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Increased incidence of vibriosis in Maryland, U.S.A., 2006–2019

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ABSTRACT

Background: Vibrio spp. naturally occur in warm water with moderate salinity. Infections with non-cholera *Vibrio* (vibriosis) cause an estimated 80,000 illnesses and 100 fatalities each year in the United States. Climate associated changes to environmental parameters in aquatic ecosystems are largely promoting *Vibrio* growth, and increased incidence of vibriosis is being reported globally. However, vibriosis trends in the northeastern U.S. (e.g., Maryland) have not been evaluated since 2008.

Methods: Vibriosis case data for Maryland (2006–2019; n = 611) were obtained from the COVIS database. Incidence rates were calculated using U.S. Census Bureau population estimates for Maryland. A logistic regression model, including region, age group, race, gender, occupation, and exposure type, was used to estimate the likelihood of hospitalization.

Results: Comparing the 2006–2012 and 2013–2019 periods, there was a 39% ($p = 0.01$) increase in the average annual incidence rate (per 100,000 population) of vibriosis, with *V. vulnificus* infections seeing the greatest percentage increase (53%, $p = 0.01$), followed by *V. parahaemolyticus* (47%, $p = 0.05$). The number of hospitalizations increased by 58% ($p = 0.01$). Since 2010, there were more reported vibriosis cases with a hospital duration $\geq$10 days. Patients from the upper eastern shore region and those over the age of 65 were more likely (OR = 6.8 and 12.2) to be hospitalized compared to other patients.

Conclusions: Long-term increases in *Vibrio* infections, notably *V. vulnificus* wound infections, are occurring in Maryland. This trend, along with increased rates in hospitalizations and average hospital durations, underscore the need to improve public awareness, water monitoring, post-harvest seafood interventions, and environmental forecasting ability.

1. Introduction

Vibrio spp. are Gram-negative rod-shaped bacteria that include more than 110 described species, many of which are known to be pathogenic to humans and animals (Baker-Austin et al., 2017, 2018; Daniels et al., 2000; Morris and Black, 1985). These bacteria occur naturally in marine and estuarine environments, flourishing in warm water with moderate salinity, especially along the coast (Kaspar and Tamplin, 1993; Singleton et al., 1982; Vezzulli et al., 2013, 2016). *Vibrio* spp. incidence is strongly influenced by environmental parameters (Hlady, 1997; Iwamoto et al., 2010); they are also associated with aquatic invertebrates, such as crustaceans, zooplankton, and bivalves, and play an important role in biogeochemical processes (Colwell, 1996; Huq et al., 1983; Krantz et al., 1969; Lovelace et al., 1968). *Vibrio cholerae,* primarily serogroups O1 and O139*,* is well-documented as the etiological agent of cholera which continues to plague developing nations (Colwell, 1996). On the other hand, pathogenic non-cholera *Vibrio* species, including *Vibrio parahaemolyticus* (serotype O3:K6, clonal type ST36) and *Vibrio vulnificus* (primarily biotype 1)*,* are more commonly the cause of disease in developed countries (Baker-Austin et al., 2017, 2018). In the United States, the Centers for Disease Control and Prevention (CDC) estimates that non-cholera *Vibrio* illness (vibriosis) causes 80,000 illnesses and 100 fatalities each year (CDC, 2019), with noted increasing annual incidence rates during the past two decades (Newton et al., 2012; Sims et al., 2011;

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Vugia et al., 2013).

Vibrio spp. concentrate in filter-feeding shellfish, especially oysters, and more than half of all cases of vibriosis in developed countries, including the U.S., are attributed to ingestion of raw oysters or shellfish contaminated with vibrios, mainly *V. parahaemolyticus* (Iwamoto et al., 2010; Ndraha et al., 2020; Shapiro et al., 1998). However, severe, and fatal cases are more prevalent with *V. vulnificus* infection, which is usually associated with brackish or ocean water exposure containing the bacterium (Baker-Austin et al., 2010, 2018; Oliver, 2013; Shapiro et al., 1998). *V. vulnificus* has a case fatality rate among the highest of waterborne pathogens, ranging from 30 to 48% (Horseman and Surani, 2011; Strom and Paranjpye, 2000). Other vibrios such as *Vibrio alginolyticus* and *Vibrio fluvialis*, have increased in abundance over the last decade, and similarly to *V. vulnificus* infections, are typically associated with brackish water exposure, leading to ear and wound infections or gastroenteritis (Baker-Austin et al., 2018). Vibriosis cases have a strong seasonal component, with most infections occurring during the warmer months (Baker-Austin et al., 2018; Daniels et al., 2000; Shapiro et al., 1998). Symptoms of vibriosis can range from mild gastroenteritis to more severe cases including wound infection and septicemia, which can lead to hospitalization, amputation, or death (Daniels and Shafaie, 2000; Horseman and Surani, 2011; Morris and Black, 1985; Shapiro et al., 1998). Populations at greater risk for severe vibriosis include those with preexisting liver disease, alcohol use disorder, diabetes, hemochromatosis, or immunodeficiencies (Baker-Austin et al., 2018; Daniels and Shafaie, 2000; Oliver, 2005; Weis et al., 2011).

Surveillance of *Vibrio* infections in the U.S. was initiated in 1989 through the Cholera and Other Vibrio Illness Surveillance (COVIS) system managed by the CDC (CDC, 2014). This program initially focused on monitoring *V. cholerae* cases from four Gulf Coast states (Alabama, Florida, Louisiana, Texas), but in 2007 all vibriosis cases became nationally notifiable (CDC, 2014; Sims et al., 2011). In 1996, the CDC also initiated the Foodborne Diseases Active Surveillance Network (FoodNet), which conducts active surveillance of *Vibrio* infections and other important foodborne pathogens in 10 U.S. sites, including the Maryland Department of Health (MDH) (CDC, 2021; Jones et al., 2007). MDH, together with the Maryland Department of the Environment (MDE) and the Maryland Department of Natural Resources (DNR) also participate in the National Shellfish Sanitation Program (NSSP), a cooperative federal/state program recognized by the U.S. Food and Drug Administration (FDA) that regulates the sanitation of shellfish produced and sold for human consumption (FDA, 2020). In addition, MDE and the DNR provide current information on the health status of Maryland's natural waters through water monitoring programs (Jones et al., 2013). Forecasting models have also been used successfully for global risk prediction of cholera (Usmani et al., 2023), and other models, such as the National Centers for Coastal Ocean Science (NCCOS) Probability Model (Jacobs et al., 2014), project *V. parahaemolyticus* and *V. vulnificus* levels in the Chesapeake Bay, MD.

Recently there is increased concern regarding the role of climate change-associated shifts in the geographical range of microbial species and the emergence and re-emergence of disease. Notably, several studies have documented a significant geographic expansion of pathogenic *Vibrio* spp., with increased numbers of reported vibriosis cases (Archer et al., 2023; Baker-Austin et al., 2013, 2017, 2013; Brehm et al., 2021; Fleischmann et al., 2022; Sterk et al., 2015; Brumfield et al., 2021, 2023; Colwell, 1996; Ford et al., 2020; Vezzulli et al., 2012, 2013, 2015). Moreover, a recent investigation in the Chesapeake Bay reported a long-term increase and extended seasonality of pathogenic *Vibrio* spp. between 2009 and 2022 (Brumfield et al., 2023). These works also highlight the potential role of extreme weather events (e.g., heatwaves and hurricanes) in the increase of more severe gastrointestinal illness and wound infection stemming from vibriosis outbreaks. It is therefore of significance to understand how *Vibrio* infection trends have changed in more northern U.S. states, such as Maryland, under warming conditions, as well as the implications for local healthcare costs which, as noted by Sheahan et al. (2022), may increase across the U.S. Of note, a study by Jones et al. (2013) covering the 2002–2008 time period is the most recent work to evaluate *Vibrio* spp. infection trends in Maryland. The current study aimed to analyze current long-term vibriosis case data, from 2006 to 2019, including changes to hospitalization risk and case fatality rates, and the relative importance of exposure type to patient infections. The latter is especially relevant given that a study from our group (Shaw et al., 2015) demonstrated that *Vibrio* spp. detected dermally from Chesapeake Bay waters added significantly to the risk of infection in recreational swimmers and might reflect a growing trend in the acquisition of severe vibriosis.

2. Methods

2.1. Data sources

To examine clinical and epidemiological information on *Vibrio* spp. infections, case data from 2006 to 2019 were obtained from the CDC's COVIS database, which receives case reports through the Maryland FoodNet program, housed at MDH. This program represents 1 of 10 FoodNet sites funded by the CDC that conduct active, population-based surveillance since 1996 on laboratory-diagnosed infections, identified by culture or culture-independent diagnostic tests (CIDT), caused by *Vibrio* as well as 7 other pathogens. Cases are defined as an individual whose biological specimen (stool, blood, wound, or other) was culture-confirmed for the presence of *Vibrio*, regardless of symptoms or date of onset. To determine whether a case was associated with seafood consumption or water exposure (leading to blood or wound infection), we reviewed variables including specimen source, evidence of a preexisting wound, exposure to brackish or ocean water, consumption of or exposure to raw seafood as well as drippings (uncooked seafood item residues that may contaminate other cooked items), occupational exposure, and date of illness onset relative to the exposure. These variables were used to make a subjective determination about the possible association (seafood or water associated infection) and followed similar methods used in a previous study (Jones et al., 2013). For instance, cases determined from a stool specimen, with consumption or exposure to raw seafood and drippings were considered to be associated with seafood consumption; while cases determined from a blood specimen and with evidence of a preexisting wound or exposure to brackish/ocean water were categorized as wound-water associated exposures. Cases without enough information to make this determination ($n = 15$) were excluded from analysis, as well as those related to known foreign or domestic travel ($n = 34$). On the basis of the 2010 census and 2020 census by the US Bureau of the Census, the population estimates for the State of Maryland of 5,773,552 and 6,177,224, respectively, were used to calculate incidence which was expressed per 100,000 population.

2.2. Data analysis

A two-sample *t*-test was used to evaluate the differences between percentage change in 2013–2019 compared to 2006–2012, for the incidence rate, number of hospitalizations, average hospital duration, and the number of seafood and wound/water associated cases. A comparison of the average vibriosis cases in the first seven years versus the last seven was chosen in order to balance interannual climatic changes over a similar period of time. For data that were not approximately normal, or for which the sample size was smaller than 20, the Mann-Whitney test was used. Additionally, analysis of variance (ANOVA) was performed to determine the significant differences between multiple variables, and the non-parametric Kruskal-Wallis test was used for non-normal data. Correlation and regression analyses were also applied to evaluate the strength of the association between the number of vibriosis cases and year of exposure, and other continuous variables. In addition, the mean annual change in cases at the county level between 2006 and 2019 was calculated for all culture-confirmed *Vibrio* spp.

infections reported by the State of MD (n = 4 cases with unknown county). Vibriosis case data by county represent the county of residence.

To estimate the probability of hospitalization, we used a logistic regression model that included region (western, capital, south, central, upper eastern shore, lower eastern shore), patient age group (0–4, 5–17, 18–65, and ≥65 years of age), race (White, Black, Asian, other, unknown), gender (female, male), occupation (child/student, retired, maritime related, non-maritime related, unknown), and the attributed exposure type (wound/water, seafood contamination). The PROC LOGISTIC command (SAS) was used, controlling for mentioned exposure variables, and the outcome group was whether or not a patient was hospitalized. The best fit logistic model was defined as: LOGIT[pr(HOSPYN = 1)] = $\beta_0 + \beta_1$ (region) + β_2 (age) + β_3 (race) + β_4 (gender) + β_5 (occupation) + β_6 (exposuretype) + β_7 (region*age*race*gender*occupation*exposuretype). Regions are defined as those including the following counties: *Western*: Allegany and Washington; *Capital*: Frederick, Montgomery and Prince George's; *Central*: Carroll, Baltimore, Harford, Howard and Anne Arundel; *South*: Charles, Calvert and St. Mary's; *Upper Eastern Shore*: Cecil, Kent, Queen Anne's, Caroline and Talbot; and *Lower Eastern Shore*: Dorchester, Wicomico, Worcester and Somerset. Of the 611 reported cases, this analysis excluded n = 69 cases of vibriosis due to incomplete information for one or more variables included in the model. Statistical analyses were performed using SAS 9.4 (Cary, NC USA).

3. Results

3.1. Epidemiologic observations and trends

From 2006 to 2019, there were 611 culture-confirmed cases of vibriosis reported in Maryland (Table 1), with an annual average of 44 cases per year and an average annual incidence rate of 0.72 cases per 100,000 population. The most commonly reported *Vibrio* spp. were *V. parahaemolyticus* (39%, 3.90 IR), *V. vulnificus* (23%, 2.31 IR), and *Vibrio alginolyticus* (12%, 1.17 IR), but other species of *Vibrio,* including *Vibrio fluvialis* and *V. cholerae* non-O1/non-O139, were also reported with some frequency, ranging from 11 to 7%, respectively.

Demographic characteristics of patients reported were similar among species, with a median age of 55 years and males accounting for 67% of all illnesses. The youngest median age reported was 38 years for *V. alginolyticus* infections, and the oldest was 67 years for both *V. vulnificus* and *V. fluvialis* infections (Table 1). Although *V. parahaemolyticus* infections were most frequently reported, they led to hospitalization in only 30% of cases and were rarely fatal, with a case fatality rate (CFR) of 1% (Table 1). *V. vulnificus*, by contrast, led to hospitalization in 81% of cases and also had the highest CFR of 11%. Infections with *V. fluvialis* and other species of *Vibrio* (*V.* other) also led to higher hospitalization rates among patients, with 60% and 59%, respectively. The overall CFR for vibriosis cases was 4% between 2006 and 2019.

The frequency of isolated *Vibrio* spp. varied by year. However, the number of vibriosis cases was positively correlated with year (r = 0.75, $p = 0.002$), and increased significantly between 2006 and 2019 (Fig. 1). The year with the most *Vibrio* infections was 2016 (n = 69) followed by 2013 (n = 57), with *V. parahaemolyticus* and *V. vulnificus* contributing to over 65% of all cases. The year with the least reported cases was 2007 (n = 26), with over 50% of infections being attributed to *V. parahaemolyticus* and *V. alginolyticus*. With the exception of 2011, where *V. vulnificus* and *V. alginolyticus* contributed to most cases, *V. parahaemolyticus* was the most frequently reported species each year (Fig. 1).

From 2006 to 2019, there were 266 (48.3%) cases associated with wound/water infections and 285 (51.7%) associated with seafood consumption or contamination (Fig. 2). The *Vibrio* species most frequently associated with seafood related infections was *V. parahaemolyticus* (58.1%), followed by *V. fluvialis* (11.4%) and *V. vulnificus* (10.4%). *V. vulnificus* was the most frequent cause of infection associated with wound/water exposure (41.2%), followed by *V. parahaemolyticus* (21.7%) and *V. alginolyticus* (18.7%) (Fig. 2).

The season with the most reported infections, both from wound/water and seafood consumption, was the summer (n = 349), including June, July, and August; followed by the fall (n = 122) season, including September, October, and November. During the summer and fall seasons, wound-water related infections (n = 242) were slightly higher than those associated with seafood consumption (n = 229). By contrast, in the winter (December, January, February) and spring (March, April, May) seasons, seafood related infections (n = 56) dominated the reported cases compared with wound/water infections (n = 24). Seasonality did not vary significantly by species (Fig. 2), data not shown.

3.2. Vibriosis percentage and average annual changes

Comparing the percentage change in *Vibrio* spp. infections reported in 2013–2019 with those in 2006–2012 (Table 2), there was an overall 39% ($p = 0.01$) increase in the average annual incidence rate (per 100,000 population), with *V. vulnificus* infections seeing the greatest percentage increase (53%, $p = 0.01$), followed by *V. parahaemolyticus* (47%, $p = 0.05$).

The number of hospitalizations as well as the average hospital duration (in days) for all vibriosis cases also increased in the 2013–2019 period compared to 2006–2012, by 58% (p = 0.01) and 35% ($p = 0.08$), respectively (Table 2). This increase was observed for most *Vibrio* species, although statistically significant only for *V. vulnificus* (63%, $p = 0.03$ for hospitalizations and 92%, $p = 0.02$% for average hospital duration) and infections with multiple *Vibrio* species (100%, $p = 0.01$ for hospitalizations). Seafood associated cases and water-associated

Table 1
Vibriosis cases, incidence rates, selected patient demographic characteristics and outcomes (hospitalizations, deaths, and case fatality rate), by species, Maryland, 2006 to 2019.

Vibrio species	Cases			Age (years)		Gender		Hospitalizations		Deaths	
	N	%	IR[b]	Median	Range	Male (n/N)	%	n/N	%	n	CFR (%)
V. parahaemolyticus	241	39	3.90	49	1–98	160/241	66	72/238	30	2	1
V. vulnificus	143	23	2.31	67	1–90	115/143	80	113/140	81	16	11
V. alginolyticus	72	12	1.17	38	2–84	50/72	69	7/71	10	1	1
V. fluvialis	47	8	0.76	67	15–93	28/47	60	28/47	60	1	2
V. cholerae Non O1/139	42	7	0.68	50	5–87	19/42	45	20/41	49	2	5
V. other[a]	66	11	1.07	57	4–87	38/66	58	39/66	59	3	5
TOTAL	**611**	**100**	**9.89**	**55**	**1–98**	**410/611**	**67**	**253/603**	**42**	**25**	**4**

Abbreviation: IR, incidence rate; CFR, case fatality rate.
[a] Includes *Photobacterium damselae* subsp. *damselae* (formerly known as *V. damsela*), *Grimontia hollisae*, *V. furnissii*, *V. mimicus*, *V. metschnikovii*, multiple species, and species not identified.
[b] Per 100,000 population.

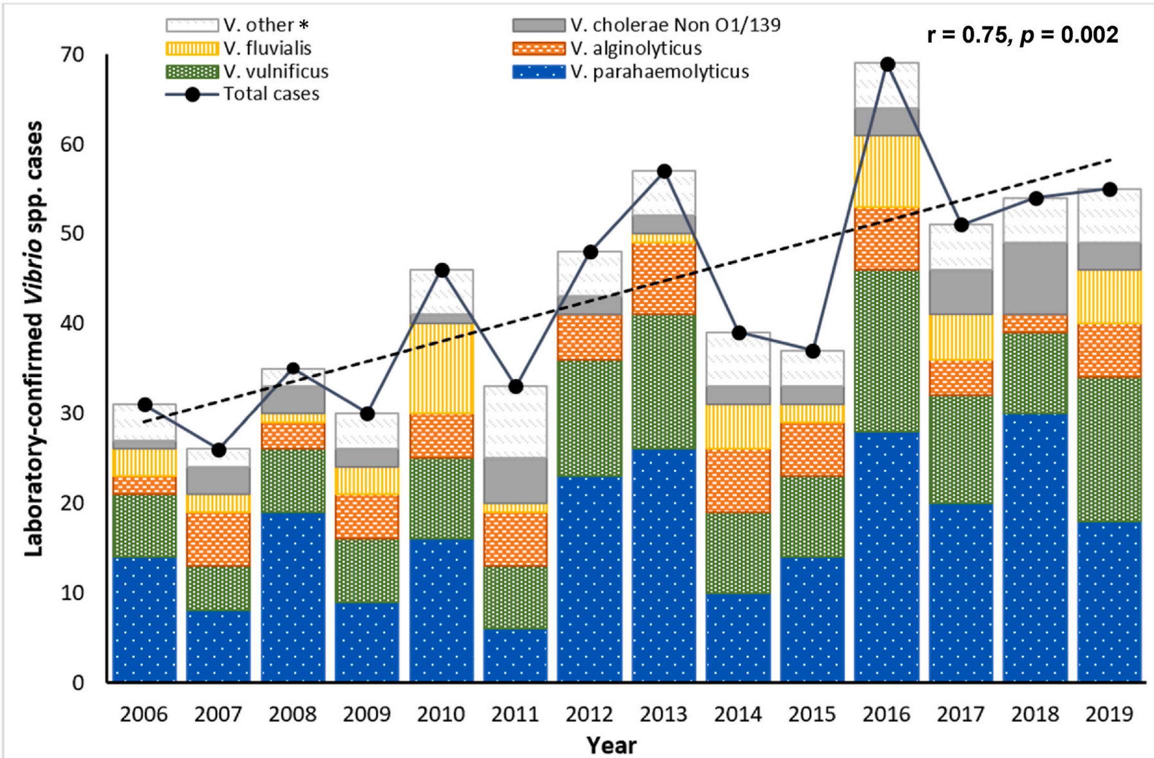

Fig. 1. Laboratory identified culture-confirmed cases of *Vibrio* illness, by species and year, Maryland, 2006 to 2019 (N = 611). *Includes *Photobacterium damselae* subsp. *damselae* (formerly known as *V. damsela*), *Grimontia hollisae*, *V. furnissii*, *V. mimicus*, *V. metschnikovii*, multiple species, and species not identified.

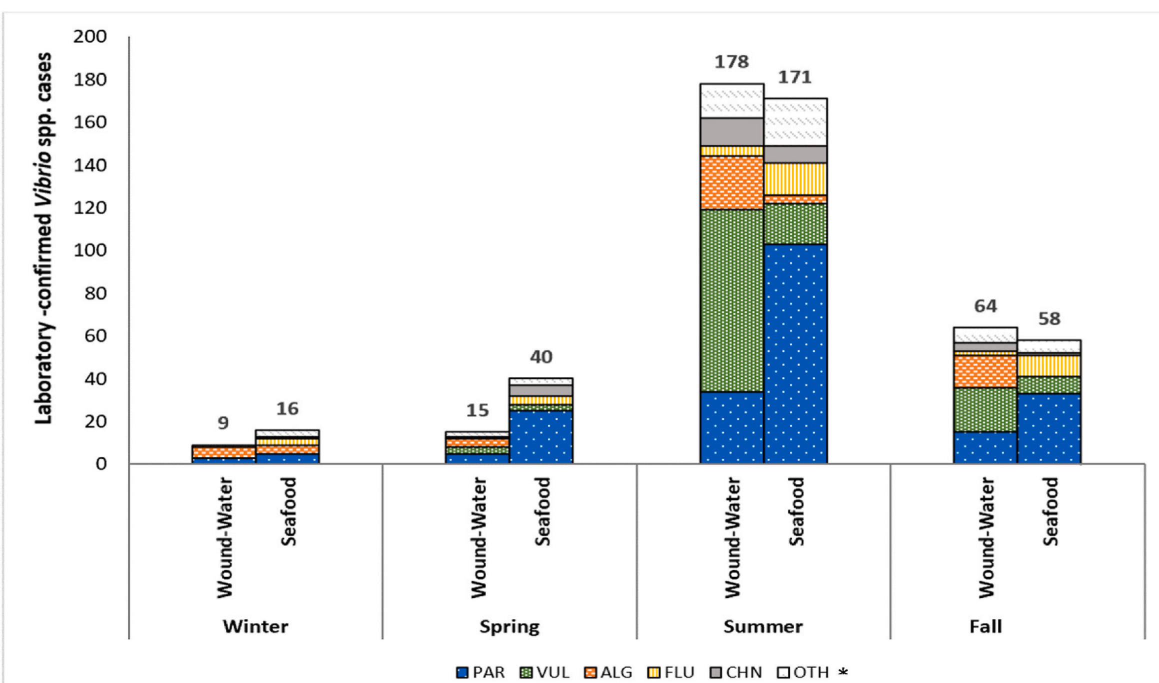

Fig. 2. Laboratory identified culture-confirmed cases of *Vibrio* illness, by species, season and association, Maryland, 2006 to 2019. PAR: *V. parahaemolyticus*, VUL: *V. vulnificus*, ALG: *V. alginolyticus*, FLU: *V. fluvialis*, CHN: *V. cholerae* Non O1/139, OTH: *V.* other. N = 551, not including n = 60 cases of undetermined association, known foreign/domestic travel or missing season information. *Includes *Photobacterium damselae* subsp. *damselae* (formerly known as *V. damsela*), *Grimontia hollisae*, *V. furnissii*, *V. mimicus*, *V. metschnikovii*, multiple species, and species not identified.

infections doubled between both time periods, with a 56% ($p = 0.02$) increase in the former and a 50% ($p = 0.03$) increase in the latter. *V. parahaemolyticus* infections as well as those with multiple species represented the greatest increase in seafood associated cases between 2013 and 2019 compared to 2006–2012, with 63% ($p = 0.04$) and 144% ($p = 0.004$), respectively; while *V. vulnificus* infections were responsible

Table 2
The percentage change in 2013–2019 vibriosis cases compared with 2006–2012 for average annual incidence rate, number of hospitalizations, average hospital duration, and number of seafood and wound-water associated cases by species, Maryland.

Vibrio species	Percentage change 2013–2019 compared with 2006–2012, % (*p*-value)[c]				
	IR[b]	No. of hospitalizations	Average hospital duration (days)	Seafood associated cases	Wound/water associated cases
V. parahaemolyticus	+47 (0.05)	+32 (0.11)	+4 (0.44)	+63 (0.04)	+23 (0.29)
V. vulnificus	+53 (0.01)	+63 (0.03)	+92 (0.02)	0 (0.50)	+82 (0.01)
V. alginolyticus	+20 (0.18)	−25 (0.35)	+47 (0.34)	0 (0.50)	+38 (0.15)
V. fluvialis	+27 (0.33)	+80 (0.19)	+84 (0.16)	+54 (0.21)	+67 (0.30)
V. cholerae Non O1/139	+41 (0.16)	+86 (0.09)	+110 (0.08)	+38 (0.34)	+13 (0.42)
V. other[a]	+15 (0.21)	+100 (0.01)	−37 (0.18)	+144 (0.004)	+40 (0.10)
TOTAL	**+39 (0.01)**	**+58 (0.01)**	**+35 (0.08)**	**+56 (0.02)**	**+50 (0.03)**

Abbreviation: IR, incidence rate.
[a] Includes *Photobacterium damselae* subsp. *damselae* (formerly known as *V. damsela*), *Grimontia hollisae*, *V. furnissii*, *V. mimicus*, *V. metschnikovii*, multiple species, and species not identified.
[b] Per 100,000 population.
[c] Average annual percentage change, for each 7-year block, reported as increase or decrease.

for the greatest increase (82%, $p = 0.01$) in water-associated wound cases (Table 2). The overall ratio of wound/water to seafood associated cases also increased slightly between both time periods, although not significantly, by 4.1% ($p = 0.43$), data not shown.

The map in Fig. 3 shows the average annual change in vibriosis cases in Maryland at the county level between 2006 and 2019. Anne Arundel and Baltimore (central region), and Wicomico (lower eastern shore) counties, showed the greatest increase in average *Vibrio* infections per year, with approximately 0.3 new cases reported each year. By comparison, slight decreases in average vibriosis cases per year were reported in Harford County (central region; 0.2 case decrease), as well as counties in the south region including Calvert (0.07 case decrease) and St. Mary's (0.15 case decrease). For all counties collectively, the average annual number of vibriosis cases increased by approximately two cases per year, data not shown.

3.3. Hospital duration and hospitalization risk trends

The average hospital duration in Maryland for vibriosis cases between 2006 and 2019, regardless of exposure type, was approximately 5 days. While we did not observe a statistically significant increase in average hospital duration over time ($p = 0.60$), after 2010 there were more reported cases with a hospital duration stay of at least 10 days (Fig. 4). This was more frequently observed for infections with *V. fluvialis*, *V. alginolyticus*, and *V. vulnificus*. In particular, *V. fluvialis* had the highest annual average hospital duration of approximately 9 days and led to average hospital durations above 10 days in 2010, 2014 and 2016 (Fig. 4).

In Maryland from 2006 to 2019, 259 (48%) vibriosis case patients out of 542 were hospitalized for whom enough data were available. The proportion of patients hospitalized varied by region, from 1% in the western counties (Allegany, Washington) to 50% in the central counties (Carroll, Baltimore, Harford, Howard, Anne Arundel) (Table 3). The highest rates of hospitalization were observed for those over 65 years of

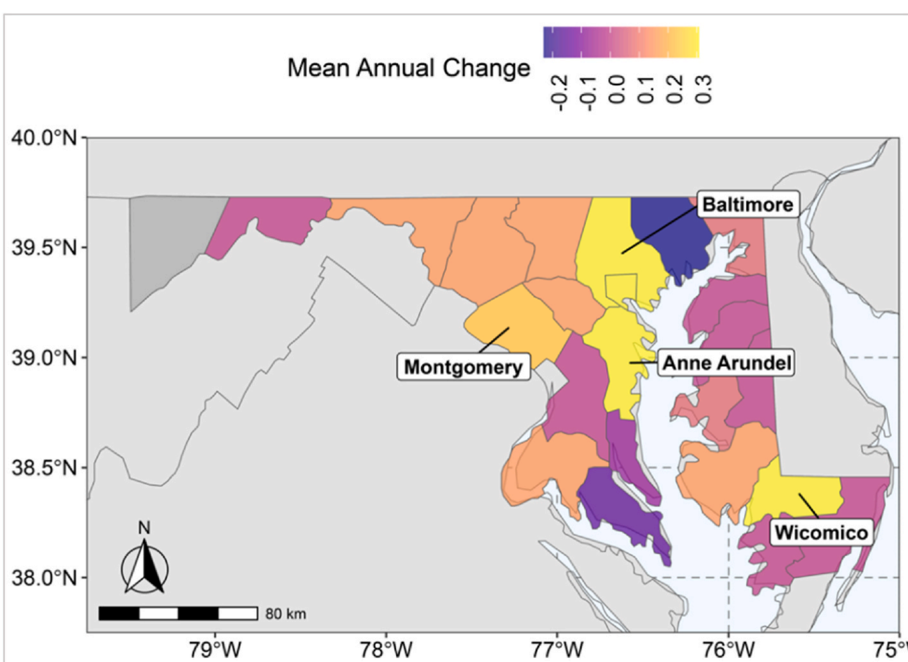

Fig. 3. Average annual change in vibriosis cases by county for the State of Maryland, 2006–2019 (N = 611). Counties showing the highest increase in average annual *Vibrio* infections are indicated. Baltimore City and Baltimore County are listed together as "Baltimore". Scale bar corresponds to distance according to World Map Data from Natural Earth (Massicotte and South, 2023).

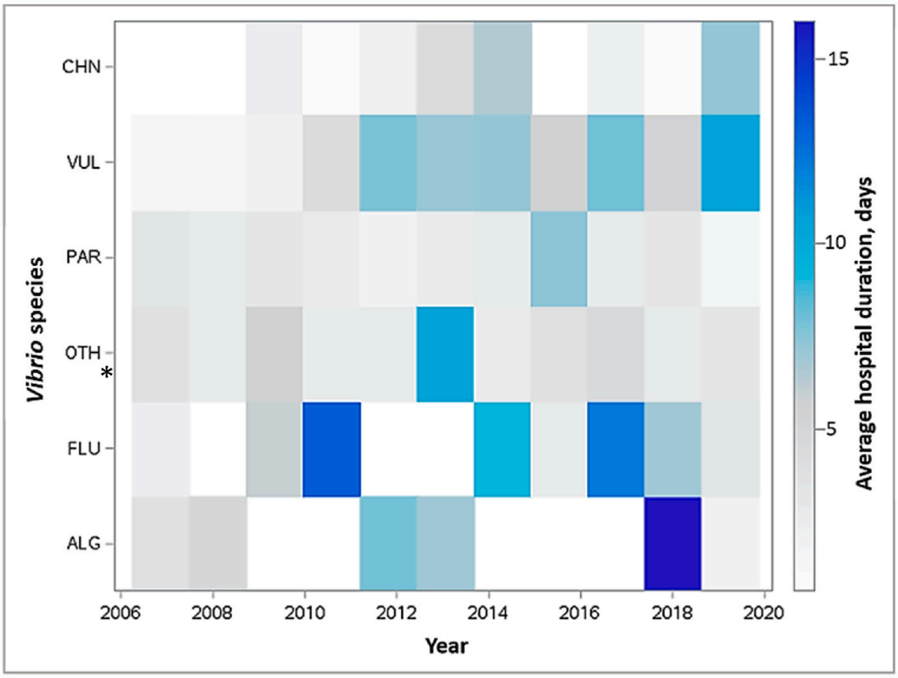

Fig. 4. Average hospital duration in days, by *Vibrio* species and year, Maryland, 2006–2019 (N = 611). PAR: *V. parahaemolyticus*, VUL: *V. vulnificus*, ALG: *V. alginolyticus*, FLU: *V. fluvialis*, CHN: *V. cholerae* Non O1/139, OTH: *V.* other. *Includes *Photobacterium damselae* subsp. *damselae* (formerly known as *V. damsela*), *Grimontia hollisae*, *V. furnissii*, *V. mimicus*, *V. metschnikovii*, multiple species, and species not identified.

age (46%), followed by those aged 45–64 (39%), and among white (69%), males (71%), and those listed as retired (37%). Fifty-two percent of patients with water-associated wound infections were hospitalized, compared to 48% for seafood-associated contamination (Table 3).

From the logistic regression model, patients in the upper eastern shore (Cecil, Kent, Queen Anne's, Caroline, Talbot counties) were more likely (OR = 6.8) to be hospitalized than those in the western region (Table 3). Patients over the age of 65 years and those aged 45–64 were more likely (OR = 12.2 and 10.7, respectively), to be hospitalized than those ages 0–4; Black patients were more likely to be hospitalized (OR = 2.3) than White patients and those retired were more likely (OR = 2.2) to be hospitalized than those whose occupation was non-maritime related. Moreover, patients with wound/water associated infections were more likely (OR = 1.8) to be hospitalized than those with seafood associated vibriosis (Table 3).

4. Discussion

Our analysis of surveillance data from the Maryland FoodNet program that monitors *Vibrio* illness indicates that the incidence of culture-confirmed vibriosis increased between 2006 and 2019. Not only did the average annual incidence rate increase 39% in 2013–2019 compared with 2006–2012, but the overall average annual incidence of 0.72 cases/100,000 population was 35% higher than the average rate of 0.47 reported for 2002–2008, in the previous Maryland study of *Vibrio* infection trends (Jones et al., 2013). The annual incidence of vibriosis was similar to that reported by two other FoodNet sites during the same time period (California and Connecticut), albeit higher than the national average of 0.42/100,000 population for all 10 FoodNet sites (CDC, 2021). Previous studies have noted higher rates of *Vibrio* infection in coastal U.S. states compared to inland states, as well as a greater contribution of *V. parahaemolyticus* towards infections (CDC, 2014; Jones et al., 2013; Newton et al., 2012; Sims et al., 2011; Weis et al., 2011), with the exception of Florida where *V. vulnificus* is the leading cause of *Vibrio* illness (Weis et al., 2011). Despite national trends, Maryland has seen a change in the most common *Vibrio* species, type of exposure, hospitalization risk, and average hospital duration.

Compared to Maryland vibriosis data from 2002 to 2008 (Jones et al., 2013), the frequency of *V. parahaemolyticus* infections decreased by 4%, while *V. alginolyticus* related cases increased by 2%, and *V. fluvialis* surpassed *V. cholerae* non-O1/non-139 infections to become the fourth most common species to cause illness in the State. Although the relative contribution of *V. vulnificus* infections remained unchanged, the incidence, number of cases that led to hospitalization, as well as the average hospital duration increased significantly, by 53%, 63% and 92%, respectively, in 2013–2019 compared with 2006–2012. Interestingly, the case fatality rate (CFR) observed from 2006 to 2019 (CFR = 11%) for *V. vulnificus* was approximately 20% lower than that reported in previous studies (Newton et al., 2012; Oliver, 2005, 2013; Sims et al., 2011; Weis et al., 2011), although the median age of infected patients was still among mostly male, older, and those more likely to have comorbidities. This likely represents greater awareness among health care providers in treating wound and blood infection cases considered to be associated with *V. vulnificus*. In fact, several studies have noted the importance of early recognition of nonfoodborne *Vibrio* infections and timely and aggressive treatment, especially within 24 h of hospitalization, to reduce mortality rates (Bross et al., 2007; Chao et al., 2013; Dechet et al., 2008; Kim et al., 2022; Yun and Kim, 2018). On the other hand, the significant increase in *V. vulnificus* incidence and higher number of cases associated with wound infection in summer and fall, highlights the need for improved public awareness of infection risk.

Currently, the "Maryland Healthy Beaches" program run by the MDE (MDE, 2023), provides *Vibrio* infection information on their website and flyers, including avoiding water contact if there are any open wounds, wearing water shoes to avoid cuts, wearing gloves when crabbing or fishing, and showering after swimming in natural waters. However, it is unclear how readily available this information is in local creeks and waterways surrounding the Chesapeake Bay or if more remote water access points also have "*Vibrio* facts" flyers posted.

Similarly, increased hospitalization rates between 2006 and 2019 and average hospital durations were observed with the less common *V. fluvialis*. However, most infections were associated with seafood

Table 3
Hospitalization rate and associated odds ratio for patients with culture-confirmed *Vibrio* spp. infections by region and demographic/epidemiologic characteristics, Maryland, 2006 to 2019[b].

Region[a] or characteristic	Hospitalized n (%)	Logistic regression model results[c]		
		Odds ratio	95% CI	p-value
Region	2 (1)	Reference	–	–
Western	32 (12)	2.80	0.49–15.74	0.24
Capital	128 (50)	3.28	0.62–17.30	0.16
Central	32 (12)	4.93	0.85–28.65	0.08
South	37 (14)	6.82	1.13–41.07	0.04
Upper Eastern Shore	28 (11)	3.71	0.64–21.43	0.14
Lower Eastern Shore				
Age group, years	1 (1)	Reference	–	–
0–4	6 (2)	0.93	0.08–11.36	0.95
5–17	32 (12)	3.58	0.36–35.87	0.28
18–44	100 (39)	10.66	1.06–107.04	0.04
45–64	120 (46)	12.15	1.19–124.48	0.04
≥ 65				
Race	179 (69)	Reference	–	–
White	58 (2)	2.33	1.36–3.95	0.002
Black	10 (4)	1.78	0.63–4.99	0.28
Asian	2 (1)	4.19	0.15–113.74	0.39
Other	10 (4)	0.52	0.22–1.26	0.15
Unknown				
Gender	184 (71)	Reference	–	–
Male	75 (29)	0.94	0.60–1.46	0.77
Female				
Occupation	6 (2)	0.81	0.21–3.12	0.76
Child or student	97 (37)	2.20	1.21–4.00	0.01
Retired	69 (27)	Reference	–	–
Non-maritime	17 (7)	2.28	0.77–6.77	0.14
related	70 (27)	1.35	0.82–2.25	0.24
Maritime related				
Unknown				
Exposure type	125 (48)	Reference	–	–
Seafood	134 (52)	1.78	1.15–2.75	0.01
Wound-water				

Abbreviation: CI, confidence interval.
[a] Counties included in each region- *Western*: Allegany, Washington; *Capital*: Frederick, Montgomery, Prince George's; *Central*: Carroll, Baltimore, Harford, Howard, Anne Arundel; *South*: Charles, Calvert, St. Mary's; *Upper Eastern Shore*: Cecil, Kent, Queen Anne's, Caroline, Talbot; *Lower Eastern Shore*: Dorchester, Wicomico, Worcester, Somerset.
[b] Excludes cases with incomplete variable information (n = 69).
[c] Estimates controlling for the variables shown.

contamination and lower CFR (2%) than *V. vulnificus* related cases. Notably, incidence of vibriosis caused by *V. fluvialis* remains relatively less frequent across other FoodNet sites (averaging 0.03 per 100,000 population) (CDC, 2021) but is considerably higher in Maryland (0.76 per 100,000 population), with increased hospitalization rates noted between 2013 and 2019. In the United States, severe cases of illness from *V. fluvialis* infection are still rare (Allton et al., 2006; Daniels and Shafaie, 2000; Klontz and Desenclos, 1990) but have been more frequently reported across other countries, e.g., Taiwan, South Korea, India, and South Africa (Huang et al., 2005; Igbinosa and Okoh, 2010; Lai et al., 2006; Lee et al., 2008; Ramamurthy et al., 2014; Shravan et al., 2021). A few of the more severe and concerning cases included symptoms of cholera-like diarrhea and acidosis, acute infectious peritonitis, and fatal bacteremia. There have also been earlier reports of *V. fluvialis* associated gastroenteritis cases among infants (Ramamurthy et al., 2014). Although infections with this pathogen are not frequently reported in the U.S., given its ability to cause severe diarrheal disease similar to *V. cholerae* (Igbinosa and Okoh, 2010), clinician recognition and prompt treatment is important in the very young and those with underlying medical conditions.

As the incidence of vibriosis increases in the State of Maryland, there may be a greater recognition of symptoms of illness, as well as more individuals seeking medical attention, and better access to medical care over time. Notwithstanding, some areas across the State may incur higher healthcare costs related to longer hospital stays, especially among Maryland's Eastern Shore counties, where the likelihood of being hospitalized was higher than in other locations. Although there were more observed *Vibrio* infection cases in central and less rural counties (e.g., Anne Arundel, Baltimore), it is concerning that more remote locations with a higher poverty level and less access to healthcare resources (Sangaramoorthy and Guevara, 2017) may have to treat more severe cases of vibriosis in years to come. According to recent estimations for waterborne-related illness in the United States, the cost per hospital stay for a *Vibrio* infection was approximately $16,000 (Collier et al., 2021). Moreover, Sheahan et al. (2022) estimated the average national cost of vibriosis under a climate warming scenario, to be around $3.9 billion per year by 2050. The burden and direct healthcare costs will likely vary by state and region but may disproportionately impact those under Medicare (over 65 years of age), who are more likely to experience complications following infection. It is also important to note that certain populations or groups (e.g., Hispanic/Latino individuals), including recently arrived immigrants (Sangaramoorthy and Guevara, 2017), and those working as watermen, may face greater barriers to health care access, and therefore, may be less likely to seek out medical attention when ill.

In Europe and across other parts of the world, including the eastern seaboard of the U.S., there are shared concerns regarding the increased burden of disease from vibriosis cases linked to rising ocean temperatures (Archer et al., 2023; Baker-Austin et al., 2010, 2018; Banerjee et al., 2018; Ferchichi et al., 2021; Sims et al., 2011; Vezzulli et al., 2016; Yun and Kim, 2018). For instance, previous studies have noted the effect of severe heatwaves and warmer water temperatures on the increased number of *Vibrio* infections, especially from *V. vulnificus*, in German North and Baltic Sea coasts (Brehm et al., 2021; Fleischmann et al., 2022; Le Roux et al., 2015), as well as a significant increase in the risk of *Vibrio*-related illness in northern European waters with projected temperature increases under a warming climate (Sterk et al., 2015). Moreover, a recent study reported on the occurrence of *V. parahaemolyticus* and *V. vulnificus* in Tangier Sound (lower eastern bay) whereby a long-term increase in and extended seasonality of these bacteria were observed (Brumfield et al., 2023). This study is of particular interest since Wicomico County (lower eastern shore) was among the locations reporting the greatest increase in average *Vibrio* infections per year (Fig. 3). These cases are likely not only associated with increased levels of seafood contamination but also increased *Vibrio* levels in natural waters, where commercial and recreational activities, such as swimming and fishing, take place. This underscores the need to improve forecasting capabilities for environmental parameters that influence occurrence and abundance of pathogenic *Vibrio* spp. (Brumfield et al., 2023; Colwell, 1996; Jutla et al., 2013; Lobitz et al., 2000; Usmani et al., 2023), as well as to raise public awareness of risks associated with open wound infection or eating shellfish during warmer months.

As mentioned in past studies (Jones et al., 2013; Newton et al., 2012; Shapiro et al., 1998; Weis et al., 2011), there should also be more targeted education strategies aimed at populations with higher risk of developing severe *Vibrio* infections (males, over the age of 45, with underlying medical conditions), or with a greater likelihood of being exposed (e.g., professional, and recreational crabbers, watermen). For example, a CDC-based public health approach used in Gulf of Mexico states worked to increase awareness among clinicians and urged those at greater risk to avoid consumption of raw oysters from the Gulf of Mexico as well as seawater exposure (Shapiro et al., 1998). This strategy was associated with a reduction in vibriosis incidence linked to raw oyster consumption, notably in Florida, where state law requires that food establishments that sell raw oysters include visible information on the risks associated with their consumption (Weis et al., 2011). In a subsequent study by Vugia et al. (2013), a similar strategy was also successful in reducing the number of cases or deaths caused by *V. vulnificus* infections from raw oyster consumption in California. However, previous studies have also recommended that prevention efforts should include public health messages that focus on the risk of vibriosis from wound infections (Newton et al., 2012; Weis et al., 2011). Moreover, it was noted that awareness among clinicians, including prompt diagnosis, was imperative to improve patient outcomes. The data show that public health education alone may be insufficient to control vibriosis (Newton et al., 2012; Vugia et al., 2013) and other measures such as improved monitoring of natural waters, awareness of pre-harvest conditions, and post-harvest decontamination of shellfish may also be needed to mitigate *Vibrio* illness. Research into newer and safer post-harvest interventions is encouraging, and methods such as high hydrostatic pressure show effectiveness in reducing the abundance of *V. parahaemolyticus and V. vulnificus* in oysters (Distefano et al., 2011; Spaur et al., 2020; Vu et al., 2018; Ye et al., 2012).

A limitation of this study is that while the MD FoodNet system can be considered representative of more severe cases where a *Vibrio* infection is culture-confirmed, mild or self-limiting cases are less likely to be represented. This has also been recognized as a limitation of the national vibriosis surveillance system (COVIS). In addition, *Vibrio* spp. are known to enter a protective state, namely viable but nonculturable (VBNC), whereby the cells become metabolically dormant and cannot be cultured using routine enteric media (Colwell, 2000). Hence, the numbers reported here are likely an underestimation of the actual total number of *Vibrio* spp. infections for the State. It is also important to note that there isn't a standardized method of classifying vibriosis by exposure type; therefore, the determination of whether a case resulted from wound or seafood contamination was subjective. Moreover, vibriosis cases are recorded based on a patient's city and county of residence and may not necessarily reflect the county in which they sought medical attention or where they were exposed to the pathogen. Lastly, certain key variables were sometimes missing, such as age, gender, race, or occupation, and results may not fully reflect the population at highest risk across the State of Maryland. Future studies would benefit from inclusion of important metrics such as underlying medical conditions and antibiotics used during treatment.

5. Conclusions

Our findings indicate that there has been a long-term increase in *Vibrio* spp. infections in the State of Maryland, with the most significant impacts observed in some coastal counties. Furthermore, the significant increase in the incidence of *V. vulnificus* between 2006 and 2019, increased risk of hospitalization, and average hospital duration, are noteworthy. Although infections with *V. fluvialis* are relatively rare, increasing trends in average hospital duration are concerning and may indicate more severe clinical strains associated with locally available seafood. These findings underscore the need to develop early warning systems, improve public awareness campaigns for individuals most-at-risk as well as for clinicians, increase water monitoring and "*Vibrio* facts" flyers in local creeks and waterways, and invest in newer and more effective post-harvest seafood interventions.

Competing financial interests

None.

CRediT authorship contribution statement

Michele E. Morgado: Data curation, Formal analysis, Investigation, Methodology, Software, Visualization, Writing - original draft, Writing - review & editing. **Kyle D. Brumfield:** Formal analysis, Investigation, Methodology, Software, Writing - review & editing. **Clifford Mitchell:** Resources, Writing - review & editing. **Michelle M. Boyle:** Resources, Writing - review & editing. **Rita R. Colwell:** Resources, Writing - review & editing. **Amy R. Sapkota:** Conceptualization, Funding acquisition, Project administration, Supervision, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Our data are publicly available data at the request of the Centers for Disease Control and Prevention.

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