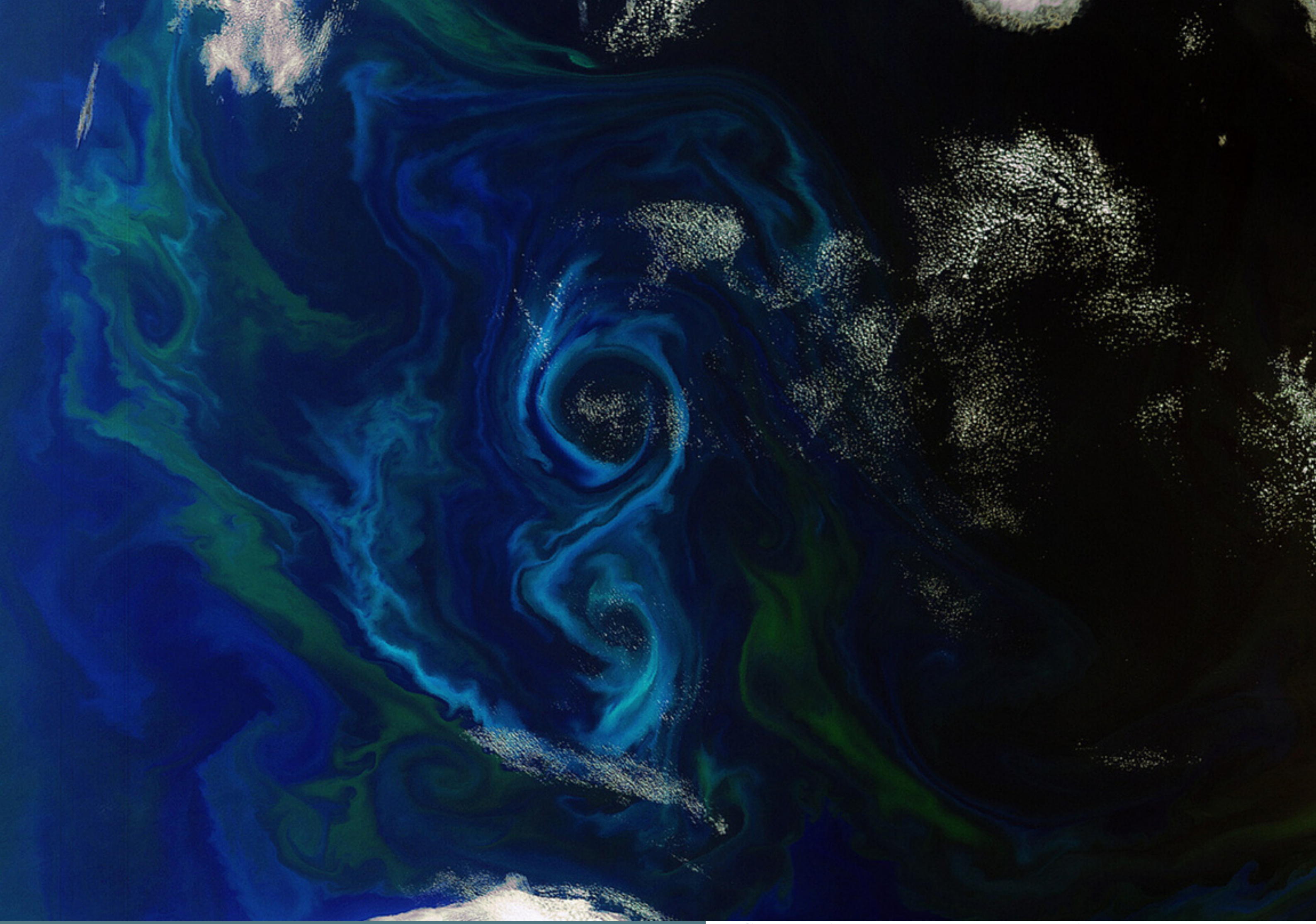

FIGURE 1. Satellite image of photosynthesizing microorganisms in the South Atlantic Ocean, near the Falkland Islands. (ESA, 2011)

BY SELENE CANNELLI

A PICASSO IN THE SEA. SO BEAUTIFUL SO DEADLY

For "Youth4Water - Space as a tool to accelerate change in sustainable water resources management, hydrology and the protection of aquatic ecosystems".
Word count: 1000

ABSTRACT

The above satellite picture might look like a beautiful painting by nature, instead, life underwater is dying, as oxygen cannot circulate. On land, harmful toxins are released, making the water unsafe to drink.

The painting was created by cyanobacteria, or harmful algal blooms (HABs). In small amounts, they are a powerful tool across industries, including pharmaceuticals, but a threat when forming dense biomass, as in the picture.

To predict and eliminate HABs in a timely manner, an innovative floating device, monitoring water conditions, has been hypothesised. It combines sensors with Earth Observation, and its position is tracked by an installed GPS.

INTRODUCTION

Our planet is endlessly astonishing, often taking on the role of an artist as satellite images capture its masterpieces. Yet, the most beautiful things can reveal themselves as the most poisonous.
It is the case of the natural occurrence of algal blooming. The white and light blue stripes (figure 1) are accumulations of phytoplankton that are nourished by the minerals that have risen from the deeper parts of the waters (Live Science Staff., 2012). In contrast, the green stripes (figure 1, 2) are harmful algal blooms (HABs), harmful to life on water and land.

This essay will elucidate what HABs are, their causes, their harm to life, and how space technologies can be used to anticipate their occurrence. Additionally, a novel deployable device that combines sensors with satellite imagery is suggested to facilitate the detection and remediation of HABs from aquatic environments.

- ### The natural occurrence of harmful algal blooms and its life-threatening and economic consequences

Algal blooms, also known as "blue-green algae", are single-celled cyanobacteria. These organisms are incredibly diverse, living in a range of habitats from deserts to hot springs and icy waters. They are also widely used in industries such as pharmaceutics and agriculture. In essence, cyanobacteria are a crucial part of the environment, providing nourishment to aquatic life and absorbing carbon dioxide.

However, when cyanobacteria form large masses, they produce cyanotoxins, causing ecological and economic damage. In 1991, a cyanobacterial bloom caused a loss of $10M AUD in Australia (Herath, 1995), and the Florida Department of Health's average yearly cost of HABs events is $22M USD (The Issue n.d.). HABs present a great threat to developing nations. They can render the already scarce drinking water unsafe and decimate fish farms. Research and data on HABs are lacking and preventive tech or chemicals to kill cyanobacteria is expensive, leaving these nations vulnerable (Abdallah et al. 2021).

This phenomenon is becoming increasingly frequent due to human activities, with bacteria thriving in high nutrient levels, mainly high phosphorus concentrations found in agricultural waste.

FIGURE 2. Lake Binder, Iowa (USA), algal bloom. Credits: Dr. Jennifer Graham, USGS (US EPA, OW 2013).

Figure 3 outlines the factors driving their exponential growth, with Figure 4 showing possible consequences once a film of cyanobacteria is formed on the water surface.
The film blocks sunlight, depriving organisms of the energy needed for photosynthesis. This lowers oxygen levels, increases carbon dioxide and leads to suffocation, eventually causing loss of species and habitats.

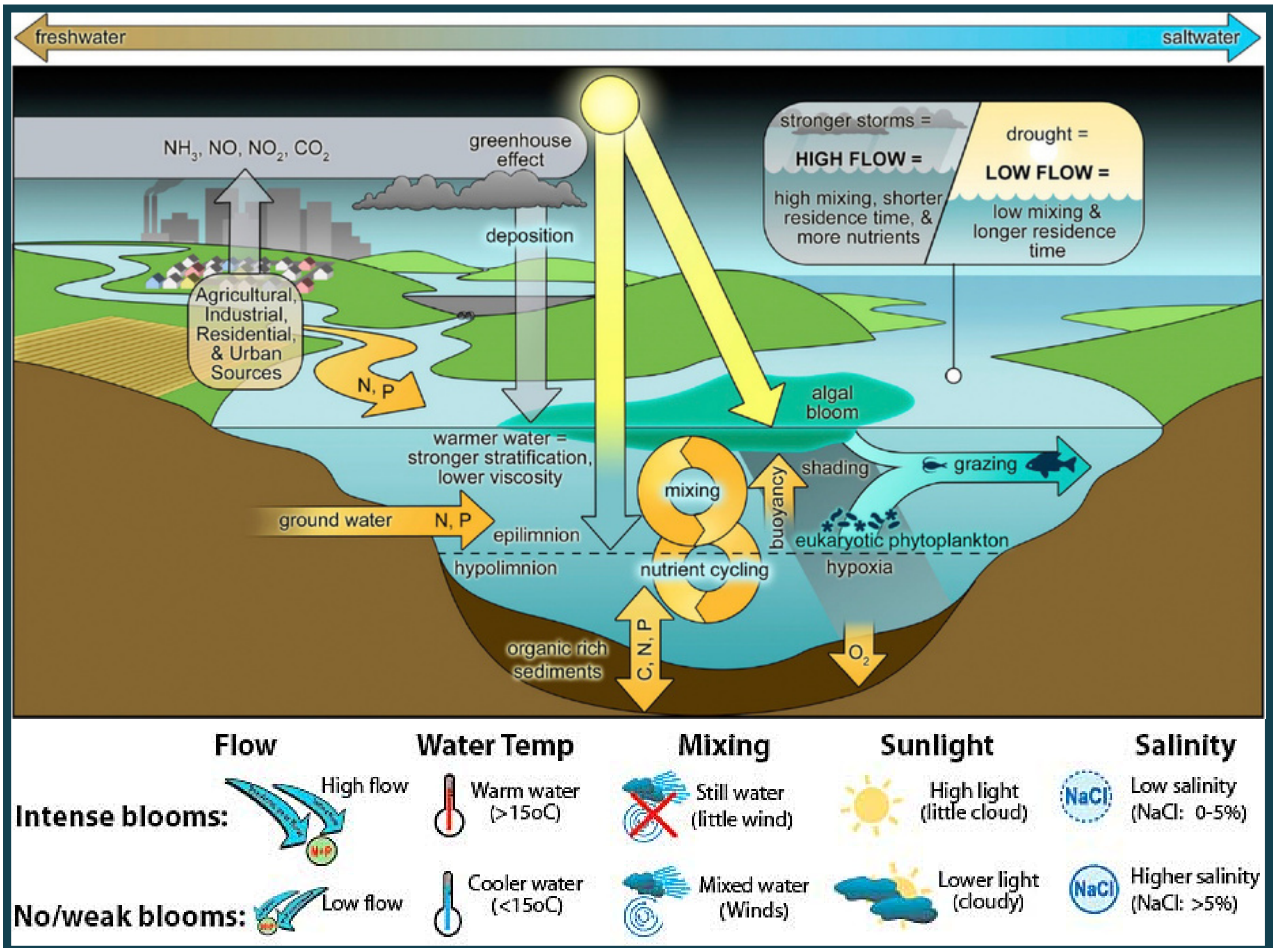

FIGURE 3. Diagram showing the factors, chemical, biological and physical, influencing the formation and exponential growth of harmful algae bloom (HAB).
The top image is taken from Kimambo ON, *et al.* (2019). The bottom diagram is taken from Rhode Island Environmental Monitoring Collaborative website (https://www.rimonitoring.org/harmful-algal-blooms/).

Exposure to cyanobacteria can cause gastrointestinal, hayfever, respiratory and skin issues. Long-term exposure to HABs toxins may lead to neurological symptoms and, in extreme cases, permanent neurological damage.

Climate change and excessive land utilization are increasing HABs events. Lab tests may take up to 5 days for results, but satellite images can give faster results on possible HABs events, in both inland and marine water, and be used by rural communities as well (Almuhtaram et al. 2021).

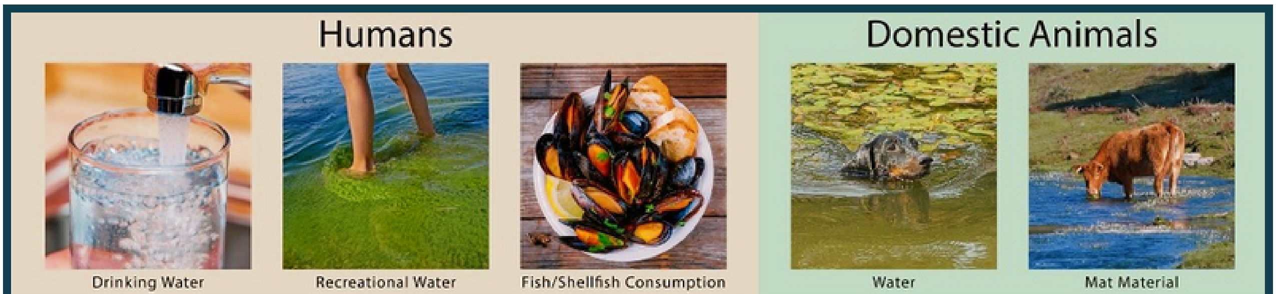

FIGURE 4. The image demonstrates how life on land can be exposed to cyanotoxins, such as by drinking contaminated water, bathing in it, coming into contact with animals that have been exposed to the toxins, or consuming them. Credits: ITRC Staff, 2023.

- S a t e l l i t e   i m a g e s :   a   t o o l   t o   p r e d i c t   H A B s   o u t b r e a k e s

An effective early warning system for detecting and monitoring HABs needs to track the formation and flow of cyanobacterial biomass through the currents, as well as provide timely detection of potential outbreaks to allow for rapid response and mitigation of their effects. To achieve this, satellites can provide spatiotemporal information (Figure 5) by reading a range of parameters, such as geophysical data (e.g. turbidity), temperature, streamflow, nutrient concentration, and more, by also reaching rural areas.. However, satellite data are still not accurate in predicting HABs in the Arctic Ocean. Here enter sediment-filled river waters, which algorithms usually mistake for chlorophyll. Additionally, the adaptation of phytoplankton to the Arctic's low light levels further complicates the situation, making it difficult to distinguish it from HABs (Garthwaite, 2020). As cyanobacteria are found in multiple environments, it means that they have different environmental factors that contribute to their growth, and we just started to scratch the surface of understanding how cyanobacteria proliferate in different ecosystems, how they spread and methods to eliminate them. Because of this, a multi-approach, that combines satellite data with *in situ* monitor sensors, is needed.

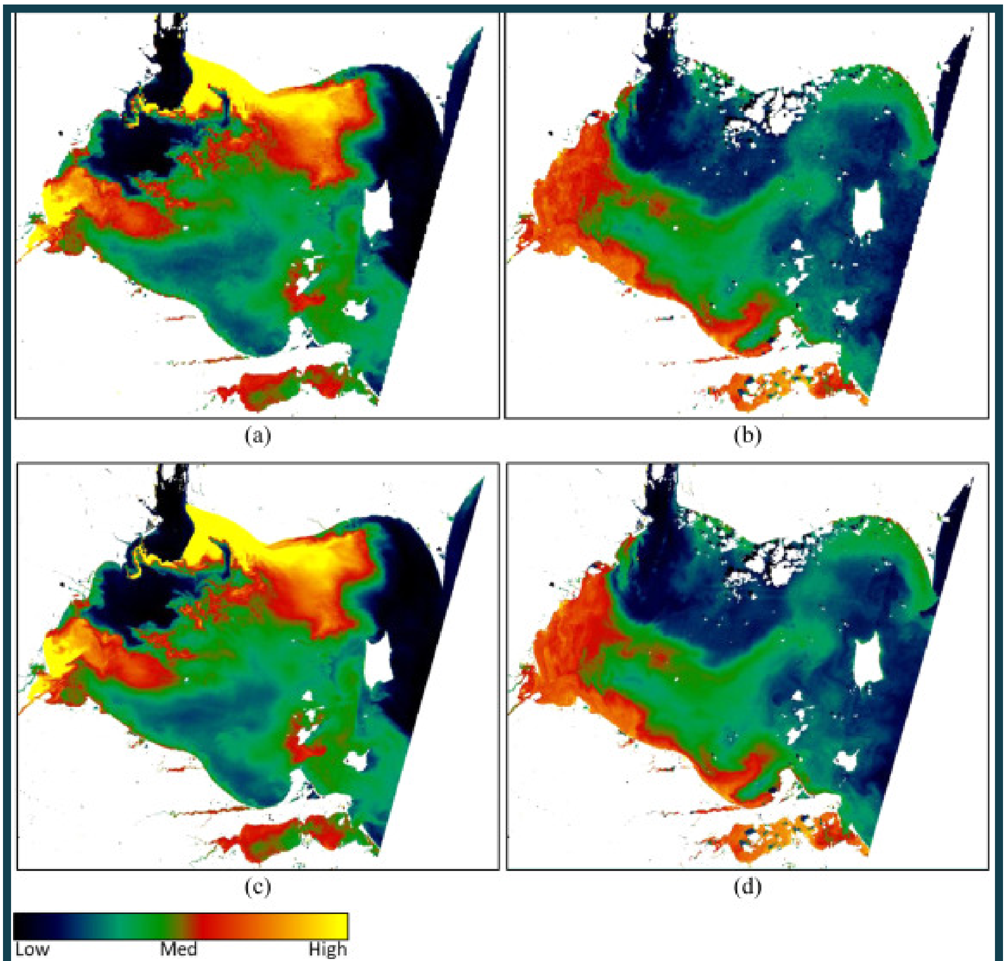

FIGURE 5. Image of western Lake Erie Canada) showing HABs spatiotemporal resolution. The (a, c) and (b, d) are the combined MODIS-Landsat satellites paired images on September 26 and August 25 in 2017, respectively. This cyanobacteria index shows a high possibility of HABs formation in the red areas (Yongquan et al., 2020).

THE ALGAE FILTRATING COMPLEX

To timely detect the HABs formation, we cannot rely solely on laboratory analyses, as they could take days and might not detect an outbreak. A multi-approach is needed to create an early warning system that is also able to follow the development and flow of the cyanobacteria biomass through the currents. Almuhtaram et al. (2021) propose a three-tier framework for a comprehensive early warning system. My idea is inspired by this, but adopting less laboratory analysis than the authors suggest, and mostly leveraging machine-learning.

When I participated in the 2021 Cassini Hackathon, I developed the Algae Filtration Complex (AFC) (figure 6).

The AFC is a deployable platform that incorporated sensors and a GPS. This allows us to acquire *in situ* sensor data and compare them with satellite data (figure 7). This will result in real-time management strategies. The platform I am suggesting is feasible, as a similar one is already been implemented in Japan, Mira Carbon water filtration solution (http://www.unido.or.jp/en/technology_db/1670/). The AFC platform is also equipped with mobile carbon-fibre filaments, where will be located bacteria that naturally eat cyanobacteria (Bauer et al., 2021).

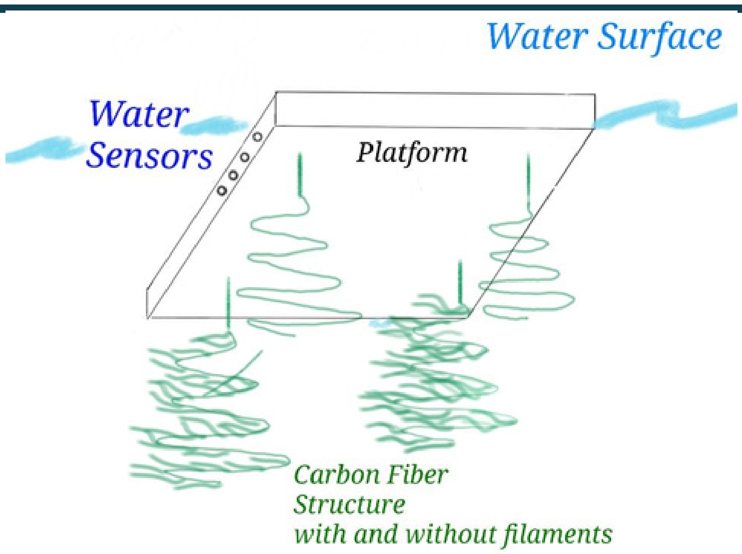

FIGURE 4. Algae Filtration Complex platform prototype.
With the first prototype, the platform will be floating to acquire surface readings from the sensors. Those readings will be combined with satellite data to generate an overview of the health of the water. If HABs are present, we will be able to obtain environmental data, and how they change, from the appearance to the disappearance of HABs.

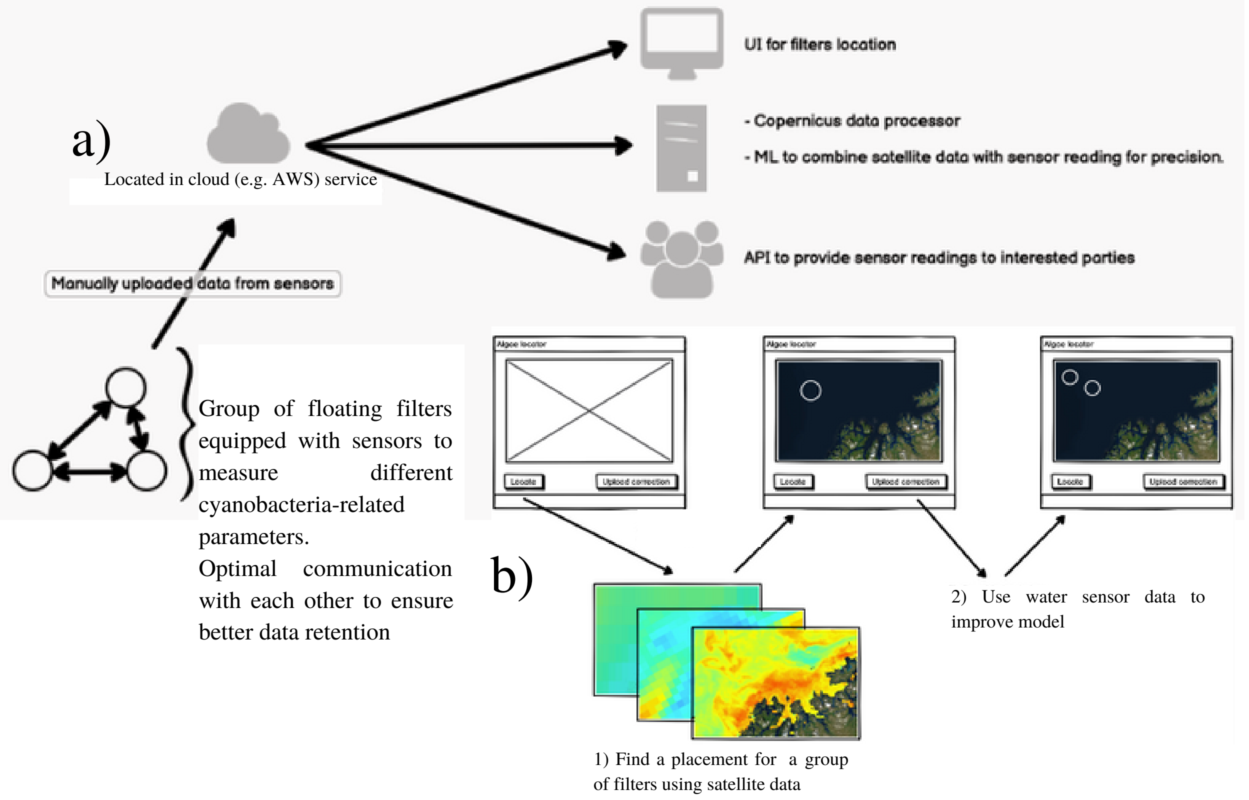

FIGURE 7. Machine-learning workflow. Water sensor and satellite data are input in the workflow to develop a more accurate prediction model. The images summarise the different analysis steps (a) and the outcome (b).
The image was created by myself taking into consideration the work of Caballero et al. (2020) and Yongquan et al. (2020).

CONCLUSIONS

Due to anthropogenic impact, we are experiencing more HABs outbreaks, a significant threat to aquatic and terrestrial life, and the economy.

To address this issue, the AFC was conceived. The AFC platform utilises *in situ* sensor and satellite data, processed through machine-learning, to validate and understand the adaptation and proliferation of HABs strains, allowing more accurate predictions of potential outbreaks and more precise strategies. More research is needed to develop the platform, but the project can begin by using commercial water sensors, which allows us to begin training a machine-learning algorithm by analysing sensor and satellite data.

We should not rely solely on one technology; combining satellite and *in situ* sensing data can speed up progress in preventing and mitigating cyanobacteria outbreaks (Almuhtaram et al., 2021). This interdisciplinary approach needs to be taken into consideration to further our knowledge and protect life on Earth.

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Place of study	Sector affected	Estimated economic losses	Predicted range of time
United Kingdom	Commercial fishery	£29-118,00	Annual
Southwest Florida	Commercial fishing industry /businesses that supply the hotel industry	$20 million	Annual
New York state	Bay scallop fishery	$2 million	Annual
Maryland	Commercial fishery	$43 million	Annual
Mid-Atlantic region, USA	Welfare (avoidance costs to avoid losses on the sale of fish)	$100 million	Monthly
Maine	Commercial fishery	$6.0 million	Annual
Calhoun Country, Texas	Oyster industry	$22,708.45	Three-monthly
Galveston Bay (Texas)	Oyster industry	$167,588	Four-monthly
Maine (New England)	soft shell clam harvests harvests of mussels	$2 million $400,000	Five-monthly
North Carolina	Fishery for brown shrimp	$32,000-1,240,000	Seven-yearly
USA	Tourism/ recreation sector due to eutrophication of freshwater	$1.16 billion	Annual
USA	Recreation and tourism	$7 million	Annual
Pacific and Grey Harbor counties (Washington)	Razor clam fishery	$20.4 million	Annual
Northwest Florida	Restaurant revenue Lodging revenue	$2.8 million $3.7 million	Monthly Monthly
Southwest Florida	Restaurant revenue	$868-3,734	Daily
Saratosa Country (Florida)	Lifeguard services on the beaches	$3,000	Seven-monthly

TABLE 1. Estimated economic impacts of freshwater Harmful Algal Blooms (HABs) and marine HABs on commercial fishery