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Social Constructions of Health-Environment Risks: A Comparison of Fishing Community and Expert Perceptions of Cyanobacterial Blooms

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ABSTRACT
Cyanobacterial blooms are expanding around the globe in frequency and intensity. Using cultural models to unravel local meanings, this study explores how stakeholders (fishers, aquaculturalists, and regional experts) from the Nyanza Gulf of Lake Victoria understand cyanobacterial blooms and their impact on human health. The study also examines resource user and expert perceptions of how these blooms have impacted the livelihoods of fishers and aquaculturalists, and how regional experts have responded. Semi-structured interviews (35 total; fishers and aquaculturalists [25], experts [10]) were used to describe cultural models used by different groups. Multiple perceptions of cyanobacterial blooms and their impact on human health emerged, influenced by the social locations of study participants. With the burden of environmental degradation unequally allocated because of dynamic social constructs, these findings reveal the importance of improving the flow of information between those involved in the design and implementation of policies and those impacted by them.

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Community-based research; coupled human and environment systems; fishing livelihoods; harmful algal blooms; microcystin

Introduction: Situating Perceptions of Environmental Risks

Local experiences and perceptions form the basis for individual and population responses to environmental risks (Pyhälä et al. 2016; Barnes et al. 2013). Both nature and environmental challenges are socially and dynamically constructed by individuals (Escobar 1999; Gudynas 1999; Proctor 1998). Yet values, beliefs, and understandings of environmental challenges differ among people depending on their social standing and power, with different realities coexisting at the same time (Kempton, Boster, and Hartley 1996). In this sense, people tend to "perceive, identify, and define environmental problems by developing shared meanings and interpretations of the issues" (Taylor 2012). Because of this tendency to develop shared meanings based on similar socioeconomic standing, Community Based Participatory Research can be critical to improving

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both our understanding of environmental problems (Balazs and Morello-Frosch 2013; Sansom et al. 2016) and local policies (Crona et al. 2013).

In this study, we ask how understanding of harmful algal blooms and their health and livelihood impacts differ across stakeholders (fishers, aquaculturalists, and regional experts) in the Winam Gulf of Lake Victoria, Kenya. The Winam Gulf faces persistent nutrient pollution, which has led to the proliferation of harmful algal blooms and caused health and livelihood risks to nearby communities. Here, we examine different stakeholder perceptions of this environmental challenge using cultural models to describe the plurality of knowledge, which can then be used to help facilitate mitigation strategies (Taylor 2012).

Cyanobacterial Harmful Algal Blooms

In Lake Victoria, harmful algal blooms are composed of cyanobacteria capable of producing toxins. Cyanobacteria appeared over 2.5 billion years ago and were among the first photosynthesizing organisms on earth (Paerl 2014). Today, diverse cyanobacterial species occupy all terrestrial and aquatic ecosystems and can survive even in extreme environments. Like other microscopic organisms that produce algal blooms, cyanobacteria take advantage of excessive nutrient loading in freshwater, brackish, and marine ecosystems, a process called eutrophication, and can potentially be harmful to human health (Millennium Ecosystem Assessment 2005). With climate change, the duration, intensity, and severity of algal blooms is expanding (Paerl 2014; Svirčev et al. 2019). The phenomena characterizing climate change, including warmer temperatures, increased light intensity, floods, and droughts may favor the growth of toxic cyanobacteria (Paerl and Huisman 2009).

Anthropogenic eutrophication in the Winam Gulf region of Lake Victoria has been a challenge since the 1980s. Population growth, unregulated wastewater and industrial discharge, and non-point source agricultural runoff have all contributed to the increase of cyanobacterial blooms over time (Hecky et al. 2010; Sitoki, Kurmayer, and Rott 2012). While not all cyanobacterial blooms produce toxins (Paerl and Huisman 2009), microcystins, a family of cyanotoxins, are acutely toxic to the liver and can lead to developmental and chronic health problems. In the Winam Gulf, microcystins are well-documented. The World Health Organization measured the levels of microcystins in the drinking water at both the intake of Kisumu's water treatment plant (Sitoki, Kurmayer, and Rott 2012) and at the fisher community's source waters (Roegner et al. 2020) and found them to exceed the maximum allowable for potable water by 10- to 100-fold (1 μg/L). The bloom-forming *Microcystis* and *Limnoraphis* spp. do not consistently produce toxins, and environmental conditions that trigger toxin production are still not completely understood (Paerl and Otten 2013). However, these blooms can produce strong odor and taste compounds, impede boat movement, and clog and degrade water treatment infrastructure (Watson 2020). They reduce the transparency of the water and impact the habitats of fish and invertebrates. Decaying mats of cyanobacteria can choke the oxygen available in the water column, causing fish die-offs and impacting other aquatic life (Paerl 2014).

Microcystins and the associated health effects of blooms are of direct concern to fishing communities because the people rely on the lake for food, water, and work (Roegner et al. 2020; Onyango et al. 2021). Local fishers and aquaculturalists, especially, experience the consequences of blooms every day, which makes capturing their distinct sociocultural perceptions important for understanding the health risks and effectiveness of responses.

Cultural Models to Examine Environmental Change

Cultural models capture social constructions as they are influenced by social location, such as gender, race, and class (Taylor 2012). Cultural models offer a context for diverging perceptions and beliefs about environmental change and public health that may exist within and between groups. By appreciating these divergences, cultural models can enhance understanding of environmental challenges and help bridge solutions for sustainable protection of human and environmental health.

Cultural models have been used to capture and unravel discrete interpretations of nature and global environmental challenges (Ignatow 2006; Kempton and Falk 2000; Kempton, Boster, and Hartley 1996; Paolisso and Chambers 2001; Paolisso and Maloney 2000; Secaira 2017; Weeks, Packard, and Paolisso 2012). By describing the patterns of a group based on joint sociocultural experience, cultural models become a type of collectively held yet distributed cognitive structure, which thereby serves as a repository of cultural knowledge (Kronenfeld 2008, 67). Such models often form the basis for how people understand the world and their place within it (Holland and Quinn 1987, 4). Cultural models are made up of schemas, which are drawn from individual experiences and memories. When individuals share the same experiences, they may share the same schemas, and, therefore, the same cultural model (Quinn 2005). As stated by Taylor (2012), environmental problems are constructed through collective processes whereby the understand meanings and interpret key issues. Importantly, different cultural models can exist at the same time (Holland and Quinn 1987), meaning people from the same group can hold different cultural models (Paolisso and Chambers 2001, 4; Thornton et al. 2020).

Cultural models have been previously employed regarding the overgrowth of algae due to nutrient enrichment of different microorganisms, like cyanobacteria and *Pfiesteria piscicida* (Kempton and Falk 2000; Kempton, Boster, and Hartley 1996; Paolisso and Chambers 2001; Paolisso and Maloney 2000; Secaira 2017; Weeks, Packard, and Paolisso 2012), and to examine fisher culture to reveal a deep interconnected relationship that extends beyond economic dependence (Blount and Kitner 2007; García-Quijano 2009; Paolisso 2007). This paper extends this literature to examine the differing cultural models of harmful cyanobacterial algal blooms held by fishers, aquaculturalists, and experts (e.g., scientists, resource managers) in the Winam Gulf of Lake Victoria. In the face of global environmental changes, integrating local perceptions and traditional knowledge from fishers and aquaculturalists can inform environmental management policies on a larger scale (Latulippe and Klenk 2020; Pyhälä et al. 2016).

Study Aims: Identifying Perceptions and Experiences of Harmful Algal Blooms

Lake Victoria supports the largest lacustrine harvest of fish globally, and more than 30 million people reside in its basin (Njiru, Aura, and Okechi 2019). We use cultural models to understand how different Lake Victoria stakeholders (fishers, aquaculturalists, and regional experts) understand harmful cyanobacterial-producing algal blooms and their impact on health and fishing livelihoods in different ways. We compare how regional experts (government officials, NGO members, researchers) and local fishers and aquaculturalists have understood and responded to the threat.

Materials and Methods

Study Site

The Winam Gulf (Appendix) is in the northeast region of Lake Victoria, in Kenya. Lake Victoria is the second largest freshwater lake and the largest tropical lake in the world, at 68,000 km^2. The lake is shared between Tanzania (51%), Uganda (43%), and Kenya (6%), and it represents the largest inland source of fishery production in Africa (LVBC 2017), with 500,000 tons of fish harvested annually (LVRLAC, 2009) by 200,000 full-time fishers (Lake Victoria Fisheries Frame Survey Regional Working Group 2013). Men are the predominant fishers in the region, with women participating in fish processing and trading (LVBC 2017). Small-scale commercial fisheries for dagaa, a small sardine-like fish, and introduced Nile perch, comprise the majority of the catch. Commercial cage farming, in which fish are caged within the lake itself, started intensively in Lake Victoria around 2005 (Aura et al. 2018).

Despite its extensive production, Lake Victoria has faced a range of environmental and social challenges over the last half century. The introduction of Nile perch in the 1950s, for example, altered the food web structure of the lake. The Nile perch boom has been linked to the spread of HIV in the region and it remains a global hotspot (Dwyer-Lindgren et al. 2019). Today, poor community health impacts the sustainability of local fishing practices (Fiorella et al. 2017). While reliance on fish for consumption is high and widespread, fish access is ultimately mediated by local incomes (Fiorella et al. 2014) and overfishing is a persistent concern (Albright 2004). In addition, an aquatic weed called water hyacinth has hampered fishing activities and made fishing challenging by blocking boats' access. International and national fisheries and water quality management efforts have aimed to address many of these challenges. In particular, the World Bank-funded Lake Victoria Environmental Management Project (LVEMP), a joint effort between the governments of Tanzania, Uganda, and Kenya to improve conditions in the Lake Victoria basin, has been key in helping to reduce the deterioration of aquatic resources (GEF 1996).

Data Collection

In July of 2019, we conducted 35 interviews: 25 with the fishing sector and 10 with regional experts. Time limitations prevented the inclusion of more experts. All interviews were individual, except for one conducted with two people, as one of the fishers did not wish to participate individually ($n = 36$ people in total). Participants included 18 fishers, seven aquaculturalists, one aquaculturalist/fisher, seven government experts, two private sector experts, and one NGO expert. The study was conducted in collaboration with the Kenya Marine and Fisheries Research Institute (KMFRI).

The semi-structured interviews addressed harmful algal blooms, cyanobacteria, and the associated costs to fishing and aquaculture communities. Interviews were guided by a series of open-ended questions, including general perceptions of (i) the state of the lake, (ii) cyanobacterial blooms, (iii) the impact of cyanobacterial blooms on the livelihoods of the fishing sector, (iv) the impact of cyanobacterial blooms on health, and (v) the ongoing management responses to cyanobacterial blooms. Photographs were shown to interviewees to confirm their knowledge of algal blooms, and to distinguish the blooms from water hyacinth.

A KMFRI researcher and an international researcher (CSZ) conducted the interviews together. The KMFRI researcher interpreted when needed; twenty-eight interviews were conducted in English and seven were conducted in Dholuo. Interviews ranged in length from 30 to 60 min.

In addition, 20 days of participant observation were carried out at eight beaches and fish landing sites of the Winam Gulf (1–2 days per site) and 11 visits were made to all the institutes represented by the expert interviewees. Observation notes about fishing activities, BMU meetings, and behaviors in response to observed water quality were recorded and integrated within the analysis of interview data to triangulate findings. For example, the bloom conditions were both discussed by fishers and observed.

Research Sites

Study sites were chosen around the Winam Gulf because of its high concentration of cyanobacterial blooms (Njuru and Hecky 2005). Sites were identified both where fishers exceeded the number of aquaculturalists yet where aquaculture cages were also present. A geographical distribution along the gulf was also desirable. In the end, eight sites were selected: Dunga, Ogal, Asat, Luanda Kotieno, Sango Rota, Kamol, Alum, and Homa Bay (Appendix).

Interview participants were selected by convenience sampling (Lopez and Whitehead 2012). Representatives from Beach Management Unit as well as fishery co-managers (Ogwang et al. 2005) identified fisher and aquaculturalist participants. Both men and women were invited to participate, but the gender balance strongly skewed toward men, which is a limitation of this study. For the experts, an initial list of key actors was generated from a literature review. A brainstorming session identified a range of expert institutions, domains, and specific individuals. Representatives from KMFRI contacted identified participants. Experts were interviewed in Kisumu and Homa Bay at their work offices.

Ethical Considerations

All participants agreed to participate; each provided oral consent and received a small monetary token of appreciation. The study was reviewed by KMFRI researchers and the

Institutional Review Board at Cornell University (Protocol: 1906008891). Participant names, institutions, and exact positions are omitted to ensure anonymity.

Qualitative Data Analysis

English interviews were transcribed. Out of seven Dholuo interviews, six were translated and transcribed by an external member and one was transcribed in real-time during the interview. Following transcription, interview text was color-coded to represent different stakeholders and to highlight manual rearrangement of quotations. Participant statements were used to identify themes, patterns, and comparisons between responses (D'Andrade 2005).

A primary analytic goal was to let participants speak for themselves, as suggested by the socio-constructivist paradigm (Creswell 2007). "Winnowing," or excerpting information into propositions, was used to recover the essence of participant statements, and these formulated the resultant themes, patterns, and comparisons between responses discussed in the results (D'Andrade 2005). The frequency of repeated words (e.g., names for cyanobacteria) and use of metaphors were also used to support the building of cultural models (D'Andrade 2005). Metaphors are common in speech and can be helpful for clarifying the ideas and perspectives participants share (Quinn 2005).

Results

Participant Profile

Fishers and aquaculturalists participated in the fishery and aquaculture (Table A1). Experts worked in relation to Lake Victoria and/or were involved in decision-making on lake issues (Table A2). Though designated as "experts," these individuals were not necessarily experts on algal blooms or cyanobacteria, nor did they have equivalent expertise. Beach Management Units are comprised on fishers, aquaculturalists, and traders that operate at a given beach, or fish landing site, and elect officials to govern these sites and participate in the co-management structure that links to the government. Within the fisher and aquaculturalists group, a number of individuals played a role in Beach Management Unit leadership. Within the expert group, individuals also played a role in Beach Management Unit coordination from within government agencies and NGOs.

Social Perceptions of Lake Victoria and Cyanobacterial Blooms

Fishers and Aquaculturalists

Fishers and aquaculturalists described Lake Victoria as the main source of their livelihoods. Most grew up around the Winam Gulf and learned fishing techniques at an early age from previous generations. Fishers often worked in more than one role, including as crew members, boat owners and/or gear owners, aquaculturalists, fish traders, and members of the BMU committee. Overlapping roles, for many, fostered a multifaceted connection to Lake Victoria. Cage farming, on the other hand, is relatively new. Several aquaculturalists mentioned their recent switch to cage farming, and, in one case, the person actively continued to fish, too.

Participants were attuned to changes within the aquatic ecosystem, with most recognizing substantial environmental changes to the lake in their lifetime. One fisher observed that “it is no longer clean, [which] it used to be.” A majority (84%) of interviewees agreed, noting a loss of transparency in the water and a change in color. A BMU leader and fisher talked about the days when he was young. At that time, “you were still able to see something at the bottom of the water, but now you cannot, even at the shore.” Another BMU committee member and fisher described the color of the water as “depreciated compared to when I was young, because in those days the water was crystal clean … [now] the water has become greenish.” Participants shared a common nostalgia for the past, relating stories of swimming in the lake, drinking untreated water, and enjoying abundant fish yields. The majority felt that, in the past, they were not negatively impacted by environmental conditions. Participants also recalled large amounts of fish captured in a single day, which they said was no longer possible.

All participants, across all ages and sectors, noted current environmental challenges, including water hyacinth, transparency loss, and cyanobacterial blooms. About half of participants agreed that environmental changes had begun in the last decade or two. “This started about 20 years ago when the situation changed,” one fisher recalled. An older participant expressed a longer trajectory for the environmental problems, which he believed were due to “the industries around Lake Victoria. Maybe [beginning] in 1973.”

Both fishers and aquaculturalists recognized that Lake Victoria has been impacted by algal blooms, although they largely referred to these not as “algal blooms” or “cyanobacterial blooms,” but rather using a range of local names and meanings; for example, *osikonyodha* means “heavy to pull” (Table A3).

Fishers and aquaculturalists had multiple explanations for the causes of algal blooms (Figure 1a). Blooms were seen as resulting, for example, from natural aquatic system processes, pollution from industry, or contaminants from cars and household cleaners. A BMU committee member and fisher said blooms happen “because of the factories. They link the water system to the lake … Also, from humans, those who are washing. If you go to Kisumu there are vehicles that are being washed inside the lake and this oil [is the cause], maybe.”

Despite participants’ heterogeneous understanding of cyanobacterial blooms, the majority (72%) mentioned the role of weather, particularly the wind. One aquaculturalist said that “the strong winds will help” clean the lake. Others agreed and reported seasonal differences blooms: “We have two seasons. During dry season [the bloom] is there and during the rainy season, because of the wind, [the bloom] is not there. The wind blows it off.”

Experts

Experts observed some of the same changes and causes as fishers and aquaculturalists, though they also suggested others. For example, they stressed the importance of distinguishing between the Winam Gulf and the rest of the lake. The gulf has its own aquatic dynamics, which differ from what they describe as “the open waters.” One natural

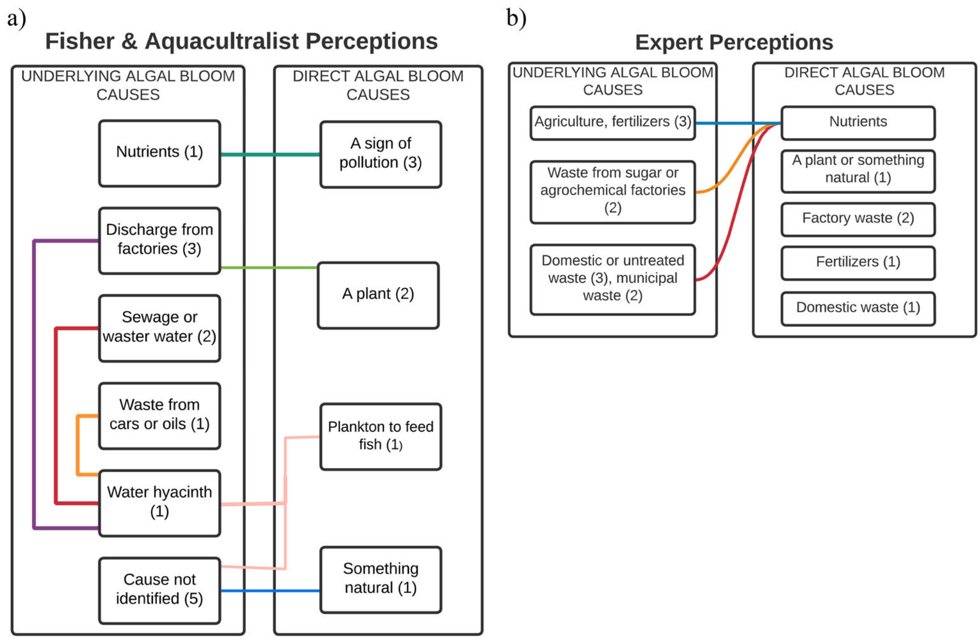

Figure 1. Perceptions of the underlying (left column) and direct (right column) causes of cyanobacterial blooms by (a) fishers and aquaculturalists and (b) experts. Numbers in parentheses indicate the number of participants that identified this cause, with participants often identifying multiple causes. Each connecting line represents the perceived combination of factors that cause cyanobacterial blooms, with different colors representing connections made by different participants.

scientist said that "if you go beyond this bay, you will go to an open lake where it is blue and beautiful. This is no Lake Victoria, Victoria is beyond." The experts suggested that the distinction between the gulf and the rest of the lake was because of algal blooms. "This gulf is like a shelter bay," said one government-sector natural scientist. "I think it keeps the right conditions for the algae blooms to show up." Participants from this group had fewer names for the blooms, but they recognized the existence of local names (Table A3).

Most experts with a natural science background also mentioned that the lake has changed over time, though their responses focused on scientific explanations for the environmental challenges facing Lake Victoria. These experts explained that cyanobacterial blooms were the result of excessive nutrients in the water (Figure 1b). For example, a female natural scientist in the private environment sector talked about the role of phosphorus and nitrogen: "Phosphorus is a challenge for us, we are trying to get a solution for it, but for nitrogen we are able to mitigate that." Excessive nutrients characterized most of the explanations offered by experts. However, some had different explanations. One government official and BMU leader in the medical sector understood cyanobacterial blooms only as the result of domestic and factory waste or discharge from factories and fertilizers. Another expert interviewee, a private sector employee from a company that used lake water, suggested that the blooms were "just plants, they are natural," an idea also expressed by some fishers and aquaculturalists.

Table 1. Comparison of fisher and aquaculturalists' to experts' perceptions of cyanobacterial bloom impacts on human health.

	Fishers and aquaculturalists		Experts	
Health problem	Causes identified	Strategies to address	Causes identified	Strategies to address
Skin	Contact with water Skin itchiness, dryness	Apply Vaseline, antibacterial, or oil before (protect) or after (relieve symptoms) contact with water	Contact with water Skin itchiness, dryness	Visit local dispensaries, hospital
Gastrointestinal	Drinking untreated water Eating fish	Add additional water treatment methods Change water source		
Breathing	Smelling blooms' strong odor	Avoid lake		
Cancer			Ingesting microcystins produced by cyanobacterial blooms	Improved water sources

Gray boxes denote an area where one group did not recognize a problem.

Perceived Impacts of Cyanobacterial Blooms on Human Health

Fishers and Aquaculturalists

The majority of participants (80%) believed blooms impact human health in multiple ways (Table 1). Several people mentioned that it affected their skin. A BMU committee member and fisher said, "It [brings] skin rashes to the fishers." Fishers tended to apply oil, Vaseline, or antibacterial lotions from the local shops before entering the lake to protect their skin, or after entering the lake to relieve the symptoms they experienced.

Gastrointestinal problems were also widely reported with consumption of untreated or inadequately treated water from the lake. "I will be fearing for my stomach," one fisher lamented. "It is obvious if you drink dirty water it will affect your health." Some people also worried about eating with utensils washed in lake water or about consuming fish exposed to the blooms. One participant explained that cyanobacterial blooms can remain inside the fish, impacting people who consume fish. In some cases, people mentioned that blooms could cause other problems, including amebic dysentery and typhoid. In response to skin, gastrointestinal, and other symptoms caused by blooms or other microorganisms, participants largely sought care at government-run hospitals, dispensaries, or clinics.

Participants also complained about the odor and taste of the water. In two cases, people suggested that the smell of the cyanobacteria could be dangerous for human health, causing breathing problems or discomfort. One BMU committee member and fisher compared blooms to smoking, while another fisher mentioned the reason he felt you could not swim. "It is not possible," he said, "because of the smell."

Experts

Most experts recognized that cyanobacteria could impact human health, with the exception of two participants (Table 1). Experts mentioned that blooms could cause dry skin, rashes, or changes in skin color. A BMU sector participant stated that for "people that interact with the lake, their skin dries and it becomes whitish. It interferes with the skin."

These same experts, on the other hand, did not believe that cyanobacterial blooms could cause gastrointestinal problems, in contrast to statements made by fishers and aquaculturalists. However, they noted that cyanobacteria could potentially impact the nervous system, negatively affect growth in children, and even cause cancer. A government-environmental sector natural scientist expressed concern over the possibility of cancer, saying, "You get some irritation in your skin. But some of [the toxins], I know, are carcinogens […] because recently they produced a map of cancer prevalence in the country and the highest prevalence was in Nairobi and the lake region." Most of the experts underscored the need for more research to understand health impacts.

The majority of experts did not know how fishing communities responded when they experienced symptoms. Only one member of the group, who was also a boat owner, mentioned the application of Vaseline before entering the lake to protect one's skin.

Access to Clean Water

Fishers and Aquaculturalists

Fishers and aquaculturalists expressed worry about the impact of blooms on access to clean water. Most of the local communities depend on water from the lake for consumption and domestic purposes. Women are commonly seen fetching water from the lake or washing clothes at the shores. Prior to algal blooms and pollution, it was common for people to drink water directly from the lake without any treatment method. A BMU committee member, fisher, and trader shared such a memory: "Initially, when we were young, we were drinking this water directly. Not even putting [in] any chemicals [e.g., chlorine]," which is something they can no longer do. An older fisher said, "When I started fishing in Lake Victoria, [the] water was very clear which is not the case as per now." An aquaculturalist echoed this sentiment: "People living around [the lake] depend on Lake Victoria greatly, so it is affecting them domestically. They do not enjoy using this water for washing, drinking. They cannot use it."

In the last 10–20 years, most participants reported the use of treatment methods, additions to treatment methods already in place, or their decision to switch water sources. The most common treatment methods were boiling, chlorination with a local brand of water guard, and filtration. An aquaculturalist discussed the intensive process of filtering the water: "They will carry at least three cloths for filtration. So, after filtration … [for] 30 minutes you do what we call decanting … you put the water down and it settles. After settling, without filtering you pour it slowly, so the [algae] remain."

Experts

Experts recognized that cyanobacterial blooms impact safe water access. The group explained that water cannot be consumed in the presence of blooms, and instead treated tap water, bottled water, or lake water away from blooms should be used. One government-environment sector expert suggested that these strategies may not be enough: "Most people along the beaches consume this water directly. This is what they use for domestic consumption. For washing, for the cattle, [for] the cows, for drinking at home. They take this water and treat, but now when it is like that you cannot even wash the clothes there." Many stated that people have boreholes to collect water. In other cases, they mentioned that it was imperative to chlorinate the water. However, even though the experts recognized that treatment was necessary, they noted that it was not always effective in eliminating cyanobacteria toxins, as mentioned by one government-environmental expert: "I don't know a method [that] reduces the algae toxins."

Impacts of Algal Blooms on Livelihoods

Fishers and Aquaculturalists

Blooms have negatively impacted both fishers and aquaculturalists. A BMU committee member, fisherman, and trader stated that cyanobacterial blooms "give us hard times when we are fishing." Aptly, algal blooms are called *osikonyodha* in Dholuo, meaning "heavy to pull," because they form a thick layer on top of the lake and make it difficult to pull in fishing nets. A fisher described the difficulty, saying the lake "has been covered by these green things which [are] so thick on top of the water. Even when we do fishing, we get our nets affected and no proper fishing can take place."

For aquaculturalists, blooms make it more difficult for fish feed to penetrate the surface and reach fish in the cages. One former fisher and current aquaculturalist described some of the challenges: "By the time we were pulling the net, the net was very, very heavy and we were wondering why […]. The net that you might pull within 30 minutes [before], sometimes it will cost you around three hours, so it is a challenge to fishers and maybe cage farmers […]. If you pour the [fish] food, the food will remain upwards, it will not pass through."

Cyanobacterial blooms also reduce the amount of oxygen in the lake, affecting fish populations. Most participants identified Nile perch (*Lates niloticus*) and Nile tilapia (*Oreochromis niloticus*) as most affected because they only tolerate a narrow range of water quality; therefore, they were found less often around blooms. Omena/dagaa (*Rastrineobola argentea*) were also mentioned, though less frequently. "Some [fish] types are more affected, like the tilapia and the omena, because they depend on some food," one fisher said, "but when they meet these ones [the blooms] they are not comfortable." Lack of availability due to blooms means that fishers must travel longer distances to find areas with desirable species present. Water quality concerns also affect aquaculturalists. "For us, the cage farmers," one shared, "it also causes some problems. Good quality of water is [needed] for the good growth of fish, so with this [bloom] the fish does not enjoy the water habitat, so it is interfering with our farm."

Experts

Experts were aware of the negative impacts of cyanobacterial blooms on fishing and aquaculture. An NGO-environmental sector expert summed up the problem succinctly: "They don't get fish because of algae." Participants recognized that the blooms created poor fishing conditions, intensifying the difficulty and time needed for fishing activities. A government-environmental sector expert confirmed the difficulty. "Species of fish that require a good quality of water, like Nile Perch, of course it will shift to the cleaner areas of the lake. So to a fisherman that is targeting that species of fish, of course it will force him to go hard, to go further to get a catch of this fish."

Perceptions of the Management Response

Fishers and Aquaculturalists

Fishers perceived little action on the part of managers to address the blooms. Only two people (combined interview) from the BMU committee mentioned regional-level management efforts to reduce the impacts of cyanobacterial blooms, specifically the Lake Victoria Environmental Management Project (LVEMP). Within this project, they recalled a reforestation effort involving community members designed to help water quality. The remaining participants could not recall a concrete project or intervention. In select cases, fishers mentioned, without many details, that water samples for research were retrieved. Though, as stressed by one member, no results of the studies had been returned to the communities. "Maybe they have not identified the problem, or they have not come to us to seek why … the lake is like that," the fisher reasoned.

Experts

In contrast to the fishing community's perceived lack of management responses, experts, and especially those with a natural science background, referenced concrete actions aimed at reducing the cyanobacterial blooms. They mentioned the ongoing LVEMP effort administered by the World Bank, which targets all catchment areas, including Kenya, Tanzania, Uganda, Burundi, and Rwanda. One participant explained that in Kenya the project has been mainly implemented through the Ministry of Environment and Natural Resources, but many institutes have been involved.

The main purpose of the LVEMP project is to improve the ecological state of Lake Victoria, including eutrophication reduction. Most experts mentioned specific intervention strategies, including reforestation, eco-toilets, and sewage lines. An NGO sector natural scientist mentioned direct involvement prior to project implementation: "They [the World Bank] came and they discovered this stress, then we started further discussing a project that could [be implemented] and then they started Lake Victoria Environmental Program."

Discussion

Cultural Models of Algal Blooms

The semi-structured interviews allowed us to unravel heterogeneous perceptions of algal blooms around Lake Victoria among different stakeholders. Fishers and aquaculturalists held diverse interpretations of bloom causes. This diversity was further reflected in the 16 names identified by the group for algal blooms. The experts, in contrast, largely referred to algal blooms in the same way and had a more uniform perception of bloom causes. This variability in community explanations versus a higher degree of uniformity among experts is consistent with other cases where perceptions of algal blooms have been explored (Borbor-Córdova et al. 2018; Brisson et al. 2017; Bunting-Howarth 2001;

Kempton and Falk 2000; Secaira 2017). However, homogeneity in explanations does not necessarily mean a more complete or accurate understanding of the complex realities of an ecosystem out of balance.

As mentioned previously, cultural models are built upon schemas (D'Andrade 1992). Schemas are mental structures that allow individuals to identify both objects and events to interpret their world. These mental structures are acquired through the individual's lived experiences. In contrasting fisher and aquaculturalist perspectives with expert perspectives, geography may play a critical role. Experts were concentrated in the regional cities of Kisumu and Homa Bay, while fishers and aquaculturalists lived closer to the lake and experienced a wider breadth of bloom conditions. Lived experiences with blooms likely differ across geographies, introducing important nuances in how the phenomena are understood. For example, while the degree to which water hyacinth and algal blooms coexist remains an open question, those members who attributed the blooms to water hyacinth might live in regions with a higher concentration of this exotic plant than other regions. Unraveling local understandings enables an appreciation of the often uneven effects of environmental challenges (Crona et al. 2013), which can improve research and mitigation tools.

In contrast, the experts shared more homogenous perceptions about cyanobacterial blooms and their causes. The natural science experts we interviewed had roles in overseeing natural resource management, working at the interface of fishery health, safety, and community interests. They conducted research, including on water quality, and provided guidance or assessment on intervention programs, such as LVEMP. All the natural science experts had similar scientific training and access to information, likely resulting in their relatively similar explanations of causes of cyanobacterial blooms in the Winam Gulf, most of which they attributed to excessive nutrient loading. Further, although experts understood the main management goal to be the reduction of nutrient loading, they identified a range of ways to achieve this, from reforestation projects to good agricultural practices to improved solid waste management and awareness campaigns. Significantly, these are efforts already implemented by LVEMP.

Studies of algal blooms in other settings have followed a similar pattern. Paolisso and Chambers (2001) explain the case of *Pfiesteria pisicida*, a harmful algal bloom caused by another microscopic organism that appeared in the Chesapeake Bay region of the United States. Scientists and environmentalists had a similar understanding of the science but different views on how to apply this knowledge to environmental challenges. At Lake Atitlán, in Guatemala, and in the Ecuadorian coastal communities of Guayaquil, authorities and experts similarly understood the root causes of the blooms (Borbor-Córdova et al. 2018 and Secaira 2017), although their perceptions on the needed interventions differed (Secaira 2017). As experts understandings do not necessarily take into account the expertise of those who live in closer contact with the blooms, they may miss other consequences of the problem and opportunities to improve management.

The Impacts of Cyanobacterial Blooms on Human Health and Livelihoods

Our findings underscore the dependence of fishers and aquaculturalists on the lake and their first-hand experience of the impacts of cyanobacteria on their health. Participants outlined a range of health concerns, particularly skin and gastrointestinal problems. The concerns raised by fishers can potentially be traced back to cyanobacteria. Studies have confirmed that, when consumed (e.g., by drinking the water), cyanobacteria can cause gastrointestinal problems affecting the small intestine and stomach, which can lead to cancer (Kubickova et al. 2019). Observationally, in Tanzania, lake community members have experienced skin, throat, and eye irritation, as well as stomach problems—including diarrhea and vomiting—during cyanobacterial blooms, and those individuals reliant on the lake as their main source of drinking water reported more stomach problems (Mchau et al. 2019). Of course, multiple factors can impact the gastrointestinal tract (Kubickova et al. 2019), and it can be difficult to differentiate the impacts of cyanotoxins relative to other pathogens that might also live within these nutrient-rich waters. Yet the co-occurrence of cyanobacteria with other pathogens may also highlight their role as a harbinger of poor water quality, interlinking a range of health concerns for participants.

Increasing evidence suggests that microcystins present not only multifactorial health risks from ingestion of microcystin-contaminated water (Massey et al. 2018), but they also threaten human health by accumulating in food sources, such as diverse fish species (Ibelings and Chorus 2007; Onyango et al. 2020) or crops irrigated with cyanobacterial-infested water (Campos et al. 2021; Mutoti, Gumbo, and Jideani 2022; Pham and Utsumi 2018). Evidence, such as this supports fisher concerns and perceptions about the changing ecosystem around them.

Fishers and aquaculturalists have attempted to mitigate these health effects, yet their options are limited and challenging to enact (e.g., additional water treatments, switching water sources). Studies have shown that in order to effectively remove the toxins, multiple interventions are required (Roegner et al. 2014; Westrick et al. 2010). Common water treatment methods to address other pathogens could even increase microcystin risks; for example, boiling water may concentrate the presence of microcystins (Roegner et al. 2014). Chlorinating water can reduce microcystins, but only under specific guidelines and after a filtration process (Roegner et al. 2014).

Experts are in a different position from fishers and aquaculturalists. They are knowledgeable about a range of health effects, but they are often not personally exposed to the risks, distancing them from the reality of the fishers and aquaculturalists—and perhaps from their own potential exposure, even to trace amounts from city water treatment plants. Their academic and professional backgrounds have provided information to understand the effects of cyanobacterial blooms from literature, not, in most cases, from first-hand experiences. The theory of social locations argues that identity factors, such as race, gender, age, and socioeconomic status can influence how people construct meanings about environmental challenges (Taylor 2012). We posit that these factors result in heterogeneous experiences of cyanobacterial blooms, particularly between fishers and aquaculturalists and designated experts.

Expert health concerns about microcystin persistence in water sources are well-founded (Butler et al. 2009; Kubickova et al. 2019). They cited a range of problems, including negative impacts on the nervous system, negative impacts on growth in children, and cancer. These health effects are largely consistent with the literature, which implicate microcystins in colon and liver cancer, neurodevelopment, and immune suppression with chronic exposure (Kubickova et al. 2019; Massey et al. 2018).

Cyanobacterial blooms reduce water transparency and oxygen saturation, thereby affecting fishery food webs and fish-dependent livelihoods. This is acknowledged by fishers, aquaculturalists, and experts. Fishers and aquaculturalists have become aware of the loss of water transparency as a result of their daily activities, facilitating comparisons to Lake Victoria's previous conditions, which they universally described as better, even pristine, in the past. Communities that depend on natural resources for their survival tend to be highly observant of their landscapes and, therefore, attuned to the changes that occur within it (Crate and Nutall 2016). The experts' awareness of these changes largely derived from water quality or fisheries monitoring data and scientific studies. As such, they described similar livelihood impacts not in historical or experiential terms, but rather as related to fishery management and catch opportunities.

Programmatic Responses: Behind the Power Relations of Knowledge

Environmental challenges are socially and dynamically constructed. Recognizing that knowledge is plural and generated from experiences that exist within these constructions is critical to understanding and addressing environmental challenges (Agrawal 1995; Burman 2012; Sium, Desai, and Ritskes 2012). The disconnect between expert and local understanding of blooms and their management is an example of such pluralities of knowledge. The overweighting of expert opinions relative to local knowledge creates a hierarchy that ultimately has negative impacts on management and outcomes.

Fishers and aquaculturalists stressed the need for solutions to improve their livelihoods and reduce exposure to blooms. However, they were largely unaware of existing efforts, like LVEMP, to restore the Lake Victoria aquatic ecosystem. LVEMP's $70 million in funding has been directed at holistic environmental remediation, including catchment afforestation, land use management (soil and water conservation), wetland management, rehabilitation of treatment plants, and water hyacinth control by weed removal, among other activities.

When certain views dominate others, decision-making processes are impacted. Limited involvement of fishing communities in a large-scale basin-wide project not only limits hope, but also threatens to perpetuate a power dynamic that excludes their realities. Inclusion of the communities of Lake Victoria could better address the most pressing issues and improve assessment of effectiveness by integrating their lived experiences (Sansom et al. 2016). Community integration can translate into the development of contextualized interventions better attuned to local needs (Corburn 2002). Further, it can challenge power relations by making research and policy-making reciprocal and inclusive of all sectors.

Limitations

The findings of this study are limited by the diversity of respondents, who were mostly men between the ages of 31 and 40. The study was also conducted partly in a foreign language, necessitating a translator for some members of the research team. Translation can impact understanding of research participants' meaning and emphasis, particularly when analysis relies on transcription (Quinn 2005).

Conclusions and Recommendations

Multiple and heterogeneous realities exist regarding the causes of cyanobacterial blooms among different stakeholders in the Winam Gulf of Lake Victoria. This study shows that the fishers and aquaculturalists, due to their immediate dependence on Lake Victoria, understand the occurrence and complexities of algal blooms through lived experience and suffer more immediate effects on health, clean water, and livelihood. Limited options to address algal bloom effects on health, water quality, and livelihoods mean that lived experience is integral to fisher and aquaculturalist cultural models depicting blooms and their causes. Experts, on the other hand, have management-based understandings of bloom causes. While they recognize the plight of people dependent on the lake and are aware of programming that aims to reduce the impacts of cyanobacterial blooms, they are often removed from the immediate effects of blooms and perceive their causes as more uniform and contained.

The multiple realities that exist, however, are not weighted equally. Expert perceptions are often assumed to trump local knowledge and experiences. This hierarchical ordering of knowledge hampers management. Improving the flow of information between the experts and the fishers and aquaculturalists could help reduce the risks of exposure to toxic cyanobacterial blooms, as well as improve scientific understanding of the causes and consequences of blooms at the local level. Incorporating fishers and aquaculturalists in the design of projects (such as LVEMP) could contribute to the development of interventions that align and resonate with their perceptions, and are thus more effective.

Interventions related to harmful algal blooms can be placed broadly under the categories of prevention, avoidance, and amelioration. Community engagement across stakeholders is necessary, however, for these interventions to be successful. Prevention strategies could use infrastructure improvements to reduce nutrient pollution from urban effluent, improve sanitation at decentralized sites, and reduce agricultural run-off. Such large-scale strategies already align with the LVEMP project. Contributions by local people can help by going beyond design strategies to facilitating the dissemination and socialization of projects that support avoidance of toxins and community-scale amelioration (e.g., through ecofences), all of which aim to restore the aquatic state of Lake Victoria but require the efforts and cooperation of those in direct contact with the lake. Inclusion of local people can also help equalize power relations, diminishing the ways in which one discourse dominates over others.

The current situation in the Winam Gulf is already alarming for those who directly depend on it for their survival. As this study has shown, during their lifetimes, both fishers and aquaculturalists have seen how the environmental challenges of Lake Victoria have escalated. The current challenges pose critical concerns for the future, as climate change will almost certainly exacerbate cyanobacterial blooms in duration and frequency. The time to act is now, and integrating a range of stakeholder perceptions in addressing cyanobacterial blooms could be a more effective way to reduce the threat.

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Appendix

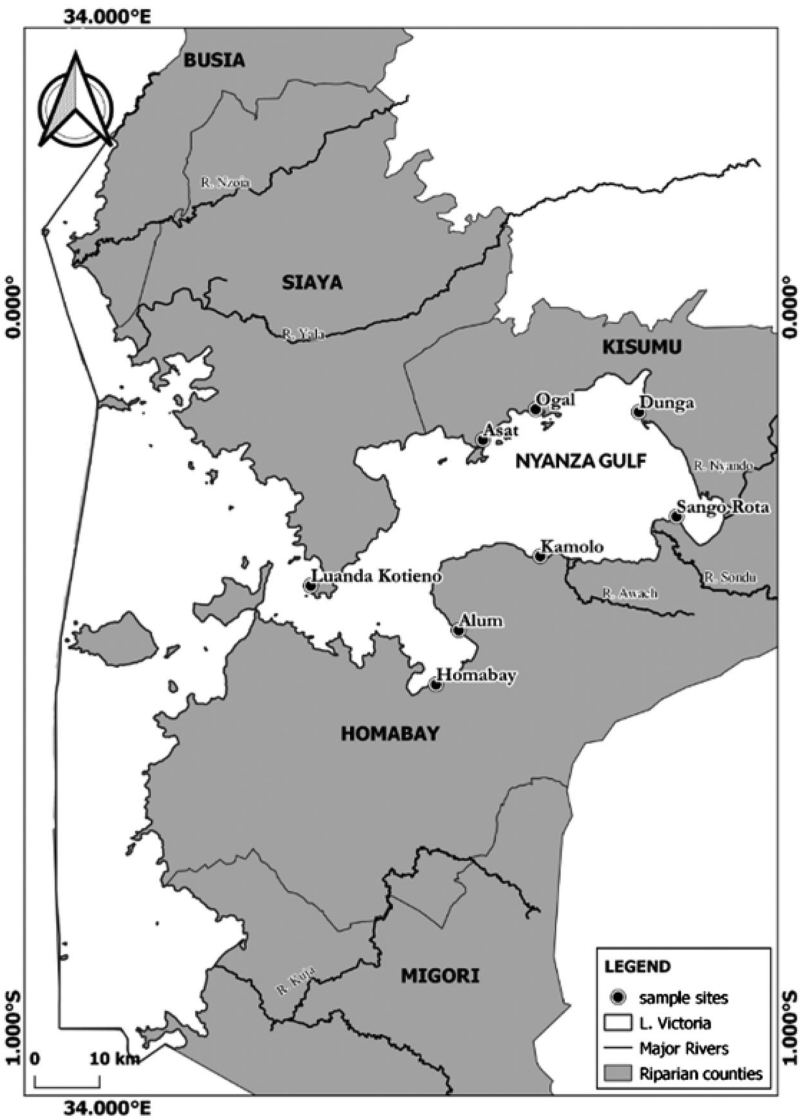

Figure A1. Kenyan side of Lake Victoria, with study sites demarcated by black circles.

Table A1. Fishers and aquaculturalists interviewed, including those holding a leadership role in the beach management units.

Actor	Number	BMU leadership role
Fishers	18	7
Aquaculturalists	7	1
Both activities	1	1
Total	26	9

Their BMU leadership positions included Chair, Chair Assistant, and Secretary.

Table A2. Expertise (2a, left) and educational (2b, right) background of experts ($n = 10$).

(2a) Expert background	Number	(2b) Educational background	Sector of current employment		
			Government	NGO	Private
Government officials	3	Natural sciences	5	1	1
Regional BMU	1	Medical	1	–	–
NGO employees	1	Graduate degree	1	–	–
Researcher at institute	3	No degree	–	–	1
Private companies	2				
Total	10	Total	7	1	2

Table A3. Names to refer to cyanobacterial blooms.

Name	Frequency of use	Language	Actor
Fishing sector			
Orwengu	5	Luo	Fishers, BMU members
Opirou	3	Luo	Fishers, aquaculturalists
Otwodo	2	Luo	Fishers/BMU members
Osikonyodha	2	Luo	Fishers, BMU members
Tuoro	1	Luo	Fisher
Yugni	1	Luo	Aquaculturalist
Pusi	1	Luo	Aquaculturalist
Twodo	1	Luo	Aquaculturalist
Expert community			
Algae blooms	8	English	Experts
Pusi	1	Luo	Expert
Othinyo	1	Luo	Expert
Onyoungi	1	Luo	Expert