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Interim guidance for managing marine benthic cyanobacteria in recreational settings in Aotearoa New Zealand

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EXECUTIVE SUMMARY

This document presents interim guidelines for the monitoring and risk management of marine benthic cyanobacteria in Aotearoa New Zealand. Marine benthic cyanobacteria, particularly mat-forming species such as *Okeania* spp., have been increasingly observed in temperate coastal regions, with recent blooms affecting public health, local ecosystems, and recreational water use. These organisms can produce cyanotoxins—such as lyngbyatoxins and aplysiatoxins—which are known to cause dermatitis, respiratory irritation, and other adverse health outcomes through dermal contact, ingestion or inhalation.

These interim guidelines consolidate national and international science, historical monitoring data, and recent bloom events across Auckland and other regions, and propose a four-stage response framework (see summary table below). This includes site assessments, taxonomic and toxin testing, public health decision-making and follow-up monitoring. Key recommendations focus on biomass estimation, safe sampling protocols, toxin testing, and risk communication to protect beach and estuary users. Roles and responsibilities are outlined for councils and health authorities, with an emphasis on interagency collaboration and partnership with mana whenua.

Response Stage	Trigger / Condition	Key Actions
1	Reports of the presence of cyanobacterial mats	Site survey, biomass estimation, sample collection, inform public health staff
2	Sample analysis	Identify dominant taxa, test for toxins, determine need for escalation or follow-up
3a	Low biomass + toxins detected	Erect information signs, monitor fortnightly
3b	High biomass + toxins detected	Issue health warning, erect warning signs, consider biomass removal
4	Ongoing presence or new blooms	Conduct follow-up sampling and monitoring every 2–4 weeks (depending presence of toxins and level of biomass)

It is important to note that these guidelines only cover the risk associated with recreational activities in or near coastal and estuarine waters. They do not cover the potential hazards from consumption of recreationally harvested shellfish or seafood contaminated with marine cyanotoxins.

Recognising the significant knowledge gaps—particularly around toxin diversity and detection, bloom triggers and exposure thresholds—the document also highlights priority areas for research and encourages the collection of data that will improve ecological knowledge on marine benthic cyanobacteria and potential remote-sensing monitoring of blooms in the future. These interim guidelines are intended to be refined over time as more data and experience are gathered.

Important note: Using this guidance material

The following guidance material provides a recommended approach based on current scientific understanding of the risks associated with marine benthic cyanobacterial mats that can wash up on beaches and estuaries in Aotearoa New Zealand and is intended for contact recreation purposes only. The guidance should be treated as interim.

These guidelines might not be regularly applied in all regions around Aotearoa New Zealand, unless re-occurring bloom events involving marine benthic cyanobacteria were experienced in the region. They have been developed so that responsible agencies have guidance on how to respond if marine benthic cyanobacterial mats do wash up on beaches and / or estuaries in their region and recommended steps on how to evaluate the potential human health risk.

Local decisions about whether to follow every aspect of this approach should ultimately result from consideration of site-specific factors (such as resource availability, management priorities and historical understanding of local harmful algal bloom conditions), as well as the guidance offered in this document. Monitoring agencies may have reason to depart from the methodologies suggested in this guidance. Public health staff should be engaged about such decisions and additional expert advice may be required.

1. BACKGROUND

1.1 MARINE BENTHIC CYANOBACTERIA

Microalgae are the foundation of all marine food webs, they support marine ecosystems, fisheries and aquaculture, and are a substantial carbon sink. Some species can form harmful algal blooms (HABs) – defined as the rapid growth and accumulation of microalgal biomass in aquatic ecosystems under favourable conditions (Smith et al., 2024). Several types of microalgae can form HABs, but most causative species belong to the groups: cyanobacteria, dinoflagellates, diatoms and haptophytes. Cyanobacteria (commonly known as blue-green algae) are photosynthetic prokaryotic organisms that are an integral part of many terrestrial and aquatic ecosystems, only becoming an issue when they increase to high concentrations, forming blooms. Cyanobacterial cells can multiply rapidly and form planktonic (suspended in the water column) blooms or dense benthic (attached to the substrate) mats. Cyanobacterial HABs are most prevalent in freshwater environments, but can also be found in marine systems, both in planktonic and benthic habitats. Cyanobacterial HABs can produce toxins, called cyanotoxins, and secondary metabolites that can be harmful to humans. It is expected that the frequency and severity of cyanobacterial blooms in all environments will increase over the next 10–30 years with rising eutrophication and water temperatures (Biessy and Wood, 2024; Paerl and Paul, 2012). These guidelines include information regarding mat-forming benthic marine cyanobacteria and the risks they pose during recreational activities.

Marine benthic cyanobacteria can form mats (Figure 1), or clumps of matted mass of filaments 10–30 cm long, sometimes referred as “mermaid’s hair”, that can grow in shallow estuaries or to depths of up to 30 m (Osborne, 2021b). These mats can become dominant on the benthos, particularly ocean floors and reefs (Berthold et al., 2021; Paerl and Paul, 2012; Paul et al., 2005). To date, blooms of marine benthic cyanobacterial mats have been prominent mainly in tropical and subtropical regions, but proliferations are increasing in temperate regions with climate warming and ongoing nutrient inputs (Curren et al., 2022; Ford et al., 2018). Marine benthic cyanobacteria can tolerate a wide range of environmental conditions, allowing them to compete with other micro- or macro-algae (e.g., seaweed). Both laboratory and field studies have shown that the growth of marine benthic cyanobacteria is influenced by nutrient availability, specifically nitrogen, phosphate and iron (Ahern et al., 2007; Albert et al., 2005). Blooms of marine benthic cyanobacteria in the field have been triggered by benthic sources of bioavailable iron, particularly from sediment communities, and supported by inputs of nitrogen and phosphate (Hanington et al., 2016). During heavy rainfalls, more extensive sediment mixing occurs, also contributing to the blooms of marine benthic cyanobacteria (Ng et al., 2012; Thrush et al., 2004). Because benthic mats are restricted to the ocean substrate, they can grow only in habitats where the sunlight can penetrate to the bottom. On sunny days photosynthetic activity can lead to high rates of oxygen production, causing the creation of bubbles within the mats, which loosens their attachment to their substrate and drives them to the surface. Storm events can also disrupt the mats growing on the benthos, sending the mats to surface waters. These mats can then concentrate further through wind and wave action, causing them to aggregate on shores, estuaries and beaches. These situations can pose a serious health risk to recreational users who will then be exposed to these potentially toxic mats through water activities (e.g., surfing, swimming; WHO, 2021).

Blooms of benthic marine cyanobacterial mats can alter trophic structure and functionality. They can smother the underlying aquatic system, resulting in food web changes and in some cases kill the underlying biota (i.e., sponges and corals; Ford et al., 2018). Once formed, the mats can affect the recruitment of marine invertebrates and other benthic taxa, impacting food webs. For example, it has been shown that there can be shifts in reef fish communities (Ullah et al., 2018) or that other toxic species (e.g., other toxic benthic microalgae) can co-occur with and inhabit benthic cyanobacterial mats (Biessy et al., 2021). Marine benthic cyanobacterial mats can also emit noxious odours when blooming and decomposing, producing volatile sulphur compounds that can include hydrogen sulphide, methyl mercaptan, and dimethyl sulphide (Zinder et al., 1977). Microbial activity during decomposition can consume dissolved oxygen, leading to lower water pH, hypoxia and fish kills (Cui et al., 2024; Ford et al., 2018).

Marine benthic cyanobacterial mats can be hazardous to human, aquatic and terrestrial organisms via the production of highly toxic secondary metabolites, known as cyanotoxins. Cyanotoxins have been associated worldwide with numerous animal mortality events and also endanger human health (Bernard et al., 2016). To date, more than 2,000 secondary metabolites have been identified from benthic marine cyanobacteria, particularly from the genera *Moorea*, *Lyngbya* and *Okeania* (El-Seedi et al., 2023; Perera et al., 2023), however, many of these metabolites are still uncharacterised and poorly studied (particularly regarding toxicology studies). The most studied groups of marine cyanotoxins are dermatoxins from the lyngbyatoxin and aplysiatoxin groups, that are known for causing dermatitis, and eye and throat irritations (Osborne, 2021b).

Figure 1: Images of marine benthic cyanobacterial mats (BCMs) on Waiheke Island (Auckland, Aotearoa New Zealand). A) Tonnes of marine BCMs washed up on Blackpool Beach in March 2023; B) BCMs washing up on shellfish beds on Shelley Beach in March 2023; C) BCMs floating to the surface near Blackpool Beach in January 2024 (credit: Merrie Hewetson); and D) Washed up BCMs on Surfdale Beach in December 2023 (credit: Auckland Council). For close-up photos, please see Appendix E.

Human exposure to marine toxins can occur in various ways, however, the most severe exposure route is generally though the consumption of contaminated seafood (Kalaitzidou et al., 2021). This guidance document does not cover this aspect in detail, with the focus being on recreational water activities. Recreational activities can also be a significant exposure route for marine cyanotoxins (see Section 1.3 for more details). Potential routes of recreational exposure to marine cyanotoxins include direct contact via exposed parts of the body and cell material trapped under clothing (i.e., bathing suits or wetsuits), accidental swallowing of contaminated water or mat material, and inhalation (Chorus et al., 2021). Filamentous marine cyanobacterial species can also accumulate on fishing nets, ropes and lines. Contact with fresh and dried material has previously caused severe skin reactions and breathing difficulties amongst workers in the fishing industry (Grauer and Arnold, 1961; Osborne et al., 2001).

1.2 MARINE BENTHIC CYANOBACTERIA IN AOTEAROA NEW ZEALAND

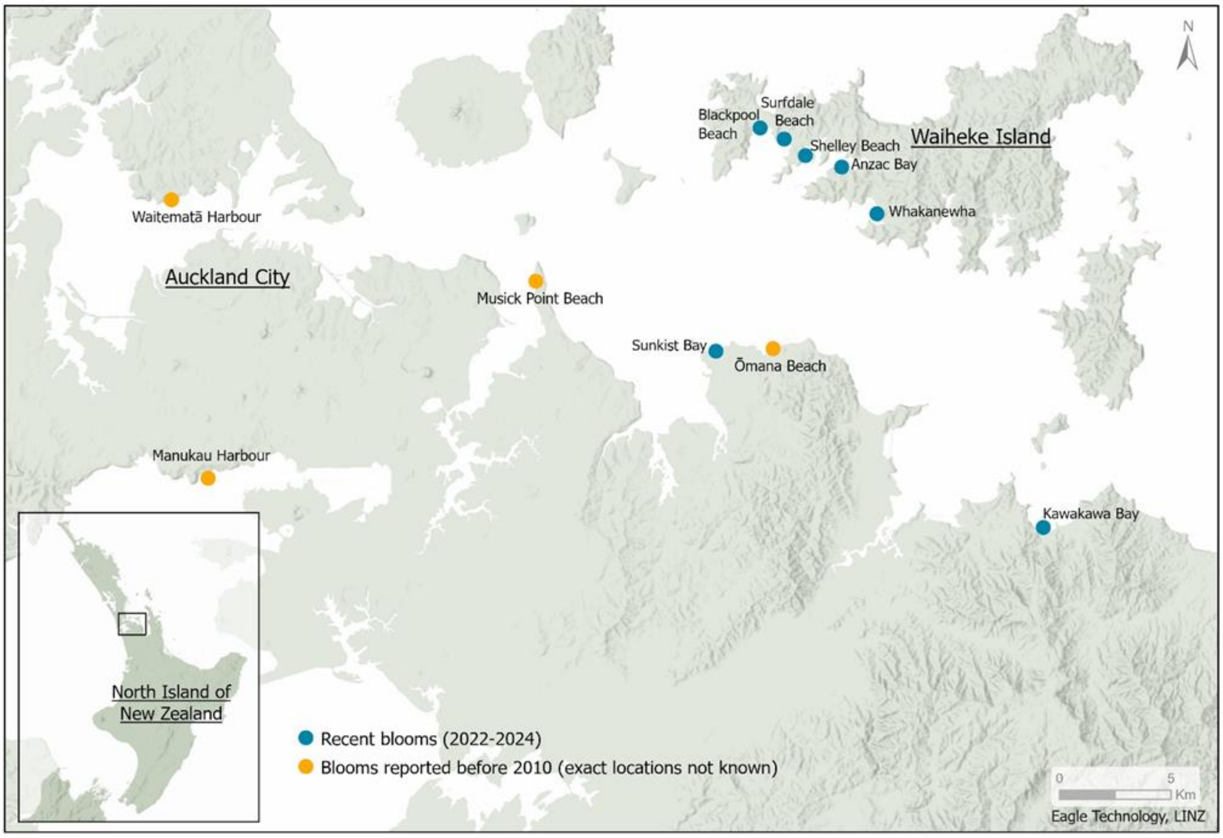
Blooms of the filamentous cyanobacterium, identified at the time as *Lyngbya majuscula*, have been reported since 1999 in various parts of the Hauraki Gulf (Figure 2), particularly in the Ōmana Beach area, Auckland Region (Nelson et al., 2015; Tricklebank and Hay, 2007). Large rafts of this species washed ashore at Ōmana Beach during summer in the years 1999–2001, 2003 and 2005 (Tricklebank and Hay, 2007), and tufts of the cyanobacteria were found entangled around brown seaweed (Wilcox, 2007). In 2007, Wilcox (2007) also reported on a summer bloom of *Lyngbya majuscula* at sites in Eastern Auckland in the Hauraki Gulf (Musick Point, Eastern Beach and Howick), as well as sites in the Manukau Harbour (Kaitarakihi Bay) and at North Head in the Waitematā Harbour. The *Lyngbya majuscula* taxon has now been reclassified and split into the genera *Lyngbya*, *Moorea*, *Moorena*, *Okeania*, *Dapis* and others (discussed in Section 1.3.1). This historical classification and the lack of genetic testing at the time makes it difficult to know which species of marine benthic cyanobacteria were present in Aotearoa New Zealand in the late 1990's to early 2000's. Samples from the 2005 bloom (there are reports of over 100 tonnes of mats being removed from the beach) tested positive for the dermatoxin lyngbyatoxin-a (Selwood and McNabb, 2005); see Section 1.3.1.

Following the initial bloom in 1999, complaints from members of the public about the smells associated with decomposition of the cyanobacterial mats resulted in a monitoring programme being initiated by Auckland Regional Council (Tricklebank and Hay, 2007). Tricklebank and Hay (2007) summarised the findings of a series of earlier reports on blooms, reviewed the monitoring programme, and made recommendations about the design of any future monitoring activities. The sampling and monitoring stopped in 2007, and no reports of marine benthic cyanobacteria occurred again until early summer in 2022. These blooms lasted five months (November 2022 to March 2023), and subsequently occurred again in the summer of 2023 / 2024. During these two summers, over 400 tonnes of marine benthic cyanobacteria, genetically identified as *Okeania* sp., washed up on Waiheke Island beaches, Auckland, affecting local communities and the environment (Figure 2; Biessy, 2023). The mats of *Okeania* sp. tested positive for lyngbyatoxin-a and this cyanotoxin was also detected in edible shellfish and gastropods / snails from the area (Biessy et al., 2024). Observations from 2024 include the presence of washed-up marine benthic cyanobacterial mats on Waiheke Island and mainland Auckland (Central Waitemata), but earlier than the previous two years (spring instead of summer), and that some of the mats in mainland Auckland (Kawakawa Bay) were present in reasonable amounts all winter, as well as Omana Beach and the beaches around the Beachlands area (Auckland Council, pers. comm.).

Reports of marine benthic cyanobacteria (microscopically identified as a species of *Oscillatoria* but genetic testing was not undertaken) have also been reported in estuaries around the Bay of Plenty, Maketu and Waihi (Hamill, 2014).

It is expected that with warmer water temperatures and increased nutrients / eutrophication, the frequency and duration of cyanobacterial blooms will increase and will likely spread to regions with historically temperate climates (Ford et al., 2018; O'Neil et al., 2012), including in Aotearoa New Zealand (Rhodes and Smith, 2022; Smith et al., 2024).

Figure 2. Locations where benthic cyanobacterial mats have been recorded in Aotearoa New Zealand. Map adapted from Biessy et al. (2024).



1.3 HEALTH EFFECTS OF MARINE BENTHIC CYANOBACTERIA

Marine cyanobacteria can produce toxins (see Section 1.3.1 below). There are three main exposure pathways for marine cyanotoxins:

Exposure through dermal contact

Some marine cyanotoxins can cause severe contact dermatitis, known as ‘swimmer’s itch’ or ‘seaweed dermatitis’. Severe skin lesions may occur when benthic cyanobacterial material is trapped under bathing garments, and these are the HAB symptoms for which the cause–effect relationship through recreational exposure has been demonstrated most tightly. Marine benthic cyanobacterial species regularly wash up on the coastlines of Australia, causing dermatitis (Osborne and Shaw, 2008) and were suspected to be responsible for an irritant syndrome in Rarotonga (Cook Islands) when 700 cases were reported and symptoms affected more than 30% of the coastal population on the island (Hajkowicz and Okotai, 2005).

Exposure through inhalation

There have been reports of respiratory symptoms (throat and eye irritation) and general malaise following water contact or inhalation of aerosols associated with blooms of marine benthic cyanobacteria (Hajkowicz and Okotai, 2005; World Health Organization, 2021). This exposure route can be amplified when undertaking recreational activities that generate sea spray (e.g., surfing, kayaking).

Exposure through accidental ingestion

Ingestion of water and cyanobacterial mats is a risk during recreational activities undertaken in the water (e.g., surfing, swimming) or activities where accidental submersion might occur (e.g., kayaking). Children playing in the vicinity of marine benthic cyanobacterial mats are also at risk from accidentally consuming cyanobacterial mats.

Marine cyanotoxins have also recently been shown to be present in seafood species in Aotearoa New Zealand (Biessy et al., 2024). Several human poisonings have also been reported internationally, related to the consumption of contaminated turtle meat (Champetier de Ribes et al., 1998; Funari and Testai, 2008; Semmouri et al., 2024) and seaweed (Grauer and Arnold, 1961; Sims and Zandee Van Rilland, 1981). These guidelines only cover the risk associated with recreational activities in or near coastal and estuarine waters. They do not cover the potential hazard of seafood contaminated with marine cyanotoxins.

1.3.1 Toxins produced by marine benthic cyanobacteria

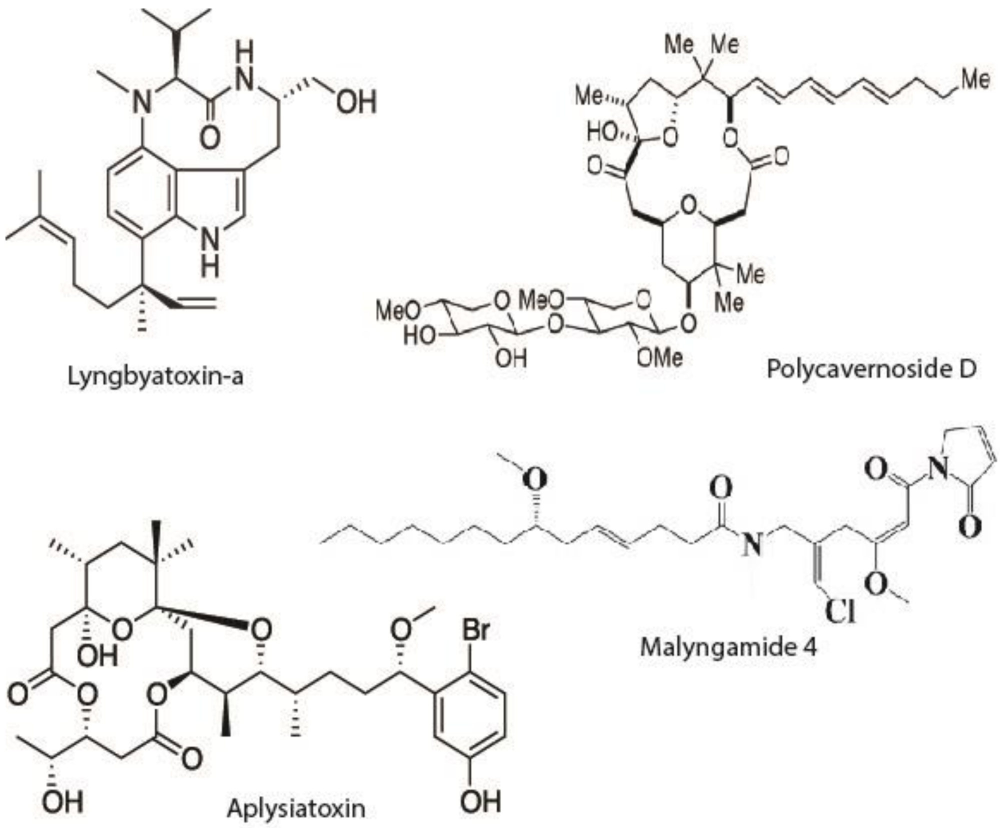
Marine benthic cyanobacteria are a prolific source of biologically active compounds, many of them still uncharacterised or poorly studied. Some species can produce toxins, called cyanotoxins, and other unknown secondary metabolites, particularly peptides with cytotoxic activity (Tan, 2010). Most marine cyanotoxins are considered dermatoxic, causing negative health effects through dermal contact and inhalation. It is important to note that robust toxicological evaluation for most of the cyanotoxins described below has not been undertaken to date, particularly regarding toxicity via dermal contact but also via the aerosolisation of toxic compounds. As a result, no guideline values for recreational exposure are available for the cyanotoxins described below, although adverse health effects related to exposure to the toxins has been documented.

Lyngbyatoxins

The most common cyanotoxin produced by marine benthic cyanobacteria are lyngbyatoxins. Lyngbyatoxins are dermatoxic alkaloids that are highly inflammatory and blistering (vesicatory) substances (Fujiki et al., 1981). So far, seven natural lyngbyatoxin analogues have been identified, namely lyngbyatoxin-a, 12-*epi*-lyngbyatoxin-a, 2-oxo-3(*R*)-hydroxy-lyngbyatoxin-a, 2-oxo-3(*R*)-hydroxy-13-*N*-desmethyl-lyngbyatoxin-a and 2,3-seco-2,3-dioxo-lyngbyatoxin-a (reviewed in Du et al. (2019. Lyngbyatoxins are mainly produced by benthic mat-forming cyanobacteria, particularly by the species historically identified as *Lyngbya majuscula*, now reclassified into the genera *Lyngbya*, *Moorea*, *Moorena*, *Okeania*, *Dapis* and others not yet identified (Curren et al., 2022; Engene et al., 2011; Engene et al., 2013a; Engene et al., 2013b; Engene et al., 2012; Engene et al., 2018; Osborne, 2021a).

The most prevalent and studied lyngbyatoxin analogue is lyngbyatoxin-a (LTA; also referred as Teleocidin-a; Figure 3). LTA can cause acute dermatitis, commonly referred to as 'swimmers itch' or 'seaweed dermatitis', as well as eye and respiratory irritation in humans due to aerosolised toxins (Osborne et al., 2001). The minimum lethal dose (LD_{100}) of LTA by intraperitoneal (ip) injection in mice has been estimated as 300 µg/kg and LTA was shown to induce severe damage to the villi capillaries, leading to bleeding in the small intestine; sublethal doses caused erosion in the stomach, small and large intestines and inflammation in the lung (Ito et al., 2002). Using topical application, the cutaneous median effective dose (ED_{50}) was estimated as 4,800 µg/kg (Chorus and Welker, 2021). No data on LTA-induced repeated toxicity is currently available, but LTA has been shown to have tumour-promoting activities via the protein kinase C activation pathway (Fujiki and Suganuma, 1996; Nakamura et al., 1989).

Figure 3. Examples of chemical structures of cyanotoxins produced by marine benthic cyanobacteria.



Aplysiatoxins

Aplysiatoxins are considered to be dermatoxic alkaloids (Van Apeldoorn et al., 2007). Five analogues have been identified to date, namely aplysiatoxin, debromo-aplysiatoxin, anhydro-aplysiatoxin, 3-methoxydebromo-aplysiatoxin, oscillatoxin-A and 31-noroscillatoxin-B (Ding et al., 2018). Similar to lyngbyatoxins, aplysiatoxins induce contact dermatitis through the activation of protein kinase C activation pathway (Pearson et al., 2016). Aplysiatoxin (Figure 3) and debromo-aplysiatoxin were also recently found to be potent tumour promoters of two-stage carcinogenesis in mouse skin (Fujiki et al., 1985). Aplysiatoxins are produced by marine benthic cyanobacteria in estuarine and coastal waters under tropical and subtropical climates (Du et al., 2019). Chemical analyses are able to detect aplysiatoxins in the environment and also evaluate the toxic effects (Ding et al., 2018). It has been shown that liquid chromatography with tandem mass spectrometry (LC-MS/MS)-based molecular networking approach is a rapid analytical technique, which can be used to detect aplysiatoxins from environmental samples (Du et al., 2019).

Malyngamides

The first malyngamides (-A and -B) were isolated in Hawaii from *Lyngbya majuscula* and described by Dalietos et al. (1978). There are now 30 malyngamide structural analogues documented, making them a dominant group of natural products produced by marine cyanobacteria (Curren et al., 2022). Most malyngamides display cytotoxicity when tested against cell lines and have also displayed toxicity to organisms such as shrimp (*Artemia salina*) and goldfish (*Carassius auratus*). Malyngamides-I and -R were toxic to *Artemia salina*, with IC_{50} values of 35 µg/mL and 18 µg/mL, respectively. Malyngamides-H and -I were mildly toxic to *C. auratus*, with IC50 values of 5 µg/mL and <10 µg/mL, respectively [reviewed in Curren et al. (2022)].

Polycavernosides

Polycavernosides are 16-membered glycosidic macrolides (a class of natural products). Polycavernosides-A and -B were first isolated as the major causative agents of fatal human food poisonings caused by ingestion of red algae which occurred in Guam in 1991 (Haddock and Cruz, 1991; Yotsu-Yamashita et al., 1993) and in the Philippines in 2002–2003 (Yotsu-Yamashita et al., 2004). Another congener, polycavernoside-D (Figure 3) was isolated from an isolate of the marine cyanobacterium *Okeania* sp. (Navarro et al., 2015), suggesting that polycavernosides have cyanobacterial origins. This report raised concerns regarding the potential widespread occurrence of polycavernoside-producing cyanobacteria in tropical marine environments. A similar new congener, polycavernoside-E was recently identified in the marine cyanobacterium *Okeania* sp. collected from the coast of Okinawa, Japan (Umeda et al., 2024), and its toxicity was evaluated in mice. The minimal toxicity of polycavernoside-E was estimated as 0.81 mg/kg by intraperitoneal injection, whereas that of Polycavernosides-A to -C were >13 mg/kg (Yotsu-Yamashita et al., 2024).

Other toxins and compounds

Thousands of secondary metabolites have been isolated from benthic marine cyanobacteria in the last few decades, the majority of the metabolites identified have been found to be biologically active (e.g., against cell lines), although the toxicity to small animals has not been evaluated for many. In particular, they have been reported to modulate cell death and apoptosis in cancer cells as well as target enzymes and they are emerging as an important source of anticancer drugs and new drug leads (Tan, 2007; Tan, 2010). However, there is very limited information on these molecules and their toxicity outside of cytotoxicity, especially the negative health effects these toxins would pose in a recreational setting [reviewed in Gerwick et al. (2001) and Tan (2007)].

The majority of these potent biomolecules, including the microcolins (18 analogues documented), dolastatins (13 analogues documented), curacin A, hectochlorin, the apratoxins, apramides, dudawalamides, guineamides, jamaicamides, majusculamides, oscillatoxins, pitipeptolides, tumonic acids, vatiamides and the lyngbyabellins, belong to the mixed polyketide–polypeptide structural class (Curren et al., 2022; Tan, 2010). Most of these molecules have been isolated from filamentous cyanobacteria of the order Nostocales, particularly members belonging to the genera *Lyngbya*, *Oscillatoria*, and *Symploca* (Tan, 2010). Almiramides are also cytotoxic peptides and have been detected in the benthic marine cyanobacteria *Oscillatoria nigroviridis* (Quintana et al., 2014).

Other cyanotoxins such as anatoxins, microcystins and saxitoxins are more commonly produced by freshwater cyanobacteria but can also be produced by marine cyanobacteria (Gantar et al., 2009; Grindberg et al., 2008; Mejean et al., 2010). Information on potential toxin-producing freshwater cyanobacterial taxa and the cyanotoxins they have been shown to produce (to date) can be found in the Aotearoa New Zealand Guidelines for Cyanobacteria in Recreational Freshwaters (Ministry for the Environment and Health New Zealand, 2024). In the absence of more comprehensive knowledge on toxin-producing marine benthic cyanobacteria, testing for the appropriate ‘freshwater’ cyanotoxin should be undertaken when a cyanobacterial genus identified as a potential toxin-producer in freshwater ecosystems is found in the marine environment.

Little is known about the biological and chemical diversity of marine benthic cyanobacteria and their toxins (Engene et al., 2011; Sharp et al., 2009) and the risk that they pose to humans. It is important to note the large gap in toxicity studies for these toxins and secondary metabolites, particularly around the risk they pose for recreational activities (e.g., aerosols productions, dermatotoxicity). There are also no validated methods to analyse most of these compounds listed above and to date, based on the toxicity data, the focus for testing and future method development should be focused on lyngbyatoxin-a, aplysiatoxins and polycavernosides.

Toxins from marine benthic cyanobacteria found in Aotearoa New Zealand

The development of methods for the detection of toxins and compounds produced by marine benthic cyanobacteria is recent and most of the toxins described above are not regularly monitored worldwide. To date, in Aotearoa New Zealand, both lyngbyatoxin-a and malyngamides have been detected in mats of *Okeania* spp. that have been washing up on the beaches around the Auckland region (see Section 1.2) but the presence of the other toxins has not been tested due to the lack of validated methodology. See Section 2.3.7 for more details on cyanotoxin testing available.

2. RISK EVALUATION AND MANAGEMENT

Risk assessment for benthic cyanobacteria is more difficult than for planktonic cyanobacteria due to the patchiness of the bloom material and a lack of understanding regarding exposure levels. Developing risk management guidance for marine benthic cyanobacteria is further complicated by knowledge gaps, particularly related to the ecology of these blooms. There is some international guidance published on marine benthic cyanobacterial blooms, as well as insights from monitoring that was previously established in Aotearoa New Zealand. These documents and information covered in the background section (Section 1) have helped to shape the suggested risk management approach described in this section. We encourage the adoption of this approach, in regions experiencing marine benthic cyanobacterial blooms, with a review of the guidance material at the end of this period of trialling the new risk management approach. The insights and data collected over this time period will allow for more robust risk management guidance to be established.

2.1 INTERNATIONAL MONITORING AND RISK MANAGEMENT APPROACHES

Blooms of marine benthic cyanobacterial mats and toxic outbreaks associated with the toxins they can produce have been reported from Japan, Hawai'i and Australia since the 1960s (Dennison et al., 1999; Grauer and Arnold, 1961; Yasumoto and Murata, 1993). Australia and Florida (USA) have developed guidance to manage risks in recreational waters and how to start a monitoring effort (described in more detail in Sections 2.1.1 and 2.1.2 below). In 2021, the World Health Organization (WHO) published guidelines for managing HAB risks in recreational waters. The primary aim of these guidelines is to protect the health of humans from threats posed by the recreational use of coastal, estuarine and fresh waters, including from benthic marine cyanobacteria (WHO, 2021). These guidelines mention that available data indicate that the risk to human health associated with the occurrence of marine cyanobacteria during recreational activities is limited to a few species and geographic areas, not including Aotearoa New Zealand. To the best of our knowledge, aside from Aotearoa New Zealand, only two other countries have developed guidance or guidelines for marine benthic cyanobacteria to date.

2.1.1 Australia

Australia, in particular Moreton Bay in the Queensland Region, has been subject to frequent blooms of marine benthic cyanobacteria for several decades. Guidelines for managing risks in recreational waters in Australia were published in 2008 by the Australian Government (NHMRC, 2008). For marine cyanobacteria, the guidelines stated that coastal and estuarine recreational water bodies should not contain *Lyngbya majuscula* (or any bloom-forming cyanobacteria) in high numbers, described by a relatively widespread visible presence of dislodged algal filaments in the water and washed up onto the beach. A risk management approach was developed based on a three-tier system:

- **Surveillance mode (green level)** defined by "history but not current presence of organism". This level involves routine sampling to measure contaminants (e.g., physical, microbial, cyanobacterial and algal).
- **Alert mode (amber level)** defined by mats "present in low numbers". This level requires investigations into the causes of the elevated levels and increased sampling, which enables a more accurate assessment of the risks to recreational users.
- **Action mode (red level)** defined by mats "present in high numbers", define as a relatively widespread visible presence of dislodged algal filaments in the water and washed up onto the beach. This level requires the local authority and health authorities to warn the public that the water body is considered to be unsuitable for primary and secondary recreational use.

The Australian guidelines recommend that, in view of its potential to cause severe irritation, people should avoid areas affected by benthic marine cyanobacteria when possible. People should also avoid direct contact with material washed up onto the beach. This includes avoiding swimming or wading in areas where the cyanobacteria is growing or floating in the water. Where mats have washed onto beaches, it is recommended that it should be cleared as soon as possible by local authorities while making sure to take precautions to minimise contact during collection, transit and disposal operations. They also recommend that people who have symptoms associated with toxins from marine benthic cyanobacteria, and have been in an affected area, should consult a doctor.

The Moreton Bay Regional Council published a HAB response plan in 2018, which included monthly monitoring using visual inspections of the extent of the mats from boats, combined with shore-based inspections for deposited material. Inspections have been undertaken by state and local government officers, community groups and fishers. The council also developed a three-level response plan. The response plan is fully described in the report from WHO (2021). It can be summarised briefly as:

- **Alert Level 1** with small to moderate bloom material at locations away from developed areas. This level requires no action to remove material, apart from placing signs to inform the public of the presence of a potentially harmful algal bloom may be appropriate.

- **Alert Level 2** defines with large quantities of bloom material washing ashore or forming rafts adjacent to developed areas or areas of high public use. The response requires to install signs immediately, issue a media release and physically remove material from shores.
- **Alert Level 3** is defined as very large quantities of material washed ashore or beginning to form large rafts adjacent to developed areas or areas of high public use. The response is the same as the response for Level 2, but closure of beaches may also be required, particularly where large amounts of blooms are growing close to the water's edge.

2.1.2 Florida (United States of America)

Following the recent Florida Blue-Green Algae State of the Science Symposium in 2023, new guidance was published for Florida on the monitoring of cyanobacterial blooms, including benthic marine cyanobacteria (Krimsky and Staugler, 2023). To cite the document:

> Benthic cyanobacterial blooms are often multi-generic and multi-specific, making identification complex and challenging. However, correct identification aids risk assessment and communication among managers and scientists. Identification of benthic cyanobacteria can be done using genetic and morphological techniques. Genetics can be used to initially aid in determining genera and species differences; once you know what to look for, morphology can be used to identify many primary organisms. Marine benthic cyanobacterial blooms can contain toxins as well as other pathogenic microorganisms including bacteria, fungus, or planktonic microeukaryotes (i.e., the eukaryotic HAB species). Many of these secondary compounds constrained within the benthic mats are still unknown. Thus, accurate identification is important for safe and effective monitoring, mitigation, and public health response. The lifecycle of benthic cyanobacterial blooms follows a simple pathway, however, specific bloom dynamics are still unknown, specifically in regards to nutrient cycling and benthic cyanobacteria can continue to reproduce up until the point of decomposition. Consistent monitoring protocols are important because how and where sampling occurs can produce different information. For example, toxin analysis of a water column sample will yield significantly lower toxin concentrations than analysis of benthic mats or time-integrative SPATT (Solid Phase Adsorption Toxin Tracking) samples.

This document highlights the following five steps for the monitoring protocol of marine benthic cyanobacteria, acknowledging that sampling procedures can be habitat dependent:

- coverage and visual assessment of the bloom,
- collection of bloom mat material for species and toxin identification,

- cleaning of mat material to remove microfauna,
- collection of water column samples,
- deployment of Solid Phase Adsorption Toxin Tracking (SPATT) devices to detect *in situ* toxins through time.

2.2 PREVIOUS MARINE BENTHIC CYANOBACTERIA MONITORING IN AOTEAROA NEW ZEALAND

Since the initial reported bloom event in 1999, the Auckland Regional Council (now Auckland Council) monitored the problem using a graduated approach (Tricklebank and Hay, 2007):

1. Regular assessments of the build-up of cyanobacterial mats during summer.
2. Closer inspection by scientific staff when mat build-up appeared 'substantial', or when complaints from the public were received.
3. Assistance sought from Public Health Services regarding the public health risk posed and the level of public nuisance.
4. After the first five years, monthly sampling was set up at locations of interest using a systematic grid and quadrats.

Some environmental parameters were also recorded (daily water temperature, weather data) but water quality and nutrient data were not.

Results from this monitoring programme showed a pattern of seasonal abundance with peaks occurring during the late summer and autumn months (February – May) and that there was a general trend for increasing abundance in the lower intertidal zone, but monitoring was missing in the subtidal zone. There was an association between the abundance of marine benthic cyanobacteria washed up on beaches and warmer sea surface temperatures with relatively low wind speeds (Tricklebank and Hay, 2007).

2.3 PROPOSED RISK MANAGEMENT APPROACH FOR MARINE BENTHIC CYANOBACTERIA IN AOTEAROA NEW ZEALAND

There are many knowledge gaps on marine benthic cyanobacteria and their toxins, hampering the development of multi-tier risk management frameworks for marine benthic cyanobacteria, see Smith et al. (2024) for more details. Based on currently available information, a response framework for marine benthic cyanobacteria has been developed.

We encourage regions experiencing blooms of this nature to apply the guidance material, as the insights and data collected will help in developing more robust guidance in the future. Substantial knowledge gaps still exist regarding the risk associated with toxic marine benthic cyanobacteria, and these guidelines will be updated in the future. Furthermore, better understanding on bloom ecology for marine benthic cyanobacteria might assist with better ability to anticipate when and where blooms may occur in the future. Section 3.1 provides more information on the development of ecological monitoring programmes in regions where blooms are a common occurrence.

Because different marine HABs are likely to occur in different regions, it is not expected that all regions would apply these guidelines on a regular basis. However, they have been developed so that responsible agencies have guidance on how to respond if HAB events do occur in their region.

When a bloom or mats of marine benthic cyanobacteria are first noticed on beaches or in estuaries and relevant public authorities are informed, these are the recommended steps that should be taken as a risk management approach (Table 1; each stage is described in more detail in Sections 2.3.1–2.3.9).

In regions where marine benthic cyanobacterial mats washing up on beaches and estuaries are a regular occurrence, sentinel sites might be established where regular monitoring (e.g., monthly) is undertaken during times of higher likelihood for blooms occurring (Spring to Autumn). The detection of blooms at sentinel sites might trigger the evaluation of other beaches in the region, in order to gain a wider understanding of the prevalence of the issue.

Table 1. Summary of the proposed risk management approach for marine benthic cyanobacteria in Aotearoa New Zealand.

Position in response	Recommended actions
Stage 1	Response triggered through reports of cyanobacterial mats being washed up on a beach or estuary, relevant human illness or their presence at sentinel sites. **Undertake a site survey** a) Biomass estimation: – Use the systematic survey described in Sections 2.3.3 and 2.3.4 so that data can be compared between regions and years. – With large blooms (e.g., covering stretches of the beach), document the extent of the bloom using photographs. b) Sample collection: – Collect samples for microscopy and potential genetic / toxin testing as described in Section 2.3.5. c) Inform public health staff, MPI (info@mpi.govt.nz) and iwi (as per local agreements) about the presence of potential toxin-producing marine benthic cyanobacteria at the beach / estuary and that samples have been collected for analysis: – If visual observation of the bloom suggests it is likely to be toxin-producing, then proceed to **Stage 3** (before sample analysis is complete) and presume that cyanotoxins are present.
Stage 2	**Sample analysis** (see Section 2.3.7 for more details) a) Evaluate cyanobacterial taxonomy: – If cyanobacterial taxonomy cannot be established through microscopy, then genetic evaluation may be required. – If potential toxin-producing taxa are present, then undertake toxin testing (**Stage 2b**). b) Undertake testing for likely cyanotoxins: – If cyanotoxins are present, proceed to **Stage 3**. – If cyanotoxins are not present, undertake follow-up monitoring in four weeks' time.
Stage 3	**Public health decision-making** (see Section 2.3.8 for more details) a) If cyanotoxins are present, but there are low levels of cyanobacterial biomass (small patches < 1 m^2 sporadically located along the beach): – Erect information signs at affected sites. – Undertake regular follow-up monitoring at least every two weeks. b) If cyanotoxins are present and there are high levels of cyanobacterial biomass (a large patch of bloom material > 50 m^2 or multiple medium / large patches of bloom material along the beach): – Issue a health warning and communicate the potential health risk. – Erect warning signs at affected sites. – Undertake regular follow-up monitoring at least every two weeks. c) If the bloom is large, persistent and in areas of high public recreational use, consider removal of cyanobacterial biomass.
Stage 4	**Perform follow-up monitoring** (see Section 2.3.9 for more details)

2.3.1 Roles and responsibilities

Close collaboration between council and public health staff will be mutually beneficial and lead to better outcomes. The agency responsible for different roles related to monitoring and reporting for public health protection needs to be established before developing a sampling and reporting programme.

Roles and responsibilities are best tailored to suit each region, and decisions will depend on many factors, such as institutional arrangements and available expertise / resources. It may help to review the roles and responsibilities for the region every year to compensate for any changes in expertise / resourcing and to act as a ‘refresher’ for those involved in marine benthic cyanobacteria monitoring and assessment.

Because of statutory responsibilities under the Health Act, public health staff should have a lead role in the response and be engaged in decision making. Councils generally take responsibility for co-ordinating and undertaking monitoring / sampling activities which provides the necessary data for public health decision making. Section B of the “Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas” (Ministry for the Environment and Ministry of Health, 2002) provides information on; roles and responsibilities, regional protocols and legal implications. We recommend that responsible agencies in areas dealing with marine benthic cyanobacteria refer to this when developing response plans.

Because of responsibilities to uphold Te Tiriti o Waitangi, these guidelines encourage the strengthening of relationships with iwi and ensuring they are involved / consulted / informed in the capacity that they deem necessary.

2.3.2 Health and safety

When sampling for marine benthic cyanobacterial mats, consideration needs to be given to protecting the sampler(s). Sampling should be done in pairs when possible. Samplers should wear shoulder-length gloves and rubber waders (rather than neoprene) or gumboots to reduce the risk of skin contact, as well as safety glasses to avoid eye irritation. When sampling in windy conditions, a dust / surgical face mask should be worn. When wading, standard water quality sampling procedures and water currents should be observed and assessed to identify hazards. Organisations should develop standard operating procedures to minimise / mitigate potential risks.

2.3.3 Collection of background and site information

When the occurrence of a bloom or mats washing on shore is first noticed or reported, the site should be visited as early as possible and background information should be recorded, including:

- date, time and location (exact coordinates),
- site description (e.g., substrate, presence of kaimoana) – photos are useful,
- meteorological parameters: time since last rain or storm event (including high winds),
- high use for recreational activities (e.g., swimming, diving, surfing),
- sites of cultural significance (wāhi tapu).

To understand which conditions are favourable for the development of benthic cyanobacterial blooms and help the development of a future monitoring programme and/or early-warning mechanisms, **when possible**, environmental parameters should be recorded, including:

- water temperature,
- salinity,
- dissolved oxygen,
- nutrients (e.g., total nitrogen and total phosphorus),
- clarity (using black disk or Secchi disk),
- chlorophyll-*a* (phytoplankton biomass; using sonde measurement or laboratory analysis),
- surface current circulation (if feasible); indirect satellite-based techniques could also be used.

Where resourcing does not allow for the collection of associated environmental data, data from a nearby monitoring site might be used; e.g., from state of the environment monitoring or other council water quality monitoring programmes.

2.3.4 Determining biomass, spatial distribution and extent of mats

For benthic species, it can be difficult to estimate biomass as they may not always appear as an extensive area covered by a layer of biomass. Instead, benthic cyanobacterial mats often are growing as small distinct patches that may be present over a large area. Sampling one mat may miss additional material in the vicinity, giving the wrong impression regarding the presence or absence of benthic cyanobacteria. A systematic sampling approach using quadrat and transects across the intertidal zone of the beach or area of interest is a good approach to estimate biomass and ensure representative sampling of mats.

In contrast to planktonic species, benthic cyanobacteria are often attached to a substrate and less likely to move with wind and wave conditions, and beaches surrounding a bloom should also be checked for mats. But if benthic cyanobacterial mats do become detached from substrates, they can move large distances from their original location under certain conditions, and also continue to grow at the original location (ITRC [Interstate Technology and Regulatory Council], 2023).

Estimation of percentage coverage of benthic cyanobacterial mats

Monitoring and sampling should be undertaken at low tide when possible. After locating a patch of cyanobacterial mats on the beach or estuary, five transects should be established along the length of the bloom area (equally spaced). Each transect should be a representative section of the bloom and span the width of the bloom and run from the lower shore to the upper shore. Observation locations will be at regular intervals at five points along each transect, resulting in a total of 25 observation points. From each fixed point on this grid, two 0.25 m^2 quadrats (Figure 4) will be randomly placed, one on each side of the transect line. This will result in the total observation area into which each quadrat might land is 10 m × 5 m (50 m^2). Appendix A provides an example field sampling sheet for documenting the monitoring data.

For efficiency, cyanobacterial mat samples from each point on the transect can be collected and combined into a composite sample for the transect (see Section 2.3.5 for more information).

Each 0.25 m^2 quadrat is divided into a regular grid consisting of 36 intercept points. Once the quadrats are placed, record:

- The relevant species (benthic cyanobacteria, seagrass, seaweed and other aquatic plants) occurring under each intercept. If several species are present, this also needs to be recorded.
- Potentially take a photo of the quadrats, for future records and comparison between different monitoring staff (for quality control purposes).
- If mats are not easily identifiable, take photos and collect a sample for microscopic identification.

- The category of substrate type (e.g. bare rock / sand, macrophytes) when possible.
- The coverage of benthic cyanobacterial mats (as a percentage of the quadrat).

These data will be used to calculate percent cover for marine benthic cyanobacteria and to collate information on species and substrate categories they are commonly associated with.

Figure 4. Example photo of a quadrat (0.25 m^2) used for sampling of benthic marine cyanobacterial mats in Ōmana Beach (Aotearoa New Zealand). Photo from Tricklebank and Hay (2007).

Quadrat design and size

Fixed-point quadrats (all intersection points on a grid) can be used to estimate cover of all large epibiota recorded with this survey. This technique has the advantage of being relatively rapid, though may bias estimates if organisms are arranged in a regular pattern (Creese and Kingsford, 1998).

The optimal size of sampling units should be selected to maximise precision, though practical considerations are also important. The 0.25 m^2 quadrat size mentioned here is consistent with the size used in many general surveys of intertidal zones (e.g., Creese and Kingsford, 1998; Tricklebank and Hay, 2007).

Estimate extent of mats

The extent of the bloom is defined as the total area (in m^2 or km^2) where the mats are present. This information is needed to guide a response from the concerned public authorities. For each area where mats are present, the extent is calculated by recording the length of the affected area and the width of the mat. For extensive areas or remote locations, the use of drone or satellite imagery might be used (see Section 3.2 for more information).

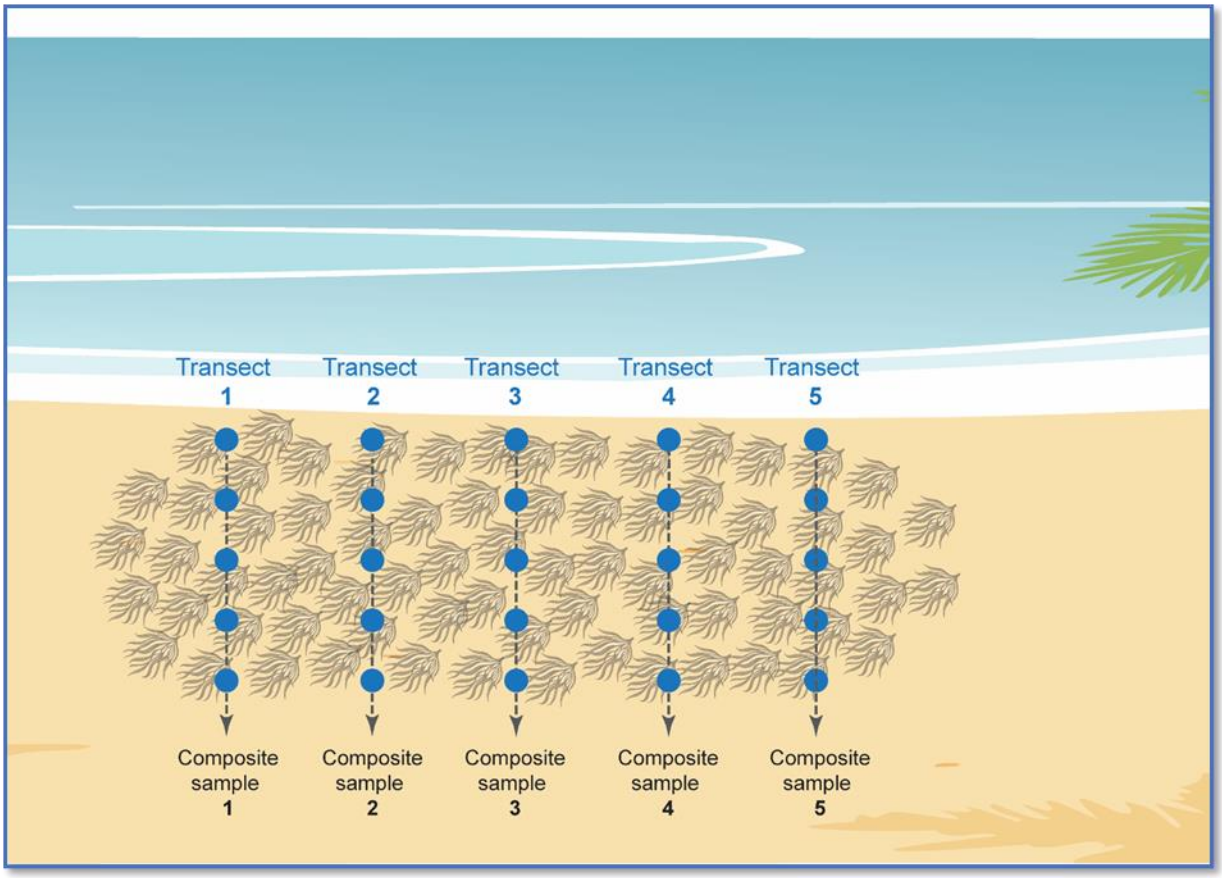
Estimate the number of bloom deposits in area

To estimate the number of bloom deposits in each area, walk along the beach or estuary for ~500 m and count the number of patches of biomass and grade them as small (<1 m^2), medium (1–10 m^2) or large (>10 m^2). Record the number of bloom deposits in each size category in Appendix A and use the data to estimate the total bloom surface area.

2.3.5 Sample collection

1. Follow Health and Safety guidance provided in Section 2.3.2.
2. Mat samples should be collected in labelled plastic bags or pottles, as dry as possible without seawater. Live samples degrade quickly, however, and a small amount of material (a subsample) should be collected and covered with local seawater and be preserved (Section 2.3.6). A clean and dry subsample should also be collected as dry as possible for potential genetic analysis.
3. To collect representative samples, five composite samples per affected area should be collected. One live sample, one preserved sample and one dry subsample should be collected per composite sample and per site.
4. Each composite sample will be a combination of five samples collected along one transect at equal distances (Figure 5). The five transects used to collect each composite samples should be equally spaced along the affected area.
5. For efficiency, sample collection can occur at the same time as biomass estimation is being undertaken (and using the same transects; see Section 2.3.4).
6. Field sampling equipment should be decontaminated with hypochlorite solution between use at different sites and prior to storage (Stewart et al., 2009).

Figure 5. Schematic layout of transects (numbered in blue) and sampling collected points (blue dots), resulting in five composite samples in the intertidal zone on the beach or estuary. The transects are spaced evenly along the survey reach and the sampling points are also spaced evenly along each transect.



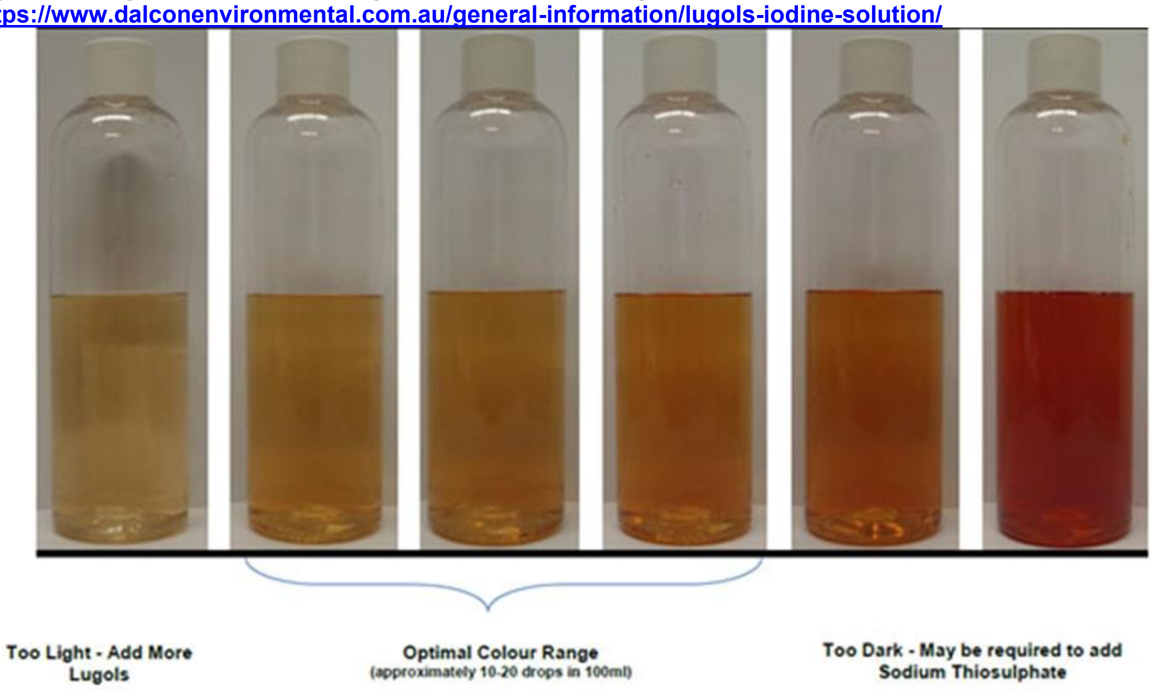
2.3.6 Sample storage and transport

The following are standard protocols for sample preservation, storage and transport of algae or cyanobacterial samples. Analytical laboratories may have specific requirements, and it is strongly recommended that you contact the relevant laboratory or research institute (see Section 2.3.7) before sample collection.

Sampling for cyanobacterial identification and enumeration

Subsamples should be preserved as soon as possible after collection by the addition of enough seawater to cover the mats and approximately 1% Lugol's iodine preservative (Pridmore, 1987). Lugol's iodine is added drop by drop until the sample is light brown (Figure 6; approximately ten drops per 100 mL in water). Dense samples (e.g., scum material or benthic mats) will absorb Lugol's and may require additional Lugol's if long-term storage is required. In that case, check samples at approximately monthly intervals and add more Lugol's if the colour fades.

Figure 6. Range of colours from Lugol solution. The photograph is from https://www.dalconenvironmental.com.au/general-information/lugols-iodine-solution/



Samples should be stored in the dark. Some plastic bottles (polyethylene) tend to absorb iodine very quickly into the plastic, so care should be taken with any samples requiring longer-term storage. It is useful to retain a portion of sample in a live (unpreserved) state, as cyanobacteria are often easier to identify in this way. Ensure there is plenty of air space above the sample and refrigerate. Examine as soon as possible after collection. Each bottle should be labelled clearly with the site name and location, approximate depth, tidal height, date, sampler's name, and whether Lugol's has been added.

Sampling for cyanotoxin testing

Samples for toxin analysis should be stored in glass bottles, where possible, as plastics may absorb cyanotoxins. The amount and number of benthic samples should be collected as described in Section 2.3.5.

Cyanotoxins can degrade, both photochemically (in light) and microbially. Samples should be transported in dark, cold conditions and kept refrigerated (4–8 °C) prior to analysis. Where samples for toxin analysis won't reach the analytical laboratory within 24 hours, samples can be stored frozen. However, note that freezing releases cyanotoxins from the cells and so only the total amount of toxins in a sample can be determined.

Sampling for genetic analysis and cyanotoxin gene screen testing

Samples for gene screen analysis should be stored in sterile sample bottles. If non-sterile bottles are used, these should be sterilised using a 2% bleach solution for a minimum of 10 min, followed by rinsing thoroughly with water and dried. Benthic samples should be collected as described in Section 2.3.5.

DNA can degrade with exposure to high temperatures, ultraviolet light and microbial activity. Samples should therefore be transported in dark, cold conditions and kept refrigerated prior to analysis. Where samples for gene screen analysis won't reach the analytical laboratory within 24 hours, samples can be stored frozen dry and without seawater.

2.3.7 Sample analysis

Identification of marine benthic cyanobacteria

For marine cyanobacterial observations and identification, microscopy can be used to identify taxonomy to the genus level (in some cases, also to species). Accurate identification of cyanobacteria, at least initially, will require specialised taxonomic expertise (which might be found in a contract testing laboratory, university or research organisation). Many cyanobacterial species, particularly marine benthic cyanobacteria, are morphologically very similar and can be difficult to identify by microscopy, so it is recommended to undertake genetic analyses to confirm which species is / are responsible for the bloom if microscopy is not conclusive. When contacting testing laboratory or research organisation to undertake genetic analysis, sequencing the 16S ribosomal RNA (rRNA) gene and 16S-23S rRNA internal transcribed spacer region (Nübel et al., 1997; Weisburg et al., 1991) will be required to identify the species present to genus or species level.

Several species can often co-occur in a bloom or mat and these species can produce different cyanotoxins. Identification of species can then help guide decisions for toxin testing. Once the species have been accurately identified, it may be possible to use macroscopic surveys to assess the abundance of benthic cyanobacterial mats (see 'cyanotoxin testing' section below).

Cyanotoxin testing

Not all benthic cyanobacteria produce cyanotoxins, and it is not possible to tell whether cyanotoxins are present through microscopy alone. Mats in the same vicinity can also contain both toxic- and non-toxic taxa or strains. Cyanotoxins can be detected even when cyanobacteria are present at low quantities and are not the dominant organisms found in a benthic cyanobacterial mat. It is important to note that methods for the detection of cyanotoxins are unable to differentiate between those produced by the benthic cyanobacteria versus a planktonic species that could be trapped / growing within / on the mats tested.

Analyses of toxins should be undertaken only where standard, replicable and reliable analyses can be performed. And as mentioned in Section 1.3.1, toxin testing is not available for all of the cyanotoxins and secondary metabolites produced by marine benthic cyanobacteria. To the best of our knowledge, LTA testing using liquid chromatography with tandem mass spectrometry (LC-MS/MS) is currently available in Aotearoa New Zealand at the Cawthron Institute (Nelson). The assays for the other cyanotoxins from marine benthic cyanobacteria would need to be developed or established using information from the literature.

Many regions of Aotearoa New Zealand have been impacted by HABs (from freshwater cyanobacteria to marine algae) and many species are known to produce a range of biotoxins. As mentioned above, mats of benthic cyanobacteria could harbor other toxic species and if taxonomy analysis concluded that several species of cyanobacteria (or other microalgae) were present in the benthic cyanobacterial mat samples, testing the benthic cyanobacterial mats for the wide range of biotoxins and cyanotoxins that are regularly present in Aotearoa New Zealand will be required. This includes testing for microcystins, nodularin, saxitoxins, anatoxins and cylindrospermopsins. Four methods (LC-MS/MS, ELISA bioassay, Mouse bioassay and cyanotoxin genes detection using quantitative PCR) are currently commercially available for biotoxins testing in Aotearoa New Zealand. For more information, depending on the toxin(s) required to be tested, specific providers should be contacted. To the best of our knowledge, the current providers are the Cawthron Institute, Hills Laboratories and Watercare Laboratory Services.

2.3.8 Public health decision-making

If sampling (Stage 1; see Section 2.3.5) and testing (Stage 2; see Section 2.3.7) confirms the presence of cyanotoxins in marine benthic cyanobacterial mats washed up on beaches or in estuaries, responsible agencies should respond by alerting the public and iwi of the potential health risk. If visual observation of the bloom suggests it is likely to be toxin-producing, then responsible agencies should presume that cyanotoxins are present and proceed with public health decision making (even in the absence of testing results).

After a preliminary assessment of the bloom has been undertaken and samples have been collected (Stage 1), public health staff should be informed that potentially toxic marine benthic cyanobacterial mats have been found on the beach / estuary. The Food Safety team at the Ministry for Primary Industries (MPI; info@mpi.govt.nz) should also be informed, so they can evaluate food safety concerns related to recreational seafood harvesting, as well as representatives from iwi (according to local agreements).

An indication of the size of the bloom should be provided to help understand the actions that might need to be undertaken. Testing of samples (Stage 2) will provide information on the potential human health risk in order to make public health decisions (Stage 3). If visual observation of the bloom suggests it is likely to be toxin-producing and there are high levels of cyanobacterial mats on the beach / estuary (see below), then a precautionary health warning should be issued before the testing results have been received. If testing results later indicated that cyanotoxins were not present, then the precautionary health warning could be removed. Table 1 (earlier in Section 2.3) provides a summary of the decisions making process and the actions to be undertaken.

Low levels of toxic cyanobacterial mats (Stage 3a): If toxins are detected in samples and the size / extent of the washed-up benthic cyanobacterial mats is low (only small patches < 1 m^2 sporadically located along the beach), information signs should be erected at the affected beach / estuary (see Appendix B for an example) and follow-up monitoring undertaken at regular intervals (see Section 2.3.9).

High levels of toxic cyanobacterial mats (Stage 3b): If toxins are detected in samples and the size / extent of the washed-up benthic cyanobacterial mats is substantial (a large patch of bloom material > 50 m^2 or multiple medium / large patches of bloom material along the beach), a health warning should be issued. Warning signs should be erected at the affected beach / estuary (see Appendix C for an example) and the communications approaches described below should be implemented. Follow-up monitoring at the site should be undertaken at regular intervals (see Section 2.3.9).

Warnings about the potential health risk should be communicated to water users, iwi, nearby residents (and potentially other high-priority target audiences) through a combination of warning signs (see Appendix C), media releases (see Appendix D) and other communication mechanisms at the disposal of the responsible agencies (social media, website information, direct communication). In person information sessions or wānanga with communities are also recommended to promote a safe ongoing relationship with the marine environment.

Warning signs erected in response to a health warning should have clear ‘danger’ signals (bright contrasting colours, exclamation points, clear warning graphics) and inform the public of what they should do to stay safe. Links to further information and images of what to look out for are also useful. To avoid message desensitisation, the warning signs should be removed when the health warning is no longer in effect.

If the site is of significance to iwi, they may decide to undertake their own mitigation measures such as a placing a rāhui in the area. It is important that regions have thoroughly engaged with mana whenua and provide them with the necessary information to make an informed decision.

Persistent high levels of toxic cyanobacterial mats (Stage 3c): If the bloom is substantial and persistent, then removal of the benthic cyanobacterial mats should be considered. See Section 2.4 for more information and precautions relating to this.

Continual community education: Regions experiencing regular blooms of benthic marine cyanobacteria might also undertake communications initiatives that inform the public about toxic cyanobacterial mats that can wash up on beaches. This could include providing information on the council's website including information on what it looks like (see Appendix E for photos and capture your own when undertaking sampling), the risk posed, and what to do if someone encounters it. The same information might also be provided as a physical factsheet or pamphlet, which might be available at council receptions, information centres, medical centres and community hubs. Whilst we do not provide examples here for benthic marine cyanobacteria, the Aotearoa New Zealand Guidelines for Cyanobacteria in Recreational Freshwaters (Ministry for the Environment and Health New Zealand, 2024) contains several examples of information sheets and pamphlets for freshwater toxic algae. Permanent information signs might be used at sites where blooms are frequently observed (see Appendix B for an example). Information signs should not contain the 'danger' signals featured in the warning signs and should have a more neutral aesthetic.

For more information on developing a risk communication programme, the Aotearoa New Zealand Guidelines for Cyanobacteria in Recreational Freshwaters (Ministry for the Environment and Health New Zealand, 2024) contains a communications section describing how to approach this for toxic algae in recreational freshwaters. This includes an explanation of how communications practice can be applied to risk communication, examples of communications resources and a case study which might inspire similar initiatives for marine benthic cyanobacteria.

2.3.9 Follow-up monitoring

Because of the likelihood of additional benthic cyanobacterial mats washing up on beaches and the potential for different cyanobacterial species to be found in fresh material, follow-up monitoring (Stage 4) should be undertaken regardless of whether toxins are found in preliminary sample analysis.

If cyanotoxins were not detected during the previous sampling, follow-up monitoring should occur to reassess the size / extent of the bloom (Section 2.3.4). If the bloom has increased in size, samples of fresh material should be collected as per Section 2.3.5 and analysed for cyanobacterial taxonomy (and cyanotoxins, if potential toxin-producing cyanobacterial species are present). When potential toxin-producing cyanobacterial species or cyanotoxins have not been detected in samples, follow-up monitoring should occur within four weeks of the previous assessment.

If cyanotoxins were detected during the previous sampling, regular follow-up monitoring should occur to track the development of the bloom and re-evaluate the toxin concentration. Follow-up monitoring should happen at least every two weeks to determine the size / extent of the bloom (Section 2.3.4). If the bloom has increased in size, samples of fresh material should be collected (Section 2.3.5) at least every four weeks and analysed for cyanobacterial taxonomy (Section 2.3.7) to determine if the composition of the bloom has changed. If different potential toxin-producing cyanobacterial species are identified in the new bloom material, then analysis of additional types of cyanotoxins might be required (see Sections 1.3.1 and 2.3.7 for more information).

2.4 REMOVAL AND DISPOSAL OF WASHED-UP MARINE BENTHIC CYANOBACTERIAL MATS

Due to the acute dermatitis, and eye and respiratory irritations associated with marine cyanobacterial blooms, handling mats is not recommended for the public. For professionals, particularly when removing decomposing cyanobacterial mats, the use of appropriate personal protective equipment (PPE) is necessary (e.g., waterproof gloves, safety glasses and protective respiratory apparatus as a minimum). Workers harvesting bulk cyanobacterial biomass need to be particularly cautious when dealing with senescent bloom material that may be subject to anaerobic decomposition, because of the potential for liberation of hazardous concentrations of hydrogen sulphide and toxins (Stewart et al., 2009). The potential for inhaling harmful amounts of cyanobacterial products in field conditions increases where desiccated cyanobacterial biomass is harvested from shorelines and beaches. Lyngbyatoxin-like toxins may be expected to cause acute respiratory symptoms if enough toxic dust is inhaled. Dry toxic cyanobacteria are considered a hazard, it is suggested that wet cyanobacterial biomass should, wherever possible, be favoured over collection of dry material. Light wetting of the required amount of desiccated material with a watering-can prior to collection could prevent dust being liberated (Stewart et al., 2009).

Regarding the disposal of cyanobacterial mats, solid waste cyanobacteria should be incinerated. In the case of small volumes, liquid wastes may be autoclaved at 121°C for

15–20 minutes if possible; up to 60 minutes for volumes of up to 10 L. If a suitably sized autoclave is not available, a chemical oxidant should be used to ensure that all cyanobacterial cells are rendered non-viable. Chlorine bleach is widely used for large liquid volumes which require sterilisation as it is effective in rendering cells non-viable. Normal application rates are 1–5 mL of commercial bleach per litre of liquid, with several hours (at least 2 to 3 hours) reaction time required. Shorter reaction times can be achieved with higher concentrations of bleach. Neutralisation of the treated solution with a reducing agent (1 mL of 25% w/v sodium thiosulfate solution per 4 mL of bleach) is required before disposal. Field sampling equipment should likewise be decontaminated with hypochlorite solution between use at different sites and prior to storage (Stewart et al., 2009).

Recent research shows that even after being composted for several months, mats of marine benthic cyanobacteria still contain LTA at similar concentrations to mats that freshly washed up on shore (Biessy et al., 2024). This demonstrates that composting is not a viable option for disposal of LTA-producing cyanobacterial mats and workers should remain cautious and use PPE at all times when handling benthic cyanobacterial mats.

3. FUTURE-FOCUSED ENDEAVOURS TO IMPROVE MARINE BENTHIC CYANOBACTERIA RISK MANAGEMENT IN AOTEAROA NEW ZEALAND

A successful marine benthic cyanobacterial monitoring programme should begin with the development of an ecological monitoring plan and response plans. Many knowledge gaps surrounding marine cyanobacteria remain, in particular their ecology, the drivers of these marine benthic blooms, their impact(s) on the environment, the toxins they produce and their toxicity. Some of these questions will need to be answered before a full monitoring plan and risk assessment can be developed for marine benthic cyanobacteria.

It is important to identify the goals of the monitoring strategies and understand the ecology of targeted cyanobacteria taxa when deciding how to monitor. The monitoring strategy should support a cyanobacterial bloom response and communications plan. In contrast to monitoring for planktonic HABs, benthic mats may be difficult for an observer to view from the surface and may require specific monitoring of the benthic zone.

3.1 ECOLOGICAL MONITORING OF MARINE BENTHIC CYANOBACTERIA

When blooms of marine benthic cyanobacteria are observed in a region, endeavours to develop better understanding on the bloom ecology might be undertaken. We currently have little information on this, but increased ecological knowledge will vastly improve our ability to manage the potential public health risk in the future. Relevant science questions might include:

- What species are the main problem in Aotearoa New Zealand?
- Where do the bloom-forming species grow?
- Do they have a preferred substrate?
- What environmental conditions encourage bloom development?
- What conditions trigger mat detachment?

Regions affected by marine benthic cyanobacterial blooms might undertake a robust spatio-temporal monitoring programme to help determine the drivers of benthic cyanobacterial blooms. Consistent monitoring of the benthos will also be important for accurately assessing the overall health of a system. The potential for bloom development in marine and estuarine waters is often associated with the availability of resources (e.g., elevated nutrient concentrations, (Anderson et al., 2002), light), as well as hydro-physical conditions that determine their access to the resources. These conditions constrain the amount of biomass that can be attained in a waterbody (Burch et al., 2021). Benthic cyanobacteria growing on submerged surfaces, including on other biota such as macrophytes, require clear water and still conditions for enough light penetration to enable photosynthesis. The environmental conditions that support benthic bloom development are likely to be species-specific, as they often depend not only on water 'quality' but also on a range of biotic and abiotic conditions, including the presence or absence of other species (e.g., grazers, beneficial species), weather conditions and hydrodynamic processes (Davidson et al., 2014).

Understanding the source location of benthic blooms is the first step in developing an ecological monitoring plan, as evaluating conditions at the beaches where detached biomass accumulates is not likely to be indicative of the conditions where the biomass is growing.

While monitoring for many HAB species normally includes evaluating cell concentrations, determining the concentration of benthic cyanobacteria is more difficult, as cells within filaments cannot be counted easily and it does not provide useful information on the amount of biomass. Coverage assessment is generally used to estimate biomass for benthic blooms. Long-term, time series data for the abundance of benthic cyanobacterial mats in Aotearoa New Zealand would improve understanding of their dynamics and ecosystem function, allow prediction of conditions that promote bloom formation and provide understanding on whether a species is new to an area.

Important parameters to monitor at sites includes temperature, salinity and chlorophyll-*a* (in the surrounding water) as a measure of microalgal biomass. Knowledge of the distribution and sources of inorganic nutrients and other microalgal growth factors is also important when planning and operating a monitoring programme (Reguera et al., 2016).

Ongoing monitoring programmes at relevant sites may already exist and provide valuable pre-existing environmental data and background information on a water body. WHO (2021) suggests collecting the following data for HAB monitoring purposes:

- nutrient concentrations (especially total phosphorus and nitrogen concentrations) and their seasonal variation,
- potential major nutrient inputs and possible input fluctuations (e.g., seasonality of surface runoff and possible long-term changes),

- activities causing nutrient loading (e.g., agricultural practices in the catchment, capacity and functioning of wastewater treatment facilities),
- water body surface area and morphology,
- patterns of thermal stratification over time,
- reports of timings of blooms and observations of surface scums or – for clear waters – lumps of detached material accumulating in the water or on the beach,
- seasonal dynamics of microalgal occurrence and taxonomic composition,
- satellite images showing microalgal (chlorophyll-*a*) abundance and distribution,
- location of bathing sites and seasonal use frequency,
- prevailing wind direction, especially during periods when cyanobacteria (particularly surface-bloom-forming species) could be abundant,
- reports of suspected or demonstrated bloom-related illness in humans and animals.

Integration within a broader programme of water quality monitoring around the blooms is necessary. This includes:

- physico-chemical variables; dissolved oxygen, water temperature and pH,
- nutrients analysis; total and dissolved forms of nitrogen and phosphorus, as well as micronutrients (in particular iron),
- optical variables; visual clarity, turbidity, coloured dissolved organic matter,
- chlorophyll-*a*.

Where existing data for a specific waterbody is not available, regional information (e.g., on dominant cyanobacterial genera) may be useful and water quality analyses as described above should be conducted. Observations may also be available from sources such as health and environmental authorities, local businesses and members of the local community.

3.2 INTEGRATING EMERGING TECHNOLOGIES

The resolution of satellite imagery has improved dramatically in the last decade, but the feasibility of its use in assessing or monitoring blooms of benthic cyanobacteria mats in estuaries or open water has not yet been evaluated. An initial evaluation and comparison of historical footage using the Copernicus Browser (https://browser.dataspace.copernicus.eu/) and Google Earth (https://earth.google.com/) indicates that satellite imaging / remote sensing of marine benthic cyanobacterial blooms will have some challenges. Because the site(s) of bloom initiation (where the benthic cyanobacteria are growing) could be up to 30 m deep in the water, they will not be visible in satellite images until the mats have washed up on the shore. Satellite images with high spatial resolution (i.e. < 1 m) would be required to detect small deposits on the beach, but the detection of large deposits might be possible. Discriminating between washed-up benthic cyanobacterial mats and chlorophyll-containing plants (e.g., sea grass) may be difficult, although, the tool might still provide a means to limit monitoring requirements and long-term data might provide a means for identifying signals that are related to aquatic plant beds. Other limitations to the use of satellite (and drone imagery) in coastal waters, includes where the water is turbid, highly coloured, affected by wind and waves, or when the mats are too deep in the water to be detected. Time of the day can also be an important consideration, due to reflections from the water surface and the impact of tidal levels.

Drone-based aerial imagery has great potential to be integrated into monitoring workflows as it can be obtained when visiting a site for other measurements and drones are relatively low-cost. Drone imagery might be used to assess a much larger area than visual surveys, which may augment visual survey data by extending it to areas not typically monitored. Although the use of drones and automated image assessment tools could be promising, some of the same limitations to satellite imagery are present. A major limitation for drone use is the presence of controlled airspace and the need for trained drone pilots.

While guidance on how satellite and drone imagery could be robustly integrated into a monitoring and risk management programme, both technologies show promise for this application. Where on-the-ground monitoring programmes are implemented, this provides opportunities for side-by-side comparisons that will allow better understanding on their limitations and how they might be best implemented.

GLOSSARY

BCMs	Benthic cyanobacterial mats.
Benthic cyanobacteria	Grows attached to the substrate of lakes, ponds, rivers and streams.
DNA	Deoxyribonucleic acid; a molecule that contains genetic information for the development and function of organisms.
Cyanobacteria	A phylum of bacteria that obtain their energy through photosynthesis (also called blue-green algae).
Cyanotoxin	Toxin produced by cyanobacteria.
Dermatotoxic	Affects the skin.
ELISA	Enzyme-linked immunosorbent assay – an antibody-based method used to measure cyanotoxins.
Eutrophication	Degradation of water quality due to enrichment by the nutrients nitrogen and phosphorus, resulting in excessive algal growth and decay, and often associated with low dissolved oxygen in the water.
Exposure	Contact of a chemical, physical or biological agent with the outer boundary of an organism (e.g., through inhalation, ingestion or dermal contact).
HABs	Harmful algal blooms.
Hapū	Kinship group for Māori that often consists of a number of whānau sharing descent from a common ancestor. An iwi (see below) might be formed from multiple related hapū in close proximity. From a global perspective, it is sometimes equated to a subtribe.
Hazard	A biological, chemical, physical or radiological agent that has the potential to cause harm.
Iwi	Extended kinship group for Māori, where people are linked through ancestry and association with a geographical area. From a global perspective, it is sometimes equated to a tribe.
LTA	Lyngbyatoxin-a, a potent dermatotoxin produce by benthic cyanobacteria.

LC-MS	Liquid chromatography-mass spectrometry – an analytical method used to measure cyanotoxins.
Mana whenua	The iwi or hapū who hold authority over and responsibilities for particular places through whakapapa.
Planktonic cyanobacteria	Grows free-floating (drifting) in the waterbody.
Rāhui	A traditional Māori practice that places a temporary prohibition on an area, resource or activity to protect the environment or allow for the dissipation of tapu.
SPATT	Solid-phase absorption toxin tracking – a passive sampling technique used to detect low levels of toxins or to integrate multiple pulses of toxins released into water.
Te Tiriti o Waitangi	One of the founding documents in Aotearoa New Zealand that laid out a partnership between Māori and the British Crown.
Wāhi tapu	Sacred places or sites for iwi and hapū that hold deep spiritual, cultural and historical significance. They are often subject to ritual restrictions on access or use.
Wānanga	A Māori cultural practice for learning through shared discussion, reflection and/or the creation of new knowledge.
Whakapapa	The genealogy that situates Māori peoples within the environment and affirms their responsibilities as guardians for the environment in their region.
Whānau	Te Reo Māori term for family, although the family unit for Māori might be wider reaching than that of other cultures.

APPENDIX A: FIELD SAMPLING SHEET

Example field sampling sheet for marine benthic cyanobacteria monitoring and sampling

Contact Information:

Name of sampler:..

Ph: ....

Email: ....

Address: ....

Sample Information:

Date:.......... /........... /..........Time (24hrs and NZST): ....

Sample description: …………………………………………………………………………………………..

Sample location (be as detailed as possible and, if possible, provide a sketch on the back of sampling sheet): ....

....

Iwi / hapū associated with the site: ..…………………….…………………………………………………..

Environmental data (water temperature, salinity, DO, last rain/storm event, etc): ....

....

Benthic cyanobacteria coverage:

Extent of the bloom: Length ……… m x Width ………… m = ………… m^2

Estimation of bloom deposits. Number of deposits: ≤1m^2:…………; 1–10m^2:…………; >10m^2:…………

Use the method overleaf to determine the percentage cover at the site.

	Transect 1	**Transect 2**	**Transect 3**	**Transect 4**	**Transect 5**	**Comments**
Transect length						
Substrate						
Detached or detaching mats?						
Sample taken?						
Photos taken?						
		% cover in transect by benthic cyanobacteria (to nearest 5%)				
View 1						
View 2						
View 3						
View 4						
View 5						
Mean % cover per transect						Average % cover at site

Method to estimate percentage coverage of benthic cyanobacterial mats:

- Take a photo of the bloom extent
- After locating a patch of cyanobacterial mats on the beach, five transects, equally spaced, should be established along the length of the bloom area (equally spaced).
- Each transect should span the width of the bloom and run from the lower shore to the upper shore.
- Observation locations will be at regular intervals at five points along each transect, resulting in a total of 25 observation points.
- From each fixed point on this grid, two 0.25 m^2 quadrats will be randomly placed, one on each side of the transect line. This will result in the total observation area into which each quadrat might land is 10 m × 5 m (50 m^2).
- Each quadrat is divided into a regular grid consisting of 36 intercept points. Once the quadrats are placed, record:
    - The relevant species (benthic cyanobacteria, seagrass, seaweed and other aquatic plants) occurring under each intercept. If several species are present, this needs to be recorded. If mats are not easily identifiable, take photos and collect a sample for microscopic identification.
    - The category of substrate type (e.g. bare rock / sand, macrophytes) when possible.
    - The coverage of benthic cyanobacterial mats (as a percentage of the quadrat).

These data will be used to calculate percent cover for the recorded species and substrate categories identified in the quadrat.

APPENDIX B: INFORMATION SIGN FOR MARINE BENTHIC CYANOBACTERIA

An effective information sign should tell the public what toxic cyanobacterial mats look like and what to do to stay safe if they come across them at the beach / estuary. Photographs on the signs can be useful to show people what to look out for. The signs should not be intimidating (e.g., neutral colours and no warning signals) as this can lead to desensitisation to the warning signs that get erected when health warnings are issued (see Appendix C for an example of this). An example of what might be included on an information sign is provided below.

INFORMATION

Toxic cyanobacterial mats sometimes wash up on this beach / estuary

Toxins produced by these cyanobacterial mats can make people and animals sick, if they come into contact with the mats or contaminated water. The cyanobacterial mats are black / brown and can smell like rotten eggs when they decompose.

Look out for:

If you see toxic cyanobacterial mats washed up on this beach / estuary:

- Keep out of the water
- Don’t touch the mats
- Keep your dog out of the water and away from the mats
- Inform < **Name of organisation** > (< **Contact details** >)

APPENDIX C: WARNING SIGN FOR MARINE BENTHIC CYANOBACTERIA

Below is an example of the text for a health warning sign for marine benthic cyanobacteria. A health warning sign should provide enough information to inform the public of the potential health risks and enable them to make an informed decision. It should be clearly dated to inform the public when the warning was issued. Photographs on signs should show the public what to look for. Warning signs should be put in place when toxins are detected in mat samples and mats are in high abundance.

WARNING!

Marine toxic cyanobacteria health hazard

Warning: toxic cyanobacterial mats are present in high levels on this beach / estuary and may affect the health of people or animals that come into contact with the water or mats.

Contact with the water or mats, or accidentally swallowing water, may cause skin, eye and throat irritation.

The cyanobacterial mats are black / brown and can smell like rotten eggs when they decompose. Prolonged exposure to this smell can cause nausea, headaches and eye-tearing.

Supervise children closely and don't let them touch the mats.
Don't let your dog eat anything, roll in the mats or swim in the water.
If illness occurs, contact your doctor or vet immediately.

NOTICE POSTED ON:	**< Date >**
EFFECTIVE UNTIL:	**< Date >**
NOTICE POSTED BY:	**< Name of organisation >**
	< Contact >
	< Website >

APPENDIX D: MEDIA RELEASE FOR MARINE BENTHIC CYANOBACTERIA

The following is sample text for inclusion in media releases relating to high amounts of toxin-producing marine benthic cyanobacteria washing up on beaches and in estuaries. The addition of a satellite image indicating the site of interest may be useful.

< Day, Month, Year >

< Time >

For Immediate Release:

Tests carried out by **< agency >** have shown high levels of toxin-producing marine benthic cyanobacteria at **< name of waterbody >** and a health warning has now been issued. Humans and animals should avoid contact with **< name of waterbody >** until health warnings are removed.

These cyanobacterial mats produce toxins that are harmful to humans and animals if swallowed or through skin contact. Accidental ingestion or skin contact with this type of toxic cyanobacteria, through swimming or touching the mats, causes symptoms such as severe skin rashes, and irritation of the eyes and throat. If you experience health symptoms after contact with contaminated water or mats, contact **< name of agency >** and visit a doctor immediately. Children playing at **< name of waterbody >** should be supervised so they do not touch or eat the cyanobacterial mats and if you suspect that they have consumed cyanobacteria – take them to the doctors immediately. Animals that consume cyanobacteria should be taken to a vet immediately.

Cyanobacteria occur naturally but can increase rapidly during warmer months in the year. Marine benthic cyanobacteria usually grow offshore attached to underwater plants and rocks, but sometimes detach and wash ashore on beaches and in estuaries. Because of this, blooms can occur without warning. The mats are usually black / brown in colour and as they decompose (rot) they can have a strong rotten egg smell. People who spend too much time around this smell can experience nausea, headaches and eye-tearing.

If a health warning is in place at a beach, avoid contact with the water and the mats. Warnings will be removed when the amount of cyanobacterial mats at the beach has reduced.

< **agency** > monitors cyanobacteria < **monitoring frequency** > at < **name of waterbody** > during summer and the public will be advised of any changes that are of public health significance.

For further information, visit **< website address >** or contact **< name and telephone number >**

Press release ends.

APPENDIX E: PHOTOGRAPHS OF MARINE BENTHIC CYANOBACTERIA

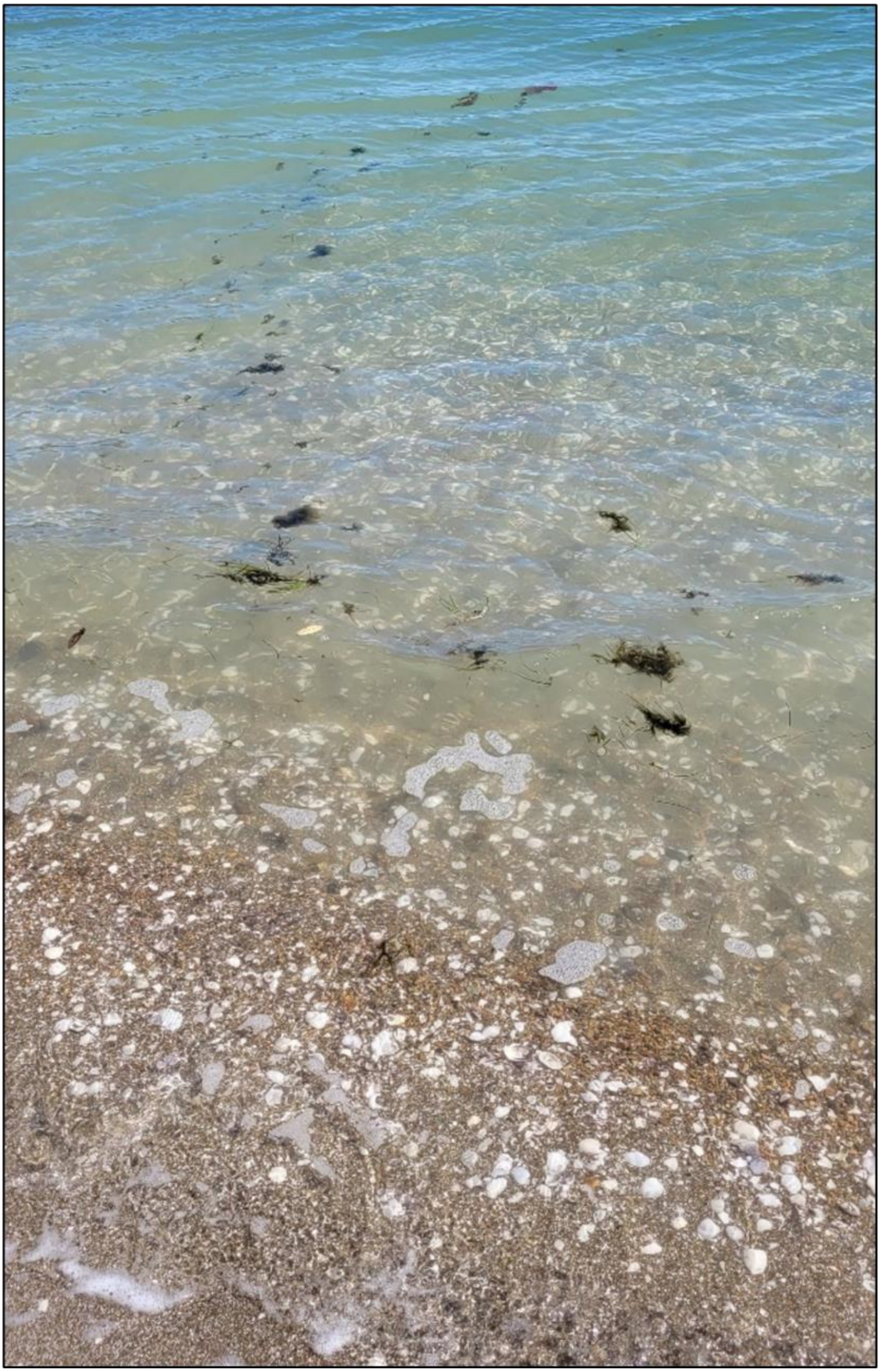
Photographic examples of marine benthic cyanobacteria

Extensive blooms (several tonnes of biomass) of marine benthic cyanobacteria (from the genus *Okeania*) at Blackpool Beach (Waiheke Island) in March 2023 (Photo credit: Jacob Thomson-Laing, Cawthron Institute).

Marine benthic cyanobacteria bloom material washed up on Blackpool Beach (Waiheke Island) in November 2023, mixed with seagrass (Photo credit: Sue Gluskie, Auckland Council).

Marine benthic cyanobacterial mats tangled in seaweed and seagrass near shellfish bed in Surfdale Beach (Waiheke Island) (Photo credit: Laura Biessy, Cawthron Institute).

Marine benthic cyanobacterial mats caught on ropes and branches in Anzac Bay and Surfdale Beach (Waiheke Island) (Photo credit: Laura Biessy and Jacob Thomson-Laing, Cawthron Institute).



Marine benthic cyanobacterial mats floating in the water in Rocky Bay / Whakanewha Bay (Waiheke Island) (Photo credit: Laura Biessy, Cawthron Institute).

Marine benthic cyanobacterial mats covering a shellfish bed, spread across a beach and partially submerged in the water (Photo credit: Laura Biessy, Cawthron Institute).

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