Harmful Algal Blooms

As their name implies, Harmful Algal Blooms (HABs) have a range of detrimental impacts, potentially affecting human and animal health, and sometimes causing enormous economic losses. While monitoring in the form of regular cell counts and chlorophyll measurements can indicate a bloom's presence in an area, the view from space provided by satellite imagery can give advance notice of its development and approach.

Here, *Quest* reports on early warning systems for HABs in the marine and freshwater environments.

OCIMS Fisheries and Aquaculture Decision Support Tool

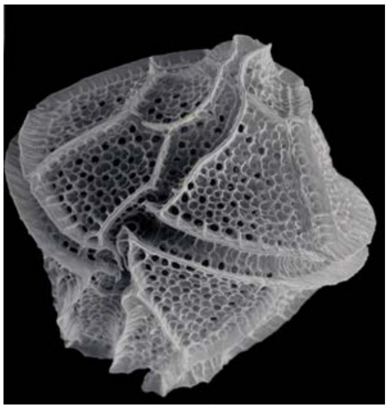
The Oceans and Coast Information Management System (OCIMS) is an initiative of Operation Phakisa, a government strategy to unlock the economic potential of South Africa's oceans. The CSIR was nominated by the national environmental department in mid-2015 to co-develop and implement OCIMS, which is intended to provide information relevant to stakeholders in a user-friendly manner. OCIMS includes a number of tools, including the vessel-tracking one featured in *Quest* Vol. 15.2 (ZACube-2 article), and the Fisheries and Aquaculture Decision Support Tool, generally called the 'HABs app', although it is not currently optimised for mobile phones.

Marufish & FWC

Harmful algal blooms in the sea are commonly called 'red tides', but the colour depends on the pigments in the phytoplankton species.

Harmful algal blooms are typically associated with excess nutrients, but in South Africa's marine environment the nutrient source is normally upwelling, which brings nutrient-rich bottom water to the surface. Upwelling driven by strong south-easterly winds in spring and early summer favours the development of diatom blooms on the West Coast, while dinoflagellate blooms tend to develop in the calmer months of late summer and autumn. This is partly because dinoflagellates can maintain their position in the sunlit surface waters by beating their whip-like flagella, while diatoms need well-mixed, turbulent water to prevent them sinking to the dark depths. Onshore currents transport the dinoflagellate blooms inshore and condense them further, particularly in sheltered bays. Depending on the species and its dominant pigments, blooms can colour the water various shades of red, green, brown, yellow or purple.

Truckloads of dead abalone were transported to waste disposal sites in Hermanus when a harmful algal bloom caused mass mortalities in aquaculture farms in early 2017.



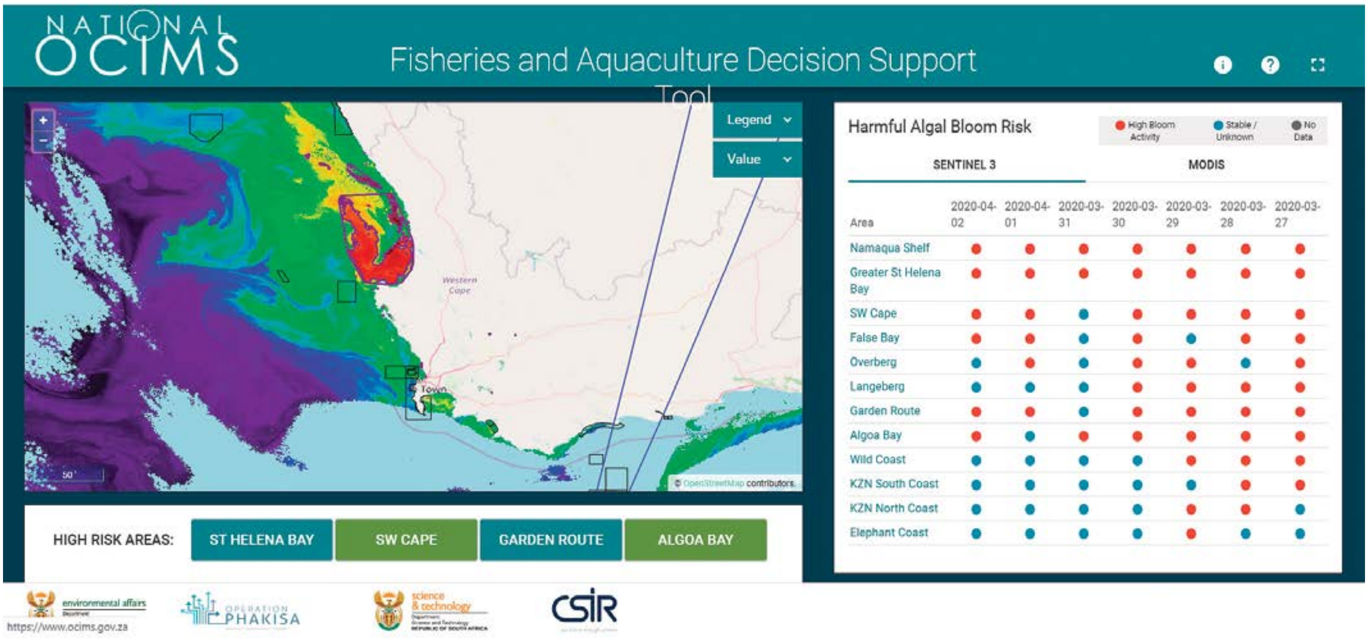
FWC Fish & Wildlife Research Institute

The dinoflagellate *Lingulodinium polyedrum* has formed extensive blooms along the south coast in recent years, and contributed to losses at abalone farms estimated at over US$30 million in 2017.

The need for a HABs-specific tool was recognised from the outset, because a few months before the project began a rock lobster 'walkout' associated with a bloom at Elands Bay on the West Coast had resulted in the death of some 200 tons of the animals – commonly known as crayfish or kreef – valued at over R100 million. This was just the latest in a long history of such events, which are caused by rock lobsters moving into shallow water in search of oxygen, and then getting washed up onto the shore by wave action, or stranded at low tide.

Like all plants, phytoplankton such as diatoms and dinoflagellates release oxygen through photosynthesis and take up oxygen for respiration, but they occur in such dense concentrations in a bloom that oxygen may be used up faster than it can be produced. This results in oxygen depletion – or hypoxia – of the water column, typically in the early hours before sunrise, when photosynthesis begins again. What's more, the bloom begins to die off as it uses up the available nutrients, and respiration by bacteria involved in the decomposition process further reduces oxygen levels.

Apart from causing low-oxygen conditions, HABs can suffocate fish and other marine organisms by clogging or irritating their gills to the point that they cannot extract enough oxygen from the water. And some HABs are composed of toxin-producing phytoplankton species that cause mass mortalities of marine life, as well as shellfish poisoning in humans. Filter-feeding organisms, such as mussels and oysters, accumulate the toxins, which



The OCIMS 'HABS app' shows a remote sensing image depicting the chlorophyll concentration of a dense bloom (in red) in St Helena Bay on the West Coast, and a HAB Risk panel indicating bloom persistence. Sea surface temperature (SST) images are also available.

necessitates periodic suspension of harvesting operations at aquaculture farms on the West Coast.

However, it was a toxic HAB event affecting the land-based abalone farms in Gansbaai and Hermanus on the south-west coast that prompted the CSIR to make a draft version of the HABs app available in mid-2017. Earlier that year, a bloom dominated by two yessotoxin-producing dinoflagellate species, *Lingulodinium polyedrum* and *Gonyaulax spinifera*, caused abalone mortalities amounting to over 250 tons, worth an estimated US$33 million. A similar bloom occurred in 2019, but this time there were no reported mortalities because – based on information from the HABs app and additional support from the scientists behind it – the abalone farms were able to shut off their intake pumps when the bloom approached, and rely on the filtration and recirculation systems they'd invested in since the 2017 event to recycle seawater through the tanks for a few days at a time.

The HABs app initially used data from the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra and Aqua satellites, but now relies primarily on the Ocean and Land Colour Imager (OLCI) on the European Space Agency's Sentinel-3 satellites. These sensors detect spectral variations in reflectance, which is essentially a measure of the sunlight reflected back from the ocean once it has been 'scattered' and absorbed by the water and its constituents. Estimates of the concentration (mg/m^3) of the photosynthetic pigment chlorophyll-a, which serves as a proxy for phytoplankton biomass, are derived using algorithms that have been optimised for South Africa's coastal waters.

Dr Stewart Bernard, the CSIR's principal researcher heading the development of the OCIMS remote sensing products, explains that although other online platforms – such as NASA's State of the Oceans and EUMETSAT's EUMETView websites – show chlorophyll too, they use standard algorithms that work best for deep oceanic waters, rather than the highly productive and relatively shallow coastal waters of the Benguela upwelling system, west of Cape Agulhas.

More specifically, the standard algorithms use reflectance in the blue and green region of the electromagnetic spectrum, while reflectance in the red and near-infrared (NIR) region is preferred for deriving chlorophyll estimates in coastal and inland waters, which typically have much higher biomass of vegetative material. However, coastal upwelling brings bottom waters to the surface, and newly upwelled water is very clear because it is practically devoid of phytoplankton.

Dr Bernard's colleague, Dr Marie Smith, found that the most accurate results are obtained for South Africa's upwelling regions if a blue-green algorithm is used for low and moderate biomass, and a red-NIR algorithm for moderate to high biomass, with a weighted blend of the two in the transition between these two categories. The HABs tool now makes use of this 'switching' algorithm, which ensures that phytoplankton biomass is not overestimated.

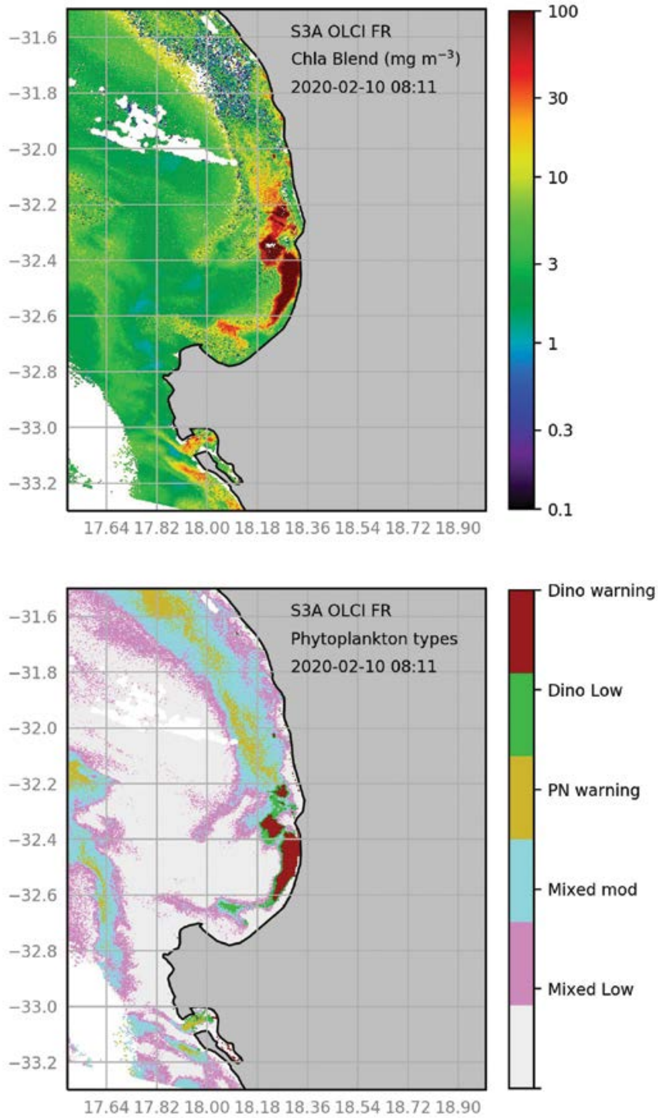
More recent research has even allowed for differentiation between blooms made up of dinoflagellates versus those dominated by *Pseudo-nitzschia*, the only toxin-producing diatom known from the Benguela upwelling system. In a paper published in *Frontiers in Marine Science* in February 2020, co-authors Dr Smith and Dr Bernard outline the methodology behind their 'probabilistic phytoplankton community classification' (PPCC), but stress that it is based on a limited dataset, and its accuracy will be refined as more data becomes available. What's needed are more examples of field-based radiometric measurements and sampling of blooms – so that phytoplankton counts and chlorophyll analyses can be done – at approximately the same time that the satellites are overhead. The PPCC method can nevertheless support existing monitoring activities, such as the microscopic counts and species identification conducted by the abalone farms, by providing information about the size, movement and status of blooms.

The PPCC images are not yet available on the HABs app, but shared via a Tumblr blog every week to 10 days during the HAB 'season' in the late summer and autumn months, or when high-risk blooms develop. Dr Bernard explains that the HABs app makes the satellite imagery for chlorophyll and sea surface temperature (SST) routinely available to users, but the team also shares information via WhatsApp groups and 'alert' emails. "As soon as you get a situation where there's a bloom around, people really want human interaction – and our ecosystem knowledge about what's likely to happen next – to help their decision-making, so we provide advisories and additional data," he says.

This information is provided in collaboration with Dr Grant Pitcher, the marine HABs expert at the Department of Environment, Forestry and Fisheries (DEFF). He and his colleagues have conducted most of the field research that has not only improved understanding of HABs in the Benguela upwelling system, but also provided data needed to validate the ocean colour algorithms.

"The reason we could implement the HABs app was because we had a long history of doing a lot of work on ocean colour – understanding the signal, building new algorithms, doing validation by measuring chlorophyll, taking hyperspectral light measurements, and measuring the scattering and absorbing properties of water – and also on the ecology and oceanography of HABs, understanding the role of wind, temperature and stratification on bloom growth and movement," says Dr Bernard. "The really exciting part for me is going from research to operation – finally we're taking this mature science and making it count."

- The HABs app can be viewed on: https://www.ocims.gov.za/hab/app/



https://csiroceancolour.tumblr.com/

Using their probabilistic phytoplankton community classification (PPCC), the CSIR Ocean Colour team can differentiate the algal biomass, indicted by the chlorophyll-a concentration (top), into a dinoflagellate bloom with high-biomass (red) and low-biomass (green) areas, a bloom with a high likelihood of *Pseudo-nitzschia* (yellow), or a mixed assemblage bloom with moderate biomass (blue) and low biomass (pink). White areas show either cloud, algorithm failure, or no data.

Lamiot, CC BY-SA 3.0

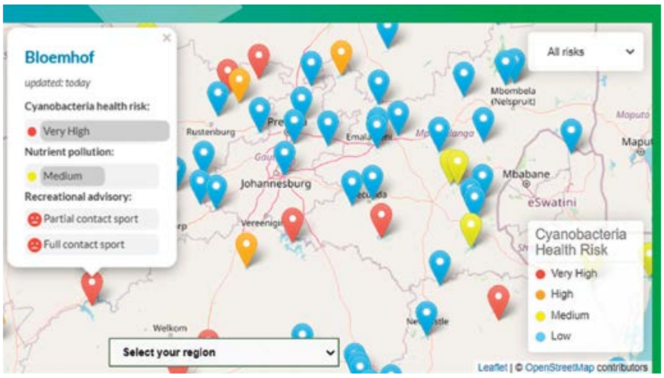
Cyanobacteria are also known as blue-green algae because they contain the blue pigment phycocyanin, as well as chlorophyll, to harvest light for photosynthesis.

Cyanolakes

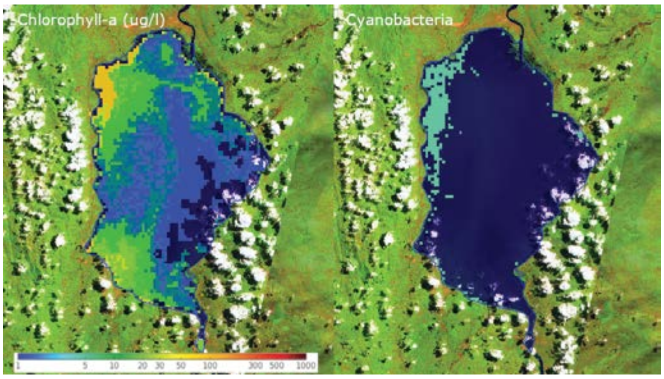
In freshwater environments, HABs are a symptom of eutrophication, or nutrient enrichment, which is often a result of human activities. The cumulative impact of wastewater effluents discharged into rivers, as well as runoff from fertilised farmlands and golfcourses, accelerate the natural build-up of nutrients in water-bodies downstream.

The most common HABs in South Africa's lakes and dams are formed not by algae, but by photosynthetic bacteria called cyanobacteria, although they are also known as blue-green algae. Both names refer to their cyan-blue phycocyanin pigment, which acts as an accessory to chlorophyll in harvesting light for photosynthesis.

Like HABs in marine environments, cyanobacteria blooms sometimes cause mass mortalities of aquatic life – typically



CyanoLakes



CyanoLakes

The CyanoLakes free service provides an advisory on cyanobacteria and nutrient status in large waterbodies, based on remote sensing data, while clients get more detailed information and maps. Cyanobacteria blooms can be distinguished from algal blooms and floating weeds.

'fish kills' – due to oxygen depletion of the water column. More importantly, they cause taste and odour problems in drinking water supplies, and may produce toxins that result in skin, eye and respiratory irritation, as well as gastrointestinal effects and even death when people or animals drink untreated water.

Although the standard chlorophyll products obtained from satellite data can give an indication of HABs in freshwater systems, it was not possible to differentiate between cyanobacteria and algal blooms, and get a biomass estimate for each, until Mark Matthews* developed an algorithm to do so for his PhD, which was supervised by Dr Bernard. This was the first algorithm in the world to distinguish cyanobacteria and algae in a quantitative way, and was well received by the international remote sensing community.

After being awarded his PhD in mid-2014, Dr Matthews set up CyanoLakes to provide a public information service and early warning system for cyanobacteria blooms. He also continued work on the algorithm, including enhancing the detection of floating weeds such as water hyacinth and salvinia. Furthermore, the algorithm had been developed using data from the Medium Resolution Imaging Spectrometer (MERIS) on the European Space Agency's Envisat satellite, but the Envisat mission had ended in 2012 when communication with the satellite was lost. Fortunately, the OLCI sensor on the two Sentinel-3 satellites – launched in February 2016 and April 2018 – is essentially an upgraded version of MERIS, so the algorithm just needed to be 'tweaked' a little. Additional calibration and validation was needed, though, and this was done during a two-year research project funded by the Water Research Commission (WRC).

The WRC also funded the three-year EONEMP project, officially titled 'The Integration of Earth Observation into the National Eutrophication Monitoring Programme'. One of the objectives was to apply the algorithm to MERIS data for more than 100 waterbodies around the country for the period 2002 to 2012 to provide a time series of cyanobacteria blooms and eutrophication. This was done within six months of the start of the project, and the data was integrated into the Department of Water and Sanitation's online Water Management System.

During the project, an operational system was developed to automate the processing of satellite data and make the results available to the public via a user-friendly online portal. It included information on cyanobacteria cell counts and the level of nutrient pollution, based on the chlorophyll concentration. Following the completion of the project, the EONEMP portal is no longer available, but the CyanoLakes website still makes summary information available on a 'dashboard' as a public service. Colour-coded icons on an interactive map indicate the health risk due to cyanobacteria at a glance, and clicking on an icon provides a nutrient pollution status and recreational advisory for that waterbody.

Dr Matthews reports that the WRC will be providing more funding during 2020, allowing CyanoLakes to offer free-tier accounts that will enable anyone to sign up and access the most recent information and maps for up to three waterbodies of their choice. The funds will also be used to develop a mobile app that will mirror the existing information on the dashboard as a free service, with additional functionality for paid subscribers.

"Since EONEMP ended we've commercialised the product, and have focused on water utilities as the main customers," explains Dr Matthews. "They're using it as an early warning surveillance tool in their cyanobacteria toxin management programmes, to help them with their decision-making. Just being able to see what's going on in their reservoirs is a game changer for them, but we also provide lots of support services, helping them understand the data and have confidence in it by comparing it with their own measurements."

The existing clients are all in the United States and Australia, but demonstration projects will soon be conducted with South Africa's largest water utilities – Rand Water, Umgeni Water and City of Cape Town – using funding from WADER (Water Technologies Demonstration Programme, a WRC and Department of Science and Innovation partnership). These three utilities already have comprehensive protocols in place for monitoring cyanobacteria and adjusting water treatment processes when blooms occur, but the CyanoLakes service would potentially allow them to reduce their sampling and laboratory costs.

- The CyanoLakes free service can be viewed on: https://online.cyanolakes.com/

* No relation to the *Quest* Editor.