WILEY

Harmful Algae:
A Compendium Desk Reference

Executive Summary

Tessa Getchis
Sandra Shumway

Background and Purpose

Toxic microalgae and their associated blooms are regular and natural phenomena and have been recorded throughout history; yet, major efforts to study their ecology, physiology, toxins, and impacts have only escalated over the past four-five decades as their presence and impacts have expanded globally. Harmful algal blooms (HAB) are caused by a diverse group of microalgal species and they can exert significant negative impacts on human, animal, and environmental health, economies, tourism, aquaculture, and fisheries. The continuing increase in numbers of toxic and harmful algal species worldwide presents a constant threat to these sectors and to the sustainable development of coastal regions.

This Executive Summary provides a summary of the key issues and state of the science with respect to harmful algal blooms as presented in *Harmful Algal Blooms: A Compendium Desk Reference* (Wiley Science Publishers, 2017) to improve management and response.

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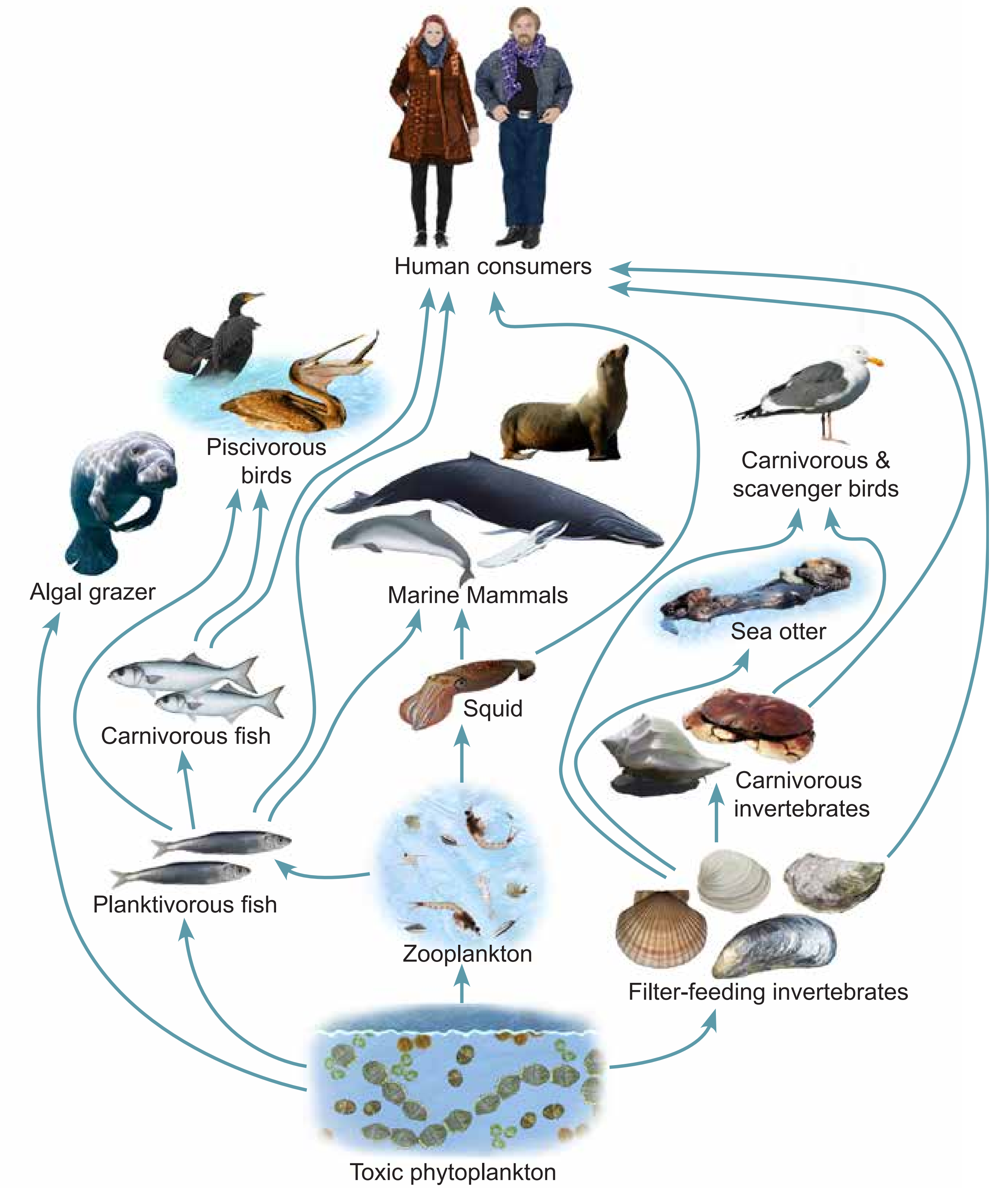
The distribution of algal toxins throughout the food web



Graphic by Eric Heupel

Introduction

Algal blooms can develop in fresh, marine, and brackish water bodies. A bloom occurs when there is a rapid increase in the abundance of phytoplankton, some species of which produce toxins. When phytoplankton are consumed by various organisms, toxins are distributed throughout the food web. These toxins can adversely affect the health of humans, animals, and ecosystems, and have substantial economic consequences.

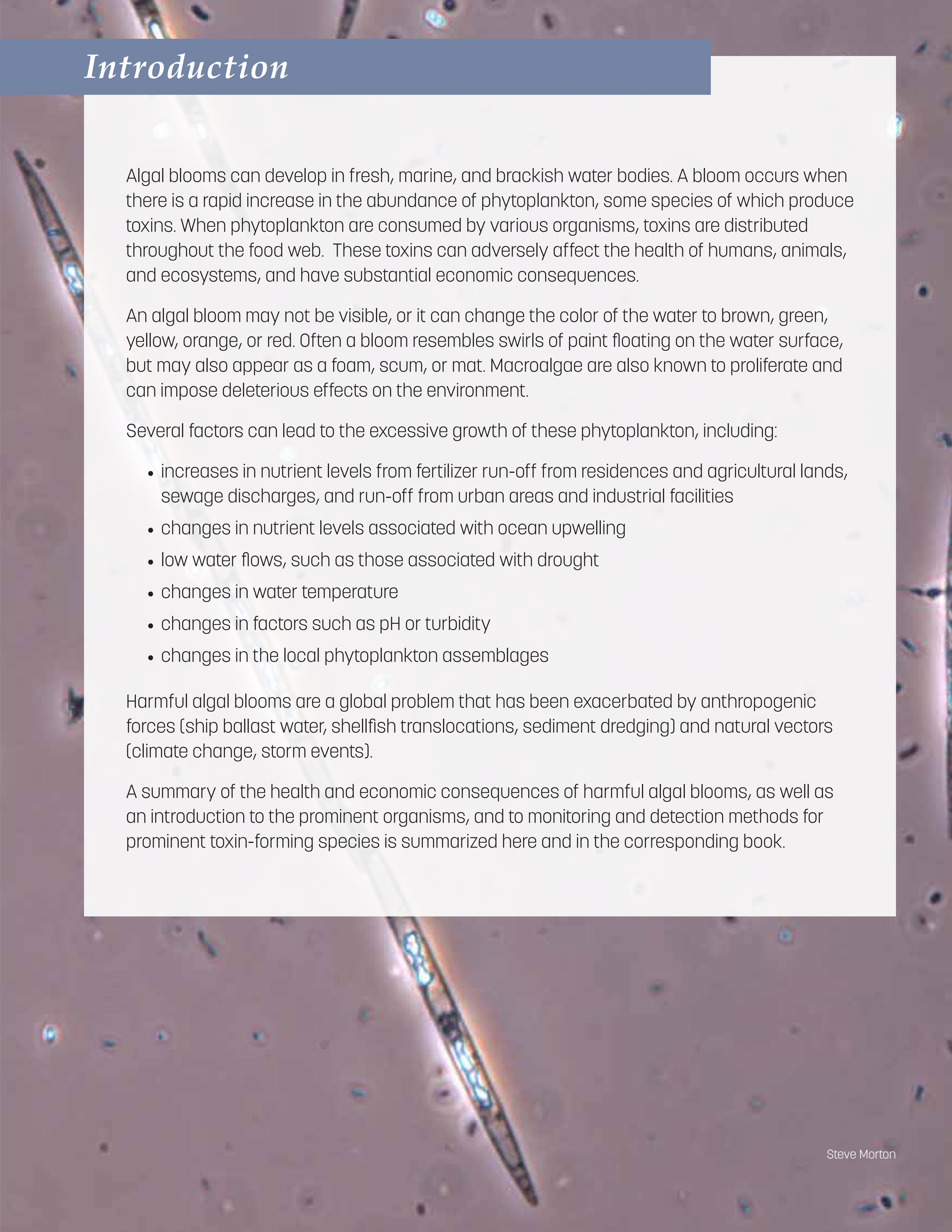
An algal bloom may not be visible, or it can change the color of the water to brown, green, yellow, orange, or red. Often a bloom resembles swirls of paint floating on the water surface, but may also appear as a foam, scum, or mat. Macroalgae are also known to proliferate and can impose deleterious effects on the environment.

Several factors can lead to the excessive growth of these phytoplankton, including:

- increases in nutrient levels from fertilizer run-off from residences and agricultural lands, sewage discharges, and run-off from urban areas and industrial facilities
- changes in nutrient levels associated with ocean upwelling
- low water flows, such as those associated with drought
- changes in water temperature
- changes in factors such as pH or turbidity
- changes in the local phytoplankton assemblages

Harmful algal blooms are a global problem that has been exacerbated by anthropogenic forces (ship ballast water, shellfish translocations, sediment dredging) and natural vectors (climate change, storm events).

A summary of the health and economic consequences of harmful algal blooms, as well as an introduction to the prominent organisms, and to monitoring and detection methods for prominent toxin-forming species is summarized here and in the corresponding book.



Steve Morton

Harmful algal blooms can cause significant human illness. Humans may be sickened by swimming, ingesting toxins by drinking contaminated water, eating contaminated seafood, or by exposure to aerosolized toxins (tiny airborne droplets) produced by algae. While the risk is significant, the annual number of illnesses is very low compared to other foodborne illnesses. This is a result of sophisticated surveillance and proactive public notification protocols in place for responding to bloom events.

The most commonly recognized illnesses include:

Illness	Toxin	Source
Ciguatera Poisoning	ciguatoxin	subtropical and tropical fish
Paralytic Shellfish Poisoning (PSP)	saxitoxins	bivalve and gastropod molluscs, crustaceans, fish
Diarrheic Shellfish Poisoning (DSP)	okadaic acid, dinophysistoxins	molluscan shellfish
Amnesic Shellfish Poisoning (ASP)	domoic acid	molluscan shellfish, crustaceans, fish
Neurotoxic Shellfish Poisoning (NSP)	brevetoxins	bivalve and gastropod molluscs
Azaspiracid poisoning (AZP)	azaspiracids	bivalve molluscs

Exposure to toxins may result in a number of symptoms including:

Gastrointestinal	Neurological	Respiratory	Dermatological
Nausea	Pain	Coughing	Itchy skin
Vomiting	Numbness	Wheezing	Rash
Diarrhea	Tingling	Rhinitis	Hives
Abdominal pain	Confusion		
	Memory loss		

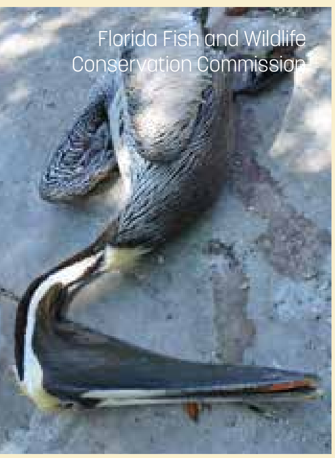
These symptoms are toxin-specific and can vary depending upon how a person was exposed, the duration of the exposure, and the particular HAB toxin involved. The onset of illness may appear within minutes or hours to days for some neurological symptoms. The effects may be acute or chronic, with mild to moderate symptoms, or in the most severe cases, death.

Routine clinical tests are not yet available for the diagnosis of HAB-related illnesses and there are no known antidotes. Algal toxins are not reliably eliminated by heat (e.g. cooking), nor are they rapidly removed, if at all, by depuration of exposed shellfish. Preventing exposure to toxins is critical to minimizing human health risks.

Animal Health


Tom Archer
University of Michigan


Associated Press


Florida Fish and Wildlife Conservation Commission


Washington State Park Service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G. Early

Many animals including birds, marine mammals, fish, and shellfish are susceptible to the toxins produced by harmful algal blooms. Many animals become ill or die when they consume toxin-contaminated fish or invertebrates. Large die-offs of whales, porpoises, manatees, and birds have been documented. Illness and deaths of dogs, cattle, and wildlife exposed to freshwater cyanotoxins have been reported.
Some phytoplankton species are not harmful to humans, but cause injury to fish and invertebrates by damaging or clogging their gills. This is an especially challenging problem for aquaculture operations. Other algal species, while not toxic, can grow uncontrolled reducing the available oxygen and sunlight necessary for plant and animal survival.

Animals can serve as early indicators of algal bloom toxicity. Birds and marine mammals are important sentinel species, and provide early warnings of existing or emerging health hazards in oceanic and coastal environments. Increases in mortality or morbidity of these animals may be a sign that HAB toxins are present. Bottlenose dolphins, California sea lions, cormorants, pelicans, and southern sea otters are examples of sentinel species used to evaluate the presence of algal toxins and other environmental threats in oceans and human health research studies.

Ecosystem Health

In addition to impacts on human and animal health, harmful algal blooms can cause significant ecological disruption including:

- accumulation of toxins in the food web resulting in animal illness or death
- changes in phytoplankton diversity which alter the food web structure
- oxygen depletion (hypoxia, anoxia)
- sunlight deprivation which impacts important habitats such as submerged aquatic vegetation

Photo by T. Joyce

Economics

Harmful algal blooms are a global problem with severe economic consequences for aquaculture, fisheries, and tourism operations, and especially for the coastal communities near impacted waterways. There are market-related losses calculated from changes in prices or quantities of goods or services such as the costs associated with harvest area closure or a shellfish recall following a HAB event. Non-market goods comprise those for which no formal market exists. Non-market losses could relate to the adverse effects of HAB on recreational uses of coastal or ocean resources, such as fishing or beach-going, or on passive uses, such as perceptions of well-being associated with healthy ecosystems.

Impacts to the following sectors include:

Aquaculture and Fisheries:

- habitat loss
- harvest area closures for finfish and shellfish
- losses of commercially important finfish and shellfish
- damage to animal gills
- fouling of gear, pumps, filters, and intake pipes

Photos by Tessa Getchis

Tourism:

- beach closures
- decreased recreational uses of beaches and waterways (via rotting biomass, offensive odors, reduced water clarity, fish kills)
- reduced recreational travel
- reduced patronage at seafood restaurants
- reduced waterfront real estate values

Coastal communities:

- reduced confidence in local seafood safety
- costly monitoring and detection programs
- increased fouling of pumps, filters, and intake pipes
- taste and odor problems in drinking water supplies
- increased costs of water treatment
- increased costs of managing aquatic resources
- altered aesthetics that can alter property values or local perceptions of water body health

Toxic and harmful algal blooms can have devastating effects on local economies and managers need to engage with local businesses, aquaculture efforts, and communities in addition to public health officials to minimize and mitigate the impacts.

Marine and Freshwater Species

Bloom-causing organisms can have both toxic and harmful ecological effects. Two types of phytoplankton, diatoms and dinoflagellates, produce harmful toxins in marine waters. Harmful algal blooms have been documented along the coastlines of the Atlantic and Pacific oceans and the Gulf of Mexico. In freshwater, the most common harmful algal bloom is caused by cyanobacteria, otherwise known as blue-green algae. These bacteria, like phytoplankton, are photosynthetic meaning that they use sunlight to create food. Macroalgae can grow rapidly, clogging waterways, preventing sunlight from penetrating the water surface, and reducing the available oxygen. Submerged aquatic plants and animals can suffer mass mortalities.

Type	Where Found
Cyanobacteria (blue-green algae)	Fresh water, occasionally marine
Dinoflagellates	Marine water
Diatoms	Brackish water

Notable bloom-forming organisms include:

Species	Common name	Where Found	Impacts
Alexandrium fundyense	Red tide	marine	causes illnesses in humans and animals; adversely affects many invertebrates
Karenia brevis	Red tide	marine	kills fish
Noctiluca	Red tide	marine	fish kills due to reduced dissolved oxygen; no risk to human health
Cochlodinium polykrikoides	Rust tide	marine	adversely affects growth of shellfish; kills fish; no risk to human health
Aureococcus anophagefferens	Brown tide	marine	no risk to human health; reduces growth and can kill shellfish; adversely impacts sea grasses due to reduced light penetration
Pseudo-nitzschia spp.	None	marine	causes illnesses and deaths in humans, marine mammals, and seabirds
Cyanobacteria such as *Microcystis* spp. and others	None	freshwater and marine	causes illness in humans and animals
Macroalgae	None	freshwater and marine	reduces light and oxygen; fish kills due to reduced dissolved oxygen

Prevention, Control, and Mitigation

A suite of prevention, control, and mitigation strategies are available to minimize effects of harmful algal bloom events, but each must be assessed for the geographic area, algal species present, and shellfish or fish produced, harvested, and distributed for human consumption. Modeling can also be a powerful tool to predict the distribution and abundance of toxin-forming algae. Deployment of models in management ranges from short-term forecasting, often driven in part by external data from remote sensors, while other approaches use fully computational simulators in a what-if predictive mode.

Prevention focuses on:

1) assessment of local land uses that may minimize proliferation of algae or cyanobacteria
2) methods to minimize human exposure or treat intoxicated individuals

Control methods focus on manipulating environmental conditions in fresh and saline systems to produce sub-optimal habitats or supporting conditions for harmful taxa. Mitigation requires direct intervention in local waters to reduce biomass of harmful algae or cyanobacteria and their associated toxins.

There is a spectrum of approaches that can be used to minimize bloom impacts, but most are temporary as ultimate control must be through rigorous land management to reduce nutrient loads that promote eutrophication and proliferation of algae and cyanobacteria.

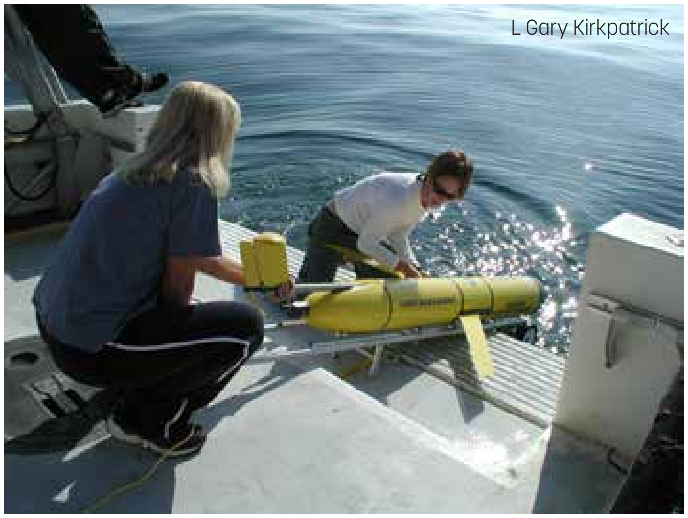
Multi-trophic aquaculture, the farming of filter-feeding shellfish and seaweeds alongside finfish, has been proposed as one way to help alleviate excess nutrients; however, the scale of nutrient loading in most coastal water bodies is far beyond the capacity for aquaculture systems alone to contribute in any significant way. With few exceptions, basin-wide alteration of major land uses has not been readily adopted due to minimal political will and inadequate funding.

Rick Dove, Dove Imaging, www.doveimaging.com

Monitoring and Detection

The ongoing collection, analysis, and interpretation of data are essential to help better understand risk factors and prevent exposure. This includes continuous monitoring to collect real-time environmental data and the use of sophisticated tools for detection of harmful algal species and toxins.

Harmful algal blooms are monitored by state agencies and the National Centers for Coastal Ocean Science. According to the Centers for Disease Control (CDC), in the past several years, HAB have been observed with increasing frequency and in more locations in the United States.


L Gary Kirkpatrick

Detection methods have become increasingly more sophisticated and reliable over the past several decades, and include tools to measure both bloom-forming organisms and the toxins they produce. These tools include those suitable for in-situ deployment or field-portable application, as well as more conventional and sophisticated laboratory use. Some are available commercially as kits and provide users with the ability to respond rapidly to HAB events. Some field tests are currently approved by the U.S. National Shellfish Sanitation Program for preliminary field screening which saves time and money in the monitoring process.

It is important to stress that the toxicity of HAB species can be highly variable such that toxicity can become uncoupled from organism presence depending upon environmental factors and resulting physiological status of the algae. This can lead to situations where cells of a given HAB species may be present or even abundant yet little or possibly no toxicity is associated with these cells. Monitoring programs frequently rely upon sampling of filter-feeding shellfish and testing for the presence of algal toxins. When phytoplankton and/or toxins exceed safe levels, public health warnings are issued and shellfish beds are closed.

The toxicity of HAB organisms can vary markedly, reflecting differences in their genetic make-up combined with the effects of multiple environmental factors. This diverse chemical structure of algal toxins requires the use of targeted detection methods. These range from animal bioassays to complex functional and structural assays and chemical analytical methodologies.

Phytoplankton monitoring involves sampling the algae by hauling a fine mesh net (mesh of 10 µm or 20 µm) through the water column or obtaining a water sample in a bottle from the surface or from a predetermined depth. Once a sample has been obtained, the species can be identified and enumerated through a number of methods including light microscopy, flow cytometry, fluorometry, spectrometry, or more rapid (and often more accurate) molecular methods.

Steve Morton

Protecting Human Health

Preventing exposure to toxic and harmful algae is key to avoiding illness. Consumers should heed advisories related to consuming contaminated fish and shellfish, always avoid consuming seafood from closed harvest areas, and only purchase seafood from certified dealers and restaurants. Further, individuals should avoid entering water that has a foul odor, appears discolored, has surface foam, scum, or algal mats, or contains dead fish or animals.

Treatment

If exposure occurs or illness is suspected:

1) Seek professional medical attention
2) Report the event to the local or state health department

Tracking Illness

The National Outbreak Reporting System is a reporting system used for foodborne and waterborne disease outbreaks. When an outbreak (2 or more illnesses) occurs, public health officials enter patient information that is subsequently reviewed and recorded by the U.S. Center for Disease Control. The One Health Harmful Algal Bloom System is a web-based tool for reporting individual human and animal cases of exposure to HAB-associated exposures. The system also collects environmental data about HAB.

Steps health officials take when an individual has been exposed to a HAB toxin:

Exposure → **Illness** → **Local Health Department Notified of Possible Outbreak**

→ **Local Health Department Conducts Outbreak Investigation** → **Local Health Department Enters Outbreak Data into NORS**

→ **CDC Checks and Analyzes Data** → **Data Summarized and Published**

Print Resources

Anderson, C., S.K. Moore, M.C. Tomlinson, J. Silke, and C.K. Cusack. 2015. Living with harmful algal blooms in a changing world: strategies for modeling and mitigating their effects in coastal marine ecosystems. Chapter 7 in: *Coastal and Marine Hazards, Risks, and Disasters*. J.F. Shroder, J.T. Ellis and D. J. Sherman (Eds.) Elsevier Science Publishers, Amsterdam. 592 p.

Burkholder, J.M. 1998. Implications of harmful microalgae and heterotrophic dinoflagellates in management of sustainable fisheries. *Ecol. Appl.* 8: S37-S62.

Landsberg, J.H., K.A. Lefebvre, and L.J. Flewelling. 2014. Effects of toxic microalgae on marine organisms. In: Rossini, G.P. (Ed.), *Toxins and Biologically Active Compounds from Microalgae*, Volume 2. CRC Press, Boca Raton, Florida: pp. 379-449.

Shumway, S.E. 1990. A review of the effects of algal blooms on shellfish and aquaculture. *J. World Aquaculture Society*. 21: 65-104.

Smayda, T.J. 1991. Global epidemic of noxious phytoplankton blooms and food chain consequences in large ecosystems food chain consequences in large ecosystems. Ch. 13. In K. Sherman, L.M. Alexander, and B.D. Gold (Eds.), *Food chains, yields, models and management of large marine ecosystems*. Westview Press. Boulder, 320 p.

Tomas, C. (Ed.) 1996. *Identifying Marine Phytoplankton*. Academic Press, Inc. 858 p.

Web Resources

Center for Disease Control Harmful Algal Bloom Associated Illness
https://www.cdc.gov/habs/index.html

Environmental Protection Agency's Advisory for Safe Seafood Consumption
https://www.epa.gov/choose-fish-and-shellfish-wisely

Fish and Wildlife Research Institute Red Tide Research
http://myfwc.com/research/redtide/

NOAA Harmful Algal BloomS Observing System
https://service.ncddc.noaa.gov/website/AGSViewers/HABSOS/maps.htm

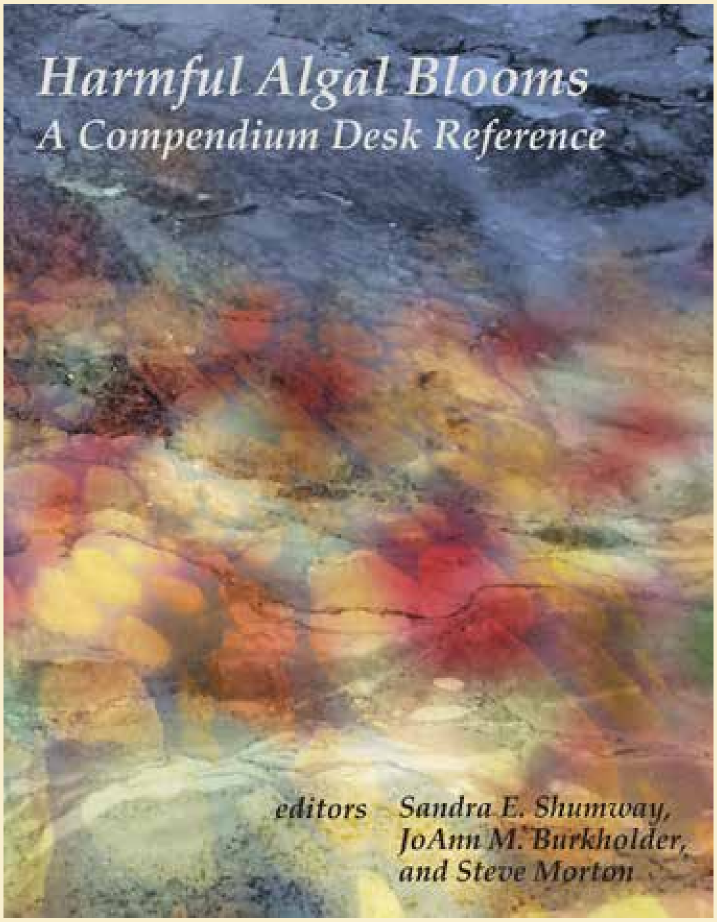
NOAA National Centers for Coastal Ocean Science Harmful Algal Blooms
https://coastalscience.noaa.gov/research/habs/

NOAA Great Lakes Environmental Research Laboratory – Great Lakes HABs and Hypoxia
https://www.glerl.noaa.gov/res/HABs_and_Hypoxia/

Woods Hole Oceanographic Institution National Algal Bloom Website
http://www.whoi.edu/redtide/home

List of U.S. State Health Departments
https://www.cdc.gov/mmwr/international/relres.html

Featured Publication



Harmful Algal Blooms: A Compendium Desk Reference provides basic information on harmful algal blooms (HAB) and references for individuals in need of technical information when faced with unexpected or unknown harmful algal events. Chapters in this volume will provide readers with information on causes of HAB, successful management and monitoring programs, control, prevention, and mitigation strategies, economic consequences of HAB, associated risks to human health, impacts of HAB on food webs and ecosystems, and detailed information on the most common HAB species.

Harmful Algal Blooms: A Compendium Desk Reference will be an invaluable resource to managers, newcomers to the field, those who do not have easy or affordable access to scientific literature, and individuals who simply do not know where to begin searching for the information needed, especially when faced with novel and unexpected HAB events.

Edited by three of the world's leading harmful algal bloom researchers and with contributions from leading experts, *Harmful Algal Blooms: A Compendium Desk Reference* will be a key source of information for this increasingly important topic.

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