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Editorial

Global harmful algal bloom status reporting

ABSTRACT

An extremely variegated picture of harmful algal bloom types and their socio-economic impacts at the regional and subregional scale emerges from the overviews presented in this special issue. The diversity of the HAB events parallels that of the causative species, which show different ranges and ecological characteristics, as well as highly variable responses to environmental changes. The intensity and frequency of specific blooms vary at regional and local scale, with increasing or decreasing trends and sudden occasional outbursts, but with no general uniform trend that can be discerned from that of increased observational efforts. In many cases intoxications and other adverse effects on human health are kept under control through increased monitoring activities, but impacts on human activities such as aquaculture, fishery, use of natural marine resources and tourism keep on posing economic activities at risk in many regions.

Introduction

The most frequently asked questions about harmful algal blooms are if they are increasing and expanding, and what are the mechanisms behind any perceived trends. These questions have been addressed in several review papers concerning HAB trends at various scales (Smayda 1990; Hallegraeff 1993; Zingone and Wyatt 2005; Anderson 2012; Gobler 2020), where evidences of expansion, intensification and increased impacts of harmful algal blooms have been gathered from a selection of examples that have gained high prominence in the scientific world and in society. Eutrophication, human-mediated introduction of alien harmful species, climatic variability, and aquaculture have all been mentioned as possible causes of HAB trends at various spatial and temporal scales.

Over the last 40 years, the capacity and monitoring efforts to detect harmful species and harmful events have significantly increased, thus increasing the reporting of harmful events across the world's seas. The resulting information is mostly scattered in the ever growing literature, with data from statutory monitoring programs often not published in peer review journals, while an extensive and detailed overview of the huge amount of information on harmful species, their spatial and temporal distribution and the trends of HABs they have caused has never been attempted so far.

The lack of a synthesis of the relevant data has hampered a sound global assessment of the present status of phenomena related to harmful algae. Following the lead of the International Panel for Climate Change (IPCC) consensus reporting mechanism, and to complement the World Ocean Assessment, the need has been expressed for a *Global HAB Status Report* compiling an overview of Harmful Algal Bloom events and their societal impacts; providing a worldwide appraisal of the occurrence of toxin-producing microalgae; aimed towards the long term goal of assessing the status and probability of change in HAB frequencies, intensities, and range resulting from environmental changes at the local and global scale. This initiative was launched in April 2013 in Paris by the IOC Intergovernmental Panel on HABs (IOC-IPHAB), and has been pursued with the support of the Government of Flanders and hosted within the IOC International Oceanographic Date Exchange Programme (IODE) in partnership with ICES, PICES and IAEA.

The invited papers collected in this Special Issue represent a first important step towards a global HAB status assessment. Taking a regional approach, each paper presents an overview of toxic and non-toxic HABs in a specific area of the world's seas, based on the existing literature and exploiting the information gathered in two relevant databases, both incorporated into the Ocean Biodiversity Information System (OBIS).

HABMAP-OBIS, the Database on the geographic range of Harmful Species (http://ipt.iobis.org/hab). Based on published information, HABMAP provides biogeographic information, as referenced maps, of the microalgal species that are listed in the *IOC-UNESCO Taxonomic Reference List of Harmful Microalgae* (Moestrup et al., 2009). The list undergoes continuous revision since its inception in 1997, currently including 103 dinoflagellates, 37 marine cyanobacteria, 29 diatoms, 8 haptophytes, 6 raphidophytes, 3 dictyochophytes and 2 pelagophytes. The database is being compiled by 12 Regional Editorial Groups, each with a Lead Editor, who also include most authors of the papers in the present special issue. Different levels of development characterise the regional databases, which are more advanced in some regions compared to others. In OBIS, the data from quality controlled HABMAP databases can be shown along with all other data entries or as separate queries for quality controlled data. Because entries concern these taxa regardless of the intraspecific variability in toxicity and impacts, the database provides a worldwide map of potential risks related to the occurrence of toxic species.

HAEDAT, the Harmful Algal Event Database (http://haedat.iode.org). HAEDAT is the only existing open access database holding information about harmful algal events from across the globe. HAEDAT data are summarized into 'events' associated with a negative health, economic, and/or ecological impact or a management action. A harmful algal event

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is defined as at least one of the following types, all causing a socio-economic impact: (i) water discolorations, mucilages, scum or foams produced by non-toxic or toxic microalgae; (ii) biotoxin accumulation in seafood above levels considered safe for human consumption; (iii) harmful algae-related precautionary bans of shellfish or other invertebrate harvesting or closures of beaches to protect human health; and (iv) any event where humans, animals, and other organisms are negatively affected by microalgae. Events are reported even when there is no information about the causative organism, but negative records or changes in monitoring activities are not recorded. The data are summarized into individual events, with information on start and finish dates for the event, area over which the event has been detected, maximum cell and toxin concentrations, types of impact and geographic range covered. Since 2003 the coastline of each country has been divided into grids with a unique area code that allows events impacting multiple areas to be entered accurately. The data are searchable by country, region, syndrome/type, and year and can be downloaded as csv files for further analysis. Data have been entered routinely in HAEDAT from a number of countries since the mid-1990s with some countries also entering historic data extending back to the late 1800s. Different geographic regions contain varying numbers of HAEDAT reports, with the largest number of records available for north-western Europe and the most limited datasets for South America, Australia/New Zealand, and the Benguela Current.

A detailed description of HAB-related databases and suggestions for their future development are presented in Zingone et al. (2021b). An analysis of the data aggregated by regions is presented in Hallegraeff et al. (2021b). HAEDAT and HABMAP have both limitations and need expert judgement to be correctly used. For example, because of inconsistent HAB reporting procedures and different observational efforts, no direct proportionality exists between events recorded in HAEDAT and toxicity in a given region. Paradoxically, areas with more HAB event records rather reflect effective management and may have much lower risk of intoxications compared to areas with insufficient monitoring and/or rare events. As for trends, changes in monitoring and regulatory approaches may have an impact on the number of aquaculture bans and hence of the events reported. Similarly, maps of toxic species often reflect the distribution of taxonomists, while geographic ranges rarely include long stretches of African and south Asian coasts. Therefore, awareness of these possible biases and deep knowledge of regional harmful species and HAB distribution are necessary to ensure a correct interpretation of the data in the current literature and in the databases.

For this special issue, the databases described above have been used by regional groups of HAB experts, along with the available literature, with the aim to provide 12 regional assessments of the HAB status and trends. This effort has given a great impetus to the compilation of the databases described above, with new information entered for several regions that were poorly covered previously. In most cases, this has been the first time the databases have been exploited, with results providing a clear demonstration of their usefulness and urging to support their continuation and further development.

Synthesis of the results

All regions are impacted by multiple HAB types, but the repertoire of HAB types and causative species vary from one region to another.

Human health toxins. With some exceptions for a few warm water and cold water species, potentially toxic species are widespread, each region of the world harbouring a high number of them. However they do not cause harmful events everywhere, nor with the same intensity at different places. DST events have a much higher incidence in European seas (Belin et al., 2021; Bresnan et al., 2021, this issue), and in the Mediterranean (Zingone et al., 2021, this issue), while they are less common than PST events in Canadian waters (McKenzie et al., 2021, this issue), along the Atlantic US coasts (Anderson et al., 2021, this issue), in the Caribbean and South America and Phillippines (Sunesen et al., 2021; Yñiguez et al., 2021, this issue). Ciguatera is mostly confined to the subtropical Pacific and the Caribbean (Chinain et al., 2021, this issue), with recent expansion in Macaronesia, east and south Asia. Other types of toxicity from benthic microalgae, namely by *Ostreopsis* spp., are recorded in the Mediterranean Sea and along the Brazilian coasts. ASP-related problems affect mainly both Atlantic and Pacific Canadian and US coasts, and the UK, as Domoic Acid in seafood rarely exceeds regulatory limits elsewhere despite the wide range and intense blooms of *Pseudo-nitzschia* species over many coastal areas. Neurotoxic Shellfish Toxins (NST) are confined to Florida (Anderson et al., 2021, this issue), with a single outbreak reported from New Zealand (Hallegraeff et al., 2021, this issue).

Fish and shellfish kills are a dominant issue in many regions, where they may affect reared or wild marine animals and present continuous impacts, or more occasional outbursts, such as marine mass mortalities by *Alexandrium catenella* in St Lawrence Estuary in 2008 (McKenzie et al., 2021, this issue). In South America, the greatest economic losses were produced by salmon deaths associated with *Pseudochattonella verruculosa* and *Alexandrium catenella* in Chile and tuna deaths related to *Tripos furca* and *Chattonella* in the Mexican Pacific (Sunesen et al., 2021, this issue). In the Philippines and in Malaysia, fish-killing algal blooms by *Chattonella, Karlodinium, Margalefidinium (Cochlodinium) polykrikoides*, and *Prorocentrum cordatum* are a recent problem. In South Africa, high biomass dinoflagellate blooms by *Gonyaulax, Lingulodinium, Prorocentrum, Protoceratium* and *Tripos* are associated with mass mortalities of marine life from anoxia during decay of the blooms (Pitcher and Louw, 2021, this issue). In Eastern Asia countries (China, Japan, Korea and Russia), finfish mortalities by *Chattonella, Margalefidinum, Karenia* and *Karlodinium*, and shellfish mortalities by *Heterocapsa circularisquama* are of greatest concern (Sakamoto et al., 2021, this issue). In the Kattegat-Skagerrak, Eastern North Sea and Norwegian Sea major fishfarm mortalities were caused by *Chrysochromulina leadbeateri* in Norway 1991 and 2019, *Prymnesium polylepis* in the Kattegat-Skagerrak in 1988, and *Pseudochattonella* spp. in the Kattegat-Skagerrak since 1998 (Karlson et al., 2021, this issue). Interestingly, several fish kills in distant and presumably ecologically different areas are caused by the same species, i.e., *Chattonella, Pseudochattonella verruculosa* and *Margalefidinium polykrikoides*, the latter also causing discolorations in the Mediterranean Sea in recent years (Roselli et al., 2020). Other species, such as *Heterocapsa circularisquama, Karlodinium* spp., and *Prymnesium polylepis* are rather quite specific to certain areas. In addition, fish kills in some areas may also be caused by species producing sea-food related toxins, such as *A. catenella.*

Impacts other than fish kills and toxicity to humans are linked to region-specific resources or particular groups of species. For example, dense blooms of non-toxic diatoms and dinoflagellates (e.g., *Asteroplanus karianus, Coscinodiscus wailesii, Eucampia zodiacus, Akashiwo sanguinea*) cause nutrient depletion and bleaching of the farmed red algae nori (*Pyropia* spp.), with considerable economic impacts in China (Sakamoto et al., 2021, this issue). HAB by cyanobacteria, either toxic or causing discolorations, have an impact mainly in the Baltic and Brazilian coasts, although some scattered reports from other areas also exist. In areas with intense tourism, such as the Mediterranean Sea, the Brazilian coasts and the Caribbean, severe impacts derive from high biomass blooms, discoloration and mucilages, which may be caused by toxic and/or non-toxic species (Sunesen et al., 2021; Zingone et al., 2021, this issue).

Trends. The wide heterogeneity of adverse effects deriving from different species in different types of coastal environments is paralleled by the lack of generalized and uniform trends among and within regions. Over the period considered in detail (1985–2018), no evidence was found of a general increase in the HAB events. Within regions, trends were heterogeneous, with increases in HABs occurring in some, decreases, or no changes in others, and affected selected HAB types. For example, biotoxins in marine mammals in the Arctic Pacific have increased, along with AST and DST-related problems along the USA coasts (Anderson et al., 2021, this issue) and blooms of *Noctiluca* in Australia (Hallegraeff et al., 2021, this issue). Instead, other types of toxic events have stabilized or decreased. In the Philippines and Malaysia, blooms of the PST producer *Pyrodinium bahamense* have stabilized or decreased compared to the 1990s, when they were a great concern, while other PST-producing species have increased (Yñiguez et al., 2021, this issue). DSP problems in Norway have decreased, and also fish kills in Seto Inland Sea of Japan and on the Atlantic Canadian coast, and mucilages in the Adriatic Sea are less frequent nowadays. What seems somehow more common is the spreading of HAB events into new areas, such as the ciguatera species in Macaronesia, problems related to *Pyrodinium bahamense* in Florida, *Ostreopsis* in the Mediterranean area, and expanding red *Noctiluca* in the Australian region and green *Noctiluca* in the Arabian Sea. All regional overviews point at intensified monitoring efforts, due to increased aquaculture and tourism, as a key driver of the increasing number of records of HAB events.

Conclusions

The variegated picture of HAB events and trends across the globe emerging from this special issue reflects the multifaceted nature of the ca. 188 (toxic to humans and animals) to about 250 (including non-toxic) marine microorganisms that cause those events, which may produce different kinds of adverse effects and respond in different ways to environmental drivers and their changes over time. Differences among apparently similar sites, various cases of trends and cases of range expansions are often unexplained, which recalls the persisting and urgent need for ecological studies of the individual phenomena at local scale.

The global problem of HABs is serious and their societal impacts are significant, while some of the increasing trends and expansion suggest that the ever-increasing need to exploit coastal marine resources, driven by the expanding human population, acts as a natural multiplier that may lead to an increase in impacts of HABs independent of their actual trend.

This is only the first of hopefully many future analyses of the HAEDAT and HABMAP databases. These databases are currently being prepared for integration within OBIS along with the development of a specific HAB user interface, With the IOC UNESCO Reference List of toxic species in WoRMS this will be launched as the IOC Harmful Algal Information System, HAIS. Improvements include ease of data entry and Quality Control, improved mapping options combining data from HAEDAT and HABMAP/OBIS and more user-friendly interface. Only with ever improving and better harmonized global data sets can we answer questions on the relationships between HABs, climate, eutrophication and aquaculture with confidence and improve our forecasts of future trends.

References

Anderson, D.M., et al., 2012. HABs in a changing world: a perspective on harmful algal blooms, their impacts, and research and management in a dynamic era of climatic and environmental change. In: Kim, H.G., et al. (Eds.), Proceedings of the 15th International Conference On Harmful Algae, pp. 3–17.

Anderson, D.M., et al., 2021. Marine harmful algal blooms (HABs) in the United States: history, current status and future trends. Harmful Algae, 101975. https://doi.org/10.1016/j.hal.2021.101975.

Belin, C., et al., 2021. Three Decades of Data On Phytoplankton and Phycotoxins On The French Coast: Lessons From Rephy And Rephytox. https://doi.org/10.1016/j.hal.2019.101733.

Bresnan, E., et al., 2021. Diversity and regional distribution of harmful algal events along the Atlantic margin of Europe. Harmful Algae, 101976. https://doi.org/10.1016/j.hal.2021.101976.

Chinain, M., et al., 2021. Ciguatera poisonings: a global review of occurrences and trends. Harmful Algae. https://doi.org/10.1016/j.hal.2020.101873.

Gobler, C.J., 2020. Climate change and harmful algal blooms. Harmful Algae 91 (special issue).

Hallegraeff, G.M., 1993. A review of harmful algal blooms and their apparent global increase. Phycologia 32, 79–99 (1993).

Hallegraeff, G.M., et al., 2021a. Overview of Australian and New Zealand HAB species occurrences and HAEDAT events in the period 1985-2018. Harmful Algae. https://doi.org/10.1016/j.hal.2020.101848.

Hallegraeff, G.M., et al., 2021b. Are harmful marine microalgal blooms and their societal impacts increasing? A 30 year global data analysis. Nat Commun (in review).

Karlson, B., et al., 2021. Harmful algal blooms and their effects along the north European Atlantic coast and adjacent waters. Harmful Algae, 101989. https://doi.org/10.1016/j.hal.2021.101989.

McKenzie, C.H., et al., 2021. Three decades of Canadian marine harmful algal events: phytoplankton and phycotoxins of concern to human and ecosystem health. Harmful Algae. https://doi.org/10.1016/j.hal.2020.101852.

Moestrup, Ø. et al. (eds), 2009 onwards. IOC-UNESCO taxonomic reference list of harmful micro algae; www.marinespecies.org/hab.

Pitcher, G.C., Louw, D.C., 2021. Harmful algal blooms of the Benguela Eastern Boundary upwelling system. Harmful Algae. https://doi.org/10.1016/j.hal.2020.101898.

Roselli, L., Vadrucci, M.R., Belmonte, M., Ciciriello, P., Rubino, F., Ungaro, N., Caroppo, C., 2020. Two-stages bloom of *Margalefidinium* cf. *polykrikoides* in a Mediterranean shallow bay (Ionian Sea, Italy). Mar. Pollut. Bull. 151, 110825.

Sakamoto, S., et al., 2021. Harmful algal blooms and associated fisheries damage in East Asia: current status and trends in China, Japan, Korea and Russia. Harmful Algae. https://doi.org/10.1016/j.hal.2020.101787.

Sunesen, I., et al., 2021. The Latin America and Caribbean HAB status report based on OBIS and HAEDAT maps and databases. Harmful Algae. https://doi.org/10.1016/j.hal.2020.101920.

Smayda, T.J., 1990. Novel and nuisance phytoplankton blooms in the sea: evidence for a global epidemic. In: Graneli, E., Sundström, B., Edler, L., Anderson, D.M. (Eds.), Toxic Marine Phytoplankton. Elsevier New York, pp. 29–40 (1990).

Yñiguez, A.T., et al., 2021. Over 30 years of HABs in the Philippines and Malaysia: what have we learned? Harmful Algae. https://doi.org/10.1016/j.hal.2020.101776.

Zingone, A., Wyatt, T., et al., 2005. Harmful algal blooms: keys to the understanding of phytoplankton ecology. In: Robinson, A.R., et al. (Eds.), The Global Coastal Ocean. Multiscale Interdisciplinary processes. The Sea: Ideas and Observations On Progress in the Study of the Seas, 13. Harvard University Press, Cambridge, pp. 867–926.

Zingone, A., et al., 2021a. Toxic microalgae and noxious blooms in the Mediterranean Sea: a contribution to the global HAB status report. Harmful Algae. https://doi.org/10.1016/j.hal.2020.101843.

Zingone, A., et al., 2021b. Databases for the study of harmful algae, their global distribution and their trends. In: Wells, M., et al. (Eds.), Guidelines For The Study Of Climate Change Effects On HABs. IOC Manuals and Guides, 88. UNESCO-IOCWiley, Paris in prep.

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