The "H," "A," and "B" of a HAB: A Definitional Framework

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Introduction

The use of the phrase "harmful algal bloom" and the acronym "HAB" originated in the marine science world, and referred to blooms also known as red tides, which can kill fish and sea life. The organisms that make up marine HABs generally do not thrive in lakes. In freshwater, HABs are most often associated with blooms of toxin-producing cyanobacteria. The term HAB started to be used broadly in the early 2000s to encompass both marine and freshwater phenomena. Beyond just lakes, cyanobacterial blooms occur in reservoirs, impoundments, streams, rivers, estuaries, or brackish water all over the world (Meriluoto 2017). In addition to cyanobacteria, other freshwater algal groups can accumulate and lead to detrimental impacts on humans, animals, the environment, and the economy.

Usage of HAB has become embedded in the lexicon of many people in the water resource and public health communities. Despite widespread use, an unambiguous definition of the phrase remains elusive, in part because of the inability to define the individual terms scientifically, or even informally. Each user, researcher, or manager of a waterbody will have different concerns. Therefore, they will have different perceptions and definitions of what is harmful and what should be called a bloom. Given this broad use, a simultaneously universal and specific definition of HAB is not feasible.

Here, we seek to break down each term and suggest ways to rebuild with all three elements to foster a shared sense of meaning among individual contexts. When these words are used inconsistently or vaguely, everyone is at risk of miscommunication, and it impedes progress on development of solutions. Lack of understanding can create false expectations, lead to missed opportunities, poorly designed studies, or inefficient use of scarce funding resources. First, we cover the adjectives (algal and harmful) before tackling the noun (bloom). Since a clear, universal, and specific definition is lacking, in this article we aim to build a framework for how to improve the contextual definition and use of HAB moving forward.

Algal/Algae

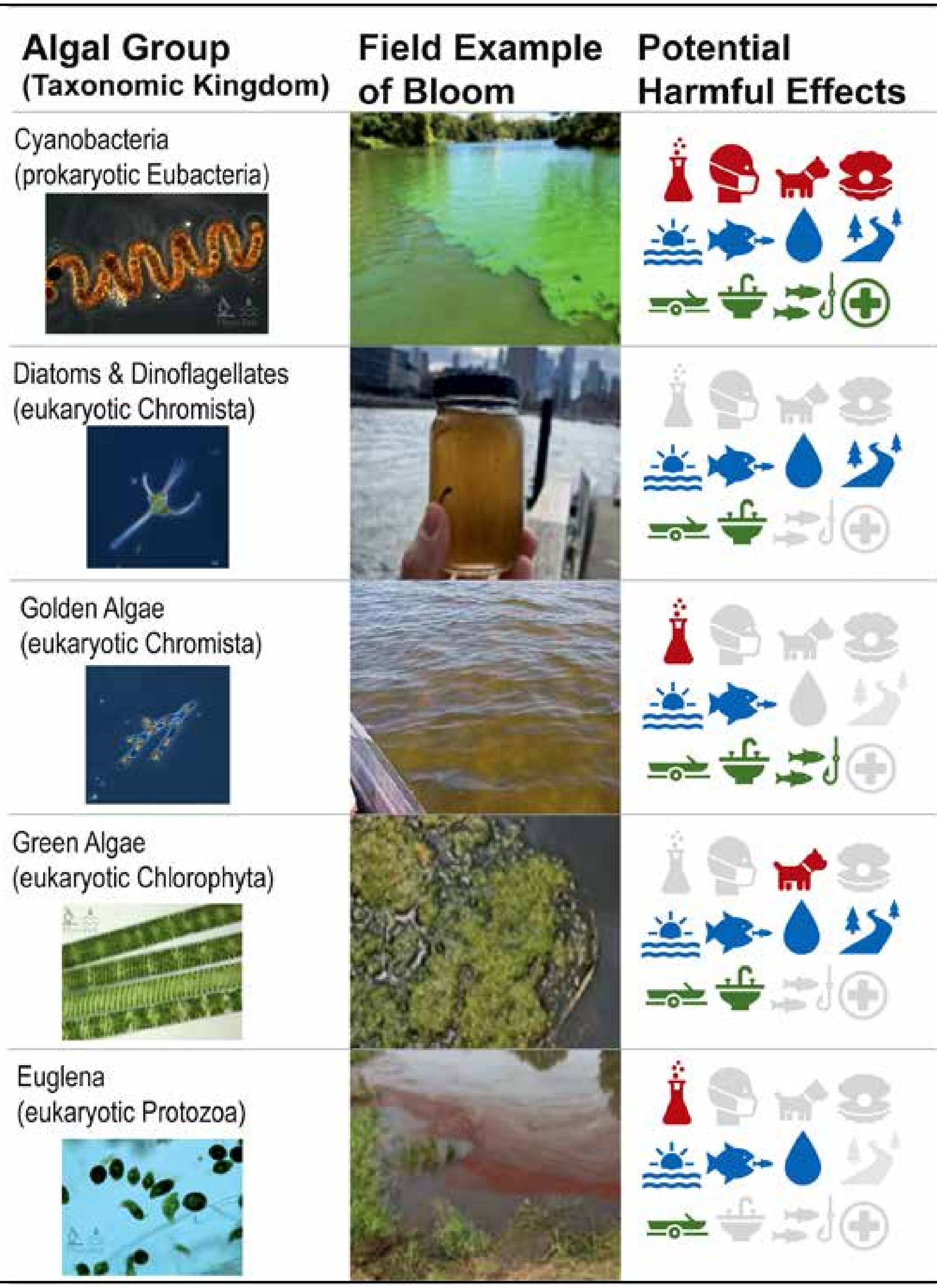
In this context, "algal" is used as an adjective to indicate that the bloom in question is made up of algae rather than flowers or your favorite fried onion dish. The term "algae" includes a diverse group of organisms with only distant genetic connections, across many taxonomic kingdoms (Figure 1). What they all have in common are a preference for living in water, a relatively simple structure (single-celled or colonies of cells) with no vascular system (unlike aquatic plants such as duckweed or pond weeds), and the ability to conduct photosynthesis using chlorophyll-*a*.

Before the advancement of modern-day genetics and microscopy, nearly all green things that grew in lakes were called algae. When it became evident that the group of organisms formerly known as blue-green algae were in fact bacteria, the name was changed to cyanobacteria, though they are still commonly referred to as algae by many people. Nearly all other aquatic algal-type organisms are eukaryotic and have a complex cell structure (cells that have a nucleus and organelles, occur as single or multi-cellular). Cyanobacteria are the only prokaryotic organisms (no nucleus or organelles, always single-celled) that contain chlorophyll-*a* and are capable of photosynthesis. Cyanobacteria have been on the planet for billions of years and evolved well before other algae, zooplankton, fish, or humans. However, the intensity and toxicity of blooms today seem higher than has been measured within the last couple of centuries (Chorus and Welker 2021).

As primary producers, algae serve as the foundation of all aquatic food webs. Algae can be planktonic (live up in the water column), benthic (located at the bottom of a lake or river) or occupy other habitats (such as attached to plants). Algal communities are often mixed assemblages of cyanobacteria, diatoms, green algae, and other algae. However, algal *blooms* are often dominated by one or a few types. The bloom appearance, as well as potential harms will depend on the dominant group (Figure 1). Several terms have already been used to identify cyanobacteria blooms (cHAB, CyanoHAB, or HCB-harmful cyanobacteria bloom), with no consensus appearing to take hold on the best of the bunch. Regardless of the specific acronym or term used, the inclusion of language that clarifies which type of algae is dominant, such as cyanoHAB or green algae bloom, more clearly defines exactly what is being described.

(Potentially) Harmful

When used as an adjective for an algal bloom, "harmful" is subjective, can be confusing, and will depend on the use of a waterbody and the algae present. Thus, the creation of a broad definition of harmful poses a challenge. Harm suggests that damage or injury has already happened, but when we call an algal bloom harmful, often what we really mean is *potentially* harmful. Whether or not a bloom has caused harm can be



LEGEND

Human & Animal	Toxin production
Human & Animal	Human illness via ingestion, skin contact, or inhalation
Human & Animal	Illness and/or mortality of pets, livestock, or wildlife
Human & Animal	Shellfish uptake of toxins
Ecological	Water discoloration/shading
Ecological	Reduced biodiversity; Food web alteration
Ecological	Hypoxia (low or depleted oxygen) may cause fish kills
Ecological	Benthic habitat alteration
Economic	Loss of recreation or tourism revenues; decline in property value
Economic	Increased drinking-water treatment costs; Cleanup costs
Economic	Loss of subsistence fisheries; other fisheries or aquaculture impacts
Economic	Increased medical and veterinary care costs

Figure 1. Potential effects on human and animal, ecological and economic health associated with common freshwater bloom-forming algal groups. Photo credits: Microscopy Photos: (A. St. Amand, PhycoTech); Field Photo Credits: Cyanobacteria (New York State Department of Environmental Conservation), Diatoms (Hudson River Park), Golden (Texas Parks and Wildlife Department), Green (A. St. Amand, PhycoTech), Euglena (B. Rosen, Florida Gulf Coast University).

difficult to determine. Though, to a lake association member, perhaps as soon as a HAB is visible, harm has been done. To a drinking water plant operator, if testing shows finished drinking water meets health standards without added treatment steps, the harm has been minimal. By comparison, if all health standards are met but taste- and odor-causing compounds are causing aesthetic issues, the harm may be substantial. To a dog owner, knowing which type of algae is in bloom and the likelihood that toxins are present will help gauge potential risk to Fido's health and inform the decision whether to let them play in the lake today.

Potential risks to human, animal, ecologic, or economic health (Figure 1) are poorly understood and have not been well quantified, especially in freshwater (Chorus and Welker 2021). Several different types of algae can pose risks, but cyanobacteria blooms are of particular concern in freshwaters due to their potential to produce several types of toxins (Meriluoto 2017) and the wide variety of potential harms they may cause (Figure 1). Algal blooms are often called harmful as a protective measure by public health, resource management, and other decision-makers. This precautionary approach prevents exposure for some but can lead to unnecessary loss of access to drinking water, agricultural water uses, or recreational resources for others. Decisions are sometimes made quickly (for example altering a drinking-water treatment process or issuing a press release) with incomplete information because of a perceived, but poorly understood, health risk that leaves members of the public with more questions than answers.

Care is needed when we talk about harms caused by toxins because only a limited number of algal toxins are routinely measured and our understanding of how toxins affect human, animals, and ecosystems continues to develop. For example, bioaccumulation of algal toxins is an important issue. Shellfish, such as mussels and clams, that live in estuaries where freshwater and saltwater mix can accumulate the toxins in their tissues and may be negatively impacted (Chorus and Welker 2021). While toxins from cyanobacteria have received a lot of attention (and rightfully so), new toxins produced by other algal groups continue to be discovered and studied. Additionally, cyanobacteria blooms can also produce other harmful substances that are non-toxic but can lead to rashes or allergic-type reactions (ITRC 2020). Because our understanding continues to evolve, we do not yet have exposure thresholds for many human or animal health effects related to toxins or other harmful substances produced by algae (Meriluoto 2017).

In addition to humans, our pet dogs, or even livestock, there are potential harms to the entire ecosystem (Figure 1). Some of these potential harms are direct, like excessive algal biomass leading to a reduction in biodiversity or alterations of the food web. Others are indirect, such as oxygen depletion related to biodegradation of algae (Figure 1). Some potential harms are surprising due to a complex chain of effects. For example, *Cladophora* (a genus of green algae) doesn't produce toxins, but when it washes on shore and decomposes, it can act as a home for *Clostridium botulinum*, a bacterium that can lead to botulism outbreaks that kill birds (Chun 2013).

The potential harms to economic health are diverse (Figure 1). There can be loss of revenue for businesses that rely on an access to water, such as marinas. Municipalities may have substantial increases in the cost to treat drinking water for toxins, taste-and-odor causing compounds, and degradation byproducts associated with high amounts of organic carbon. There are also costs that are more difficult to quantify but are certainly detrimental, such as the loss of the use of water for irrigation, or loss of access to subsistence fisheries for Native American communities. When a bloom occurs, end users benefit from as much information as possible.

The combination of the variety of health effects and the scientific unknowns regarding several algal groups warrants the continued use of the word harm in the development of a definition of HAB. Managers might seek to achieve a balance of awareness and alarm among constituents by providing detail on the known impacts of the bloom, and how to reduce harm in the short term. The appropriate outreach will need to be context-dependent such as closing a beach (even on a busy holiday weekend) for swimmers, or in a lake with no swimming, a warning sign at a public boat launch. Many people (including the authors!) tend to use the term HAB and leave it up to the listener or reader to infer the potential harm an algal bloom may impose. Instead of relying on an implicit understanding of the word harm, strive to be explicit about the harms of concern. These potential harms will certainly vary by the waterbody, water user, or scientific study.

Blooms

The word "bloom" has many meanings and is usually associated with a flourishing condition. In the case of algal blooms in aquatic ecosystems, it can imply the potential for negative consequences. Algal blooms can be a completely natural phenomena or can be caused by environmental imbalances related to disturbance, anthropogenic influences, or other factors that promote rapid growth. Because algae are present in most waterbodies, the term "bloom," at the minimum, needs to express an excess in density as compared to background conditions.

Most types of blooms are associated with water discoloration and accumulations of algal material that forms thick scums or mats. Visible indications are, in essence, the simplest way to define a bloom (if you can see it, it's a bloom). But the hue of the water does not necessarily explain the type of algae present, the presence of toxins, or other potential harms. For example, algae, as well as cyanobacteria, may appear green, blue-green, red, brown, or yellow (Figure 1). At times, blooms are present even without the usual visual indicators. This is especially the case for benthic cyanobacteria, which usually don't have the trademark lime green coloration, and deep-water lake blooms that don't float at the surface (ITRC 2022).

Blooms are also notoriously difficult to sample, which makes the documentation of how much algae is growing a challenge. Algal blooms can be highly variable in time and space. Anyone who has seen a bloom in the morning only to find no trace a few hours later understands this issue. Furthermore, surface scums are more likely at the shoreline rather than the middle of a lake, but there could be variable amounts present along a shoreline, within a cove, or around a whole lake. Distribution can easily change with variable water depth, wave action, or daily wind patterns. So how can someone estimate how much of a lake is impacted by a specific bloom?

To further explore how confusing the term bloom can be, below are several indicators that may be used to define a cyanobacteria bloom (adapted from Chorus and Welker 2021 and Hardy et al. 2021):

- an increase in biomass over a relatively short period of time (such as daily, between a few days, or one to two weeks)
- a large algal population indicated by measurement of the algae (such as cell density or biovolume) or proxy measure of a pigment such as chlorophyll-*a* or phycocyanin
- an algal community dominated by a single group or species, such as cyanobacteria
- a visual accumulation of cyanobacteria at the water surface
- a reduction in water clarity
- an event associated with the presence of toxin(s)
- excess growth that extends over a defined area.

Each indicator may have temporal, qualitative, or quantitative thresholds that need to be met for a bloom to be declared present. But the thresholds themselves can vary among states, countries, and habitat types (Hardy et al. 2021). Sample analysis is needed for several of the indicators, which can be costly and time-consuming, but ultimately provides useful data and supports qualitative observations such as photos (Table 1). The parties who collect, analyze, and interpret sample results are often not one and the same. It is important that all people involved have a shared understanding of how a sample should be collected and how the results will be evaluated and shared. Using a spatial component when defining a bloom has tremendous value to making people aware of their exposure risk, as not all blooms affect an entire lake or river.

Communication is particularly important for benthic HABs because they are not always visible at the water surface (ITRC 2022). Cyanobacteria blooms perhaps get the most attention, but there is a wide range of harms associated with other algal blooms and many of the indicators mentioned above can be applied to those different groups.

The design of monitoring programs and setting of thresholds are often focused on public health protection rather than the ecological health. For example, if a bloom occurs in an area where there is limited public access, sampling may not occur, and the bloom is less likely to be documented. Another limitation of monitoring programs is timing, both within a week and throughout the year. A HAB that occurs on a weekend can leave response teams underprepared as staff are not on duty. Many recreational areas are only monitored regularly during the summer, but the waterbody may be used as a drinking-water supply year-round. A bloom that begins in November or occurs under ice could easily be missed or be under-reported.

Since there are so many ways to characterize a bloom, explicit definitions are necessary when communicating to assure all parties are on the same page (Table 1). It is important to describe which indicator measures they used,

Table 1. Several common indicators and examples of thresholds to be met to define a HAB (thresholds adapted from Chorus and Welker, 2021).

[<, less than; >, greater than; µg/L, micrograms per liter; mm^3/L, cubic millimeters per liter]

Indicator	Example Threshold	Benefit	Limitation	Relative Cost
Visual report	Meets visual appearance of a HAB	Rapid, highly protective	Potential for incorrect judgement, no quantification of risk	$
Waterbody Imagery or Micrographs	Meets visual appearance of a HAB and/or cyanobacteria present	Highly protective	Requires expertise for identification, limited quantification of risk	$
Water Clarity (Secchi Disk Depth)	<2 meters visibility	Rapid, highly protective	Potential for incorrect judgement	$
Chlorophyll-*a*	>12 µg/L chlorophyll-*a* with dominance of one algal group	Characterize risk for algal exposure	Time for sample collection & analysis; Not necessarily an indication of the presence of cyanobacteria	$$
Cyanotoxin (toxins specific to CyanoHABs)	>8 µg/L microcystin	Characterize risk for cyanotoxin exposure	Time for sample collection & analysis	$$-$$$
Microscopy	>0.3 mm^3/L biovolume of toxin-producing cyanobacteria	Characterize risk for cyanobacteria exposure	Time for sample collection & analysis	$$$

whether the measures were qualitative or quantitative, if thresholds were used and what they were, and which spatial or temporal characteristics were considered. All these aspects add context to the determination that a bloom was present, its temporal and spatial extent, and how it may lead to harm.

Definitional Framework:

To wrap up, those communicating about HABs benefit their audience by defining each of the three components of the acronym as described above. When interacting in a scientific or public context, strive to be as explicit as possible. Here are some suggestions:

Harmful: Whenever possible, provide information about the relevant potential risks to human, animal, ecological, or economic health associated with excessive algal growth (Figure 1). This information will be context-dependent (for example, recreation versus drinking water treatment) and in consideration of multiple users and potential impacts.

Algal: For communication purposes, cyanobacteria can remain under the umbrella words algae and algal. A clarifying term that specifies which type of algae is present in a bloom (if known) can be used to describe the conditions. If unknown, that is worth stating too.

Bloom: Be explicit about the qualitative or quantitative nature of bloom identification. If quantitative information is used, articulate the specific indicator(s) and threshold(s), along with the data used to derive these. If a spatial or temporal component is known, this provides even more information.

Bottom Line: Because of the current range in state, federal, and international guidelines, the diversity of water users, and the many scientific unknowns, it is not possible at this point to come to a consensus on a single definition of a HAB. To avoid confusion, we highlight the use of this definitional framework where each term is explicitly defined. This small, but concrete step improves communication by not simply using HAB by itself and assuming that the definition is known to the audience.

References

The following resources include extensive information on how to define cyanbacteria-dominated harmful algal blooms. We summarized to a great extent here and have included them as additional publicly available resources on the topic for any readers that want to learn more.

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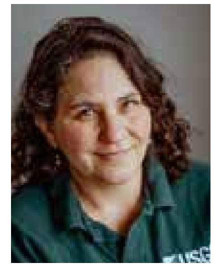

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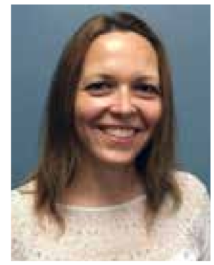

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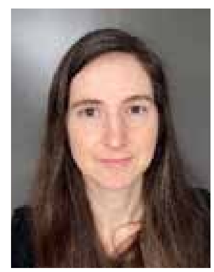

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