IOC e-learning Course on
Harmful Marine Microalgae

University of Copenhagen

Intergovernmental Oceanographic Commission

KØBENHAVNS UNIVERSITET
UNIVERSITY OF COPENHAGEN

Module 1

Introduction to Harmful Algae

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Harmful Algal Blooms

Outline of module

1. **The HAB phenomenon**
   - HAB diversity and habitats
   - What is a bloom? Toxic vs non-toxic blooms
   - HABs and climate change
2. **Impact on human health**
   - Six types of shellfish and fish poisoning
   - Respiratory problems
   - The drinking water problem
3. **Economic impact**
   - Human illness caused by shellfish or fish poisoning
   - Fish kills may be devastating to the aquaculture industry
   - Collapse of markets if seafood is regarded unsafe to eat
   - Recreational resources may be affected through anaesthetic water conditions, swimmers itch etc.
4. **Management and mitigation**
5. **References**

Recommended reading

Berdalet, E., Fleming, L.E., Gowen, R., Davidson, K., Hess, P., Backer, L.C., Moore, S.K., Hoagland, P. Enevoldsen, H. 2015. Marine harmful algal blooms, human health and wellbeing: challenges and opportunities in the 21st century. – J. mar. biol. UK 96: 1-31. doi:10.1017/S0025315415001733

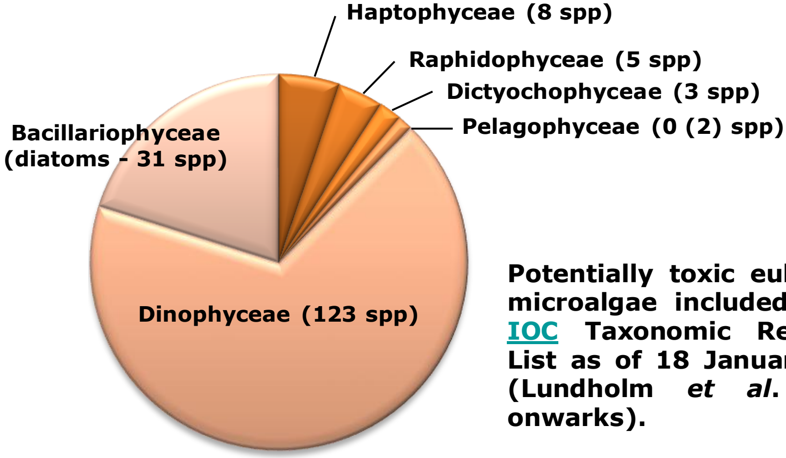
Dorantes-Aranda, J.J., Seger, A., Mardones, J.I., Nichlos, P.D. & Hallegraeff, G.M. 2015. Progress in understanding algal bloom-mediated fish kills: the role of superoxide radicals, phycotoxins and fatty acids. – PLoS ONE 10(7): doi:10.1371/journal.pone.0133549.

Hallegraeff, G.M., Enevoldsen, H. & Zingone, A. 2021. Global harmful bloom status reporting. – Harmful Algae 102 - 101992

Sanseverino, I., Conduto, D., Pozzoli, L., Dobricic, S. & Lettieri, T. 2016. Algal bloom and its economic impact. – EUR27905EN; doi:10.2788/660478.

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.

1. The HAB Phenomenon - HAB Diversity and Habitats



Potentially toxic eukaryotic microalgae included in the IOC Taxonomic Reference List as of 18 January 2025 (Lundholm *et al*. 2019-onwarks).

HAB species are very diverse, and taxonomically they belong to several different classes, notably Bacillariophyceae, Cyanophyceae, Dictyochophyceae, Dinophyceae, Haptophyceae and Raphidophyceae. As of January 2025, 170 species of eukaryotic marine microalgae are recognized as potentially toxic with an additional 43 species of potentially toxic prokaryote cyanophytes (blue-green algae) most of which occur in fresh water habitats (Lundholm *et al*. 2019-on). Most toxic species belong to the Dinophyceae and these species are causative of the various human syndromes except ASP which is caused by diatoms (mainly *Pseudo-nitzschia* spp). Also non-toxic microalgal species may be considered HABs as they may cause adverse effects with considerable socio-economic impact. Hallegraeff *et al*. (2021) indicate that about 250 species may be considered harmful.

Also macroalgae (seaweeds), particularly species of the cosmopolitan genera *Ulva* (incl. *Enteromorpha*) (Ulvophyceae) and *Sargassum* (Phaeophyceae) may be considered harmful (Smetacek & Zingone 2013, Liu & Zhou 2018). The macroalgae are not toxic to humans but tonnes of accumulated floating algal masses may smother coastal areas with impact on the tourist industry, aquaculture activities, and artisanal fishery as the algal masses may hinder the use of fishing gear and operation of small boats.

A large variety of other species of macroalgae belonging to the brown (class Phaeophyceae), green and red algae (phylla Chlorophyta and Rhodophyta) as well as the blue-green algae (class Cyanophyceae) and pennate diatoms (class Bacillariophyceae) may also be deemed harmful causing adverse effects with severe economic impact on seaweed farming (Sahu *et al*. 2020). According to FAO (2020), the world production of marine macroalgae has more than tripled from 2000 to 2018 when the production reached 32.4 million tonnes. Farmed seaweeds may be damaged by overgrowth by various epiphytic macro- or microalgal species leading to decreased quality or even destruction of the seaweed crops.

Masses of free-floating Sargassum sp. accumulated on the beach of Sierra Leona (from Smetacek & Zingone 2013)

A great variety of microalgae may be considered harmful in certain circumstances – the following taxonomic course modules (modules 2-11) will focus on potentially toxic microalgae in accordance with the IOC Taxonomic Reference List.

1. The HAB Phenomenon - HAB Diversity and Habitats

Harmful microalgae occur in both pelagic and benthic environments but most monitoring programmes include only planktonic species.

The two environments harbour completely different populations of microalgae with no (or very few) species in common. The total number of species in pelagic environments (5000 spp) is almost certainly under estimated while the total number in benthic species is unknown but likely to be very high in the order of 10^4-10^5 due to the diversity of benthic diatoms.

	Planktonic	Benthic
Diatoms	30	1
Haptophytes	8	0
Dinoflagellates	123	47
Raphidophytes	5	0
Dictyochophytes	3	0

Pelagic environments

Usually a very stable environment with slow (annual) changes in temperature and salinity

- **ca. 5000 spp**
- **~ 300 HAB species**
- **~ 85 toxic species**

Benthic environment

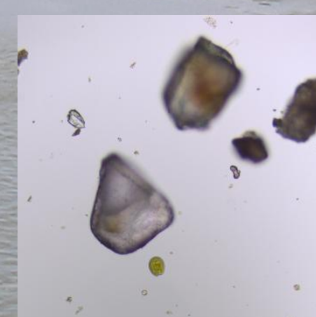
Benthic habitats may be highly variable with rapid fluctuations of particularly temperature and salinity due to tidal movements, precipitations, evaporation etc.

- **Species ??**
- **~ 250 species of dinoflagellates**
- **~ 47 toxic species**

Benthic dinoflagellates occur in many different habitats

- **(Intertidal) sediments**
- **Seaweeds and sea grasses**
- **Mangroves**
- **Corals**

Padina sp.



Information on HAB species from Moestrup, Ø.; Akselmann-Cardella, R.; Churro, C.; Fraga, S.; Hoppenrath, M.; Iwataki, M.; Larsen, J.; Lundholm, N.; Zingone, A. (Eds) (2009 onwards). IOC-UNESCO Taxonomic Reference List of Harmful Micro Algae. Accessed at http://www.marinespecies.org/hab on 2020-10-09. doi:10.14284/362

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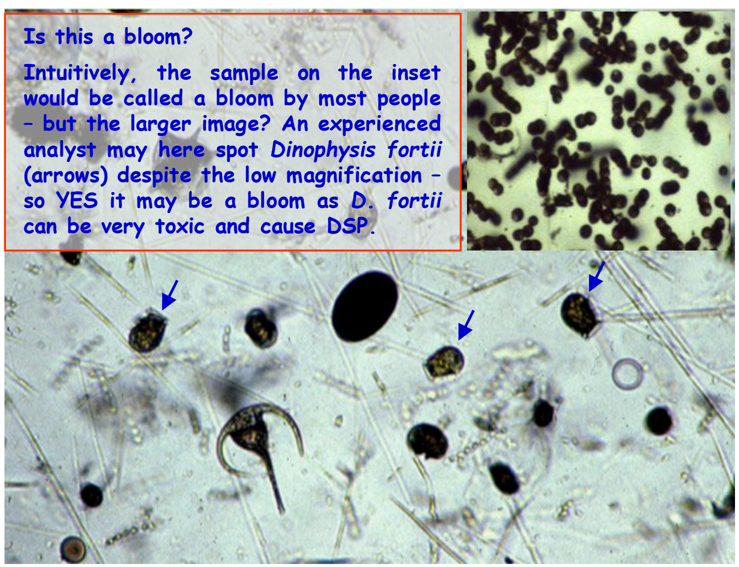
1. The HAB Phenomenon - What is a Bloom ?

The expression 'Red Tides' is still widely used for harmful algal blooms in the literature – but it is unfortunate for several reasons

- **It is not a tidal phenomenon**
- **HABs may have different colours**
- **Shellfish toxicity may occur at very low cell concentrations, i.e. <1000 cells L^{-1}**

What is a bloom ?

There is no clear definition of a bloom. The best suggestion is that 'it is a sufficiently high concentration of a species to cause adverse effects'.



Is this a bloom?

Intuitively, the sample on the inset would be called a bloom by most people – but the larger image? An experienced analyst may here spot *Dinophysis fortii* (arrows) despite the low magnification – so YES it may be a bloom as *D. fortii* can be very toxic and cause DSP.

Some HAB species may form toxic or non-toxic high biomass blooms. Harmful effects may be caused by toxins or by oxygen depletion or by a combination of these effects. Toxic species may cause shellfish toxicity or fish mortality at very low cell concentrations. Below are indicated typical cell concentrations as order of magnitude at which harmful effects may occur.

High biomass blooms (non-toxic or toxic species)

- **Red tides, discolouration of the water** — **>10^6 cellsL^{-1}**
- **Cell concentrations may reach** — **10^8 cellsL^{-1}**

Toxic blooms

- **DSP – *Dinophysis/Phalacroma* spp.** — **10^2 cellsL^{-1}**
- **PSP – *Alexandrium* spp., *Gymnodinium catenatum, Pyrodinium bahamense*** — **10^4 cellsL^{-1}**
- **ASP – *Pseudo-nitzschia* spp.** — **10^5 cellsL^{-1}**
- **Ichthyotoxic species (e.g. *Karenia* spp.)** — **10^6 cellsL^{-1}**

1. The HAB Phenomenon – What is a Bloom ?

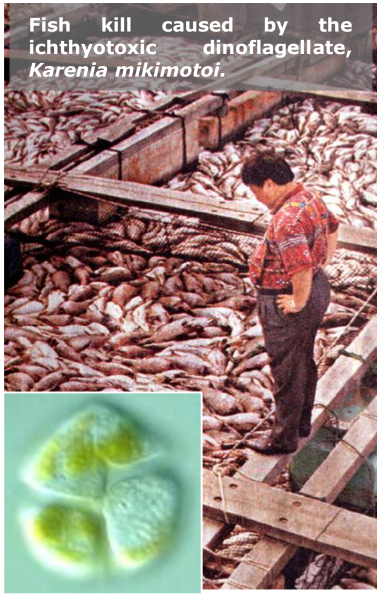
Some adverse effects

- **Human syndromes, notably ASP, AZP, CFP, DSP, NSP, and PSP, see below and Berdalet *et al*. 2015 and Sanseverino *et al.* 2016**
- **Fish kills caused by ichthyotoxic species with severe econimic impact on the aquaculture industry**
- **Marine mortality caused by toxic or non-toxic high-biomass blooms associated with anoxia (H_2S)**
- **Physical damage of fish gills caused by large diatoms (e.g. *Chaetoceros* spp)**
- **Oil and mucus production may affect sea birds**
- **Epiphytic growth on farmed seaweeds e.g. *Pitophora* spp (*Porphyra*) may damage or destrroy the production**
- **Economic impact on the tourist industry**
- **HABs may interfere with the operation of desalination plants**


Near-shore bloom of *Alexandrium*, Spain


Marine mortalilty (fish and lobster)l caused by a bloom of the non-toxic dinoflagellates, *Prorocentrum micans* and *Ceratium furca*

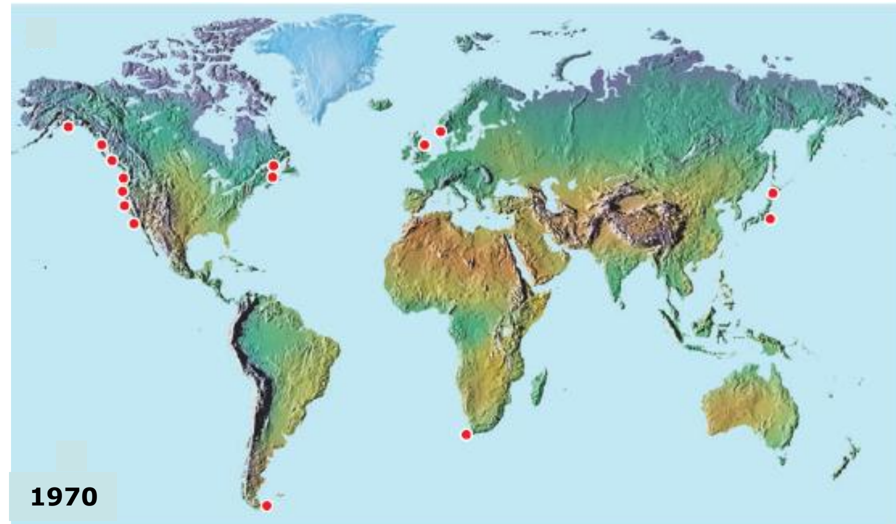
Farmed seaweeds may be damaged or destroyed by epiphytic growth of benthic diatoms or other seaweeds.


Fish kill caused by the ichthyotoxic dinoflagellate, *Karenia mikimotoi.*


Some species of the diatom genus *Chaetoceros* may attach to fish gills (arrows) and damage the epithelium.

1. The HAB phenomenon

HABs are natural phenomena and present in all aquatic environments (freshwater, brackish and marine). There is a general scientific consensus that HABs are increasing in severity and frequency, and biogeographical range. In some cases this can be attributed to human activities such as eutrophication or introduction of exogenous species, but causes are complex. Also climate change may contribute to the increase in HABs.



Distribution of events up to 1970 and 2009, respectively, where paralytic shellfish poisoning toxins were detected in shellfish or fish (Anderson *et al*. 2012, Fig.2).

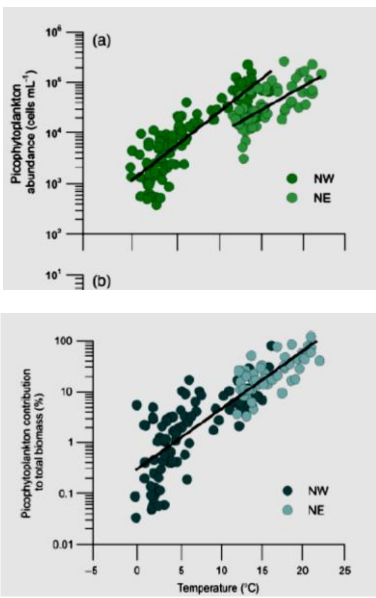
It appears that HABs are spreading and increasing in intensity

- Increased awareness and improved monitoring of HAB events
- Climate change, increasing sea surface temperature (SST)
- Spread of HAB species between countries or geographical regions through e.g. trading of shellfish for farming or ship's ballast water

1. The HAB phenomenon and Climate Change

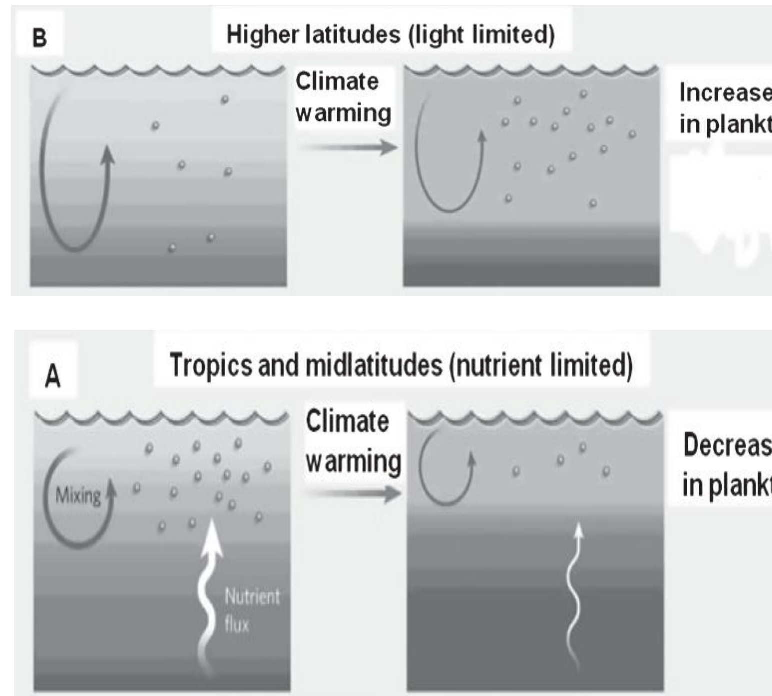
Global warming may affect phytoplankton in several ways

- **Cell abundance and community structure**
- **Phenology – recurring annual bloom events may expand with increasing sea surface temperature**
- **Species diversity and bloom events**



From Moran *et al.* 2010

Moran *et al.* (2010) showed that temperature alone was able to explain 73% of the variance in the relative contribution of small cells to total phytoplankton biomass regardless of differences in trophic status or inorganic nutrient loading. This analysis predicts a gradual shift toward smaller primary producers in a warmer ocean. Because the fate of photosynthesized organic carbon largely depends on phytoplankton size, we anticipate future alterations in the functioning of oceanic ecosystems.



From Hallegraeff 2010

It is hypothesized that global warming may lead to a decrease in the phytoplankton in at mid- and low latitudes (tropical) while at higher latitudes the phytoplankton may increase (Doney 2006).

Increasing sea surface temperature leads to stronger stratification and decreased mixing of the water masses – at lower latitudes where the water is often oligotrophic a stronger stratification may lead to decreasing nutrient flux from deeper water and therefore a decrease in phytoplankton. At higher latitudes a larger proportion of the phytoplankton may stay in the photic zone and thus lead to an increase in biomass.

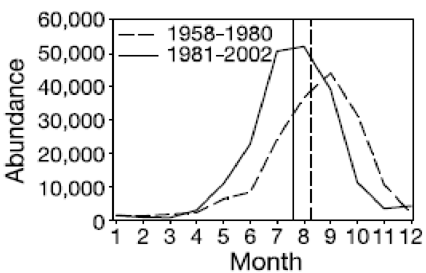
Slide 8

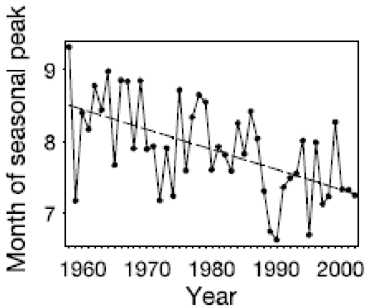
Global warming may affect phytoplankton in several ways

1. The HAB phenomenon and Climate Change

- Cell abundance and community structure
- **Phenology – recurring annual bloom events may expand with increasing sea surface temperature**
- Species diversity and bloom events

Seasonal cycles of the dinoflagellate *Ceratium* (*Tripos*) *fusus* during the periods 1958–1980 and 1981–2002 showing average cell concentrations and time of seasonal peaks.
The timing of the seasonal peaks,





From Edwards & Richardson 2004

A possible consequence of global warming may be high-biomass blooms occurring more frequently and their duration may increaseAdverse effects caused by the related species *Tripos furca*

In 1997 a bloom of *Ceratium* (*Tripos*) *furca* caused anoxia and killed 1500 tonnes of lobster in Elands Bay on the east coast of South Africa.

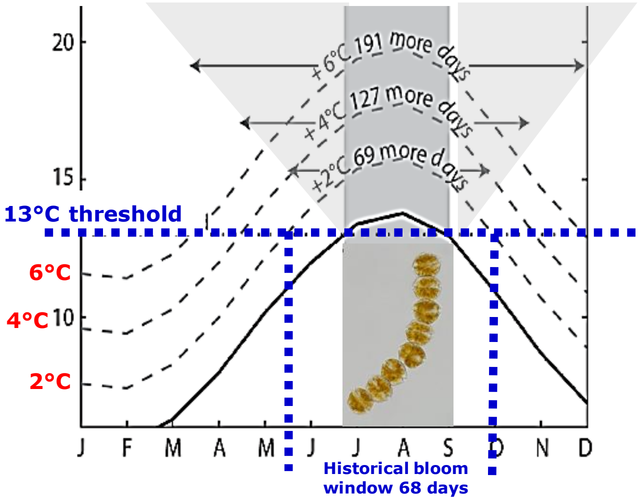
In 1994 a mixed bloom of *Ceratium* (*Tripos*) *furca* and *Prorocentrum micans* caused and killed 60 tonnes of lobster and 1500 tonnes of fish were in St. Helena Bay, South Africa.

Potential climate change impact on shellfish toxicity

***Alexandrium catenella* forms bloom in Puget Sound in Washington State, USA. Water temperatures greater than 13°C accelerates growth of this species and shellfish toxicity occurs usually in late summer and early autumn (Moore *et al*. 2008).**

Hypothetical bloom windows

+2°C - 137 days, mid-May – end-September
+4°C – 195 days, mid-April – end-October
+6°C – 259 days, mid-March – end-December



Modified from Moore *et al.* (2008)
photo: Gert Hansen

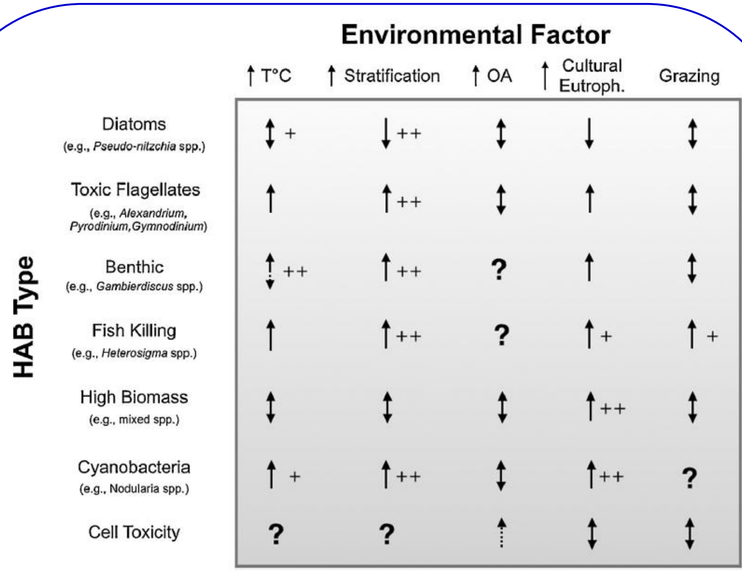
Increasing sea surface temperature may expand the period for optimal growth considerably. Thus a two degree increase expands the duration of the potential bloom window to double length (vertical blue lines).

This hypothetical scenario may be applicable to other toxic species and other areas

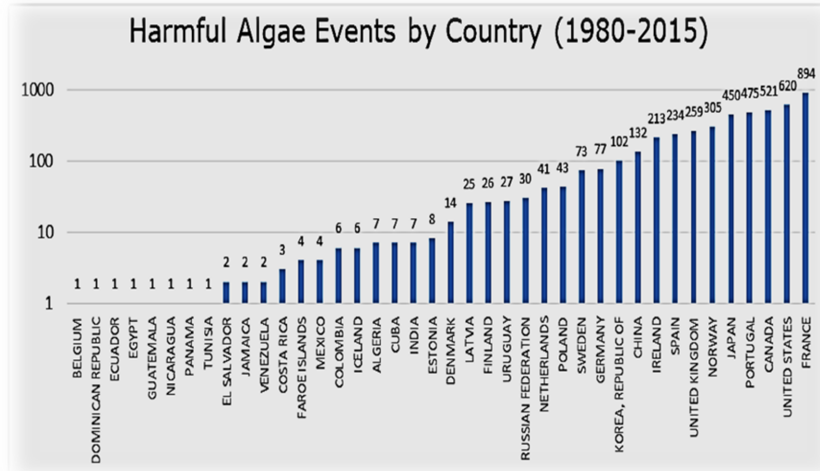
1. The HAB phenomenon and Climate Change

Global warming may affect phytoplankton in several ways

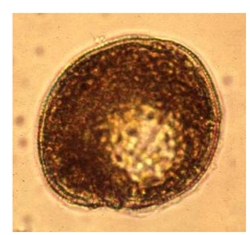
- Cell abundance and community structure
- Phenology – recurring annual bloom events may expand with increasing sea surface temperature
- **Species diversity and bloom events**



General overview of the current understanding of how different HAB types may be affected by climate change stressors. Arrows indicate changes that either increase, decrease, or can occur in both directions. Symbols suggest the level of confidence: + (reasonably likely), ++ (more likely). From Wells *et al*. (2015, Fig. 2).



The total number of HAB events reported to the Harmful Algal Events Dataset (HAEDAT) during the period 1980-2015 (from Sanseverino *et al*. 2016, Fig. 4). Causes are complex for the reported increases, but intensified monitoring is undoubtedly an important factor.



***Gambierdiscus* sp.**

2. Impact on human health
Six Human Syndromes

About 150 HAB species may produce toxins and cause human illness, and in severe cases death, through shellfish or fish poisoning. The algal toxins do not give bad smell or taste to the seafood, and the toxins are not destroyed by cooking or by processing. Presence of toxins in seafood must be analysed by bioassays and/or chemical analyses.

- Amnesic shellfish poisoning – ASP
- Azaspirazid poisoning – AZP
- Diarrheic shellfish poisoning - DSP
- Neurotoxic shellfish poisoning - NSP
- Paralytic shellfish poisoning - PSP
- Ciguateric fish poisoning – CFP

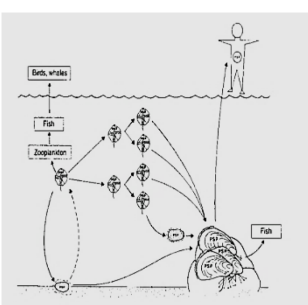
The toxins causing these syndromes are generally well described, but other types of toxins may also affect human health and wellbeing (Berdalet *et al*. 2015, Farabegoli *et al*. 2018). Thus aerosols containing brevetoxins produced by blooms of *Karenia brevis* and the toxins produced by *Ostreopsis* spp may cause respiratory problems.

Contamination of drinking water reservoirs by particularly blue-green algal toxins is a problem in many tropical areas, but is beyond the scope of this course.

2. Impact on human health

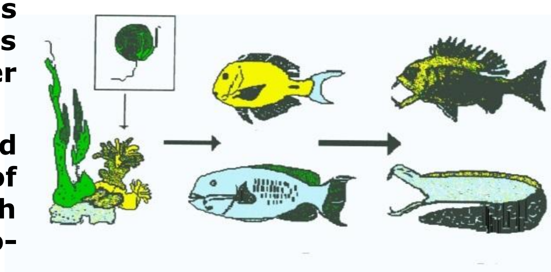
Human syndrome	Main causative species	Symptoms	
		Mild	**Severe**
ASP	*Pseudo-nitzschia* spp.	After 3-5 hours: nausea, vomiting, diarrhoea, abdominal cramps	Decreasing reaction to deep pain, dizziness, hallucinations, confusion, short-term memory loss, seizures
AZP	*Azadinium* spp.	-	Nausea, vomiting, severe diarrhoea, stomach cramps
CFP	*Gambierdiscus* spp., species of *Ostreopsis, Coolia*, and *Proro-centrum* may also be involved	After 12- 24 hours: gastro-intestinal symptoms such as diarrhoea, abdominal pain, nausea, vomiting.	Neurological symptoms such as numbness and tingling of hands and feet, cold objects feel hot to touch; difficulty in balance, low heart rate and blood pressure, rashes. In extreme cases death through respiratory failure.
DSP	*Dinophysis* spp., *Phalacroma rotundatum, P. mitra, Prorocentrum* spp.	After 30 min.- a few hours (seldom more than 12 hours): diarrhoea, nausea, vomiting, abdominal pain.	Chronic exposure may promote tumour formation in the digestive system.
NSP	*Karenia brevis*	After 3-6 hours: chill, headache, diarrhoea, muscle weakness, muscle and joint pain, nausea and vomiting	Paraesthesia, altered perception of hot and cold; difficulty in talking and swallowing
Palytoxins	*Ostreopsis* spp.		nausea, vomiting, severe diarrhoea, abdominal cramps, lethargy, tingling of the lips, mouth, face and neck, lowered heart rate, skeletal muscle breakdown, muscle spasms and pain, lack of sensation, myalgia and weakness, hypersalivation, difficulty in breathing.
PSP	*Alexandrium* spp., *Pyrodinium bahamense, Gymnodinium catenatum*	Within 30 minutes: tingling sensation or numbness around lips gradually spreading to face and neck, prickly sensation in fingertips and toes, headache, dizziness, nausea, vomiting, diarrhoea.	Muscular paralysis, pronounced respiratory difficulty, choking sensa-tion, death through respiratory paralysis may occur within 2-24 hrs.

Information compiled from Hallegraeff 2003, and Berdalet *et a*l. 2015. Some dinoflagellates may produce pectinotoxins and/or yessotoxins (*Lingulodinium polyedrum, Protoceratium reticulatum, Gonyaulax spinifera*) or cyclic imines (*Karenia* spp., a.o.).

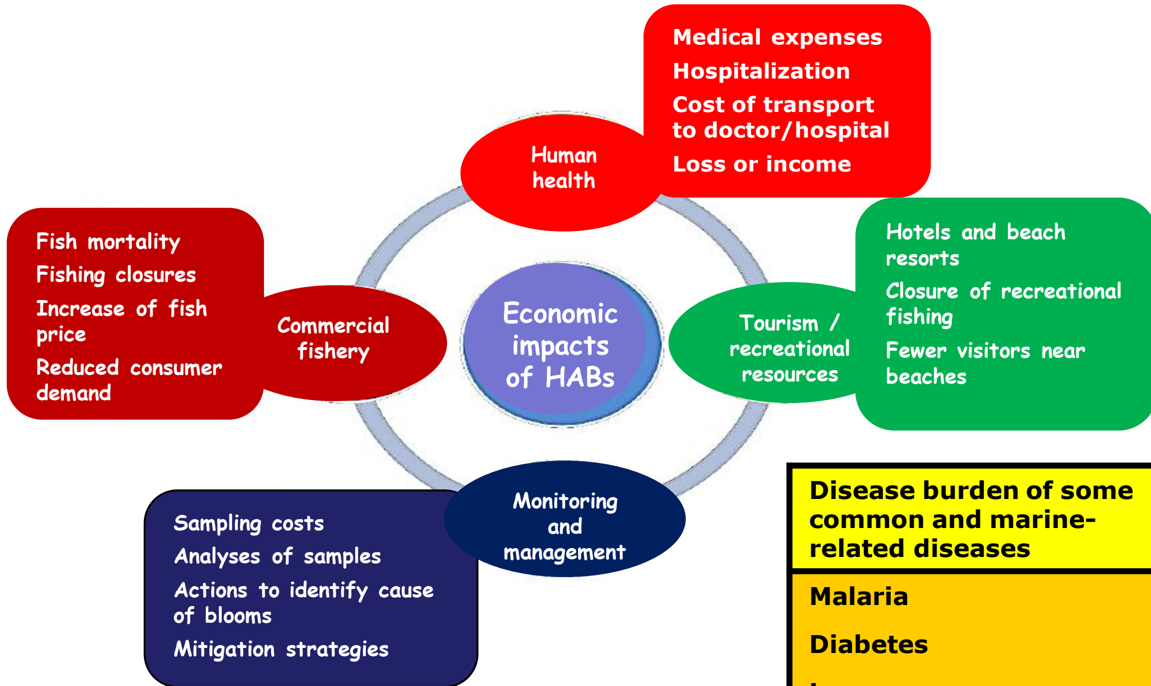


Shellfish poisonings are usually caused by species occurring in pelagic habitats and the food chain is relatively simple from the causative species through filter feeding shellfish to humans.

Fish poisoning (CFP) may involve a more complex food chain from benthic HAB species through several steps of small herbivore and carnivore fish to larger carnivore fish and finally to humans. Accumulation as well as bio-transformation of toxins may occur during this food chain.



3. Economic impact



Modified from Sanseverino *et al.* 2016

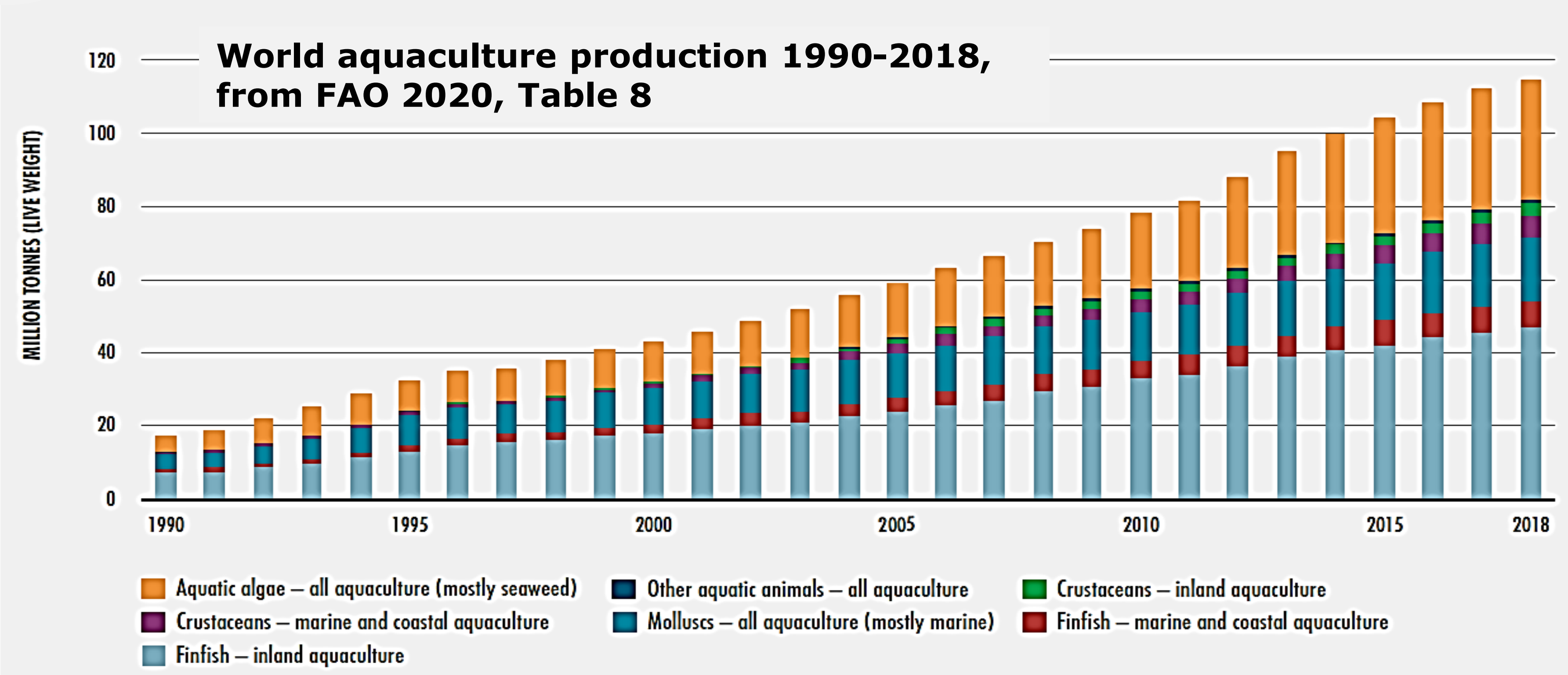
There is no comprehensive global assessment of the economic impact of HABs. Assessments are extremely complex because the several socio-economic factors may be affected by HABs. The most important are

- **Human health impact including loss or productivity and working days**
- **Commercial fisheries, consumers loss of confidence in seafood products in case of poisoning incidents, reduced demand**
- **Tourism and recreational impact**
- **Costs associated with monitoring and mitigation.**

Disease burden of some common and marine-related diseases	Economic impact Billion US$
Malaria	124.0
Diabetes	44.0
Lung cancer	35.0
Upper resp. tract infections	5.2
Trachoma	4.0
Dengue fever	3.0
Japanese encephalitis	3.0
Diseases related to marine contamination	
Bathing and swimming	1.6
Seafood consumption (hepatitis)	7.2
Seafood consump. (algal toxins)	4.0
Marine contamination, sub-total	12.8

Source: UNEP (Global Environmental Outlook 3, 2002)

3. Economic impact



According to FAO (2020), the world aquaculture production reached an all-time record of 114.5 million tonnes in 2018. The production has increased on average 5.3% annually in the period 2001-2018.

HABs may have severe, sometimes devastating, economic impact on the aquaculture industry. However, assessment of economic losses is hampered by lack of sufficient data and recognized protocols for assessment. A global HAB Workshop held in 2019 (Trainer 2020) focussed on how economic studies may be used to assess and mitigate economic impacts of HABs.

CONSERVATIVE ANNUAL COST

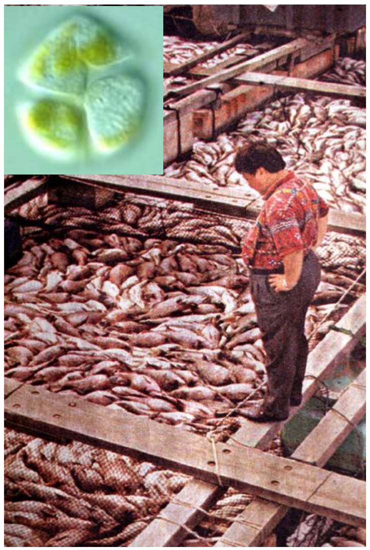
Marine HABs	
USA	± US$ 95 million
Europe	> US$ 850 million
Japan	> US$ 1 billion
Freshwater HABs	
USA	± US$ 4,6 billion
China	± US$ 6,5 billion (1998, Lake Tai)
Australia	± US$ 150 million
UK	± US$ 150 million
South Africa	± US$ 250 million

Source: Bernard et al., 2014, Developing global capabilities for the observation and prediction of harmful algal blooms. Oceans and Society: Blue Planet. Cambridge Scholars Publishing.

From Kudela *et al.* 2015

3. Economic impact

Blooms of fish filling species may cause massive economic losses. Ichthyotoxicity has been attributed to production of various combinations of reactive oxygen species (ROS), free fatty acids, and phycotoxins such as brevetoxins or karlotoxins. However, it remains unclear how the ichthyotoxic HAB species kill fish (Dorantes-Aranda *et al*. 2015).



Karenia mikimotoi

- **Blooms have caused fish mortality in several countries with severe economic impact (Li *et al.* 2019)**
- **A recent bloom in China caused mortality of farmed abalone with economic loss estimated to 350 mill US $.**

Chattonella antiqua

- **Mortality of yellow tail (*Seriola quinque-radiata*) in Japan 1972**
- **Economic loss estimated to 230 mill USD (Imai *et al*. 1998).**

Chrysochromulina leadbeateri

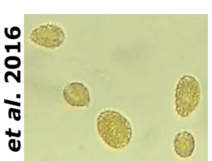
- **Caused mortality of salmon in northern Norway in May 2019**
- **Cell concentrations reached 7.7 mill L^{-1}**
- **Economic loss mounted to 100 mill US $**

Ceratium (Tripos) furca

- **Fish mortality in Van Phong Bay, S. Vietnam in Nov 2016**
- **Cell concentration reached $3{,}9 \cdot 10^6$ L^{-1}**
- **About 250 tonnes of fish were killed due to anoxic water**
- **Economic loss estimated to 1 mill USD**

Margalefidinium polykrikoides

- **Blooms have caused fish mortality in several countries, particularly in Asia**
- **Cell concentrations may reach mill L^{-1}**
- **Severe economic losses**



From Clément *et al.* 2016

Pseudochattonella sp.

- **Caused mortality of salmon in Chile in March 2016**
- **Cell concentrations reached 7.7 mill L^{-1}**
- **Economic loss mounted to 500 mill US $**

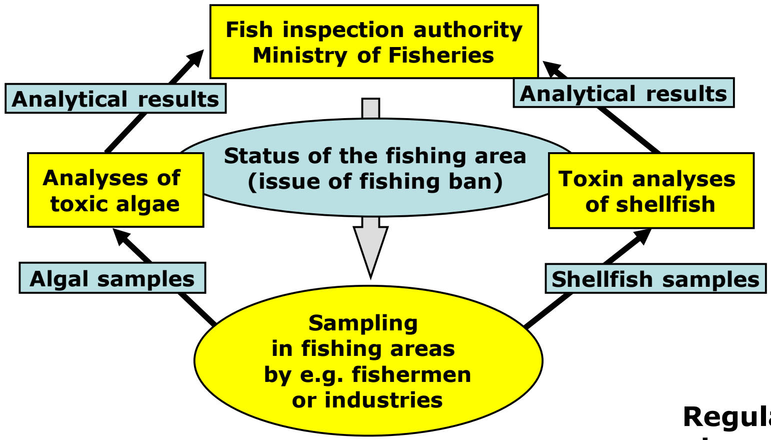
3. Economic impact

Recreational resources may be severely affected by HABs including hotels and beach resorts and associated industries. It may also affect closure of recreational fishing and shellfish collection and in general fewer visitors near beaches

Phaeocystis globosa may produce huge massses of mucus causing unaesthetic conditions on beaches. It may also produce irritant substances (acrylic acid) and which may clog fish gills.

4. Management and Mitigation

In monitoring programmes, rapid communication, clear definition of responsibilities, and traceability are all important issues



HABs cannot easily be eliminated or prevented, but they can be monitored and predicted, and the potentially negative consequences can be managed and mitigated. Changes in human activities and behaviour could also contribute to **prevent or minimize** certain HABs and their deleterious effects.

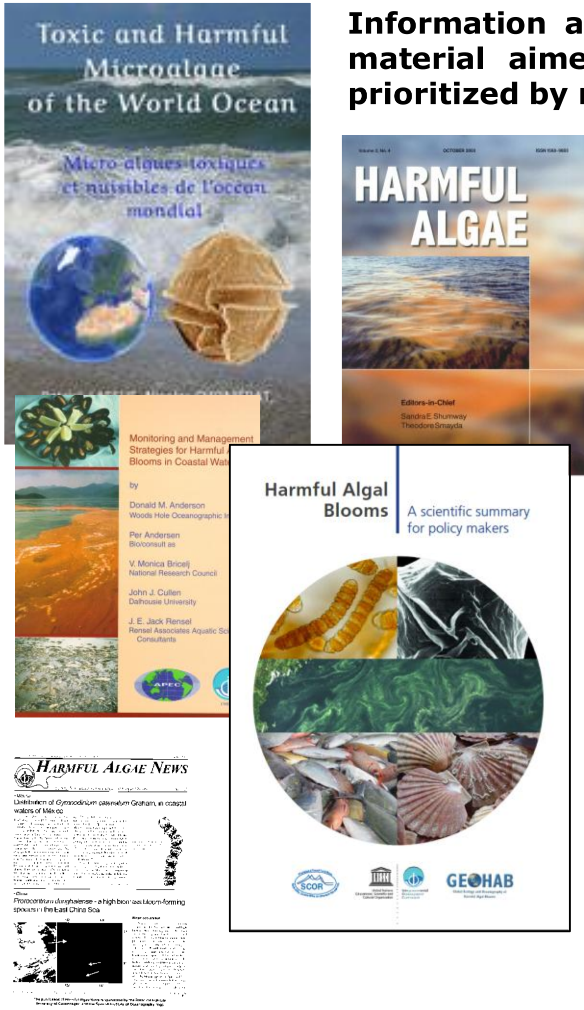
Kudela *et al.* 2015

Regulatory limits, lowest observable adverse effect level (LOAEL), no observable effect level (NOAEL), and acute reference dose (ARfD) (from Visciano *et al*. 2016, Table 2).

Marine biotoxins	Regulatory limits	Exposure after consumption of 400 g portion at the EU limit	LOAEL (1) NOAEL (2) µg/kg b.w.***	Safety factors Human data (H) Animal data (A)	Acute reference dose (ARfD)	Maximum concentration in shellfish meat (400 g portion) not exceeding ARfD
Okadaic acid	160 µg OA eq.*/kg SM**	64 µg OA eq./kg person	1 (1)	3 (H)	0.3 µg OA eq./kg b.w.	45 µg OA eq./kg SM
Azaspiracid	160 µg AZA eq./kg SM	64 µg AZA1 eq./kg person	0.4 (1)	10 (H)	0.2 µg AZA1 eq./kg b.w.	30 µg AZA1 eq./kg SM
Pectenotoxin	160 µg PTX eq./kg SM	64 µg PTX2 eq./kg person	–	–	0.8 µg PTX2 eq./kg b.w.	120 µg PTX2 eq./kg SM
Yessotoxin	3.75 mg YTX eq./kg SM	400 µg YTX eq./kg person	5000 (2)	100 (A)	25 µg YTX eq./kg b.w.	3.75 mg YTX eq./kg SM
Saxitoxin	800 µg PSP/kg SM	320 µg STX eq./kg person	2 (1)	3 (H)	0.5 µg STX eq./kg b.w.	75 µg STX eq./kg SM
Domoic acid	20 mg DA/kg SM	8 mg DA/kg person	1000 (1)	10 (H)	30 µg DA/kg b.w.	4.5 mg DA/kg SM

**eq. = equivalent; **SM = shellfish meat; ***b.w. = body weight; – = not reported.*

4. Management and Mitigation

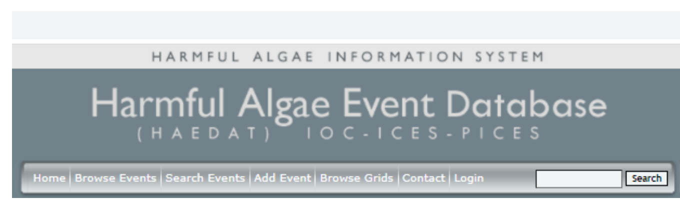


Information about HABs is important – and at all levels. Unfortunately information material aimed at the general public or basic level education is scarce and not prioritized by many researcher.

- **General public**
- **Fish farmers**
- **Investors and other stake holders**
- **Teaching material for primary and secondary schools**

Some important Web resources

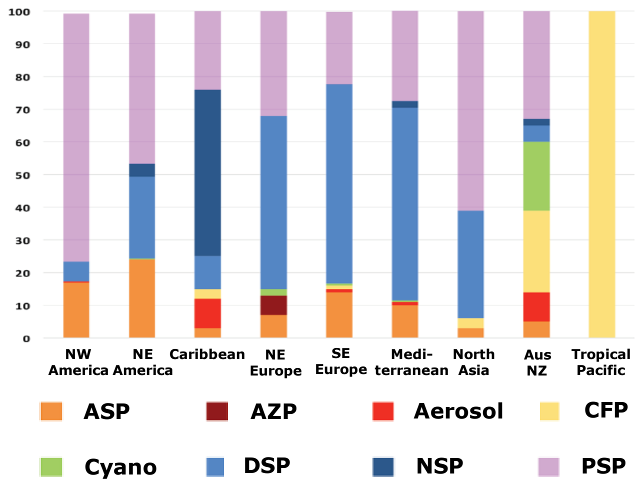
http://www.marinespecies.org/hab/



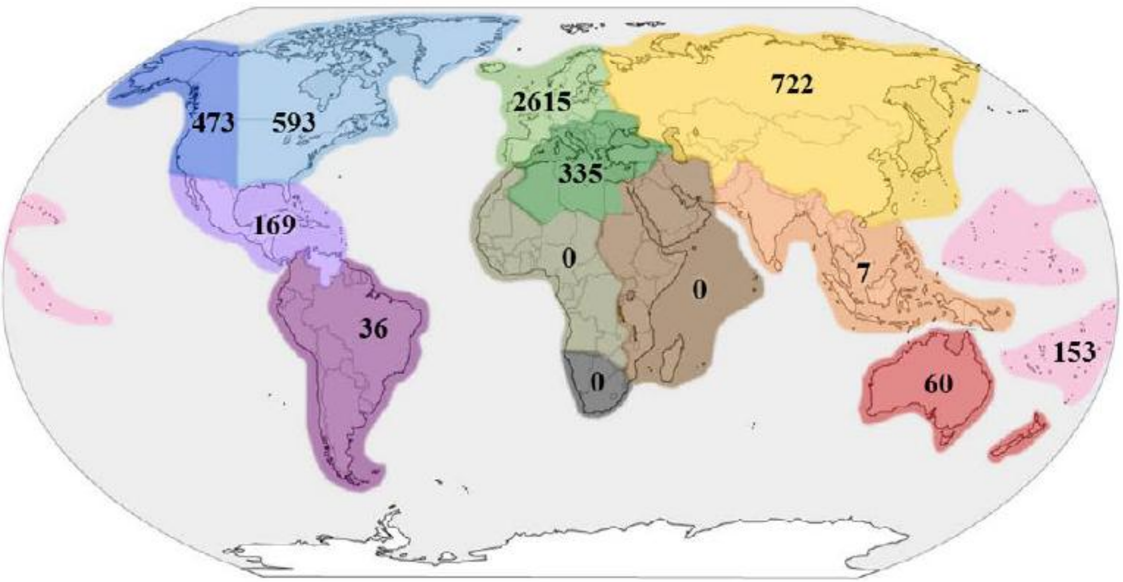
http://haedat.iode.org/

4. Management and Mitigation

Information retrieved from HAEDAT



Relative abundance of different seafood toxin syndromes in different geographical regions. Based on analysis of 5774 HAEDAT events recorded as of 01.03.2018. Data compiled by Hallegraeff & Schweibold) (Hallegraeff 2019).



Total number of HAEDAT records in the different OBIS regions of East Coast America, West Coast America, Caribbean Central America, Northern Europe, Southern Europe, Mediterranean, Australia/New Zealand, North Asia and Pacific. The regions of South America, Africa and South East Asia represent key missing data sets. Data as of 01.03.2017. Compiled by L. Schweibold (Hallegraeff *et al.* 2017)

4. Management and Mitigation

Monitoring HAB species

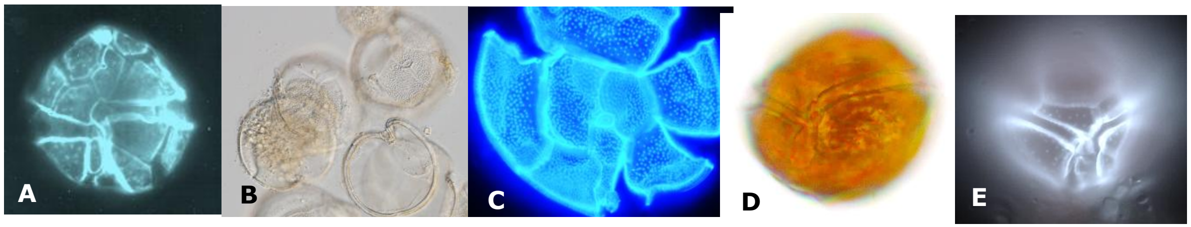
Increasing diversity – a challenge for monitoring personnel

An important element of sustainable management of marine resources is effective monitoring programmes for occurrence of HABs. The importance of correct species identification has already been addressed by Pitcher (2012) and this issue has been further accentuated by the discovery of several new nano-planktonic species, cryptic species, and non-toxic species resembling potentially toxic species strongly suggesting that these species have been confused in the past.

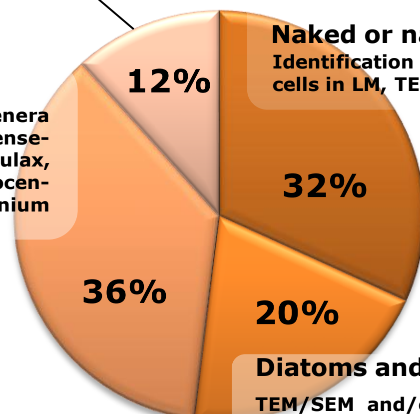
Species which cannot be identified in LM but require SEM/TEM and/or molecular analyses for identification obviously presents a challenge for monitoring personnel. It is estimated that only just over one third (36%, see next slide) of the species included in the IOC Taxonomic Reference List (Lundholm *et al*. 2009 onwards) can be reliably identified in preserved samples in LM.

Based on experience from the IOC training courses in identification of HAB species during 1995-2020, it seems that species identification in many (most?) monitoring programmes is carried out on preserved material, often using inverted microscopes which limited possibilities to observe cells from different angles. Monitoring personnel also do not generally have time or facilities to examine species in SEM/TEM, nor to carry out molecular analyses. They relay here on collaboration from research institutions in the country and often on a voluntary or 'out of scientific interest' basis. As a consequence, species requiring examination beyond observation in LM may be properly identified only when they form blooms with severe impact on human health or the marine environment. This means that occurrences of e.g. raphidophyte species, *Prymnesium* spp., or *Pseudo-nitzschia* spp. without associated adverse effects can be assumed to remain either unreported or reported only at the generic level, impeding further insight into the geographical distribution, seasonal occurrence etc. of these species.

Various types of potentially toxic, eukaryotic microalgae grouped according to methodological requirements for identification to the species level. Percentage indicated of the total number of species (154) in the IOC Taxonomic Reference List. (Moestrup *et al*. 2021).

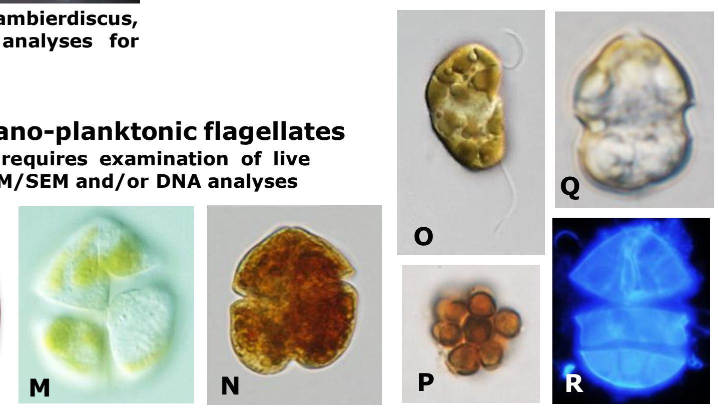


Species belonging to the Alexandrium 'tamarense-complex', and the cigua-toxic genera Coolia, Gambierdiscus, and Ostreopsis differ by subtle morphological differences and most species require DNA analyses for identification



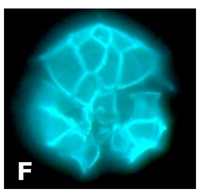
Naked or nano-planktonic flagellates

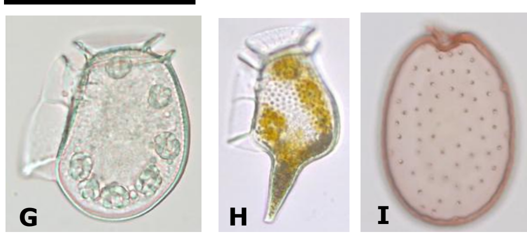
Identification requires examination of live cells in LM, TEM/SEM and/or DNA analyses

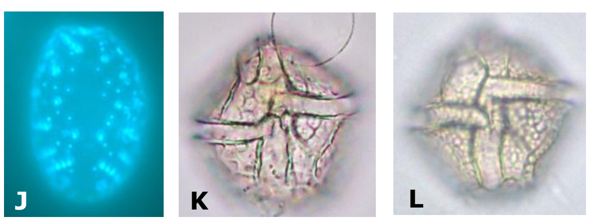


Dinoflagellates

Species belonging to the genera Alexandrium (except the 'tamarense-complex'), Dinophysis, Gonyaulax, Lingulodinium, Phalacroma, Prorocentrum, Protoceratium, and Pyrodinium can usually be identified in LM

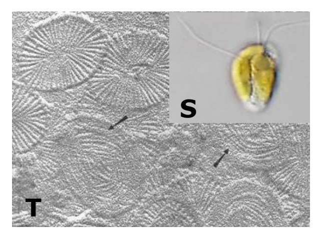






Diatoms and haptophytes

TEM/SEM and/or DNA analyses required for identification



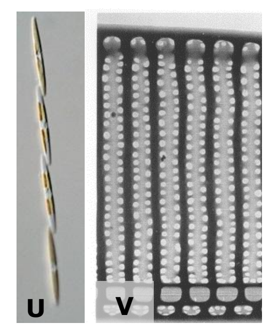


Fig. A. Alexandrium tamarense, ventral view; Figs B-C. Gambierdiscus australes, apical view; Figs D-E. Coolia tropicalis; Fig. F. Alexandrium minutum, ventral view; Fig. G. Dinophysis fortii; Fig. H. D. caudata; Fig. I. Prorocentrum lilma; Fig. J. P. rhathymum; Fig. K. Protoceratium reticulatum; Fig. L. Lingulodinium polyedrum; Figs M-N. Karenia mikimotoi, live cell (Fig. M) and preserved cell (Fig. N); Figs O-P, Heterosigma akashiwo, live cell (Fig. O) and preserved cell (Fig. P); Figs Q-R. Azadinium spinosum, both ventral view); Figs S-T. Prymnesium parvum, LM (Fig. S) and TEM (Fig. T); Figs U-V. Pseudo-nitzshcia sp. (LM, Fig. U) and P. australis (TEM, Fig. V).
Photos not to scale. Fig. S, photo: G. Hansen; Figs U-V, photos: N. Lundholm.

5. References

Anderson, D.M., Cembella, A.D. & Hallegraeff, G.M. 2012. Progress in Understanding Harmful Algal Blooms: Paradigm Shifts and New Technologies for Research, Monitoring and Management. – Annu. Rev. Mar. Sci. 4: 143-176. doi:10.1146/annurev-marine-120308-081121

Berdalet, E., Fleming, L.E., Gowen, R., Davidson, K., Hess, P., Backer, L.C., Moore7, S.K., Hoagland, P. Enevoldsen, H. 2015. Marine harmful algal blooms, human health and wellbeing: challenges and opportunities in the 21st century. – J. mar. biol. UK 96: 1-31. doi:10.1017/S0025315415001733

Dorantes-Aranda, J.J., Seger, A., Mardones, J.I., Nichlos, P.D. & Hallegraeff, G.M. 2015. Progress in understanding algal bloom-mediated fish kills: the role of superoxide radicals, phycotoxins and fatty acids. – PLoS ONE 10(7): doi:10.1371/journal. pone.0133549.

Edwards, M & Richardson, A.J. 2004. Impact of climate change on marine pelagic phenology and trophic mismatch. – Nature 430: 481-484.

FAO 2020. The State of World Fiskeries and Aquaculture 2020. sustainability in action. Rome. – https://doi.org/10.4060/ca9229en

Farabegoli, F., Blanco, L., Rodríguez, L.P., Vieites, J.M. & Cabado, A.G. 2018. Phycotoxins in marine shellfish: origin, occurrence and effects on humans. – Marine Drugs 16, 188 – doi:10.3390/md16060188

Hallegraeff, G.M. 2003. Harmful algal blooms: a global overview. – In: Hallegraeff, G.M., Anderson, D.M. & Cembella, A.D. (eds) 2003. Manual on harmful marine microalgae, - Monographs on oceanographic methodology 11, Unesco, Paris, pp. 25-49.

Hallegraeff, G.M. 2010. Ocean climate change, phytoplankton community responses, and harmful algal blooms: a formidable predictive challenge. – J. Phycol. 46: 220-235.

Hallegraeff, G.M. 2019. Global HABs, Global HAB Status Reporting, and Climate Change. – Harmful Algal News 62.

Hallegraeff , G.M., Bresnan, E., Enevoldsen, H., Schweibold, L. & Zingone, A. 2017. Call to Contribute to Global Harmful Algal Bloom Status Reporting. - Harmful Algal News 58.

Hallegraeff, G.M., Enevoldsen, H. & Zingone, A. 2021. Global harmful bloom status reporting. – Harmful Algae 102 - 101992

Imai, I., Yamaguchi, M. & Watanabe, M. 1998. Ecophysiology, life cycle, and bloom dynamics of *Chattonella* in the Seto Inland Sea, Japan. – In: Anderson, D.M., Cembella, A.D. & Hallegraeff, G.M. (eds). Physiological ecology of harmful algal Blooms. Springer-Verlag, Berlin, pp. 95-112.

Kudela, R.M., Berdalet, E., Bernard, S., Burford, M., Fernand, L., Lu, S., Roy, S., Tester, P., Usup, U., Magnien, R., Anderson, D.M., Cembella, A., Chinain, M., Hallegraeff, G., Reguera, B., Zingone, A., Enevoldsen, H. & Urban, E. 2015. Harmful Algal Blooms. A Scientific Summary for Policy Makers. - IOC/UNESCO, Paris (IOC/INF-1320.).

Li, X., Yan, T., Yu, R. & Zhou, M. 2019. A review of *Karenia mikimotoi*: bloom events, physiology, toxicity and toxic mechanism. – Harmful Algae 90 – https://doi.org/10.1016/j.hal.2019.101702.

5. References

Lio, D & Zhou, M. 2018. Green tides of the Yellow Sea: massive free-floating blooms of *Ulva prolifera*. – In: Glibert, P.M., Berdalet, E., Burford, M.A., Pitcher, G.C. & Zhou, M. (eds). Global Ecology and Oceanography of Harmful Algal Blooms, Ecological Studies 232, Springer, Switzerland, pp.317-326.

Lundholm, N.; Churro, C.; Escalera, L.; Fraga, S.; Hoppenrath, M.; Iwataki, M.; Larsen, J.; Mertens, K.; Moestrup, Ø.; Murray, S.; Tillmann, U.; Zingone, A. (Eds) (2009-onwards). IOC-UNESCO Taxonomic Reference List of Harmful Micro Algae. Accessed at https://www.marinespecies.org/hab on 2024-06-22. doi:10.14284/362.

Moore, S.K., Trainer, V.L., Mantua, N.J., Parker, M.S., Laws, E.A., Backer, L.C. & Fleming, L. 2008. Impacts of climate variability and future climate change on harmful algal blooms and human health. – Environmental Health 7(suppl 2):S4; doi:10.1186/1476-069X-7-S2-S4

Moran, X.A.G., López-Urrutia, A., Calvo-Diaz, A. & Li, W.K.X. 2010. Increasing importance of small phytoplankton in a warmer ocean. – Global Change Biology 16: 1137-1144. – doi:10.1111/j.1365-2486.2009.01960.x

Pitcher, G.C. 2012. Harmful Algae – The requirement for species-specific information. – Harmful Algae 14: 1-4.

Richlen, M.L., Morton, S.L., Jamali, E.A., Rajan, A. & Anderson, D.M. 2010. The catastrophic 2008-2009 red tide in the Arabian gulf region, with observations on the identification and phylogeny of the fish-killing dinoflagelllate *Cochlodinium polykrikoides* . – Harmful Algae 9: 163-171.

Sahu, S.K., Kapilkumar, N.I. & Mantri, V.A. 2020. Epiphytism in Seaweed Farming: Causes, Status, and Implications. – In: Gothandam, K.M., Ranjan, S., Dasgupta, N. & Lichtfouse, E. (eds). Environmental Biotechnology, vol. 1, Environmental Chemistry for a Sustainable World 44, Springer Nature, Switzerland AG, pp. 2227-242. – https://doi.org/10.1007/978-3-030-38192-9_9

Sanseverino, E., Conduto, D., Pozzoli, L., Dobricic, S. & Lettieri, T. 2016. Algal Bloom and its economic impact; EUR 27905 EN; doi:10.2788/660478.

Smetacek, V. and Zingone, A. (2013) Green and golden seaweed tides on the rise. Nature, 504, 84-88.

Trainer, V.L. (ed.) 2020. Global HAB. Evaluating, Reducing and Mitigating the Cost of Harmful Algal Blooms: A Compendium of Case Studies. – PICES Sci. Rep. 59, 107 pp.

UNEP 2002. Global Environmental Outlook 3.

Visciano, P., Schirone, M., Berti, M., Milandri, A., Tofalo, R. & Suzzi, G. 2016. Marine biotoxins: Occurrence, toxicity, regulatory limits and reference methods. – Front. Microbiol. 7: 1051. – doi:10.3389/fmicb.2016.01051

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.