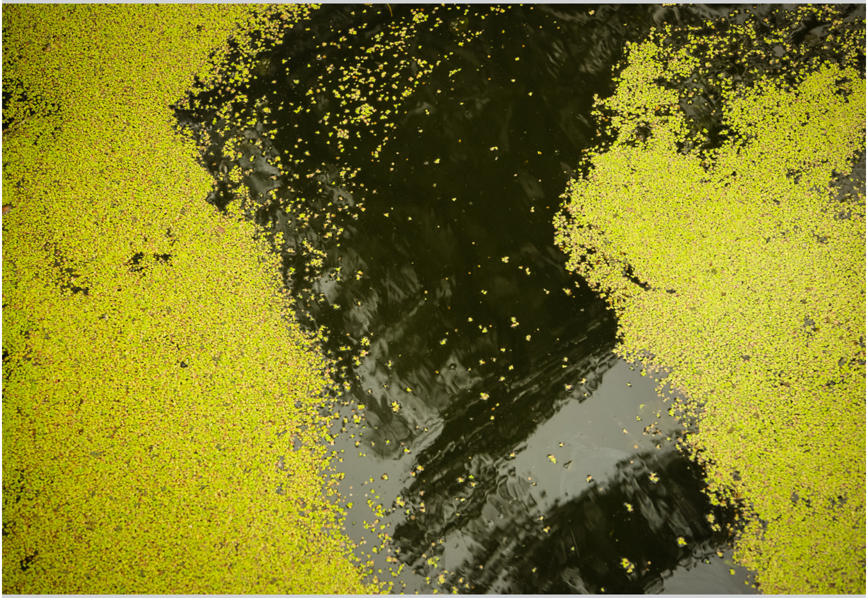
JEFFERSON REPORT

Harmful Algal Blooms:
A Threat to the Waters of the World

By Patricia M. Glibert, Ph.D.
University of Maryland Center for Environmental Science
Horn Point Laboratory



JEFFERSON
EDUCATIONAL SOCIETY

JEFFERSON
EDUCATIONAL SOCIETY

The Jefferson Educational Society will periodically publish reports on issues important to the Erie region. This report was written by Patricia Glibert, participant in Global Summit XI.

JES MISSION

The Jefferson Educational Society was created as a Pennsylvania nonprofit organization on Sept. 29, 2008 and on that same date received tax-exempt status by the Federal department of the Treasury under Employment Identification Number 26-3460486. The Jefferson operates under a 501 (c) (3) educational nonprofit charter, though it does not offer degrees or programs for formal academic credit. The Jefferson was founded to stimulate community progress through education and research activities. Its mission also includes a commitment to operate in a non-partisan, non-denominational manner without a political or philosophical bias. As such, the Jefferson intends to follow the examined truth wherever it leads and is neither liberal nor conservative, Democratic nor Republican in philosophy or in action.

OUR BUILDING PARTNERSHIP

The Jefferson Educational Society of Erie and the Brith Sholom Congregation of 3207 State Street entered into a shared-use building agreement in October 2008. Under the terms of this arrangement, the Jefferson utilizes facilities in the Southern Wing, which houses an adult education facility in order to offer lectures, courses, seminars, and sponsored research. The Brith Sholom Congregation continues to use the building's Northern Wing for religious and congregational purposes. The Jefferson Educational Society purchased the building in August 2013 and has invested in its renovation.

3207 STATE STREET
ERIE, PENNSYLVANIA 16508-2821

www.JESerie.org 814.459.8000

Harmful Algal Blooms: A Threat to the Waters of the World

By Patricia M. Glibert, Ph.D.

University of Maryland Center for Environmental Science
Horn Point Laboratory
PO Box 775
Cambridge, MD 21613
glibert@umces.edu

Introduction to the phenomenon of harmful algal blooms

In 1770, Captain James Cook, in his exploration of the coast of Australia, wrote, "There appeared in the water a kind of brown scum."

In 1793, a member of Captain George Vancouver's exploration team died and five crew members were sickened after eating contaminated mussels harvested in the uncharted coastline of what is now known as British Columbia.

In 1799, 100 members of a Russian expedition near Sitka, Alaska, died of Paralytic Shellfish Poisoning, which resulted from the consumption of contaminated shellfish (Feder 1975).

All of these historical events, as well as the Biblical reference of waters turning to blood (Exodus— 7:20,21), are now known to be associated with the natural phenomenon of blooms of toxic or harmful algae. Algae (here, referring to microalgae) are the microscopic plants that form the base of the food web, and it is this microscopic life on which all aquatic life ultimately depends for food (Glibert et al. 2005). The majority of algae in marine and freshwaters are not only beneficial but also necessary to the functioning of aquatic ecosystems. Algae produce oxygen and also play an important role in regulating atmospheric CO_2 by sequestering it during production and transporting it to deeper waters. Yet, a comparatively small subset of the total known microscopic algal species can cause environmental or human health problems. These problems can occur when these select species accumulate in sufficient numbers, when they produce toxins, or when they directly or indirectly interfere with other organisms or alter the physical habitat indirectly, negatively impacting the growth of others. These are known as the harmful algae, and their associated proliferation events are referred to as harmful algal blooms, or HABs. It is these natural algae which, while long-time residents of aquatic systems, are increasing in frequency and in geographic extext. HABs may be caused by the rapid growth of a single species that dominates the water column, but HABs may also be the result of highly toxic cells that do not accumulate in high numbers. Therefore, in some cases, toxic conditions can occur when the water is clear with very low cell concentrations of the toxic species. The term HAB also includes the freshwater cyanobacteria (often called CyanoHABs) that are technically not algae but rather photosynthetic bacteria. The effects of HABs, detailed in the next section, are as varied as the organisms themselves.

The harm in harmful algal blooms

HABs can be harmful in several fundamental ways. Many (although not all) HABs produce toxins, some of which are among the most potent toxins known. These toxins have various vectors by which harmful effects are transferred through the food chain or to human consumers, and there is a wide range of potency. In many cases people are exposed to these toxins through consumption of shellfish. Such toxins include brevetoxin, the cause of Neurotoxic Shellfish Poisoning (NSP); saxitoxin, the cause of Paralytic Shellfish Poisoning (PSP); okadaic acid, the cause of Diarrhetic Shellfish Poisoning (DSP); domoic acid, the cause of Amnesic Shellfish Poisoning (ASP); and azaspiracid, the cause of Azaspiracid Shellfish Poisoning (AZP). People can also be exposed to some of these toxins in aerosols, as in the case of brevetoxin which can be carried by sea spray. In the case of freshwater toxins, direct exposure can occur from swimming or other water contact – or more importantly, from drinking water that has not been adequately decontaminated of these toxins. These are many freshwater toxins, the most common of which is microcystin. Of the freshwater toxins, chronic exposure can result in cancers, including liver cancer. For fish or shellfish, these toxins may kill the organisms directly, or may have little effect on them, depending on the mode of toxin action (Landsberg 2002, Burkholder et al. 2018). There are no known antidotes for poisonings caused by HAB toxins.

Major poisonings associated with harmful algae, the vectors and human health symptoms

Syndrone or Illness	Major Vector	Symptoms
Amnesic Shellfish poisoning (ASP)	***Domoic acid*** from *Pseudo-nitzschia* sp. in Shellfish	Short-term memory loss; vomiting, cramps
Diarrheic shellfish poisoning (DSP)	***Okadaic acid*** from *Dinophysis* spp. in shellfish	Diarrhea, vomiting, cramping
Neurotoxic shellfish poisoning (NSP)	***Brevetoxin*** from *Karenia* spp. in shellfish, aerosolized toxins	Nausea, diarrhea, Respiratory distress, Eye irritation
Paralytic shellfish poisoning (PSP)	***Saxitoxin*** from *Alexandrium* spp. and other species in shellfish	Numbness around lips and mouth; Respiratory paralysis; Death
Cyanotoxin poisoning	***Microcystins*** and other toxins from cyanobacteria in water	Skin irritation; Respiratory irritation; Tumor-promotion; Liver cancer, failure

Another fundamental way in which HABs can be harmful is through shear accumulation and aggregation of cells. It was such an accumulation that was seen by Captain Cook. It is these aggregattions, or visible blooms, that can result in water discoloration, sometimes spectacularly. As these examples show, some blooms result in water – that is visibly red, and thus the origin of the term “red tide” to describe such events; but not all blooms are red – some are green or brown, depending on the pigmentation of the causative algae. Such accumulations of algae can reduce light penetration in the water, causing shading of submerged vegetation (such as seagrass) which harms their growth. Once these aggregated cells begin to die, their decomposition consumes oxygen that can, in turn, result in hypoxia or anoxia, the so-called “dead zones” of the sea. Global occurrences of such dead zones are expanding (Diaz and Rosenberg 2008).

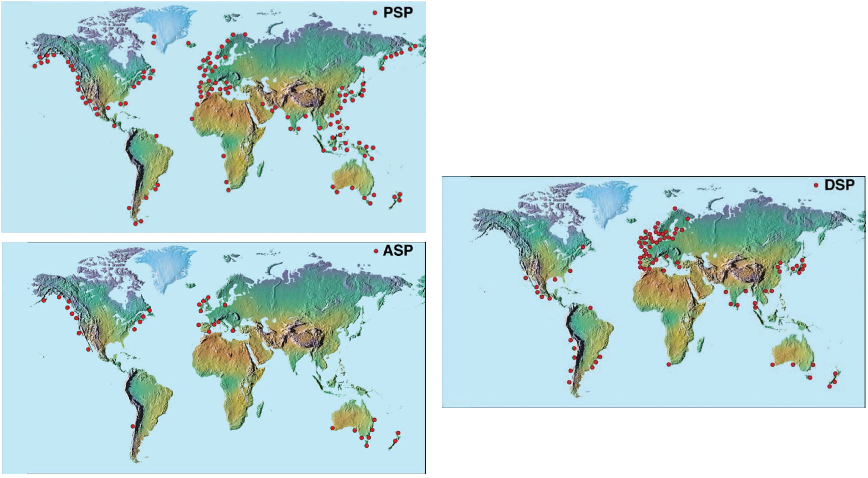
PHOTOS OF HABS

Many HABs are produced by the accumulation of vividly colored cells in surface waters. The blooms shown here are from the Philippines (panel A, photo: http://taqplayer.info/philippine-red-tide); Florida (panel B; photo: http://www.politicnote.com/army-corps-of-engineers-battles-guacamole-thick-florida-algae/); Qingdao, China (panel C; photo: www.sailjuice.com); Long Island, New York (panel D, photo by C. Gobler); Sydney Harbour, Australia (panel E; photo: https://bioweb.uwlax.edu/bio203/f2013/bradford_andr/habitat.htm); and a freshwater bloom in Uganga (panel F; photo by P. Glibert). These high biomass blooms can cause hypoxia and can contribute to toxicity of fish and shellfish, and can cause other environmental problems. Photo collage reproduced from Glibert et al. (2018a).

Many types of harmful ecosystem effects occur from HABs that are not directly toxic. Some HAB species have physical structures, such as spines, that can lodge in fish gills and can cause irritation and eventual suffocation. Some HAB species have more subtle effects on the ecosystem or effects that are more difficult to quantify in the wild; for example, some inhibit the spawing of oysters. Blooms that are known to disrupt ecosystem function but which may or may not necessarily be toxic are considered ecosystem disruptive algal blooms (EDABs; Sunda et al. 2006). These algae may form what can be thought of as a dead-end food chain; their productivity does not support fish production.

Causes of the worldwide HAB phenomenon

HABs are now found worldwide, but different types of HABs are common in specific regions. HABs are increasing in frequency, magnitude and geographic extent and virtually every coast and major water body in the United States has had major HABs in the past few years.

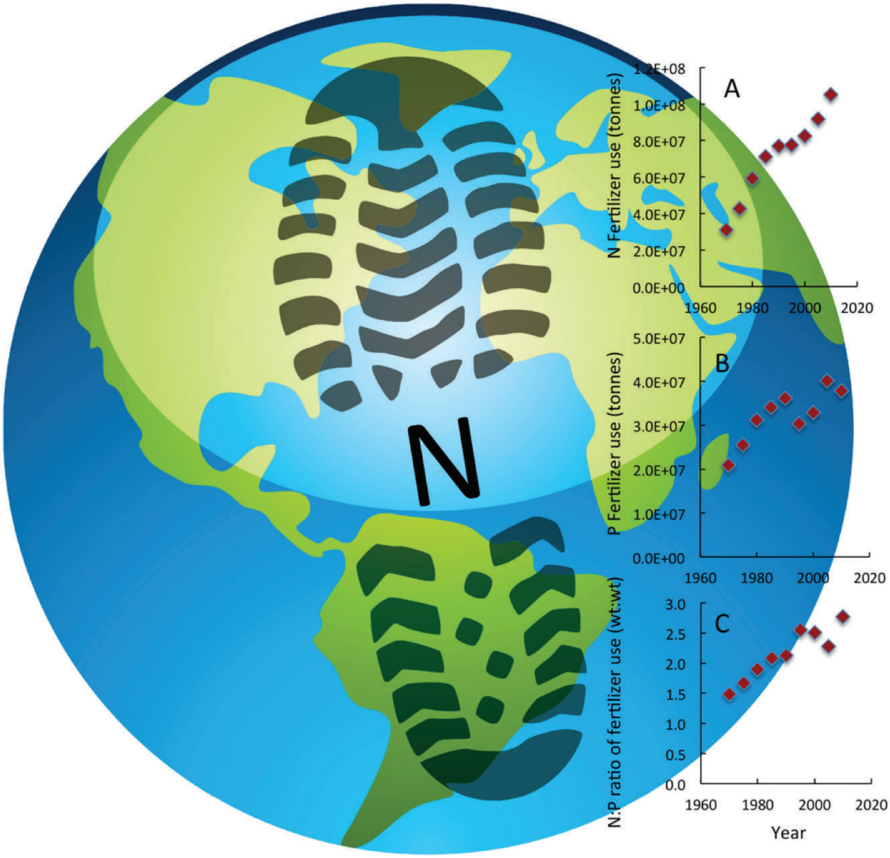


3 DIFFERENT MAPS OF HABS

Global distribution of HABs that cause some of the common HAB-associated syndones (see Table). Maps reproduced from whoi.edu/redtide.

Although some of the factors contributing to the regional and global expansion of HABs are natural, such as biological species dispersal, many others are considered to be a result of human activities. Increases in nutrient loading, a result of people and agriculture and aquaculture practices as well as global climate change are now well recognized to be important in the global increase in HABs (Glibert et al. 2005, 2018, Heisler et al. 2008, Wells et al. 2015, Glibert 2019). Population growth and increased food production result in major changes to the landscape, in turn increasing sewage discharges and run-off from farmed and populated lands, resulting in eutrophication in both marine and freshwaters.

By far, the greatest change in the past several decades has been the rate and composition of nutrient loading to aquatic systems. The industrial fixation of nitrogen gas (N_2) to ammonia (NH_3), is considered to be one of the most important chemical reactions in the world (e.g., Smil 2001) and "the greatest single experiment in global geo-engineering ever made" (Sutton et al. 2013). This reaction has produced the nitrogen (N) fertilizers that have contributed to the "green revolution" responsible for increased food production that has supported the expansion of human population from about 2 billion in the early 20th century to more than 7 billion people today (Smil 1999, Erisman et al. 2008). This major increase in use of chemical nitrogenous fertilizers began in the 1950s and is projected to continue to escalate in the coming decades (e.g., Smil 2001, Glibert et al. 2006, 2014). From 1960 to 1980, the use of nitrogen-based fertilizers in the US grew at a rate of 400,000 metric tons per year, and even in the past 20 years, there has been increased use of nitrogen fertilizers. Use of phosphorus fertilizers, on the other hand, increased through the 1980s, but usage has been essentially constant since the 1990s. Accordingly, the nitrogen footprint–both in the United States and globally is large. Although these fertilizers enhance the growth of agricultural crops, a sizable percentage of these fertilizers runs off the land to local waters, where they then support the growth of algae.



GLOBAL NITROGEN FOOTPRINT AND GRAPHS
The global nitrogen footprint. Panels on the right show (a) N and (b) P (as P_2O_4) fertilizer use and (c) the change in N:P ratio of fertilizer use by weight for the world.
Figure reproduced from Glibert and Burford (2017).

The development of concentrated (confined) animal feeding operations (CAFOs) is another increasing, major source of nutrient pollution (Mallin et al. 1997, Mallin 2000, Burkholder et al. 2007, United States Environmental Protection Agency 2013). Animal agriculture is expanding to meet the dietary demands of an increasing population, and increasingly animal production is concentrated in large industrial feeding operations which results in dense animal populations per unit landscape area (Burkholder et al. 1997 and references therein). Although accurate estimates are difficult due to permitting and legal definitions that vary by state, by 2012, the US had more than 1.4 trillion animals in CAFOs, but in the following years, approximately 1 million cattle, half a million dairy cows and more than 10 million hogs and 500 million broilers were added to this inventory (Glibert in review). This compares to a human population in the US of just over 300 million. Yet, for these animal operations, there is no waste treatment – other than holding lagoons where wastes are stored mostly in open-pit lagoons and then spread on adjacent lands. The high concentration of wastes per unit area, in comparison to traditional animal production practices, commonly causes contamination of adjacent waters with nutrients and associated pollutants such as suspended solids and pathogenic microorganisms (Burkholder et al. 2007). To understand the scale of this nutrient source, as an example, in the Cape Fear River basin of North Carolina, it is estimated that there are 5 million hogs, 16 million turkeys, and 300 million chickens produced annually, yielding 82,700 metric tons of nitrogen and 26,000 metric tons of phosphorous in animal waste (Mallin et al. 2015, and references therein). The estimated "manure footprint" for the United States is about 150 million metric tons (Rumpler 2016). In China, tens of thousands of CAFOs are estimated to produce more than 40 times as much N pollution as from other types of industries (Ellis 2008). For some parts of the United States, animal waste N and P exceeds that of people by similar factors (Glibert in review). Industrial farming cannot maintain the traditional balance between waste generation of animals and that used to fertilize crops; now, farms import fertilizer and feed and the waste produced far outpaces that which can be safely recycled back on the land. Many of the animals are exported – either out of state or out of country, but their waste is not, and it seeps into local waters and volatilizes to the atmosphere where it can contribute to ammonia deposition and greenhouse gas pollution.

WASTE HOG LAGOON

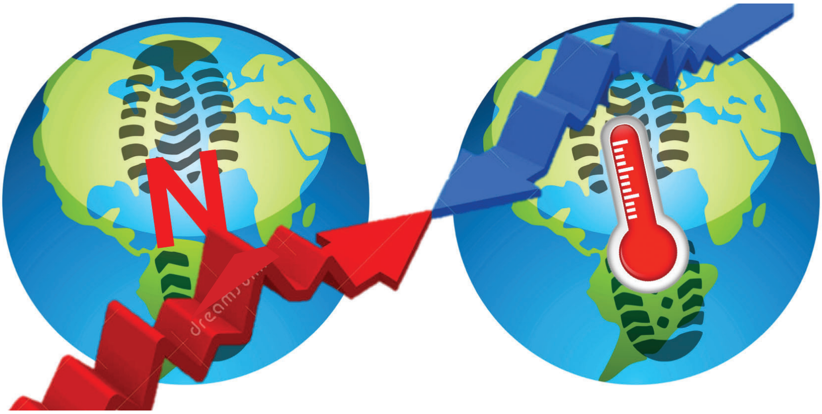
Hog production facility in North Carolina.
Photo reproduced from https://civileats.com/2018/06/26/in-north-carolina-new-pollution-allegations-add-to-residents-woes-over-factory-farms/.

While nutrient pollution is the primary driver of eutrophication, we now recognize that the relationship between nutrient pollution and HABs is more complex than previously thought (Glibert et al. 2005, Heisler et al. 2008): not all nutrient loads result in HABs, and not all nutrient effects that result in HABs cause other eutrophication impacts (i.e., visible scums, hypoxia). Nutrient inputs yield changes in HAB biomass, but the how and why of changes in biodiversity are far more complicated. It takes the right nutrients at the right time relative to the needs of the individual species for specific HABs to form. It also takes the right combination of light, temperature and other physical conditions – all factors that select for individual species.

PUZZLE

Many environmental factors must come together at the right place and the right time for specific species to proliferate.

In addition to nutrient loads, climate is also changing. Changes in temperature certainly affect the habitat for HABs. Increasing temperatures should positively affect those species that prefer warm temperatures for growth, while conversely negatively influencing those species that prefer cooler environments. Climate changes may further influence harmful algal species expansions due to altered precipitation patterns, including increases in droughts in some regions, and/or increased frequency or intensity of storm events in other regions (e.g., Heisler et al. 2008, O'Neil et al. 2012, Glibert 2019a). Episodic storm events and climate variability affect the timing of freshwater flow, water residence times, the magnitude and timing of nutrient pulses, and resulting biotic responses (e.g., Heisler et al. 2008). Undoubtedly, these extreme precipitation and flooding events alter freshwater or coastal habitats and may create conditions more conducive to HABs through the massive associated quantities of runoff, as nutrient supply is tightly coupled with freshwater input. The combination of more freshwater input and warmer temperatures has been found to enhance the probability of, and habitat for, at least some types of HABs (e.g., Paerl and Huisman 2008, O'Neil et al. 2012, Wells et al. 2015).



COLLISION OF NUTRIENT AND CLIMATE FOOTPRINTS

Nutrient pollution and climate change may synergistically interact in promoting HABs.

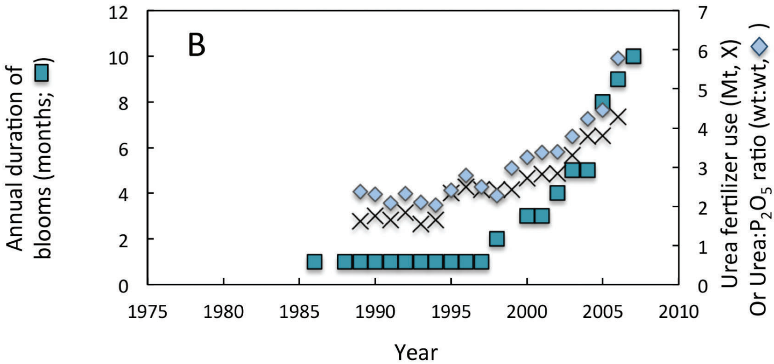
Several examples from different parts of the world and different parts of the US are given to highlight the complexity of the HAB phenomenon and the widely varying impacts of different types of HABs.

Freshwater Blooms

Freshwater HABs are among those expanding rapidly. An extreme example of freshwater bloom expansion is that of Lake Tai (or Taihu), China, where blooms of the toxigenic cyanobacterium (CyanoHAB) *Microcystis* have increased in duration from about one month per year to nearly 10 months per year over the past 15 years (Duan et al. 2009), concomitant with increasing fertilizer use in the watershed and other nutrient sources (Glibert et al. 2014).

PHOTO AND GRAPH OF LAKE TAIHU

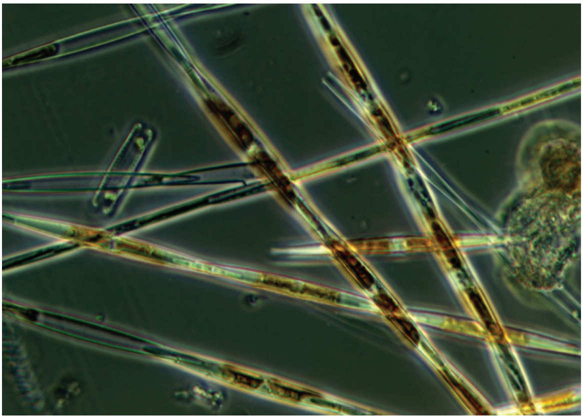
Panel A- photo of *Microcystis* blooms in Lake Taihu, China (photo by P. Glibert); Panel B- Change in annual duration of *Microcystis* blooms in Taihu in months, urea fertilizer use scaled to that in the Changjiang watershed and the ratio of use of urea: phosphorus fertilizer. Data sources and figure are from Glibert et al. (2014)



Similar blooms are now regularly seen in the US. Over roughly the past decade, toxic *Microcystis* blooms, easily visible from satellite imagery, have expanded to cover the entirety of Lake St. Clair (Michigan and Ontario, Canada) and much of Lake Erie (Michalak et al. 2013, NOAA 2015, ESA 2016). In August 2014, the city of Toledo, Ohio, issued a "Do not drink or boil" advisory to about 500,000 people after microcystins in the city's finished drinking water were measured at up to 2.5 µg L^{-1} (Fitzsimmons 2014). *Microcystis* blooms have become common features in Florida's major river systems, the St. Johns and Caloosahatchee; in Lake Okeechobee (the tenth largest lake in the United States); and in the freshwater tidal St. Lucie Estuary, where huge outbreaks have been sustained seasonally every year over the past decade (Neuhaus 2016). Blooms in coastal lagoons of Florida in recent years have been described as "guacamole thick."

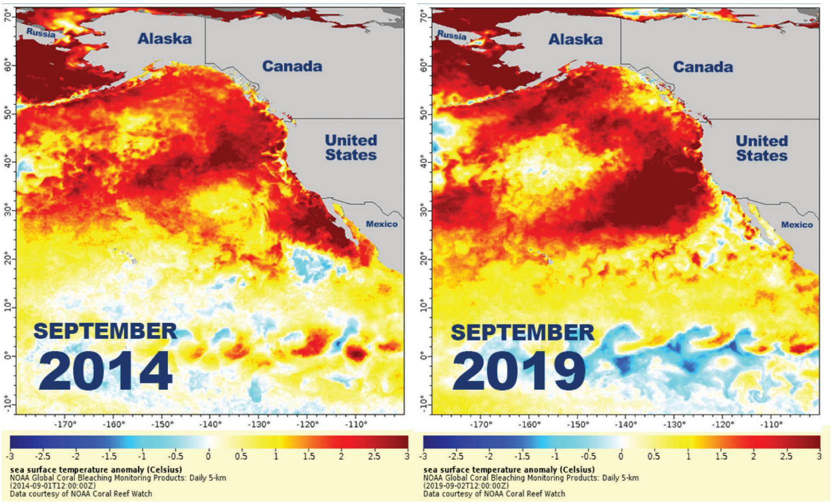
The West Coast bloom of 2015-16

A very different HAB species, the diatom *Pseudo-nitzschia,* began to bloom along the United States West Coast in late 2013, when anomalously warm water developed in the northeastern Pacific Ocean, a feature that persisted through much of 2016 (e.g., Bond et al. 2015, Freeland and Whitney 2015). Affectionately known as "the blob," this warm water moved over the continental margin, eventually extending from southern California to Alaska by spring 2015. Coupled with seasonal upwelling, the conditions were ideal for *Pseudo-nitzschia* to proliferate: it had sufficient nutrients, and the right nutrients, and suitable temperatures for rapid growth. This species produces domoic acid, the toxin that results in Amnesic Shellfish Poisoning, the syndrone that is associated with short-term memory loss and even death if exposure if high enough. Regulatory limits of domoic acid were exceeded along the entire coast for months, and toxin impacts were felt at many levels of the food chain, from razor clams and Dungeness crabs to sea lions, whales and porpoises (McCabe et al. 2016). This was the largest toxic *Pseudo-nitzschia* bloom on the West Coast thus far, and portends of future outbreaks with conditions of increasing temperature and nutrient supply (Smith et al. 2018). It is worth noting that a new "blob" has been observed very recently.



THE DIATOM PSEUDO-NITZSCHIA

The HAB diatom *Pseudo-nitzschia*

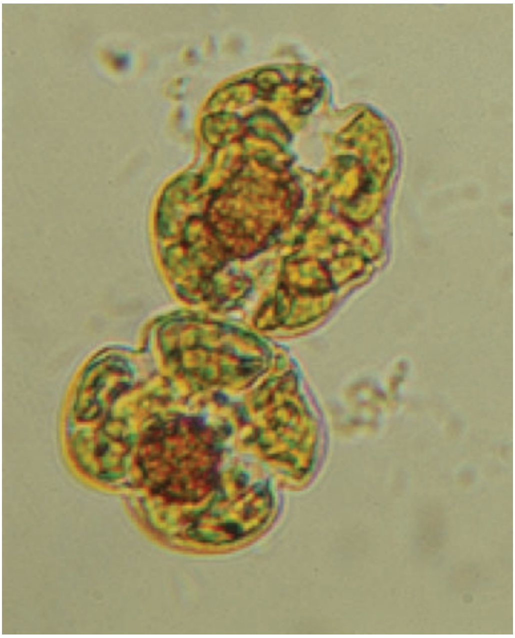


TEMPERATURE ANOMALIES

Temperature anomalies in 2014 and 2019. This unusually warm water has been termed "the blob".

The Florida Bloom of 2018-19

Yet a different relationship with changing climate and nutrient effects was seen in the massive HAB event that occurred along the Florida coast in 2018-19. In this case, a bloom of *Karenia brevis*, a dinoflagellate, expanded to a degree not seen in a decade. This organism has been recognized to bloom in Gulf of Mexico waters since at least the Spanish explorers noticed the red water phenomonen (Steidinger 2009), not unlike the phenomena encountered by the West Coast explorers. These tiny cells normally grow when waters warm in late summer, but often stay offshore in the deeper Gulf of Mexico waters. When transported to nearshore waters, these cells can encounter sources of nutrient from land-based pollution. This bloom appears to have intensified greatly in September 2017, after Hurricane Irma hit Florida. This was a powerful storm, with drenching rains and winds high enough to knock over trees and cause power outages. With all this water washing nutrients from the land, the algae had plenty of nutrients and they started to grow all during the fall of 2017 and into the winter. With the warm temperatures of the summer, the bloom grew even larger; there is even some evidence that multiple blooms of this species developed in slightly different locations and ultimately merged forming a mega-bloom. More rains came, as the summer of 2018 was very wet, so the nutrients kept coming too. This HAB species produces brevetoxin which is responsible for Neurotoxic Shellfish Poisoning and which can be deadly for fish and other marine organisms. Brevetoxin also causes digestive stress in people when contaminated shellfish are consumed, but more importantly it causes respiratory distress in those exposed to the aerosolized toxins, primarily the beach-goers. In 2018, the deadly result due to this bloom included over 100 tons of fish that washed up on beaches, as well as more than 100 manatees and 300 sea turtles. Many people sought treatment in emergency rooms due to respiratory distress. Moreover, more than 300 jobs and millions of dollars were lost as the tourist season suffered when beaches and other water-related activities, including sea-side dining and sport fishing, were closed.



KARENIA BREVIS

The HAB dinoflagellate *Karenia brevis*

Actions: What's next

In all, the problem of harmful algal blooms is increasing. Our anthropogenoic footprint is large – from expanding human populations and coastal development, to our desire for more meat and eggs in our diet, and our reliance on agricultural products that consume huge quantities of added fertilizers. We enrich our waters with the perfect recipe for HABs each time we add fertilizer to our lawns or when we fail to insist on policies that would reduce waste from CAFOs, or when we allow governments to relax regulations that protect the environment from nutrient pollution.

Many managers have traditionally focused on phosphorus pollution as the means to control blooms. This stems from one of the most central tenets of aquatic science – that algal biomass and production in lakes and other freshwaters is limited by the availability of phosphorus, while that in marine waters is more often limited by the availability of nitrogen (e.g., Ryther and Dunstan 1971, Schindler 1977). However, not only is phosphorus limitation in lakes not universal (Lewis and Wurtsbaugh 2008) but runoff and other land-based nutrient pollution, particularly nitrogen pollution, is changing the composition of nutrients from fresh to marine waters. In enriched systems, both fresh and marine, some HABs are more common under conditions of elevated nitrogen relative to phosphorus and of even greater concern, many are more toxic under such conditions (Glibert 2017 and references therein).

Without doubt, phosphorus reductions are important, but as a strategy to reduce blooms, such reductions are insufficient. Control of nitrogen is essential as well. We increase the likelihood of more blooms, more toxins, and more ecosystem impacts and more human health impacts in more places unless we act. Reductions in use of fertilizers and improved management of animal wastes are good places to start. Climate changes make these actions ever more pressing.

References cited

Bond, N.A., M.F. Cronin, H. Freeland, N. Mantua. 2015. Causes and impacts of the 2014 warm anomaly in the NE Pacific. *Geophys. Res. Lett.,* 42:3414-3420, 10.1002/2015GL063306.

Burkholder, J.M., B. Libra, P. Weyer, S. Heathcote, D. Kolpin, P.S. Thorne and M. Wichman. 2007. Impacts of waste from concentrated animal feeding operations on water quality. *Envir. Health Perspect.,* 115: 308-312.

Burkholder, J.M., S.E. Shumway, and P.M. Glibert. 2018. Foodweb and ecosystem impacts of harmful algae. In: S.E. Shumway, J.M. Burkholder and S.L. Morton (eds), *Harmful Algal Blooms: A Compendium Desk Reference.* Wiley-Blackwell, Singapore, pp.243-336.

Diaz, R.J. and R. Rosenberg. 2008. Spreading dead zones and consequences for marine ecosystems. *Science,* 321: 926-929.

Duan, H. R., X. Ma, F. Xu, F. Kong, S. Zhang, W. Kong, J. Hao and L. Shang. 2009. Two decade reconstruction of algal blooms in China's Lake Taihu. *Envir. Sci. Techn.,* 43: 3524- 3528.

Ellis, L. 2008. A China environmental health project research brief: Environmental health and China's concentrated animal feeding operations (CAFOs). Available at: https://www.wilsoncenter.org/sites/default/files/factory_farms_feb28.pdf.

Erisman, J.W. M.S. Sutton, J.N. Galloway, Z.Klimont, W. Winiwater. 2008. How a century of ammonia synthesis changed the world. *Nature Geosci.,* 1: 636-639

European Space Agency (ESA) 2016. Earth watching. Available at: https://earth.esa.int/web/earth-watching/change-detection/content/-/article/algal-blooms-in-lake-erie-north-america.

Feder, B.1975. When the red tide strikes. New York Times, August 24, 1975. Available at: https://www.nytimes.com/1975/08/24/archives/when-the-red-tide-strikes-when-the-red-tide-strikes.html.

Fitzsimmons, E.G. 2014. Tap water ban for Toledo residents. The New York Times (August 3, 2014). Available at: https://www.nytimes.com/2014/08/04/us/toledo-faces-second-day-of-water-ban.html

Freeland, H., Whitney, F. 2014. Unusual warming in the Gulf of Alaska. *North Pacific Marine Organisation (PICES) Press*, 22: 51-52.

Glibert, P.M. 2017. Eutrophication, harmful algae and biodiversity-challenging paradigms in a world of complex nutrient changes. *Mar. Poll. Bull.,* 124: 591-606. doi.org/10.1016/j.marpolbul.2017.04.027.

Glibert, P.M. 2019a. Harmful algae at the complex nexus of eutrophication and climate change**.** *Harmful Algae*, 10.1016/j.hal..2019.03.001.

Glibert, P.M. 2019b. Why were the water and beaches of Florida so gross in summer 2018? Red tides! *Frontiers for Young Minds.*, 7:10. doi: 10.3389/frym.2019.00010.

Glibert, P.M. From hogs to HABs. Manuscript in review.

Glibert, P.M., E. Berdalet, M. Burford, G. Pitcher and M. Zhou. 2018. Harmful algal blooms and the importance of understanding their ecology and oceanography. In: Glibert, P.M., E. Berdalet, M. Burford, G. Pitcher and M. Zhou (Eds.), *Global Ecology and Oceanography of Harmful Algal Blooms (GEOHAB).* Springer, Cham, Switzerland, pp. 9-25.

Glibert, P.M., A.H.W. Beusen, J.A. Harrison, H.H. Dürr, A. Bouwman, and G.Laruelle 2018b. Changing land, sea- and airscapes: Sources of nutrient pollution affecting habitat suitability for harmful algae. In: Glibert, P.M., E. Berdalet, M. Burford, G. Pitcher and M. Zhou (Eds.), *Global Ecology and Oceanography of Harmful Algal Blooms (GEOHAB).* Springer, Cham, Switzerland, pp. 53-76.

Glibert, P.M. and M.A. Burford. 2017. Globally changing nutrient loads and harmful algal blooms: recent advances, new paradigms, and continuing challenges. *Oceanography,* 30 (1): 58-69,

Glibert, P.M.and J.M. Burkholder. 2018. Causes of harmful algal blooms. In: S. Shumway, J.M. Burkholder, S.L. Morton (Eds.), *Harmful Algal Blooms: A Compendium Desk Reference.* Wiley Blackwell, Singapore, pp. 1-38.

Glibert, P.M., J. A. Harrison, C.A. Heil, and S. Seitzinger. 2006. Escalating worldwide use of urea—A global change contributing to coastal eutrophication. *Biogeochem.,* 77: 441-463.

Glibert, P.M., R. Manager, D.J. Sobota, and L. Bouwman. 2014a.The Haber-Bosch-Harmful algal bloom (HB-HAB) link. *Envir. Res. Lett.,* 9: 105001(13 pp). doi: 10.1088/1748-9326/9/10/105001.

Glibert, P.M., S. Seitzinger, C.A. Heil, J.M. Burkholder, M.W. Parrow, L.A. Codispoti, and V. Kelly. 2005. The role of eutrophication in the global proliferation of harmful algal blooms: new perspectives and new approaches. *Oceanography,* 18:198-209.

Heisler, J., P.M. Glibert, J.M. Burkholder, D.M. Anderson, W. Cochlan, W.C. Dennison, Q. Dortch, C.J. Gobler, C.A. Heil, E. Humphries, A. Lewitus, R. Magnien, H.G. Marshall, K. Sellner, D.A. Stockwell, D.K. Stoecker, and M. Suddleson. 2008. Eutrophication and harmful algal blooms: A scientific consensus. *Harmful Algae,* 8: 3-13.

Howarth, R.W., A. Sharpley and D. Walker. 2002. Sources of nutrient pollution to coastal waters in the United States: Implications for achieving coastal water quality goals. *Estuaries,* 25: 656-676.

Landsberg, J.H. 2002. The effects of harmful algal blooms on aquatic organisms. *Rev. Fish. Sci.,* 10: 113-390.

Lewis, W. M., Jr. and W.A. Wurtsbaugh. 2008. Control of lacustrine phytoplankton by nutrients: Erosion of the phosphorus paradigm. *Internat. Rev. Hydrobiol.,* 93: 446-465.

Mallin, M.A., M.R. McIvor, A. Robuck and A.K. Dickens. 2015.Industrial swine and poultry production causes chronic nutrient and fecal microabil stream pollution. *Water, Air, Soil Poll.* 226: 10.1007/s11270-015-2669-y.

Mallin, M.A. 2000. Impacts of industrial-scale swine and poultry production on rivers and estuaries. *Amer. Sci.,* 88:26–37.

Mallin, M.A., J.M. Burkholder, G.C. Shank, M.R. McIver, H.B. Glasgow, J. Springeret al. Comparative impacts of effluent from poultry and swine waste holding lagoon spills on receiving rivers and tidal creeks. *J Environ Qual.,* 1997;26:1622–1631

McCabe, R.M.,B.M. Hickey, R.M. Kudela, K.A. Lefebve, N.G.Adams, B.D. Bill, F.M.D. Gulland, R.E. Tomson, W.P. Cochlan, V.L. Trainer. 2016. An unprecedented coastwide toxic algal bloom linked to anomalous ocean conditions. *Geophys. Res. Lett.,* 10.1002/2016GL070023.

Michalak, A.M., E.J. Anderson, D. Beletsky, S. Boland, N.S. Bosch, T.B. Bridgeman, J.D. Chaffin, K. Cho, R. Confesor, I. Daloğlu, J.V. DePinto, M.A. Evans, G.L. Fahnenstiel, L. He, J.C. Ho, L. Jenkins, T.H. Johengen, K.C. Kuo, E. LaPorte, X. Liu, M.R. McWilliams, M.R. Moore, D.J. Posselt, R.P. Richards, D. Scavia, A.L. Steiner, E. Verhamme, D.M. Wright, and M.A. Zagorski. 2013. Record-setting algal bloom in Lake Erie caused by agricultural and meteorological trends consistent with expected future conditions. *Proc. Nat. Acad. Sci. (USA),* 110: 6448-6452.

National Oceanic and Atmospheric Administration (NOAA). 2015. Harmful algal blooms in the Great Lakes. Available at: https://www.glerl.noaa.gov/pubs/brochures/bluegreenalgae_factsheet.pdf.

Neuhaus, L. 2016. Miles of algae and a multitude of hazards. *New York Times* (July 18, 2016).

O'Neil, J.M., T.W. Davis, M.A. Burford, C.J. Gobler. 2012. The rise of harmful cyanobacteria blooms: the potential roles of eutrophication and climate change. *Harmful Algae,* 14: 313-334

Paerl, H.W. J. Huisman. 2008. Blooms like it hot. *Science,* 320: 57-58

Rumpler, J. 2016. Corporate agribusiness and the fouling of America's waterways. Environmental Virginia Research and Policy Center. 46 pp.

Ryther, J. H. and W.M. Dunstan. 1971. Nitrogen, phosphorus and eutrophication in the marine environment. *Science,* 171: 1008-1013.

Schindler, D. W. 1977. Evolution of phosphorus limitation in lakes. *Science,* 195: 260-262.

Smil, V. 2001. *Enriching the Earth: Fritz Haber, Carl Bosch, and the Transformation of World Food.* The MIT Press, Cambridge, United Kingdom, 338 pp.

Smith, J., A.G. Gellene, K.A. Hubbard, H.A. Bowers, R.M. Kudela, K. Hayashi, and D.A. Caron. 2018. *Pseudo-nitzschia* species composition varies concurrently with domoic acid concentrations during two different bloom events in the Southern California Bight. *J. Plankt. Res.,* 40: 29–45.

Steidinger, K.A. 2009. Historical perspective on *Karenia brevis* red tide research in the Gulf of Mexico *Harmful Algae,* 8: 549-561.

Sunda, W.G., E. Granéli, and C.J. Gobler. 2006. Positive feedback and the development and persistence of ecosystem disruptive algal blooms. *J. Phycol.,* 42: 963-974.

Sutton, M.A., A. Bleeker, C.M. Howard, M.Bekunda, W. Grizzetti, W. de Vries, H.J.M. vanGrinsven, Y.P.Adhya, G. Billen, E.A. Davidson, A. Datta, R. Diaz, J.W. Erisman, X.J. Liu, O. Oenema, C. Palm, N. Raghuram, S. Reis, R.W. Scholz, T. Sima, H. Westhoek, F.S. Zhang. 2015. *Our Nutrient World: the Challenge to Produce More Food and Energy with Less Pollution. Global Overview of Nutrient Management*. Centre for Ecology and Hydrology, Edinburgh on Behalf of the Global Partnership on Nutrient Management and the International Nitrogen Initiative.

Wells, M.L., V.L. Trainer, T.J. Smayda, B.S. Karlson, C.G. Trick, R.M. Kudela, A. Ishikawa, S. Bernard, A. Wulff, D.M. Anderson, and W.P. Cochlan 2015. Harmful algal blooms and climate change: learning from the past and present to forecast the future. *Harmful Algae,* 49: 68-93.

JEFFERSON
EDUCATIONAL SOCIETY

3207 STATE STREET
ERIE, PENNSYLVANIA 16508-2821