



PHYTOPLANKTON: THE ESSENTIAL DRIFTERS OF THE GLOBAL CARBON CYCLE AND DRIVERS OF MARINE DISEASES

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Abstract: Phytoplankton are abundant in this world and predominant in the minor and major water bodies all around the world. They are the primary producers playing a key role in influencing the global cycle; by this, they also aid the marine food webs and the freshwater food webs in a larger volume. They are generally photosynthetic in nature and play an important role in the balance of the global carbon cycle. Few various phytoplankton species also play their own unique roles in the global carbon cycle. They can negatively impact the worldwide nations due the variations in various human activities, climate change, increase in temperature, decrease in the concentration of few dissolved gases and other global environmental changes. The overabundance of nutrients can lead to harmful algal blooms. They can release harmful toxins causing various diseases that could be severe for humans and also act as a threat to aquatic life.

Key words: Primary producers, marine food webs, freshwater food webs, global carbon cycle, global environmental changes, algal blooms, toxins, diseases.

1. INTRODUCTION

Phytoplankton are generally microscopic in nature. They range in size from less than 1 μm to 10^{-3} μm . They are mostly unicellular organisms, photosynthetic (autotrophs) and are essential by forming the base food for the aquatic organisms. 'Phytoplanktons' are free-floating, photosynthetic, aquatic microorganisms, which move from one place to another, either actively by their locomotory organs (flagella) or passively by water currents. The name 'phytoplankton' came from the Greek words 'φυτόν' (phyton), meaning 'plant', and 'πλαγκτός' (planktos), meaning 'wanderer' or 'drifter'. The term 'plankton' was first used by the German biologist Victor Hensen in 1887. According to Hensen, 'plankton included all organic particles which float freely and involuntarily in open water, independent of shores and bottom (Pal *et al.*, 2014). Phytoplankton also pump out oxygen and sequester carbon. Five hundred million years ago, a bloom of plankton created the breathable oxygen-rich atmosphere that humans depend on today. Phytoplankton are of different species, which are Dinoflagellates, Diatoms, Coccolithophore, Cyanobacteria and Green algae (Stegman, 2024). Carbon makes up the backbone of all life on Earth. It's found in the cells of all living things, is abundant in rocks and sediments, and is also found in the atmosphere and ocean. Carbon does not remain in one place. Individual atoms move from one reservoir to another: between the atmosphere and the oceans, from plants to animals to decomposers, to sediments and rock, and eventually back to the atmosphere. This movement of carbon from one place to another, which is caused by natural and human processes, is known as the carbon cycle. Plant-like phytoplankton living in the ocean convert carbon dioxide into sugars that feed marine ecosystems. (Basilio, 2024). As phytoplankton die, and the creatures above them in the food web die or poop, a small fraction of the carbon the phytoplankton took in during their lifetimes sinks down below the sunlight layers of the ocean. As this organic matter sinks, it becomes food for deeper dwelling animals, but also nourishment for bacteria, which release it back into inorganic forms like CO_2 . This slow movement of carbon from the atmosphere, through phytoplankton, up the food chain, and into the deep ocean is called the biological pump, and is a key player in

the Earth's carbon cycle. The suspended inorganic carbon in the deep ocean alone amounts to about 70 times more carbon than is found in the atmosphere (Dutkiewicz, 2022). The global carbon cycle comprises the carbon stocks, or pools, in the atmosphere, ocean, and terrestrial biosphere and the fluxes that link these pools, driven by a complex set of biological and geochemical processes (Steve, 2023). Plankton are vital components of marine and freshwater water-column ecosystems. They also make major contributions to global biogeochemical cycling, and ameliorate atmospheric accumulation of carbon dioxide by 'pumping' carbon to the deep sea. The integrity of these roles is under threat from climate-related physiological impacts on individual organisms and on the wide-scale distribution of plankton communities (Brierley, 2017). Phytoplankton manages the responsibility of bringing the carbon dioxide from the atmosphere to the marine bodies as they can photosynthesize and restore the oxygen gas. At least 50% of the oxygen present in Earth comes from the marine regions, which is by phytoplankton. However, there are negative effects which afflict oceanic and terrestrial life, for example, Algal blooms. Algal blooms are dense layers of tiny green plants that occur on the surface of lakes and other bodies of water when there is an overabundance of nutrients (primarily phosphorus) on which algae depend. These are usually caused by Eutrophication. (Sumeep, 2017). Phytoplanktons have other harmful effects by releasing certain toxins which leads to diseases like Paralytic Shellfish Poisoning (PSP), Neurotoxic Shellfish Poisoning (NSP), Amnesic Shellfish Poisoning (ASP), Diarrhetic Shellfish Poisoning (DSP), Ciguatera Fish Poisoning (CFP), Harmful Algal Bloom-Related Illness, Skin irritations, Respiratory issues and Kidney disease (Biswajita, 2022).

2. PHYTOPLANKTON: SPECIES AND THEIR ROLES IN THE GLOBAL CARBON CYCLE

2.1 DINOFLAGELLATES

Dinoflagellates (Fig.1) sustain most of the marine food webs and play key roles in ecosystem functioning and biogeochemistry (Wei *et al.*, 2024). They are numerous one-celled aquatic organisms bearing two dissimilar flagella and having characteristics of both plants and animals. They are an important component of phytoplankton in all but the colder seas and are an important link in the food chain. Dinoflagellates range in size from about 5 to 2,000 micrometres (0.0002 to 0.08 inch). Most are microscopic, but some form visible colonies (Britannica, 2017). Three major nutrient mechanisms, phototrophy, heterotrophy and mixotrophy, are all found and adopted by various dinoflagellates species, and among them approximately 50% of dinoflagellates are phototrophic (Bi *et al.*, 2019). They have a pivotal role in converting inorganic carbon into organic matter through photosynthesis. They are involved in almost all stages of the marine biological pump and play a pivotal role in climate regulation, with the organic carbon they produce contributing significantly to the global organic carbon balance (Wen *et al.*, 2025). The harmful dinoflagellate is *Dinophysis norvegica*, which causes Diarrhetic Shellfish Poisoning (Fig.2).



Fig.1: Dinoflagellata (*Gonyaulax*)



Fig. 2: *Dinophysis norvegica* (Harmful algae)

2.2 DIATOM

Diatoms (Fig.3) are single-celled microscopic algae. Diatoms are characterized by their unique silicified cell walls (i.e., frustules) that are made of nanometer-sized particles of SiO_2 deposited in diverse, regular geometric patterns. The siliceous shells could not only provide the necessary support for the large vacuole, protect diatoms against copepod grazing, and thus maintain high abundance in the euphotic layer. They are found in most aquatic habitats and in damp terrestrial habitats and in many of these habitats the diatoms represent the most abundant and diverse algal class. They are an important component of the phytoplankton, benthos, and attached algal communities of marine and fresh waters. Species composition is highly sensitive to water quality and many species are habitat specific. Further, diatoms grow rapidly and under favorable conditions produce many cells within a short period (Cameron, 2013). They are playing a critical role in the biogeochemical cycles of chemical elements such as carbon. Diatoms are crucial climate modulators for their contribution to carbon dioxide absorption and the biological pump of carbon. diatoms, as a major group of phytoplankton, are believed to contribute approximately 40% of particulate organic carbon export and significantly affect the efficiency of the biological pump. They could make contributions to the export of organic carbon in several aspects, including their significant contribution to oceanic primary production, their proliferation potential and subsequent marine ranching, their large sizes and the essential role of silica frustules in protective function and ballasting sinking particles (Fu *et al.*, 2022).



Fig. 3: *Diatom*

2.3 COCCOLITHOPHORE

Coccolithophores (Fig.4) are unicellular, autotrophic organisms belonging to the marine phytoplankton that during certain phases of their cycle of life are able to produce calcium carbonate plates called coccoliths that cover the cell in a structure called coccosphere. This group is sometimes called calcareous nannoplankton. Cell size is usually lower than $30\text{ }\mu\text{m}$ and their reproduction is mainly by binary division (mitotic), although in several cases more complex processes have been observed. Once the cells die, their coccospheres, complete or disintegrated, descend to the sea floor where they constitute one of the most important contributors to oceanic sediments since the late Triassic (Flores, 2025). The coccolithophores are calcifying protists that have formed

a significant part of the oceanic phytoplankton since the Jurassic. Their role in regulating the Earth system is considerable. Through their secretion of a tiny composite exoskeleton (the coccosphere made of multiple coccoliths), the coccolithophores are estimated to be responsible for about half of all modern precipitation of CaCO_3 , in the oceans. Coccolithophores thus play a primary role in the global carbon cycle. The ecological and biogeochemical impacts of their skeletons are multiple and act on a wide range of ecological to geological time scales (De Vargas *et al.*, 2007). They have an ecological importance, particularly for carbon cycling and sequestration (Renshaw *et al.*, 2023). They also have a unique influence on the global carbon cycle by performing both photosynthesis and calcification. Coccolithophores influence ocean-atmosphere CO_2 exchange and the export of organic and inorganic carbon to the deep ocean through the ballasting effects of their calcium carbonate shells and subsequent sedimentation to the deep sea (Krumhardt *et al.*, 2017). The shells of the coccolithophores sink and become part of ocean sediments, locking away carbon.



Fig. 4: Coccolithophore

2.4 CYANOBACTERIA

The cyanobacteria (Fig.5) are unicellular, colonial or filamentous, freshwater/marine or terrestrial algae. The colonies are generally surrounded by gelatinous sheath. They often form blooms in polluted water bodies. Some of these organisms can fix atmospheric nitrogen in specialised cells called heterocysts. They are also referred to as blue-green algae. They have chlorophyll 'a' similar to green plants and are photosynthetic autotrophs (Taufiq, 2024). Cyanobacteria perform photosynthesis, using sunlight to convert carbon dioxide and water into glucose and oxygen. As one of the first organisms to produce oxygen through photosynthesis, they significantly contributed to the Great Oxygenation Event, leading to increased atmospheric oxygen and shaping Earth's current atmosphere. These eubacteria species contribute mostly to nitrogen fixation and oxygen cycle of the earth's atmosphere (Bettina, *et al.*, 2015).



Fig. 5: Nostoc Species

4. GLOBAL CARBON CYCLE

Carbon is an essential element for life and plays a pivotal role in regulating Earth's climate through its presence in the atmosphere as carbon dioxide. It is the chemical backbone of all life on Earth. The carbon cycle (Fig.6) describes the process in which carbon atoms continually travel from the atmosphere to the Earth and then back into the atmosphere. On Earth, most carbon is stored in rocks and sediments, while the rest is located in the ocean, atmosphere, and in living organisms. These are the reservoirs, or sinks, through which carbon cycles. Carbon is released back into the atmosphere when organisms die, volcanoes erupt, fires blaze, fossil fuels are burned, and through a variety of other mechanisms. Blue carbon is the term for carbon captured by the world's ocean and coastal ecosystems. Sea grasses, mangroves, salt marshes, and other systems along our coast are very efficient in storing CO₂. In the case of the ocean, carbon is continually exchanged between the ocean's surface waters and the atmosphere, or is stored for long periods of time in the ocean depths (NOAA, 2024). The phytoplankton plays an important role in the carbon cycle. Phytoplanktons die, and the creatures above them in the food web die or excrete and a small fraction of the carbon the phytoplankton took in during their lifetimes sinks down below the sunlight layers of the ocean. As this organic matter sinks, it becomes food for deeper dwelling animals, but also nourishment for bacteria, which release it back into inorganic forms like CO₂. This slow movement of carbon from the atmosphere, through phytoplankton, up the food chain, and into the deep ocean is called the biological pump. It is a key player in the Earth's carbon cycle. The suspended inorganic carbon in the deep ocean alone amounts to about 70 times more carbon than is found in the atmosphere (Isson, *et al.*, 2019).

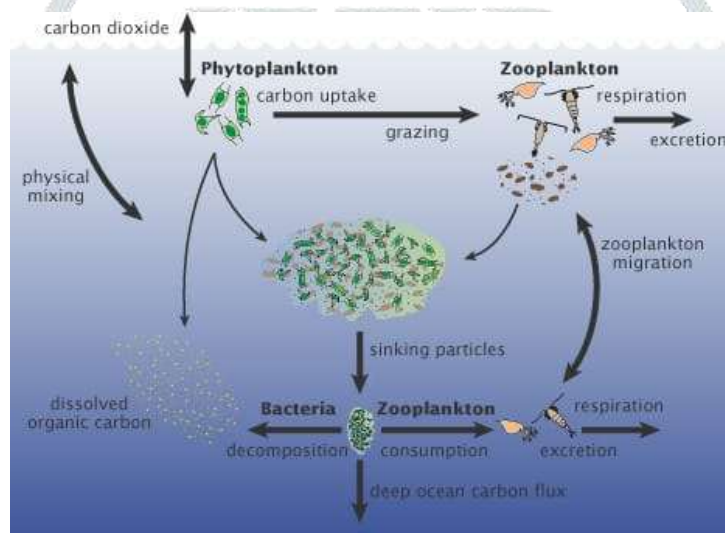


Fig. 6: Carbon Cycle

5. INFLUENCE OF CLIMATIC VARIATIONS ON PHYTOPLANKTON GROWTH DYNAMICS.

Phytoplanktons play a key role in biogeochemical cycles at global scale. Its functions mainly depend on factors like temperature, light intensity, nutrient availability. There can be other factors like, wind, flow of water, salinity and various other factors. However, if these factors are imbalanced with each other, this will affect the phytoplankton in terms of growth and functions. Phytoplankton dynamics in the ecosystem have been changing rapidly and that change is driven mainly by bottom-up climatic processes (Padmini *et.al.*, 2020).

5.1 TEMPERATURE

Phytoplankton have optimal growth temperatures. Deviations from this optimal range can lead to decreased growth rates or even mortality. The growth of phytoplanktons, metabolic processes, and photosynthesis accelerates when the water temperature rises, however if the temperature of water increases beyond its optimal range of temperature, it may kill the phytoplankton. Temperature shifts can also re-structure its community composition, favoring heat-tolerant species like cyanobacteria and green algae, while suppressing cold-adapted diatoms, resulting in altered biodiversity and ecosystem function (Barton *et al.*, 2019.)

5.2 LIGHT INTENSITY

Light intensity refers to the measure of the amount of light energy per unit area, often per unit time, that reaches a biological system, such as a plant leaf. It's a crucial factor influencing biological processes, particularly photosynthesis in plants. Phytoplankton rely on light for photosynthesis, but their response to light intensity is complex. At optimal light levels, their growth and carbon fixation are efficient. However, if light becomes too intense, it can damage their photosynthetic system leading to photoinhibition. Phytoplankton species also vary in their light tolerance, with some adapting better than others. This makes light a critical factor in determining their productivity, distribution, and survival in aquatic ecosystems (Hintz *et.al.*, 2022).

5.3 NUTRIENT AVAILABILITY

Nutrient availability is one of the primary factors for regulating the phytoplankton growth and community structure in all aquatic ecosystems. Nutrients limiting phytoplankton growth in the ocean are a critical control on ocean productivity and can underpin predicted responses to climate change (Browning *et.al.*, 2022). The availability of nutrients in the upper ocean frequently limits the activity and abundance of these organisms. Experimental data have revealed two broad regimes of phytoplankton nutrient limitation in the modern upper ocean (Moore *et.al.*, 2013). Few species can adjust to the changing levels of the nutrient availability in its living environment.

6. DISEASES CAUSED BY PHYTOPLANKTONS

The following highlights various diseases and harmful effects associated with toxin-producing phytoplankton. These microscopic organisms, while vital to marine ecosystems, can generate potent toxins that contaminate seafood, harm marine life, and pose significant risks to human health. Understanding these phytoplankton-related illnesses is essential for improving monitoring efforts, protecting public health, and managing the growing threat of harmful algal blooms in changing marine environments.

6.1 PARALYTIC SHELLFISH POISONING (PSP)

Paralytic shellfish poisoning (PSP) (Fig.8) is caused by several structurally related tricyclic guanidium alkaloids that are found in several species of marine dinoflagellates. The toxins are concentrated in shellfish, particularly bivalve shellfish, such as mussels, clams, and scallops, the ingestion of which serve as the major cause of PSP. The PSP toxins, including saxitoxin, neosaxitoxin, gonyautoxin, and decarbomyl toxin, block voltage-regulated sodium channels in myelinated and nonmyelinated nerves, resulting in relaxation of vascular smooth muscle, depression of cardiac muscle action potentials, and inhibition of axonal impulse transmission to skeletal muscles (Solter *et.al.*, 2002). Saxitoxin originates in a unicellular dinoflagellate known as *Gonyaulax*. Since bivalve mollusks are filter feeders, they concentrate the toxins from *Gonyaulax* in their digestive glands called the hepatopancreas (Jong, 2017).

6.2 NEUROTOXIC SHELLFISH POISONING (NSP)

Neurotoxic shellfish poisoning (NSP) (Fig.9) is a type of disease caused by consumption of molluscan shellfish contaminated with brevetoxins primarily produced by the dinoflagellate, *Karenia brevis*. Blooms of *K. brevis*, called Florida red tide. They are a group of more than ten natural neurotoxins produced by the marine dinoflagellate, *Karenia brevis* (formerly known as *Gymnodinium breve* and *Ptychodiscus brevis*). Brevetoxins are neurotoxins which activate voltage-sensitive sodium channels causing sodium influx and nerve membrane depolarization. Brevetoxins comprise a group of toxins with primarily neurological and gastrointestinal effects. Blooms of *K. brevis* can cause the ocean to appear red, brown, or simply darkened due to the dense aggregation of cells which often includes several species of unicellular algae. Blooms are usually accompanied by massive fish kills and mortalities in marine mammals and seabirds (Watkins *et al.*, 2008).

6.3 AMNESIC SHELLFISH POISONING (ASP)

Amnesic shellfish poisoning (ASP) (Fig.7) is caused by consumption of shellfish that have accumulated domoic acid, a neurotoxin produced by some strains of phytoplankton (Jeffery *et.al.*, 2004). Domoic acid (DA) is a well-known phycotoxin that causes amnesic shellfish poisoning (ASP) and is mainly produced by diatom species belonging to the genus *Pseudo-nitzschia* (Wang *et al.*, 2023). ASP differs from most other neurotoxic marine poisonings because the main effect is on the central nervous system (CNS). The people who were affected with ASP developed gastrointestinal symptoms within 24 hours (vomiting, abdominal cramps and diarrhoea) and/or neurological symptoms within 48 hours (headache, loss of short-term memory, disorientation, lethargy, seizures and, sometimes, convulsions and coma). Mortality was also recorded. The most relevant clinical effects were memory loss, the condition was termed ASP (Tubaro *et.al.*, 2007).

6.4 DIARRHETIC SHELLFISH POISONING (DSP)

Diarrhetic shellfish poisoning (DSP) (Fig.14) is a syndrome in humans caused by the ingestion of shellfish contaminated by toxins produced by dinoflagellates in the genera *Dinophysis* and *Prorocentrum*. DSP symptoms include diarrhea, nausea, vomiting, and abdominal pain starting 30 min to a few hours after ingestion of the toxic shellfish, with complete recovery within three days. Tumor-promoting, mutagenic and immunosuppressive effects shown in animals to be associated with diarrhetic shellfish toxins (DSTs) including okadaic acid (OA) and the dinophysis toxins (DTXs) have not yet been quantified in humans. However, there is speculation that chronic exposure may increase the risk of gastrointestinal cancers (Trainer *et al.*, 2013).

6.5 CIGUATERA FISH POISONING (CFP)

Ciguatera Fish Poisoning (CFP) (Fig.10) is the most frequently reported seafood-toxin illness in the world, and it causes substantial physical and functional impact. It produces a myriad of gastrointestinal, neurologic and/or cardiovascular symptoms which last days to weeks, or even months. It is a foodborne illness affecting humans worldwide. Humans acquire this illness by eating reef fish containing the naturally occurring toxins, ciguatoxins. Multiple ciguatoxins have been identified, but in this paper ciguatoxins will be referred to collectively as “CTX.” CTX is derived from benthic dinoflagellates of the genus *Gambierdiscus*, growing predominantly in association with macroalgae in coral reefs in tropical and subtropical climates. The toxin is transferred through the food web as the algae is consumed by herbivorous fish, which are consumed by carnivorous fish, which are in turn consumed by humans. IV mannitol is one of the appropriate treatments for CFP and prevention can be done by avoiding the Ciguatera fish (Friedman *et al.*, 2008)

6.6 HARMFUL ALGAL BLOOMS

Some naturally occurring algae can proliferate under certain environmental conditions, causing deoxygenation of seawater, or releasing toxic compounds (phycotoxins), which can harm wild and cultured finfish and shellfish, and also human consumers. These are called the harmful algal blooms - HABs (Brown *et.al.*, 2019).

6.6.1 RED TIDE

Red tide (Fig.11) is a marine event where protistas, including algae and dinoflagellates, go through a tremendous growth period, called bloom. In a 2–3 week period, it is possible for each algal cell to produce one million daughter cells. This usually takes place in the spring and summer in response to an increase in light intensity. During this time, the warm, shallow seawater tends to become discolored by the enormous concentration of algae. This discoloration is dependent on the species of algae and may be the result of the various pigments, including orange, yellow, blue, green, brown, or red. Some may not be visible at all. As red is the most common pigment, the phenomenon is called ‘red tide’ (Guy, 2005).

6.6.2 CYANOBACTERIA BLOOMS

Cyanobacteria blooms (Fig.13) can deplete oxygen in water bodies, leading to dead zones where aquatic life cannot survive. They can produce toxins harmful to animals, humans, and ecosystems. These blooms can disrupt food webs and impact recreational, fishing, and drinking water activities. Additionally, they may release unpleasant odors and taste into the water (Bettina, *et al.*, 2015). Cyanobacterial blooms can produce toxic by-products known as cyanotoxins under the right conditions like light intensity, temperature, salinity and nutrients. These can occur in most freshwaters including wetlands, lakes, reservoirs, streams and rivers. Cyanotoxins are produced and contained within the cyanobacterial cells (intracellular). The release of these toxins in an algal bloom into the surrounding water occurs mostly during cell death and lysis (i.e., cell rupture) as opposed to continuous excretion from the cyanobacterial cells. However, some cyanobacteria species are capable of releasing toxins (extracellular) into the water without cell rupture or death. Once these toxins are released, they can cause numerous health effects ranging from minimal (diarrhea, headaches, and skin irritation) to life threatening death (Sylvain, *et al.*, 2013).

6.6.3 COCCOLITHOPHORE BLOOMS

Two unusual blooms were observed in Scottish waters during summer 2021: one in the Clyde Sea and the other by the east coast of the Shetland Islands. Both had the appearance of coccolithophore blooms (Fig.12). Transmission electron microscopy of a sample from the Clyde Sea confirmed the presence there of the coccolithophore *Emiliana huxleyi* (Renshaw *et al.*, 2023). The coccolithophore species *Emiliana huxleyi* forms extensive blooms in the temperate and subpolar surface ocean, characterized by detachment and overproduction of coccoliths in the bloom decline phase. The accumulation of these high-refractive-index calcite particles increases the light backscattered from the ocean surface and colors the water milky-turquoise (Terrats, *et.al.*, 2020). This species is also the host for the coccolithovirus (EhV), which is responsible for the demise of large oceanic blooms formed by this alga (Michaelson *et al.*, 2010).



Fig.7: Amnesic Shellfish Poisoning



Fig.8: Paralytic Shellfish Poisoning

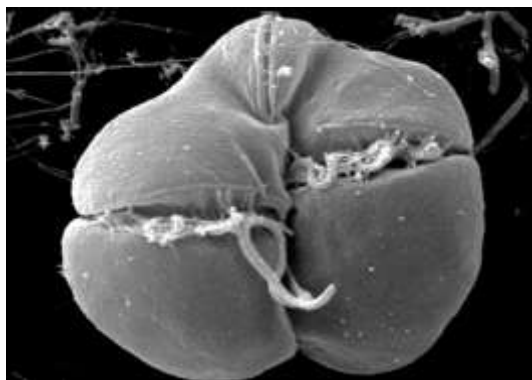


Fig.9: Neurotoxic Shellfish Poisoning

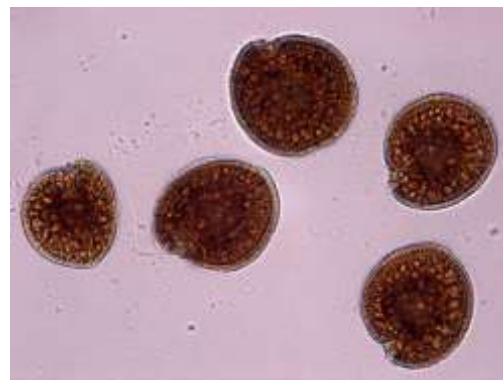


Fig.10: Ciguatera Fish Poisoning



Fig.11: Red tide



Fig.12: Coccolithophore blooms



Fig.13: Cyanobacteria blooms

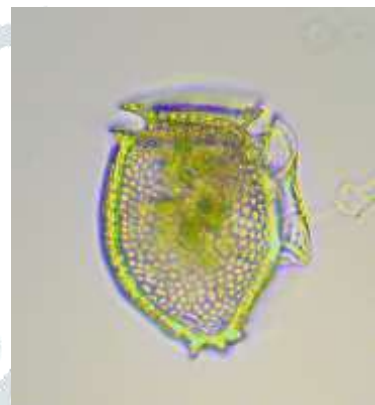


Fig.14: Diarrhetic shellfish poisoning

7. CASE STUDIES

The following case studies explore the diverse ecological roles of phytoplankton, the environmental pressures shaping their distribution, and their broader significance in regulating marine ecosystems and the global carbon cycle. Together, they highlight how shifts within phytoplankton communities serve as both indicators and drivers of ocean health in a rapidly changing climate.

7.1 CASE STUDY-1

The ocean's striking green glow, often visible from space, is caused by massive blooms of *Noctiluca scintillans*, a bioluminescent plankton that signals a serious environmental imbalance. These blooms have become increasingly common in regions like the Gulf of Oman due to climate change, altered monsoon patterns, warming seas, dam construction, and agricultural runoff that enrich ocean waters with excess nutrients. Unlike beneficial diatoms that support marine life, *Noctiluca* disrupts the food web by consuming other plankton and releasing ammonia, which depletes oxygen and creates "dead zones" where marine life cannot survive. It bypasses key steps in the food chain, starving fish larvae and threatening biodiversity and local fisheries. Though visually beautiful, the glow masks an ecological crisis. Scientists use satellite imagery and field data to monitor and study these blooms, while experts stress the need to reduce pollution, control nutrient discharge, and respond to the broader impacts of climate change. This glowing phenomenon is not just a natural wonder, it is a powerful warning sign that marine ecosystems are under growing stress from human activity (Adam, 2025).

7.2 CASE STUDY-2

A pivotal study, "Trait-based approaches to phytoplankton ecology" by Litchman presents a trait-based framework to understand how phytoplankton influence global biogeochemical cycles, particularly the carbon cycle. Rather than categorizing phytoplankton by taxonomy alone, the researchers focused on key functional traits such as cell size, nutrient uptake rates, growth strategy, and sinking speed. These traits determine phytoplankton's ecological roles, including how efficiently they fix carbon and contribute to its export to the deep ocean. For instance, larger cells like diatoms sink faster and are more likely to remove carbon from surface waters, while smaller picoplankton dominate nutrient-poor areas and support recycling in the upper ocean. The study also highlights how climate change-driven shifts in trait composition such as the decline of large, fast-sinking species could reduce the efficiency of the biological carbon pump. By linking physiological traits with ecological outcomes, this research underscores the importance of community composition in determining phytoplankton's global carbon sequestration potential (Litchman *et al.*, 2015).

7.3 CASE STUDY-3

In 2024, NASA launched a satellite mission called PACE (Plankton, Aerosol, Cloud, ocean Ecosystem) to study the role of phytoplankton in Earth's climate system. Phytoplankton are tiny ocean plants that absorb carbon dioxide (CO₂) during photosynthesis, helping reduce the amount of greenhouse gases in the atmosphere. PACE uses advanced sensors to observe the color of the ocean and identify different types of phytoplankton from space. By tracking where and when these microscopic plants grow, scientists can better understand how much CO₂ is being removed from the atmosphere and stored in the ocean. This mission helps researchers see how changes in ocean temperature, pollution, or weather affect phytoplankton, which in turn affects the global carbon cycle. The information gathered by PACE will help predict how our oceans respond to climate change and how we can protect marine ecosystems in the future (Matt, 2024).

7.4 CASE STUDY-4

Coccolithophores are microscopic phytoplankton that play a significant role in the global carbon cycle by absorbing carbon dioxide (CO₂) through photosynthesis and forming calcium carbonate shells called coccoliths through a process known as calcification. Satellite observations have identified the "Great Calcite Belt" in the Southern Ocean which is a vast, bright region rich in coccolithophores, highlighting their large-scale presence and impact. These blooms influence the ocean's carbonate chemistry and increase the export of carbon to the deep ocean. When coccolithophores die, their heavy chalky shells sink, carrying carbon with them and effectively storing it for hundreds or even thousands of years. This natural carbon transport system helps reduce atmospheric CO₂ levels and plays a role in slowing global warming. However, environmental stressors like ocean warming and acidification may reduce coccolithophore populations, potentially weakening this vital carbon-sequestration process. Their sensitivity to climate change makes them a key indicator species for ocean health and an important focus in understanding Earth's changing carbon balance (Balch *et al.*, 2005).

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