PROJECT NATURE

PROJECT NATURE NEWSLETTER

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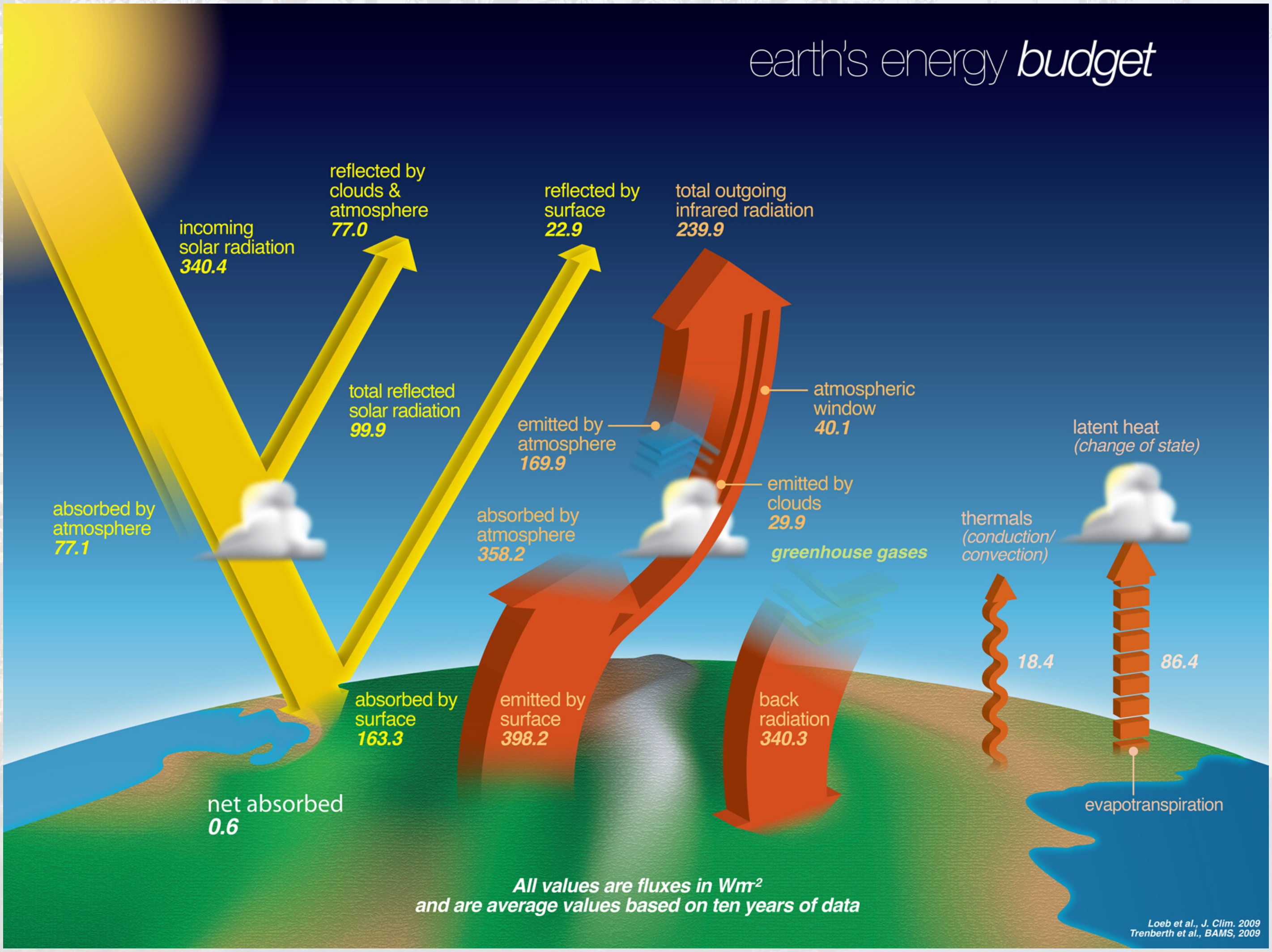
Ecosystem - II

The Biotope

The biotope or the abiotic component of the ecosystem is comprised of the non-living elements of the environment, such as the sun, the atmosphere, water, and soil, which contains minerals and other nutrients. The biotic (living) and abiotic (non-living) components of the ecosystem interact with one another in numerous ways. These interactions between the living organisms among themselves and with their environment take place through two main forces — flow of energy, and cycling of nutrients and water through the system. Water is cycled through the ecosystem by means of evaporation (transforming from liquid state to water vapor) of surface water from ocean and land, transpiration (water lost by plants through evaporation from its aerial parts, such as leaves, flowers and stems) and precipitation (in the form of rain, hail and snow). Nutrients from the soil are drawn by the plants, which are then consumed by animals. After both the plants and animals die, they decay, and the nutrients return back to the soil. Hence, the flow of energy and cycling of water and nutrients connect the biotic and abiotic components of the ecosystem.

Earth's Energy Budget

Earth's energy budget describes the balance between the radiant energy received from the sun and the energy that is returned to space. The primary source of all energy on Earth is the sun. Globally, the land surfaces, oceans and atmosphere collectively absorb an average of 240 Watts per square meter, over the course of a year. Owing to its spherical shape and being tilted from the vertical with respect to its orbit, the solar energy is not distributed equally on the planet — spatially or temporally. For example, in the tropics, more energy is absorbed than emitted, creating a surplus of energy. At high latitudes, there's a corresponding energy deficit. This unequal spatial distribution of energy across the planet drives the atmospheric and oceanic circulations. Hence, the atmospheric and oceanic systems constantly work to redistribute this energy through convection, evaporation, and precipitation, in the form of ocean currents, winds, rainfall, and other climatic phenomena. This redistribution of energy through the different systems of the planet is referred to as Earth's "***heat engine***".



Graphic Souce: www.nasa.gov

Energy from the sun is mainly in the visible part of the electromagnetic spectrum. Approximately, 29% of solar energy that arrives at the top of Earth's atmosphere is reflected back to space by clouds, particles in the atmosphere and bright surfaces on the ground, such as snow and sea ice. Of the 71% energy that enters the Earth's geosphere, 23% is absorbed by water vapor, dust and ozone, and the remaining 48% passes through the atmosphere and is absorbed by the Earth's surface.

After redistributing the sun's energy through Earth's systems, the Earth's engine, as any thermodynamic heat engine, must reject part of the energy, which it does as thermal radiant energy, mainly in the infrared part of the electromagnetic spectrum, back into space. This net flow of energy into and out of the Earth's system is called **Earth's energy budget**.

The Earth's systems — atmospheric and oceanic — are constantly trying to maintain a balance between the energy received from the sun and the energy radiated from the Earth back into space. If this radiative equilibrium is disturbed — either by natural phenomena, such as volcanic eruptions, or by human-activity — the planet's temperature will increase or decrease in order to restore the energy balance.

How is Earth's Energy Budget Measured?

NASA's ***Clouds and the Earth's Radiant Energy System*** (CERES) project makes satellite-based observations to measure the ***Earth's radiation budget*** (ERB). The project has been collecting data since 1997, using seven instruments installed on five satellites (TRMM, Terra, Aqua, S-NPP, and NOAA-20). The project's goal is to produce a long-term, integrated global climate data record for detecting decadal changes in the Earth's radiation budget from the surface to the top-of-atmosphere. This would enable improved understanding of how Earth's radiation budget varies in time and space and the role that clouds and other atmospheric properties play. Such comprehensive data collected over an extended period of time would support and improve climate model evaluations.

Biogeochemical Cycle (or Nutrient Cycle)

Elements such as carbon, hydrogen and oxygen, and nutrients, such as nitrogen, sulfur and phosphorus, provide the essential building blocks for all life in the ecosystem. (Hydrogen, oxygen, carbon and nitrogen alone make up almost 99 percent of the mass of most cells.) For life to be sustained on the planet, these elements must be constantly cycled through the ecosystem. The biogeochemical cycle considers the biologic, geologic and chemical aspects of the cycle of these elements. The cycle can be considered to have a reservoir or pool of nutrients and the parts of the system that facilitate the exchange and cycling of these nutrients between the biotic and abiotic components of the ecosystem.

These life-building elements, among additional supporting elements, such as calcium and iron, are present in the environment, usually in small proportions, but the living organisms are able to capture and concentrate them to combine in different ways to form cells. When the organisms die, these elements are released back into the environment, and a perpetual cycle of these elements takes place in the ecosystem, alternating between inorganic (when the elements are present in the rocks, soil or air) and organic (when they are present in the living cells of an organism) states. And thus, the living organisms drive the biogeochemical cycle.

Hydrologic Cycle

All the water on Earth, which includes the liquid and frozen surface water, the groundwater held in sedimentary rocks and soil, and the atmospheric water vapor, constitutes the *hydrosphere*. The hydrosphere consists of discontinuous layers of water reservoirs, such as the atmosphere, oceans and groundwater, and the process by which it is transferred from one reservoir to another or from one state to another, is called the hydrologic cycle. Oceans constitute over 95% of Earth's water. The majority of Earth's freshwater is held deep within the rocks as groundwater. Water evaporates from land and ocean surface, driven by solar energy, and is held in the atmosphere for about 10 days before precipitating as rain or snow. Evaporation accounts for 90 percent of water in the atmosphere. The remaining 10 percent is owed to plants, which release water into the atmosphere through transpiration. Over oceans, evaporation exceeds precipitation, which implies that the balance is transported to the land as water vapor where it precipitates as rain and snow. A small fraction of the water falling on the land seeps into the ground to accumulate as groundwater, while the rest runs off into lakes and rivers. From there, the water is carried back to the ocean primarily through rivers, and a small fraction through groundwater.

Carbon Cycle

Carbon is the chief element upon which all life is built. All organic (or living) matter on Earth is made up of carbon, and it is the conversion of the inorganic carbon into living tissues that creates life. In the inorganic state, carbon is present in the atmosphere, in the hydrosphere, and in the lithosphere (rocks and soil). In the atmosphere, carbon is present in gaseous phase in the form of carbon dioxide (CO_2); in the water, the atmospheric carbon dioxide dissolves to form carbonic acid (H_2CO_3); and is present in rocks, such as limestone in the form of compounds, such as calcium carbonate ($CaCO_3$); in the soil it is present in the biomass of dead organic matter as well as trapped in the permafrost (frozen soil) of the arctic regions as methane (CH_4). Some part of carbon constantly cycles between the atmosphere and the hydrosphere, through dissolution of the atmospheric carbon dioxide in water (to form carbonic acid) and then released back into the atmosphere. Carbon is continuously dissolved out of the rocks through the movement of acidic water.

The biological or the organic carbon cycle starts with green plants converting atmospheric carbon dioxide into living tissue through *photosynthesis*. From there, carbon propagates further up the food chain. Animals continue to cycle the carbon by releasing carbon dioxide back into the atmosphere through respiration. When terrestrial plants and animals die, the carbon goes back into the soil in the form of biomass. In marshes, such as Florida's everglades, the dead organic matter would accumulate over millions of years to form fossil fuels, such as coal. In the ocean, when sea creatures die, the carbon in the hard shells of sea creatures present as calcium carbonate, settles on the seabed, which over geologic time forms sedimentary rocks, such as limestone. Similarly, when the *plankton* (microscopic marine organisms) die and settle on the ocean floor, the deposit turns into oil or petroleum over time.

Primary Productivity

Solar energy is chiefly responsible for all life on Earth. Most of the energy reaching Earth's surface is at wavelengths unsuitable for photosynthesis. Only 1 to 2 percent of the sun's energy is captured by green plants, which supports all the life forms on the planet.

Plants play a major role in the global carbon cycle. The total amount of energy used by algae and plants (*autotrophs*) in producing chemical energy of organic compounds in a given ecosystem is measured in terms of **gross primary productivity**. Not all of this chemical energy, produced by photosynthesis, is converted into organic matter. A large part of it is used up for plant's own metabolic needs, such as breaking down carbohydrates, fats and proteins. The energy used in forming plant tissues and organic matter is called the **net primary productivity**. Alternatively, net primary productivity can also be defined as the amount of carbon dioxide taken by plants during photosynthesis minus the amount of carbon dioxide released during respiration (metabolizing sugars and starches for energy). Primary productivity is dependent on seasonal changes. For example, in mid-latitudes, productivity peaks in the summer for each hemisphere, followed by a gradual decline in fall and winter. Tropical forests have high productivity year-round, however, their productivity is highest in the dry season. This is because during the dry season, the trees have plentiful supply of groundwater that builds up after the rainy season, and they grow better when clear skies in the dry season allow more sunlight to reach the forest.

Among terrestrial ecosystems, the highest net primary productivity occurs in rainforests, swamps and marshes, while the lowest productivity occurs in deserts. In aquatic ecosystems, estuaries (region where rivers meet the sea), algal beds and reefs have the highest net primary productivity. Hence, such high-productivity ecosystems are particularly important and critical to the health of the global environment. Similarly, the rate at which the consumers convert the chemical energy in their food into their own biomass is referred to as the **secondary productivity**, and is usually 10 percent. In general, the efficiency at which energy is transferred from one trophic level to the next is called the **ecological efficiency**. Productivity is often measured in terms of increased biomass — mass of all living organisms — in a given area.

How is Primary Productivity Measured?

Estimate of the net primary productivity is made from data collected from satellites. NASA's ***Moderate Resolution Imaging Spectroradiometer*** (MODIS) instrument installed on satellites ***Terra*** and ***Aqua*** makes detailed measurements across the planet. Terra's orbit around the Earth is timed so that it passes from north to south across the equator in the morning, while Aqua passes south to north over the equator in the afternoon. Hence, MODIS installed on each satellite view the entire Earth's surface every 1 to 2 days, acquiring data in 36 spectral bands (or groups of wavelengths). MODIS plays a vital role in developing interactive Earth system models that are able to accurately predict global changes to assist policy makers in making sound decisions and formulating policies consistent with the protection of the environment.

Nitrogen Cycle

Nitrogen is an important element for plant growth. Just like carbon, nitrogen also cycles through the atmosphere, hydrosphere and lithosphere. Nitrogen exists mainly in the atmosphere as nitrogen gas, and makes up almost 80% of the atmosphere. Plants need nitrogen for growth but unlike carbon dioxide, they cannot consume nitrogen gas. Instead, they assimilate nitrogen in the form of ammonium (NH_4^+) and nitrates (NO_3^-). The process of converting nitrogen gas from the atmosphere into ammonium and nitrates is called *nitrogen fixation*, and bacteria are mainly responsible for performing this important function. Animals can only consume nitrogen in the organic form, through plants. When plants and animals die, the decomposers of the ecosystem convert the organic nitrogen from the biomass to ammonium, which can be used up again by growing plants, and a small portion of the organic nitrogen is converted into nitrogen gas and returned back to the atmosphere by the denitrifying bacteria as they break down the nitrates to obtain oxygen. A similar nitrogen cycle happens in the marine ecosystem, where nitrogen gas dissolves into the surface ocean water, which is then fixed by marine microbes into ammonia and nitrates. Aquatic plants consume the "fixed" nitrogen, and is then carried through the marine community via the food chain. After the marine organisms die, they decompose and release the nitrogen in the form of ammonium, some of which is re-used by organisms and the rest is converted back into nitrogen gas by the denitrifying bacteria.

Sulfur Cycle

Another important element for lifeforms is sulfur. Sulfur is mostly held in the rocks from which it weathers to form sulfates (SO_4^{2-}), which can then be assimilated by plants and microbes. Just like nitrogen, animals can consume sulfur only through plants. When organisms die, some of the sulfur is held in the tissues of the decomposers, and some sulfur is released back as sulfates. There is a continual loss of some sulfur from the terrestrial ecosystems through runoff, and drained through rivers into oceans. Some sulfur also enters the ocean directly from the atmosphere. In the ocean, it cycles through the marine community through the food chain. When organisms die, the sulfur deposits as sulfate salts within ocean sediments, which over millions of years form sedimentary rocks, and are then brought back to the surface through tectonic activity. Sulfur is released into the atmosphere primarily in three ways — through sea sprays in the form of evaporated salts, such as dimethyl sulfide ($(CH_3)_2S$), through the microorganisms that undergo anaerobic respiration (respiration without oxygen) and release hydrogen sulfide (H_2S) gas, and through volcanic activity releasing sulfur dioxide (SO_2) gas.

Phosphorus Cycle

Phosphorus is the scarcest of all elements that are cycled through the biosphere, but extremely crucial to life as it is involved in the transfer of genetic information in the DNA (deoxyribonucleic acid) of all cells. It is also mainly present in rocks and is released through natural weathering. Phosphorus is an important nutrient for plants. Unlike carbon, nitrogen and sulfur, phosphorus is not present in the atmosphere since it does not occur in gaseous form. The phosphorus released from rocks occurs as phosphates (PO_4^{3-}) in the soil, which is taken up by plants, and carries up the food chain, and returns back to soil after the organisms die. In marine ecosystems, phosphorus reaches the oceans through river runoff, where it is first consumed by the plankton on the surface, and then moves up the food chain, finally settling on the ocean floor with ocean sediments after the organisms die.

The productivity of plants is often tied to the content of phosphorus, along with nitrogen, in the soil. Hence, these elements are of particular importance in agriculture.

Other essential nutrients, such as potassium, iron, calcium and magnesium, do not have a volatile gaseous form, just like phosphorus. These elements are stored in rocks and are released by weathering, and undergo similar cycling through the biosphere.

How is Nutrient Cycle Measured?

Scientists are able to study the cycling of energy and nutrients using techniques, such as **radioisotope tracers** and ***microcalorimetry*** combined with applied mathematics and computer models, which enables the ecologists to label, track and measure the movement of nutrients and energy through the ecosystem.

Humans and Ecosystem

Humans have made a major and lasting impact on the ecosystem. Starting about 12,000 years ago when we domesticated crops and invented farming, we started to control aspects of the ecosystem. That was the beginning of taking larger and larger control. Cattle and livestock came next as we domesticated other animals for our needs. [To learn about domestication, read the December 2019 issue of Project Nature newsletter.] Our civilization prospered, and as it grew, we continued to expand. And so did our demands. We cleared forests, grasslands, and prairies, and drained wetlands for more farmland and other development. And with that we lost the rich biodiversity that helped sustain the balance of the ecosystem. We prevented the natural forest fires from occurring and in doing so, not only did we thwart the cycle of natural succession, we also increased the propensity of larger fires.

Humans had already changed the face of the planet significantly by the 18th century. Then started the Industrial Revolution. *Terraforming* is the term that refers to altering the Earth's surface for human needs. Through agriculture, mining, industrialization and urban developments, we have now terraformed 75% of ice-free land on the planet. In our pursuit of more prosperity, we tried to extract even more from the ecosystem than what it was sustainably providing us. Our large-scale industrial agriculture demanded greater supply of water. When rainwater and other freshwater sources weren't enough, we tapped into the groundwater – the aquifers that accumulated over several thousand or even millions of years, and would take equally long to replenish. We straightened our rivers and streams, failing to realize that in doing so, we were impacting the entire aquatic as well as terrestrial ecosystem around the river that helped in maintaining good water quality and providing other benefits. [To learn about water quality, read the July 2019 issue of Project Nature newsletter.] We redirected and changed the course of streams and rivers, which has resulted in the drying of several freshwater lakes, such as the Aral Sea in Central Asia. Recent studies have found that in two decades, the global water demand would exceed the supply by 40 percent. The 2018 edition of the **United Nations World Water Development Report** (UNWWDR) stated that nearly 6 billion peoples will suffer from clean water scarcity by 2050.

We have disrupted the energy and nutrient cycles that maintained the Earth's systems in balance. Earth's heat engine keeps the planet in a radiative equilibrium when the flow of incoming solar energy is balanced by an equal outflow of heat into space. Oceans, forests and soil are the major reservoirs of carbon, and help maintain an equilibrium between the carbon in the atmosphere and the carbon sequestered in water, soil and organic matter. We have depleted these carbon-sequestering reservoirs through deforestation, clearing of prairies and draining of wetlands. This has disrupted the equilibrium, resulting in more carbon released into the atmosphere — causing global warming. We have added an incredible amount of greenhouse gases in the atmosphere, altering the carbon cycle, in such a short time that the Earth's heat engine is unable to reject the same amount of heat to space as it intakes, resulting in even further warming of the planet. Human activity, such as burning of fossil fuels and processing of metals, has released large amounts of oxides of nitrogen and sulfur, affecting the nitrogen and sulfur cycles. As rain falls through these gases, it creates the phenomenon known as **acid rain**, which in addition to being corrosive, weakens the trees and lowers biodiversity. Large-scale agriculture has disrupted the phosphorus cycle as we have added great amounts of phosphorus to the soil. Runoff from agricultural fields carries this phosphorus, along with other nutrients, and dumps it into lakes and rivers [To learn about runoff, read the September 2019 issue of Project Nature newsletter]. This extra phosphorus causes the population of the aquatic microorganisms to explode, which results in the **Harmful Algal Bloom** (HAB), like the one caused in Lake Erie. This algal growth floats on the surface and not only reduces the sunlight reaching the lower layers of the water body, but also decreases the available oxygen, resulting in suffocation of fish and other animals.

But this is not the final conclusion. We have the ability to change the course of things. There are numerous examples around the world that have demonstrated the viability of sustainable solutions and practices, which lead to restoration of the ecosystem goods and services. The **United Nations Environment Programme** (UNEP) fosters the **Integrated Ecosystem Management** (IEM) approach "to sustain ecosystems to meet both ecological and human needs". These are well-researched solutions available to us. We just need to act upon them!

Ecological Footprint

The **Global Footprint Network** (footprintnetwork.org) calculates the **Ecological Footprint** (EF) — a concept originally developed by William Rees and Mathis Wackernagel at the University of British Columbia — to quantify and measure the impact of humans on Earth and its resources. The EF measures the ecological assets that a given population requires to produce the natural resources it consumes and to absorb its waste, especially carbon emissions. The Global Footprint Network also measures the **biocapacity** of a given city, state or country, which represents the productivity of its ecological assets, such as cropland, grazing land, forest land, and fishing grounds. Such quantification is extremely helpful to the local, state and federal governments of the countries of the world in formulating policies that improve sustainability and well-being of the people. It also helps the citizens in understanding their impact on the planet.

Both EF and biocapacity are expressed in **global hectares** — globally comparable, standardized hectares with world average productivity. If a region's biocapacity exceeds its Ecological Footprint, it has an **ecological reserve**. If a population's Ecological Footprint exceeds the region's biocapacity, that region runs an **ecological deficit**. The world's ecological deficit is referred to as global ecological overshoot. Since the 1970s, humanity has been in an **ecological overshoot**, with annual demand on resources exceeding what Earth can regenerate each year. Based on vast amounts of data (available publicly at footprintnetwork.org), the Global Footprint Network estimates that today, humanity uses the equivalent of 1.75 Earths to provide the resources we use and absorb our waste. This means it now takes the Earth one year and eight months to regenerate what we use in a year!

The Global Footprint Network estimates the **Earth Overshoot Day**, which marks the date when humanity's demand for ecological resources and services in a given year exceeds what Earth can regenerate in that year. For 2020, the Earth Overshoot Day is August 22, 2020. (*Note: This year, the Earth Overshoot Day is over three weeks later than last year, thanks to the reduced carbon emissions as well as a decrease in wood harvest due to COVID-19 lockdowns.*)

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Epilogue

Humans are not separate from the ecosystem. We evolved on this very planet in this very ecosystem, and hence are an inseparable part of the system. As our species developed into more modern humans with higher intelligence, we invented newer and better methods for survival, which soon gave us an edge over all the other organisms and made us into a dominant species on the planet. But somewhere along the way, we lost humility and got carried away with our pride in “engineering” nature.

In our pursuit to gain more and more “control”, we got greedier and greedier. The pride in our engineering prowess soon turned into arrogance. And in that arrogance, we failed to see that we were never in control. The current global pandemic of COVID-19 is a stark reminder of that!

We rely on the ecosystem for our own survival. The air we breathe, the clean water we drink, the food we eat — collectively referred to as the *ecosystem goods and services* — are the basic life-supporting necessities that the ecosystem provides us with. We may have invented high-tech large-scale farming tools, but for pollination, we still desperately rely on nature’s pollinators. Hence, it’s only in our own best interest to protect this precious “life-support”. It’s rather ironic that the most intelligent species on the planet is unable to comprehend this basic and fundamental fact!

Both the biotic and abiotic components of the ecosystem play an important and crucial role in keeping the Earth’s systems balanced and stable. The ecosystem is always in the state of dynamic equilibrium, such that there are always minor disturbances, but the system adapts itself to attain a new equilibrium. However, if the disturbances become larger than what the components of the system can counteract to stabilize the system back to equilibrium, the ecosystem is thrown off-balance. In the past, such disturbances have been natural cataclysmic events, which have resulted in mass extinctions. Such events destabilize the system and it takes the planet several million years to achieve equilibrium. But the “new” planet is always very different from the one before the event. For example, the dinosaurs thrived on the planet for almost 200 million years until the drastic events at the end of the *Cretaceous* period, some 65 million years ago, wiped them out, among many other species. The system was destabilized, but it eventually found a new, albeit a different equilibrium, paving way for mammals and eventually for the human species to come forth and thrive on the planet!

Human activity has disturbed the Earth systems in such a short period of time that many scientists fear it is akin to the cataclysmic events of the past, where if the current trends were to continue, the ecosystem — as we know it — may not be able to bounce back. The question is not whether the planet will survive this destabilization. The planet will find a new equilibrium, just like it has several times before throughout the course of Earth's history. The question is whether the human species will be able to survive!

We have increasingly detached ourselves from the natural world to the extent that it becomes extremely difficult to think of the role humans, as a species, play in the ecosystem. Unlike all the other organisms in the ecosystem, we only seem to take from the system and not give anything back in return. A hard implication of this fact is that while the ecosystem can survive without us, we cannot without the ecosystem!

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