Expert report on the likely causes of the South Australian Algal Bloom 2025

Prof. Perran Cook[1]

Assoc Prof. Ruth Reef[2]

Assoc Prof. Ailie Gallant[2,3]

Dr. Michael Barnes[2,3]

Dr. Peter van Rensch[2,3]

[1]School of Chemistry, Monash University
[2]School of Earth Atmosphere and Environment, Monash University
[3]Australian Research Council Centre of Excellence for Weather of the 21st Century.

Question 1: Can you please explain the factors that contributed to the South Australian algal bloom and whether and how they are connected to climate change? In answering this question, please also: a) Briefly explain what an algal bloom is, with specific reference to the South Australian algal bloom.

1. In summary, the South Australian algal bloom was most likely cause by the hottest weekly sea temperatures on record in March 2025, coinciding with when the bloom was first observed. This observation is consistent with the literature globally that suggests the incidence of algal blooms of the type observed here (dinoflagellates) are likely to increase in temperate waters with increased global temperatures. The rationale and approach to this finding is detailed as follows.

2. To answer this question, we have used our expertise in biogeochemistry, oceanography, coastal processes, weather and climate (see CVs), as well as government reports, peer reviewed published literature including scientific preprints, senate inquiry submissions as well as sourcing our own data.

3. Algal and cyanobacteria (hereafter referred to broadly as algae) blooms refer to the accumulation of algal biomass to the point where it is visible in the water and/or begins to have human health and ecological impacts. Visibility includes cloudiness and discolouration of the water. Ecological and health impacts include fish kills, and neurotoxins that impact humans. These harmful algal blooms are often referred to as HABs. The fundamental cause of an algal bloom is when growth rates exceed 'loss' rates through processes such as grazing by marine organisms or sinking from the water column. This can be caused by a rapid growth rate of algae themselves, or a lack of palatability to grazers (either through toxic or physical mechanisms) that means they are not consumed. In addition, small cell size, buoyancy control and motility, can mean that algae do not settle out of the water column. The fundamental drivers of algal blooms are typically considered to be light, temperature, nutrients and water column stability.

4. The South Australian algal bloom of 2025 has been widely reported in the media and its general location is shown in Figure 1. It was first observed to the South of the Fleurieu Peninsula in March, after which it moved north though Backstairs Passage

into the Spencer Gulf and Gulf of St Vincent (Kämpf, 2026). The dominant class of algae were dinoflagellates, which are known to cuase 'red tides' owing to their red pigmentation. They are also capable of moving through the water column with their 'flagellum' (tail) which gives them an advantage when the water column is stratified (poorly mixed) because it enables them to move to the surface to obtain light, and deeper waters to obtain nutrients. Species identified include *Karlodinium sp*., including *Karenia mikimotoi*, and *Karenia kristata*, and the latter has been shown to produce brevetoxins (Murray et al., 2026). Brevetoxins are nerve toxins harmful to humans and marine life causing mass marine life mortalities as well as gastrointestinal problems, tingling sensations, muscle pain, loss of coordination, and respiratory distress in humans.

Figure 1. Shows the region impacted by the algal bloom in 2025

b) Outline the attribution studies, peer-reviewed literature and any projections that you have utilised to reach your answer.

5. 3 key factors may have contributed to this algal bloom as previously identified by the South Australian State government (SA, 2026) including a marine heatwave, and nutrient inputs from the River Murray flood 2 years prior to the event as well as upwelling (mixing of nutrient rich deep ocean water to the surface) during 2023-2024. In addition, we consider the possibility of increased water column stability (contributing to stratification) as indicated by anomalous wind speeds and direction. Nutrients can induce algal blooms by providing more 'food' which allow algae to grow faster and accumulate biomass. Increased temperature can increase the growth rate of algae (depending on their adapted maximum), speed up nutrient recycling, and lead to increased water column stratification. Increased water column stratification can favour motile (mobile) species such as dinoflagellates which can move to the surface to obtain light and deeper waters to obtain nutrients. We will now briefly consider each of these.

6. **<u>Marine heatwave</u>**
A marine heatwave off the Northwest of Australia extending to South West Western Australia and into the Great Australian Bight occurred at the start of 2025

(Chandrapavan, 2025). This heatwave also extended into South Australia in March 2025 as seen in the US National Oceanic and Atmospheric Administration Optimum Interpolation Sea Surface Temperature (NOAA OISST) (Huang et al., 2021) dataset shown in Figure 2.

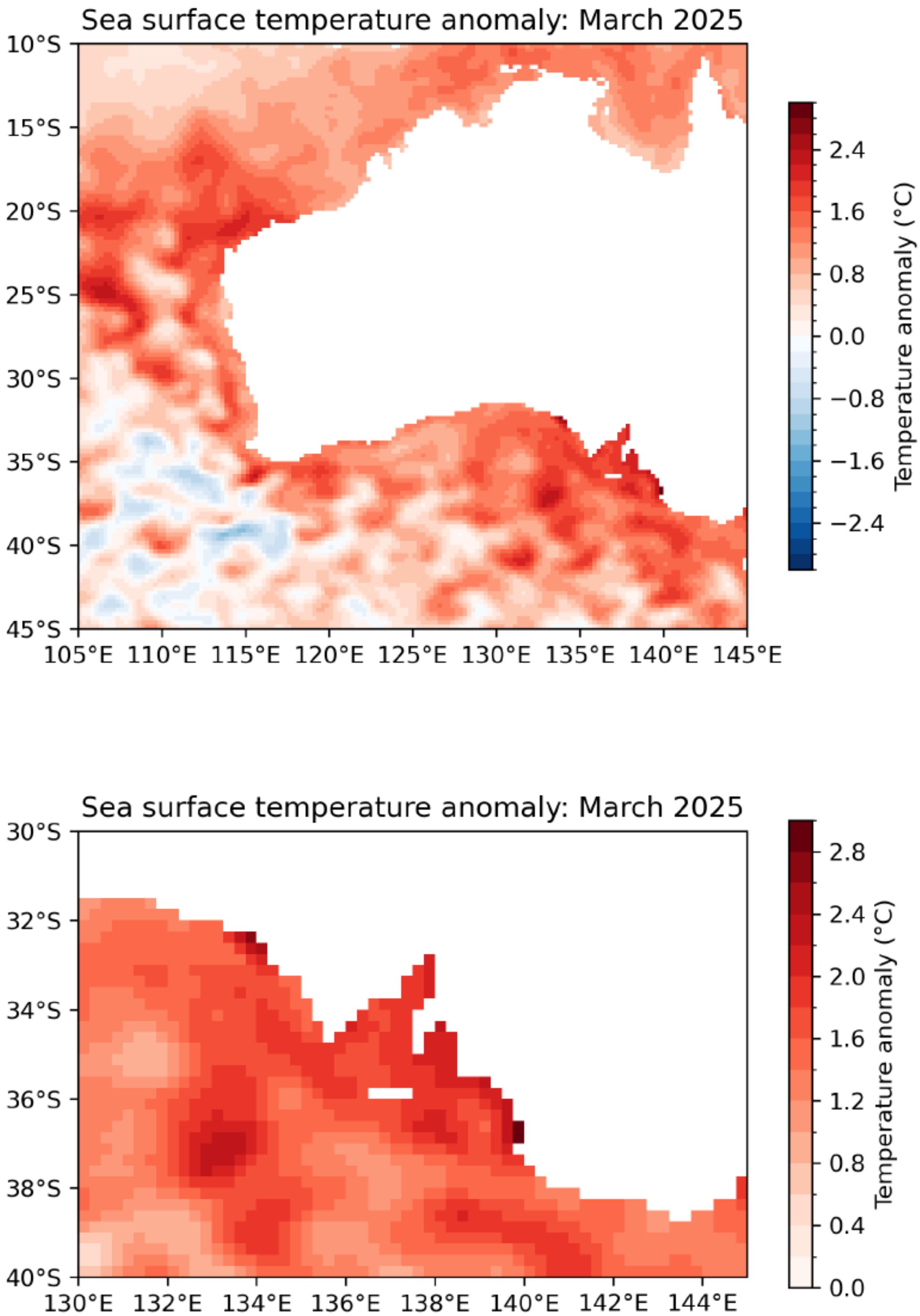

Figure 2. Sea surface temperature anomaly for March 2025 surrounding Australia (Top) and zoomed into South Australia (bottom).

7. To assess the extent of the marine temperature anomalies over a long time period as possible temperature data was obtained from the NOAA OISST data seta and was collected from a 3km radius around -35.625, 138.738 (Figure 3). Average weekly data were used for the analysis. This site was chosen as it was proximal to the site of where the bloom was first reported, but offshore to avoid land contamination of the signal. The highest weekly temperature anomaly in the record of the data set occurred in the second week of March 2025, which is the highest weekly temperature anomaly observed in the data set (Figure 4).

Figure 3. Red dot shows the area where the ocean sea surface temperature time series was obtained, in the sea adjacent to where the algal bloom was first observed.

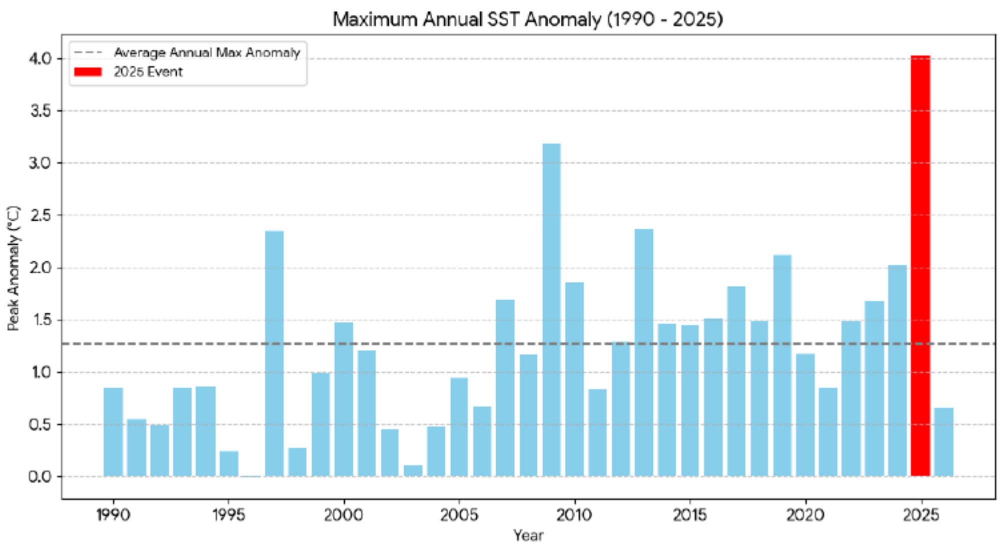

Figure 4. Peak weekly temperature anomalies for each year in the period 1990-2026 for the region shown in Figure 3. The highest weekly peak temperature anomaly in the entire record was observed in March 2025 coinciding with the first reports of the bloom.

8. **Nutrients**
   The River Murray flood occurred between November 2022-February 2023, peaking at 186 GL/day and was the largest flood since 1956, and the third largest on record (EPA, 2025). These floodwaters would have also transported significant loads of nitrogen from the catchment into the coastal waters off the Fleurieu Peninsula. Nitrogen is typically the key nutrient that limits algal growth in coastal waters. A first order estimate of the nitrogen load can be obtained by multiplying the total volume of the flood (~10000 GL) by the approximate concentration of total nitrogen in the water, which is ~1 mg/L (Cook et al., 2010). This equates to about 1000 tonnes of nitrogen. The fate of this nitrogen is highly uncertain particularly over the timescale of 2 years. It is however highly likely that most of this nitrogen would have been dispersed into the broader coastal environment, as well as denitrified to N_2 gas. For context, the Western Treatment Plant discharges ~3000 tonnes of nitrogen into Port Phillip Bay each year, which is a more enclosed system without the occurrence of major algal blooms in the water column (Jenkins et al., 2024). The direct contribution of nitrogen from the River Murray to the bloom is therefore unlikely. It is also possible other nutrients and organic matter derived from the floods contributed to the bloom, however, given the timeframe and dispersion outlined above we consider this highly unlikely. This conclusion is in agreement with A/Prof Luke Moseley's submission to the Senate Inquiry into Algal Blooms in South Australia (Mosley, 2025).

9. The other major source of nutrients for the region is upwelling, from deeper oceanic waters associated with the Bonney upwelling system and it is possible these nutrients from this process contributed to the bloom. There was a large upwelling event in January 2024 (Voiland, 2025), however the warm sea surface temperatures in late 2024-2025 suggest little upwelling. Given that the Bonney upwelling is a well-documented and recognised process contributing to the productivity of the region (Kämpf, 2024), it is unlikely that this triggered the bloom.

10. **Local weather anomalies**
    Given that stratification and water column stability are known to contribute to algal bloom formation, we also investigated if there were any clear local weather anomalies such as wind speed. Daily accumulated wind speed was calculated from ERA-5 data (Hersbach et al., 2020) and showed that the winter preceding the bloom was relatively calm, but there were no wind speed anomalies during the bloom period itself (blue lines indicating periods of low wind activity, Figure 5). Any connections of the bloom to local weather anomalies are therefore not obvious and not evident immediately prior to the event.

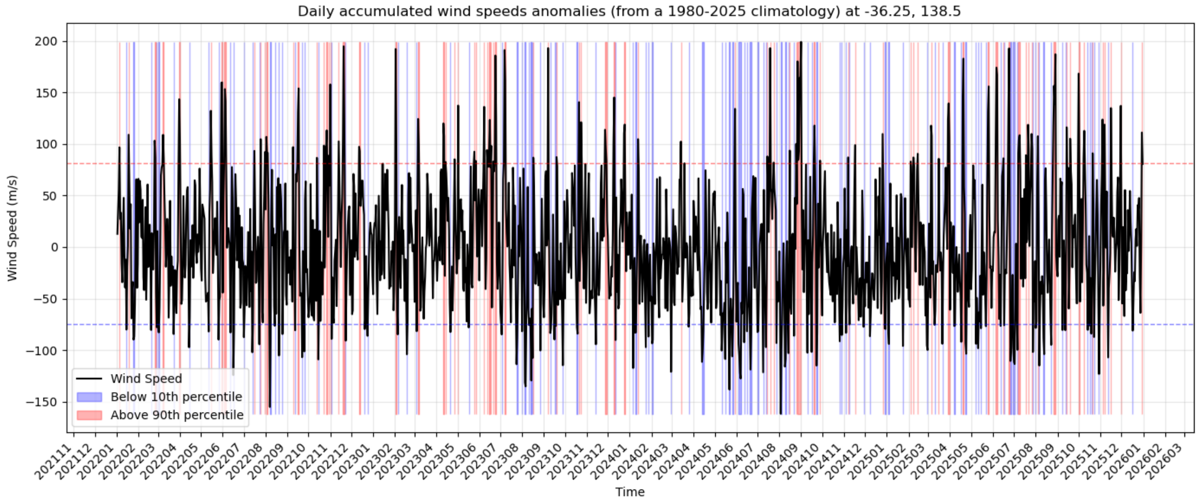

Figure 5. Daily wind accumulated wind speed anomalies (based on the 1980-2025 data) from 11/2021 -03/2025 at location -36.25, 138.5.

11. In summary, the South Australian algal bloom of 2025 was most strongly associated with a marine heatwave compared to other likely drivers. This heatwave originated in the ocean to the NW of Australia. To date, there have been no published attribution studies linking the South Australian algal bloom to climate change. Further attribution studies are needed to establish the extent to which climate change contributed to this specific event, and the biogeochemical and ecological mechanisms by which it contributed to the bloom.

Question 2: Based on the current state of knowledge and best available science, please explain the extent to which climate change could contribute to future algal blooms in South Australia and across Australia, more generally.

12. To answer this question, we have surveyed the literature including reviews as well as reference to the previous section.

13. <u>**Estuarine and Lagoon Systems**</u>
The way in which climate change will manifest itself across Australia is complex. It is predicted to lead to increased rainfall in the north of the continent, decreased rainfall in the south with the potential for increased episodic events (Thiery et al., 2025). This will have complex effects with increased rainfall likely to lead to increased algal blooms in estuarine and lagoon systems, and reduced blooms with reduced rainfall (Chilton et al., 2021; Cook & Holland, 2012). Although it should be noted for some systems such as the Coorong, low rainfall leads to hyper salinity which itself if associated with high algal biomass (Mosley et al., 2023). Additionally climate change will increase fire risk, and an increased prevalence of fires is likely to increase the incidence of algal blooms driven by the runoff of nutrient rich ash from the fires (Cook & Holland, 2012). Climate change is therefore likely to both contribute to and mitigate algal blooms in a highly unpredictable manner in estuarine and lagoon systems.

14. **Coastal and Marine Waters**
    Marine heatwaves are likely to increase with climate change (Thiery et al., 2025). The strong association of the 2025 South Australian algal bloom with a marine heatwave is also consistent with the literature. Reviews that suggest HABs, and in particular flagellates, benefit from warmer temperatures by increased growth and an expanded realised niche (Griffith & Gobler, 2020; Wells et al., 2015). Recent observations confirm a strong association with increased algal blooms, including harmful algal blooms with temperature (Cheung et al., 2021; Pathirana et al., 2024; Wei et al., 2023; Yang et al., 2026). Predictive modelling studies suggest dinoflagellate blooms are likely to increase in temperate regions of China, but decrease in the more tropical waters (Su et al., 2025).

15. In addition to marine heatwaves it is expected that parts of the ocean will become more stratified with climate change, leading to reduced nutrient inputs to the surface layer where algae can grow (Wells et al., 2015). This might be expected to favour algal taxa such as flagellates, and there is evidence that algal biomass can increase with temperature with increased stratification (Pathirana et al., 2024). It is also possible that reduced amounts of nitrate in the surface layer caused by increased stratification will favour flagellates based on observational and model evidence extrapolated from observations in the Pearl River estuary (Yang et al., 2026).

16. In conclusion the observed strong association of the South Australian algal bloom with a marine heatwave is highly consistent with predictions and observations from the global literature. Furthermore, the occurrence of a dinoflagellate bloom is consistent with the likelihood of increased stratification due to increased ocean temperatures. Climate change is therefore likely to increase the incidence of harmful algal blooms such as dinoflagellates in temperate coastal water such as those off southern Australia. However, whether this applies also to tropical regions is less clear (Su et al., 2025).

References cited

Chandrapavan, A. (2025). *Western Australia's marine heatwave update - 27 March 2025.* https://library.dpird.wa.gov.au/cs_marineheatwave/4

Cheung, Y. Y., Cheung, S., Mak, J., Liu, K., Xia, X., Zhang, X., Yung, Y., & Liu, H. (2021). Distinct interaction effects of warming and anthropogenic input on diatoms and dinoflagellates in an urbanized estuarine ecosystem. *Global Change Biology*, *27*(15), 3463-3473. https://doi.org/https://doi.org/10.1111/gcb.15667

Chilton, D., Hamilton, D. P., Nagelkerken, I., Cook, P., Hipsey, M. R., Reid, R., Sheaves, M., Waltham, N. J., & Brookes, J. (2021). Environmental flow requirements of estuaries: providing resilience to current and future climate and direct anthropogenic changes. *Frontiers in Environmental Science*, 534.

Cook, P., Aldridge, K. T., Lamontagne, S., & Brookes, J. (2010). Retention of nitrogen, phosphorus and silicon in a large semi-arid riverine lake system [Article]. *Biogeochemistry*, *99*, 49-63. http://www.springerlink.com/content/8555271h2h7w8355/fulltext.pdf

Cook, P., & Holland, D. P. (2012). Long term nutrient loads and chlorophyll dynamics in a large temperate Australian lagoon system affected by recurring blooms of cyanobacteria [Article]. *Biogeochemistry*, *107*(1-3), 261-274. https://doi.org/10.1007/s10533-010-9551-1

EPA. (2025). doi: 10.1175/JCLI-D-20-0166.1. Retrieved 15 May 2026 from https://soe.epa.sa.gov.au/environmental-themes/river-murray/state-of-the-murray/2022-23-river-murray-flood

Griffith, A. W., & Gobler, C. J. (2020). Harmful algal blooms: A climate change co-stressor in marine and freshwater ecosystems. *Harmful Algae*, *91*, 101590. https://doi.org/https://doi.org/10.1016/j.hal.2019.03.008

Hersbach, H., Bell, B., Berrisford, P., Hirahara, S., Horányi, A., Muñoz-Sabater, J., Nicolas, J., Peubey, C., Radu, R., Schepers, D., Simmons, A., Soci, C., Abdalla, S., Abellan, X., Balsamo, G., Bechtold, P., Biavati, G., Bidlot, J., Bonavita, M., . . . Thépaut, J.-N. (2020). The ERA5 global reanalysis. *Quarterly Journal of the Royal Meteorological Society*, *146*(730), 1999-2049. https://doi.org/https://doi.org/10.1002/qj.3803

Huang, B., Liu, C., Banzon, V., Freeman, E., Graham, G., Hankins, B., Smith, T., & Zhang, H.-M. (2021). Improvements of the Daily Optimum Interpolation Sea Surface Temperature (DOISST) Version 2.1. *Journal of Climate*, *34*(8), 2923-2939. https://doi.org/https://doi.org/10.1175/JCLI-D-20-0166.1

Jenkins, G. P., Black, K. P., & Cook, P. L. M. (2024). Effects of varying levels of nutrient inputs to coastal marine systems: a case study of a semi-enclosed bay influenced by a large urban population. *Proceedings of the Royal Society of Victoria*, *136*(1), RS24006. https://doi.org/10.1071/RS24006

Kämpf, J. (2024). The Bonney Coast upwelling: How physical processes shape the feeding behaviour of blue whales. *Continental Shelf Research*, *279*, 105277. https://doi.org/https://doi.org/10.1016/j.csr.2024.105277

Kämpf, J. (2026). Prediction of the spreading of an unprecedented harmful algal bloom in South Australian gulfs. *Continental Shelf Research*, *297*, 105631. https://doi.org/https://doi.org/10.1016/j.csr.2025.105631

Mosley, L. (2025). *Submission to the Senate Environment and Communications References Committee Inquiry into Algal Blooms in South Australia*. https://www.aph.gov.au/Parliamentary_Business/Committees/Senate/Environment_and_Communications/AlgalBloom48P/Submissions

Mosley, L. M., Priestley, S., Brookes, J., Dittmann, S., Farkaš, J., Farrell, M., Ferguson, A. J., Gibbs, M., Hipsey, M., Huang, J., Lam-Gordillo, O., Simpson, S. L., Tyler, J. J., Waycott, M., & Welsh, D. T. (2023). Extreme eutrophication and salinisation in the Coorong estuarine-lagoon ecosystem of Australia's largest river basin (Murray-Darling). *Marine Pollution Bulletin*, *188*, 114648. https://doi.org/https://doi.org/10.1016/j.marpolbul.2023.114648

Murray, S. A., Bolch, C. J. S., Brett, S., Chan, C. X., Doubell, M., Farrell, H., Gaiani, G., Greenhough, H., Hallegraeff, G., Smith Harding, T., Harwood, D. T., Hatfield, R. G., MacDonald, N., Moody, I., Bastos de Oliveira, H., Rhodes, L., Selwood, A., Seymour, J., Siboni, N., . . . Smith, K. (2026). A catastrophic marine mortality event caused by a complex algal bloom including the novel brevetoxin producer, Karenia cristata (Dinophyceae). *bioRxiv*, 2025.2010.2031.685766. https://doi.org/10.1101/2025.10.31.685766

Pathirana, G., Min Noh, K., Lee, D.-G., Park, H.-J., Wang, D., & Kug, J.-S. (2024). Intensified surface chlorophyll responses to the Indian Ocean Dipole under greenhouse warming. *Environmental Research Letters*, *19*(6), 064072. https://doi.org/10.1088/1748-9326/ad4db8

SA, G. (2026). South Australian Government https://www.algalbloom.sa.gov.au/

Su, S., Luo, Z., Kang, J., Guo, X., Wang, C., Jin, R., Du, J., Zheng, X., Hii, K. S., Fu, S., Hu, W., & Chen, B. (2025). How Does Climate Change Influence the Regional Ecological–Social Risks of Harmful Dinoflagellates? A Predictive Study of China's

Coastal Waters. *Global Change Biology*, *31*(7), e70323. https://doi.org/https://doi.org/10.1111/gcb.70323
Thiery, W., Cavitte, M., & Laridon, A. (2025). *Expert Report on attribution and projections of extreme events Over Australia and exposure for young generations.* .
Voiland, A. (2025). *Filaments of Phytoplankton in Australia*. https://science.nasa.gov/earth/earth-observatory/filaments-of-phytoplankton-in-australia-152322/
Wei, W., Han, Y., & Zhou, Y. (2023). Nutrients and sea surface temperature drive harmful algal blooms in China's coastal waters over the past decades. *Environmental Research Letters*, *18*(9), 094068. https://doi.org/10.1088/1748-9326/acf0d7
Wells, M. L., Trainer, V. L., Smayda, T. J., Karlson, B. S. O., Trick, C. G., Kudela, R. M., Ishikawa, A., Bernard, S., Wulff, A., Anderson, D. M., & Cochlan, W. P. (2015). Harmful algal blooms and climate change: Learning from the past and present to forecast the future. *Harmful Algae*, *49*, 68-93. https://doi.org/https://doi.org/10.1016/j.hal.2015.07.009
Yang, S., Feng, L., Dai, Y., Liu, X., Zheng, C., Wang, D.-Z., Zhou, K., & Zhai, X. (2026). Phytoplankton Blooms in the Coastal Seas Around China Increase in Response to Warming. *Journal of Geophysical Research: Oceans*, *131*(1), e2025JC022348. https://doi.org/https://doi.org/10.1029/2025JC022348