When Things Go South, It Does Affect You

Perceptions of Vibrio-Related Occupational Risk and Harm Among Chesapeake Bay, USA,-Based Watermen

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Abstract: Commercial fishing is a dangerous profession with known hazards for musculoskeletal injuries, yet minimal examination of microbiological or attendant psychosocial hazards from water- and food-borne pathogens like *Vibrio vulnificus* and *V. parahaemolyticus* exists. Improving knowledge of *Vibrio*-related hazards addresses Total Worker Health® concerns for commercial fisheries workers. **Methods:** Following a grounded theory approach, we conducted semistructured interviews with watermen and related workers who fish and harvest shellfish in the Chesapeake Bay, USA, to investigate risk perceptions and understanding, and compliance with regulations intended to reduce worker and consumer illnesses and injuries from pathogen exposures. **Results:** Worker and consumer illnesses and injuries, and threat of fishery closures—with regulatory and organizational factors—influence this workforce. **Conclusions:** Our findings support interventions that promote monitoring, surveillance, and awareness of *Vibrio*-related risk among watermen, regulatory officials, medical professionals, and the public.

Keywords: Vibriosis, watermen, fishermen, Chesapeake Bay, microbiological hazards, Total Worker Health®

LEARNING OUTCOMES

After reading this article, the audience will be able to:

- Identify ways that microbial agents such as *Vibrio* spp. present Total Worker Health® threats to watermen, seafood processors, and those in associated industries in the Chesapeake Bay region.
- Explain Total Worker Health®.
- Explain examples of interventions that may help to prevent adverse health outcomes in workers.

The United States (US) commercial fishing industry is one of the most lucrative components of the economy[1]—and one of the most hazardous.[2,3] From 2000–2015, there were 725 reported deaths of commercial fishermen in the US, yielding a rate substantially higher than the combined rate of all other sectors in the country (117/100,000 workers versus 4/100,000 workers, respectively, on average per year).[3] In comparison to individual sectors, the commercial fishing mortality rate is third only to loggers (the industry with the highest fatality rate in 2022) and roofers.[4] Despite COVID-19 slowing overall fishing industry activities in 2020, 0.92% (n = 44) of the 4764 reported occupational fatalities were attributed to fishing. Of those, 19 deaths occurred while shellfish fishing.[5] These rates have remained consistently elevated since 2019 after a prior period of decline,[6,7] which suggests that existing policies and safety

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C.A.G. led conception of this project, managed recruitment, conducted all interviews, and led the writing of this paper. S.F. contributed to the conceptualization of the project, provided technical expertise and mentorship to and review of the data collection and analytical phases, and reviewed and edited the paper throughout the writing process. D.L.W. provided advice on recruitment and technical expertise and edits during the writing of this paper throughout the writing process. M.T.B. contributed to the conceptualization of this project and provided technical expertise and edits to the paper throughout the writing process. D.J.B. contributed to the conceptualization of this project and provided edits to the paper throughout the writing process. M.F.D. contributed to the conceptualization of the project, provided technical expertise and mentorship during all phases of the data collection and analysis, and provided edits throughout the writing process.

The author team adhered to COREQ guidelines for data collection and STROBE guidelines for reporting.

Data availability: Given the qualitative nature of this research, the data that supports the findings of this study are not publicly available due to privacy and ethical restrictions. However, we have included some data, such as our codes, in a supplementary file associated with this manuscript.

Ethical considerations & disclosure(s) (e.g. IRB Information, consent process, if applicable): This study's methodology was reviewed and approved by the Johns Hopkins Bloomberg School of Public Health Institutional Review Board, IRB Number: CR00001232.

Consent was provided via oral consent, at the start of each interview. The interviewer read the same consent form to each individual, asked for questions, and then asked if the individual consented to participate in the interview.

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procedures may have reached the limit of their effectiveness and/or that new challenges face the industry.

Occupational hazards that occur in fishing are understudied.[2] Most contemporary research concentrates on a few key means by which harm can occur to those who work on the water, predominantly through slips and falls,[6] or through cuts, strains, and broken bones.[8–11] However, gaps remain in official occupational safety reporting and data about some of the less-visible, job-related injuries including secondary microbial exposures that can lead to infection after becoming wounded at work. These may be underreported or may not be classified as occupational injuries or deaths because they may manifest with a time lag, sometimes months or years after the original health event. Furthermore, exposure to infectious agents such as *Vibrio spp.* also can impact psychosocial health and well-being of the workers, colleagues, and customers. From a Total Worker Health® (TWH) perspective, overlooking microbial exposures results in substantial underestimates of the injury burden experienced by these workers. TWH is a holistic approach that considers multiple contributors to workers' overall well-being, including psychosocial and economic impacts, and thus is a fitting framework for studying microbial exposures in fishermen.[12]

The bacterial strains of interest to this study, *Vibrio vulnificus* and *V. parahaemolyticus* (collectively, *"Vibrio* spp."), are halophilic, Gram-negative bacteria that can produce a range of deleterious health effects in humans—collectively known as "vibriosis."[13] Each species of bacteria can lead to food-borne illness, including vomiting, diarrhea, and dehydration.[14,15] Additionally, each may cause severe illness (eg, extreme dehydration, cellulitis, septicemia, necrotizing fasciitis, gangrene) that may lead to hospitalization, amputation, and death.[14,16,17] Illnesses resulting from exposure to *V. parahaemolyticus* most commonly occur through ingestion of contaminated seafood, though dermal exposures do occur and often cause a less severe infection.[15] In contrast, *V. vulnificus* exposures predominantly occur through dermal routes, although foodborne exposures also occur, and may cause a very serious, even life-threatening illness. *V. vulnificus*-related vibriosis has the highest mortality rate associated with seafood-borne disease.[15,17] Risk factors associated with severe health outcomes following *V. vulnificus* exposure include being male, over 40, and having preexisting hepato-renal comorbidities such as diabetes mellitus, hepatitis, cirrhosis, or certain cancers.[15,17] Consumer illness, or in certain parts of the country, in situ levels of *V. vulnificus* and *V. parahaemolyticus* detected through surveillance above an advisory limit, can trigger shellfish recalls or closures. As demonstrated by other types of marine hazards that impact food systems, these measures can contribute to considerable economic losses and subsequent sociocultural effects such as degradation of community connection and support.[18,19]

While particularly in light of climate change, and thus changing conditions in which the bacteria propagate and spread,[20] one may anticipate more cases to occur in occupational settings, data regarding where and how exposures occur are limited at local levels and not available at a national scale. Thus, there are little explicatory data regarding how widespread vibriosis may be within the overall fishing industry.

We conducted a series of qualitative interviews with watermen and related workers such as individuals who work with seafood processors, business management staff, state and federal government officials, academics, and nonprofit leaders in the Chesapeake Bay region in order to bring the perspectives of frontline workers who experience vibriosis disease risk to the occupational health literature and inform policy discussions (N.B., watermen: a nongendered term employed to refer to wild-catch and aquaculture seafood harvesters, including individuals collecting oysters, hard clams, and crabs; additionally, seafood processors is a nongendered term referring to individuals who process seafood for commercial sale, including picking crabs or shucking oysters) about the health risks associated with occupational exposure to *V. parahaemolyticus* and *V. vulnificus.*

METHODS

Data Collection

We used an iterative grounded theory approach to guide data collection and analysis[21] with semistructured key informant interviews, per the Consolidated Criteria for Reporting Qualitative Studies (COREQ) guidelines, to collect data.[22] The extended parallel process model, rooted in perceived threat and efficacy,[23] provided the basis for developing our interview guide which included as initial domains demographics, workplace injuries related to *V. vulnificus* and *V. parahaemolyticus* exposures, knowledge of these bacteria and understanding how exposures occur, perceptions of personal risk and risk to consumers, and views on regulations. In keeping with the iterative approach to data collection and analysis that characterize qualitative research methods, we updated and refined the interview guide as interviewees revealed unanticipated information or the analytic process yielded new insights.

Inclusion criteria included being a waterman in the Chesapeake Bay region, a member of an affiliated industry (eg, industry or trade organization, union, government agency), or a related sales or marketing professional. We also required that participants be over 18 years of age and be able to conduct the interview in English. Recruitment was performed and data were collected throughout the period of June 2021 through March 2022; the two were performed concurrently, and out of respect for participants' schedules, we endeavored to hold interviews at our participants' convenience, sometimes within hours of initiating contact. We conducted 28 interviews (including one reinterview) with 27 participants via telephone[4] or video call[24] (Zoom, Version: 5.10.4 [6592]). Initial contact was made via email, with follow-up via email and telephone, using a script.

We used a combination of purposeful and snowball sampling to identify interview participants. For the purposeful sample, we conducted Internet searches using the following terms to identify potential contacts from company websites: *oyster farm Maryland, oysters Virginia Chesapeake Bay, oyster farm Virginia, watermen Maryland, watermen Virginia, crabbers Virginia, crabbers Maryland, seafood processor Virginia, seafood processor Maryland, oyster shucking facility* processor Maryland, oyster shucking facility* processor Virginia, oysters Maryland Chesapeake Bay, Virginia Department of Health, Maryland Department of Health, Virginia Department of Environmental Quality, Maryland Department of Environmental Quality, Virginia Department of Marine Affairs, Maryland Department of Marine Affairs.*

For government and nonprofit staff, we sourced potential contacts from staff pages on websites for the state departments of health, environment (or similar), marine resources (or similar), and other related agencies. We complemented these systematic search strategies with people identified through our professional networks. We then asked all interviewees to recommend other potential participants at the conclusion of each interview (snowball sampling).[24] We continued holding interviews and, per our study design, conducting our concurrent data analysis until it seemed as though we had reached data saturation.

We did not provide incentives for participants. Every participant provided oral consent. Our methodology was approved by the Johns Hopkins Bloomberg School of Public Health Institutional Review Board (IRB CR00001232). Consent was provided via oral consent, at the start of each interview, following identical processes. The interviewer read the same consent form to each individual, asked for questions, and then asked if the individual consented to participate in the interview.

Data Analysis

We transcribed every interview using NVivo (version 1.6.2 [4831]; QSR International; Australia) and supplemented this auto

transcription with human transcription when the technology failed to process segments of the recorded interviews accurately. We checked the fidelity and quality of the resulting transcripts by reviewing each transcript while concurrently listening to the relevant recording. We then coded each interview employing an iterative process. C.A.G. first read each interview twice to identify a set of initial codes. During the second review, we began assigning codes throughout the transcripts. After every interview was coded, C.A.G. then rereviewed and recoded each interview to harmonize the codes across interviews for the purpose of reflecting common concepts emerging from the data. We followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines for presenting our data collection, analysis, and presentation.[25] Please see the associated checklist in Supplementary Digital Content file 1 (http://links.lww.com/JOM/B731).

Reflexivity Statement

The first author (C.A.G.) managed recruitment, conducted all interviews, and led the analysis that resulted in the explanatory domains presented in this article. She is a native of Central Virginia with a background in marine biology, enjoys a lifelong love of oysters and crabs, and is devoted to helping the individuals who harvest these products.

RESULTS

The 27 participants with whom we spoke represent 30% of the 87 people we invited to participate. Most who were invited but did not participate cited not having appropriate expertise, although some were restricted by their job from participating (these were all state government workers). Interviews typically lasted between 40 to 45 minutes, although some were shorter, whereas others were much longer (up to 95 minutes). Twenty-three participants (85%) were based in Virginia or Maryland, the two states bordering the Chesapeake Bay. We spoke with experts from policy, academia, and nonprofit organizations in other areas of the country. Among the 10 participants who actively work in the commercial fishing industry (primarily oysters, also crabs and finfish) in the Chesapeake, three also own or manage processing facilities. We present our findings in this section following the domains and subthemes that emerged from the analysis. Table 1 delineates industry demographics represented in our sample.

Our interview process yielded 45 codes (Supplementary Table 1, http://links.lww.com/JOM/B732). Through the process of reviewing the coded data, we identified five main domains that constitute the results presented herein, which were as follows:

- Health and *Vibrio*
- Ability or willingness to limit *Vibrio* exposure among consumers
- Communications, regulations, and policies
- Risk perception and understanding
- Research and knowledge gaps

Domain 1—Health and Vibrio

Physical Health

The watermen we interviewed were aware of *V. vulnificus* and *V. parahaemolyticus*, including the human health concerns that can arise from exposure to these pathogens, and to varying degrees, knew how to avoid developing disease; however, participants told us that seafood processors often are not aware of vibriosis and associated health risks, beyond being aware of a "crab disease" that causes inflammation and skin infection. We heard about watermen's routine injuries—cuts on their hands and legs while working—that per their recollection often become red, painful, and inflamed, an indication of potential development of vibriosis from *V. vulnificus* exposure.[26] Others reported vibriosis diagnoses from *V. parahaemolyticus,* which resulted in intense bouts of gastroenteritis and diarrhea. Many participants mentioned knowing personally or knowing of someone who either had been seriously sickened by vibriosis, or had product linked to consumer illness. Two watermen had customers die from *V. vulnificus*-related vibriosis exposures linked to their products. One waterman told us he previously had surgery on his hand due to *V. vulnificus* infection caused when he was "spined by a bluefish fin." Many interviewees told us about acquaintances working on the water or in processing facilities who had lost fingers or were hospitalized because of vibriosis.

Most participants shared avoidance measures they take to prevent personal illness, irrespective of whether they professed concern to us regarding their own risk of severe illness or death from exposure to either species of *Vibrio.* For example, one of our participants stated, when asked if he was concerned about vibriosis risk, "We have a rule [for our employees] that if you suffer a wound while on the job... we require you to flush it out with hydrogen peroxide or some other agent.... The job requires you to be on the water a lot, so it's kind of one of the risks of the job... but you hear stories all the time about folks having to have surgery or losing a limb." Another waterman told us that he advises all new watermen to "proactively clean those wounds out and aggressively treat on the front end of that instead of waiting for a problem." They described these actions as a response to financial concerns—staying healthy means they can continue to work and collect a paycheck. It also means they can avoid costly investigations and recalls of their products should illnesses be linked to their seafood. Each waterman we spoke with mentioned how they treat cuts quickly and described treating every cut with triple antibiotic ointment or washing their hands constantly with water, soap, and diluted bleach (a medical countermeasure recommended for other microbial skin diseases, including methicillin-resistant *Staphylococcus aureus*[27]).

Some participants also mentioned that they do not harvest during warmer months when *Vibrio* is more prevalent out of concern for their own health as well as that of their customers. Some watermen told us that they or their employers added their own *Vibrio* safety protocols to employee handbooks, requiring training in first-aid and hygiene in addition to food safety measures. Some participants said that they take care because they want to set a good example for younger workers. One man explained how the nature of the job provides so many opportunities for *Vibrio* exposure and vibriosis development that he wished more of his colleagues would take better personal care to protect themselves, further elaborating that it would "freak everybody out if they realized the [bacterial] levels" in the water where they work and the shellfish they handle.

Although we heard that gloves can be cumbersome or restrictive, nearly all our watermen reported using gloves at least some of the time to prevent and reduce the severity of cuts, or to prevent water from entering open wounds. We heard that gloves limit dexterity and speed, and catch on shells, which can be problematic. One interviewee told us that an acquaintance started wearing thick rubber gloves on the job after he developed vibriosis from *V. vulnificus* and had a finger amputated.

Conversely, with regards to glove and other personal protective equipment (PPE) application, we heard from three participants that gloves and first-aid materials such as triple antibiotic ointment or handwashing stations often are limited in processing facilities. Participants described that many processors also elect not to wear gloves as, in addition to affecting dexterity, the gloves often are made of latex, tear easily, and thus do little to prevent injury. These same participants discussed that seafood processors often do not have reliable

TABLE 1. Participants' Industry Demographics

Industry	No. Participants (%)
Watermen (incl. oystermen, crabbers, hard-clammers, and individuals who own or manage processing/shucking facilities	10 (37)
Federal employees	9 (33)
Extension agents, academics, and representatives from trade organizations and nonprofit organizations	8 (30)

transportation or health insurance and are in rural areas that do not have public transportation options; thus, we heard it can be difficult for processors to receive and afford medical care.

Despite the risks and injuries, watermen described a general reluctance to seek medical care, even for suspected vibriosis infections, albeit for different reasons. Watermen almost exclusively cited that it is not "macho" or "manly" to seek medical care, that getting hurt at work is a part of the job, and that they can self-treat cuts and gastrointestinal infections. Many also reported avoiding professional healthcare because providers often seem unsympathetic to, or unknowledgeable about the exposures, hazards, and symptoms faced by people working on the water, making accurate diagnosis difficult. Watermen described how going to the doctor means less time at work, and thus less pay; and that long work hours and living and working in rural areas with fewer healthcare providers are barriers to workers receiving medical care. Furthermore, we heard that workplace-based health insurance is not guaranteed as many of our participants were self-employed or considered independent contractors, making healthcare costs prohibitive. Interviewees noted that available medical clinics dramatically declined during the COVID-19 pandemic, thereby further reducing access.

Relationship to Mental and Economic Health Impacts

Mental health impacts of vibriosis were noted as a concern by all participants. Participants told us that when a company's products are linked to consumer illnesses, this impacts employee morale. Multiple watermen described the stress and panic of understanding how their companies operate on thin profit margins and are susceptible to variations in consumer purchasing after illnesses linked to their products, or changes to food safety regulations. We also heard how long-term stress and fear of consumer illness and economic effects have ramifications for psychological well-being. One waterman told us he had been hospitalized for stress-related mental health reasons because he was so worried about the viability of his business and the increasing regulatory demands. We spoke with extension agents and federal workers who discussed the psychological trauma they see in watermen that stems from knowing their product sickened a customer; fear of losing consumer trust and sales, and not being able to provide for their families; and hopelessness about the future of their business.

Six participants mentioned the impact that the COVID-19 pandemic had on the commercial shellfish industry in the Chesapeake Bay. Three participants specifically shared comments similar to the following, with regards to changes in market forces, supply chain, and necessary pivots in how sales were made: "Like 90 percent or so of the harvested oysters go to restaurants eventually. So, when all the restaurants closed down, pretty much everybody lost all the markets. We had a few farms that were able to transition into some online sales, farmers' market sales… local deliveries, that kind of thing. But it wasn't enough to really fill that void [created by the loss of a major revenue stream]." Two individuals also mentioned that the rurality of the areas in which most watermen and seafood processors live and work was significant, as already-limited medical facilities had even less availability for patient care during the pandemic.

Two participants who work directly with seafood processors told us that seafood processors in Maryland are almost all seasonal female migrant workers from Mexico on H2-B visas, who make their families' annual income working in Chesapeake-region processing facilities.[28,29] One of the participants commented that processors are "terrified" of occupational injury and illness, but that "gloves keep them from processing the seafood as quickly and making quotas" that ensure continuous employment.

Domain 2—Ability or Willingness to Limit Vibrio Exposure Among Consumers

Nearly all the watermen we interviewed and many of the workers in adjacent parts of the industry talked about traceback and the associated economic and psychological implications. Interviewees described the responsibility of safe transport and sale (including in restaurants) placed on individuals outside of their companies, even with adherence to hazard analysis and critical control point (HACCP) plans, as being stressful. Current policies and regulations require an illness investigation into any products sold concurrent with the sale of a product that leads to consumer illness due to the potential for cross-contamination, also known as co-mingling (for instance, two oysters sold as a part of the same sampler platter, or crabs or clams from different companies that were sold on the same plate of steamers). Nearly all of our participants mentioned how "sampler platters" of oysters, in particular, inadvertently can lead to cross-contamination, and are the sources of simultaneous investigations of multiple companies. These investigations entail halting a company's sales pending an outcome that quantifies *Vibrio* levels for each product (eg, sales may resume when the product has been deemed safe for sale and consumption). Participants mentioned that this can have serious economic effects for all but the largest seafood companies. Many watermen discussed how the food supply chain—from harvest, to packaging, to transport, to commercial sale—often involves many different individuals and companies, thus providing ample opportunity for errors that enable the bacteria to propagate. They also mentioned how shipping companies may not follow temperature and storage policies, thus enabling the *Vibrio* bacteria to increase to levels that can cause human illness despite the best efforts of the supplying companies to maintain safe practices. Notably, three participants mentioned that the COVID-19 supply chain disruptions affected and changed the means in which watermen reach consumers: the watermen now can ship their product directly, rather than following historic methods of selling product through seafood markets or similar, relying on multiple shipping companies and methods, and assuming adequate food safety practices are followed.

Domain 3—Communications, Regulations, and Policies

Some government employees we interviewed told us that additional food safety regulations were unnecessary "because the seafood industry is about as regulated as you can get," but that there is a need for improved *in situ* (water, shellfish) surveillance and predictive modeling, including expansion of federal pathogen forecasts. They described how difficult it is to monitor and test within aquaculture environments, because of the volume and quantity of seafood that is harvested, the bacterial variability within each animal and location, and funding and capacity limitations to conduct these activities.

Watermen noted that the Interstate Shellfish Sanitation Conference, as the formal body for overseeing US shellfish safety,[30] is "a good platform" that convenes and involves federal, state, fishing industry, and research representatives in the policy process; however, participants told us that the bureaucracy involved with the Interstate Shellfish Sanitation Conference can be "extremely burdensome" and "very, very complicated."

Domain 4—Risk Perception and Understanding

Watermen generally conveyed a basic understanding of the threats of *Vibrio* exposure and how exposures occur; although, some watermen confused *V. parahaemolyticus* with *V. vulnificus*, stating that all *Vibrio*-related illnesses were linked to oral and dermal exposures. All but two of the watermen participants stated that they were more concerned about impacts to their customers' physical health from exposures to *Vibrio* spp. than their own health and described being "kept up at night" worrying about the guilt of causing or contributing to illness or death, as well as the resultant implications for protecting their families from the financial consequences of consumer illness.

Regulator Knowledge

One consistent concept that emerged from our interviews: US seafood is safe, but there are myriad risks for watermen and seafood processors that are understudied and there is a need for better predictive modeling. Many expressed concerns about the lack of research and data on *Vibrio* as an occupational hazard. Multiple individuals in regulatory positions said that it was difficult to consider additional regulations for protecting watermen and seafood processors from *Vibrio* as there are limited data on cases among these workers and inconsistent information on how cases among consumers affect watermen. Participants stated they had not considered the effects of microbial hazards on occupational health because those are not as visible or frequently reported as deaths from falls overboard or musculoskeletal injuries; additionally, they told us that it is difficult to track and follow up with seafood processors. Many told us that it is virtually impossible to find documentation of microbial injuries and illnesses for these types of workers. In part, they attributed this gap to the fact that watermen may not be aware of their ability to report workplace injuries or receive worker's compensation. One interviewee in a regulatory position told us how concerned they were about the impacts of vibriosis on watermen. This person stated that they "routinely get calls from guys crying their eyes out about being scared about not being able to provide for their families" due to vibriosis concerns.

Domain 5—Research and Knowledge Gaps

Education and Training

Multiple participants referenced workshops and trainings on workplace safety and shared that protecting oneself and customers from vibriosis through use of PPE, sanitary measures (eg, hand-washing), and by following state regulations is a common training topic. Notably, participants discussed that local, regional, and national watermen's associations offer comprehensive trainings on *Vibrio* and vibriosis. One waterman told us these trainings were intended to "scare the hell out of" watermen, and to impress the hazards of *Vibrio* upon members of the industry. Despite these existing interventions, participants reflected that education is lacking for watermen entering the industry. Numerous individuals from all industries told us that trainings and products should be offered as required elements of the permitting process, in addition to the trainings that already are offered. From their perspectives, this would be more effective than the optional trainings which may not hold the attention of new watermen. A few participants mentioned past efforts, including the development a waterproof (laminated) information sheet distributed at the time of licensing for watermen to post on their boats—although some questioned the value of this resource, stating doubts of whether anyone reads the materials.

One individual mentioned that there is little to no education on vibriosis for seafood processors, and that if any is provided, "it usually is anecdotal, and not always accurate. Or you'll have the facility manager posting [an instructional] card in English or maybe Spanish, but not showing pictures, which is a problem when many of the processors have limited literacy."

Educating the Public and Medical Practitioners

Many participants emphasized the need to improve education to the public, including understanding risk, knowing how to identify vibriosis symptoms, and knowing when to seek medical care. Many participants noted a need for medical practitioners—including clinicians and mental health professionals—to be educated on different types of occupational hazards faced by this worker population, inclusive of associated mental health impacts. Watermen told us that they want to be "heard" by the medical community.

They told us that this is important for protecting the seafood industry given the serious economic consequences that consumer illnesses can have for watermen and their families. They also expressed concerns about people who are uneducated about the potential severity of *Vibrio* and the impacts it can have on watermen and their communities. To this point, one waterman said that he knows of individuals who are immunocompromised or older in age who ordinarily avoid raw or undercooked foods but will eat raw oysters, accepting an inherent risk. Should those individuals become sick or die from vibriosis, watermen will suffer. Multiple participants stated that medical practitioners need specific training on *Vibrio* also to inform their patients—recognizing symptoms, providing accurate care, and advising patients on safe food handling and consumption practices.

Other watermen and other industry interviewees told us that the public needs to learn about food safety, including safe storage and handling practices for raw seafood to prevent exposure and illness and subsequent effects to Chesapeake Bay fishing communities. An interesting observation was how the COVID-19 pandemic has affected the role that watermen play in ensuring consumer safety. While previously watermen largely were responsible for following food safety guidelines and regulations for food storage and shipping, the COVID-19 pandemic opened channels that now enable them to engage directly with consumers and thus educate the public when delivering product.

DISCUSSION

Here we examine how *V. parahaemolyticus* and *V. vulnificus* may affect the TWH of Chesapeake watermen, in one of the only papers to consider microbial hazards to this population. We assess the economic and social importance of *Vibrio* to the Chesapeake's fisheries. Impacts of *Vibrio* and vibriosis on watermen and fishing communities, as well as the industry more broadly, are under-studied and underreported. This is despite a broad understanding that commercial fishing is one of the most lucrative and dangerous industries in the US.[1,2]

This paper advances the field by exploring mechanisms by which watermen and seafood processors may be affected by microbial hazards. US-based fishing industry research tends to be regionally focused, potentially neglecting the US fishery landscape as a whole, and missing an opportunity to understand the epidemiology of risk and policy measures that could be implemented to better serve all fishermen. While this paper is regional in scope, it is intended to serve as an initial foray into research that could be expanded to other parts of the nation. It also provides some baseline knowledge and understanding of how microbial hazards affect watermen.

Our objective was to identify the barriers to achieving and maintaining safe work environments by examining the experiences of watermen and seafood processors, and to describe how they perceive vibriosis disease risk and after-effects resulting from exposure. We confirmed that waterborne bacteria such as *Vibrio* are perceived as occupational health threats by watermen and associated professionals, and that economic and psychosocial effects should be a metric for assessing the occupational well-being of watermen. This has implications for protecting watermen and seafood processors around the country from other microbial hazards.

How Harm May Occur

We noted many commonalities in how *Vibrio* exposures and related harms occur among Chesapeake watermen, seafood processors, and the population's collective ability to prevent or mitigate health effects, including those painting the TWH picture pertaining to this biological agent. Watermen and people who work with seafood processors described workers getting cuts on their hands that became red, inflamed, or infected, or developing serious gastroenteritis after eating raw seafood. In some cases, participants, or their colleagues and customers, experienced severe health outcomes such as hospitalization, mental health effects, amputation, or death. They identified ensuring the long-term financial security of their families as their primary motivation in protecting themselves and consumers from exposure and illness. Fear of not being able to provide for their families, failing in

their jobs, or becoming ill themselves also motivated participants to take preventive measures. However, processors especially were described as being disadvantaged in preventing harm as their immigration status and family's income often are dependent upon them making quotas; they also have limited access to affordable healthcare. Thus, we were told the workers often ignore injuries.

Mitigation or Prevention of Harm

Nearly all of the current or former watermen we interviewed discussed taking optional, proactive measures to prevent illness, as well as adhering strictly to state and federal food safety policies and guidelines. That said, most told us they often avoid seeking professional medical treatment either because of lack of concern or feeling miscounted by healthcare providers. We can conclude that the preventative measures adopted by the watermen (eg, applying immediate first-aid, hand-washing, etc.) have made a difference in protecting themselves and their industry. However, one would expect even better health outcomes with improvements in the medical system, as suggested by Turner et al., 2018; Doza et al., 2022.[31,32] These include destigmatizing medical care seeking, providing consistent training on and access to basic hygiene and first aid materials, ensuring employers offer improved PPE that is consistently available, and training watermen and seafood processors on the symptoms and risks of vibriosis. Expanding access to healthcare for these workers was another consistent theme we heard, and that bears consideration by state and federal agencies, including the Occupational Safety and Health Administration (OSHA) for their protection. This includes improving how care-providers understand potential exposures and risks faced by watermen, as well as the fundamental nature of the fishing industry. Furthermore, options for affordable, easily accessible healthcare should be incentivized and expanded in the rural Chesapeake Bay region, something that could be implemented by nonprofit organizations or local healthcare service providers, as well as by the respective states' Departments of Health.[32–34] As Teisberg et al.[35] indicate, there are direct correlations between overall improved health and overall improvements to value-based, affordable, and holistic care.

Our participants discussed how the COVID-19 pandemic has altered and shifted the burden of food safety and vibriosis risk in the supply chain. Previously, the supply chain for watermen often consisted of packaging and transporting products through truckers and shipping companies, and then relying on sale through restaurants or markets, thus creating more opportunities for HACCP plans to fail. However, this has changed with COVID, as many watermen noted they now can sell directly to consumers, thus removing some potential opportunities for failures in food safety mechanisms.

A key facet to protecting watermen is improving monitoring, surveillance, and predictive capabilities of the bacteria in the water and in shellfish, as well as the incidence of vibriosis among watermen. Many of our participants referenced the value of pathogen forecasts, such as those maintained in the Chesapeake by the National Oceanic and Atmospheric Administration (NOAA). Improved resolution of these forecasts and improved monitoring, plus expanded availability of associated tools such as NOAA's *Vibrio* harvest calculator,[36] may help watermen better assess personal and consumer risk of high *Vibrio* concentrations and potential infections. This may provide real-time information to watermen on *in situ* bacterial concentrations and could inform food safety managers throughout the supply chain about potential risk of illness in consumers. Additionally, these data could be used to inform consumers as they consider their risk prior to eating raw shellfish. While bacterial concentrations can and do increase following harvest and storage, improved monitoring could help to provide a baseline concentration of the pathogen at time of collection. Given the concerns we heard from many watermen about cross-contamination during shipping and in retail settings, we see a need for technology that will enable waterman to track the temperature of their product as it proceeds through the supply chain, thereby reducing some of the burden of proof should their product be linked to consumer cases of vibriosis (and reducing risk as well). We also see a need for improved glove design that is resistant to cuts but not constrictive or restrictive, is flexible, and does not impede the ability to work quickly and comfortably. Designing a protective glove that addresses users' concerns could increase uptake and therefore protection among workers.

Finally, many of the state and federal government representatives who participated mentioned that current CDC data do not track whether illnesses were linked to occupational exposures. CDC data, which are collected from states and made publicly available via the *Cholera and Other Vibrio Illness Surveillance (COVIS)* System,[37] do not provide information on the environment or activity in which exposure occurred; while states may collect relevant data, the data are not uniform between states and may not be publicly available for analysis. This impedes researchers from determining where opportunities for health interventions may lie and federal policymakers from understanding how they can provide the best resources to protect watermen.

We also heard that basic adjustments could be made to the permitting process for new or prospective owners of shellfish leases or fishing permits, which may help to prevent new cases. Multiple participants suggested the benefits of requiring *Vibrio*-specific training during the permitting or onboarding processes for watermen, particularly if these efforts are created in conjunction with state-based, regional, and national watermen's groups, as well as extension agents. While education is one element of preventing *Vibrio* harm, it is important that individuals entering this industry understand the risks and how exposures and harm may occur, along with methods or solutions to reduce risks to themselves and consumers.

Limitations

We were unable to speak directly with seafood processors. They are a significant component of the seafood industry in the Chesapeake, critical and a key component to food safety. They fulfill some of the most fundamental positions within our nation's commercial seafood industry and provide a physically difficult service. Another, related limitation is that we did not include individuals who were unable to complete the interview in English. Inclusion of non-English-speakers may have influenced and enriched our research by providing some cultural or contextual information on understanding scientific and medical information that, to a native English-speaker, may require little to no additional information. These individuals' input should be considered in future research.

CONCLUSIONS

Fishing is extremely difficult work, physically, emotionally, and socially. The methods used by many individuals in this industry have not changed demonstrably over the past century, and unlike in many other industries, the risks of occupational harm may not have declined substantially. This is important as our global climate is changing, as vibriosis risk becomes more likely and the need for worker and consumer awareness must be heightened.

The physical difficulties associated with fishing are reflected in the focus of much of the literature on occupational hazards facing individuals who work on the water. Additionally, the vast majority of watermen in the Chesapeake Bay region operate or work in small businesses; thus, any economic impacts incurred as a result of personal injury or illness, fisheries closures, or costs incurred due to consumer illness have serious, long-term ramifications for overall community health. However, despite and perhaps because of the challenges, the difficulties are viewed as being "a part of the job" and a point of pride, and the seafood produced is viewed as an extension of the workers. Their livelihoods are a part of their identities. The commercial fishing industry in the Chesapeake Bay represents a strong, proud tradition. There are myriad opportunities beyond those identified herein to continue to

ensure their resilience through the end of this century and into the next. This industry, with its rich tradition, and the collective workers composing it, needs assistance from local, state, and federal programs to enhance protections for workplace environments, to address disparities in risk; providing resources versus regulations. Additionally, we recommend that a larger, survey-, and interview-based study be undertaken to better understand how *Vibrio* may present and is perceived to be an occupational hazard in other areas of the country.

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