GLOBAL Harmful Algal Bloom

STATUS REPORT 2021

United Nations Educational, Scientific and Cultural Organization

Intergovernment Oceanographic Commission

International Society for the Study of Harmful Algae (ISSHA)

IAEA International Atomic Energy Agency — Atoms for Peace

International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer
ICES CIEM

PICES

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GLOBAL Harmful Algal Bloom STATUS REPORT 2021

- An extremely variegated picture of harmful algal bloom types and their socio-economic impacts at the regional and subregional scale has emerged from a comprehensive overview of OBIS and HAEDAT data in the period 1985 to 2018.
- 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 uniform global 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.

Among the approximately 10,000 beneficial species of marine phytoplankton in the world's oceans today, some 200 taxa can harm human society through the production of toxins that threaten seafood security and human health. These toxins are also responsible for wild or aquaculture fish-kills, may interfere with recreational use of coastal or inland waters, or cause economic losses. Non-toxic microalgae attaining high biomass can also cause Harmful Algal Blooms (HABs) by producing seawater discolorations, anoxia or mucilage that negatively affect the environment and human activities.

The most frequently asked questions about harmful algal blooms are if they are increasing and expanding worldwide, and what are the mechanisms behind this perceived escalation. These questions have been addressed in several review papers concerning HAB trends at various scales, 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 [1,2,3,4]. 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 [5,6].

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.

This 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.

As a first step towards a global HAB status assessment, a Special Issue of the journal *Harmful Algae* (vol. 102, February 2021) has been published comprising 12 papers [7-18] each presenting an overview of toxic and non-toxic HABs in a specific area of the world's seas. The regional overviews build on existing literature and exploit the information gathered in two relevant databases, both incorporated into the Ocean Biodiversity Information System (OBIS).

Global Harmful Algal Bloom data available

The data bases available on HAB events (HAEDAT) and distribution of the causative microalgae (OBIS/HAB-MAP) described at the end of this brochure 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.

As of 10 December 2019 a total of 9,503 HAEDAT events had been entered from across the globe, comprising 48% seafood biotoxin, 43% high phytoplankton counts and/or water discolorations causing a socio-economic impact, 7% mass animal or plant mortalities, and 2% others (including foam and mucilage production). In a number of HAEDAT records, a single incident was categorized into multiple event types, such as both water discoloration and high phytoplankton count (11% were multiple event types) which affected aquaculture activities rather than human health in most cases except for Ciguatera. Among all events linked to seafood toxin syndromes, Paralytic Shellfish Toxins (PST) accounted for 35%, Diarrhetic Shellfish Toxins (DST) 30%, Ciguatera Poisoning (CP) and marine and brackish water cyanobacterial toxins each 9%, Amnesic Shellfish Toxins (AST) 7%, and others 10% (including Neurotoxic Shellfish Toxins (NST), Azaspiracid Shellfish Toxins (AZT), and toxic aerosols) (Fig. 1).

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, and in the Mediterranean, while they are less common than PST events in Canadian waters, along the Atlantic US coasts, in the Caribbean and South America and Phillippines. (Fig. 2). Ciguatera is mostly confined to the subtropical Pacific and the Caribbean, with recent expansion in Macaronesia. Other types of toxicity from benthic microalgae,

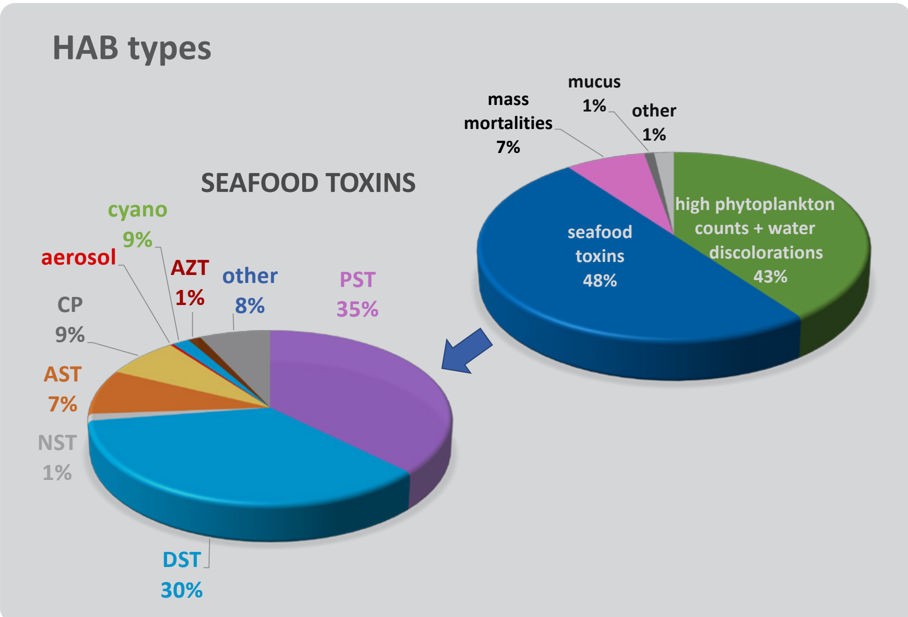


Fig.1. Partitioning of global HAEDAT events (as of Dec 2019) into the HAB types seafood toxins, high phytoplankton counts +water discolorations, marine mortalities; and the further breakdown of seafood toxins into different types of toxins, the most commonly reported being PST and DST.

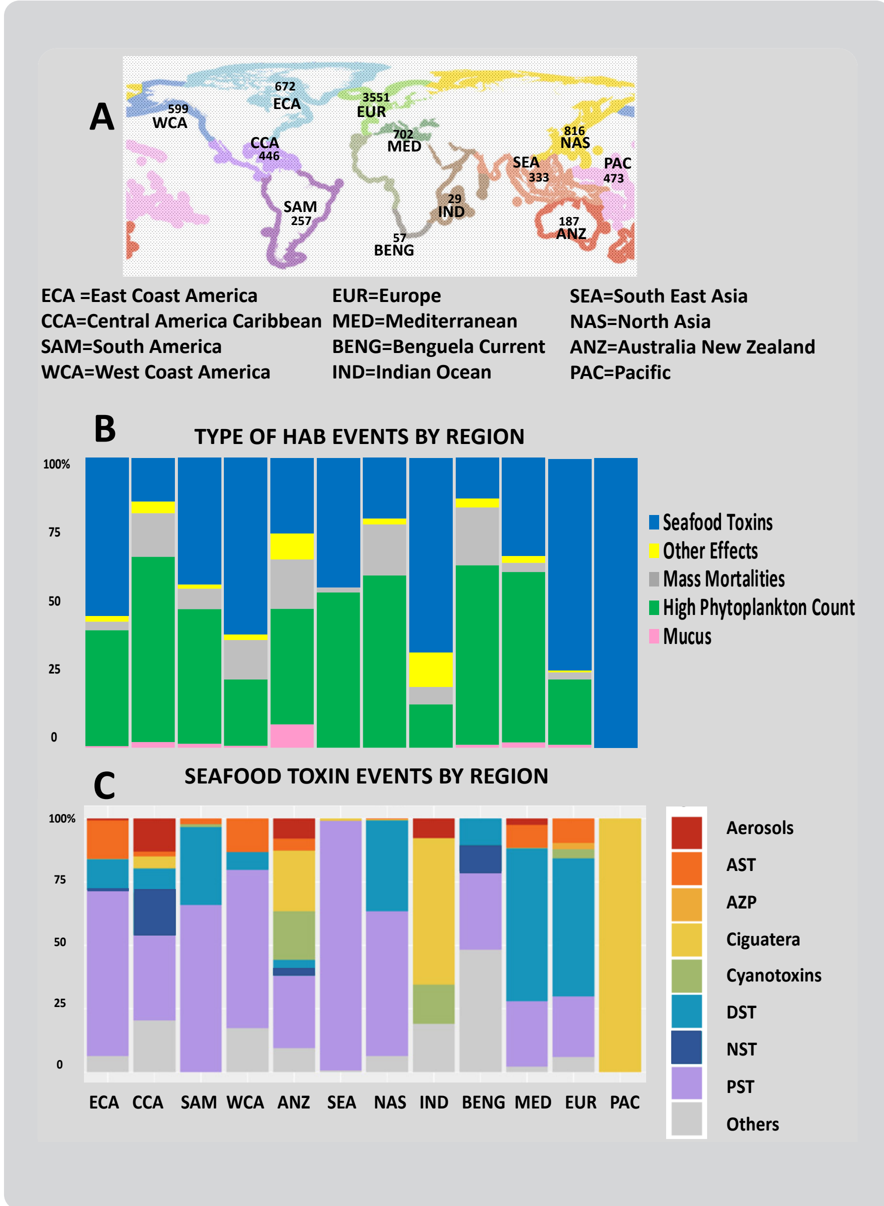


Fig.2. A: Total number of recorded HAB events in each of twelve geographic regions. B: Relative abundance of different types of harmful algal phenomena; and C. Seafood toxin syndromes. Paralytic Shellfish Toxins were dominant in East Coast America (ECA), South America (SAM), West Coast America (WCA), South East Asia (SEA) and North East Asia (NAS), Diarrhetic Shellfish Toxins were prevalent in the Mediterranean (MED) and Europe (EUR), and Ciguatera was predominant in the Indian Ocean (IND) and tropical Pacific (PAC). Australia/New Zealand (ANZ) and Central America/Caribbean (CCA) displayed mixtures of events, while Benguela (BENG) had a large proportion of other syndromes.

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, while 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, with a single outbreak reported from New Zealand.

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. In South America, the greatest economic losses are 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. 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

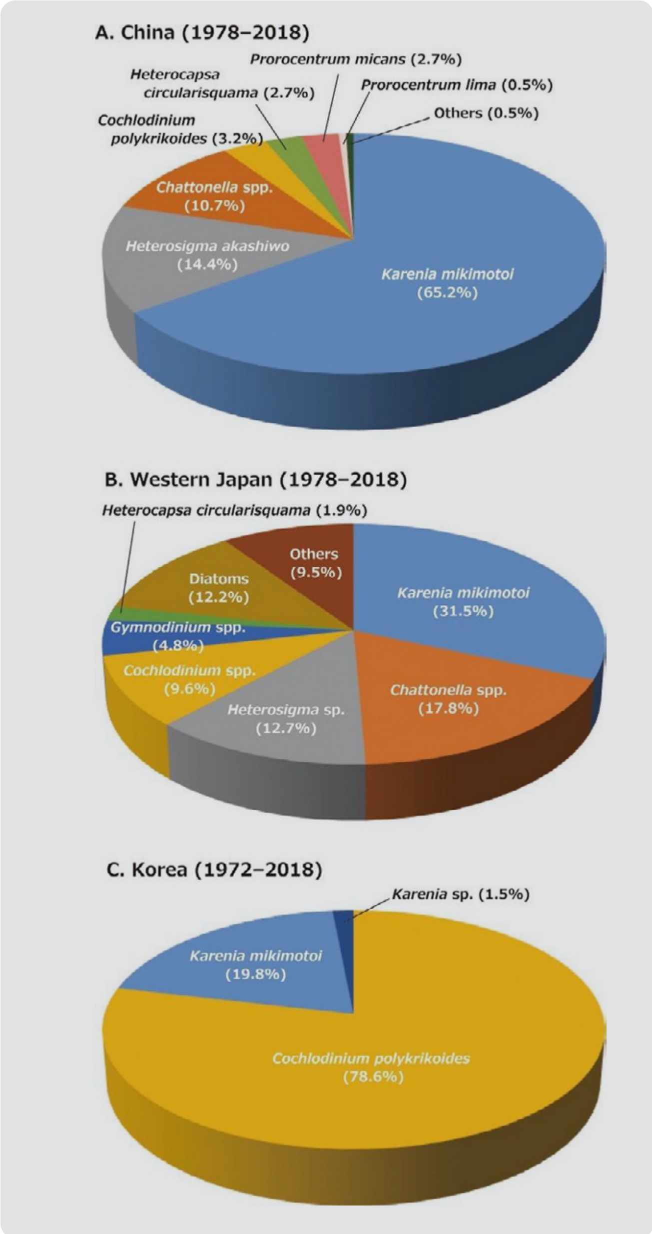


Fig. 3. Finfish killing HABs are of great concern in China, Japan and Korea, but the causative species vary regionally [11]

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. In countries of the west Pacific coasts (China, Japan, Korea and Russia), finfish mortalities by *Chattonella, Margalefidinum, Karenia* and *Karlodinium*, and shellfish mortalities by *Heterocapsa circularisquama* are of greatest concern (Fig. 3). 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. Interestingly, several fish kills in distant and presumably ecologically different areas are caused by the same species, but other species, such as *Heterocapsa circularisquama, Karlodinium* spp., and *Prymnesium polylepis* are quite specific to certain areas.

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 can cause nutrient depletion and bleaching of the farmed red algae nori, with considerable economic impacts in China. HABs by cyanobacteria, either toxic or causing discolorations, have an impact mainly in the Baltic and Brazilian coasts, although sscattered 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.

Massive mortality of marine fish due to harmful algae. St Helena, South Africa. Photo: Grant Pitcher

Analysis for Global HAB trends

A much reproduced map of Paralytic Shellfish Poisoning (PSP) in 1970 and 2009 [4], largely based on oral reports presented at HAB conferences, mostly reflects increased awareness of the distribution of the causative dinoflagellate organisms, rather than the actual occurrence or abundance of Paralytic Shellfish Toxins (PST) in seafood or the incidence of human poisonings.

This map mostly reflects increased awareness of the distribution of the causative dinoflagellate organisms, rather than the actual occurrence or abundance of Paralytic Shellfish Toxins (PST) in seafood or the incidence of human poisonings.

Exploring trends by examining the total number of HAEDAT events between 1985 and 2018, a 4x fold increase is evident for positive global records of the main causative species of Diarrhetic Shellfish Poisoning DSP (belonging to the dinoflagellate genus *Dinophysis*), a 7x fold increase of global observations of the causative organisms of Amnesic Shellfish Poisoning (mainly in the diatom genus *Pseudo-nitzschia*), and 6x fold increase of global observations of the main causative species of Paralytic Shellfish Poisoning (belonging to the dinoflagellate genus *Alexandrium*) (Fig. 4.). The latter poisoning syndrome is also caused by the less-widespread dinoflagellates *Gymnodinium catenatum* and the tropical *Pyrodinium bahamense*.

However, a meta-analysis of the global HAEDAT and OBIS data sets shows no conclusive evidence for a statistically significant, uniform trend of "increased global frequency and distribution of HABs" in the period 1985 to 2018 [20]. When statistically correcting regional HAEDAT events for varying monitoring capabilities or cov-

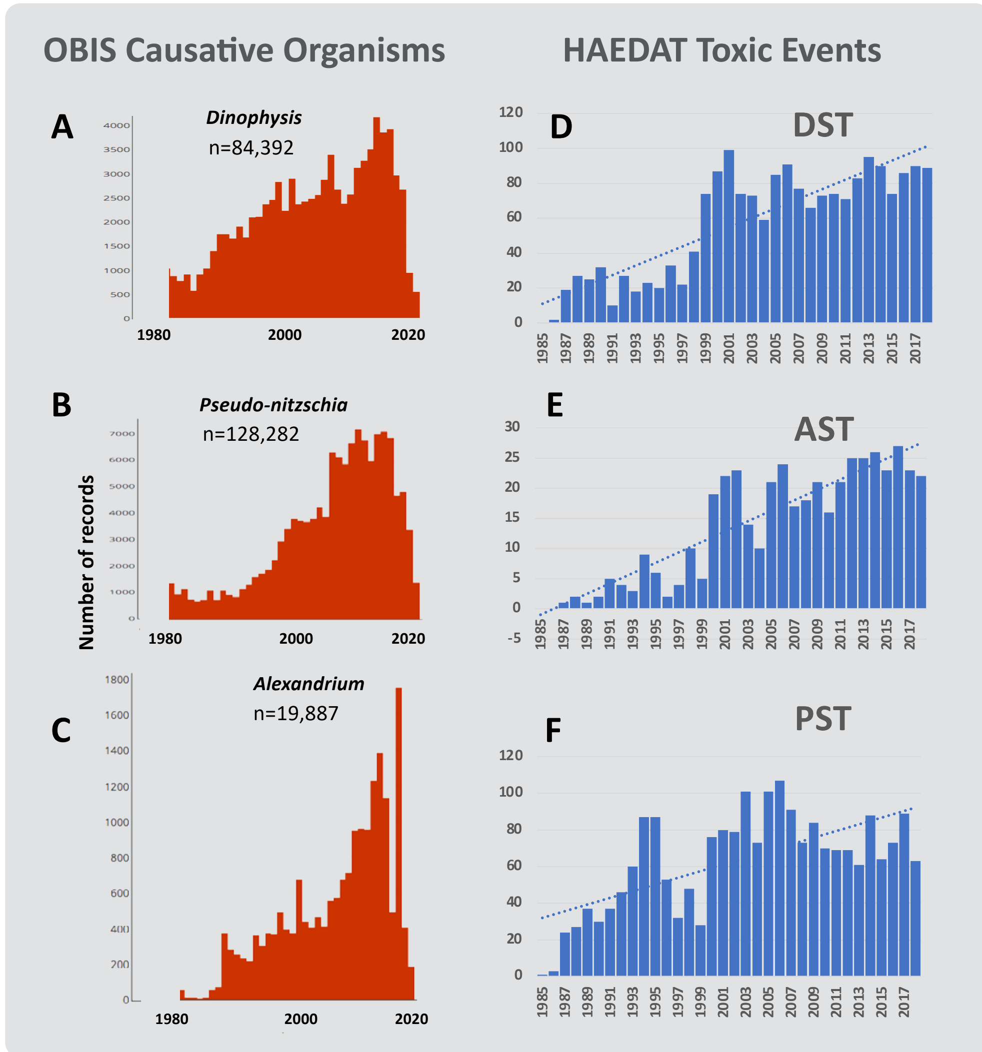


Fig.4. Increases from OBIS data between 1985 and 2018 of the total number of global observations of the causative organisms of: A. Diarrhetic Shellfish Poisoning (DSP); B. Amnesic Shellfish Poisoning (ASP); and C. Paralytic Shellfish Poisoning (PSP), together with D, E, F. The number of records of HAEDAT Toxic Events of DST, AST and PST.

A 45M AUD tuna aquaculture mortality in Port Lincoln, Australia, 1996, caused by the HAB species Chattonella marina. Photo: B.Munday and G.Hallegraeff

The toxic dinoflagellate Karenia brevis produces brevetoxins, which can cause fish kills, contamination of shellfish, and respiratory problems in humans. Gulf of Mexico, USA. Photo: NOAA

Cells on a sampling net of the toxic benthic dinoflagellate Gambierdiscus. which produces toxins that may cause ciguatera poisoning. French Polynesia. Photo: M. Chinain.

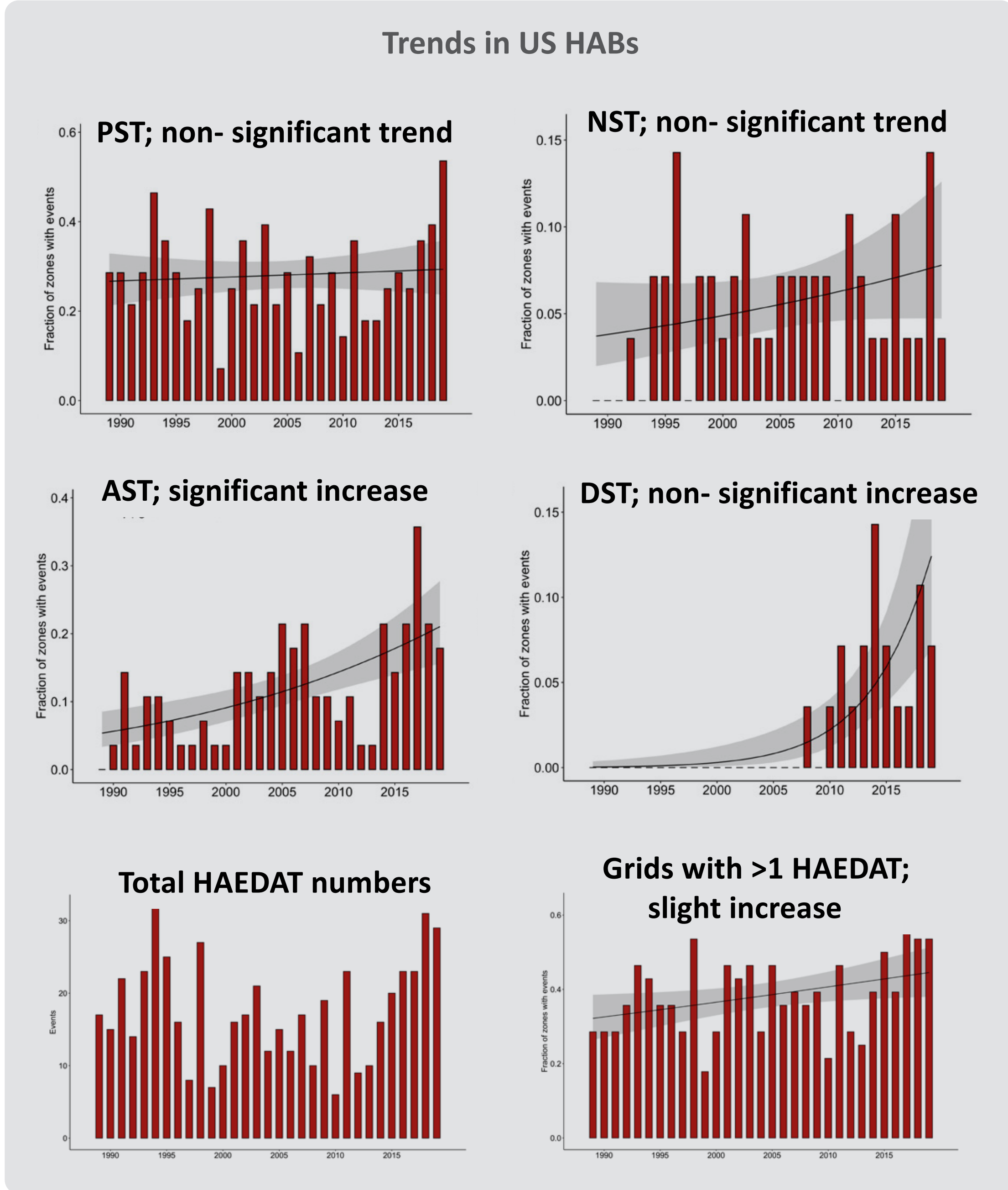


***Fig. 5.** The frequency of PST , NST, AST, and DST events in the US (defined as at least one closure in a defined region or HAEDAT zone in a given year derived from HAEDAT in the period 1990-2019. From [7]*

erage (HAEDAT adjusted for OBIS microalgal records), regional cases of both increases, decreases or stable number of harmful event incidents were demonstrated for different regions. While using OBIS microalgal data as a proxy for sampling effort may not be fully representative of HAB sampling in all regions, this approach confirms sampling effort as a key driver of observed regional patterns. Similar regional variations emerge using the number of geographic grids with HAB events, which is less prone to inconsistencies in sampling effort. Within regions, trends are also heterogeneous and concern selected HAB types. In the US, the toxin syndromes PST and NST thus shows no statistically significant change over the period considered, but AST shows a significant increase while DST shows a non-significant increase [7] (Fig. 5). Exploring trends of human Ciguatera Poisonings, in Hawaii poisonings have been decreasing, in French Polynesia and the Caribbean numbers remained stable, whereas CP is a new phenomenon in the Canary Islands (Fig. 6).

While biotoxins in marine mammals in the Arctic Pacific have increased, 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. DSP problems in Norway have decreased, and also fish kills in Seto Inland Sea of Japan and on the Atlantic Canadian coast, while mucilages

SCUBA Divers Collecting near shore sediment cores for A. catenella cyst analysis in Newfoundland and Labrador, Canada. Photo: C. McKenzie

Sampling for benthic micralgae causing Ciguatera poisoning. French Polynesia. Photo: M. Chinain.

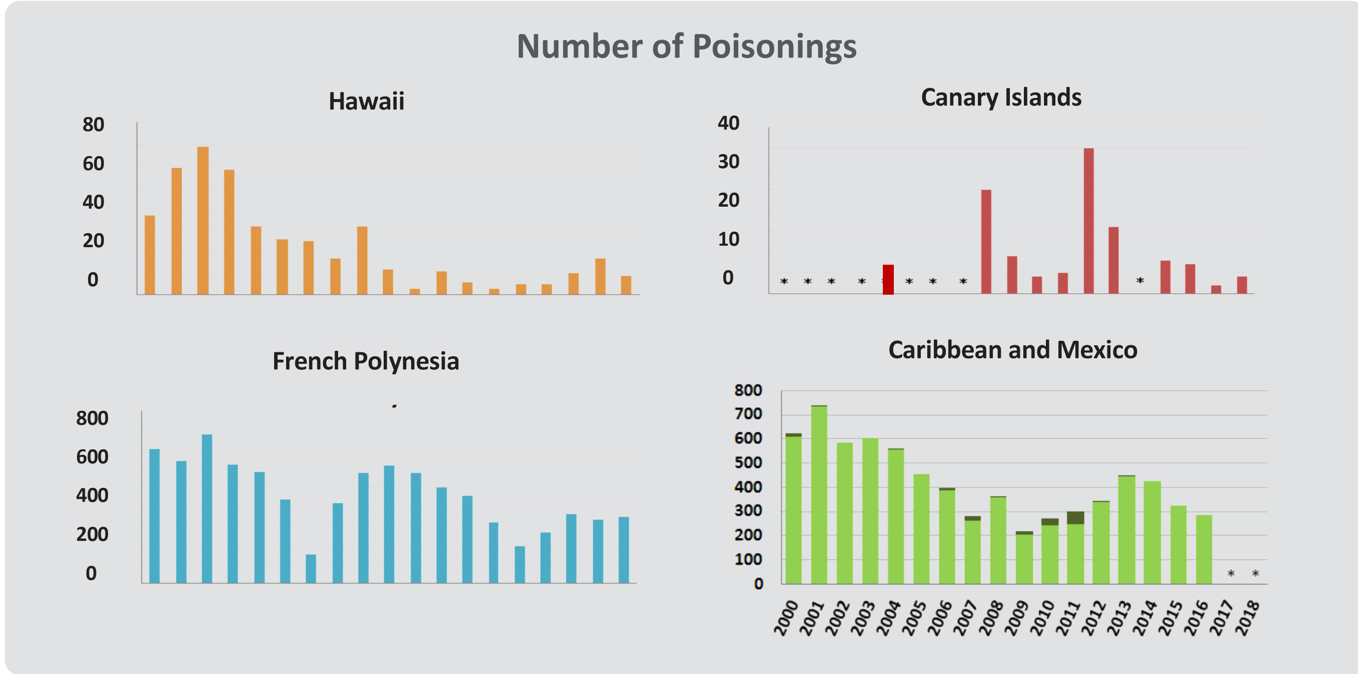
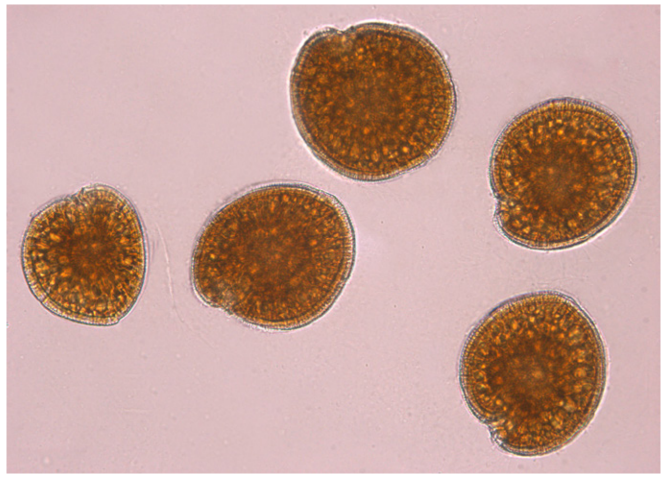


Fig. 6. Trends between 2000 and 2018 in the number of human ciguatera poisoning cases in Hawaii, French Polynesia, Canary Islands, the Caribbean (light green) and Mexico (dark green). Adapted from [18].

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, and the regional emergence of new HAB syndromes or impacts, as a key driver of the increasing number of records of HAB events. The overall conclusion is that broad statements on global HAB trends increasing are not supported by the meta-analyses, but trends in HABs are best assessed on a species-by-species and site-by-site basis.

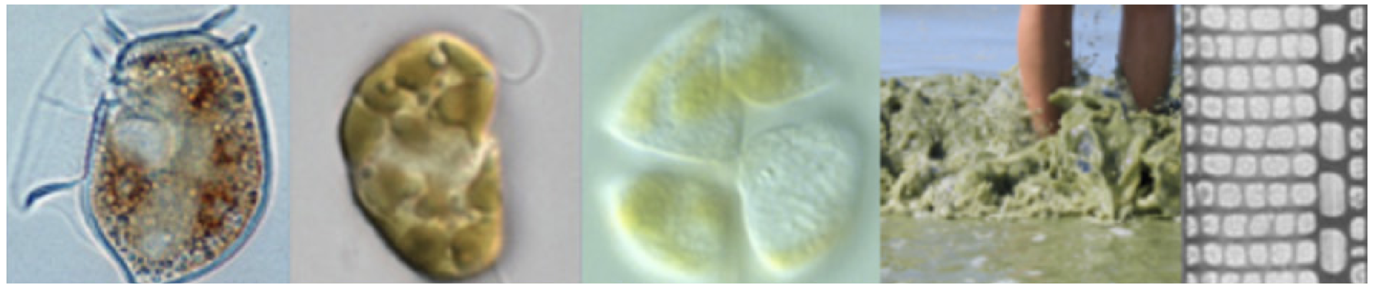
This is only the first of hopefully many future analyses of the HAEDAT database. The HAEDAT and HAB-MAP-OBIS databases are currently being prepared for integration within OBIS along with the development of a specific HAB user interface (https://hab-dev.iode.org/). With the IOC UNESCO Reference List of 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 HAB-MAP/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.



Cells of the toxic benthic dinoflagellate Gambierdiscus. Photo: M. Chinain.

Underwater mussel lines and an Alexandrium bloom approaching from the left. Gulf of St. Lawrence, Canada. Photo: C. McKenzie.

Developing a Global Harmful Algal Information System



Access to data on HAB events, impacts and the causative species is the basis for enabling the preparation of a Global HAB Status Report. The establishment of the **Harmful Algal Information System** (HAIS; http://hais.ioc-unesco.org) in collaboration with the IOC International Oceanographic Data Exchange (IODE) programme is a response to the need for an authoritative and co-ordinated world-wide on-line source of information about harmful algae. HAIS consists of databases on harmful algae developed in partnerships between IOC UNESCO, the International Council for the Exploration of the Seas (ICES), the North Pacific Marine Science Organization (PICES), and the International Society for the Study of Harmful Algae (ISSHA). HAIS presently consists of two main databases:

OBIS-HABMAP, *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* [19]. The list undergoes continuous revision since its inception in 1997. The database is being compiled by 12 Regional Editorial Groups. 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 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. 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 data-sets for South America, Australia/New Zealand, and countries of the Benguela Current Region.

A detailed description of HAB-related databases and suggestions for their future development are presented in Zingone et al. (2021) [20]. A meta-analysis of the data aggregated by regions is presented in Hallegraeff et al. (2021) [21].

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Global Harmful Algal Bloom

Status Report 2021

The most frequently asked questions about harmful algal blooms are if they are increasing and expanding worldwide, and what are the mechanisms behind this perceived escalation. These questions have been addressed in several review papers concerning HAB trends at various scales, 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.

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. This Global HAB Status Report for the first time compiles 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 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.

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