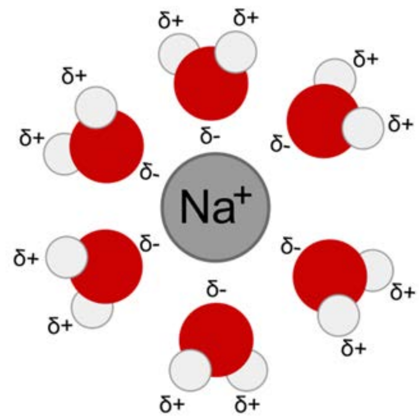
Why is Water Unique





Without water, life on earth would not be possible. Water fulfils several functions that do not only make life possible, but also have an enormous influence on the way the world and its inhabitants function. Water is referred to as H_2O, meaning it has one oxygen molecule and two hydrogen molecules. Oxygen has two electrons in its outer orbit, and hydrogen one. The oxygen and hydrogen share this total number of electrons in their outer shells, which results in two free pairs of electrons. This gives one side of the water molecule a "positive charge" and the other side a "negative charge. The charge forces water molecules into a structured pattern. This pattern has many consequences, giving water its unique characteristics.

As virtually with all liquids and gases, water becomes denser as it becomes colder. We know this as divers, because the warmer layers of water are found close to the surface, while colder water is found "under the thermocline". Water starts behaving differently once it is cooled to a temperature of about 4° Celsius. At that point it changes its behaviour. When water is cooled further down to ice, it expands to occupy about 9% more space then water of 4° Celsius (which is liquid). This explains how ice can float on water and why only "the tip of the iceberg" is above water. If water would behave "normal", ice would sink to the bottom, where it would most probably stay in its solid form because it would be beyond the reach of the energy of the sun.



Due to the polar characteristics (different charge at opposite sides), water is a good solvent. Salt (NaCl) can serve as an example. When in water, salt splits into a positively charged Na^+ and a negatively charged Cl^- ion. The water molecules then position themselves around these ions (molecules with an electron too much or too little, giving them a "charge"), making them part of the structure of the liquid. Molecules that dissolve in water are named "hydrophilic". Molecules that do not dissolve in water are named "hydrophobic". Salts, sugars, acids, alkalis and gases such as oxygen and carbon dioxide are hydrophilic. The major components of the cells in the human body, such as DNA and proteins) are also hydrophilic. Fats and oils are hydrophobic. As a result, spilled oil does not dissolve, but either float at the surface where it is a danger for birds and washes up at shorelines, or sinks to the bottom where it provokes abundant bacterial activity.

Another consequence of the polar characteristics is a strong attractive force between the individual water molecules. This gives water a high surface tension, and with that a capillary force. Capillary action means that water tends to move up against gravity when a tube (or similar shape) of small diameter is available. You probably know this from holding paper or a towel in a bucket of water. The water moves up the tissue. It is the same mechanism that allows groundwater to "rise" to the depth that can be reached by the roots of plants. Also plants and trees use this principle to allow transport of water to the higher parts (although plants have some additional mechanisms that play a role).

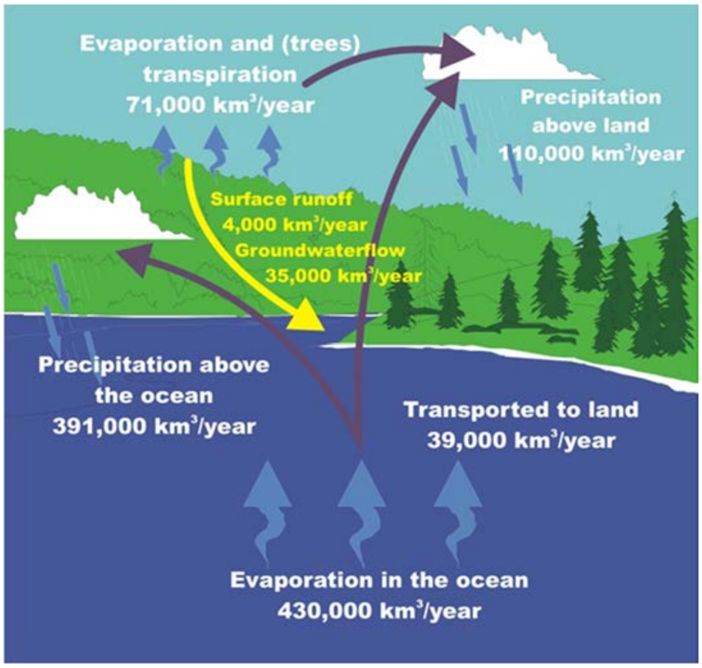
Water has both a high heat capacity and a high heat of vaporization. The heat capacity helps keep the climate in large parts of the world moderate. In warm regions (or in the warm season in the same region) water heats up and stores the related energy. This dampens the local climate. Land far away from sea experiences far more extreme temperature fluctuations than coastal zones. Water is transported over long distances, making heat energy from warmer areas available to temperate zones. The high heat of vaporization is important for cooling processes, including sweating. Molecules need more energy as a gas than as a liquid. By allowing a liquid to change its state from liquid to gas, it will result in evaporative cooling. The skin and vessels under the area where the water changes its state will release energy, resulting in a cooling effect.

The Water Cycle

Water is not confined to a single location, but takes part in the water cycle. However indirect that might be, eventually all water is connected. The world's seas and oceans are in direct contact, but also all fresh water will at some point return to the ocean where it came from.

The water cycle starts with evaporation. The quantities are enormous. A total water-volume of 501,000 km^3 per year is transferred to the atmosphere – most of it by evaporation, a smaller amount by transpiration from plants and trees. All this water will then precipitate. Of the 430,000 km^3 that evaporates each year from the ocean, 391,000 km^3 falls straight back in (as rain or other forms of precipitation).

The remaining 39,000 km^3 is transported in the atmosphere and ends up above land. There it is added to the 71,000 km^3 coming from evaporation on land and transpiration from trees. This brings the total annual precipitation above land to 110,000 km^3. To keep the cycle in balance, the 39,000 km^3 that were transported (via the atmosphere) from ocean to land must be replenished. This happens via surface runoff (4,000 km^3) and groundwater flow (35,000 km^3).



The fact that (eventually) all water is connected has consequences for many environmental (and political) issues. With only a limited amount of fresh water available, it is becoming a more and more valuable asset for the increasing world population. Most water using for consumption and for growing crops must come from runoff and ground water (the smallest flows in the water cycle). If one region takes more from this flow than its fair share, it could very well be a cause of major conflict. For the environment, it means that an increasing number of water bodies are strained beyond their capacity. This leads to lakes and rivers having a water level far below what was “normal” only one or two decades ago.

For the environment, the water cycle represents a “one way street” for pollutants. Although water evaporating from the ocean can carry some impurities with it, these are traces at best. The flow of groundwater and runoff carry large amounts of substances to the ocean. Also precipitation “cleans the air” of pollutants at the cost of the purity of the world’s oceans. It is true that the ocean is big. With an average depth of 3,790 metres and a surface of approximately 360,000,000 km^2, it has a volume of more than 1,300,000,000 km^3. In such a large volume even big quantities of pollutants can go unnoticed. There are limits to the amount of substances that can be introduced into the ocean without consequences. The rise in ocean acidity and the dead-zones developing in area’s such as the Gulf of Mexico and the Baltic Sea are alarming examples that will be covered in later sections of this book. Such examples become particularly scary when you realise that it is hardly (if at all) possible to retrieve substances from the ocean once they are in. It takes a long time before a threshold is reached, but once it is, there is no feasible way back.

The Energy Cycle

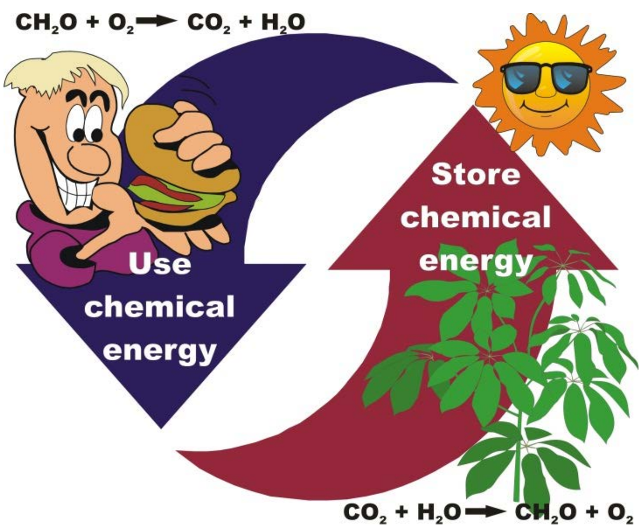
The formulas for primary production and consumption are (given in their most basic form only):

$$CO_2 + H_2O \rightarrow CH_2O + O_2 \text{ (for production)}$$

$$CH_2O + O_2 \rightarrow CO_2 + H_2O \text{ (for consumption)}$$

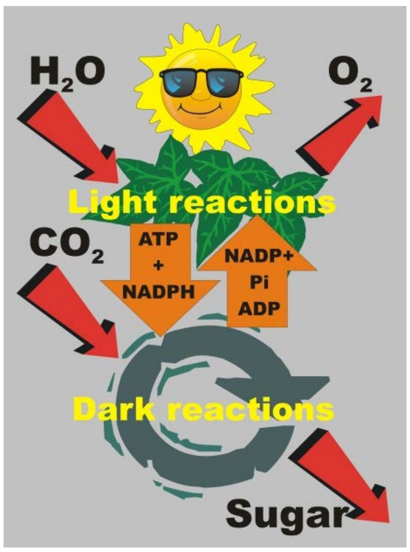
Primary producers are organisms that can make use of the energy of the sun to create molecules with a high energy content, which can be used elsewhere in the organism for life processes, such as reproduction, defence against physical challenges or pathogens, growth, etc. Some of the molecules are stored for later use or for the use of their offspring (fruit for example). Plants and algae (including phytoplankton) are primary producers.

Other organisms cannot produce their own energy and must eat energy rich food. Those that feed directly on primary producers are called herbivorous (plant eaters) and animals feeding of herbivorous species are called carnivorous (meat eaters). Some (like humans) have a mixed diet, which makes them omnivorous. Consumers drive the photosynthetic reaction in reverse to release the energy stored in the sugars. Don't forget that primary producers do the same – primary production only takes place in the upper layers (the green parts of the plant). In other regions such as the stem, they make use of the energy rich molecules they have produced themselves – after all – they did not store the energy for those who eat them. The intended use is for the plant's own needs.



Primary producers take in all they need from water, soil and air. The environment is their source of nutrients. Consumers depend on primary producers for all they need. Food is not only their source of energy, but also for other needs such as vitamins. If primary production cannot keep up with the speed of consumption, the cycle is disrupted and consumers will starve.

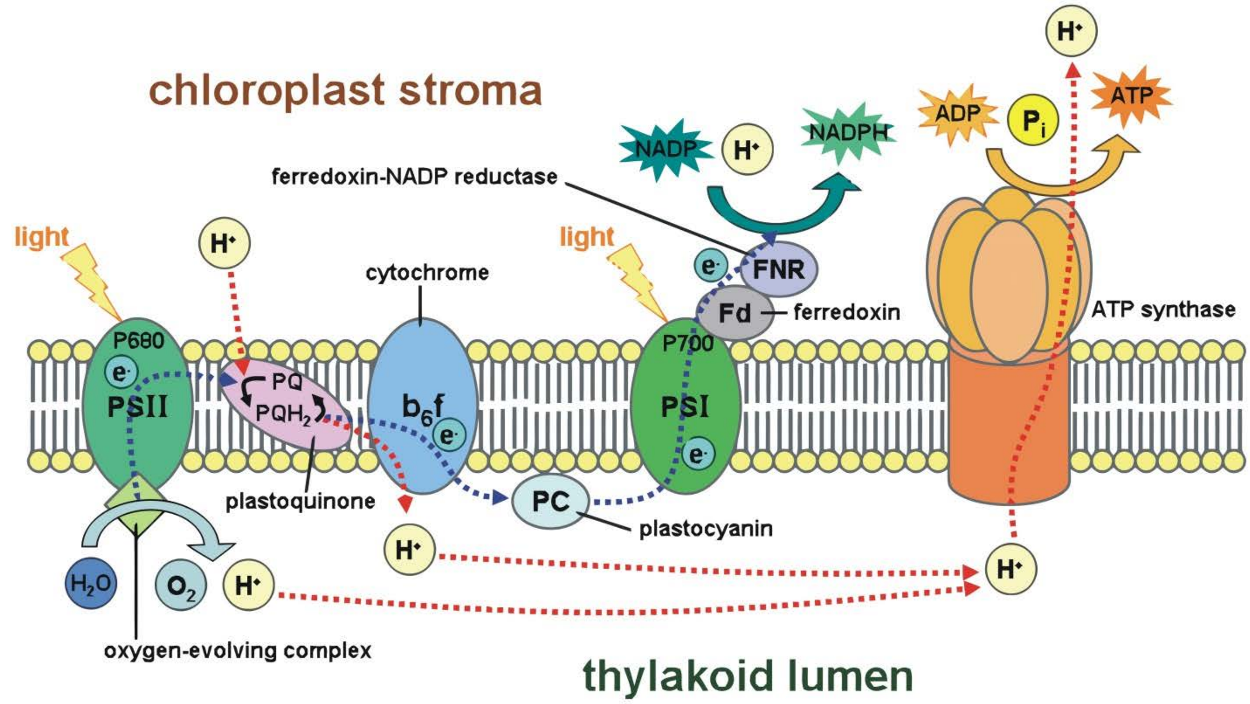
It is important to realize that the reaction of primary production and consumption mirror each other. If one reaction would run faster than the other, eventually the needed reactants would be depleted, because the other reaction cannot keep up. Another important point is the location of the reactants – it does not help a consumer in a city that plants in a rainforest produce an abundant amount of sugar. In the same sense, an algal bloom is a regional event – the local production exceeds the local consumption. Even when global production and consumption would be "in balance", local and regional cycles can be severely disrupted.



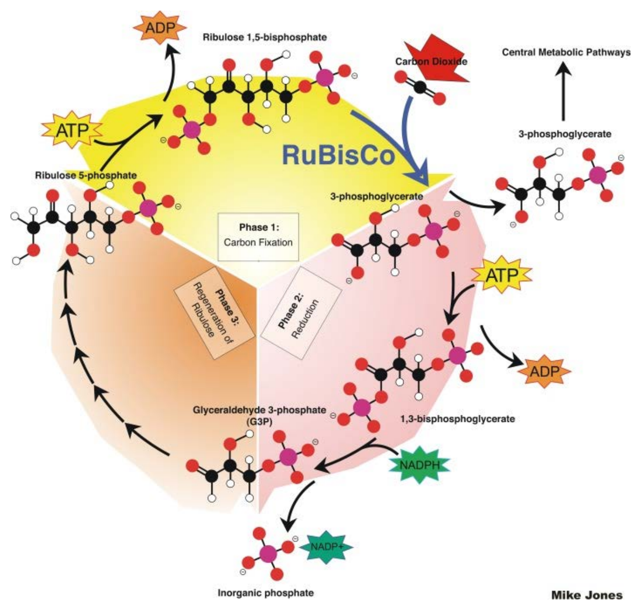
Although a simple formula $CO_2 + H_2O \rightarrow CH_2O + O_2$ lets us believe that the photosynthetic reaction is easy to understand, the process is enormously complex. The simplified formula first of all gives the impression that the C from CO_2 is split off and connected to the water molecule to create sugar and to allow O_2 to escape as a waste product. This is not the case. Note that it is not necessary to either remember, or completely understand photosynthesis. It is important to know that photosynthesis is only possible if certain criteria are met. To make that clear, it is necessary to explain the mechanism in some detail.

First the energy of the sun is used to split water into protons (H^+), electrons (e^-) and oxygen. The protons and electrons are used to create intermediate products (loaded with "energy") that are then used in a second reaction chain, called the Calvin cycle (also referred to as the "dark reaction", which is essentially wrong, as it runs both in light and in darkness).

Without going into detail, you can imagine the light reaction as follows: the energy of the sun is used to force the negative charge to one side of a membrane (the e^-) and the positive charge to the other side (H^+). The oxygen is released as waste product. For this purpose, the electrons "jump" over a chain of molecules. A proton "cannon" called ATP synthase then makes use of the positive/negative potential to



"shoot" the protons to the other side of the membrane. There the protons are connected to an intermediate product (NADP becomes NADPH), while the energy is being used to connect a phosphorus molecule to ADP (D stands for Di or two) to become ATP (T stands for Tri or three). Energy contained in these intermediate molecules is used in the dark reaction, where sugar is created. ATP is an energy transporter. It allows an organism to transfer energy into a transportable form in one part of the body to be used in another. No different than electricity that is "transportable". It is generated in an electrical plant and then used in your home.



Carbon dioxide only comes into play in the "dark reaction" or "Calvin Cycle". It enters the cycle one molecule at a time (see the red arrow). After the energy of the ATP is used (and it is returned to its original state of ADP and molecular phosphorus), it returns to the light reaction. The protons that are included in the sugar are carried there by NADPH, which returns to the light reaction without the proton as NADP.

Note that ADP and ATP contain phosphorus (the P at the end). This explains why this element is essential to sustain life – a lack of phosphorus would prevent the creation of ADP and ATP and without these, photosynthesis could not function.

In particular the light reaction shows a chain of highly specialized molecules. Each of these is made-up out of a specified number of different elements. Not only carbon, hydrogen, oxygen, nitrogen and phosphorus, but in some cases metals or other molecules are needed. These molecules are needed in very small quantities (only to create some very specialized molecules) and are called trace elements. Trace elements can thus be a "limiting factor". In the oceans of the southern hemisphere, this is the case for biologically active iron (Fe).

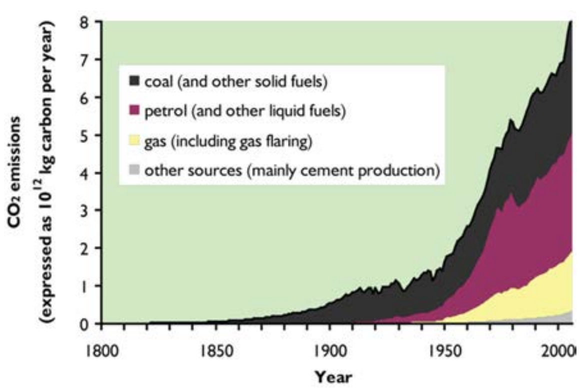
The energy cycle gives the impression that production and consumption are a relationship without (too long) delays. In general this is true, farmers grow new crops which are immediately brought to the market, but there are exceptions. When production exceeds consumption, it can be that the surplus (under specific conditions) is stored. The carbon rich sugars accumulate underground. In the past, such accumulations have developed over a timeframe of millions of years. These accumulations are now coal, oil and natural gas. The use of these fossil fuels is currently disrupting the carbon cycle, which is the subject of the next section.

The Carbon Cycle

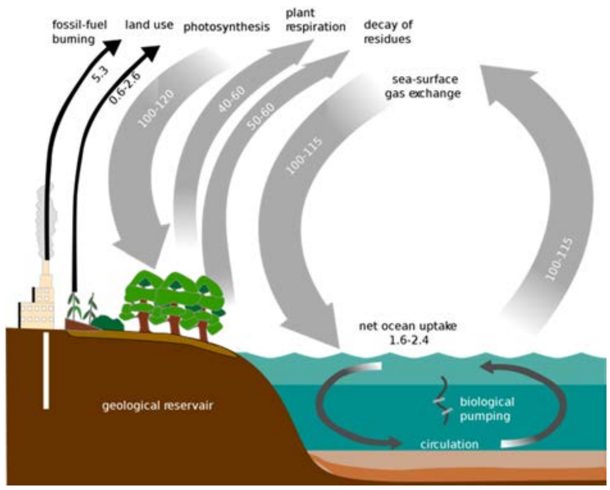
In order to understand the carbon cycle, we must distinguish between the geological cycle and the biological cycle. The geological cycle refers to a cycle of matter that progresses extremely slowly – mostly in the order of millions of years. The geological cycle decreases the availability of elements (specific molecules such as nitrogen or oxygen) for shorter cycles, such as the biological cycle. In faster cycles, elements are used and reused in a matter of hours, days, months or decades. Elements in the fast cycle are accessible for their consumers, where elements in the geological cycle are out of reach – buried deep in the soil, or deposited on the bottom of the ocean. Typically, the elements stored in the geological cycle need a "geological event" to be reintroduced in the faster cycles. A volcano is an example. Humans have a history of interfering with the cycles of matter by removing geologically stored deposits from the deeper soil or the bottom of the ocean. The removal of aluminium from bauxite is an example. To illustrate possible consequences of such actions, we will take a look at the carbon cycles.

The amount of carbon altering between carbon dioxide and carbon hydrates in "natural processes" every day is enormous. The reaction is driven by sunlight and has just been covered in the section on the energy cycle. It would thus be logic to assume that the production of carbon hydrates stops during the night and is more intense in summer than in winter. On a longer timescale however primary production must be in balance with consumption. If that would not be the case, one reaction would deplete its own resources, while its product accumulates. The balance between primary production and consumption is nearly perfect. The near constant oxygen content in the atmosphere can serve as an indicator for that statement.

Some carbon hydrates are removed from the cycle for an extended period of time. Biomass is an example in point. Trees, cattle, human beings and all other living organisms are mainly made up out of carbon hydrates and water. This carbon is not available for the cycle during their life span. Another part (to a large extent from skeletons from micro-organisms) sinks to the bottom of the ocean as calcium carbonate ($CaCO_3$), only to come to the surface again where it is exposed to the energy cycle, millions of years later as (for example) limestone. Some biomass ends up in an environment without oxygen. Here it cannot be consumed. In such an environment, the carbon hydrates slowly degrade. They lose their oxygen and become molecules with only hydrogen and carbon. These are called hydrocarbons. They are removed from the cycle for millions of years. These energy-rich molecules first become peat, then brown-coal, black coal, oil and finally degrade to natural gas. All together we refer to them as fossil fuels. Fossil fuels are returning to the cycle as a result of geological processes, such as erosion. This aids to keep the system in balance. The loss of carbon hydrates in oxygen poor environments is compensated by the return to the cycle of hydrocarbons created some million years before.

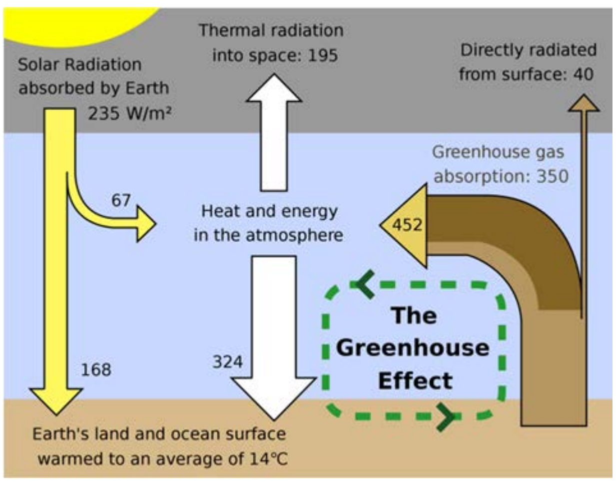


Humans have disrupted that cycle. Fossil fuels are burned far too fast. To replenish the fossil fuels that we burn in a single year, we would have to invest the entire primary production (leaving nothing to consume) of land and ocean for the next 400 years. This leaves 21.3 billion tons of carbon dioxide in the atmosphere, of which only about half can be taken up in natural processes. This seems to be a lot, but the figure only represents less than 4% of the total production of carbon dioxide. The difference is that natural production has a counterpart. Other organisms are using the produced carbon dioxide at more or less the same speed. The burning of fossil fuels has no counterpart. The produced carbon dioxide is not consumed and stays in the atmosphere and in the ocean. There are several problems related to this accumulation of carbon dioxide, of which global warming is the best known.



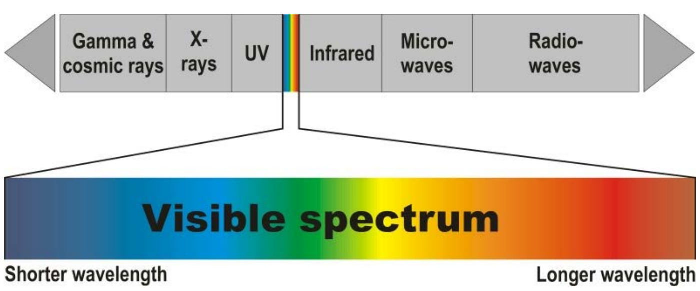
Problems less known, but also important, are ocean acidification and an increased growth rate of plants.

Global Warming

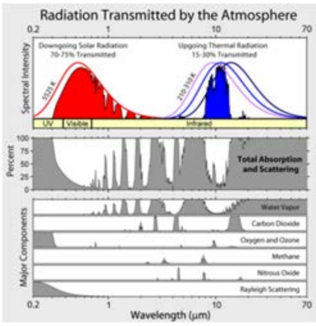


Sunlight reaches the earth and warms its surface. The heated earth, as a result, radiates energy back into space, much like the radiator of a heating system. Once it is heated, it starts radiating. The average temperature on earth is the balance between incoming and outgoing radiation. You can imagine that when either the incoming or outgoing radiation changes, the temperature system is disrupted. The average temperature will change.

Temperature variations are nothing new. A periodic cycle of such changes results from variations in the radiation of the sun. But even with a more or less constant average temperature on land, there are local variations. Warm summer weather in the northern hemisphere is compensated by a cold winter in the southern hemisphere. Differences in local temperatures result in air movement, which is the cause of wind. Bigger differences result in intensified air movement. There are also factors stabilizing temperature. Water plays an important role in buffering against temperature changes. It can absorb enormous amounts of heat energy (it takes a lot of energy to heat up a volume of water due to its high heat capacity) and the stored energy is then available for cold areas elsewhere or colder periods later.



The gasses in the atmosphere of the earth are filtering both the incoming and outgoing radiation. The colour of the incoming radiation differs from the outgoing. Incoming radiation is mainly made up of visible light and ultraviolet, the outgoing radiation is largely infrared. Different molecules filter different frequencies. Ultraviolet is filtered by ozone. Luckily because ultraviolet radiation damages photosynthetic cells and can cause skin cancer. Visible incoming light is partly blocked by clouds. Infrared light is not of one single frequency. What we refer to as infrared is actually a whole range of frequencies. Also infrared light is partly blocked by clouds. In addition to clouds, some infrared frequencies are blocked by gases in the atmosphere. These gases are called greenhouse gasses. Thanks to the greenhouse gasses and especially water vapour and clouds, the average temperature on earth is some 30°C higher than it would be without an atmosphere. Without the greenhouse effect, earth would be too cold to support life.

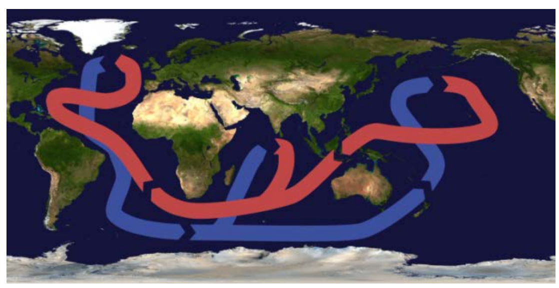


When measuring the incoming and outgoing radiation both at the surface of the earth and outside the atmosphere (in a satellite), it becomes clear which frequencies are filtered to what extent. The absorption of light in the atmosphere ranges from almost 0% to complete absorption (100%) depending on the frequency. Most ultraviolet frequencies are absorbed by ozone and oxygen and most infrared frequencies by water vapour. There are some gaps (holes) left in the spectrum absorbed by water vapour, through which radiation escapes from the atmosphere. It is these gaps that prevent the earth from heating up too much. Greenhouse gasses tend to close these gaps. This disturbs the balance between incoming and outgoing energy. This is the cause of global warming. Water vapour is the most important greenhouse gas. It plays an essential role in the effect that made life on our planet possible. Our current problems are caused by greenhouse gasses closing the gaps left by water vapour. These are mainly carbon dioxide and methane.

Possible Consequences of Global Warming

It is hard to predict how severe the consequences of global warming will be and when certain thresholds will be reached. As land ice stored in glaciers and polar ice caps melts, the sea level will rise. It is easy to calculate a maximum rise in sea level by assuming all ice will melt, but that will probably not be the case. The expansion of water when it gets warmer also has to be taken into account. Temperature rise caused by global warming is not evenly distributed over the planet. The average temperature will rise, but that does not mean that the temperature will rise evenly everywhere.

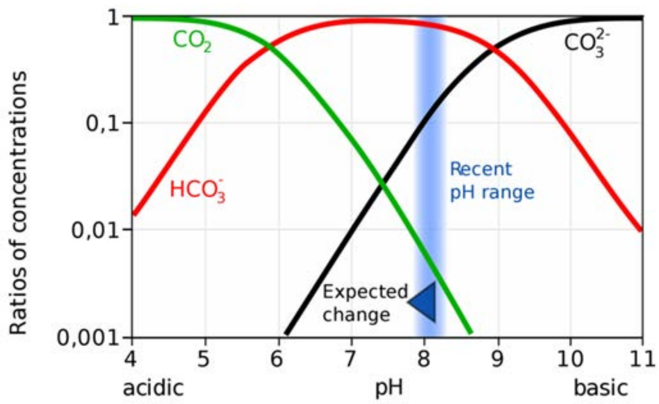
For example: the great ocean conveyor belt moves warm water to the region between Norway and Greenland. The energy stored in the warm water is then radiated to the local atmosphere assuring a relatively mild climate in the region. The water gets colder and heavier than the surrounding water – it sinks to thousands of meter depth and returns along the bottom to the Indian and Pacific Oceans.



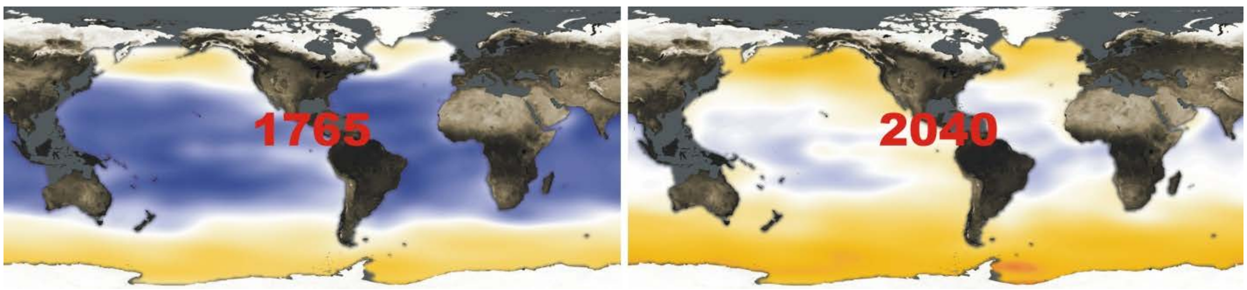
If global warming melts the icecap of Greenland, fresh water will be introduced in the area where the great ocean conveyor belt starts. Fresh water is lighter than salt water and the cooled water in the region cannot sink anymore. The current will slow down or stop. If that happens, no warm surface water will be transported anymore to the region and the local climate will get colder (despite of an increase in the world average temperature). This could be the start of a new ice age, increasing the size of the ice cap and thus a lowering of the sea level. The opposite of what will happen when the conveyor stays active. Although it is easy to predict a rise in average temperature, predicting the consequences is hardly possible. That is the reason for the high number of conflicting news articles about climate change.

Ocean Acidification

It was mentioned before that about half of the carbon dioxide resulting from burning fossil fuels can be taken up by natural processes. Most of this excess carbon dioxide is taken up by the ocean. You could say that the ocean has been buffering against climate change.



At normal levels, carbon dioxide also has another buffering function. It aids to keep the pH (acidity) of the ocean constant around pH8. This happens as follows. In water part of the CO_2 (carbon dioxide) becomes carbonic acid (H_2CO_3) as a result of the reaction between H_2O and CO_2. The carbonic acid can separate a proton (H^+) and becomes bicarbonate (HCO_3^-). The bicarbonate can then split another proton and become carbonate (CO_3^{2-}). If more protons get into the water and the pH is reduced (more acid), carbonate and bi-carbonate bind with them until the pH is back at around 8. This is the normal pH for ocean water. If the pH of the ocean gets higher (more basic), carbon dioxide and bicarbonate split protons until the pH is back to normal.



At the current level of carbon dioxide in the ocean, the buffering system seems to be getting out of bal-ance. A shift to a lower pH is already measured and expected to continue changing in the acid direction. The above illustration is a projection based on measurements indicating that carbon saturation has already progressed to great depths. The process is referred to as ocean acidification. Ocean acidification has consequences for organisms with calcium carbonate ($CaCO_3$) structures such as shells or skeletons. Such structures are affected by acid. They become weaker, because calcium carbonates solute in acid.

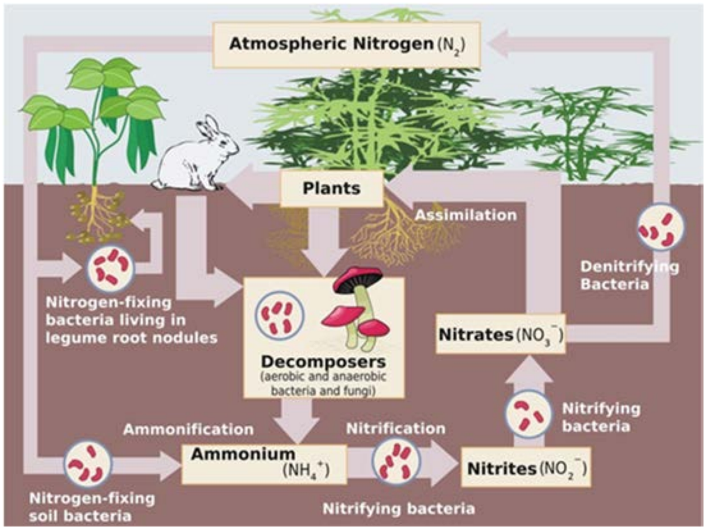
Looking at the graph with different species of carbon dioxide in water, there is an indication of another potential problem. We see that the quantity of carbonate (CO_3^{2-}) reduces quickly when the pH is re-duced. Animals with calcium carbonate structures can only use carbonate (not bicarbonate or carbonic acid) to produce their shells or skeletons. A reduced availability of carbonate will impair growth. The extent of this problem is not yet completely clear. Research has shown impaired growth in several spe-cies (shellfish, corals, algae, etc.).

The Nitrogen Cycle

The nitrogen cycle is the last example of a cycle to be given in this chapter. Obviously there are cycles for all chemicals. The water cycle was an example of quantity only. It explains where the different quan-tities of the same substance (water) are found and how it wanders from one to the other. The energy cycle explained how two reactions are each other's opposite, and how the productive activities of one provide the energy rich food for the other. The carbon cycle was directly related, but indicated some additional consequences and complexities. The nitrogen cycle is now used to show the dependence on bacterial activity to make a cycle work the way it should.

Nitrogen (N_2) is said to be inert under normal room conditions. The cause of this inertness is the very strong triple bond of N_2. This means that the two elemental N molecules share three pairs of electrons in their N_2 configuration. Before nitrogen can react with another element, such as oxygen, the bond must be broken. That requires a lot of energy or "special tools". Living organisms need nitrogen to be able to live, grow and reproduce, but they cannot use the inert nitrogen from the atmosphere.

The required amount of energy can be available in other conditions than "normal room conditions". In a car engine for example, the temperature (energy) is high enough to allow a reaction between the nitrogen (either from the air or as a contaminant in the car fuel) and the oxygen in the air. The resulting nitrogen oxides are "reactive nitrogen species". They are amongst the causes of environmental challenges such as acid rain, increased greenhouse effect (temperature rise) and nutrient loading (eutrophication). Nitrogen oxides are not the sole cause of these problems, but contribute to each of these challenges.

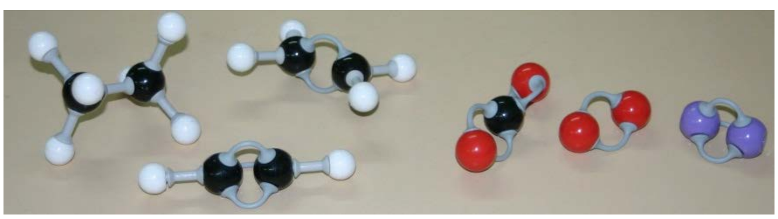


Some organisms have "special tools" (enzymes such as nitrogenises) to create reactive nitrogen species from bimolecular atmospheric nitrogen (N_2). In ecological farming, clover is sometimes used for nitrogen fixation, rather than commercial fertilizers. Clover has this unique ability to make atmospheric nitrogen react with other molecules. The clover is not removed from the land, but mixed with the soil to allow food plants to subsequently use the reactive nitrogen from the clover. In most cases, organisms that create reactive nitrogen are bacteria.

A problem with nitrate (NO_3^-) is that it is readily soluble in water. This characteristic explains why nitrate is washed out of soil rapidly and soon ends up in aquatic systems. Other species, such as inert N_2 and ammonia (NH_3) are lost to the atmosphere (it is mainly the ammonia that creates the odour associated with applying manure to cropland).

Without bacteria that run a reverse reaction, creating N_2 out of reactive nitrogen species (de-nitrification), the accumulation of reactive nitrogen in soil and water would be enormous and step by step the atmosphere would be depleted of its nitrogen. These bacteria thus play an essential role in the "cycles of life". There is some evidence that de-nitrification loses in efficiency when antibiotics accumulate in aquatic systems. Sources of antibiotics include wastewater (antibiotics washed away or excreted by humans) and antibiotics applied to livestock and in fish farms.

To illustrate single, double and triple molecular bonds, the picture below shows ethane (C_2H_6), ethylene (C_2H_4) and acetylene (C_2H_2) to the left. To the right carbon dioxide (double bonds), oxygen and then Nitrogen with its strong triple bond.

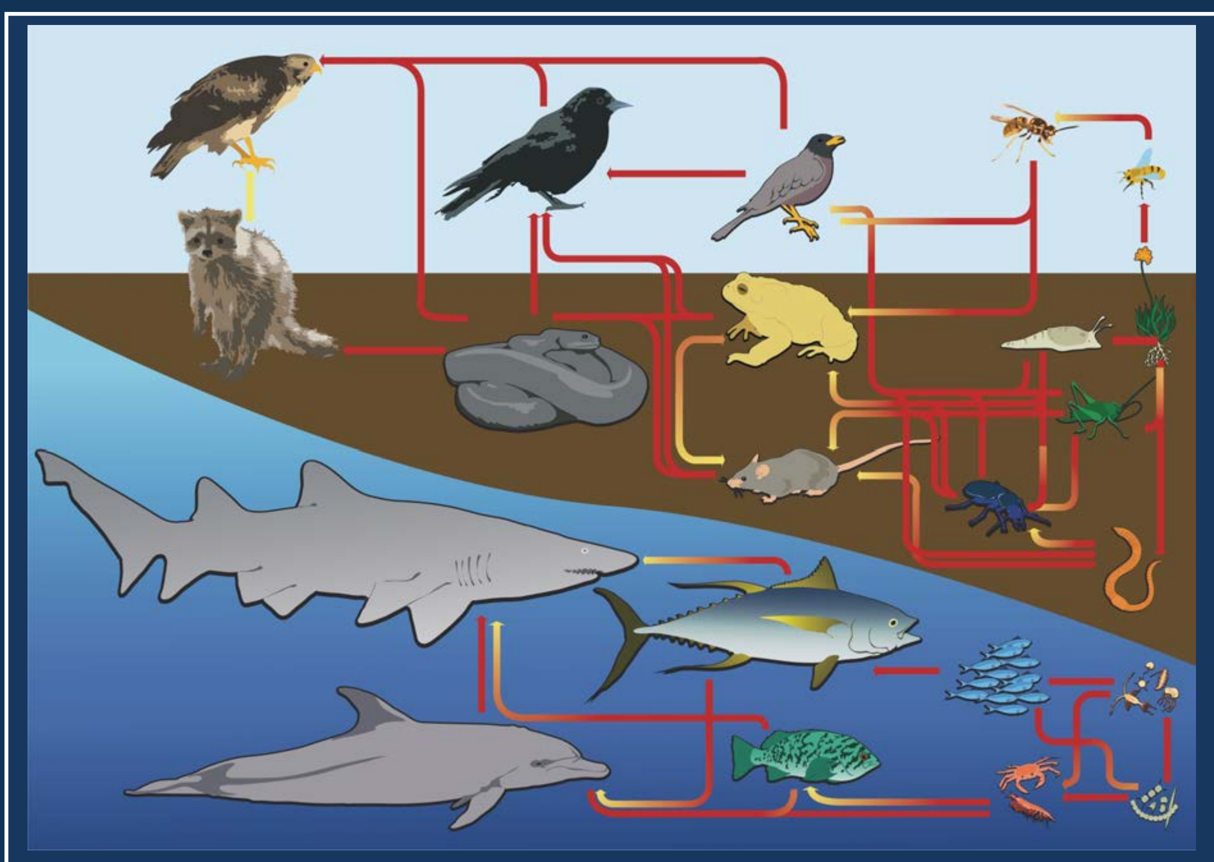


Naturalist

The object of study for biologists was originally the different forms and manifestations of life, the conditions and laws under which these phenomena occur, and the causes through which they have been effected. It was introduced as the doctrine of life. In the past much of the work of biologists was to categorize all life forms on earth. Based on their (assumed) relations to other species they were given names to bring them in relationship with other species.

Most modern biology can be encompassed with five unifying principles. First: the cell theory that places emphasis on the passing on of hereditary information via DNA. Second: the evolution theory that explains why certain species are still alive today, while others are not by concentrating on natural selection. Third: genetics in which (again) DAN plays a central role. Fourth: homeostasis in which living organisms regulate their internal environment by means of multiple dynamic adjustments of equilibrium. And fifth: energy, explaining that continues need for new energy exists and that some species draw energy from the sun, making it available for the entire following food chain (or web).

This chapter starts with differences between the world underwater and on land, which can be seen in the light of evolution. It then progresses to the systematic in which different organisms are assembled into groups to which they belong. The interactions that are covered then are an introduction to ecological aspects of biology. The drawing below represents a food-web, which belongs to the ecological branch of biology.



Land vs. Water

The aquatic world is completely different from the terrestrial environment. This is because of physical and structural differences. Organisms underwater look different than organisms on land. Let's look at a few physical and structural differences.

The density of water is approx. 800 times higher as the density of air. This brings a bigger need for streamlining. Some animals on land have rather a streamlined position, such as a puma, but most experience no restriction in the relationship between their speed and being streamlined. Under water all predators have a streamlined shape and position to allow them to move fast enough to hunt.

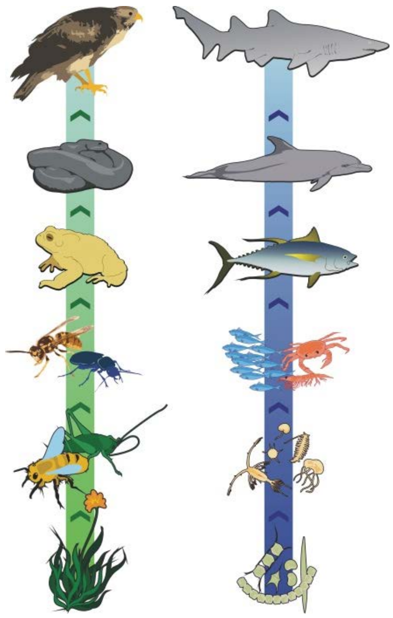
Also gravity is a major cause of differences. Even birds have to fight gravity – they have to sit down from time to time, because flying (fighting gravity) takes a lot of energy. A small bird or an insect has to make an enormous amount of movement with its wings in order to "hover motionless" to eat and drink. A Lionfish hardly has to move at all to hover in one position. Organisms under water do sense gravity – they swim with the correct side up – but they are less affected by it.

Gravity requires that organisms on land have stable skeletons and strong muscles. Under water you can find organisms without any skeleton at all, such as the jellyfish. On land every kilo has to be lifted against the effect of gravity. This limits the potential size of organisms – these restrictions hardly count under water. The potential size of organisms is a lot bigger.

On land eggs need to be protected against gravity, which is not the case under water – under water the eggs look like jelly. Some organisms have not developed hard scale eggs and therefore need to return to the water for reproduction (toads). Land organisms that returned to the water, like sea turtles, have developed the ability to make hard scaled eggs – they return to land to reproduce. Movement under water is 3 dimensional, which allows things to travel in different patterns than on land and which has consequences for the distribution of oxygen and nutrients. Plankton cannot move by itself, but is transported by the flow of the water. Animals feeding on plankton just follow the stream.

Many animals underwater don't have to go looking for food. The food comes to them, allowing them to stay in a fixed position like anemones, coral, worms, etc. Animals that are fixed to one location like a plant cannot survive on land. Larvae and seeds can travel enormous distances. Even some land based plants rely on water to make sure that their seeds are transported far enough from their own location (others rely on wind, birds or other for the same purpose).

In air the Oxygen is equally distributed – this is not the case in the water where there are oxygen rich layers and layers with hardly any oxygen at all. To take oxygen from the water, lungs do not work. Animals "breathing" underwater use gills. Mammals living in the water rely on the surface to get their Oxygen. With increasing depth, both the intensity of light and the amount of colours reduce. Plants need



light to live and to produce Oxygen, meaning that plants can only live close to the surface. The maximum depth at which sufficient light could penetrate for any meaningful photosynthesis is 180 meters, but depending on visibility this is normally much less.

On land plants dominate the eco system, which you can already learn from the names of the different environments – rain forest, grass land, prairie, etc. Under water the animals are dominant with respect to the environment – hence names like coral reef, oyster bank, mussel bank, etc. The number and variation in plants under water is very limited compared to land. The food chain underwater can be longer than the food chain on land. On land, plants can be eaten directly by larger animals, which on their turn are eaten by predators. In the water, plant plankton is eaten by animal plankton, which is eaten by smaller fish, which in turn are eaten by bigger fish. This adds a step to the food chain. This "longer" food chain is however rather theoretical. Both on land and underwater the relationships are far more complex. This is why we prefer to speak of a food-web, such as the one in the illustration on the first page of this chapter.

Underwater Animals and Divers

If animals are perceived as dangerous or not is mostly a matter of the amount of fear they provoke - mostly unjustified fear that an animal could attack for reasons such as evil, revenge or similar. Such unjustified emotions are normally assigned to animals such as shark, moray eel, stingray, alligator, barracuda, sea snake, orca, etc. Other animals with a potential to do harm, such as anemones, sea urchins, coral, cone shells and most nudibranchs do normally not provoke this fear. You will hardly hear anyone say –"the sea-urchin jumped right under my foot when I entered the water".

Animals do not attack out of emotions such as evil or revenge. There are basically 4 real reasons for a potential attack:

- To defend them – for example when you put your hand in a hole, housed by a moray eel.
- To defend territory, a mate or a young – for example the cone shaped territory of a trigger fish.
- To obtain food – this does not affect divers, because we are not on the menu of any known creature in the water (except maybe salt water crocodiles).
- By mistake – the well-known example of a surfer being mistaken for a sea turtle by a shark looking for food.

To avoid an attack, the following solution applies:

- First you need to identify the animal correctly on first sight.
- Secondly your knowledge of the marine environment must be adequate to estimate the severity of an attack or of contact with the animal.
- Finally you have to know what your options are to take corrective measures.

Human perceptions can also be wrong and have consequences for themselves or the environment. Animals can be seen as non-living objects. A diver may see coral as rock and see no problem in walking on it or breaking it. A diver may see animals as a flower or a plant. On land, our attitude toward plants allows us to walk over and climb on them. Walking on the lawn or through a forest is done without any consideration for the grass or the plants. When we see an animal, such as anemones, underwater as a plant, we could approach them with that same attitude.

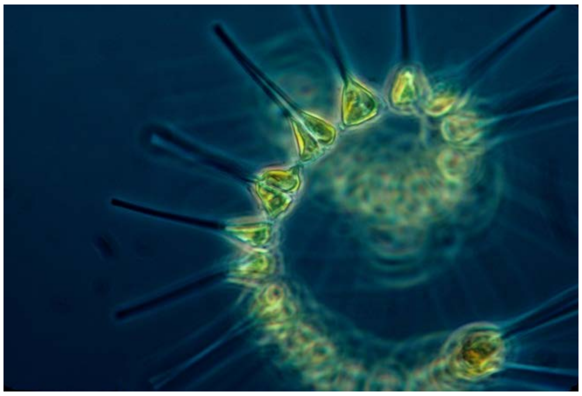
These perceptions are mainly dangerous for the environment. The danger for the diver comes when organisms are seen as harmless, or as having human characteristics. We are used to see lions in shows and in the zoo. If we think they behave the same in nature, we could approach them in a way that would cause them to defend themselves, which could do us a lot of harm.

The Taxonomic System

With 1.5 million known different creatures on earth, it is necessary to have a system to identify them. Through the process of evolution, all of these creatures have some sort of genetic relationship to all of the others, but most of the time this relationship is not immediately apparent. For example – it is easy to see that both salmon and barracudas are fish, but is not so easy to see that a dolphin is more closely related to a cat than to a shark. To make the relationship more clear, a system of classification was developed, which is called the taxonomic method. In taxonomy we begin with a large group and then get more specific step by step.

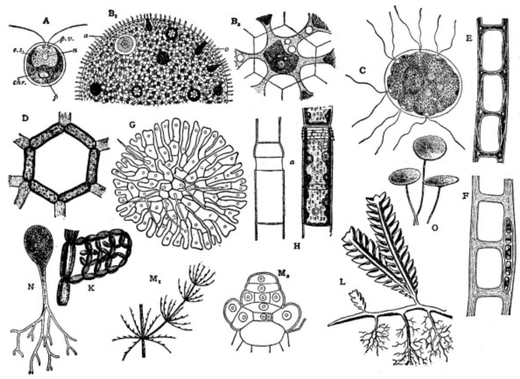
The scientific name is Latin and a combination of the Genus and the species, but most people will prefer to use the common name in their own language.

Common name	Octopus	Sea squirt	Bottlenose dolphin	Human
Domain	Eukarya	Eukarya	Eukarya	Eukarya
Regnum or Kingdom	Animalia	Animalia	Animalia	Animalia
Sub Regnum	Eumetazoa	Eumetazoa	Eumetazoa	Euetazoa
Phylum or Division	Mollusca	Chordata	Chordata	Chordata
Subphylum or subdivision		Tunicata	Vertebrata	Vertebrata
Class	Cephalopoda	Ascidiacea	Mammalia	Mammalia
Order	Octopoda	Stolidobranchia	Odentoceti	Primates
Family	Octopodidae	Pyruridae	Delphinidae	Hominidae
Genus	Octopus	Halocynthia	Tursiops	Homo
Species	O. vulgaris	H. pupillosa	T. truncatus	H. sapiens



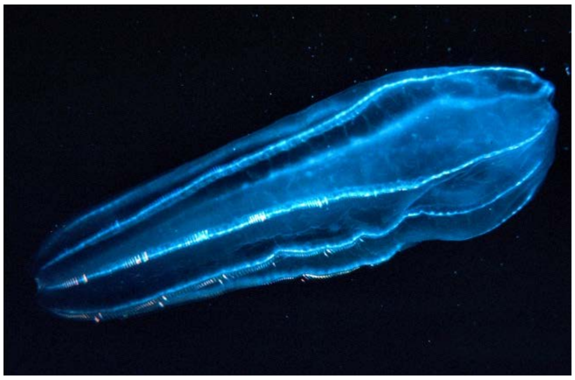
Plants (Plantae) are always the first step in a food chain. They need sunlight and carbon dioxide to produce material that is used as food. In the water there are 3 different groups of plants. Phytoplankton is plant plankton. It is one-celled and can only be seen under a microscope. It is drifting in the water – mostly close to the surface. The phytoplankton is the beginning of the food chain, without it there is no life in the water.

Algae are the most common plants under water. Algae are found in fresh water and in salt water. The



larger (attached) algae (macro algae) are commonly called seaweed. Algae have no true stems, leaves or flowers. Bigger algae in most cases have some sort of root like structure (hold-fast). They hold the plant on hard rocky bottoms, but they are not roots, because they cannot absorb nutrients from the bottom. The whole plant absorbs water with nutrients. Some algae are held erect with gas-filled bladders. The 3 groups are red, brown and green algae. The red alga is the only one that can be found at greater depth, because they make use of blue and green light only. To reproduce many bigger plants release spores.

Flowering plants are plants that returned from land to the water. Only 0.018% of all plants are found underwater. They are often mistaken for seaweed, but have real stems, leaves, roots and flowers. They are normally found in shallow water on sandy bottom.



Single-celled animals (Animalia) belong to the Sub regnum Protozoa – **Phylum Protozoa**. Just like the simple plants, the Protozoa are part of the plankton – animal plankton = zooplankton. Plankton does not move by itself, but is transported by the flow of the water. In the single cell animals all bodily functions are carried out in a single cell – they do not have specialized cells as bigger animals have. Protozoa feed on a variety of organic substances from the water. Some absorb the substances directly from the water, while others actively feed on bacteria or catch other protozoa. In some cases multiple one-celled animals live in a sort of colony as a group of loosely aggregated cells. Both in fresh and in salt water there are large numbers of protozoa in many different forms.

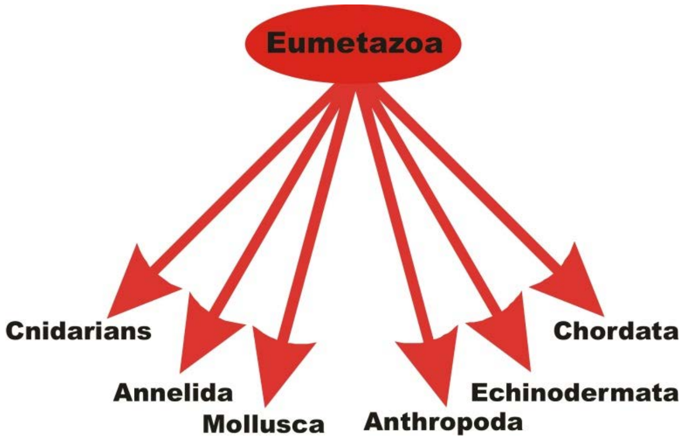
Sponges belong to the Subregnum Parazoa – **Phylum Porifera**. This is an intermediate group between one-celled and more-celled animals. The Phylum Porifera consists only of sponges. Sponges have existed for over 200 million years and have not changed in that time – they are perfectly adapted to what they do. Sponges are a group of cells working together, with no true tissues or organs. Each sponge consists of 3 types of cells. The cells are organized around a system of pores, channels and chambers. All cells consist of soft tissue and needle like structures (spirules). The spirules form the body of the sponge. The shape and size of the spirules are specific to the type of sponge. There are two main groups. First sponges that take the shape of a vase and secondly, sponges that spread flat on the bottom. All are attached to hard bottom, like a rock.

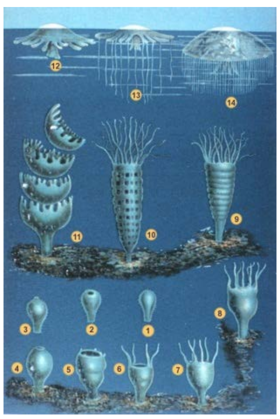
The outside of any sponge is covered with small pores that are lined with special cells called collar cells. These cells are flagellated. The only thing these cells do is moving the little flagella. This pulls water into the body of the sponge. The cells filter the food particles from that water and in vase shaped sponges all water exits through a big hole called the osculum. Flat sponges have a series of smaller oscula.

An average sized sponge filters hundreds of litres of water every day, which makes them the cleaning mechanism of the sea. Sponges are vulnerable to silt. When a diver stirs up silt and it falls on a sponge, some of the silt will fall off, but if too many passages are blocked by silt, the sponge will die of starvation.

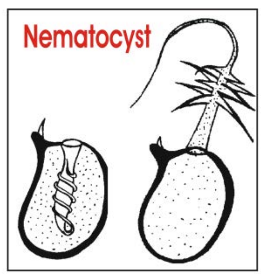
The **Subregnum Eumetazoa** regroups the animals that have specialized cells that work together in the form of organs. Most cells have no direct contact with the environment, which brings the need for a nervous system and a digestive tract. All animals which we consider to be "an animal" on first sight, both on land and in the water belong to this group which includes both vertebrates and invertebrates. We will cover the different Phylums:

- Phylum Cnidarians – anemones, corals, jellyfish
- Phylum Annelida – segmented worms
- Phylum Mollusca – chitins, clams, snails, octopus, squids
- Phylum Arthropoda – insects, spiders, crabs, lobster, shrimp
- Phylum Echinodermata – sea stars, urchins, cucumbers
- Phylum Chordata – sea squirts, vertebrates

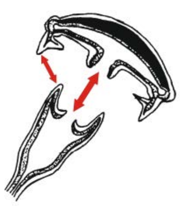




Sea anemones, corals and jellyfish belong to the **Phylum cnidarians**. These animals are all radial symmetrical (their bodies look like the spokes of a wheel). They have very simple organs and a one-way digestive tract – a mouth/anus ringed with tentacles. They are all carnivores (meat eaters) and capture their prey with their tentacles.

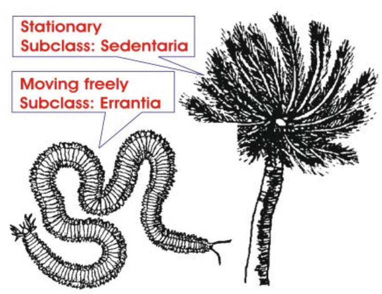


The most notable characteristic is that all cnidarians have stinging cells. These are located in the tentacles. Within these cells we find a capsule called a nematocyst. When the cell is activated (by touch, chemical stimulus or a nerve impulse form the animal itself), pressure inside the capsule causes the nematocyst to discharge. The barbed harpoon of the nematocyst penetrates the target and envenoms it. Each nematocyst can only fire once and it takes hundreds of them to have any influence on the prey.



Cnidarians come in two basic forms that share common characteristics: the polyp form and the medusa form. These two forms alternate each other (sometimes there is only one form). The polyp form is found in animals such as sea anemones and corals. Each is attached to something hard by a basal disc, with the mouth (two way digestive tract – mouth and anus at the same time) directed up. The medusa form is known as jellyfish – they are free swimming and the mouth is generally pointed down.

Segmented worms belong to the **Phylum Annelida**. Worms can live virtually everywhere: on land, in fresh water, as parasites in the body of other animals and in the marine environment. There are more phyla of worms, but the Phylum Annelida is the most important one (annelida = ringed). They are segmented animals. The segments look like rings. Most of the marine worms are of the class polychaeta (with many bristles). The two other classes of the annelida (oligochaeta and hirudinea) are mostly fresh water and land worms.

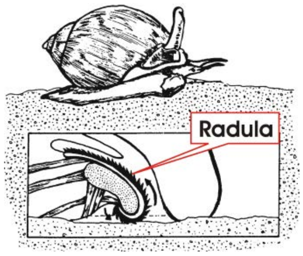


From this phylum onwards, all animals are bilateral symmetric. This means that they have a left and a right side, which form mirror images of each other. Organ systems become more developed. They all have a one-way digestive tract. Animals are becoming bigger, so there is a need for a circulatory and a respiratory system.

The segments of the polychaetes are all identical, with the exception of the first body segment, which contains the sensory organs and the second which contains the mouth. There are two major subclasses: the sedentary worms (sedentaria) and the free-moving worms (errantia).

The sedentary worms mostly live in tubes. They must wait for the food to come to them. These worms eat small particles that they filter out of the water, or they use long, thin tentacles which come out of the tubes. Some worms live in the sand and simply eat the sediment around them and then throw out what they can‘t use. The free living worms are real hunters and have organs for locating prey and jaws to capture it. Some graze on sponges and coral.

The **Phylum Mollusca** consist of chitins, clams, snails, octopus and squid. Mollusc means head on the foot and that is the main body form of these animals. There are over 75.000 species of molluscs. It is surprising that these seemingly diverse animals are closely related. Most molluscs have certain common characteristics:



- They all have bodies that are soft and fleshy.
- Most have a muscular foot that takes a variety of forms, but is usually used for propulsion.
- All have a tongue-like structure with fine teeth, called a radula that can be used for scraping and cutting.
- A portion of the mollusc's body is the mantel, a structure that surrounds the body. In shelled molluscs, the mantel produces the shell.

Molluscs can be found in both fresh and in salt water and on land. The 4 classes of molluscs that are of interest to divers are:

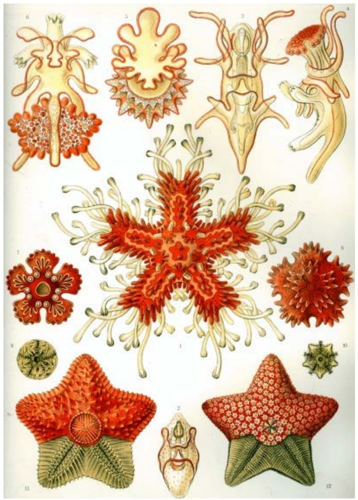
Class Placophora – chitins
Class Gastropoda – snails
Class Bivalvia – clams, oysters, mussels
Class Cephalopoda – octopus, squid

The **Phylum Arthropoda** consists of insects, spiders, crabs, lobsters and shrimp. Arthropoda is the largest phylum in the animal kingdom, both in number of species and number of individuals. Most species of this group are insects, of which we find only a few in the water. The arthropods have a few things in common. They have segmented bodies. The segments are different in form and function. All segments have a pair of extremities.

All arthropods have an external skeleton made of chitin. This skeleton provides protection, but gives problems with growing. Therefore every arthropod must go through a moulting process. This process is controlled by hormones. When the animal is ready to moult, the body begins to swell. Then the shell splits and the animal fights itself free of the old shell. At this time the animal is most vulnerable to predators. It takes a while until the skin is hardened enough to protect the animal again.

The arthropods have well-developed sense organs. Many have facet eyes, or they have eyes on stalks. They also have internal sensors to keep their balance. Under water we find mostly species of the class crustacean. The most familiar crustacean (crabs, lobsters and shrimp) are a member of the ordo decapods.

The sea stars, urchins and cucumbers in the **Phylum Echinodermata** are radial (5 ray) symmetric organisms (their larvae are bilaterally symmetric). They are all marine animals. They have an internal skeletal structure composed of spines. They have a unique organ system: the water vascular system. They use this system for movement. The system operates through hundreds of tube feet.



We distinguish 5 classes of Echinodermata:

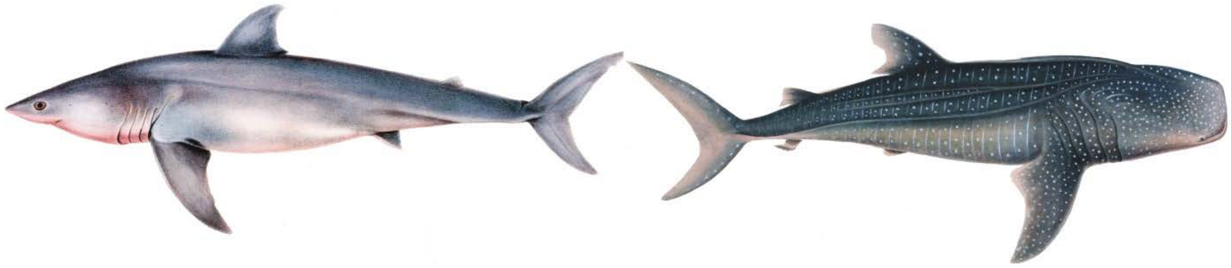
- Classis Crinoidea are sea lilies. This is the only group of Echinodermata that live at least a part of their life attached with a stalk to the seafloor. Their mouth is pointed upwards (opposite to the other Echinodermata). They have 5 arms, which can be forked. The arms are feathered. With the feathers they catch plankton.
- Classis Asteroidea are sea stars. Sea stars are free living animals which live on the seafloor. Most sea stars have five arms. They have no clear separation between the body and the arms. They use their tubular feet to pull the shells of bivalves apart, so that they can eat them.
- Classis Opiuroidea are brittle stars and basket stars. The body is clearly separated from the arms. They have five long, thin arms which are used for picking up food. The arms can break off easily, but grow back rapidly.
- Classis Ecinoidea are sea urchins. In this class of Echinodermata the arms have disappeared, but the 5-ray radial symmetry is still there. They have five rows of tubular feet and they have five teeth, arranged in the "Aristotles Lanthern". With this mechanism they scrape everything off the bottom.
- Classis Holothuroidea are sea cucumbers. These species look bilateral symmetric, but they are just like all other Echinodermata 5-ray symmetric. They have a long body with a mouth located on one end of their body and an anus on the other end. Some feed on plankton and others pick up organic debris from the seafloor.

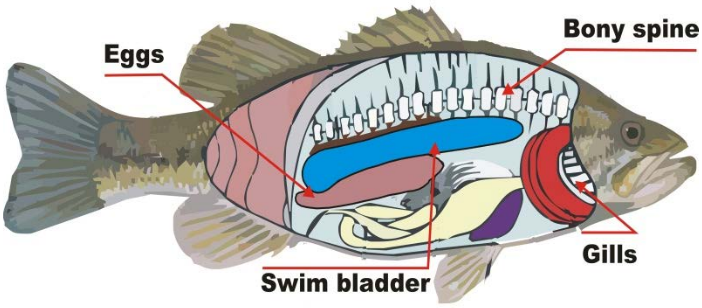
The **Phylum Chordata** consists of vertebrates and sea squirts. This is the phylum we know most of, because the human belongs to the Chordata and also the best known animals. The subphylum Tunicata is sea squirts. This is a group between the true vertebrates and the true invertebrates. In the larval stage the animals have the characteristics of a vertebrate, where they look like a tadpole. They have a tale with the beginning of a backbone in it. As they develop they lose the tail and settle on the seafloor. As adults they look like a sponge. The body is covered with a gelatinous leathery tunic. They look simple, but they have a highly developed organ system. They get their food by filtering the water. As they are from the phylum Chordata, they are closer related to humans than octopus, lobster or squid.

The **subphylum vertebrata** are the true vertebrates. The vertebrata are all bilateral symmetric animals with a backbone. The main sensory organs and the nervous system lay in the head. Behind the body we find, in principle, the tail. Primary aquatic vertebrates have gills, where terrestrial animals breathe through lungs. All vertebrates have an internal skeleton, mostly made of bone (exception Chrondrichthys).

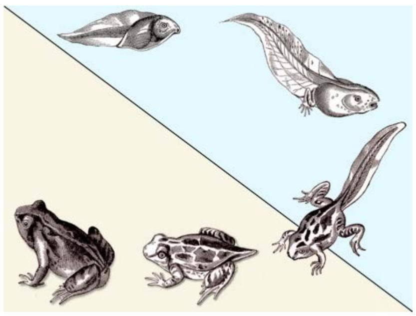
The **Class agnatha** are jawless fishes (lampreys and hagfishes). They are the most primitive fish with only 2 living representatives. The lamprey has well-developed eyes while the hagfish has none at all.

The **Class Chondrichthyes** is characterized by having an internal skeleton made of cartilage. They are skates, rays and sharks. Just like all fish, they have gills and limbs in the form of fins.





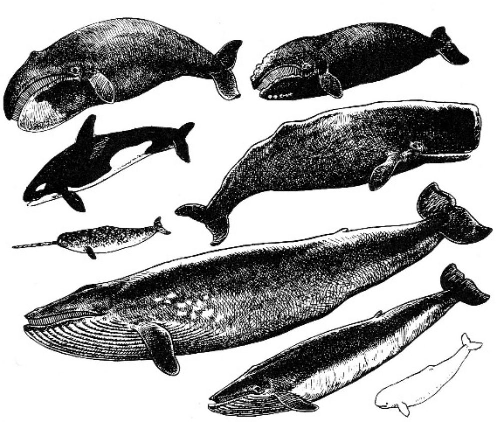
Class Osteichtyes are bony fish. Bony fish have an internal skeleton of real bone. The outer body of the osteichtyes is covered with overlapping scales. There is a tremendous diversity in body shape, size and colour (more than 20,000 species worldwide). Bony fish stay in position in the water column by an internal buoyancy control device, the swim bladder.



The **Class Amphibia** has larvae that live in fresh water. Most of the adults live on land, nearby the water. They have to go into the water for fertilization and to lay eggs.

Class Reptilia consists of turtles, crocodiles, alligators and snakes. Reptilia are animals that live on land. A few species have returned to the water. This is the first class that has a hard-shelled egg, which allowed them to invade the terrestrial environment. They have lungs, so they have to come to the surface to breathe. Eggs have (mostly) to be laid on land.

Class Mammalia are animals that give birth to well-developed young and the females feed their young with milk. Mammalians that live in the sea are species that have returned from land, such as manatees, dolphins, whales, etc. These animals are the most complex in the animal kingdom. They are warm-blooded. This means that they no longer depend on the environmental temperature and can also live in colder regions. They must all return to the surface to breathe (unless they use scuba equipment).



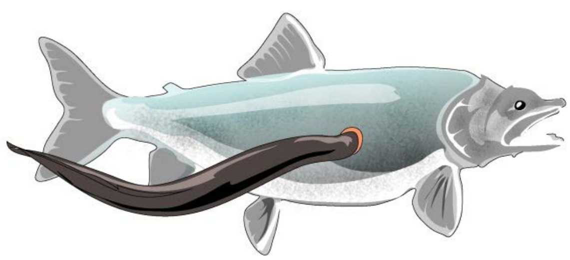
Marine relationships

Animals don‘t live in a vacuum, isolated from other animals. Animals may have strong effects on each other. They can interact in many ways. One of these relationships is predator and prey. One animal eats the other for food. There are a lot of strategies involved, both for the predator and the prey. Animals try to prevent becoming prey by means of defensive structures, such as shells or spines, by being distasteful or poisons, or they camouflage themselves.

Another way of interaction is symbiosis. Members of different species live together in close association. The smaller partner in the symbiosis is usually called the symbiotic, the larger, the host. We distinguish between three different types of relationships:

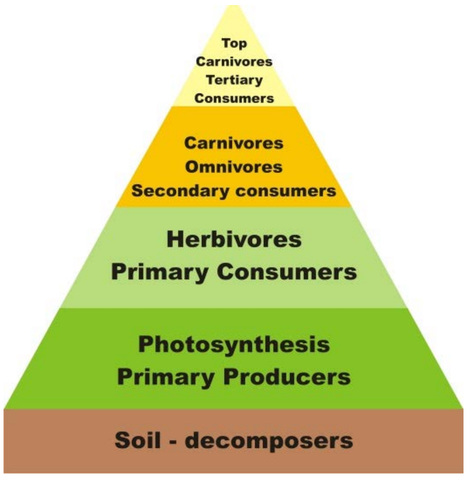
Mutualism means that both of the species that are living together benefit from the relationship. The best known examples of mutualism are the cleaner fish. The small fish remove the parasites from the bigger fish. The cleaner fish gets a meal, the bigger fish gets rid of the parasites. In this type of symbiosis, the partners can eventually live without the other. Sometimes neither of the partners can live without the other. An example of this is the coral and its little algae called zooxanthellae. When the algae go, the coral dies (bleaches).

Commensalism. In this form of symbiosis one of the species clearly benefits, while the host does not benefit and is not harmed. The symbiotic is most probably looking for food or shelter. The pilot fish feed on the morsels of food falling from a feeding shark (or as in the picture from a titan triggerfish). The shark neither benefits, nor is harmed.



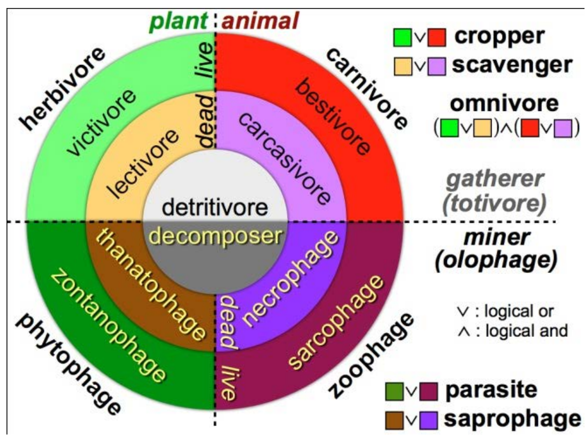
Parasitism. One species, the parasite, lives in or on the host. The parasite benefits at the expense of the host. Best known examples are the parasites living in the guts of the host. The host will experience reduced food reserves, less resistance to disease and general vigour. The host may die due to infection, starvation or predation, but not directly due to the parasite.

To assign organisms a place in the food web, they are often assigned names such as primary producers, primary consumers, secondary consumers, tertiary consumers and so on. In this representation, loss of energy at the different trophic levels is taken into account. Not all plants can serve as food. The wooden parts of trees cannot be eaten or digested by most species; certain leaves are not accessible for others, and so on. Only about 10% of the energy that was fixed by primary producers will be available for primary consumers. Primary consumers use most energy for life processes, such as moving, maintaining body heat, reproduction, and so on. Not all primary consumers become prey – some live until they die of old age. You could thus assume that again only 10% of the energy that was consumed by primary consumers will become available as energy for secondary consumers.



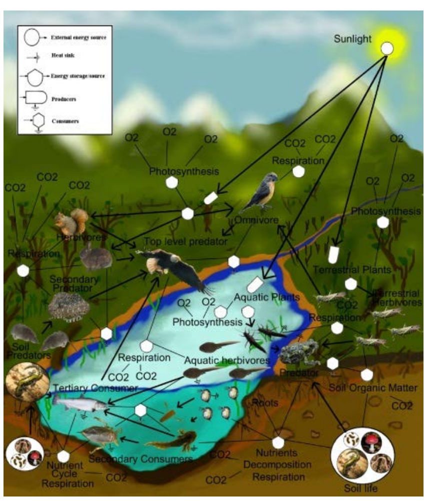
To illustrate the loss of energy at the subsequent trophic levels, they are often placed in a food-pyramid. In the food-pyramid the higher levels occupy a smaller space, indicating that the number of individuals (and their accumulated body volume) decreases because there is simply not enough energy available for a larger population.

In reality the food chain is not as simple as this type of illustrations would let you believe. A chain in which the plants produce leaves which are eaten by small herbivores, which in turn are eaten by bigger carnivores (or omnivores that eat both plants and animals) to serve as food for the last category of top carnivores is not what we find in reality. Whale sharks are primary consumers, as are manta rays. Their size makes them an unlikely prey for secondary or tertiary consumers. If we now take organisms living in the soil into account, the food relationships become even more complex. Top carnivores are not only sharks, lions and other “top hunters” but also worms, parasites and other. Depending on if bigger animals are eaten dead or alive, they are going to be different consumers.



If all transformation of biomass is to be included in a food chain, it will not anymore suffice to speak of primary producers, herbivores, carnivores and omnivores alone. The relationships would then need to specify if food is eaten dead or alive and if the food is gathered above the soil (or the bottom) or is mined for in the bottom or soil.

Population ecologists are biologists who map the actual transfer of biomass in an ecosystem. Based on their findings they propose a food-web, rather than a food-chain. An example of such a web is provided below.



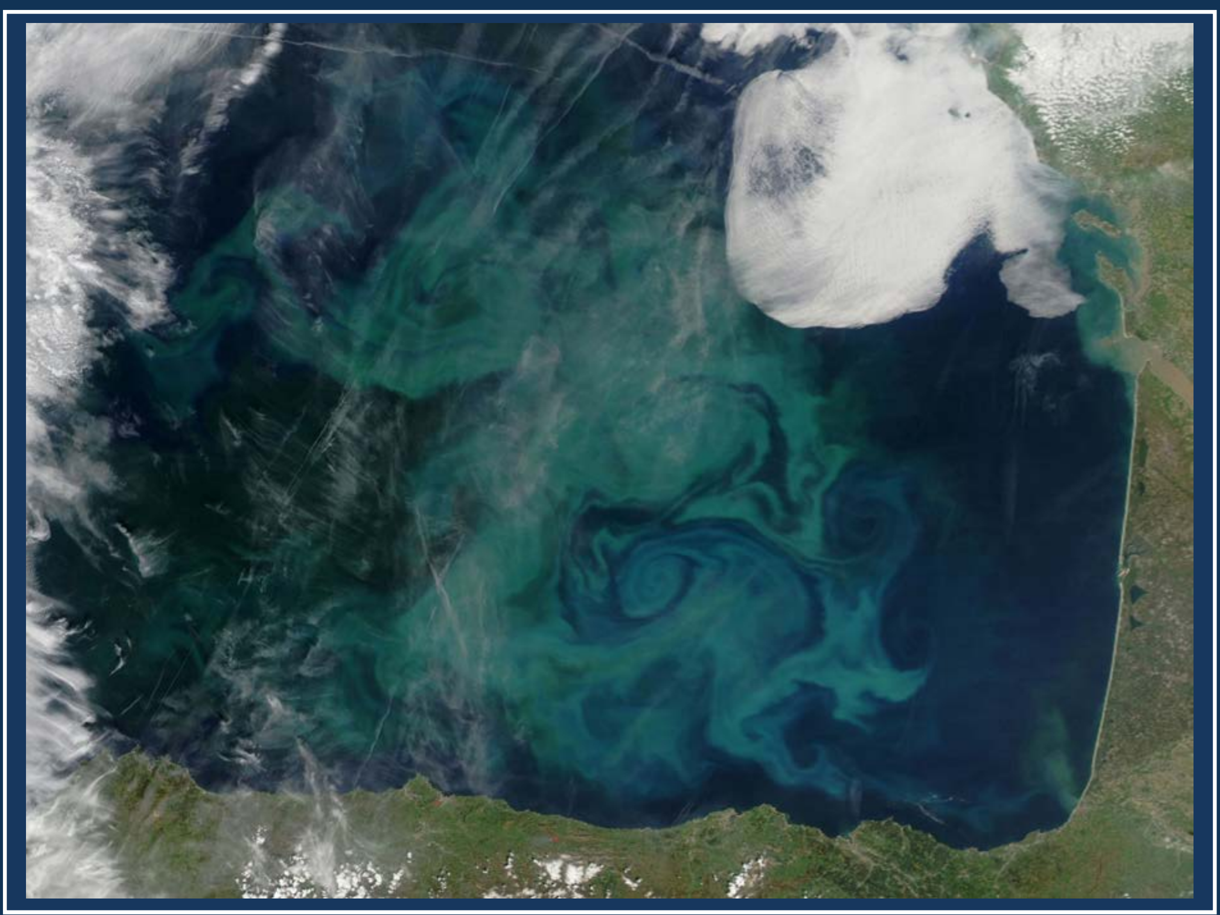
With so much complexity in the relationships for who eats what, when and where, it is often necessary to concentrate the understanding of the relationships in an ecosystem on a single aspect. The food-pyramid is such an example. It explains that the combined weight of all primary producers (mainly plants and trees) is 10 times bigger than the maximum weight of all primary consumers combined. If only 10% of the available energy is available as food, the population of primary consumers can simply not grow more. In reality the population is even a lot smaller than that. Part of the consumers is eaten by secondary consumers and much of the energy that was taken up with their food is used for moving, reproduction, maintaining body heat, and other purposes. The pyramid thus explains how big a population can be sustained at the different levels. Similar approaches could be applied to the nitrogen cycle or other requirements that organisms impose on their environment. Research (as discussed in the last chapter) is often a single issue effort.

Chemistry

Although the name of this chapter is chemistry, it is where all different aspects (physics, biology and chemistry) come together. So far subjects have been covered (mostly) as isolated facts and events. In any ecosystem there is a delicate balance. This balance is constantly disrupted; leading to a new balance which is never reached because before it gets to that point the process is likely to be disrupted again. The influences that cause disruption can be physical, chemical or biological in nature. For that reason, this chapter aims to combine these aspects.

Water chemistry is a very large field of study. Problems are caused by a large variation of factors, such as residue from medical drugs or the anti-birth pill. Other examples are pollution with oil, strong acids, and industrial waste. For this chapter choices had to be made. Eutrophication is form of pollution that allows explaining several mechanisms and is thus well suited for our purpose. Nutrients are needed. If no nutrients were present in a lake or the ocean, all organisms would die. The subject of nutrients is thus about maintaining a balance – a situation with too little nutrients is just as bad as too much.

If the level of nutrients is too high, the condition is referred to as eutrophication. It leads to algal blooms (see picture below) and then possibly to the development of dead-zones. In dead-zones there is now more oxygen close to the bottom. As a consequence all organisms depending on the bottom will die. This chapter covers the mechanisms behind eutrophication and provides insight into how such situations can be prevented.

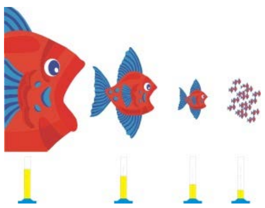


Nutrients

Ecosystems have different levels of nutrients. The nutrient level, together with factors such as climate, ground water level and others, defines which type of ecosystem can develop at the specific location. On land, conditions with respect to nutrients can vary substantially at short distances. Nutrients travel slowly in soil; hence, a nutrient poor environment could be only meters away from a nutrient rich spot. In water there is a more even distribution.

Nutrient levels are described as nutrient rich (eutrophic) medium nutrient level (mesotrophic) or nutrient poor (oligotrophic). The local vegetation is adapted to the environmental factors, including the availability of nutrients. Nutrient poor environments often have the biggest biodiversity as different adaptive features of different species allow the use of different niches. Although by feeling you might suspect the opposite, tropical rain forests hardly have any nutrients in the deeper soil. In eutrophic regions, we are often confronted with dominance of a few species that make best use of the ample supply of nutrients and that thereby take light and water away from others.

If nutrients accumulate in a mesotrophic or oligotrophic environment, we speak of nutrient loading or eutrophication. Although natural mechanisms exist that can cause such events, it is usually the result of human action (or lack of action). Eutrophication provokes unchecked growth of species that can make best use of the additional nutrients. These species will then take up much of the available space in the local environment. The "normal" species will be dominated by the abundant presence of the "new" species and biodiversity will suffer. The new situation can be totally different from what it used to be. In water, the species that benefits most from additional nutrients is algae. Algal growth can have serious consequences for the "traditional" species in the aquatic system.

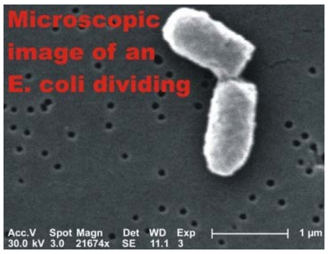


Some environmental problems are related to persistent manmade chemicals. "Persistent" means that nature is not readily able to break down the substance, which is the reason it stays in the environment for a long period of time and can accumulate in organisms higher up in the food chain. Some of the biggest challenges however concern substances that are "normal" in the environment. In that case, the environmental problems are related to distribution. Accumulation of a substance in one location while depleting it in another.

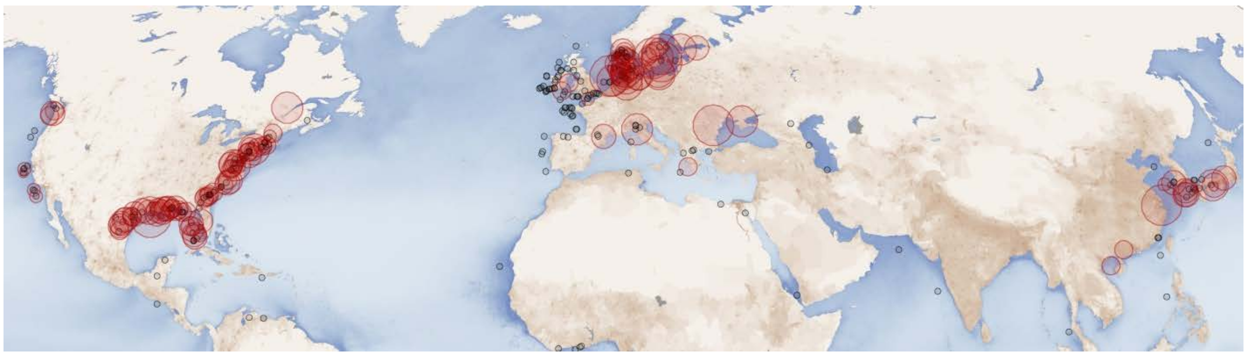
The distribution of nutrients is disrupted in many ways. The total quantity on earth is increased by fertilizers and other products from the chemical industry. The additional presence of fertilizers goes beyond the capacity of nature to change it back into atmospheric nitrogen (see the nitrogen cycle in chapter 1).

Another disruptive cause is the great distance between food production and consumption. Nutrients are consumed and excreted in urban areas, where there is little need for nutrients. Agricultural areas deplete the soil of nutrients by harvesting the crop. They are forced to make use of fertilizers to replenish the soil. Added nitrate is soon lost because it is easily dissolved in water (hydrophilic) and will travel to aquatic systems. Phosphate is more persistent, but when the soil is saturated with phosphate, it will also leak to the groundwater and eventually the surface water (our diving environment). Fertilizers are important. Without them, farmers would produce less food per area of land and mankind would be forced to dedicate larger areas to food production, probably at the expense of nature.

Primary production stands at the basis of the food chain. Solar energy is stored as chemical energy by photosynthesis (see chapter 1). Plants and algae have chlorophyll in which solar energy is transferred to “usable energy”. Other living organisms (including humans) depend on the organisms that can produce chemical energy from sunlight. Algae are thus (just as plants) very important for life on earth. Too little plankton would result in starvation of many organisms as a consequence.



The growth of all living organisms is limited by one factor or another. This must be – if one specific organism were not limited, it would soon dominate all other species on earth. Organisms that do not require a partner to reproduce (asexual reproduction) have the advantage that they are able to reproduce at any moment if the conditions are right. In the case of one celled organisms, they just split in two, to double their population. This can occur quickly: 1 – 2 – 4 – 8 – 16 – 32 – 64 – 128 – 256 – 512 – 1024 – etc. This is a pattern to be expected with bacteria. Phytoplankton (or algae in general) belongs to the organisms with the potential of explosive reproduction. If nutrients are scarce, many reproduce sexually, but if conditions offer optimum chances (no limiting factors) they can reproduce by releasing spores that can develop into an adult without the need for a second parent. Such events are commonly referred to as algal blooms.



If increased production of phytoplankton (plant plankton) continues for some time, the quantity of biomass in the water exceeds the appetite of herbivores (many herbivorous species reproduce sexually and cannot immediately adapt their population to the luxury of unlimited food-supplies). The excess phytoplankton will then die before it is eaten and sink to the bottom. Bacteria decompose the biomass and use oxygen in the process. While they feast on the abundant food, their population expands exponentially. They deplete the oxygen in deeper water. When no more oxygen is available, decomposition of the plankton continues, but now by other bacteria. These are bacteria that do not need oxygen to live (sometimes the same bacteria can do both). Other organisms living on the bottom do not have that luxury. They need oxygen to survive. In the oxygen depleted zone all other life will thus have to escape (if it can), or the organism will die (organisms living in and on the bottom that cannot swim away). The locations of such dead-zones (either permanent or seasonal) are shown on the map above.

Dead-zones are not the only problem related to nutrients. Algae grow on coral reefs. Not a lot, because coral reefs are (in the normal situation) nutrient poor (oligotrophic). Herbivores such as parrotfish (picture), surgeonfish and sea urchins consume the algae when they are still young (and small). When the area is loaded with nutrients, algal growth will increase. As long as there are enough herbivores, this should not create damage. If the nutrient loading is combined with a reduction in herbivorous species, the algae will start to grow bigger and will dominate the reef. Coral cannot win the competition with algae for available space on the reef. The “coral reef” becomes an “algal reef”. Biodiversity is important for the prevention of such events. It can always happen that a pathogen (virus) decimates the population of a specific herbivorous species. In such a situation it is important that another species can take over its share in the consumption of algae. In Jamaica, over fishing of reef fish, combined with a pathogen that killed the sea urchins has led to the collapse of reefs.

In shallow inland waters, flowering water plants are part of the ecosystem on the bottom. Algal blooms can cover the surface, or reduce the visibility. The water plants receive less (or none at all) light on their leaves and photosynthesis stops. These water plants then die and the herbivorous species feeding on them along with that. The ecosystem that had an abundant diversity in species will now be dominated by algae and bacteria. The resulting turbid water ruins the attractiveness of that aquatic system as a dive location.

Limiting Factors

Next to the elements needed in the "energy cycle", additional elements (other than Hydrogen, Oxygen and Carbon) are needed to "construct" the body of an organism. A single cell contains an enormous variation in different molecules. Each of these molecules requiring a specific set of elements (construction materials). These elements must be present in the body in order to complete the required construction work (the human body can make most molecules itself, provided the required elements are present. Those that cannot be made within the body must be taken in with food and are called vitamins). If one of the construction materials runs out, building stops, regardless how many of the other materials are still available.

The fact that nutrients can be seen as "building materials" explains that a certain quantity of them is "stored" in living organisms. Construction materials already used are not available for another construction site. Nutrients only become available for a next cycle once an organism has died and is decomposed. Nutrients are elements that are needed in bigger amounts. Some other elements are only needed for very specific molecules and thus in very small quantity. These last elements are called "trace elements".

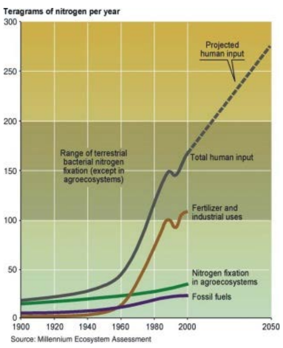
Some nutrients are thus removed from the cycle for the duration of the lifespan of the organism in which they are used to construct its body. A distribution problem can result if too many organisms grow in one location, but move somewhere else to die and be decomposed. Such a pattern would slowly but surely deplete the entire stock of nutrients in the soil from which the organisms depart. Carbon dioxide, oxygen and water are not affected by this mechanism, because they are distributed via the atmosphere.

Nitrogen (an also phosphorus) cannot be used as construction material in any form (species) in which it is present. Divers know that atmospheric N_2 is inert – it does not react under normal conditions. The N_2 from the air has thus no value as a nutrient. If nitrogen must react with other elements to create a specific molecule, nitrogen must be presented in a non-inert form – a nitrogen build in a molecule that can be "digested". In many cases this is nitrate (NO_3). In the body the N is taken from the NO_3 molecule, while the three O's are discarded. Different molecules containing nitrogen as a key element are called nitrogen species. Those species that can be "digested" by an organism are called biologically active species. Species can differ in their "digestion tools". As explained in chapter 1, some bacteria can "digest" atmospheric nitrogen. These bacteria are important to keep the cycle in balance. After all, biologically active nitrogen lost from the cycle must be replenished in some sort of way.

Growth of an individual organism or the size of the population is limited by various factors. The available space or amount of food is not unlimited and can thus be said to be a limiting factor. A limiting factor is something of which there is not enough to sustain an "endless" population size. Limits are important. If one individual species were not bound by limits, the species would soon dominate all other species. The unchecked growth of one species would in itself become a limiting factor for all other species.

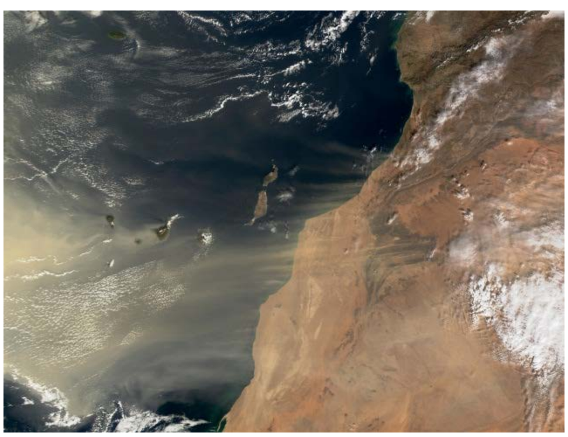
With respect to nutrients, in average algae in the ocean require them in what is called the Redfield ratio. Redfield has measured the ratio between different nutrients in algae and found a rather consistent ratio between carbon, nitrogen and phosphorus of 106:16:1. Since the organism uses building materials in this ratio, they must ideally be available in amounts reflecting this ratio. If there is more than 16 times as much biologically active nitrogen in the ocean than phosphorous, then phosphorous is the limiting factor. If there is less than 16 times as much, the nitrogen will become the limiting factor.

It must be said that the Redfield ratio does not necessarily apply for each individual species. It is an average for species living in the ocean. In fresh water there is more variation between different species than in salt water. Still, the Redfield ratio is a good starting point.



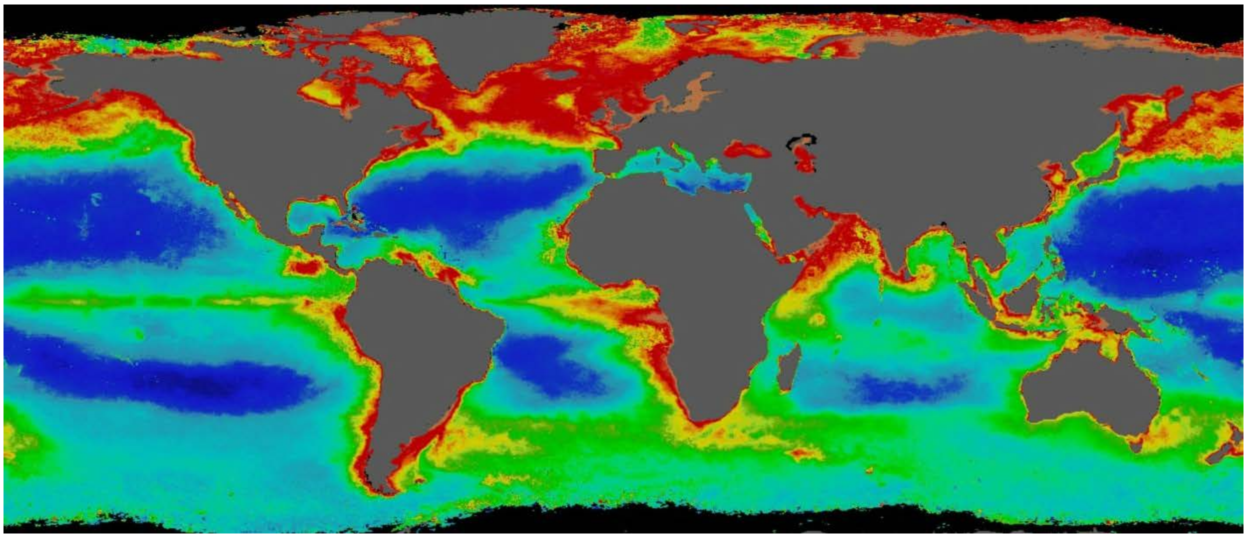
Changes in ecosystems may threaten the condition of our favourite dive sites. Although many changes are “natural”, the biggest threats come from human influences. In many aquatic systems, the quantity of nitrogen (as nitrate) is less than 16 times the quantity of biologically active phosphorus. This can be related to substantial human phosphate inputs in natural waters. It used to be common to include phosphate as a softener in washing powders. In many countries, the phosphate input has been reduced, but in others you will still find products marking “contains phosphate”. The input of biologically active nitrogen in ecosystems has been increasing massively in recent years and is expected to grow further in the future.

Altering human behaviour (and with that nutrient outputs) can change a situation for the better. A good example is the recovery of the Black Sea after the collapse of the USSR. During the USSR period, it was common to provide farmers in the region with ample stocks of fertilizer sponsored by the state. The intent was to provide for maximum food production by using every hectare of land to its maximum. With the collapse of the USSR the fertilizer program was discontinued. Farmers did not have access to big amounts of fertilizers anymore, or could not afford to pay for the supply themselves. Until the collapse, the Black Sea was known for algal growth and corresponding problems in the form of massive dead zones. Only a few years after the use of fertilizers was reduced, the ecosystems in the Black Sea recovered. The example shows that environmental gains are possible when human input in aquatic systems is reduced.



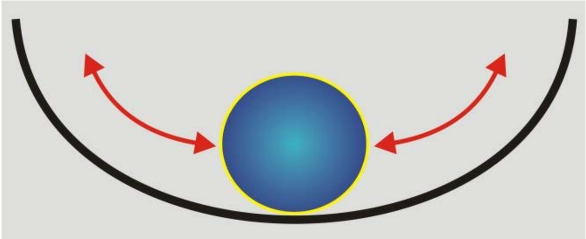
High nutrient levels combined with high levels of solar radiation do not always imply an imminent environmental disaster. Scientists have been pondering for many years why plankton growth in the oceans of the southern hemisphere is as limited as it is. There are sufficient nutrients during summer, but growth levels stay low. It was found that the cause must be a lack of the trace element iron. In contrast with fresh water, sea water is poor in biologically active iron species. The biggest source of reactive iron is desert sand blown into the ocean during storms. Apparently not enough of this sand is reaching the ocean in the southern hemisphere (which seems logical, because most deserts are located north of the equator).

A controversial plan to stimulate algal growth in the ocean to get rid of some atmospheric carbon dioxide is based on the concept of using active iron species as an "ocean fertilizer" to provoke algal blooms. This plan was made in the hope that these algae would sink to thousands of meters of depth after their death. As these algae contain carbon in their body, the carbon would be removed from the biological cycle (see chapter 1) and could thus aid in reducing the carbon dioxide content in the atmosphere. With that it would help to fight global warming.



The above image shows satellite data on the amount of chlorophyll in the water (the cells in plants and algae where photosynthesis takes place. It is based on data from July, which in part explains the low values in the southern hemisphere, but not entirely (in July it is winter in the southern hemisphere). The southern hemisphere has consistently lower levels of plankton.

Stable States



Ecosystems change constantly, always working toward a new "stable" situation. However, "real stability" is never reached. There are always parameters changing and many of these were a limiting factor for an organism. If the system changes in one direction, there is normally a point where it returns in the other. Just imagine the ecosystem to be the blue ball in the drawing. The ball is repeatedly pushed out of its position in the centre, but there are forces in play that will make it return toward the position of stability in the centre.

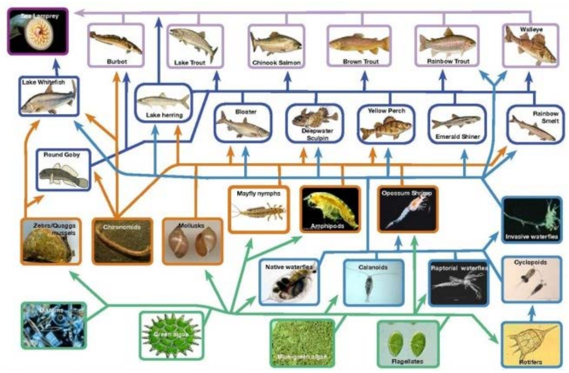
Example: *if the population of rabbits in ecosystem increases substantially, foxes are attracted to the area. More foxes eat more rabbits, which in turn reduces the rabbit population. If the resulting lower population of rabbits is not sufficient for the hunger of the current population of foxes, they must either look for an alternative food source; leave the area or die of starvation. The situation returns to its starting point. Less foxes reduce the pressure on the rabbit population, which can result in renewed population growth.*

If a change in an ecosystem occurs, species that can adapt quickly to a new luxury (an abundant supply of a resource that was scarce until then) benefit most. Species with the capacity to grow and/or reproduce fast can become a plague when limiting factors fall away.

Example: *both water plants and phytoplankton use nutrients and grow in the presence of enough sunlight. Phytoplankton can reproduce faster and is likely to benefit more.*

Some changes occur frequently. Each day (night/day), regularly (dry weather/rain), annually (summer/winter) or other. Other changes take thousands or millions of years to develop (climate change, changes in sea level, etc.).

Example: *When a period with heavy rain is followed by a sunny period, weeds (as fast growing plants) benefit from the situation and cover all bare land (this is why they are sometimes called pioneer species. They occupy empty space rapidly).*

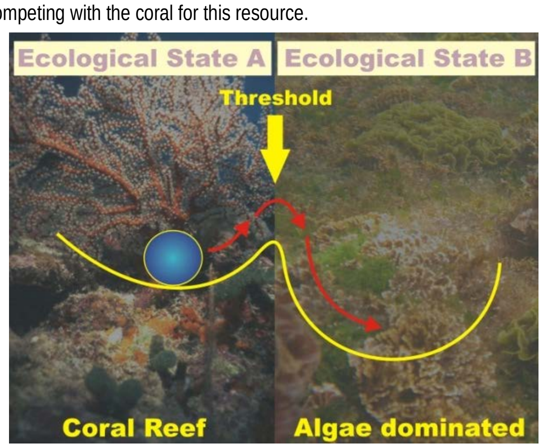


Although we normally speak of a food chain, it is better to refer to a food web. Several species compete for each resource and when one resource is missing, most species can (and will) make use of an alternative. The bigger the biodiversity, the bigger the number of species can be that compete for the same resource. In this way biodiversity makes an ecosystem more resilient. The NOAA illustration of the food web in the great lakes is an example of multiple species competing over the same resources.

Example: *Young algae on coral reefs are grazed by several species, amongst which are parrotfish, surgeonfish and sea urchins. They compete for the resource. If fishermen remove too many parrotfish and surgeonfish from the reef, the sea urchins have more food available than they need. The population could grow, which would alter the entire eco system. If the population of sea urchins does not grow, more and more algae reach adult age (at that size they are not attractive for consumption anymore) and take up space that is not available for coral anymore. If for some reason the sea urchins disappear from the reef, and if other consumers of algae have been decimated, the algae can grow unchecked and start to dominate the reef. Such a risk is reduced when more species compete over the resource algae. Biodiversity makes the reef more resilient.*

The example of algae on coral reefs can also be used to explain the concept of two different stable states.

- The coral reef is in a stable state with producers and consumers living a balance. As long as this stable state is maintained, the ecological condition of the reef stays as it is.
- If the quantity of nutrients reaching the reef is increased, the algal growth will increase. Initially this is not a big problem as it will only lead to a bigger consumption and probably population-growth for grazers.
- At some point either the algal growth exceeds the hunger of the grazers, or some other factor reduces the number of grazers on the reef. As a consequence more and more algae can reach adult size. They take up space on the reef, competing with the coral for this resource.
- Now that algae dominate more space than "normal", they will not simply "go away" when nutrient levels are reduced to a lower level (the level that was present before the algae began their domination of the reef). Nutrient levels probably have to sink to much lower levels before the algae will die and before their reproductive success is reduced enough to make the space lost for corals available again.



Once the threshold that allows algae to dominate a reef is passed, the way back is more difficult. Rather than a "linear" degradation of the reef we can be dealing with an almost normal situation until the threshold is breached. What follows is a rapid shift to an "algal reef". Prevention is thus the better option. This includes keeping nutrient levels low and maintaining an adequate biodiversity.

Consequences of Size

The bigger the medium in which pollutants (or in this case nutrients) end up, the more they are diluted. This means that big quantities of harmful substances can be introduced in an enormous volume such as the ocean, before it is possible to detect any change and before it becomes obvious that there are harmful consequences.

The situation of the ocean is further complicated by what is called “the tragedy of the commons”. The ocean does not have a single owner. Every person or country can take from it, or throw into it, as it pleases without major problems with respect to international law. Public outrage is the only factor limiting the abuse of the ocean. It must be said that efforts are made to come to international agreements that are meant to protect the ocean. An example is the OSPAR agreement (after OSlo and PARis, where the meetings took place). It should be realized though that it takes a long time to increase the quantity of pollutants in the ocean to a level that becomes measurable in analyses – it takes as much (if not more) time and effort to get it out again once it is in.

Public outrage requires that people are informed, but where the ocean is concerned there seems to be an inadequate information flow. Carbon dioxide has become a subject of global concern. The issue is addressed in newspapers, television and other media in relation to the atmosphere and global warming. For the general public it goes largely unnoticed that the quantity of carbon dioxide accumulating in the ocean is bigger than the quantity in the atmosphere. Problems relating to global warming would have advanced a lot further if this would not be the case. The consequences of carbon dioxide for the ocean have only become apparent in a later stage. The ocean is becoming more acid. Although acidification is not directly related to nutrient loading, it is a problem of concern for underwater environments that are confronted with nutrient loading. In a more acid environment one could expect impaired growth of corals (as in other organisms having calcium carbonate structures in or around their bodies). This makes corals weaker and lets them grow slower. That in turn reduces their potential to compete with algae.

The ocean responds slower to inputs of pollutants than fresh water environments, because these are much smaller. All lakes, ponds and rivers together, including the ground water, make up 1% of the volume of the ocean. An individual lake or pond is several dimensions smaller and will thus respond quicker. The atmosphere responds faster than the ocean (a problem everybody is aware of in relation to global warming, ozone alarms on warm days or acid rain). This difference might be explained by the difference in weight. The hydrosphere is almost 500 times as heavy as the atmosphere. As water is about 800 times denser than air, the atmosphere is slightly bigger than the hydrosphere, but it holds far less molecules, which makes smaller quantities of contaminating molecules noticeable.

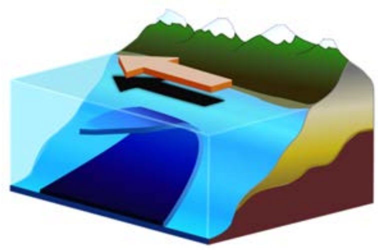
A situation in which the surface of the water is covered with algae is therefore possible in a small pond, but unlikely in a deep and large lake. The smaller an aquatic system is, the bigger the variations in the nutrient content can be in a relatively short time frame. Variations can also be big if the exchange of water with “the bigger volume” is limited. In some cases part of a sea or lake is connected to the main volume only by a small passage. Think for example of the Baltic Sea and the Mediterranean Sea. The nutrient levels in such an isolated part of the sea or a lake can vary substantially, compared to the levels in “the main volume”. Restricted exchange does not only play a role in such situations, but is also possible in the “vertical distribution”.

In the ocean, the vertical distribution of nutrients is not even at all depths. Even if it would be, such a situation could not persist for a longer period of time. Photosynthesis only takes place in the upper layer of the water – the layer in which light can penetrate. This is called the photic zone. This is the zone that receives sunlight and thus makes photosynthesis possible. In this zone, the available nutrients are consumed in the process of primary production. Since consumption goes faster than the nutrients can be replenished, the nutrient concentrations remain low (except in winter, where nutrients can accumulate in this zone until spring).

The deeper water is nutrient rich, because the nutrients are not used at depth and diffuse to the shallower layers at an extremely low speed. This is however not the only reason why nutrients accumulate in deep water. Organisms dying in the upper layers of the water can sink to the bottom before they are consumed. This indicates that there is a constant flow of nutrients to deeper water (the nutrients contained in the body of organisms that are not yet decomposed).

The great ocean conveyor starts with water sinking to great depth between Norway and Greenland. The deep water first travels through the Atlantic Ocean and then to the Indian Ocean and the Pacific Ocean. The trip takes hundreds to thousands of years. All the time the water is "in the deep", it receives input of nutrients (from dead organisms). The deep ocean water thus starts nutrient poor, but accumulates nutrients on the way. The deep water in the Atlantic Ocean thus contains fewer nutrients than the deep water in the Indian Ocean, which in its turn contains fewer nutrients than the deep water in the Pacific Ocean. (Do not confuse the great ocean conveyor with the predominant great surface currents – clockwise on the northern hemisphere and counter clockwise on the southern hemisphere. To some extent they are related, but are caused by different mechanisms).

In some locations, the deep ocean water returns to the surface. These locations are known for their very high biological activity and are called upwelling zones. The west coast of Africa and the Americas are well known upwelling-zones. On these locations the nutrient rich deep water comes to the surface and allows intense primary production. Such zones are permanently nutrient rich and the ecosystem is adapted to that abundance. Upwelling could be seen as "natural nutrient loading".

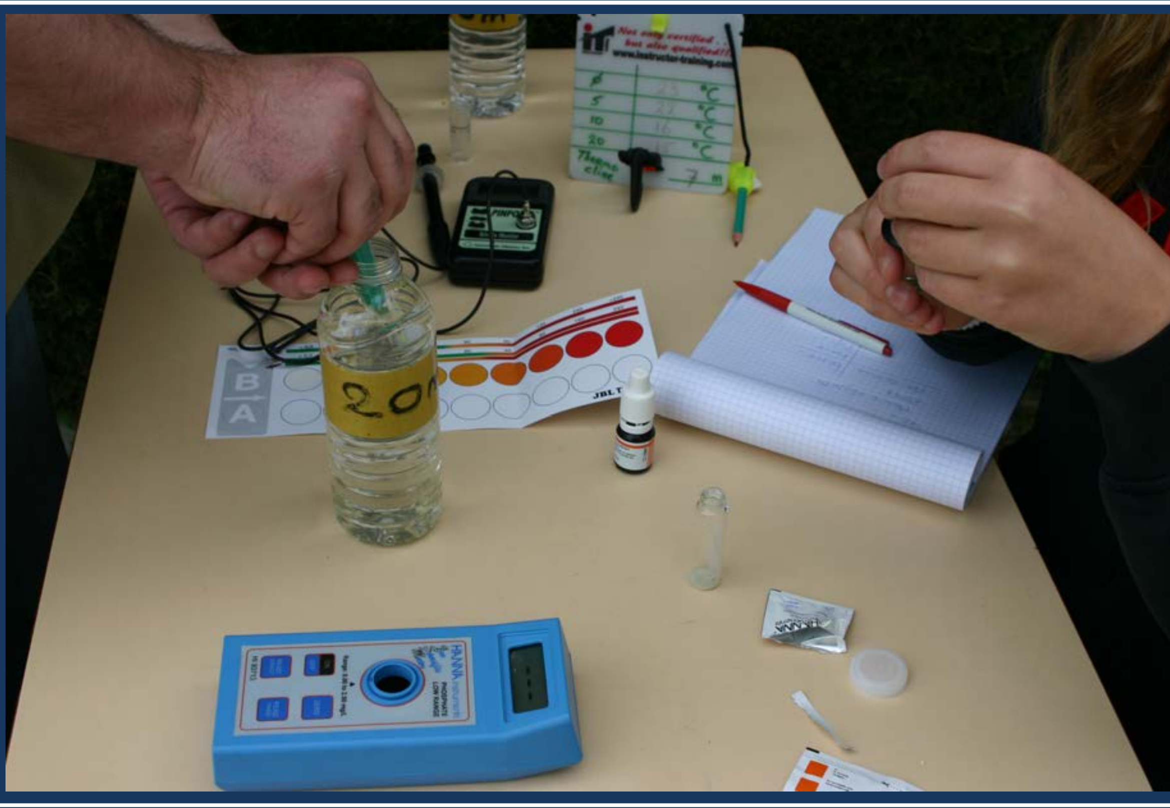


Research

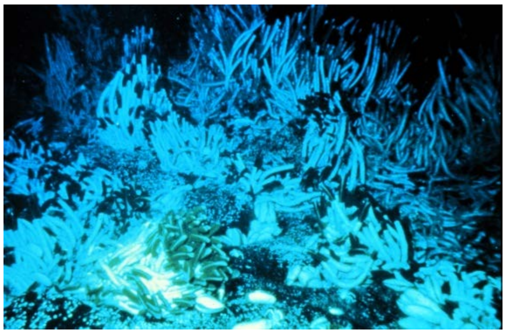
Research is meant to find answers about the world around us. Research can be related to any scientific discipline (physics, physiology, biology, archaeology, history, geology and so on). With such a wide range of possible subjects, the methods used vary widely. Research is not an activity for academics and scientists only. Everybody who wonders about some aspect of the world and then takes action to find an explanation is doing research.

The role of non-scientists in research can vary. Divers can assist research efforts by collecting data for scientists, but can just as well develop their own research programme and take responsibility for all the steps involved. Such a project may be related to the condition of a local lake, the relationships between different species on a reef, the interaction between divers and the environment or any other subject that you (are the group of which you are part) are interested in.

This chapter is meant to provide input on methods used by scientists. Such methods are meant to increase the validity of the findings of research. Although you are not bound by obligations that apply to “official” science, you will still want to have results that are as accurate as possible. The chapter will also provide input on techniques to measure different aspects of the underwater world. The goal of this part is to provide you with (the start of) a toolbox to do research projects.



Research Projects



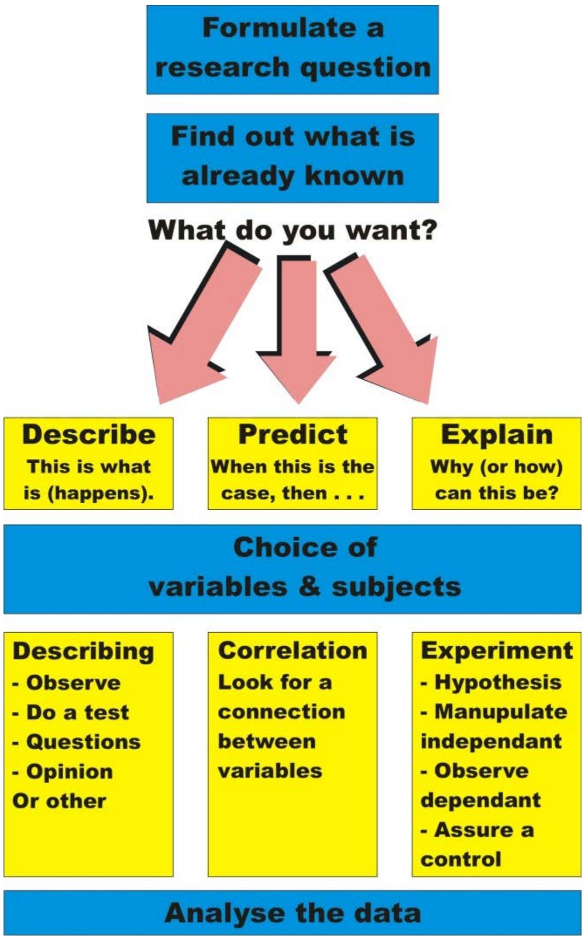
The underwater world is grossly under-sampled. The often heard statement "we know more about the surface of the moon than about the bottom of the ocean" may be over-exaggerated, but the fact remains that it took until 1977 until entire photosynthesis-independent ecosystems around the "smokers" on oceanic ridges were observed for the first time (see picture). Both inland and coastal waters are visited by divers on a regular basis. One could imagine that the observations made by divers could provide the scientific community with information to fill data-gaps.

Projects in which scientists make use of external parties for the purpose of collecting samples or data are characterized by enthusiasm for possibilities of receiving cost-efficient data which would normally be hard to obtain. Often it concerns companies or people who travel to locations where sampling time-series would normally be costly. The opposite also exists. Rather than companies or the public in the service of science, Dutch "science-shops" place science in a position to serve the community. In this model, the public can address themselves to a "science-shop" with an issue for which they feel research is needed. If accepted, the project is allocated to a (group of) scientist. In both cases, the non-scientist are only involved in a part of the process.

The intent of this section is not to prepare divers for a (small) role in "official" science projects. The provided information will help towards becoming an assistant for scientists, but the goal is to provide enough information to engage in community-science (also known under the name "participatory research"). In community-science, the community (in this case scuba divers) do their own research projects. They formulate the questions to be answered, find out what is already known, choose the methods to be used, collect the data and interpret the results of the project. Such projects can be done with or without assistance from scientists. In "real science", the collected data and the conclusions these justify are the only important factors – the rest is just work. In community-science, all steps in the project are of equal importance, because each step provides learning opportunities. Community-science is about "learning by doing".

Research is done to get answers on questions. As a consequence, all research projects start by formulating a question. Such a question must be specific. Asking yourself "why visibility in fresh water varies" will not allow you to find an answer via research. There are too many variables involved. You need to have a question that is as specific as possible. For example: "what influence does rain have on the visibility in lake xyz?" Research questions deal with one issue at a time. If you need to address multiple issues, you have the option to ask multiple questions. A second and third question in the above example could be: "does the intensity and duration of daylight affect the visibility in lake xyz?" and "do differences in water temperature at 2, 5, 10 and 20 meters depth affect the visibility in lake xyz?"

Chances are that you are not the first person (or group) having questions on variation in visibility. It is very well possible that research has already been done. Probably not in lake xyz, but information on influences on visibility might be available. The second step after formulating a research question is therefore to study existing information. For that purpose you do an internet search. Find sources of information addressing your subject. The closer they are related to your project, the better it is, but it can be worth your while to expand the search to include a wider range of information (such as for example factors that influence visibility in salt water).



Before continuing the project, it is now time to look at your question and to decide in which (of three) category it belongs. Do you want to describe, predict or explain? Describe would simply mean that you observe to collect true and reliable information about a subject. True and reliable information is a prerequisite for developing understanding. With regard to visibility this could simply mean that the visibility in a lake in measured on a daily basis and on the same location in order to have **correct data** on variations in visibility.

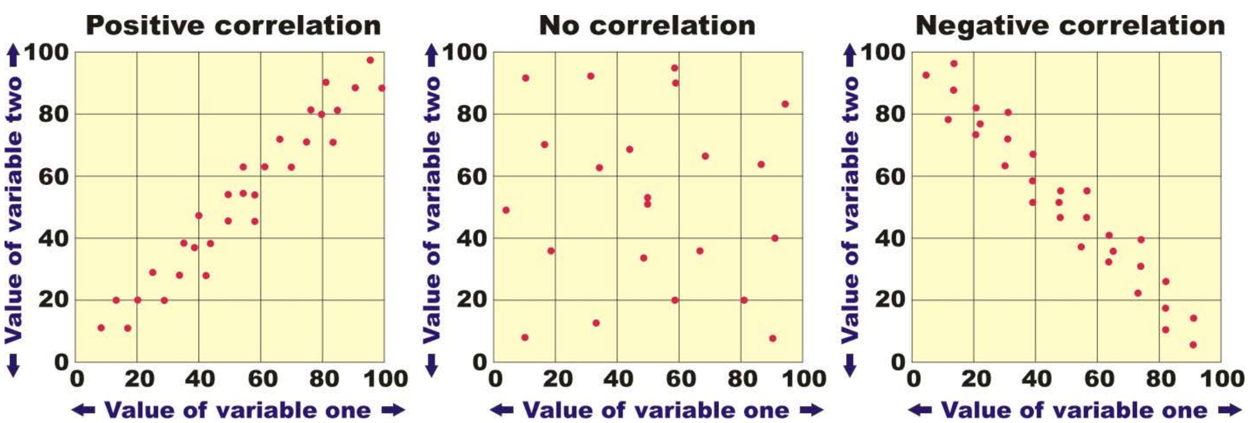
As diver you might desire to **predict** visibility. In order to do that, you need “cause and effect” relationships. You are looking for correlation. Positive correlation means that two things happen together. For example “after an hour or more of 2mm/hr. of rain, the visibility is reduced.” Negative correlation means the opposite. For example: “if the number of daylight-hours is reduced to less than eight, visibility improves.” If one variable decreases, the other increases. With the example of rain and visibility, it is rather clear which one is the cause and which one the effect. You can hardly expect bad visibility to cause rain. This is not always the case. Sometimes it is possible to establish correlation, but without being able to tell for sure which variable is causing changes in the other. Also be aware that correlation does not at all have to mean that there is cause and effect. There can very well be a third factor that is the cause of both of your observations.

So, the first category deals with “what happens” and the second with “when does it happen”. A last type of question deals with “why or how does it happen”. In this case more detailed information might be needed. To answer the question, you have to start with an assumption. Based on your question you make a statement called a hypothesis. For example: “if the number of daylight-hours is reduced to less than eight, visibility in lake xyz improves **because** plankton growth will be substantially reduced”. In this statement, the number of daylight hours is the independent variable and plankton growth (and with that the visibility) the dependent variable. As a researcher you must now manipulate the independent variable (artificially change the number of daylight hours) and observe what happens to the dependent variable. While doing this, you need a control. The control is a sample (or situation) to compare. In the control everything is the same as with the dependent variable with the exception that the independent variable is not manipulated. The difficult part of this type of research is to make sure that only the independent variable changes and nothing else. After all, if not only the number of hours of light change, but the water temperature as well, which one is then the cause of the changes in visibility?

The choice for one of the three categories is decisive for all remaining aspects of the research project. We will start the explanation with the simplest form, which is describing. Collecting data can be done in different ways. One technique is naturalist observation. A question could for example be: do sea urchins change their location and, if yes, at what average speed. For that purpose you could mark individual sea urchins by sticking (for example) the isolating plastic from electrical wire on their pins, note the time and mark their location. In a next dive you now measure the distance covered and take note of the time again. Naturalist observations can be biased. The behaviour of an organism could be influenced or even caused by the observer. This "reactive behaviour" is mostly not the information you are looking for (except of course when you are researching how an organism reacts to divers)

Your research could also be about divers or the general public. When your subjects are humans, you have additional tools available. You could ask questions to measure behaviour or opinion: "do you verify the cleaning products you buy for the absence of phosphate?" or "do you think that diving should be prohibited in this lake?" You could also measure differences in understanding or knowledge between different groups of people. As an example you could prepare a test to measure environmental awareness and use it on different groups of people. The intent of this type of research is not to identify a cause or a reason for something. It is simply about establishing (measuring) something. It is therefore often the first step in a longer research process. After establishing something, the question of how and why can be addressed in a next research step.

If you are looking for correlation, you must measure multiple variables simultaneously. Sea urchins feed mainly on algae, but can also feed on sea cucumbers and a wide range of invertebrates, such as mussels, and sponges. Assuming that sea urchins relocate when their current location does not provide enough food, you could add data on the environment where a sea urchin is located to the data on distance covered. Finding that sea urchins on a rock covered with algae and sponges cover less distance than sea urchins on a sandy bottom will provide you with a (negative) correlation between available food and distance covered. A research project on correlation cannot provide you with a cause and effect relationship. The rock will not only have more available food, but also has a different structure than sand while algae and sponges could very well hinder the sea urchin in its movement. To establish why a sea urchin travels further on sand than on rock, you would have to do an experiment in which only one variable is changed, while all other remain the same. Correlation research is still important, because there will be many cases in which it would not be acceptable to do the manipulations to the environment that would be required for a valid experiment.



Doing an experiment requires some thought. In an experiment, one factor (the independent variable) must be manipulated while all other factors remain unchanged. At the same time you must "control" all other factors that could have an influence on your dependent variable. If that is not possible, a "control situation" is needed in which everything is the same as in the experiment, with the exception that the independent variable is not manipulated. That allows comparing the results of the experiment with what would "normally have happened in the current conditions".

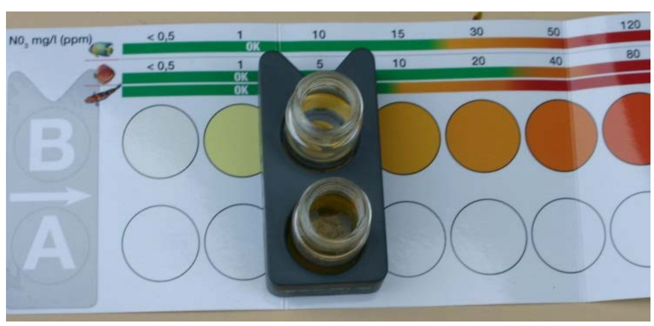
Underwater, this cannot always be done. Imagine you would want to experiment with the assumed negative influences of eutrophication on a coral reef. As was addressed in the previous chapter, on land a nutrient rich environment can be just metres away from a nutrient poor spot. Underwater, nutrients are distributed much faster and more evenly. So, how do you load only part of a reef with nutrients (without affecting the rest of the reef), how do you make sure that all other factors like current, sunlight, presence of species (especially herbivorous) do not change and are (on top of that) identical to the “control reef”? The required effort is probably beyond what is reasonably possible.

When doing an experiment, you have to answer (a part of) the question that stands at the basis of your project. Your answer will become your hypothesis. In a hypothesis you formulate what you know (or think) is going to happen. Predicting what is going to happen is much more difficult than explaining an event in hindsight. It requires a profound understanding of a situation. Formulating a hypothesis and doing a successful test that supports it are the biggest challenge of this research method. To test a hypothesis, you have to operationalize the variables. That means that you have to figure out a way to measure the probability of your hypothesis.

Let’s say that your research question is asking if an octopus is able to learn. Your hypothesis would then be that the octopus living on your house reef is able to learn. Your problem is that you have to decide on a method with which you can measure learning. “Learning” cannot be measured until you come up with a very specific action that can measure that learning did take place. You could consider presenting a shrimp in a pickle-jar. This would require the octopus to twist the lid to get access to the food. As the octopus is not used to jars with a lid, it will probably take a while before he figures out how to open it. For your experiment you measure the time needed. If learning did take place, you could assume the octopus to open the jar much faster the next day when you present it again. Variables to control would be the time of day (assuming that is related to the appetite of the octopus), the species and size of shrimp to be presented (should be identical), how tight the lid is placed on the jar, and so on.

Methods for Research

If your project only requires you to measure distance or time, this can easily be done with a watch or measuring tape. Counting the number of organisms (or other) in a specified area can be simplified with a grid. You can also consider the use of a line to mark an area on a sloping bottom to observe variations with increasing depth. If your project involves small organisms, it may be necessary to take water samples for later observation under a microscope. Sometimes you need to improvise. If you need to quantify light intensity at different depths (for example if your project involves photosynthesis), you can use a simple photo camera to see which shutter speed the camera recommends (having manually set the ISO and F-stop). This will give you information on the light intensity. If your project addresses water chemistry, your measurements become more complicated.



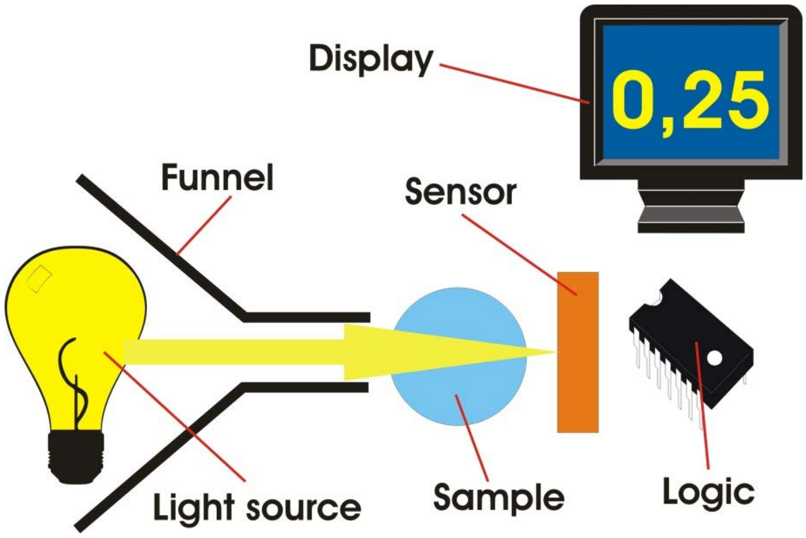
There are different methods to measure the chemistry of water. The cheapest and most readily available method is the use of a set of chemicals with a colour comparison chart. Such sets are available for a wide range of measurements. The intent of these sets is normally the monitoring of the water quality in aquariums, or for monitoring a well for drinking water. The range and accuracy of the sets are adapted to those purposes, rather than for the purpose of the environmentally interested diver. In both cases it is important to know if water values are “in the green”, rather than knowing the exact concentration of nutrients.

The consequence is that the detection limit can be higher than the nutrient content in natural waters and that the measuring scale has a low resolution. There are in most cases only 4 to 10 steps between extremely low values and extremely high values. Even if it is possible to estimate an intermediate between two colours, the resolution is often not satisfying.

The procedure is as follows. You fill two small containers with the water to be sampled. The chemicals are only added to one of the bottles. After adding the chemicals you have to follow the instructions that came with the set. This may involve shaking, a waiting period, a required minimum water temperature or other. After the waiting period, the bottle with the chemicals in placed on the white field of the colour chart and the bottle without chemicals on the coloured field. To prevent too big an influence from ambient light, the lower part of the bottle is placed in a holder. You now slide the holder over the colour chart while looking from the top. When both bottles appear to have the same colour (one coloured by the chemicals over a white field, the other with the natural colour of the water and the coloured field under it) you have found the concentration of the chemical and can read the value on the top of the colour chart. You should note wether the set is meant for saltwater or freshwater, or both.

The next option is a single parameter photometer. Single parameter means that the instrument can be used for one type of measurement only. Universal photometers will be discussed on the next page. Although it might seem desirable to have a single instrument that can do multiple measurements, single parameter photometers have one big advantage – the instruments logic is set to provide the user with a direct reading of the concentration of the nutrient being measured. There are no parameters to be set, which limits the margin of error.

Single parameter photometers are used only with chemicals intended for the instrument. The functioning is based on the sample being placed between a light source and a sensor. The sensor takes the coloration of the intended chemical into account. A different chemical (with another colour reaction) would not result in measurements that the logic of the instrument can interpret correctly.



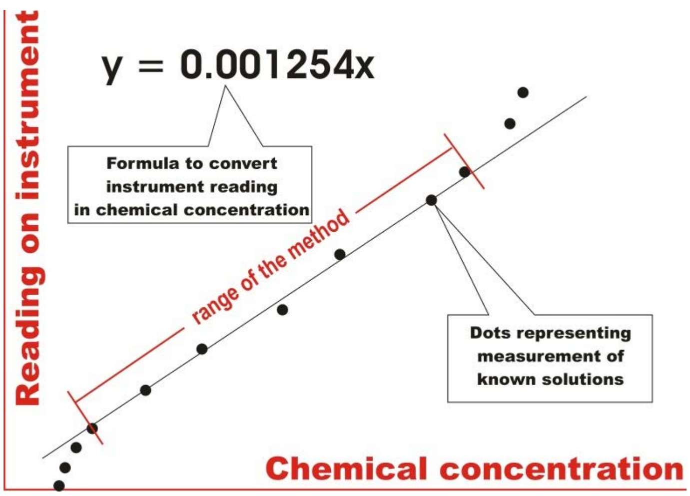
The quantity of light (in the colour or frequency affected by the chemicals) that falls on the sensor is reduced by the level of coloration in the sample. The more of the chemical there is in the sample, the less light that will reach the sensor. The intensity of the light is communicated to the logic of the instrument. The logic then assigns a numeric value to the light intensity. This value can be read on the display immediately as the nutrient content of the water sample. The display gives a reading directly in ppm (or mg/l). It is the presence of the logic and the display that makes the difference between a single parameter and universal photometer. The universal photometer stops at the sensor. The reading given by such meters is the light intensity measured by the sensor (in a voltage or resistance in ohm). In this case it is up to you to convert that reading to a nutrient content in mg/l.

Also in a photometer, the “natural colour” of the water must be taken into account. This is done with a “zero setting”. To zero the instrument, a cuvette (small bottle) with the sample water, but without chemicals, is placed in the instrument. You then push the “zero” button. The instrument will now calibrate for the colour of the water itself. This is done to assure that only the change in colour is taken into account in the reading of the concentration of the chemical.

As with any procedure involving chemicals, you need to follow the procedure with respect to exact measurements of water, powders and drops to be added, shaking, stirring or waiting periods. The instructions for use that comes with the instrument will provide you with all the details on the procedure to be followed. A photometric analysis of samples offers a high resolution. Measurements are given in small steps because the sensor can register differences that are hardly visible to the human eye.

Universal photometers can be used to get a reading on the coloration of various water samples with chemicals that induce colouring at the presence of certain chemicals in the sample. As the photometer “does not know” what you are measuring, the instrument cannot help you with transferring the reading to a chemical content in the water. The flexibility comes with the inconvenience that you will need to do the calculations yourself. Unfortunately, that is not the only inconvenience. You first have to find out how to do the calculation and that will require you to have readings of samples with a known concentration. If you do not have these, a universal photometer is useless.

The working principle of a universal photometer is thus the same as we have seen in the single parameter photometer, but without the luxury of providing a reading of the nutrient concentration directly. The advantage is that a single instrument can be used for various purposes and that the instrument also provides readings below the threshold level. Readings below that level are not accurate, but at least give an idea of the situation. Single parameter photometers “refuse” to give a reading when the sample falls outside of the range for which the meter has the accuracy promised in the product specifications.



To allow the readings on the volt or ohm meter to be converted in a nutrient content, you need a set of readings for water samples with a known concentration. An easy way to obtain such samples is by ordering them via a distributor of selective membrane equipment (discussed later). That sort of equipment requires the use of calibration samples.

The known solutions are used to create a regression line. Once this line is established, accurate readings of any solution between the calibration points can be done. The regression line can be extended below the lowest known concentration and above the highest. Readings in that area can however not be assumed to be accurate. The accuracy within the “verified” range can only be assumed to be accurate to the level at which the measured points fall on (or close to) the regression line. The point where the reading of known samples begins to move away from a straight line is to be considered the maximum range of the chemicals used.

Imagine you have 3 known solutions (1, 10 and 100 mg/l nitrate). You can easily use these to create 5 samples with known content – the 3 stock samples and a 50/50 mix of the 1 and 10 mg/l (giving a 5.5 mg/l sample) as well as a 50/50 mix of the 10 and 100 mg/l (giving a 55 mg/l sample. Each sample is first inserted in the instrument to "zero" for the natural colour of the liquid. Then the chemicals are added and shaking and waiting time requirements respected. The sample is then measured for meter reading. The procedure is repeated for the other known solutions. To create a regression line (and with that a formula to calculate the nutrient content), you are advised to use a computer.

Some manufacturers of universal photometers supply regression lines for a variation of chemicals with the instrument. With any photometric procedure, you have to prevent ambient light from corrupting the measurements. If the photometer is not equipped with a cap to block sunlight, you should only use it in the shadow. You might also be able to cover any parts where light is likely to penetrate the instrument.

All the methods discussed thus far have required the use of chemicals. This is not the case for ion selective membrane equipment. Ion selective membrane equipment has a probe that is held in the water. A membrane (selective) only allows the target chemical to enter the measuring chamber of the probe. In the chamber the ion activity is measured, giving a reading that informs you of the concentration of the target ion.

As we have seen for photometer equipment, in this case there are also two options. The probe can be connected to an instrument that is programmed to directly give a reading on the concentration of the chemical in ppm, or it can be connected to an instrument that gives a reading in volt or ohm (depending on the circuitry). In the first case calibration of the probe is needed, in the second case you need to create a regression line for the probe.

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