Algal blooms in South Australia

Submission to an inquiry by the Environment and Communications References Committee

Invasive Species Council

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About the Invasive Species Council

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SUMMARY

In this submission we raise the question of whether *Karenia mikimotoi* – or the strain causing the algal bloom in South Australia – is native or introduced. There appears to be no published evidence to support a recent assumption that *K. mikimotoi* is native and that the bloom is 'naturally occurring'.

Understanding whether *K. mikimotoi* is native or introduced is important for understanding the emergence and nature of the blooming and has implications for biosecurity.

In the absence of evidence of nativeness, this harmful algal bloom species should be regarded as 'cryptogenic' – for the following reasons:

> **Other countries**: Since the 1960s, *K. mikimotoi* blooms have been recorded for the first time in numerous countries, with several authorities attributing some of these to ballast water introductions. *K. mikimotoi* is classified as introduced to northern Europe and China.
>
> **Evidence suggestive of recent arrivals**: Sediment core analysis from China's East China Sea shows *K. mikimotoi* cysts first appeared only in the 1970s. A recent bloom in Alaska occurred after 2 years of absence in phytoplankton samples.
>
> **Detections in ballast water**: *K. mikimotoi* is able to form resting cysts and has been detected in the ballast water of ships in Chinese and Russian ports. Ballast water is a confirmed major vector for harmful algal bloom species globally.
>
> **Genetic evidence**: A molecular study found isolates from Europe and New Zealand are more closely related to each other than to Japanese isolates, inconsistent with a natural cosmopolitan distribution.

Recommendations

1. **Investigate origins**: Investigate the relationship of the South Australian population of *K. mikimotoi* to other Australian and global populations. Molecular genetics can help tease apart a species' history over time and space. Until conclusive evidence is available, classify *Karenia mikimotoi* as cryptogenic.

2. **Strengthen biosecurity:** Review the effectiveness of ballast water rules to prevent both international and interstate transfers of *K. mikimotoi*. Also investigate other potential pathways for the spread of *K. mikimotoi* in Australian waters.

3. **Avoid premature claims:** Until there is a clearer understanding of drivers, avoid definitive claims about the causes of the South Australian algal bloom.

1. A neglected question – is *Karenia mikimotoi* introduced?

The South Australian Government is treating *Karenia mikimotoi* as a native species, saying the bloom is 'naturally occurring' [1,2]. We find this puzzling – for there appears to be no published evidence to support a presumption of nativeness (no early records or genetic studies, for example) and *K. mikimotoi* is considered introduced and invasive in several other countries.

In the absence of such evidence, we recommend that *K. mikimotoi* be regarded as 'cryptogenic' – a species that cannot be definitively classified as either native or introduced.

This is consistent with its classification as cryptogenic and a possible ballast water introduction in a 2004 paper on introduced species in Port Phillip Bay, co-authored by researchers from the CSIRO Centre for Research on Introduced Marine Pests [3]. It is supported by the conclusion of a 2025 preprint paper by a South Australian oceanographer that causes of the current algal bloom are unknown 'but most likely related to bioinvasion' [4]. *K. mikimotoi* is classified in the World Register of Introduced Marine Species as alien in other regions [5], is able to form resting cysts that could enable transport in ballast water, and has been detected in ballast water in Chinese and Russian ports [6].

In this submission, we explain why understanding origins is important and outline reasons for considering *K. mikimotoi* a potential introduction.

2. Why is it important to investigate the origins of *K. mikimotoi*?

Understanding whether a species is native, and therefore co-evolved with other native species, can be important for understanding its ecology and environmental impacts. Establishing whether a species is native or not can also be important for biosecurity reasons – in deciding whether greater precautions are warranted and for public education about the risks of species introductions.

2.1 A growing wariness about cosmopolitan marine species

According to a 2010 compilation, at least 429 marine species in Australian waters are exotic or cryptogenic [7]. Some of the latter are 'cosmopolitan' (globally widespread) species once assumed to be native everywhere because of the apparent lack of marine barriers to natural spread, particularly for small mobile organisms with high dispersal capacity, such as micro-algae [8].

But as marine invasion biology has matured since emerging in the 1970s, there has been a 'mounting wariness' of assuming that species with cosmopolitan distributions are native [9]:

> The burgeoning literature describing anthropogenic introductions of marine taxa … has paralleled increasing circumspection directed at the paradigm of marine cosmopolitanism.

This wariness has applied to the microalgae that cause harmful blooms. Some marine scientists say the increasing frequency of reports of harmful blooms can be explained in part by species introductions and that 'most modern phytoplankton phytoplankton invasions have simply been overlooked' [9,10]. The 'smalls' rule of invasion biology – 'the inverse correlation of body size with the ability to be recognized as non-native' – highlights the tendency to overlook the potential non-native origins of small species [9]:

> Long-standing complexities of diatom and dinoflagellate taxonomy, the lack of historical data bases, the existence of dinoflagellate resting cysts that may remain undetected for long periods of time,

and the boom-and-bust cycles of many phytoplankton species, among other challenges, have all served to obfuscate the detection and verification of phytoplankton invasions.

A genetic study finding that isolates of *K. mikimotoi* from Europe and New Zealand are closer to each other than to isolates from Japan is difficult to reconcile with the notion of a naturally cosmopolitan distribution [11].

Some marine scientists attribute the apparent increasing frequency of harmful blooms mainly to other factors – as an artifact of increasing scientific scrutiny or due to environmental degradation or changes such as increased aquaculture activity, coastal eutrophication, global warming, or reduced grazing pressure [10,12,13].

Multiple drivers are likely. But whatever the balance of the causes, surely a fundamental question about an emerging harmful organism with a limited historical record should be whether or not it is introduced. This is not just to satisfy curiosity.

2.2 Ecological reasons for investigating origins

Understanding whether a species is native or introduced is foundational knowledge, and often helpful for understanding harmful interactions with other species. Invasion biology has become one of Australia's most important sciences because the impacts of introduced species here have been so transformative and damaging. It has revealed a multitude of ways in which the addition of novel species can cause species declines and extinctions and alter the composition, structure and function of ecological communities.

If *K. mikimotoi* has been introduced to Australia – whether once, twice or more, whether recently or decades ago, and whether in addition to existing native strains – that knowledge is likely to change how its impacts are understood. Introduced species may cause harm because of a lack of evolved defences in native species (naivety) or due to fewer competitors, predators or pathogens to constrain their abundance in their new environment (enemy release). Another possibility is that an introduced strain of an already present species is better adapted or that it hybridises with the existing strain [14]. It is difficult to link a bloom to a specific introduction event because it can take many years after introduction for a species to establish, adapt and proliferate [14].

Even if *K. mikimotoi* has been introduced, it doesn't mean that local conditions are not influential in triggering blooms – but it expands the scope of potential explanations for the sudden emergence and increased global frequency of blooms.

2.3 Reasons to be cautious about attributing drivers

The drivers and ecological processes of bloom formation of *K. mikimotoi* and other dinoflagellates around the world remain largely unknown. No model can explain or predict when and where *K. mikimotoi* blooms occur [15]. Likewise, predicting the impacts of global warming on harmful algal blooms is 'fraught with difficulties' [16]. Different consequences such as increased temperature, acidification, stratification, photosynthetic stimulation and extreme events are likely to produce 'contradictory species- or even strain-specific responses'.

Numerous factors have been proposed as potential drivers or influencers of *K. mikimotoi* blooms – including abiotic factors such as temperatures, salinity, nutrient levels or ratios, and stratification and biotic factors such as competition, predation and infection (Box 1). They have occurred around the world under a great diversity of conditions. For example, blooms with extremely high concentrations of cells (>5 million a litre) have occurred under prevailing sea temperatures of 8–12 °C (Alaska), 17–19 °C (China), 19–22 °C (English Channel), 26–29 °C (Japan) and 30–31 °C (India) (see [17] for a compilation).

Given this and the diversity of postulated drivers, it seems premature to claim that any particular factors have driven the current SA bloom. As concluded in the summary of the recent South Australian science forum on the algal bloom, 'further research is needed to understand drivers' [18].

Box 1. Suggested drivers of K. mikimotoi bloom formation around the globe

Following are a few examples of proposed influences on *K. mikimotoi* blooms from around the world. Most studies have focused on abiotic (non-biological) factors such as water temperature, nutrients and salinity. But biotic interactions – predators, pathogens, competitors – may also be crucial regulators of bloom development and decline [19].

Temperatures – East China Sea, China [20]: Sea temperature has a strong negative correlation with *K. mikimotoi*. While *K. mikimotoi* tends to thrive in colder waters, other *Karenia* species prefer warmer conditions. This implies that ocean warming may drive changes in the species composition of *Karenia* communities, leading to succession from *K.* mikimotoi to multiple *Karenia* species dominating coastal waters during blooms.

Silicates – East Johor Straits, Singapore [21]: Silicates are needed for diatom growth, so reduced silicate levels (due to modified river watersheds) reduce the diatom population, which reduces competition for dinoflagellates and promotes blooms.

Nutrients – East China Sea [15]: *K. mikimotoi* seem more acclimated and competitive in nutrient-depleted conditions than nutrient-replete conditions. Blooms are often observed in areas with relatively low nutrient availability in the East China Sea.

Salinity – Western English channel [22]: Persistent summertime rainfall and the input of low-salinity high-nutrient river water were associated with significantly higher densities of *K. mikimotoi* from 1992 to 2010. Silicate concentrations over 2.6 umol/L were also associated with significantly higher cell densities.

Salinity – Tongxin Bay, Fujian, China [23]: An increasing trend since 2012 with 3 massive blooms from 2012 to 2016 were associated with reduced salinity after heavy rainfalls. Not due to increasing nutrient availability. A laboratory study showed a metabolic shift that enhances the growth of *K. mikimotoi* under lower salinity.

Salinity and water stratification – Kachemak Bay, Alaska [17]: The bloom development coincided with salinity minima and maximum water column stratification. Stratification was breaking down during the period that the *K. mikimotoi* bloom was declining.

Pathogens and grazers – Fujian coast, China [19]: A study of a dinoflagellate closely related to *K. mikimotoi*, *Karenia longicanalis*, found that a lower infection rate may aid blooms by enabling the diversion of resources from defence to cell proliferation, and conversely that pathogens and ciliate grazing may suppress blooms. The abundance of Rhodobacteracea bacteria was negatively correlated with the abundance of *K. longicanalis* (and this bacterial family has been shown to cause high mortality of *K. mikimotoi* [24]).

2.4 Biosecurity reasons for investigating assumptions of nativeness

'Biosecurity risks' associated with harmful algal blooms was noted as a key knowledge gap by the South Australian science form on *K. mikimotoi* [18]. We strongly endorse this as an important focus – even if the

South Australian strain is regarded as native. Most known harmful algal bloom species 'have been documented in viable form from ship's ballast water' and the only effective ballast water treatment is biocides [25].

There is no public information about whether extra biosecurity precautions have been considered or are in place to limit the risk of transfer of *K. mikimotoi* from the current bloom locations to other coasts. Have there been communications, monitoring and enforcement to ensure compliance with ballast water rules? Have other potential pathways for transferring microalgae (e.g. fishing gear) been assessed?

Australia should also consider the risk of introduction of additional strains being introduced. Different strains of *K. mikimotoi* vary in their toxicity to different species – for example, 2 Chinese strains are highly but variably toxic to brine shrimp (*Artemias salina*) while the Zealand strain is not [26]. The risks of introducing native species to other parts of Australia have been highlighted by the establishment of invasive *Caulerpa taxifolia* in South Australia [27].

If *K. mikimotoi* is introduced, it is also important to use it to build public awareness of the risks of invasive species and the importance of strong biosecurity. As perhaps indicated by the response *to K. mikimotoi*, with climate change being such a major concern for Australians, it is easy for people to forget about other potentially catastrophic new threats, including invasive species.

3. Reasons for investigating *K. mikimotoi* as an introduction

3.1 K. mikimotoi is considered introduced in other countries

The first *K. mikimotoi* bloom was recorded in Japanese waters in 1934, although earlier Japanese blooms, from 1905 to 1918, were also suspected to be of *K. mikimotoi* [28]. Particularly since the 1960s, harmful blooms have been recorded for the first time in many other countries – mainly in Asia and northern Europe [28] (Table 1).

Some authorities consider the increasing frequency of blooms as due in part to the long-distance introduction of *K. mikimotoi* in ballast water followed by regional spread with currents. AlgaeBase, a global algal database, says *K. mikimotoi* 'appears to have been spread in ballast water and is now a major cause of algal blooms throughout the world' [29]. The World Register of Introduced Marine Species lists *K. mikimotoi* as alien in the following regions, based on regional reports [5]: the Chinese part of the Eastern China Sea, Germany, the Swedish part of the Kattegat sea area, the Norwegian and Swedish parts of the Skagerrak, United Kingdom, Mexico, Baltic Sea, Mediterranean Sea and North Sea.

Table 1 provides a list of first *K. mikimotoi* bloom records for which researchers have proposed or suggested that it is an exotic introduction – Norway, China, India, Alaska and Hokkaido (Japan). It is often difficult to prove an introduction, and other accounts of first recorded blooms often do not address the question of origins.

One interesting recent case was an 'immense' bloom in Kachemak Bay, Alaska, initiated during the autumn of 2013 [17]. It occurred during a period when phytoplankton samples were being regularly collected, so researchers were able to determine that *K. mikimotoi* cells had not been present during the previous 2 years and were also absent after the bloom ceased. The researchers concluded that *K. mikimotoi* had probably arrived either in ballast water – the inlet was a highly trafficked waterway – or with debris that floated to Alaska from Japan after the 2011 tsunami [17]. Despite low temperatures during the bloom of 8–12 °C, the

K. mikimotoi concentrations in Kachemak Bay were among the highest reported globally (up to 20 million cells/litre). It ceased growing when water temperatures dropped below about 8 °C and died out when they dropped below 3.0–5.5 °C.

The strongest evidence for an introduction comes from China. Sediment cores from the East China Sea indicate that *K. mikimotoi* cysts have been present only since the 1970s, and *K. mikimotoi* has been detected in ballast water in ships in Chinese ports [30] (section 3.2). Since the first major bloom in 1998, China has suffered repeated blooms – 137 from 1998 to 2017, 16 described as 'massive', recorded in all 4 seas around China [31]. The blooms have occurred from temperate to subtropical latitudes, with sea temperatures ranging mainly from 19 to 28 ◦C [26,31]. One bloom, in 2012, caused massive abalone mortality, resulting in financial losses exceeding $US 330 million. Other *Karenia* species may be involved in some blooms [26].

Table 1. First recorded K. mikimotoi blooms identified as potentially due to an introduction

Country	Year first recorded	Suggestion or evidence of introduction
Norway [32,33]	1966	Regarded as non-indigenous and probably introduced in ballast water. Suddenly appeared in 1966 off the southern Norwegian coast, then spread throughout the North Sea to become one of the most common toxic dinoflagellates in northern European waters.
China [30,31]	1998	Regarded as a likely ballast water introduction that has spread to all 4 Chinese seas. First appears in sediment from the 1970s in the East China Sea. The first major bloom was in 1998 in Hong Kong and the Pearl River estuary but earlier blooms in 1986 in the East China Sea may have been *K. mikimotoi*.
Cochin inlet, India [34]	2009	The first recorded bloom in one of the Indian west coast's busiest ports considered likely to be due to ballast introduction.
Alaska, USA [17]	2013	An immense bloom in Kachemak Bay. *K. mikimotoi* previously unknown from the bay, and not detected for 2 years prior or 3 years following the bloom, suggesting cells were introduced. Proposed options include ballast water or floating debris from the Japanese tsunami.
Hokkaido, Japan [35]	2015	Recorded for the first time in southern Hokkaido, in Hakodate Bay. Attributed to cells being transported by ballast water or by the Tsushima/Tsugaru Warm Currents.

3.2 *K. mikimotoi* forms resting cysts and has been detected in ballast water

In 2019, Chinese researchers reported that *K. mikimotoi* is able to form sexual resting cysts – a dormant stage of their life cycle that can provide protection from viruses, predators, parasites and adverse environmental conditions, and contribute to bloom initiation [6].[1] They have been detected both in the East China Sea and South China Sea [6,37]. Resting cysts have been preserved intact for at least 50 years in sediments in the East China Sea [30].

[1] Sexual reproduction and resting cyst formation in dinoflagellates has been regarded as a survival tool to cope with 'environmental insults' and is triggered by adverse environmental conditions [36]. Two gametes (haploid cells) fuse to produce a diploid planktonic zygote, which develops into a resting cyst that settles to the sediment and becomes dormant. They may be instrumental in initiating blooms. It has also been proposed that sexual reproduction in *K. mikimotoi* might promote cell proliferation and the resulting enhanced genetic diversity may increase resistance against pathogens and environmental stress, to boost or extend a bloom [36].

A resting stage could facilitate the spread of *K. mikimotoi* in ballast water or ballast tank sediments – and help explain the expanding occurrence and frequency of blooms [6]:

> The confirmation of resting cyst production in *Karenia mikimotoi* may also provide a mechanistic explanation for the worldwide expansion (both tropical and temperate regions, including countries in Japan, Korea, China, India, Singapore, Australia, New Zealand, Mexico, United States, and a number of European countries such as Norway, Ireland, UK, and France) and frequent bloom occurrences of *K. mikimotoi*.

Ballast water is known to be a frequent vector for the dispersal of dinoflagellates and diatoms, including to Australia [12,38]. A recent eDNA study of historical ballast sediments and port sediments found 13 of the 14 algal taxa known to cause harmful blooms that were present in the sediments collected from ports were present in historical samples from ballast tanks [39]. Eight of the 14 taxa present in port sediments were only in port sediments sampled since 1996, suggesting a recent increase. The study confirmed ship ballast tanks as 'key dispersal vectors' for algae that cause harmful blooms [39].

Although *K. mikimotoi* has not been detected in ballast water tanks sampled in Australia, it has been reported in the ballast water of foreign ships in Chinese ports [40–43] (all papers are in Chinese and cited in [6,28]) and a Russian port (Vladivostok) [44]. Two other *Karenia* species – *K. cristata* and *K. papilionacea* – were detected in tank sediments collected 2001–2003 from ships entering the Great Lakes or Chesapeake Bay in the United States [45]. Their presence in ballast sediments collected 16 to 18 years previously indicates that, like *K. mikimotoi*, they can also form cysts.

There is therefore good reason therefore to investigate whether the South Australian population of *K. mikimotoi* is likely to have been introduced.[2]

4. Recommendations

1. **Investigate origins**: Investigate the relationship of the South Australian population of *K. mikimotoi* to other Australian and global populations. Molecular genetics can help tease apart a species' history over time and space. Until conclusive evidence is available, classify *Karenia mikimotoi* as cryptogenic.
2. **Strengthen biosecurity:** Review the effectiveness of ballast water rules to prevent both international and interstate transfers of *K. mikimotoi*. Also investigate other potential pathways for the spread of *K. mikimotoi* in Australian waters.
3. **Avoid premature claims:** Until there is a clearer understanding of drivers, avoid definitive claims about the causes of the South Australian algal bloom.

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