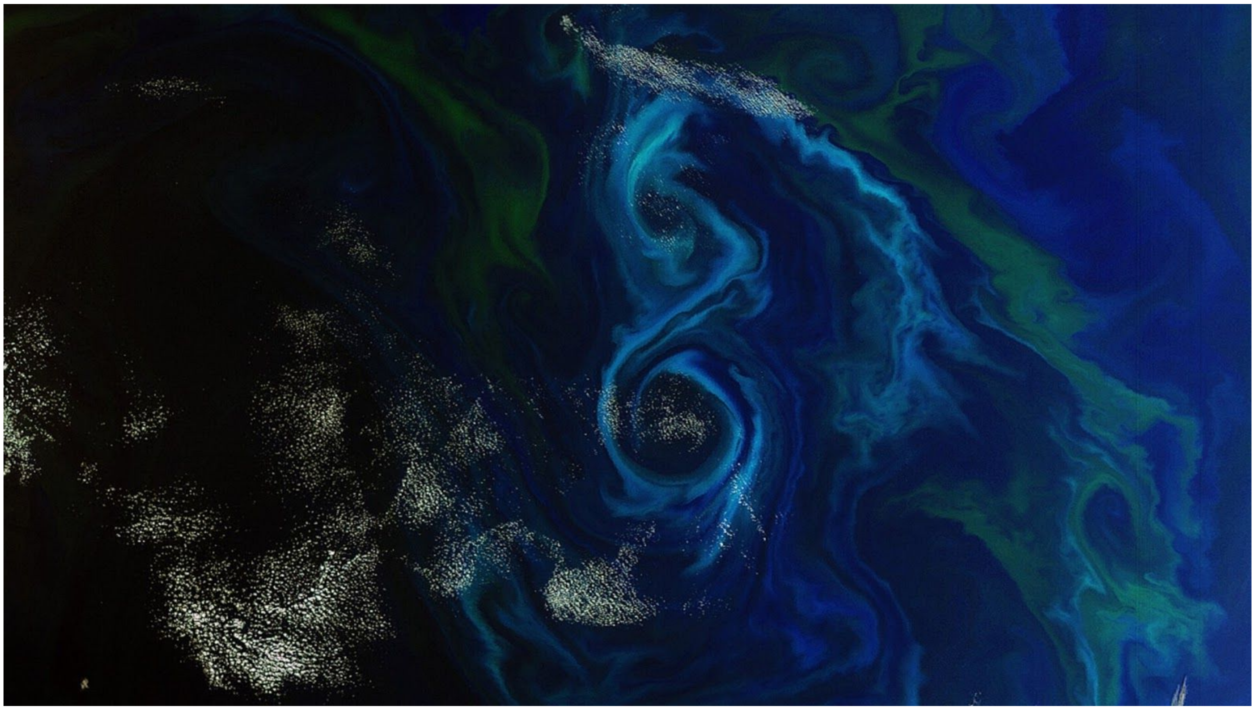

Thinkathon 2020

Course : Genetics BB222

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Phytoplanktons

Overview

Phytoplankton or microalgae are a key part of oceans, seas, and freshwater basin ecosystems. They are similar to terrestrial plants, as they have chlorophyll to capture sunlight and use photosynthesis to turn it into chemical energy. Apart from consuming carbon dioxide and sunlight to release oxygen, they also require nutrients such as nitrate, phosphate, silicate, calcium and some trace elements like iron to grow.

Significance

These phytoplanktons are the foundation of the aquatic food web. They are the primary producers of the ocean ecosystem, feeding on everything from microscopic animals to multi-ton whales. Apart from being the cornerstone of the food web, phytoplanktons contribute more than 50 percent of the oxygen in the earth's atmosphere (to put into perspective, the Amazon rainforest contributes less than 20 percent). Some of the carbons consumed by phytoplanktons are carried to the deep ocean as they sink to the ocean floor after their death, which makes life possible in the deep ocean. Further, they play a critical role in ocean biogeochemical cycles by transforming, recycling and sometimes even producing scarce vitamins and other micronutrients that help sustain other marine life.

Identified problems

I. Climate Change

Phytoplanktons need an optimal temperature for their growth and survival. The temperature sensitivity stems from the fact that the warmer the surface water becomes, the lesser is the mixing between the surface water and the deeper nutrient-rich water. As nutrients become scarce at the surface, phytoplankton growth and overall productivity declines. In recent times, due to climate change, the ocean surface is warming up which is either killing the phytoplanktons or driving them towards cooler environments creating a huge imbalance in the ocean ecosystem. Moreover, their insufficiency would cause more rapid accumulation of carbon dioxide in the atmosphere, which in turn would result in further warming of the atmosphere.

II. Phytoplankton Bloom

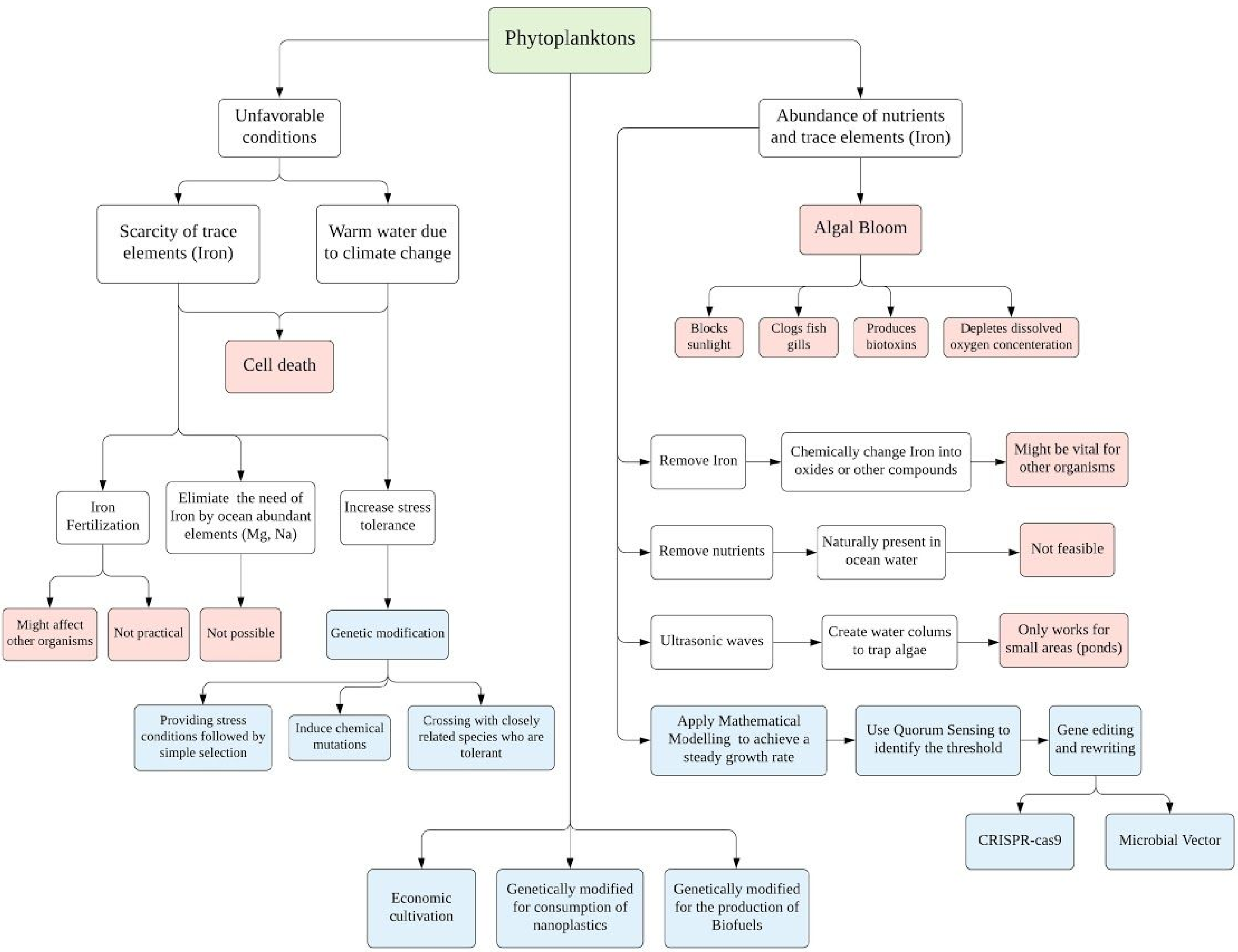
Phytoplankton can also cause mass mortality. In a nutrient-rich environment, their growth can be uncontrollable causing explosion blooms. These blooms can block light to organisms lower in the water column, or even clog or harm fish gills. Sometimes these blooms produce biotoxins which are not only fatal for primary consumers but secondary consumers too. In the aftermath of a massive bloom, dead phytoplankton sink to the ocean floor. The bacteria that decompose the phytoplankton deplete the oxygen in the water, suffocating animal life resulting in a dead zone.

Problem Statement

Propose a solution to prevent phytoplankton blooms while ensuring a steady growth rate even in the warmer temperatures.

Mind map

Here I have made an attempt to hypothesise and come up with a solution. The identified problems or adverse effects are marked by red boxes. The optimal approaches are marked by blue boxes.



Mathematical model

To keep the model simple external factors like ecosystem and geographical conditions are ignored and rates are denoted by constants instead of differentials. The threshold is the final constant. Our aim is to achieve a steady population. Just after crossing the threshold, the total population would be equal to the threshold.

Let's say $threshold = x$

After reaching the threshold,

$current\_population = x$

$death\_rate = d$

$growth\_rate = g$

Using the above variables :

To get a steady-state $death\_rate = gowth\_rate$ => $d = g$

For, $d = g$, let's say we need $extra\_death = n$

Therefore probability for apoptosis would be : $p = \frac{extra\_death}{current\_population}$ => $p = \frac{n}{x}$

Given below is the pseudo-code for the function of the mathematical model.

```
apply_model( )
{
        // the goal is to ensure death_rate == growth_rate

        with_probability_p
        {
            return apoptosis( );
        }
}

if (concn_of_microbes > threshold)
{
        apply_model( );
}
else{
        do_nothing( );
}
```

Proposed solution

The nutrients needed by phytoplanktons are naturally present in the ocean water. Despite the presence of nutrients, unavailability of Iron can limit their growth. Iron is a trace element which is necessary for photosynthesis and it is highly insoluble in seawater. Iron fertilization i.e intentional introduction of iron to iron-deficient areas can be done to ensure iron availability. This process can be costly and a foreign supply of iron might disturb the ecological balance of the ecosystem. The other method could be the elimination of the very need for iron and replacing it with sodium or any other element which is naturally present in the ocean. The problem is that iron is involved in the synthesis of chlorophyll, and it is essential for the maintenance of chloroplast structure and function. Therefore eliminating the need for iron is not feasible, at least not with the current biological knowledge we have.

The unavailability of sufficient micronutrients and warming of the water surface because of climate change both can be solved by genetic modification techniques. The idea is to increase the stress tolerance of the phytoplanktons. Naturally, some of the phytoplanktons or other species closely related to phytoplanktons have evolved to tolerate these hostile environments. They will be chosen by simple selection. Their genes can be incorporated into non-tolerant planktons using transgenic approaches followed by simple selection. This stress tolerance can also be induced by chemical mutagenesis and by providing artificial stress conditions.

Phytoplankton blooms are the result of an abundance of nutrients mainly iron. To control blooms limiting nutrients is not at all possible because they are naturally present in the ocean water as soluble solutes. Although the availability of iron can be limited because of its insoluble nature, we can convert the free form into their oxides or other complexes. But it might indirectly affect other organisms living in that ecosystem as well. Reiterating a topic presented in Thinkathon 2019, these blooms can be controlled by ultrasonic waves. It works by trapping algae into water columns. This method might work for small areas like ponds or lakes but for phytoplanktons, we are talking about giant blooms spread in thousands of kilometres.

My proposed solution is to use quorum sensing to get an estimate of the algal population. If the concentration of algae crosses a certain threshold then turn on a gene which will initiate apoptosis in that algal population with a probability (p). This probability (p) will be determined by mathematical modelling and might depend on types of phytoplanktons, geographical environment, and the ecosystem. The goal of apoptosis would be to ensure the death rate equals the growth rate. The result would be a constant and steady population similar to the log phase growth in continuous culture.

This quorum sensing and mathematical model can be induced in phytoplanktons using genetic engineering. The idea is to incorporate a rewritten quorum-sensing gene into the target organism. This can be achieved by using appropriate microbial vectors for quorum sensing and altering them to provoke apoptosis with the probability (p). Gene-editing methods like CRISPR-cas9 can be used to alter the vector sequences.

Future works include creating a man-made ocean ecosystem for the cultivation of phytoplankton. Phytoplanktons fix carbons into sugars therefore they can be genetically modified to increase the production quality and quantity of the starch and lipids which could be used as biofuels. The vast reach of these planktons in oceans can be exploited to treat nano plastics in the ocean. For example, zooplanktons do eat nano plastics but they excrete it as it is. If we genetically modify these planktons to break nano plastics into simpler forms. Then this has the potential to clean up the oceans without any means of chemicals or any other technical efforts.