ANZ Marine HAB Network

Submission to the Australian Senate Inquiry into Algal Blooms in South Australia

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Australian and New Zealand Marine Harmful Algal Bloom Network

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1. Who are the Australian and New Zealand Marine Harmful Algal Bloom Network?

The Australian and New Zealand Marine Harmful Algal Bloom Network (ANZ HABNET) was established in July 2025 following the South Australian HAB to represent the expertise of scientists, regulators and industry professionals in the field of marine harmful algal blooms. While freshwater cyanobacterial HABs and water research bodies exist in Australia, **marine HABs differ substantially** from **freshwater HABs** in fundamental biology (prokaryotes vs eukaryotes, a different domain of life), diversity, toxins, ecological drivers, and human and environmental impacts, hence we believe that a specific body for marine HABs is required. Current membership is drawn from 5 Australian states/territories and New Zealand, representing **government agencies, academic institutions, and industry bodies.** Our collective expertise spans many areas from monitoring, regulation and management of marine HABs and seafood safety to chemical, ecological, modelling, genetics and identification of HABs, over the past **~18 - 30+ years**.

General marine science conferences (e.g. Australian Marine Science Association) rarely feature HAB research, but it is more commonly presented at discipline-focused conferences such as the Australasian Society for Phycology and Aquatic Botany (**ASPAB** - https://www.aspab.org/) and the Australian Shellfish Quality Assurance Advisory Committee (**ASQAAC**). The committee members of ANZ HABNET belong to the International Society for the Study of Harmful Algae (**ISSHA**), and ISSHA Council, are past and present Editorial Board members of the peak journal in the field, *Harmful Algae* (Elsevier). They currently serve, or have served, on international panels, the International Oceanographic Commission/UNESCO International Panel on Harmful Algal Blooms and its sub-committees (IOC Intergovernmental Panel on Harmful Algal Blooms (IPHAB) - Harmful Algal Bloom Programme). Our terms of reference are contained in Appendix 1. This network is currently not externally funded but is powered by the voluntary inputs of members. We will actively seek funding opportunities to ensure our **sustainability as an organisation.**

2. What is our motivation for this submission and which ToR do we address?

Members of the ANZ HABNET aim to ensure that relevant, expert knowledge on marine HABs is applied to this issue. Marine HABs have occurred across all Australian states and New Zealand, from those that provoke public interest to those with serious consequences. Importantly, fish-killing (ichthyotoxic) blooms of *Karenia* species have occurred in Australia before and investigated by members of our network. HAB species vary in environmental preferences, toxin production, and human health and environmental effects. Our experience is that effective response and management of marine HABs **requires species-specific information**. Within our network, we include members who:

- Routinely establish and grow marine HAB species in the laboratory.
- Have detected and discovered new marine HAB species from Australia, New Zealand and the Pacific.
- Have identified and characterised new marine HAB toxins in Australia or New Zealand.
- Have researched and trialled strategies to mitigate harmful impacts on marine life.
- Developed statistical models to understand and predict marine HAB growth and dynamics.
- Developed rapid detection tools for marine HABs to support early warning and response efforts.
- Have research uptake and accumulation of HAB toxins in seafood species
- Have established NATA accredited laboratories for the identification of phytoplankton species, including HABs for aquaculture, wild harvest and public heath programs
- Are responsible for managing marine HABs i**n relation to seafood safety and export market access.**

This submission will address the following Senate enquiry terms of reference:

a. contributing environmental, land management or water quality factors;
b. ecological, economic, cultural and social impacts of algal blooms with particular reference to:
   iii. marine biodiversity and ecosystem health;
c. the coordination of state and federal government responses, including support, industry engagement and scientific advice;
e. the current support and recovery arrangements for impacted industries and communities, including:
   iii. research, monitoring and restoration efforts;

f. the adequacy of long-term monitoring, forecasting and prevention strategies, including funding and institutional support for marine science and environmental data collection;

3. What is a Marine Harmful Algal Bloom (HAB)?

- Microalgae (or phytoplankton) are single-celled organisms that naturally live in the ocean, photosynthesising and producing the oxygen we breathe. There are >50,000 different species of microalgae (phytoplankton) in the ocean, a small number of which **(~200) can be harmful**.
- Harmful algal species can become numerous (up to **millions of cells per litre**), forming a harmful algal bloom (HAB). Some species can also be harmful at concentrations of only a **few hundred cells per litre**.
- HAB species can cause damage even when they are not the most common phytoplankton species present.
- HABs can **seriously impact marine life and ecosystems**. They can cause mortality in marine life through gill damage, through a range of toxins or toxicological effects, or reducing oxygen in the water. HABs can also cause long-term disruption to the marine environment due to changes to ecosystems.
- HABs can cause **human health impacts** through either aerosols affecting breathing and eyes, skin contact or consumption of seafood that has bioaccumulated algal toxins.
- HABs can **disrupt industries**: aquaculture, fisheries, and tourism - as seen during the 2012 *Alexandrium catenella* bloom in Tasmania, which led to a global recall of shellfish contaminated with paralytic shellfish toxins.
- HAB events are **difficult to predict**. They are driven by natural factors and can be made more likely due to anthropogenic factors.
- **Climate change** may increase the frequency and intensity of some, but not all, HABs, through factors like increased water column stratification, altered rainfall, and storms changing nutrient distributions. Ocean warming can cause 'tropicalisation' in temperate areas and change HAB species present.
- HABs can last from a **few days to several months** and can occur from the tropics to the poles.
- Some **HABs can reoccur** in specific locations. Others occur only once or infrequently.
- Some HABs are visible by satellites and/or cause water discolouration or surface foam. Others **may go unnoticed** but still pose health and environmental risks.
- In Australia, common marine HABs are species of: *Alexandrium, Dinophysis, Gambierdiscus, Gymnodinium, Heterosigma, Karenia, Karlodinium,* and *Pseudo-nitzschia.* Within a bloom there may be one dominant species or a mix.
- Each **species of HAB has individual toxicological effects**. Correct identification and on-going monitoring using light and electron microscopy and molecular genetic quantification and sequencing is critical to predict and manage impacts and understand conditions leading to HABs.

4. Background: Marine HABs in Australia and New Zealand

Marine HAB species are a common component of coastal and estuarine phytoplankton and have occurred in most coastal areas of Australia and New Zealand. The IOC-UNESCO HAB database HAEDAT lists 124 events in Australia between 1770 and 2025 (Hallegraeff et al 2021). A summary of some of the marine biotoxins produced by HABs in Australia is given in Ajani et al (2017) and Hallegraeff (2024). Common marine HAB-forming taxa in the region are: *Alexandrium, Dinophysis, Gambierdiscus, Gymnodinium, Heterosigma, Karenia, Karlodinium,* and *Pseudo-nitzschia* and other genera. The largest and most impactful marine HABs in Australia in recent decades have been:

1. *Alexandrium catenella* producing paralytic shellfish toxins (PSTs) has occurred from 2012-present in Tasmanian waters. On at least one occasion HABs persisted for ~6 months, along 350 km of coastline, with PST concentrations of 180 times the regulatory limit, causing ~$23M in losses (Campbell et al. 2013, Ruvindy et al. 2024, Ruvindy et al 2018, Turnbull et al. 2021, Turnbull et al. 2025), Hallegraeff and Bolch 2016). This was devastating for fisheries and aquaculture industries and resulted in a ban on exports of Australian shellfish to Japanese markets for up to three years.
2. *Alexandrium pacificum* blooms producing paralytic shellfish toxins (PSTs), have occurred annually from 2016 – 2022 in NSW, persisted for 2+ months, impacting hundreds km of estuaries and coastal regions,

resulting in weeks to months of mussel and oyster harvesting closures, PST concentrations 8 times the regulatory limit, (Farrell et al 2013, Barua et al. 2020).

3. *Karlodinium veneficum* blooms in the Swan-Canning estuary in WA, producing karlotoxins, have occurred most years since 2000, causing fish kills almost annually (Adolf et al. 2015). This species has also caused the deaths of >10,000 fish in Jervis Bay, NSW in January 2011 (Ajani et al. 2017).
4. *Pseudo-nitzschia cuspidata* bloom in 2010 producing amnesic shellfish toxins (ASTs), in Wagonga, NSW, resulted in 16 weeks of shellfish harvesting closures and a loss of $1M (Ajani et al. 2013).
5. *Gambierdiscus* - Ciguatera poisoning via ciguatoxins produced by species of the genus *Gambierdiscus* cause ~ 300 human illness cases per year in Australia, mainly in QLD and more recently also in NSW (i.e. Lewis 2006, Murray et al. 2025).
6. Mass deaths of fish on fish farms have been caused by *Chattonella marina* ($45M loss to Port Lincoln tuna aquaculture in 1996, Hallegraeff et al. 2021), *Heterosigma akashiwo* (commonly causing deaths of prawns on Queensland prawn farms, Mann et al. 2017), *Prymnesium parvum* (impacted Darwin barramundi farms in 2009 (Seger et al. 2015)) and *Karenia longicanalis* which impacted salmon farms in Tasmania in Dec 1989 and May 2003, 4$M loss, (Hallegraeff et al. 2021).
7. A HAB of *Pseudochattonella verruculosa* occurred in the Swan-Canning in July 2017 (Murray 2017).
8. Beaches in Perth and Sydney have been closed due to water discolourations of cyanobacterium *Trichodesmium erythreum* (e.g., Mullaloo and Ocean Reef beaches, Perth, Jan 2024 (WA Government 2025)) and dinoflagellate *Noctiluca scintillans* (e.g., Sydney beaches, 1999 (Murray and Suthers 1999), and Nov 2012 (The Guardian, 2012).

New Zealand experiences blooms of many of the same HAB species as Australia including *Alexandrium* spp., *Pseudo-nitzschia* spp., *Dinophysis* spp., *Pseudochattonella* spp., *Gymnodinium* spp., *Ostreopsis* spp., *Heterosigma* spp. and *Karenia* spp. (see reviews: Rolton et al. 2022; Hallegraeff et al. 2021). Species that produce paralytic shellfish toxins (PSTs; *Alexandrium pacificum, A. minutum, A. ostenfeldii, Gymnodinium catenatum*) are the most common type of HAB in New Zealand, with multiple shellfish harvest closures each year. Diarrhetic shellfish toxin (DST) producers (*Dinophysis* spp., *Prorocentrum* spp.) are also common in parts of New Zealand.

5. What is the Australian and New Zealand experience with HABs of *Karenia*?

The family Kareniaceae is a group of microalgal species belonging to the Dinophyceae (dinoflagellates). HABs involving Kareniaceae are well known for their fish-killing (ichthyotoxic) effects and some species have substantial human health impact due to the production of toxins, including neurotoxins (nerve-toxins) called brevetoxins. Many species of *Karenia* look very similar under high-powered microscopes and can be **very difficult to distinguish** from one another. Even for experts, identification can difficult using morphology alone.

Members of our network also know of several **undescribed species** of *Karenia* that occur in Australian waters whose toxicity is not known. For this reason, it is critical that full investigations are conducted after reports of abundant *Karenia* species with unknown toxicological impacts.

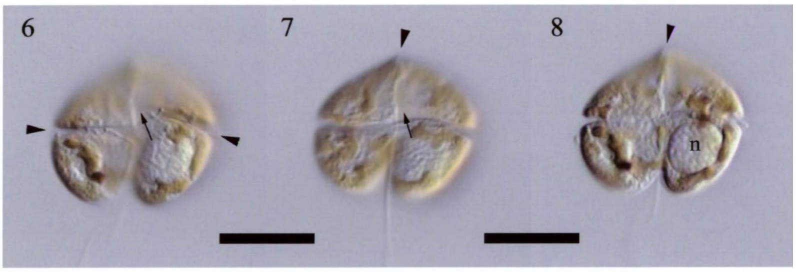
Several species of Kareniaceae have been identified in Australian waters (Adolf et al 2015, Ajani et al 2017, de Salas 2004, de Salas et al 2005, NSW DPI, Verma et al 2024) using light microscopy, molecular genetic methods and in some cases laboratory isolation and culturing:

- *Karenia asterichroma,*
- *Karenia mikimotoi*
- *Karenia papilionacea,*
- *Karenia selliformis,*
- *Karenia longicanalis,*
- *Karlodinium australe,*
- *Karlodinium veneficum,*
- *Takayama tasmanica*
- *Takayama helix*,
- further uncultured *Karenia* species

Karenia mikimotoi and *K. papilionacea* have been found in NSW during monitoring for shellfish safety (NSW DPI). Blooms of *Karenia mikimotoi* have previously been recorded in South Australia, notably in Coffin Bay in March 1995 and February 2014, where they were associated with mass fish mortalities (PIRSA, 2014, Verma et al 2024). The species *Karenia longicanalis* has occurred on salmon farms in Tasmania in Dec 1989 and May 2003, causing a 4$M loss (Hallegraeff et al. 2021). These historical events highlight the **recurring nature of *Karenia* blooms in Australian coastal waters** and the importance of long-term monitoring and species-specific research.

In New Zealand, the biggest toxic HAB events associated with *Karenia* occurred in 1992/1993 in the Hauraki Gulf (Jasperse, 1993) with **180 reported cases** of human Neurotoxic Shellfish Poisoning (NSP) due to brevetoxins from eating shellfish, and associated reports of a respiratory irritation from residents. This HAB was associated with a species of *Karenia* that was not conclusively identified at the time. The event shut down the aquaculture industry across the country **for more than six months**, until a biotoxin monitoring programme was implemented. Other significant *Karenia* HAB events in New Zealand include an unprecedented bloom of *Karenia brevisulcata*. The bloom affected almost all biota in the Wellington Harbour, resulting in high mortalities of fish, invertebrates and algae (Kröger et al. 2006). Over **500 cases of human respiratory distress** were reported during this event, although no food poisoning was recorded. This species produces a range of ichthyotoxic compounds including brevisulcatic acids (BSX) and brevisulcenals (KBT), both chemically distinct from brevetoxins (Holland et al., 2012). Blooms of *Karenia mikimotoi, Karenia selliformis,* and *Karenia longicanalis* regularly cause fish mortality events of wild and farmed fish species.

Since the 1992 HAB of *Karenia* species in New Zealand, weekly monitoring of phytoplankton and biotoxins in shellfish from commercial and also non-commercial (i.e., recreational shellfish harvesting) sites has occurred, involving the collection and analysis of water samples using light microscopy. If light microscopy is not sufficient to identify a species, molecular genetic methods are applied.



Figures 6.6-6.8: Light micrographs of a live field sample of *Karenia papilionacea* from Moulting Bay, Tasmania. Scale bars = 20 µm

Figures 6.12 – 6.14: Light micrographs of *Karenia mikimotoi* strain CAWD63, from the Cawthron Institute, New Zealand. Scale bar = 10 µm.

Figure 1. *Karenia papilionacea* and *Karenia mikimotoi* . (de Salas 2004)

6. Who is responsible for monitoring and managing marine HABs?

HABs in Australia are monitored and managed by a range of organisations (Appendix 2, Table 1). **Management differs between states, and between types of marine HABs**, ie whether a HAB is 'visible', has a known impact on seafood safety, recreational fisheries, public health via respiratory or dermal exposure, or on marine environments and wildlife. Agencies involved can include health departments, food safety regulators, primary resources managers (water, fisheries and environment), environmental regulatory bodies, local government and community groups (see Appendix 2 Table 1). The impact of HABs crosses multiple sectors and needs to be managed with a holistic approach.

In Australia, blooms with human health implications must be monitored in commercial bivalve shellfish under the Chapter 4 of the Australia New Zealand Food Standards Code (FSANZ 2025, see https://www.foodstandards.gov.au/business/primary-production-and-processing), as stated in the Australian Shellfish Quality Assurance Program operations manual (ASQAAC, 2024, see https://safefish.com.au/wp-content/uploads/2024/12/ASQAAC-Manual-v8-2024.pdf). Each state has its own Shellfish Quality Assurance Program that only covers commercial shellfish harvesting growing areas. In these areas, HABs are monitored at a minimum monthly frequency (weekly in some areas) via marine toxin testing in shellfish, along with routine estuarine/coastal water samples to identify HABs using light microscopy.

Outside of the commercial food safety programs, **routine monitoring for marine HABs is inconsistent.** General food safety advice is to avoid recreational harvest of shellfish due to the unknowns around contaminants. While long-term programs are established in select regions of some states (e.g. Western Australia's Healthy Estuaries WA initiative; Swan Canning Riverpark,WA; Hornsby Shire Council, NSW) monitoring in other states tend to be infrequent, limited in scope and often restricted to specific seasons (e.g. The Tasmanian Rock Lobster Biotoxin Monitoring Plan). The majority of estuarine water quality monitoring includes **chlorophyll a** as a proxy for phytoplankton abundance. This is **not suitable for HAB monitoring,** because while some HABs consist of high cell concentrations and are easily visible as water discolourations, **others are highly toxic at low cell concentrations**. High density 'visible' HABs are more likely to be reported. Similarly, fish kills are a 'visible' event and more likely to be reported.

Monitoring for HABs that can cause fish kills **is not legislated** in any state in Australia. Outside of the select monitoring programs noted above, data are limited, may not be publicly available and/or subject to confidentiality clauses. This may involve private business where, for example, finfish aquaculture in Tasmania undertakes operational monitoring. The Australian National Investigation and Reporting Protocol for Fish Kills was developed in 2007 (Commonwealth of Australia 2007, see https://www.agriculture.gov.au/agriculture-land/animal/aquatic/reporting/fish-kills-protocol#daff-page-main) and the individual protocols for responding to fish kills vary between states and territories in Australia (see Appendix 2, Table 1). These protocols are general in approach across a range of environmental conditions. Often HABs are not investigate in cases of fish kills.

In New Zealand, monitoring of HABs in commercial bivalve shellfish aquaculture areas is funded by the shellfish industry. At select locations in New Zealand, where recreational collection of wild shellfish for personal consumption is popular, the Ministry for Primary Industries is responsible for the collection and analysis of routine water and shellfish samples to inform risk management (see https://www.mpi.govt.nz/fishing-aquaculture/recreational-fishing/where-unsafe-to-collect-shellfish/shellfish-biotoxin-alerts/). MPI issue warnings to the public about the risks of consuming non-commercial shellfish when toxicity in shellfish (from commercial and non-commercial sites) exceeds pre-determined limits. Monitoring for HABs that cause shellfish toxicity is well established in New Zealand but if there is a bloom of a HAB species associated with a dermal or respiratory illness or other health issue, ad hoc sampling is done by regional councils or public health officials. If there is a risk MPI will work with the National Public Health Service to issue a public health warning.

The **framework for successful HAB management relies on a rapid response with a coordinated approach**. To achieve this, state and federal agencies should have clearly defined roles and responsibilities, **with established and practised HAB response plans**. The USA provides an example of a nationally targeted response to HABs, through refinement of decades of research. A recognition of the threats posed by HABs and hypoxia (severe oxygen depletion) in coastal and freshwater systems by the US Congress, led to the authorisation of the Harmful Algal Bloom and Hypoxia Research and Control Act of 1998 (see https://cdn.coastalscience.noaa.gov/page-attachments/research/habhrca.pdf, and 2014 amendments see https://www.govinfo.gov/content/pkg/BILLS-113s1254enr/pdf/BILLS-113s1254enr.pdf). A collaborative working group of 13 federal agencies was established through the Act to further research, monitoring and detection, as well as the development of a national program for control and mitigation of HABs and hypoxia events. The Act specified funding priorities and allocations, and the interagency approach encompassed the various aspects of health, food safety, environment, agriculture, science and commerce.

In Australia, management responses to HABs has mostly been reactive. The recent events in South Australia highlight a worst-case scenario of a large and prolonged HAB of high biomass that produces toxins with implications for public health, the marine environment and natural resources. **Cross-border collaboration and data sharing** at a national scale is fundamentally important and needs to be established.

7. What Information do we need to understand and manage marine HABs?

Effectively managing a marine HABs requires very specific scientific knowledge and monitoring systems (Figure 2). The following types of information are fundamental and must be collected at the time of the HAB:

1. Identifying the causative species - Accurate species identification is critical and requires either microscopy by a trained analyst and/or highly specific molecular genetic tools. In the case of novel HABs or HABs in new areas, microalgae must be isolated as a single cell and grown in laboratory cultures to facilitate identification, to investigate the nature/type of toxins it may produce, and to establish the health and environmental risk associated with the species. This process requires a range of highly specialist skills rarely available within a single institution. Despite this expertise, some HAB species may not be culturable, therefore conclusive identification and toxicity studies may not be possible. In Australia, **marine HAB expertise, and specifically taxonomic expertise, is extremely limited (~5-10 people).** The need for collaboration and cooperation among experts highlights the importance of a coordinated network such as ANZ HABNET and ongoing training and research opportunities for new scientists and environmental managers entering the field.

General marine monitoring networks are not suitable for HAB detection. For example, NCRIS funded systems in Australia, such as the Integrated Marine Observing System (IMOS) network of buoys and water sample collection are not designed for HAB detection. Both the microscopy and molecular genetic methods employed in these programs (e.g. IMOS/BPA Marine Microbiome project; SSU V4 based amplicon sequencing) are not suitable for marine HAB detection because they cannot discriminate different HAB species, and sampling frequencies in most cases are too sparse (e.g monthly) necessary to detect/track often rapid (<weekly) changes on concentration and distribution of HABs. Oceanographic detection methods that detect pigments such as chlorophyll a or other algal pigments, including **methods that detect haptophyte-specific pigments** like fucoxanthins, are not able to detect *Karenia* at the species level. Even methods that claim to detect *Karenia*-specific pigments will detect a range of species that contain these pigments.

2. Determining the toxins - Each HAB species can produce different levels or types of marine biotoxins that have different toxicological effects on humans and marine life. Conclusive identification of which species are responsible and the type of toxins, can only be identified through detailed chemical analysis of cultured HAB species. This process requires specialised laboratories with trained biotoxin chemists who have access to necessary chemical standards for specific toxins of interest. In the case of new toxins, they must first be chemically characterised. Currently, **only a few facilities** in Australia and New Zealand have the knowledge and capability to perform this work. Ecotoxicological tests, such as the fish gill cell line or other bioassays, can provide critical insight into toxic mechanisms (Dorantes-Aranda et al.), success of mitigation measures (Seger et al. 2018) and early warning of broad toxic activity.

3. Rapid detection tools - Fast and reliable methods are needed to identify and count HABs at the species level and measure toxins. Molecular methods like quantitative **Polymerase Chain Reaction (qPCR)** (Murray et al 2011, Ajani et al 2021, Ajani et al 2022, Ruvindy et al 2024) and Enzyme Linked Immunosorbent Assays (ELISA) are included in this category. The development of rapid assays targeting HAB species known to occur in a region allows us to obtain **fast (~2 hours)** HAB species quantification and to avoid delays due to limited HAB expertise. Methods to pre-screen samples for the presence of toxins, such as as antibody-based test toxin detection test kits can supplement monitoring programs and be used on farm harvest decision making) if properly validated Turnbull et al. 2018, Dorantes-Aranda et al. 2018)..

For informing our **longer term** understanding of factors causing individual HABs in a region, the following additional data is important:

4. Species ecology and physiology - HAB species can be phototrophic (use sunlight) or mixotrophic (use both sunlight and feed on other organisms). Different species have differing temperature ranges, may grow best at different temperatures, light conditions, salinities, require different amounts or chemical forms of nutrients. Establishing each HAB species optimal growth parameters through laboratory studies helps predict which species blooms when (seasonal window), and how a bloom might respond to changing environmental conditions.

5. Ongoing information collection for environmental modelling and HAB prediction– Water sampling should occur at least fortnightly. Key environmental factors to measure include macronutrients (phosphates, nitrates, silicates), micronutrients (trace metals), water properties (temperature, salinity, dissolved oxygen, pH, carbon levels). **Satellite remote sensing can help in some cases, but it has many limitations:** it will likely miss low-biomass blooms, it cannot distinguish between harmful and harmless species, it only detects surface blooms (~5 metres deep), and is less reliable in shallow water due to bottom reflectance. Long-term knowledge of species distributions and abundances, seasonality, environmental preferences, when combined with oceanographic data (currents, upwelling, and downwelling patterns), can in time form the basis of HAB models and potential bloom forecasting systems.

6. HAB modelling/predictions - Steps 1-5 above highlight the long-term information collection needed to inform models and prediction. Examples of such models for Australian marine HABs: Ajani et al. 2016, *Dinophysis acuminat*a; Ajani et al. 2018, *Prorocentrum minimum*; Ajani et al. 2021, *Pseudo-nitzschia*; Condie et al. 2019, *Alexandrium catenella*. While understanding oceanography of coastal environments can be useful, species ecology and physiology amongst HAB species varies greatly and needs to be established so that it can be integrated into any model. Similarly, not all HABs are high biomass (or visible). This means that the utility of satellite data is limited in such instances.

7. **Understanding seafood safety risk & management/intervention options -** Harmful blooms of mixed species, such as the current one in South Australia, require careful consideration of the bioaccumulation of algal biotoxins across trophic levels, associated regulatory levels (if established) and knowledge of options for management/intervention. The risk in seafood products is typically managed by monitoring toxin levels in conjunction with phytoplankton cell counts and preventing harvest/sale should levels considered safe for human consumption be breached. This approach benefits from understanding of the toxin uptake and depuration kinetics of different seafood species (e.g. Turnbull et al. 2020, Seger et al. 2020, Turnbull et al. 2021) and requires an integrated monitoring approach, similar to the one proposed for managing the paralytic shellfish toxin risk in Tasmania (Turnbull et al. 2025). More knowledge of the risk of biotoxin uptake across SA species is required to refine management protocols/implement biotoxin management plans.) and requires an integrated monitoring approach, similar to the one proposed for managing the paralytic shellfish toxin risk in Tasmania (Turnbull et al. 2025). More knowledge of the risk of biotoxin uptake across SA species is required to refine management protocols/implement biotoxin management plans.

Mitigating marine biotoxins from HABs requires intervention at the site of the bloom, and can include treatments such as chemicals to break algal cells, physical barriers such as perimeter skirts/bubble curtains or application of flocculants, such as clay to remove algal cells and toxins. These techniques tend to be deployed to protect localised resources and their effectiveness needs to be validated not only for the removal of algal cells, but also their associated toxins. For example, fragile cells, such as *Karenia* type species, may lyse during treatment due to turbulence/chemical action and/or physical contact with flocculants, releasing intracellular toxins. While this can potentially amplifying fish-killing effects, such as was observed during clay mitigation efforts in South Korea (Seger et al. 2018), selecting the right type of clay to immediately mop up thus released toxins can effectively eliminate toxic activity of *Karenia* cells (Seger et al. 2022). This shows that the effectiveness of mitigation measures needs to be carefully evaluated through trials of increasing scale to assess to assess suitability and prevent collateral damage of non-target organisms. Urgent guidance & assessment of the efficacy of different mitigation techniques is required to inform regulators of their suitability to SA conditions and support the development of novel treatment options.

In an example of a well-designed HAB early warning system, regional forecasts for *Karenia brevis* blooms in Florida and Texas (Appendix Figure 3) were **made possible through decades of research**. Most of this work began in 1999 following the authorisation of the Harmful Algal Bloom and Hypoxia Research and Control Act of 1998 (see https://cdn.coastalscience.noaa.gov/page-attachments/research/habhrca.pdf). The forecasts incorporate **numerous data sources, field studies and ongoing refinement** of research results across many agencies and research groups. As part of this US program, seven areas are prioritised as critical for developing HAB forecasting for *Karenia* and other HAB species (see https://coastalscience.noaa.gov/project/harmful-algal-bloom-hab-forecasting/). These findings are interesting for the Australian experience of *Karenia* HABs, but cannot be applied directly locally as *Karenia* species and oceanographic systems in South Australia differ. It is of interest as an example of the amount of information and effort involved in setting up early warning HAB forecasting for individual HAB species in one area. HAB forecasting is a long term goal rather than a short term response.

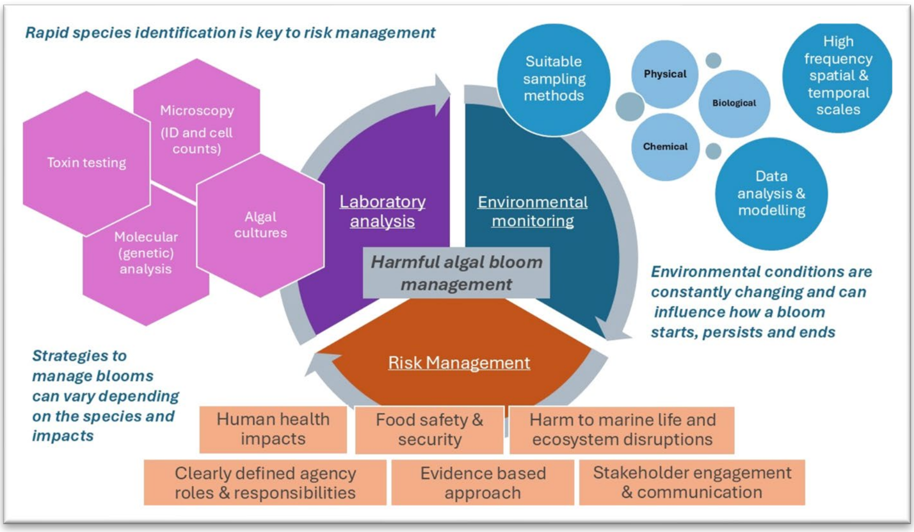


Figure 2. Diagram of how to manage a marine HAB.

In Australia, while we may have access to high quality oceanographic equipment and oceanographic data, we generally lack long term information on HAB species abundances taken at the level of species discrimination and the frequency (ie weekly or fortnightly) required to inform HAB modelling or forecasting. **Oceanographic data and equipment alone is not useful for HAB monitoring**. Equipment like microscopic flowcams that can be attached to oceanographic buoys require ‘training’ on local phytoplankton information, and also cannot distinguish highly morphological similar species such as those of *Karenia* and *Alexandrium*. Such data can only become useful once paired with long term time series of the types of information outlined above.

1. What do we know – and not know – about this HAB?

While investigations have identified the species *Karenia mikimotoi* as present in South Australian waters since March 2025 (Murray and Gaiani, 2025), since then, a **further 3-4 *Karenia* species** have been recognised in bloom samples. The identities of these additional species are currently being confirmed. The identity of the species responsible for brevetoxins detected in South Australian shellfish during the bloom is not yet known. Efforts are underway to establish the range of species in lab culture, extract DNA to determine species identity and toxicity. With cultures, other aspects of species biology can be studied in more detail. These processes are complex and time-consuming, often taking many months **to years to complete** in the case of other unexpected or novel marine HABs in Australia and elsewhere.

In the absence of this information, **it is not possible to determine with certainty** the factors that led to their growth and proliferation. For example, given that we are not clear on the species of *Karenia* in this HAB, it is not possible to determine with certainty **whether a marine heat wave, or higher than usual nutrient concentrations contributed to their growth**. Satellite-based remote sensing data shows only the change in distribution of phytoplankton (chlorophyll-a) over time, not sufficient to distinguish the HAB species from other phytoplankton, or determine the bloom origin and contributing factors. As an example, despite decades of research, the species involved in, and the exact mechanisms and contributing environmental factors behind annual *Karenia* blooms in Florida are still being refined (https://myfwc.com/research/redtide/). HABs of *Karenia* species are often mixed blooms consisting of multiple *Karenia* species and therefore this further complicates the interpretation of the causal pathways.

Advanced molecular methods such as qPCR (Murray et al 2011, Ajani et al 2021, Ajani et al 2022) offer fast, quantitative and more precise species level HAB identification, but must be designed with knowledge of likely target species of interest. Given that the identities of the taxa of interest are not yet known, this work has not yet begun. Once HAB species identities have been established, qPCR assays can be designed that offer a rapid assessment tool that can potentially be automated and used with limited expertise.

2. What is the role of Climate Change in marine HABs?

While climate change may be increasing the frequency of HABs worldwide, it has not led to uniform increases in HABs in Australia or any other country (Hallegraeff et al. 2010). Many HAB species preferentially grow in cold water or low nutrient conditions. Understanding the causes of individual HABs **will always require painstaking and complex data collection and analysis** at the species level as described in Section 7. This has not yet occurred for this current South Australian HAB.
We can expect climate change will lead to:

- range expansion of warm-water species at the expense of cold-water species, which are driven poleward;
- species-specific changes in the abundance and seasonal windows of growth of HAB taxa;
- and
- secondary effects for marine food webs, notably when individual zooplankton and fish grazers are differentially impacted (“match-mismatch”) by climate change.

Some species of harmful algae may become more abundant (e.g.,those benefitting from land runoff and/or water column stratification, tropical benthic dinoflagellates responding to increased water temperatures and coral reef disturbance) while others may diminish as conditions no longer suit them. An example of the complexity of HAB-climate interactions is provided by the east coast of Tasmania. While there exists strong evidence from ancient DNA in 9,000 yr old sediment cores that the red-tide dinoflagellate *Noctiluca* represents a recent (since 1990s) NSW range extension, the unexpected bloom event in 2012 by the cold-water *Alexandrium catenella* may reflect a response to changing near-shore stratification conditions in the cold-water winter period.

3. What short and long-term research, funding and institutional support is needed to respond to marine HABs in Australia?

Research priorities for the current *Karenia* bloom in South Australia can be grouped into short-, mid-, and long-term needs, reflecting the urgency of the event and the foundational knowledge required for future preparedness.

In general, in Australia, research into HABs by agencies such as the Fisheries Research and Development Corporation **has been reactive, following a HAB** of high concern to the fisheries and aquaculture industry. This funding covers applied research of immediate concern to industry. Often little on-going funding is available for fundamental research to create transformational change in our understanding of this complex area. This was seen for example following illnesses due to Ciguatera Poisoning in relation to Spanish Mackerel consumption in NSW in 2016 and following the Tasmanian *Alexandrium catenella* HABs beginning in 2013. While this is necessary and important, it has meant that long term, on-going research funding into HABs in different states and territories Australia has been extremely scarce. It has also meant that when it was necessary, research has been required extremely quickly, in a reactive way, and issues such as this South Australian *Karenia* HAB have not been predicted or quickly understood. In addition, the fisheries and aquaculture industry in Australia should not be the sole providers of research with human health and environmental impacts that are much wider than those effecting only one industry.

Very little research funding on HABs has been provided by other organisations in Australia that offer competitive research grant funding, such as the Australian Research Council. Funding amounts available in general via the ARC have been declining in real terms, and success rates are low (~10-20%). Other, large scale, temporarily funded (generally 6 years, ie until 2027) marine science research initiatives such as the Marine and Coastal Hub funded under the Australian government's National Environmental Science Program (NESP) had, until recently, never funded research into marine HABs. We suggest that a new, on-going funding mechanism for HAB research could be considered, so that longer term preparedness can occur, new scientists can be trained, and capability can be extended and solidified.

Short-term priorities – whilst the bloom is active

1. Confirming the identity of the toxin producing species through isolation and culturing to enable toxicity testing (impacts on animal health) and analytical testing for brevetoxins (human health/market access).
2. Identify seafood species at risk of accumulating toxins. This will inform public health advice and help safeguard domestic and export seafood markets.

Mid-term priorities

3. Developing rapid detection methods for HAB species and their toxins in both water and seafood (e.g. qPCR, toxin bioassays).
4. Laboratory experiments on cultures to understand environmental conditions that favour bloom development, mechanisms of toxicity, and the species' ecologies.
5. Understand the impacts on marine animals, identifying which species are most affected and how.
6. · Understanding accumulation and depuration rates in various seafood to underpin risk management e.g. sampling frequencies, translocation risks associated with moving seafood during events, depuration times.
7. Develop and deliver training and response capacity among regulators, marine industry and government stakeholders.
8. Support for information sharing, networking, and collaboration

Long-term priorities

9. Establish effective and consistent monitoring of coastal waters for marine HAB species and relevant environmental parameters.
10. Improve sampling techniques, analysis tools, and risk assessment frameworks to support comprehensive monitoring. This includes the use of passive samplers for qPCR, eDNA and toxins, molecular and microscopic microalgae assessment and satellite monitoring.
11. Explore mitigation techniques that could protect high value areas and marine life during future events such as the application of clay to suppress blooms in their early stages.
12. Building predictive models based on better understanding of bloom drivers and species-specific behaviour will be essential for long-term management and preparedness.

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Appendix 1. Australian and New Zealand Marine Harmful Algal Bloom Network

Establishment: July 2025.

Terms of Reference

The committee of the Australian and New Zealand Marine Harmful Algal Bloom Network will facilitate Australian and New Zealand information gathering and sharing on marine harmful algal blooms. We will promote and disseminate information in relation to marine harmful algal blooms, including but not limited to training opportunities, conferences, workshops, and relevant local and international research advances. We will be available to provide advice and identify relevant experts when called on.

Suggested purposes/roles

- Identification of experts
- Capability development
- Networking and collaboration
- Sharing isolates/cultures of harmful algal strains for research purposes
- Links to international HAB research and management communities – e.g. International Society for the Study of Harmful Algae, International Oceanographic Commission/UNESCO HAB programs
- Identifying knowledge gaps in relation to marine HABs locally
- Developing research and management priorities
- Maintaining open data sets
- Moving towards centralised data repositories
- HAB data quality control for public domain data
- Providing advice on marine HABs

Membership

Membership should be open in the first instance to relevant representatives of government, aquaculture and fisheries and research communities in each Australian state and territory and in New Zealand.

Committee members: Interim committee will run for 6 months during which these ToR will be finalised. After 6 months nominations will be called to fill the positions and votes called if necessary.

Managing Committee:

The committee will a lead the Australian and New Zealand Marine Harmful Algal Bloom Network in its activities.

Roles:

President, Vice President, Secretary, Communications Officer, General Committee Members (including early career researcher), State/Country representatives.

Quorum: More than 50% of committee members

Meetings:

Minimum three (3) times per year, one (1) of which will include a showcase of research initiatives. Hybrid meetings to encourage wide attendance.

Minutes:

To be circulated to all members and attendees

Interim (Founding) Committee Members (alphabetical order) (will remove if you like)

Alison Turnbull	(UTAS, Tasmania)
Christopher Bolch	(UTAS, Tasmania)
Gustaaf Hallegraeff	(UTAS, Tasmania)
Hazel Farrell	(DPIRD, New South Wales)
Kirsty Smith	(Cawthron Institute, New Zealand)
Ruth Eriksen	(CSIRO, Tasmania)
Shauna Murray	(UTS, New South Wales)
Steve Brett	(Microalgal Services, Victoria)
Tim Harwood	(Cawthron Institute, New Zealand)

Appendix 2. Table 1. Organisations responsible for HAB management and response in Australia and New Zealand.

		Sector					
		Human Health advice/Seafood Safety Advice	**Food safety regulation of commercial bivalve shellfish aquaculture (phytoplankton and/or toxin monitoring)^**	**Visible algal blooms**	**Fish Kills**	**Marine mammal, reptile or seabird impacts (injured or death)**	**Beach closures***
Region	**Queensland (QLD)**	QLD Health, QLD Dept of Agriculture and Fisheries https://www.qld.gov.au/health/staying-healthy/food-pantry/food-safety-for-consumers/potentially-hazardous-foods-processes/seafood/naturally-occurring-seafood-toxins	Safefood QLD https://www.safefood.qld.gov.au/food-business/accreditation/seafood-scheme/seafood-bivalve-molluscs/	QLD Dept Agriculture & Fisheries, Dept of Science & Innovation https://www.qld.gov.au/environment/water/quality/algae/outbreaks	QLD Dept of the Environment, Tourism, Science & Innovation https://www.qld.gov.au/environment/management/pollution-management/reporting/pollution-hotline	QLD Parks and Waterways Service https://www.detsi.qld.gov.au/our-department/news-media/down-to-earth/stranded-marine-mammal	Local councils
	New South Wales (NSW)	NSW Health https://www.health.nsw.gov.au/Infectious/factsheets/Pages/seafood_poisoning.aspx NSW Food Authority https://www.foodauthority.nsw.gov.au/consumer/special-care-foods/recreational-harvest-of-seafood	NSW Food Authority (NSW Shellfish Program) https://www.foodauthority.nsw.gov.au/industry/shellfish	Water NSW https://www.waternsw.com.au/water-services/water-quality/algae	NSW Dept of Primary Industries and Regional Development (Fisheries) https://www.dpi.nsw.gov.au/fishing/habitat/threats/fish-kills	NSW National Parks and Wildlife Service https://www.environment.nsw.gov.au/topics/animals-and-plants/native-animals/sick-or-injured-animals/marine-wildlife-incidents	Local councils

Victoria (VIC)	Dept of Health VIC https://www.betterhealth.vic.gov.au/health/healthyliving/Harmful-algal-blooms	Victorian Fisheries Authority https://vfa.vic.gov.au/aquaculture/publications/shellfish-quality-asurance PrimeSafe https://www.primesafe.vic.gov.au/resources/seafood-safety-regulations-2024/	Environmental Protection Authority (EPA) Victoria https://www.epa.vic.gov.au/what-pollution-and-waste-you-can-report	Environmental Protection Authority (EPA) Victoria https://www.epa.vic.gov.au/what-pollution-and-waste-you-can-report	Wildlife Victoria https://www.wildlife.vic.gov.au/wildlife-emergencies/whale-and-dolphin-emergencies	Local councils or specific coastal authorities
Tasmania (TAS)	Health Tasmania https://www.health.tas.gov.au/health-topics/food-safety/food-safety-consumers/wild-shellfish#toxic-algal-blooms	Tasmanian Shellfish Quality Assurance Program/ShellMAP https://nre.tas.gov.au/aquaculture/shellmap/about-shellmap#:~:text=ShellMAP%20is%20the%20Shellfish%20Control,Rachel%20McKay	EPA Tasmania https://epa.tas.gov.au/working-together/make-a-report	EPA Tasmania https://epa.tas.gov.au/working-together/make-a-report Biosecurity Tasmania https://nre.tas.gov.au/biosecurity-tasmania/biosecurity-emergency-management	Tasmanian Parks & Wildlife Service https://parks.tas.gov.au/discovery-and-learning/wildlife/marine-mammals	Local councils or Tasmania Parks and Wildlife Service

South Australia (SA)	SA Health https://www.sahealth.sa.gov.au/wps/wcm/connect/public+content/sa+health+internet/public+health/water+quality/water+quality+alerts https://www.sahealth.sa.gov.au/wps/wcm/connect/c83edf44-b177-4d32-ac79-58c8347916a6/Factsheet+Harmful+Microalgae+FINAL.pdf?MOD=AJPERES&CACHEID=ROOTWORKSPACE-c83edf44-b177-4d32-ac79-58c8347916a6-psvPVES	SA Shellfish Quality Assurance Program https://pir.sa.gov.au/biosecurity/food_safety/shellfish_sasqap	SA Department for Environment & Water, SA Department of Primary Industries & Regions, SA EPA https://pir.sa.gov.au/sardi/aquatic_sciences/marine_ecosystems https://www.environment.sa.gov.au/news-hub/news/articles/2025/08/sa-harmful-algal-bloom-update https://www.epa.sa.gov.au/environmental_info/water_quality/harmful-algal-blooms	SA Department of Primary Industries & Regions https://www.pir.sa.gov.au/recreational_fishing/reporting https://www.epa.sa.gov.au/environmental_info/water_quality/harmful-algal-blooms	SA Department of Primary Industries & Regions, National Parks & Wildlife Service SA https://pir.sa.gov.au/recreational_fishing/reporting/marine_mammals https://www.parks.sa.gov.au/park-management/what-to-do-if-you-find-an-injured-animal/dolphin-whale-strandings	Local councils and Dept for Environment and Water
Western Australia (WA)	WA Health https://www.healthywa.wa.gov.au/Articles/A_E/Algal-blooms	WA Shellfish Quality Assurance Program https://www.health.wa.gov.au/Articles/S_T/Shellfish-biotoxin-monitoring-and-management Department of Primary Industries and Regional Development (DPIRD) https://www.dpird.wa.gov.au/businesses/aquaculture/western-australia-shellfish-quality-assurance-program/	WA Department of Water & Environmental Regulation https://www.wa.gov.au/service/natural-resources/water-resources/algal-blooms	WA Department of Water & Environmental Regulation https://www.wa.gov.au/service/natural-resources/water-resources/fish-kill-events	WA Department of Biodiversity, Conservation and Attractions https://www.wa.gov.au/service/environment/marine-life-protection/marine-wildlife-response	Local councils

Northern Territory (NT)	NT Health https://nt.gov.au/emergency/community-safety/recreational-water-and-your-health NT Government (Food Safety & Regulations) https://nt.gov.au/industry/hospitality/accommodation-and-food-businesses/food-safety-and-regulations/primary-food-production/primary-production-and-processing-standards	NT Government https://nt.gov.au/marine/commercial-fishing/fishery-licenses/mollusc-industry-and-licences NT Dept of Agriculture and Fisheries https://daf.nt.gov.au/fisheries/aquaculture/aquaculture	NT EPA https://ntepa.nt.gov.au/make-a-report/pollution-report-form	NT Government (Aquatic Biosecurity) https://nt.gov.au/marine/recreational-fishing/make-a-report/report-injured-marine-animals-fishkills-ghostnets	NT Department of Environment, Parks and Wildlife https://nt.gov.au/marine/marine-safety/make-a-report/report-a-marine-wildlife-incident-or-injury	NT EPA (for environmental damage or pollution)
New Zealand	Health NZ https://www.tewhatuora.govt.nz/publications/the-environmental-case-management-of-persons-exposed-to-harmful-algal-bloom-and-cyanobacteria-guidelines-for-public-health-officers NZ Ministry for Primary Industries https://www.mpi.govt.nz/fishing-aquaculture/recreational-fishing/where-unsafe-to-collect-shellfish/what-toxic-shellfish-poisoning/	Shellfish Biotoxin Monitoring Program NZ Ministry for Primary Industries/New Zealand Food Safety https://www.mpi.govt.nz/food-business/food-monitoring-surveillance/monitoring-and-testing-fish-and-seafood/ https://www.mpi.govt.nz/food-business/seafood-processing-storage-testing/bivalve-molluscan-shellfish-growing-harvesting-and-processing/growers-and-harvesters-of-bivalve-molluscan-shellfish/	NZ Ministry for Primary Industries https://www.mpi.govt.nz/fishing-aquaculture/recreational-fishing/where-unsafe-to-collect-shellfish/what-are-toxic-algal-blooms/#:~:text=If%20you%20have%20questions%20about,info@mpi.govt.nz	NZ Ministry for Primary Industries https://report.mpi.govt.nz/pest/	NZ Dept of Conservation https://www.doc.govt.nz/nature/native-animals/marine-mammals/marine-mammal-sightings/	Local councils

*in conjunction with other government agencies

^monitoring programs established under Chapter 4 of the FSC (FSANZ, 2025) and the

Australian Shellfish Quality Assurance Program
Operations Manual (ASQAAC, 2024)

Appendix 3

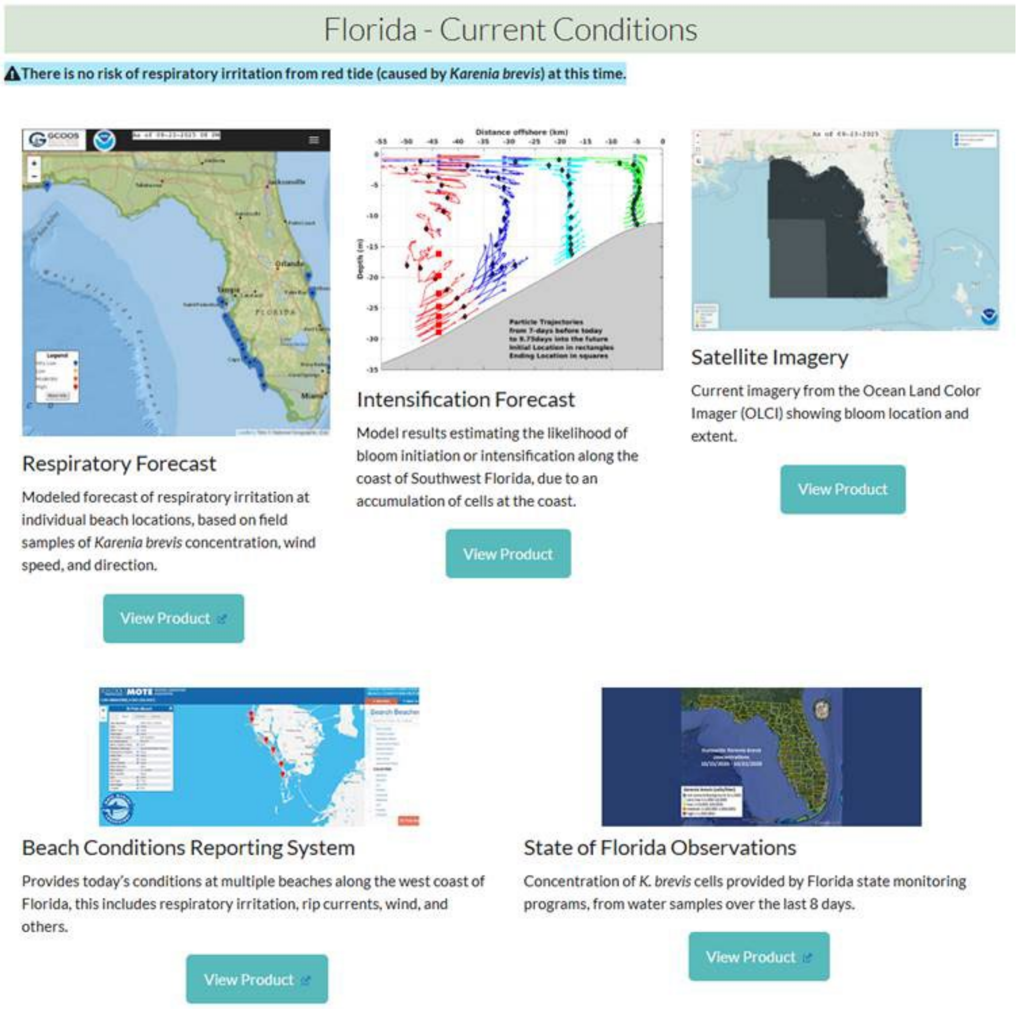

Figure 3 – example of HAB forecast for *K. brevis* blooms in Florida. Source: https://coastalscience.noaa.gov/science-areas/habs/hab-forecasts/gulf-coast/