Perspective: The need for interdisciplinary solutions to climate change exemplified by harmful algal blooms

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It is generally understood that climate change is both a threat to health and a complex problem that requires accordingly complex solutions. In this commentary piece, I discuss the causes for and health implications of harmful algal blooms (HABs). I describe the effects that these blooms have on communities across Canada, especially in the Northern regions with particular focus on Indigenous communities who experience disproportionate harms due to HABs. I then examine Arctic Canada as a case study to motivate an interdisciplinary approach to understanding HABs which spans disciplines and knowledge systems. In doing this, I hope to illustrate the point that the causes and effects of HABs pose a problem too large to adequately address through any one field of study because of the complex and nebulous factors involved. Thus, the examination of this problem through alternative disciplines, ways of thinking, and world views, otherwise known as a "One Health", collaborative, or trans-disciplinary approach, is warranted.

Introduction to Harmful Algal Blooms: Causes & Effects

Harmful algal blooms (HABs) are a critical area of focus in climate change science that are posing an increasing threat to the health and wellbeing of ecosystems and society.[1-3] They are caused by microalgae such as cyanobacteria, dinoflagellates, and diatoms, with complex and sometimes harmful effects on people, animals, and the environment.[4] Cyanobacteria, or blue-green algae, can produce potent toxins that target the liver, brain, and lungs of many animals including humans, livestock, pets, and wild animals.[5-8] These cyanobacteria can be found across most aquatic and marine environments and are common culprits behind HABs, especially in freshwaters.[9] Dinoflagellates are common bloom-causing algae in marine environments, and these organisms cause diseases like paralytic and diarrhetic shellfish poisoning;[10,11] we expect to see more marine dinoflagellate blooms in Northern waters as temperatures increase.[2,4] HABs cause the build-up and subsequent decomposition of algal cells, and this process depletes the water of oxygen, resulting in die-offs of fish and other animals whose respiratory systems are designed to obtain oxygen directly from the water.[5] These processes create problems for drinking water treatment,[6] fishing, and recreation.[4,12] These effects are especially pronounced within Indigenous communities in Canada, as many reserves rely on lakes for drinking water,[13] and many traditional food sources like fish and hunted meat are threatened by HABs.[4-7]

While some progress has been made in recent years to illuminate the abiotic factors that contribute to HABs,[1-4] many biotic causes of HABs remain elusive. While HABs can occur naturally, anthropogenic activity has increased the frequency and intensity of their occurrence.[1-4] HABs are increasing with climate change because microbial growth in general is strongly regulated by temperature,[14] so warmer water promotes faster algal growth. Blooms tend to occur when nutrients are abundant, specifically nitrogen and phosphorus.[15] Other chemicals also affect blooms in complex ways: changes in concentration of chemicals like iron and calcium can affect microalgal communities by influencing metabolic processes.[15,16] The acidification of water that results from CO2 accumulation promotes growth of certain algal species over others, many of which unfortunately cause HABs.[17]

In freshwater ecosystems, water chemistry changes can occur naturally, such as when some lakes turn over seasonally,[18] but it is also commonly the result of

agricultural, industrial, and urban pollution.[19-22] When farmers apply fertilizer to their fields, the excess is often washed out into nearby water sources.[23] Similarly, urban water treatment plants can be a significant source of nutrient pollution, especially if there are leaks or other breaches within the system.[24,25] There are regulations that aim to reduce nutrient pollution in Canadian freshwaters, though HABs remain a prevalent threat;[4,22,26-28] pollution with nitrogen and phosphorus still causes harmful algal growth in many freshwaters near major Canadian cities such as Lake Winnipeg and Lake Erie.[12,22,27,28] Industrial practices can also contribute to this pollution.[29] The problems that affect freshwaters are also relevant in marine ecosystems, but some problems are specific to marine systems due to their larger size and connectivity. Marine ecosystems are vast, and the microbial community varies significantly between regions.[30] Thus, the transportation of microalgae from one ocean region to another poses the potential for risks like invasive species and introduction of potentially harmful species.[4,31] Transfer of ballast water from ships, transplantation of shellfish between regions, and coastal infrastructure that alters water flow are all activities that require consideration in marine and large freshwater ecosystems.[32]

Despite the governmental and industrial efforts to mitigate HABs in Canada, the frequency and severity of HABs are increasing, particularly in Northern regions due in part to the effects of disproportionate global warming at high latitudes.[26,29] Given this, I believe that we have an ethical obligation to enact more effective measures to prevent HABs to protect both ecosystem and human health. This becomes especially relevant when considering that HABs are disproportionately impacting Indigenous Peoples in Canada because of the relatively large Indigenous populations in Northern communities,[33] as well as the close relationship with the land that these groups traditionally hold[34] and the threat to traditional food and water sources posed by HABs.[4] If we as a community care about health, social, and ecological justice, then it is imperative that we work together across disciplines to reduce HABs.

The Case for an Interdisciplinary Approach to Thinking About Climate Change & HABs

Within the realm of science, HABs have been studied through many lenses. Perhaps the most obvious branches of science that deal with this problem are environmental/Earth science,[35] ecology,[17,36] and toxicology.[4,37] However, HABs are also within the purview of health scientists due to the adverse effects of HABs on the health of people.[5,12] Similarly, veterinary scientists and animal biologists require an understanding of HABs due to their ill effects on companion animals and livestock, as well as wild animals in the environment.[5] Psychologists and other scientists interested in human development are also required for the study of HABs because of the potential for these events to cause harm and trauma to the mental and developmental health of the people who experience them.[38] Many scientists tend to frame their thinking within their specific discipline of interest; however, this narrow focus limits our capacity to understand complex phenomena, and I contend that our collective understanding of HABs would benefit from taking an interdisciplinary approach.

While taking an interdisciplinary scientific perspective on HABs would benefit the scientific community at large, this would still fail to encompass many relevant perspectives concerning the mitigation of HABs. For example, philosophers have a place in the HAB discussion because they deal in the realm of ethics, epistemology, and aesthetics, all of which inform our understanding of and relationships to HABs as a component of climate change,[39,40] and thus should be considered when trying to understand HABs. Artistic disciplines deal with the emotional aspects which motivate people to become concerned with HABs in the first place;[41] however, the role of art, and especially Indigenous art, has been historically devalued.[42,43] Consideration of the realm of pedagogy and the ways in which we teach about climate and HABs is also important.[41] Because it is empirical, science cannot account for the non-quantifiable aspects in human decision making that affect and are affected by HABs, so if our goal is to understand and ultimately mitigate HABs, we should consider these alternative approaches, even if they fall outside the usual purview of science.

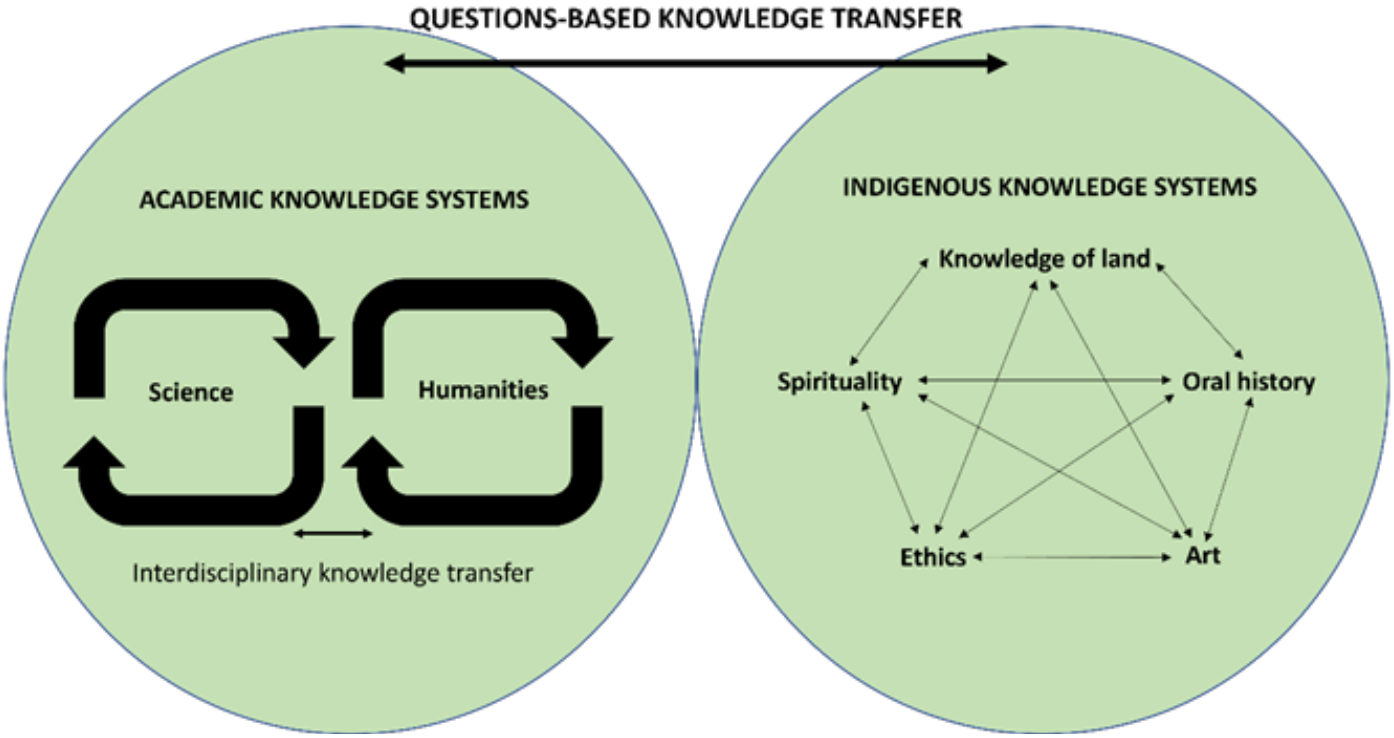

Figure 1 | Conceptual diagram of proposed knowledge transfer between Academic and Indigenous Knowledge Systems to improve climate change and algal bloom mitigation. The diagram shows two circles beside one another, touching but not overlapping, with the leftmost circle labelled "Academic Knowledge Systems" and the rightmost circle labelled "Indigenous Knowledge Systems". There is a horizontal two-way arrow above the circles labelled "Questions-Based Knowledge Transfer" which represents questions as the proposed point of knowledge transfer between the two somewhat disparate systems. The circle representing Academic Knowledge Systems contains two cyclic arrow diagrams labelled "Science" and "Humanities", respectively; these cyclic arrow diagrams are connected by a horizontal two-way arrow labelled "Interdisciplinary Knowledge Transfer". The circle representing Indigenous Knowledge Systems contains an interconnected network with five loci labelled "Knowledge of Land", "Spirituality", "Oral History", "Ethics", and "Art"; these loci were adapted from.[61] All loci in the Indigenous Knowledge System circle are connected to all others by two-way arrows, indicating that consideration is given to each locus at the same time.

Indigenous Knowledge Systems are fundamental to the discussion of HABs. Even if we span traditional academic thought in our discussion of HABs, we are still missing out on valuable other perspectives. Indigenous Knowledge Systems are fundamentally distinct from the traditional academic realm[33] while providing valuable insight into the processes related to HABs[44] (Figure 1). These Knowledge Systems are especially relevant in Canada given its historical relationship with Indigenous Nations.[45] Importantly, Indigenous Knowledge Systems are philosophically robust with ethical frameworks, spiritual tradition, and a holistic land-based metaphysics.[33,48] By emphasizing Indigenous perspectives, we could gain deeper consideration for future generations, as well as ethical cases for conservation of land and water because of their sacred aspects. Many scholars have made the point that Indigenous perspectives represent a valuable and often underappreciated contribution to the discussion and understanding of climate issues,[12,46,47] and HABs are no exception.

In this discussion, it is crucial that the knowledge transfer goes both ways. We must avoid solely informing Indigenous communities of the results of our science after it has taken place. Because Indigenous and academic knowledge systems are fundamentally distinct, comparing between the two is problematic. To avoid the comparison of two disparate systems, I believe that we should shift our focus from results to questions. By promoting a questions-based knowledge transfer that engages with diverse communities of people from the onset, we can improve the relevance and importance of the questions we are asking and thus increase the value of our findings.

Case Study: HABs on Arctic land under Canadian jurisdiction

Clearly, HABs are a vast problem that spans disciplines. Here, I investigate HABs across the northernmost parts of Canada, highlighting their disproportionate effects on Indigenous communities. Traditionally, Indigenous Peoples across Turtle Island (North America) share a close relationship with the land which recognizes humans as within the environment rather than outside it.[33,48] Importantly, the dispossession and radical alteration of land can be extremely challenging and traumatizing for Indigenous Peoples, hence it is especially important here to recognize and emphasize the link between health of people and the environment.[33,48,49] Although many share this collective understanding of the environment, Indigenous Peoples are not an ideological monolith,[33,48,50,51] and they should not be treated as such. There are some examples of Indigenous Knowledge complementing scientific freshwater research,[44] but this is an emerging field that warrants further investigation. Thus, I aim to provide a general survey of the effects of HABs on the people of the Arctic in Canada with a special emphasis on Indigenous communities. I seek to motivate consideration of Indigenous perspectives regarding HABs in the Canadian context.

The Arctic region is a common case study used to describe effects of climate change because it is warming faster than any other part of the world[46] and there are numerous groups in the Arctic with competing interests.[41,52,53] The Arctic spans at least 5 countries, is home to diverse Indigenous cultures, and is subject to intensive resource extraction and trade that will continue to increase with decreasing ice cover.[41,54] Within Canadian borders, the Arctic accounts for 40% of the total land; there are roughly 150,000 people living in the Arctic under Canadian jurisdiction, over half of whom are Indigenous.[54]

In one case, the city of Yellowknife has experienced unprecedented HABs in a local lake (Jackfish Lake) over recent years.[29] This city has a large proportion of Indigenous residents (~24%),[55] and the HABs in this community have directly affected traditional food and water sources used by the Indigenous communities in the region.[29,56] Health officials have even warned people to wear gloves when handling fish from the lake.[56] Unfortunately, this is not an isolated incident, as we continue to see increases in HAB occurrence across the Arctic and sub-Arctic.[12,26,29,31]

Because of its rapid warming, the Arctic has undergone intensive climate research, and HABs are no exception. The Arctic has both freshwater and marine environments that could be subject to HABs, though they have been historically limited by the cold temperatures.[28] Many researchers have taken a scientific approach to understanding HABs within their respective disciplines.[4,5,12,17,35,36] These approaches have allowed us to generate models to predict that the severity and intensity of HABs will increase across Northern landscapes as the climate changes[12] along with the harmful impacts this will have on human and animal communities.[28,46,57,58] Indigenous communities in the region possess a wealth of knowledge obtained through their own systems of knowing that can positively contribute to HAB research.[44,52,53,59]

Recent work has taken interdisciplinary approaches to HAB reduction.[46,47,60] However, because HABs are still expanding and increasing,[12,28] further effort must be invested into translating these different forms of knowledge about Arctic HABs across disciplines. This must include questions-based knowledge transfer between science and the humanities, as well as between Indigenous and academic knowledge systems. By focussing our efforts on interdisciplinary approaches to understanding HABs in Arctic ecosystems, we can protect and foster the health and wellbeing of the communities most affected global climate change.

Conclusions

HABs are happening at an unprecedented pace both in the Canada[12] and globally.1 This is happening in both marine and freshwater environments, as increased temperatures and altered water chemistry causes shifts in the community dynamics of the algae responsible for the blooms.[1,12] This is already having severe effects including unprecedented blooms and increasing harms in Arctic communities.[28,58] The increase in HABs is a pressing health issue that affects people, animals, and the environment; to understand this health issue, it is necessary that we take an interdisciplinary "One Health" approach, as well as implementing a questions-based knowledge transfer system. The implementation of this approach could increase societal awareness of HABs, which could ultimately provide the motivation required to mitigate them.

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