Water quality

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Deconvoluting the impacts of harmful algal blooms in multi-stressed systems

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Water quality impacts by harmful algal blooms co-occur with anthropogenic chemicals and waste pollution. We need to embrace multidisciplinary approaches to advance the science and improve the practice of water quality assessment and management.

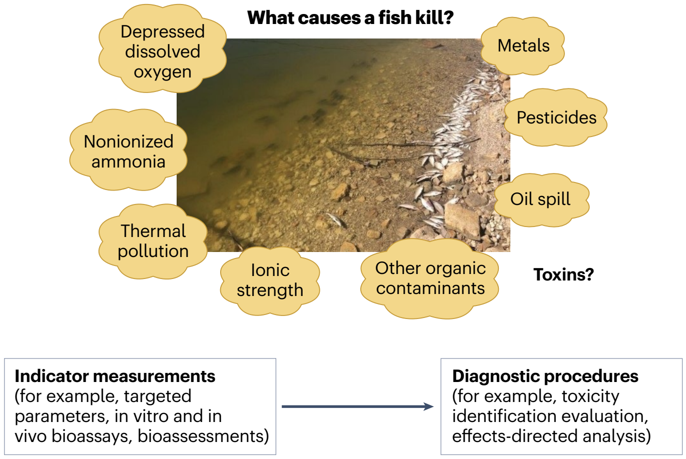

Fig. 1 | A fish kill caused by *Prymnesium parvum* in Lake Kemp, Texas, USA. Note the 'golden' colour of surface waters when harmful algal blooms of *P. parvum* occur. Photo credit: Wes Dutter, Texas Parks and Wildlife Department.

Aquatic systems around the world are stressed by diverse human activities. Water pollution comes, for example, from direct releases of chemicals and microorganisms in sewage and reclaimed waters but it can also be a consequence of runoff of pollutants from urban areas and agricultural landscapes to groundwater, rivers, lakes, and oceans. A more indirect process of water contamination originates from the release of sufficient amounts of nutrients that promote the excessive growth of algae. These organisms can cause taste and odour problems, along with promoting the formation of disinfection byproducts, which can be problematic for drinking water. Nutrient pollution and stoichiometric conditions can also stimulate the production of toxins by harmful algal blooms (HABs) that can affect business operations, public health, and the environment.

Traditionally, the quality of water resources has commonly been monitored through an indicator approach using specific chemicals, physical parameters and microorganisms, and diagnostic procedures are employed to determine whether the levels of these water quality indicators are acceptable for various human uses and ecological integrity. The expansion of such approaches with the incorporation of biomonitoring, most commonly with aquatic bioassays, has allowed detecting toxicity of wastewater discharges and ambient surface waters even when contaminant indicators do not reach problematic levels. When water quality degradation was observed, forensic methods, initially termed toxicity identification evaluations (TIEs), were developed to identify causative stressors and then to apportion these impacts among specific perturbations within watersheds for restoration of degraded systems and prevention of future water resource threats (see, for example, ref. 1). These contributions were non-trivial, providing foundational components of a water quality-based approach aimed at realizing clean water for all.

The indicator approach for water management is decidedly necessary, but it is far from perfect. Relying on a handful of water quality indicators is challenged by global chemical manufacturing trajectories, which are outpacing effective, efficient and equitable implementation of treatment technologies and environmental management systems around the world. Furthermore, the expanding diversity of chemicals in commerce continues to extend beyond the capabilities of traditional approaches and forensic tools. For example, over 350,000 chemicals and their mixtures have been globally registered for commercial use[2], but analytical chemistry methods targeting specific chemicals for water quality monitoring, along with sufficient toxicology information necessary for risk evaluations, are only available for a small fraction of this diverse chemical space. Similarly, reliance on traditional environmental forensic tools has improved water quality but has failed to illuminate blind spots of importance to public health, biodiversity and ecosystem services, particularly with such increasing chemical complexity.

Recognizing the limitations of previous approaches, new approach methodologies are supporting next-generation water quality research and applications. For example, researchers have been augmenting these original diagnostic methods to include diverse in vitro assays, which were primarily developed to identify biological activity profiles of drug candidates, during effects-directed analyses of stressor–response relationships for key molecular initiation events leading to adverse outcomes. These in vitro bioanalytical tools and omics techniques are advancing diagnostic specificity, and when coupled with advances in analytical chemistry, particularly using suspect screening and non-targeted analyses of chemical contaminants[3] and data science[4], are charting a new course for water resource assessment and management. Such water quality trajectories are timely, important and necessary, because an increasingly complex reality of anthropogenic chemicals and waste threats is further complicated by naturally produced toxins that can co-occur in multi-stressed aquatic systems.

HABs present unique challenges for water quality assessment and management. In fact, water quality impacts of HABs can be more severe than anthropogenic pollutants[5]. Harmful blooms of diverse phytoplankton appear to be increasing in frequency and magnitude, but routine water quality monitoring for HAB species and associated toxins is not occurring around the world. For example, *Prymnesium parvum*, a euryhaline, eurythermal, and mixotrophic HAB-forming species, is commonly called 'golden algae' because surface waters can appear golden during a HAB event (Fig. 1). *P. parvum* routinely causes fish kills at the global scale[6], most notably along coastlines, but also in inland waters when salinity is slightly elevated and other conditions are favourable[7]. However, optimum conditions for growth of *P. parvum* can be decoupled from toxins production, resulting in differential development of multiple toxins across the freshwater to marine continuum[8]. It is important to note that a number of toxins are also produced in different amounts per cell by other HAB species, including cyanobacteria, across environmental gradients. Furthermore, HAB toxins can confound traditional water quality assessments, which were primarily developed for chemicals directly released by human activities[9]. Thus, we need innovative approaches to identify and apportion water quality impacts caused by HABs and anthropogenic pollutants.

Now, writing in *Nature Water*, Beate Escher and colleagues report their approach to address this need, which originated in response to a *P. parvum* HAB event that killed hundreds of metric tons of fish in the Oder River basin of Europe[10]. The project team started sampling about a week after the bloom was initially reported, which is not an uncommon response time for HAB events. A diverse array of environmental chemistry and toxicology approaches were employed to understand causes of the fish kill. The study built substantially on historic TIE and other diagnostic methods to incorporate both more traditional green algae, cladoceran and zebrafish bioassays with in vitro tools to characterize biological activity of extracted water and fish tissue samples from the field. In addition to passive sampling for pesticide analyses by gas chromatography–mass spectrometry, Oder River samples were examined using liquid chromatography–mass spectrometry analyses of other targeted anthropogenic pollutants, and higher resolution analyses using ion mobility-quadrupole-time-of-flight mass spectrometry was leveraged to identify prymnesins produced by *P. parvum*. It is important to recognize that many of the anthropogenic contaminants and the prymnesins reported by Escher et al. are not part of the traditional indicator approach used for water quality. The authors then performed mixture toxicity modelling to identify how neurotoxicity was primarily driven by algal toxins, though organic micropollutants also contributed to this major fish kill.

Escher and colleagues conclude that "complex interactions between natural and anthropogenic toxicants may underestimate threats to aquatic ecosystems." I agree. In fact, in over two decades of studying the ecology, chemistry, toxicology and treatment of cyanobacteria and *P. parvum*, I am unaware of a similarly scaled effort aimed at deconvoluting HAB impacts on water quality from anthropogenic contaminants. Looking forward, we need to advance the science and improve the practice by embracing the types of multidisciplinary approaches presented here, not just to diagnose water quality impacts after they occur, but to understand and to predict the initiation, termination and toxins production dynamics by HABs across the freshwater to marine continuum. Due to the complexities associated with HAB-forming species, multidisciplinary efforts will be necessary to improve our ability to forecast HAB events, understand interactions with chemicals and waste, and more sustainably manage water quality in multi-stressed systems. Public health, biodiversity and ecosystem services depend on it.

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Competing interests

B.W.B. has previously published with Beate Escher, Nils Klüver, Maria König and Stefan Scholz.