ACUTE GASTROENTERITIS AT SEA: AN EVALUATION OF PUBLIC HEALTH POLICIES AND PROGRAMS FOR THE MANAGEMENT OF ENTERIC DISEASE RISK ON PASSENGER CRUISE SHIPS

by

GEORGE HERMAN VAUGHAN, JR.

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ABSTRACT

Passengers and crew aboard cruise ships are at risk of acquiring certain communicable diseases associated with international travel and the cruise ship environment. Currently, an estimated 29.7 million passengers travel on cruise ships, including 15.4 million North American travelers. Since 1975, the Vessel Sanitation Program (VSP) of the Centers for Disease Control and Prevention (CDC) has assisted the cruise industry in developing effective public health programs to manage the risks associated with communicable disease transmission aboard cruise ships. Additionally, under foreign quarantine regulations, the VSP is charged with preventing the introduction, transmission, and spread of communicable disease pathogens into the United States from cruise ships carrying 13 or more passengers with foreign itineraries and making U.S. port calls. Cruise companies have recently built increasingly larger cruise ships capable of transporting over 9,000 passengers and crew. In addition to the larger transport capacities, a shift from disease risks of enteric pathogens linked to contaminated food and water in the 1970s to mid-1990s to viral pathogens associated with person-to-person transmission and environmental contamination has resulted in the threat of enhanced communicable disease transmission in the semi-enclosed, densely populated modern cruise ships. Moreover, viral enteric pathogens have increased pathogen transmission on cruise ships. Since 2002, the primary enteric pathogen associated with such outbreaks of acute gastroenteritis is norovirus, implicated in over 92% of cruise ship-associated AGE outbreaks. New approaches to disease prevention and public health policy strategies are required to minimize the risks associated with viral enteric pathogens and protect the health of cruise ship passengers and crew as well as those in U.S. port communities. This dissertation evaluates the effectiveness of key VSP programs and policies in managing communicable disease risks associated with travel on passenger cruise ships.

INDEX WORDS: Acute gastroenteritis (AGE), AGE outbreaks, Vessel Sanitation Program (VSP), Maritime Illness Database and Reporting System (MIDRS), Vessel Sanitation Program Information Reporting System (VSPIRS), Cruise ships, Diarrheal disease, Bacteria, Viruses, Norovirus, Genogroup II.4, Periodic operations inspection, Environmental health, Public health policy, VSP Operations Manual, Interrupted time series analysis (ITSA), Longitudinal analysis, Passengers, Crew

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TABLE OF CONTENTS

ACKNOWLEDGEMENTS iv
TABLE OF CONTENTS vi
LIST OF TABLES ix
LIST OF FIGURES xi
CHAPTER 1: INTRODUCTION 1
Significant Changes in the Cruise Ship Environment 1
Statement of the Problem 4
Conceptual Framework 6
Purpose of the Study 8
Summary of Research Methods and Hypotheses 9
Significance and Relevance of the Study 10
CHAPTER 2: LITERATURE REVIEW 12
Establishment of the Vessel Sanitation Program 14
Epidemiologic and Virologic Aspects of Noroviruses 25
Changing Epidemiology of Cruise ship-associated Acute Gastroenteritis (AGE) 32
Summary 37
CHAPTER 3: AN ASSESSMENT OF THE ASSOCIATION BETWEEN VSP OPERATIONS INSPECTION OUTCOMES, CRUISE SHIP CHARACTERISTICS, AND ACUTE GASTROENTERITIS INCIDENCE 43
Abstract 44
Introduction 45

Research Aims 49

Research Methods 50

Data Analysis and Results 54

Discussion 59

Limitations 61

Summary 62

CHAPTER 4: AN ASSESSMENT OF PUBLIC HEALTH POLICY AND THE MANAGEMENT OF ACUTE GASTROENTERITIS INCIDENCE AMONG PASSENGERS AND CREW 74

Abstract 75

Introduction 76

Research Aims 79

Research Methods 80

Data Analysis and Results 90

Discussion 106

Limitations 115

Summary 116

CHAPTER 5: DISCUSSION AND CONCLUSION 147

Recommendations for Future Research 149

Impact of SARS-CoV-2/COVID-19 Pandemic on Shipboard Communicable Disease Control 157

Prioritized Recommendations for Future Research and VSP Program Improvements 161

REFERENCES 164
APPENDIX A: VSP ACUTE GASTROENTERITIS LOG 190
APPENDIX B: 2000 VSP OPERATIONS MANUAL SCORE SHEET 191
APPENDIX C: 2005 VSP OPERATIONS MANUAL SCORE SHEET 192
APPENDIX D: 2011 VSP OPERATIONS MANUAL SCORE SHEET 193

LIST OF TABLES

Table 1: Fee Schedule by Vessel Size-Operations Inspections and Reinspections 39

Table 2: Fee Schedule by Vessel Size-Construction and Renovation Inspections 39

Table 3: Comparison of Point Distribution in VSP Operations Manuals-2000, 2005, 2011 40

Table 4: GII.4 Variant Strains, Years of Circulation, Epidemic Season, and Other Names 41

Table 5: Summary of Cruise Ship Periodic Inspections and the Relative Risk of Failure, 2001-2019 66

Table 6: Summary of Cruise Ship Characteristics and Inspection Region and Periodic Operations Inspection Status, Vessel Sanitation Program, 2001-2019 (N=4,597) 67

Table 7: Multivariable Linear Regression Model of Periodic Inspection Scores and Cruise Ship Characteristics and Inspection Region 69

Table 8: Multivariable Binary Logistic Regression Model of Periodic Inspection Outcomes by Cruise Ship Characteristics 72

Table 9: Acute Gastroenteritis Mean Incidence Rate Per 100,000 Travel Days for Passengers and Crew by Selected Cruise Ship and Voyage Characteristics, Maritime Illness Database and Reporting System, 2001-2019 (N=74,047) 122

Table 10: Acute Gastroenteritis Among Passengers on Cruise Ships, Maritime Illness Database and Reporting System, Vessel Sanitation Program, 2001-2019 124

Table 11: Acute Gastroenteritis Among Crewmembers on Cruise Ships, Maritime Illness Database and Reporting System, Vessel Sanitation Program, 2001-2019 125

Table 12: Number and Rate of Acute Gastroenteritis Outbreaks* per 1,000 Voyages Among Passengers and Crew by Cruise Ship Size, Voyage Length and Regional Port of Arrival – Maritime Illness Database and Reporting System, Vessel Sanitation Program, 2001- 126

Table 13: Multivariable Linear Regression Model for Passenger and Crew Attack Rates and Selected Independent Variables, Maritime Illness Database and Reporting System, Vessel Sanitation Program, 2001-2019. 128

Table 14: Poisson Regression Model of Passenger and Crew Acute Gastroenteritis Attack Rates by Embarkation Year, Maritime Illness Database and Reporting System, Vessel Sanitation Program, 2001-2019. 132

Table 15: Multivariable Logistic Regression Analysis of Acute Gastroenteritis Elevations and Outbreaks for Passengers and Crew (N=74,047 voyages), Maritime Illness Database and Reporting System, Vessel Sanitation Program, 2001-2019. 134

Table 16: Aggregate Interrupted Time Series Analysis for Passenger Incidence Rates*, All Cruise Ships, Maritime Illness Database and Reporting System, Vessel Sanitation Program, 2001-2019. 137

Table 17: Aggregate Interrupted Time Series Analysis for Crew Acute Gastroenteritis Incidence Rates*, All Cruise Ships, Maritime Illness Database and Reporting System, Vessel Sanitation Program, 2001-2019. 138

Table 18: Interrupted Time Series Analysis of Mean Passenger Attack Rates, Maritime Illness Database and Reporting System, Vessel Sanitation Program, 2001-2019. 140

Table 19: Interrupted Time Series Analysis of Mean Crew Attack Rates, Maritime Illness Database and Reporting System, Vessel Sanitation Program, 2001-2019 141

LIST OF FIGURES

Figure 1: Social-Ecological Model (SEM) and Public Health Policy Development Adapted to the Cruise Ship Environment 42

Figure 2: Acute Gastroenteritis Incidence Rate by Status and Year 142

Figure 3: Acute Gastroenteritis Outbreaks Per 1,000 Voyages 142

Figure 4: Acute Gastroenteritis Outbreak-related Cases by Traveler Status and Embarkation Year 143

Figure 5: Passenger Acute Gastroenteritis Incidence Rate per 100,000 travel days 143

Figure 6: Crew Acute Gastroenteritis Incidence Rate per 100,000 Travel Days 144

Figure 7: Mean Passenger Acute Gastroenteritis Attack Rate 144

Figure 8: Mean Crew Acute Gastroenteritis Attack Rate 145

Figure 9: Domains Influencing Evidence-Based Health Decisionmaking 146

CHAPTER 1: INTRODUCTION

Since the early 1990s, the global cruise industry has experienced steady growth, due to the increasing popularity of cruising for vacation and travel. Between 1990-2008 the annual rate of increase in worldwide cruise passengers was reported at 7.4% (Brida & Zapata, 2010; Wondirad, 2019; Cruise Lines International Association [CLIA], 2020). Globally, the cruise industry's annual passenger volume increased from 3.8 million in 1990 to 29.7 million in 2019 (CLIA, 2021; Cruise Market Watch, 2021). In 2019, approximately 50% (15.4 million) of global passengers were North American (CLIA, 2020). This rapid growth has been attributed to several factors, including new cruise destinations, increased consumer disposable income, more leisure time, affordable options for a larger segment of the population, and strong marketing and advertisement by the cruise industry (Vogel, 2011; Wondirad, 2019).

Initially, cruising was primarily considered a form of transportation and accommodation for large numbers of people. However, the cruise industry changed this perspective by investing heavily in multifaceted shipboard experiences that address expanding and diverse passenger needs and expectations (Stefanidaki & Lekakou, 2014). This effort has led to cruise ships becoming the core component of the vacation experience, rather than simply transportation and hotel accommodations for travel to different ports of call (Weaver, 2005). Today, many cruise lines market the ports of call as an extension of the cruise ship experience rather than the destination (Weaver, 2005; Sheridan & Teal, 2006).

Significant Changes in the Cruise Ship Environment

In the early 2000s, the cruise industry began building cruise ships as floating resorts dedicated to leisure, offering various services and activities that rivaled their land-based counterparts (Dowling, 2006). The shift in construction resulted from cruise ship companies' desire for passengers to spend more time and money aboard ships rather than in ports of call (Vogel, 2011). The increased onboard activities and services reduced hours ashore at ports of call while generating increased onboard revenue (Di Vaio & Varriale, 2013).

Another important trend in the cruise industry was the dramatic increase in cruise ship size and passenger-carrying capacity. In the 1970s, the average passenger capacity of a cruise ship was approximately 800 (Stefanidaki & Lekakou, 2014), which had grown to 1,900 by the early 2000s (Stefanidaki & Lekakou, 2014). In 2003, Cunard Cruise Line launched the Queen Mary 2 (QM2), which, at that time, was the largest ocean liner ever built at 151,400 gross registered tons (GRT), with the capacity to carry approximately 2,620 passengers and 1,253 officers and crew (Ship Technology, 2013). Several major cruise lines, including Carnival Cruise Line (CCL), Royal Caribbean International (RCI), Norwegian Cruise Line (NCL), Mediterranean Shipping Company (MSC), Celebrity Cruises, and Princess Cruise Line followed by launching larger, more complex cruise ships. RCI leads in the construction of the largest cruise ships in the world. Currently, the Oasis-class ships (Oasis of the Seas is the first ship built for this class), first launched in 2009, are a group of ships built by RCI that are all at least 225,000 gross registered tons. RCI launched Symphony of the Seas, on June 9, 2017, with an internal volume of 228,081 GRT and a maximum capacity of 6,680 passengers and 2,200 crew (Royal Caribbean International [RCI], 2022a). Currently, the largest cruise ship in the world is the Wonder of the Seas, completed on January 27, 2022, at 235,600 GRT and a capacity of 7,084 passengers and 2,204 crew (Royal Caribbean International [RCI], 2022b). However, it is soon to be surpassed by the Icon of the Seas at 250,800 GRT and a maximum capacity of 7,600 passengers and 2,350 crewmembers, scheduled to begin sailing in January 2024 (Royal

Caribbean International [RCI], 2022c). By 2019, several major cruise lines constructed cruise ships capable of accommodating over 6,000 passengers and crew while offering a variety of onboard activities and services. This trend is expected to continue as new construction replaces aging fleet inventory and has substantial implications for future shipboard public health policy, programs, and practices.

Modern cruise ships are now constructed to be self-contained floating platforms with multiple, complex public health systems to accommodate the increasing numbers of passengers and crew, including (Kak, 2015):

- multiple food and beverage outlets, including buffets, restaurants, bars, and cafés,
- complex potable water production, storage, and distributions systems,
- large numbers of staterooms and cabins to accommodate passengers and crew,
- numerous shipboard activities and entertainment venues (e.g., theaters, dances, casinos, spas, and boutiques),
- elaborate recreational water facilities (swimming pools, water slides, and whirlpool spas),
- shared heating, ventilation, and air-conditioning (HVAC) systems, and
- multiple public spaces and recreational areas, including neighborhoods

Additionally, shipboard medical practices have been modified in response to emerging communicable disease threats primarily associated with person-to-person transmission, including changes to contact-tracing and monitoring practices, medical treatment, patient management, and isolation protocols. Additionally, more stringent housekeeping infection control strategies and effective chemical disinfectants have also become necessary to control communicable disease transmission in more densely populated cruise ships. The resulting industry growth, including greater passenger and crew capacities, the increasing complexity of environmental and public health systems, and the emphasis on the ship itself as the center of the vacation experience, potentially places more passengers and crew at risk of communicable diseases.

Statement of the Problem

Acute gastroenteritis (AGE) is a significant public health issue for the Centers for Disease Control and Prevention's Vessel Sanitation Program (VSP), cruise industry partners, and the traveling public. Cruise ship travel can place passengers and the crew at increased risk of AGE due to the persistence of enteric pathogens in the semi-enclosed environment and multiple modes of transmission. Exposure to these pathogens can lead to enteric disease outbreaks that can adversely impact the health and safety of everyone on board, as the shipboard environment is conducive to pathogen transmission. Moreover, infected crew members may serve as a reservoir of infection for subsequent voyages, since most remain on the cruise ship at the end of the voyage following passenger disembarkation (Gunn et al., 1980; Isakbaeva et al., 2005; CDC, 2021). Newly embarking, susceptible passengers may become infected due to frequent interactions with infected crewmembers or contact with contaminated environmental surfaces.

Impacts of Acute Gastroenteritis on the Cruise Industry

AGE cases and outbreaks can result in substantial economic costs to the cruise industry. Bartsch and colleagues (2020) reported that symptomatic AGE cases linked to norovirus, the leading cause of cruise ship-associated AGE outbreaks, cause an average of $48 in direct medical costs per case, although visits to the ship's medical center can be as high as $70. From 2008 to 2014, the VSP reported 172,810 AGE cases among passengers and crew seeking medical service aboard cruise ships (Freeland et al., 2016). Assuming similar rates, the industry would have incurred direct medical costs of approximately $8.3 million (USD) from 2008-2014. However, most costs to the cruise industry during AGE outbreaks are likely indirect, resulting from lost crew member productivity, intense infection control procedures (i.e., hiring additional cleaning crews), delayed embarkations, or interrupted service to stop the transmission cycle.

The impact of AGE outbreaks extends beyond the direct effects of passenger and crew morbidity and the indirect costs associated with infection control procedures. AGE outbreak response efforts demand an increased workload for all crew members: an “all hands” approach is required for prompt outbreak mitigation and subsequent resolution. Crew members must be trained in pre-designated outbreak response roles and execute those duties, while simultaneously completing their everyday operational and professional responsibilities. These additional workload requirements often lead to high staff turnover and the loss of highly skilled shipboard personnel, requiring the cruise company to invest additional resources for recruitment, training, and supervision, resulting in increased corporate workforce labor and management costs.

Disease control for AGE outbreaks requires strict medical isolation for infected passengers and crewmembers and intense infection control measures to reduce or eliminate communicable disease transmission. During surges in AGE cases, cruise ship personnel must take strict actions to prevent further transmission, including curtailing high-risk activities. These measures often reduce shipboard and shoreside recreational and restrict passenger dining opportunities, leading to decreased customer satisfaction with the cruise experience.

Further, AGE outbreaks tend to be high-intensity media events, elevating negative public perceptions while reducing confidence in the cruise industry and government oversight. This negative public perception and loss of trust affect the entire cruise industry, regardless of the specific ship or line directly impacted by the outbreak. Negative public health risk perceptions influence customer decision-making for travel and leisure, potentially reducing booking opportunities for new and repeat customers, with concurrent loss of revenue.

Conceptual Framework

The conceptual framework that characterizes the dynamics of AGE transmission and the development of risk mitigation strategies aboard cruise ships approximates the social-ecological model (SEM), first described by Bronfenbrenner (1977) and adapted for health promotion and disease prevention by McLeroy and colleagues (1988). The SEM framework contains five levels, considering intrapersonal and interpersonal characteristics, organizational factors (formal and informal policies and procedures), community/industry factors, and federal laws and regulations driving public health policy (Clayton et al., 2015). The SEM model also emphasizes the importance of developing interventions that address interpersonal, organizational, community/industry, and policy factors that support healthy behaviors and practices (McLeroy et al., 1988). AGE risk management practices established through collaborative efforts by the VSP and cruise industry stakeholders focus primarily on bacterial enteric pathogens transmitted through food and water. Historically, AGE outbreaks on cruise ships have been associated with common bacterial enteric pathogens, such as *Salmonella spp*, *Shigella spp*, and *Escherichia coli*. As these enteric pathogens are not typically transmitted person-to-person, the individual risk is limited to consuming contaminated food and water. Basic risk mitigation strategies to protect passengers and crew from exposure are grounded in standardized food and potable or recreational water safety practices. While bacterial enteric pathogens continue to cause sporadic foodborne and waterborne outbreaks, their frequency has diminished dramatically due to improvements in the engineering practices, equipment, and technologies of public health systems; crew training; and enhancements in public health practice.

More recently, the emergence of viral enteric pathogens, such as noroviruses, as the predominant cause of AGE outbreaks on cruise ships has required a change in communicable disease management. Norovirus transmission occurs through multiple modes, including contact with an infected person, consumption of contaminated food or water, or contact with contaminated environmental surfaces (Isakbaeva et al., 2005). Cruise ships' predominant transmission mode appears to be person-to-person contact, facilitated by frequent interactions with other passengers and crewmembers in shared living, dining, and recreational spaces (Cramer et al., 2006). The cruise industry has expanded shipboard public health programs to prevent norovirus transmission by implementing strong infection control strategies such as enhanced cleaning and disinfection of high hand-contact surfaces, prompt reporting of acute gastroenteritis symptoms to the medical center, and strict isolation policies for ill passengers and crew. Passenger and crew behaviors affect the propagation of communicable diseases throughout the ship. Therefore, daily public health messaging on the importance of frequent hand hygiene to passengers and crew is an essential risk mitigation component, and hand sanitizing stations are provided at strategic public locations throughout the ship. Some cruise lines have begun installing handwashing stations at the entry of passenger and crew buffets to minimize fomite contamination in dining areas. Figure 1 at the end of this chapter outlines the SEM framework adapted for the cruise ship environment, including key factors and considerations necessary for developing effective shipboard public health programs.

Noroviruses are highly contagious and spread readily in environments where people are close to each other. Its low infectious dose (as few as 18 virions can cause illness), high viral shedding titers in feces and vomitus, and prolonged environmental persistence are recognized as contributing factors to high rates of virus transmission (Atmar et al., 2008; Hall et al., 2011; Barclay et al., 2014; Kirby et al., 2016). Furthermore, up to 30% of norovirus-infected individuals are asymptomatic but can shed the virus in large quantities, spreading the infection and hampering control efforts (Atmar et al., 2008). The combined characteristics of the cruise ship environment and noroviruses' properties can facilitate the pathogen's rapid spread throughout a cruise ship. Outbreak prevention and management strategies for these enteric pathogens rely on sound infection control principles (Barclay et al., 2014).

Purpose of the Study

This study aims to assess the effectiveness of foundational programs and policies formulated through the joint efforts of the VSP and cruise industry partners, and the execution of these interventions by cruise ship staff, to manage AGE risk on passenger cruise ships. The increasing size and complexity of cruise ships and changing enteric pathogen threats with multiple modes of transmission require the development of sound public health policies and risk mitigation strategies that effectively reduce exposure to currently recognized enteric pathogens. While the collaborative efforts of the VSP and cruise industry partners have been identified as effective in improving overall sanitation standards, adverse health outcomes associated with onboard enteric pathogens remain. Annual AGE outbreaks continue, resulting in significant morbidity, substantial economic loss to the cruise industry, and diminished public confidence in the cruise industry and the VSP (CDC, 2019).

The persistence of these outbreaks indicates that enhanced food and waterborne disease prevention practices alone are insufficient for AGE outbreak prevention and control. While it is unreasonable to expect the full elimination of enteric pathogens from the cruise ship environment, continuous improvement in public health policy and best practices may reduce the number and severity of AGE outbreaks.

Summary of Research Methods and Hypotheses

This dissertation investigates the relationship between compliance with VSP operational requirements and AGE incidence rates on cruise ships and considers the impact of failing an operations inspection. To examine this association, this study undertakes a regression analysis of cruise ship inspection scores on AGE incidence, controlling for selected covariates (ship age, ship size [gross registered tonnage], fleet size, and port/region of inspection) proven important when examining AGE outcomes (Cramer et al., 2003). For this assessment, the following research questions were examined:

- Is the overall trend in AGE incidence associated with VSP operations scores?
- Are operations inspection outcomes (pass/fail) associated with selected cruise ship characteristics?
- Do operations inspection scores predict AGE incidence or outbreaks?

To assess whether the trends in AGE incidence were associated with VSP policy implementations, an interrupted time series analysis was conducted to examine the impact of the 2005 and 2011 VSP operations manual requirements on AGE incidence between 2001-2019. To my knowledge, no published studies have examined the impact of the cruise industry's public health policy on AGE outcomes using an interrupted time series approach, chosen due to the longitudinal nature of cruise ship voyages and the grouping of cruise ships within cruise brands and lines. In addition, this approach allowed examination of whether AGE incidence and outbreak trends were consistent across cruise ships and cruise lines. For this assessment, my research questions include the following:

- Do public health policies implemented in the VSP Operations Manuals for 2005 and 2011 significantly reduce AGE incidence rates (including outbreak rates) on cruise ships?

- Are the trends in AGE incidence consistent across cruise lines and cruise ships?
- Is there an association between operational inspection scores and AGE incidence, including incidence rates over the study period? If so, is the correlation consistent across cruise brands/cruise lines?

I hypothesize that these policies, if implemented effectively, will likely cause a gradual and sustained reduction in AGE incidence and outbreak rates in passenger and crew populations when compared to pre-implementation levels. Furthermore, I hypothesize that robust public health policies and programs should maintain effectiveness during epidemic variants of common enteric pathogens to protect passengers and crew from preventable morbidity.

Significance and Relevance of the Study

The complexities of modern cruise ships, including larger shipboard populations requiring more supportive public health systems and changes in enteric pathogen threats, present industry-wide challenges that require sound risk mitigation strategies enforced through policies and practices tailored to this unique environment. These strategies must incorporate disease control practices that augment the traditional food and potable/recreational water safety routines that have successfully reduced AGE risk over the past 45+ years. Since 2002, the VSP and cruise industry partners have gradually implemented increasingly rigorous housekeeping and infection control protocols, requirements for prompt illness reporting, strict enforcement and compliance with isolation procedures, written outbreak response plans, and hand hygiene standards as essential components to shipboard enteric disease control programs. With the increasing frequency of norovirus outbreaks, VSP revised their 2005 and 2011 operations manuals to reflect evolving science and experience regarding the best methods for controlling emerging enteric pathogens on cruise ships. This research can support the evidence that VSP and cruise industry partners require to develop sound, evidence-based public health policies, programs, and practices.

CHAPTER 2: LITERATURE REVIEW

During the early 1970s, the cruise industry experienced several large diarrheal disease outbreaks aboard passenger cruise ships. Specifically, outbreaks caused by *Salmonella typhi* (Davies et al., 1972) and *Shigella flexneri* (Merson et al., 1975a) raised concerns about health and safety among the traveling public and government officials of the United States and Canada. Between 1970-1975, the United States Center for Disease Control and Prevention (CDC) investigated diarrheal disease outbreaks on 13 cruise ships (Merson et al., 1976a). In six of these outbreaks, the identified etiologic agents included salmonella (n=3), shigella (n=1), and *Vibrio parahemolyticus* (n=2), suggesting that seafood was likely contaminated with seawater during food handling activities (Lawrence et al., 1979). In six of the seven remaining outbreaks, epidemiologic evidence suggested the etiologic agents were acquired aboard the ship but did not identify food or water as possible vehicles (Merson et al., 1976a). Other investigations of diarrheal disease outbreaks aboard cruise ships implicated other bacterial enteric pathogens, including nontoxigenic *E. coli* linked to consumption of contaminated cold food (Synder et al., 1984), *enterotoxigenic E. coli* contamination of crab meat (CDC, 1976), and bacterial contamination of potable water systems (O'Mahony et al., 1986) from poor system maintenance and bunkering of drinking water from non-potable sources (Daniels et al., 2000). In these notable enteric disease outbreaks, poor food handling practices and improper water system maintenance resulted in substantial preventable morbidity among passengers and crew. These shortcomings in public health prevention practices prompted the CDC to take necessary actions to reduce the risk of foodborne and waterborne enteric diseases aboard passenger cruise ships.

Between 1970 and 1975, the CDC Sanitation and Vector Control Activity of the Quarantine Division conducted sanitation inspections and investigations on arriving cruise ships reporting cases of diarrheal illness or acute gastroenteritis to quarantine stations, due to the risk of outbreaks associated with cruise ship activities and operation. Priority investigations took place when an outbreak was suspected to be caused by a federal quarantine and isolation pathogen such as *Vibrio cholera* (Werner et al., 1976). The CDC Quarantine Division assigned small inspection teams, composed primarily of civil servants, to quarantine stations at major seaports or airports in large U.S. large cities, to provide ready access to arriving cruise ships requiring inspection or investigation services.

The primary focus of the sanitation inspection was to identify violations in food handling practices and potable water/recreational water system management (Personal communication, Daniel Harper, Former Deputy Chief, VSP, August 20, 2021). Additionally, quarantine staff inspected cruise ships for unsanitary conditions associated with rodent infestation to prevent the introduction, transmission, and spread of communicable diseases into the United States, as outlined in federal quarantine and inspection statutes (Regulations to Control Communicable Diseases, 2011). During the early 1970s, the Sanitation and Vector Control Activity inspected approximately 47 cruise ships annually, with a capacity of 800-1,200 passengers routinely making U.S. port calls (Personal communication, Daniel Harper, Former Deputy Chief, VSP, August 20, 2021). In 1974, 95 foreign-flag and six domestic-flag cruise ships visited U.S. ports (Merson et al., 1976a).

Early efforts to control diarrheal disease incidence aboard cruise ships were reactive rather than proactive, as quarantine staff conducted shipboard sanitation inspections or investigations in response to reported cases of diarrheal illness. The primary pathogens of concern were bacterial, specifically those observed to cause food and waterborne outbreaks on cruise ships and land. Shipboard sanitation inspections were based on the World Health Organization (WHO) *Guide to Ship Sanitation,* which, at the time, was the preeminent standard for ship operations; however, implementation was inconsistent across the cruise industry. Through 1974, cruise ships passing sanitation inspections were issued a Certificate of Sanitation, attesting to satisfactory compliance with sanitary standards (Merson et al., 1976a). While the CDC Quarantine Division maintained a routine inspection program for all cruise ships making port calls at U.S. ports, no routine inspections were required for cruise liners traveling across international waters (Werner et al., 1976). Therefore, the CDC determined that federal oversight and collaboration with the cruise industry should be broadened and strengthened to mitigate enteric disease risks effectively and prevent outbreaks associated with cruise ship travel.

Establishment of the Vessel Sanitation Program

On July 1, 1975, the CDC established the Vessel Sanitation Program (VSP) to address widespread deficiencies in food safety and water sanitation practices identified during outbreak investigations of diarrheal diseases aboard passenger cruise ships (Merson et al., 1976a). Concurrently, the CDC provided a list of guidelines for safe food handling and potable water sanitary practices to all cruise lines (Merson et al., 1976a). Specific recommendations included: 1) improving the availability and use of handwashing stations by food workers, 2) improving refrigeration facilities and practices, 3) improvements in holding temperatures for cold food (≥45°F or ≥7°C), 4) upgrading warewashing facilities and practices for washing and sanitizing dishes, glasses, and utensils, and 5) instituting continuous halogenation or other acceptable water treatment methods, and routine coliform testing of all potable water (CDC, 1974). Additionally, the CDC requested that cruise lines improve the surveillance of diarrheal disease cases during a voyage and report all cases by radio to U.S. quarantine stations (Merson et al., 1976a; Werner et al., 1976). Investigations of shipboard medical logs indicated significant underreporting of diarrheal diseases, making estimating actual diarrheal illness difficult (CDC, 1974; Merson et al., 1976b). Moreover, the previous reporting only required masters of cruise ships to report diarrhea illnesses that interfered with work or regular activity (CDC, 1974).

Legislative Authority and Mission

The mission of the VSP was to assist the cruise ship industry in developing and implementing comprehensive, performance-based public health programs to protect the health of the traveling public and cruise ship personnel, and has remained unchanged since its inception (CDC, 2000, Forward, page ii). In addition, program aimed to prevent the introduction, transmission, and spread of communicable diseases on passenger cruise ships entering the United States through its seaports (CDC, 2019).

The authority to conduct VSP activities is based on the Public Health Service Act (42 United States Code § 264 Quarantine and Inspection - Regulations to control communicable diseases). This law authorizes the Surgeon General to make regulations to prevent the introduction, transmission or spread of communicable diseases from foreign countries into the United States or its possessions through inspection and other appropriate sanitary measures (Government Printing Office [GPO], 2019). Federal authorities established operational guidance in 42 Code of Federal Regulations Part 71-Foreign Quarantine. VSP standards are applied to all cruise ships carrying 13 or more passengers, having a foreign itinerary, and making port calls in the United States or its territories (CDC, 2019).

From July 1, 1975 through 1986, the VSP operated continuously from all major U.S. seaports. The CDC initially provided operational costs for the program through taxpayerappropriated funds. However, in 1986, the U.S. Congress, concerned with the expenditure of federal funds for cruise ship inspections and industry complaints that VSP public health standards were too stringent, requested CDC discontinue some VSP program activities. In place of complete VSP oversight, Congress asked the cruise industry to develop a self-inspection program based on the contents of the VSP public health guidelines. Operating agreements were made between the cruise industry, the National Sanitation Foundation (NSF), and external public health consultants to conduct shipboard sanitation inspections. Sanitation inspection reports were forwarded to the VSP for program oversight and review as part of these agreements. However, following a series of public meetings held due to public concerns regarding cruise ship outbreaks, the VSP was restructured and resumed operations on March 1, 1987. The congressional mandate included specific language regarding CDC appropriations and required the VSP to 1) reestablish unannounced operational inspections, 2) conduct follow-up inspections, 3) provide construction consultation, 4) investigate gastrointestinal illness outbreaks, and 5) publish bi-weekly inspection scores and additional reports on request. At the same time, the VSP became a part of the National Center for Environmental Health (NCEH) (CDC, 2018, p. ii).

VSP Programs and Operations

The VSP, which operates under the National Center for Environmental Health (NCEH) within the CDC's Division of Environmental Health Science and Practice (DEHSP), is led and staffed primarily by commissioned United States Public Health Service (USPHS) officers. Currently, the complement of commissioned officers includes highly trained personnel in environmental health (n=10) and epidemiology (n=2). Since 1988, the VSP has been authorized to charge user fees to ship owners for operational inspections, reinspections, and construction inspections or significant renovations. These user fees, based on ship size according to their gross registered tonnage (GRT) listed in *Lloyd's Register of Shipping* (CDC 2019), are published in the Federal Register (84 FR 43602) and currently comprise the primary revenue source for all VSP program activities. Tables 1 and 2 at the end of this section present, respectively, the most recent fee schedules for operations and construction/renovation inspections/reinspections.

In mid-March 2020, VSP operational inspections were temporarily discontinued, due to the SARS-CoV-2/COVID-19 pandemic and the issuance of the No Sail Order (NSO), Conditional Sailing Order (CSO), and subsequent extensions levied by the CDC. These actions eliminated this source of funding for program operations. During that time, VSP personnel actively supported CDC's COVID-19 pandemic response through the Emergency Operations Center (EOC) Global Migration Task Force Maritime Unit. VSP secured funding through the Coronavirus Aid, Relief, and Economic Security (CARES) Act of 2020 received by the CDC to support its pandemic response (Personal communications, Amy Freeland, Deputy Chief, Vessel Sanitation Program, November 1, 2021) until user fees were collected again in January 2023.

VSP Syndromic Surveillance Program

In 1975, the Vessel Sanitation Program (VSP) established a reporting system to monitor AGE among passengers and crew aboard cruise ships making port calls in the United States. The authority to collect gastroenteritis case data is outlined in federal regulations found in 42 CFR§71.2 (a) and (c)-Foreign Quarantine-Report of Death or Illness (Government Printing Office [GPO], 2020). The current regulation requires the master (or designated staff) of cruise ships carrying 13 or more passengers with an international itinerary and making port calls in the U.S. to report all AGE in passenger and crew populations at predetermined intervals, at least 24-36 hours before arrival at the first U.S. port. When additional AGE cases are diagnosed in the medical center beyond this deadline, the ship must provide an updated cumulative report no later than four hours before arrival in the U.S. Under routine reporting criteria, cases reporting signs and symptoms of AGE to the medical center 15 days or more before arrival at the first U.S. port may be excluded. Though VSP requires no reports during the last four hours before the cruise ship's arrival, AGE case data are maintained in the shipboard Acute Gastroenteritis Surveillance Log (formally known as the Gastrointestinal Illness Surveillance System [GISS] Log) and evaluated during operations inspections and AGE outbreak investigations. The VSP requires the ship's medical staff to maintain an AGE Surveillance Log for each voyage, even if there are no reportable cases (CDC, 2018b), in which case cruise ship personnel must complete the AGE Surveillance Log header section and maintain it on the ship for 12 months. When there are reportable AGE cases, the VSP requires collection of specific patient data, maintained onboard for 12 months and subject to VSP inspection (see the header section of Appendix A).

Current VSP reporting does not require cruise ships to submit an end-of-voyage report. since federal regulation does not require it. However, the VSP has implemented additional reporting as operational requirements when the cruise ship medical department observes a significant elevation in AGE cases, measured as a cumulative proportion of reportable AGE cases of 2% or more in passenger or crew populations within 15 days of arrival at the first U.S. port. In this case, the ship's master, designated staff, or corporate representative must submit a Special Report, which prompts VSP staff to begin daily monitoring of AGE cases until the end of the voyage or when reportable cases reach the threshold of 3%, when an outbreak is declared. This classification requires the ship's master to submit a second Special Report to the VSP. A cruise ship exceeding the 3% threshold is subject to a mid-voyage onboard outbreak investigation, provided there is an opportunity to board the ship. Otherwise, an investigation team may board at disembarkation to conduct an environmental health inspection and limited epidemiologic investigation. Special reports differ from routine reports, as all reportable AGE cases must be included for a voyage or voyage segment. VSP Operations Manual lists special report requirements, and significant violations are considered critical, leading to a possible 4-point deduction during the subsequent operational inspection (CDC, 2018b).

In 2005, the VSP added a secure web interface for the electronic reporting of gastrointestinal illness cases to the Maritime Illness Database and Reporting System (MIDRS), now the primary method for AGE case reporting (CDC, 2018a). The most recent operations manual states that cruise ships should report AGE cases electronically when feasible (CDC, 2018b). Before 2000, a reportable AGE case was based solely on diarrhea (diarrheal disease), defined as three or more loose stools in 24 hours (CDC, 2018b). With the update of the VSP Operations Manual in 2000, VSP expanded the reportable case definition to include vomiting and at least one additional symptom, including one or more loose stools, bloody stool, feeling feverish, a measured temperature of ≥100.4°F (≥38°C), abdominal cramps, headaches, and muscle aches (myalgia) (CDC, 2000). The change in the reportable AGE case definition was necessary due to norovirus infection, where the absence of diarrhea is common (Teunis et al., 2008; Atmar et al., 2008), which may have led to underreporting of AGE cases and outbreaks.

The MIDRS surveillance system continues to be integral to VSP's ability to monitor AGE trends over time, detect unusual case clusters, and respond to outbreaks as needed. Additionally, the periodic review of surveillance reports provides criteria to improve shipboard management of AGE cases. Furthermore, surveillance data are helpful for systematic evaluations of program effectiveness, and provide cruise industry-specific evidence to guide public health policy and program development.

VSP Operations Inspection Program

The VSP is authorized to conduct environmental sanitation inspections (under 42 CFR Section 71.41 General Provisions, Foreign Quarantine-Requirements Upon Arrival at U.S. Ports: Sanitary Inspections) to determine the presence of pests, contaminated food or water, or other unsanitary conditions. The VSP inspection program is based on recognized public health standards important to the prevention of food and waterborne disease and outbreaks on cruise ships, including relevant chapters and sections of the *WHO Guide to Ship Sanitation* (World Health Organization [WHO], 2011) and the *FDA Food Code* (Food and Drug Administration [FDA], 2017). The 1989 VSP Operations Manual, which consolidated these recognized public health standards, guided the cruise industry until its update in 2000 (CDC, 2000), which expanded requirements for food safety practices, improved AGE reporting, and updated swimming pools and whirlpool spa management (Cramer et al., 2008). Additional operations manual revisions were published in 2005, 2011, and 2018 (CDC, 2018b). The VSP seeks to revise the operations manual every 3-5 years to adopt pertinent changes in public health practice, advances in food safety, potable and recreational water system technology, and other important technological advancements (CDC, 2018b). These operations manuals are considered industry-wide standards used in North America and have been adopted, in whole or in part, by other maritime public health programs worldwide.

All cruise ships operating under U.S. jurisdiction are subject to twice-yearly unannounced operations inspections (CDC, 2018b, p. ii). Though VSP leadership indicates that these inspection activities are primarily performance-based, new initiatives include more evidence-based policies generated through research collaborations between VSP staff and cruise industry associates (CDC, 2018b). VSP operations inspections aim to assess cruise ship compliance with recognized public health standards outlined in the current VSP Operations Manual, considered the minimum public health standards for passenger cruise ships. Cruise lines are strongly encouraged to implement policies and programs that exceed the minimum standards appropriate for their respective fleet (Personal communications, Amy Freeland, Deputy Chief, Vessel Sanitation Program, September 30, 2021). Since 2000, VSP Operations Manuals have updated public health standards, including prevention and control strategies to address emerging norovirus threats aboard cruise ships.

Operations inspections are conducted by a team of one to four Environmental Health Officers (EHOs) of the U.S. Public Health Service (CDC, 2019). The size of the inspection team is determined by the size and complexity of shipboard public health systems, with inspection lengths between 8-10 hours. Specific areas covered during an operations inspection include medical case management and reporting (VSP Operations Manual, chapter 4), potable water systems (chapter 5), recreational water systems (chapter 6), food safety (chapter 7), integrated pest management (IPM) (chapter 8), housekeeping and infection control (chapter 9), child activity centers (chapter 10), and heating, ventilation, and air conditioning systems (chapter 11). The team records findings on a 44-item inspection form, scored using risk-based weighting, with each critical violation resulting in a three-to-five-point deduction. Critical violations are associated with outbreaks of infectious diseases; most link to gastrointestinal illnesses spread by food and potable and recreational water.

However, a few critical inspection items are associated with case reporting. For example, missed, inaccurate, or untimely submission of MIDRS reports can result in a four-point deduction during operational inspections. In the early years of VSP operations, a single critical violation in food safety or water systems management, such as food out of temperature or lack of sufficient residual halogenation in the potable water system, carried a 15-point deduction and a failing inspection score. If the cruise ship operators can correct the critical violation during the inspection, they avoid the 15-point deduction (Personal communication, Daniel Harper. Former Deputy Chief and Senior Environmental Health Officer, Vessel Sanitation Program, August 20, 2021). Non-critical violations may result in a one- or two-point deduction, based on frequency, severity, or a history of repeat violations. Table 3 lists all major operation inspections categories with the assigned point deductions; appendices B, C, and D present the score sheets for the 2000, 2005, and 2011 VSP Operations Manuals, provided to the cruise ship's leadership at the out-brief following each inspection.

Cruise ships are graded on a scale from 0 to 100, with an 86 or above considered a passing score, representing satisfactory compliance with VSP public health standards. A cruise ship failing an operations inspection must undergo an unannounced reinspection within one month (CDC 2018b; CDC, 2019). The VSP maintains procedures for post-inspection reporting of corrective action, requiring cruise lines to submit a corrective action statement and management monitoring plan. Food safety violations represent 62% of inspection point totals, while 23% relate to the improper management of water systems (potable and recreational) violations. This inspection focus is consistent with VSP's historical emphasis on food- and potable water-related illnesses. Table 3 compares the point distribution for the 2000, 2005, and 2011 VSP Operations Manuals. All inspection results, violations, and corrective action statements are published on the CDC website (https://www.cdc.gov/nceh/vsp/) for public viewing, along with a searchable database of inspection report summaries and complete reports.

Impact of the Vessel Sanitation Program

The CDC has periodically evaluated the impact of VSP public health initiatives since its establishment. The first assessment, conducted by Dannenberg and colleagues (1982), examined the relationship between performance on sanitation inspections and the frequency of diarrheal disease outbreaks, finding that cruise ships failing sanitation inspections were more likely to have diarrheal disease outbreaks than those that passed. Later, Addiss and colleagues (1989) found that the collaborative efforts of VSP and cruise industry partners resulted in a significant decline in diarrheal disease incidence rates during outbreaks, from 26.6 per 100,000 passenger days between 1975-1979 to 8.2 per 100,000 passenger days between 1980-1985. Their report also revealed that cruise ships with passing inspection scores were less likely to experience diarrheal disease outbreaks. In a similar study of diarrheal disease from 1986 to 1993, Koo and colleagues (1996) reported overall outbreak incidence rates of 1.4 per 1,000 voyages, or 2.3 outbreaks per 10 million passenger days, for voyages 3-15 days in duration, as well as a decline in outbreak-related diarrheal disease incidence (6.0 per 100,000 passenger days). The CDC reported 31 diarrheal disease outbreaks during the study period, with laboratory confirmation of infectious agents, including etiologic agents (21 outbreaks, or 68%), bacterial enteric pathogens (12, or 39%), and Norwalk or Norwalk-like viruses (i.e., norovirus) (9, or 29%), implicating deficiencies in food safety practices, including improper seafood cooking, unpasteurized eggs, poor food handling by caterers for shore excursions, and food employees working while ill. The investigators stated that improving these food safety practices would likely have prevented 63% of the diarrheal disease outbreaks (Koo et al., 1996).

Cramer and colleagues (2003) examined the relationship between performance on environmental health inspections and diarrheal disease incidence; they found that median inspection scores increased significantly (89-93%) between 1990 and 2000, demonstrating significant improvements in overall shipboard sanitation practices. Additionally, diarrheal disease incidence rates among passengers decreased substantially, from 29.2 cases per 100,000 passenger days in 1990 to 16.3 cases per 100,000 passenger days in 2000. Concurrently, diarrheal disease outbreak-related illness rates declined, from 4.2 to 3.5 per 100,000 passenger days. Further, passenger diarrheal disease incidence rates were significantly lower on cruise ships with passing environmental inspection scores than on those with failing scores. However, a follow-up study by Cramer and colleagues (2006) reported that, during 2001-2004, performance on environmental health inspections did not correlate with AGE incidence; annual AGE incidence rates increased from 17.4 in 2001 to 28.5 per 100,000 passenger-days in 2004. This rise was attributed to the increasing frequency of AGE outbreaks caused by noroviruses (Cramer et al., 2006), both on land and cruise ships (Widdowson et al., 2004; Isakbaeva et al., 2005; Vinje, 2015).

These studies suggest that the VSP and cruise industry partners' collaborative work effectively reduced the overall incidence of diarrheal disease. Additionally, the frequency of outbreaks and outbreak-related illnesses on cruise ships attributable to bacterial enteric pathogens linked to foodborne and waterborne outbreaks also declined, though improper food safety practices continued to contribute to AGE outbreaks. Furthermore, Norwalk and Norwalk-like viruses (i.e., noroviruses) were confirmed as etiologic agents in an increasing proportion of these outbreaks, due partly to improved laboratory techniques, including novel molecular methods such as polymerase chain reaction (PCR). The increase in norovirus outbreaks presented new challenges in disease control aboard cruise ships due to the multiple modes of norovirus transmission, including person-to-person transmission and general susceptibility of the shipboard populations. Moreover, due to the emphasis on foodborne and waterborne enteric disease transmission during operational inspections, the current inspection framework may not be sensitive to protecting against AGE outbreaks associated with person-to-person spread or environmental contamination (Taylor, 2018).

Epidemiologic and Virologic Aspects of Noroviruses

Human noroviruses, which cause both sporadic and epidemic acute gastroenteritis, are the leading cause of epidemic, nonbacterial acute gastroenteritis (AGE) worldwide. Noroviruses have emerged as AGE's most common etiologic agent in the United States, with an estimated 19-21 million annual cases (Scallan et al., 2011). Moreover, noroviruses are estimated to cause 1.7-1.9 million outpatient visits, 400,000 emergency department visits, 56,000-71,000 hospitalizations, and 570-800 deaths annually (Hall et al., 2013). As the leading cause of epidemic gastroenteritis worldwide, noroviruses account for more than 90% of viral gastroenteritis outbreaks and approximately 50% of annual all-cause AGE outbreaks in the U.S. and Europe (Patel et al., 2008; Yen et al., 2011), and 40-58% of all U.S. foodborne outbreaks (CDC, 2009; Hall et al., 2013; Gould et al., 2013). In addition to morbidity and mortality outcomes associated with norovirus infections, global estimates indicate $4.2 billion in direct health system costs and $60.3 billion in societal costs per year (Bartsch et al., 2016).

Noroviruses affect people of all age groups at risk of contracting the infection. Young children (<5 years of age) are at the most significant risk of severe complications and hospitalizations from the infection, and elderly persons (>65 years of age) are at the highest risk of mortality. Immunocompromised persons have the highest infection risk, higher complication rates, and prolonged viral shedding (Banyal et al., 2018).

Norovirus Taxonomy and Characteristics

Noroviruses are a group of small, genetically diverse nonenveloped RNA viruses belonging to the genus *Norovirus* in the family *Caliciviridae* (Vinje, 2015). The *Calicivirus* family is subdivided into 11 genera; seven members (*Lagovirus*, *Norovirus*, *Nebovirus*, *Recovirus*, *Sapovirus*, *Valovirus,* and *Vesivirus*) infect mammals, two (*Bavovirus* and *Nacovirus*) infect birds, and two (*Minovirus* and *Salovirus*) infect fish (Vinje et al., 2019). Human caliciviruses include the genera Norovirus and Sapovirus. Of these, Norovirus is the most clinically important, frequently identified as the cause of AGE in humans (Vinje et al., 2019).

The human norovirus genome consists of a 7.5-kb single-stranded, positive-sensed RNA molecule organized into three open reading frames (ORFs). ORF1 encodes six non-structural proteins; ORF2 and ORF3 encode major structural capsid protein (VP1) and minor capsid protein (VP2), respectively (Vinje et al., 2019). Structurally, the norovirus genome is encapsulated by VP1 and VP2 proteins (Vinje et al., 2019).

Norovirus genetic diversity is represented by its classification into ten genogroups designated GI-GX, 49 genotypes, and 60 P-types (Chhabra et al., 2019; Vinje et al., 2019; Cheng et al., 2021). Genogroups GI, GII, GIV, GVIII, and GIX (formerly GII.15) infect humans, causing acute gastroenteritis (Chhaabra et al., 2019; Vinje et al., 2019; Cheng et al., 2021; Ludwig-Begall et al., 2021). Genogroups generally differ by approximately 40-60% of amino acid sequences, and genotypes by about 20-40% (Debbink et al., 2012; Vinje, 2015; Parra, 2019). Genogroups are divided into genotypes (9 GI, 27 GII, 3 GIII, 2 GV, 2 GIV, and one genotype for GVII, GVIII, and GIX) (Chhabra et al., 2019); Noroviruses can be further subclassified as variants within a genotype (Banyai et al., 2018). Norwalk virus, the prototype strain belonging to the GI, was first implicated in a gastroenteritis outbreak at an elementary school in Norwalk, Ohio, in 1968 (Adler & Zickl, 1969). The etiologic agent was subsequently visualized by immune electron microscopy and named "Norwalk virus" (Kapikian et al., 1972). Norwalk virus was the first virus recognized to cause acute gastroenteritis (Shah & Hall, 2018)

The involvement of noroviruses in gastroenteritis outbreaks varies substantially by genogroup. GI and GII noroviruses cause most gastroenteritis in human populations, with approximately 85% of acute gastroenteritis cases caused by genogroup II, and 15% by genogroup I (Pringle et al., 2015; Simons et al., 2016). A 2014 analysis of norovirus outbreaks reported to CDC's CaliciNet indicated that 11% of outbreaks (n=435) were typed as genogroup I noroviruses (including Norwalk virus strain (GI.1)). By comparison, 89% of outbreaks (n=3,525) were classified as genogroup II noroviruses (Vega et al., 2014). These GII noroviruses are associated with person-to-person transmission, whereas genogroup I variants are often linked to foodborne and waterborne outbreaks (Vinje, 2015). Additionally, GII noroviruses have a >100-fold higher viral load than genogroup I noroviruses, resulting in greater transmissibility (Chan et al., 2006). General population susceptibility to GII variants and the predominance of person-to-person spread lead to more outbreaks and greater potential for viral mutations.

Molecular virologic and epidemiologic studies have improved the understanding of the complex diversity of noroviruses, demonstrating that these viruses are constantly evolving, with new strains emerging due to genetic drift and the influence of population immunity (Siebenga et al., 2009; Debbink et al., 2012). Genogroup II noroviruses have been the most predominant strain identified in norovirus outbreaks (Pringle, et al., 2015): GII.4 strains are consistently identified as the predominant genotype, with new strains emerging every two to five years (Zheng et al., 2010; Debbink et al., 2012; Vega et al., 2014; Karst & Baric, 2015; Pringle et al., 2015; Vinje, 2015; Lucero et al., 2021). The first reported GII.4 pandemic strain occurred in

1995 and was caused by GII.4 US95/96 (e.g., Grimsby variant) (Noel et al., 1995; White et al., 2002; Vinje, 2015). Since the mid-1990s, several epidemic and pandemic GII.4 strains have emerged, including GII.4 Farmington Hills in 2002 (Lopman et al., 2004; Widdowson et al., 2004), GII.4 Hunter in 2004 (Bull et al., 2006), GII.4 Den Haag (Tu et al., 2008; Eden et al., 2010) and GII.4 Yerseke (2006a) in 2006 (Siebenga et al., 2009), GII.4 New Orleans in 2009 (Vega et al., 2011) and GII.4 Sydney, which replaced GII.4 New Orleans in Australia and New Zealand in late 2012 (Eden et al., 2013, 2014).

Table 4 describes GII.4 variants, years in circulation, epidemic seasons, and other strain names used in the literature (Pringle et al., 2015). These GII.4 viruses account for most norovirus-related AGE outbreaks worldwide; however, they do not always lead to increases in the frequency of outbreaks (Vega et al., 2011; Yen et al., 2011; Leshem et al., 2013; Pringle et al., 2015). For example, in the United States, GII.4 New Orleans and GII.4 Sydney did not lead to an increase in norovirus activity (Pringle et al., 2015; Vinje, 2015). Several non-GI.4 strains were reported to have emerged between 2009 and 2012, accounting for approximately 11-15% of all outbreaks, but did not persist beyond a single norovirus season (Vega et al., 2014). CDC has reported increases in norovirus-related AGE cases and outbreaks on cruise ships during these pandemic norovirus periods, with most caused by the predominant circulating pandemic strains. The prevalence of norovirus strains in the regions of cruise ship travel is likely an essential point of introduction into the cruise ship environment, amplifying onboard AGE cases.

Norovirus Transmission

These highly contagious noroviruses spread easily across populations due to viral evolution, a low infectious dose (18-1,000 virions), a high viral load with extended shedding, and the ability to spread via several transmission routes, including person-to-person, by direct contact or ingestion of aerosolized virus particles and consumption of contaminated food or water (Chan et al., 2006: Teunis et al., 2008: Siebenga et al., 2009; Shah & Hall, 2018). Contamination of environmental surfaces and fomites with viral particles and environmental persistence also contribute to illness propagation (Siebenga et al., 2009; Lindsay et al., 2015; Shah & Hall, 2018).

Gastroenteritis outbreaks involving multiple strains of noroviruses can occur, with simultaneous GI and GII infections usually linked to foodborne and waterborne transmission (Bitler et al., 2013; Verhoef et al., 2015). Waterborne outbreaks have also been associated with GI strains (Matthews et al., 2012). Studies also indicate that person-to-person transmission is commonly associated with GII.4 noroviruses (Matthews et al., 2012; Bitler et al., 2013; Verhoef et al., 2015), possibly through multiple modes within the same outbreak (Verhoef et al., 2015). In the United States, person-to-person spread is reported to be the predominant mode of transmission in norovirus outbreaks (Hall et al., 2013).

A significant proportion of norovirus infections (up to 32%) are reported to be asymptomatic; however, these individuals can readily transmit the virus (Graham et al., 1994). Symptomatic and asymptomatic norovirus cases shed large amounts of virus in the stool (10^5-10^{11} virus copies per gram of stool) at similar levels, and viral shedding in persons without diarrhea (e.g., in emesis) is commonly observed (Teunis et al., 2008; Atmar et al., 2008). Viral shedding can occur 3-14 hours before symptom onset (Atmar et al., 2008). Peak viral shedding occurs 2-7 days following infection (Atmar et al., 2008; Kirby et al., 2014). Prolonged viral shedding may occur in infants, the elderly, and immunocompromised persons (Atmar et al., 2008; Green, 2014). Additionally, the duration of viral shedding varies by norovirus variant in children and is associated with increased transmission (Cheng et al., 2021). Teunis and colleagues (2015) reported that approximately 25% of cases shed noroviruses for three weeks after symptom onset. Similarly, Atmar and colleagues (2008) found that volunteers in a human challenge study shed Norwalk virus for 4-8 weeks after symptom resolution. These characteristics of norovirus infection and transmission make sporadic cases and outbreaks challenging to control in the community setting and semi-enclosed congregate environments, such as hospitals, long-term care facilities, schools, colleges, universities, and cruise ships.

Clinical Presentation of Norovirus Infection

The clinical presentation of norovirus infection is characterized by an incubation of 24 to 48 hours and acute onset of projectile vomiting or non-bloody diarrhea (Shah & Hall, 2018). Other symptoms may include abdominal cramps, nausea, low-grade fever, myalgia, headache, malaise, and anorexia (Lindsay et al., 2015; Shah & Hall, 2018). Norovirus infections are typically mild and self-limiting in most healthy individuals, with full recovery usually occurring within 2-3 days without medical intervention (Shah & Hall, 2018). However, risk groups, such as young children less than five years of age, elderly adults, and immunocompromised patients, can have prolonged duration of symptoms or severe health outcomes, including hospitalization and death (Harris et al., 2008; Roddie et al., 2009; Lopman et al., 2011; Trivedi et al., 2013; Green, 2014; Lindsay et al., 2015; Shah & Hall, 2018). Adults 65 years and older have the highest norovirus-associated mortality rates, approximately 200% higher than those of children under five years (Lindsay et al., 2015). The severity of acute gastroenteritis appears to vary by norovirus strain. GII.4 noroviruses cause more severe illnesses, hospitalizations, and deaths than non-GII.4 strains (Desai et al., 2012; Shah & Hall, 2018).

Acquired immunity following norovirus infection is conferred following symptom resolution; however, protection is limited to the variant causing the initial infection and is likely of limited duration. Multiple norovirus infections from other norovirus genotypes can occur during a lifetime, resulting from the limited period of immunity and lack of cross-protection among different norovirus genotypes (Saito et al., 2014; Para, 2019). Duration of immunity was thought to last from six months to two years (Parrino et al., 1977; Johnson et al., 1990), but more recent modeling estimates suggest the duration of immunity ranges from four to eight years and may last up to nine years (Simmons et al., 2013).

Treatment and Prevention of Norovirus Infection

Medical intervention for norovirus infections is usually not necessary. Rehydration and electrolyte consumption may be required to prevent dehydration in high-risk persons. However, safe and effective antivirals are essential for individuals with persistent norovirus infection, including immunocompromised persons, young children, and elderly adults (Ludwig-Begall et al., 2021). There are no antiviral drugs to treat norovirus infections; however, research into the development of antiviral therapy is ongoing (Ludwig-Begall et al., 2021). Similarly, while no licensed norovirus vaccines currently exist, there are several in various stages of clinical evaluation and review (Atmar et al., 2018; Kim et al., 2018; Treanor et al., 2020; Ludwig-Begall et al., 2021). The strain diversity of noroviruses and their propensity to escape population immunity mean that vaccines would likely require regular updating to provide adequate coverage (Van Beek et al., 2018). Primary vaccine candidates include vulnerable populations at risk of severe health outcomes from norovirus infection, including young children, older adults, and immunocompromised persons (Desai et al., 2012). Other target groups that may benefit include healthcare staff, food workers, military personnel, and travelers (including cruise ship travelers) (Lucero et al., 2018; Ludwig-Begall et al., 2021).

Laboratory Identification of Noroviruses

Before the mid-1990s, noroviruses were relatively unknown as a cause of sporadic and epidemic gastroenteritis (Vinje, 2015). In the 1970s and 1980s, noroviruses were identified using electron microscopy techniques (Caul, 1996; Hutson et al., 2004). The identification of noroviruses as etiologic agents of acute gastroenteritis was facilitated by the complete genome sequencing of the Norwalk virus in 1990 (Jiang et al., 1990). In 1992, this sequencing led to the development of molecular assays, such as enzyme-linked immunosorbent assays (ELISA) and conventional and real-time (R.T.) reverse transcriptase-polymerase chain reaction (RT-PCR) techniques, considered reliable methods for detecting noroviruses in stool specimens (De Leon et al., 1992; Jiang et al., 1992). Molecular cloning of noroviruses has improved awareness and understanding of their virology, epidemiology, and disease burden (Patel et al., 2009).

Changing Epidemiology of Cruise ship-associated Acute Gastroenteritis (AGE)

During the mid-1990s, the CDC observed a change in the epidemiology of diarrheal disease outbreaks on passenger cruise ships (Koo et al., 1996). Increasingly, more cruise ship AGE outbreaks confirmed Norwalk and Norwalk-like viruses as the etiologic agents. In the early 2000s, the VSP shifted its program focus to include infection control strategies in response to the increasing number of AGE outbreaks caused by noroviruses linked to person-to-person spread and environmental contamination. Additionally, continued improvements in food safety practices and potable and recreational water system management have further reduced AGE outbreaks epidemiologically linked to bacterial pathogen contamination within these systems.

During the 1990s, GII.4 noroviruses were first identified as a significant epidemic strain in AGE outbreaks (Lindesmith et al., 2008) and have emerged as the predominant strain associated with AGE outbreaks worldwide, on land as well as on cruise ships (Fankhauser et al., 1999; Fankhauser et al., 2002; Widdowson et al., 2004; Blanton et al., 2006; Cramer et al., 2006; Zheng et al., 2010; Freeland et al., 2016: Jenkins et al., 2021). GII.4 strains accounted for 5.3% of infections in 1994; by 2006, that number had risen to 85.2%, with similar increases in GII.4 strains observed for cruise ship norovirus outbreaks (Zheng et al., 2010). The increasing proportion of confirmed norovirus outbreaks on land and aboard cruise ships is likely due partly to improved surveillance and laboratory detection methods (Vinje, 2015). Peaks in norovirus outbreaks aboard cruise ships are correlated with the predominant circulating GII.4 variants identified in land-based outbreaks (Cramer et al., 2006; Vinje, 2015; Freeland et al., 2016, Jenkins et al., 2021).

In 2002, the VSP surveillance system detected an abrupt increase in shipboard AGE outbreaks linked to noroviruses (Widdowson et al., 2004). Between January 1 and December 2 of that year, VSP reported 21 AGE outbreaks, compared to four in 2000 and seven in 2001. Laboratory analysis of stool specimens from 14 outbreaks on 12 cruise ships confirmed caliciviruses as the etiologic agent in 12 of these. A novel strain of GII.4 norovirus, provisionally named Farmington Hills based on the first recorded cases in the Michigan town of that name, was identified in 10 cruise ship-associated outbreaks (Widdowson et al., 2004). Additionally, local health authorities in several states reported that the Farmington Hills strain caused land-based AGE outbreaks. During the 2000s, at least one norovirus variant was initially detected from clinical specimens collected during cruise ship-associated AGE outbreaks, most likely due to aggressive case finding and better laboratory testing of clinical specimens.

In 2006, the CDC National Calicivirus Laboratory confirmed the emergence of two new pandemic strains, GII.4 Laurens/2006a (Yerseke cluster) and GII.4 Minerva/2006b (Den Haag cluster), implicated in several multistate norovirus outbreaks in the U.S. (Zheng et al., 2010). The

GII.4 Minerva/2006b strain was also identified as the genotype that caused several norovirus outbreaks on cruise ships in the U.S. and Europe between 2006 and 2009 (Tu et al., 2008; CDC, 2019). Moreover, studies tapped these new GII.4 variants as the predominant strains causing increased norovirus-associated gastroenteritis in Asia, Australia, Europe, and New Zealand (Takkinen, 2006; Tu et al., 2008; Verhoef et al., 2008; Siebenga et al., 2009; Eden et al., 2010).

In October 2009, GII.4 New Orleans, a novel strain of noroviruses emerged, replacing the GII.4 Minerva strain and causing most norovirus outbreaks in land-based communities and on cruise ships (Vega et al., 2011). In 2012, the GII.4 Sydney strain emerged and continues circulating in certain populations (Pringle et al., 2015).

Recent Trends in AGE Incidence and Outbreaks on Cruise Ships

The VSP analyses MIDRS data for patterns in AGE incidence trends, to assess program effectiveness and provide evidence to guide program policy. Freeland and colleagues (2016) evaluated VSP surveillance data for 2008-2014, reporting that the annual passenger AGE incidence rate ranged from 27.2 per 100,000 travel days in 2008 to 20.9 per 100,000 travel days in 2013; the rate among crew dropped from 21.6 per 100,000 travel days in 2008 to 19.3 per 100,000 travel-days in 2014. However, the trend was not statistically significant. Moreover, surges in AGE incidence rates identified in 2012 and 2013 were most likely associated with GII.4 Sydney, a norovirus variant that emerged in 2012 in Sydney, Australia (Freeland et al., 2016). AGE outbreaks investigated by the VSP indicated noroviruses were the etiologic agent implicated in over 90% of cruise ship-associated AGE outbreaks (Freeland et al., 2016).

Jenkins and colleagues (2021) conducted the most recent analysis of VSP surveillance reports, covering 2006 to 2019, reporting a decrease in passenger AGE incidence rates from 32.5 per 100,000 travel days to 16.9 per 100,000 and a drop from 13.5 per 100,000 travel days to 5.2

per 100,000 travel days for crew. AGE incidence rates were associated with ship size (gross registered tonnage [GRT]) and voyage length, with higher rates observed for larger cruise ships and voyage durations of seven days or longer. At the time of writing, Norovirus GII.4 variants remain the predominant etiologic agents associated with cruise ship AGE outbreaks.

Challenges of Norovirus Control on Cruise Ships

The findings of these studies provide necessary information to guide evidence-based policy and programs for the cruise industry. While the foundational elements of land-based public health policy largely apply, cruise ships present unique challenges and require specific mitigation strategies to reduce AGE risks associated with cruise ship travel. Several key features of norovirus infections also complicate mitigation plans in the cruise ship environment. The low infectious dose, high viral loads with substantial viral shedding in symptomatic and asymptomatic cases, and high transmissibility via multiple routes can rapidly spread in such semi-enclosed, congregate environments (Atmar et al., 2008; Teunis et al., 2008). Moreover, prolonged viral shedding may lead to secondary spread through person-to-person transmission among passengers and crew. It has been reported that viral shedding may be prolonged, lasting from a few days to several weeks, and may begin before the onset of symptoms and continue after symptom resolution (Dolin, 2007). In addition, infected crew members may serve as reservoirs for newly arriving passengers on subsequent voyages (CDC, 2002).

While person-to-person spread is the predominant transmission mode of noroviruses on cruise ships, they may also spread via contaminated food, water (potable and recreational), and environmental spaces. Since food safety and potable/recreational water systems have historically been evaluated during operations inspections, strict food safety and potable/recreational water system management policies have been in place since the establishment of the VSP. With the increasing numbers of confirmed norovirus outbreaks linked to person-to-person transmission, strategies require focusing on the challenges of norovirus control. Essential methods include enhanced infection control practices, medical case management, hand hygiene, and public health education campaigns for cruise ship travelers.

Environmental contamination can occur from vomiting incidents (Marks et al., 2000) or fecal contamination of surfaces with viral particles that may propagate outbreaks (Patel et al., 2009). Moreover, vomiting has been implicated in aerosol, person-to-person transmission, and environmental contamination on cruise ships (Ho et al., 1989; Wikswo et al., 2011). Following the deposition of viral particles, noroviruses remain viable on environmental surfaces for over a month (Fankem et al., 2014), and fomite contamination is an important vehicle in norovirus transmission (Repp & Keene, 2012). The stability of noroviruses in the environment and their resistance to common commercial disinfectants make shipboard infection control challenging. Improper cleaning and disinfection of environmental surfaces, including fomites, may contribute to sustained AGE transmission across multiple voyages with additional morbidity (Gunn et al., 1980; Isakbaeva et al., 2005). The U.S. Environmental Protection Agency (EPA) provides guidelines for infection control, including a list of approved products for norovirus disinfection (Environmental Protection Agency [EPA], 2021). Proper cleaning and disinfection with appropriate disinfectant concentrations and contact times are critical to norovirus infection control on cruise ships.

The changes in the cruise ship environment in terms of increased size and complexity, greater passenger load capacities, increased time engaging in shipboard activities, and the introduction of emerging strains of noroviruses are challenges facing the VSP and cruise industry stakeholders. Constant monitoring of AGE incidence and outbreak patterns by the VSP is required to protect the traveling public and crew. Examining whether policy interventions and program activities effectively mitigate AGE risk and make appropriate adjustments based on emerging communicable disease threats will also become necessary.

Summary

The CDC established the Vessel Sanitation Program to help the cruise industry respond to several significant outbreaks of diarrheal disease aboard passenger cruise ships from bacterial pathogens, develop comprehensive public health programs to prevent the introduction, transmission, and spread of enteric pathogens into the U.S., and manage the risk of communicable disease transmission among passengers and crewmembers. Between 1975 and 2000, collaborative efforts between the VSP and cruise industry partners led to significant improvements in shipboard sanitation, especially in food and potable water safety practices. However, beginning in the mid-1990s, noroviruses emerged as a pathogen of concern in land-based and shipboard enteric disease outbreaks. By 2000, AGE outbreaks involving noroviruses required VSP and cruise industry partners to reassess the focus of cruise ship public health programs, by enhancing housekeeping and infection control protocols, modifying the reportable case definition, improving medical management of enteric disease cases and close-contact monitoring, and reevaluating the primary modes of transmission in the semi-enclosed congregate environment of passenger cruise ships. Moreover, the characteristics of noroviruses, changes in the cruise ship environment, and the uniqueness of cruise ship travel produced substantial challenges to disease control and outbreak management, requiring reassessment of public health risks and resulting modifications to standard operating procedures and practices to control these emerging communicable disease threats.

Enteric pathogens pose a significant risk to the health and safety of passengers and crewmembers. AGE outbreaks continue to occur as novel norovirus strains emerge, threatening land-based receiving communities and shipboard populations and adversely affecting the profitability and public impression of the cruise industry and the credibility of the government-industry collaboration.

Table 1: Fee Schedule by Vessel Size-Operations Inspections and Reinspections

Vessel Size (GRT[1])	Inspection Fee (USD)
Extra Small (<3,000 GRT)	$1,495
Small (3,001-15,000 GRT)	$2,990
Medium (15,001-30,000 GRT)	$5,980
Large (30,001-60,000 GRT)	$8,970
Extra Large (60,001-120,000 GRT)	$11,960
Mega (120,001-140,000 GRT)	$17,940
Super Mega (>140,001 GRT)	$23,920

Note. [1]Gross register tonnage in cubic feet, as shown in Lloyd's Register of Shipping. Source: Government Printing Office (2022). Fees for Sanitation Inspection of Cruise Ships. *Federal Register*. *87*(230), 73767-73768.

Table 2: Fee Schedule by Vessel Size-Construction and Renovation Inspections

Vessel Size (GRT[1])	Inspection Fee (USD)
Extra Small (<3,000 GRT)	$2,990
Small (3,001-15,000 GRT)	$5,980
Medium (15,001-30,000 GRT)	$11,960
Large (30,001-60,000 GRT)	$17,940
Extra Large (60,001-120,000 GRT)	$23,920
Mega (120,001-140,000 GRT)	$35,880
Super Mega (>140,001 GRT)	$47,840

Note. [1]Gross register tonnage in cubic feet, as shown in Lloyd's Register of Shipping. Source: Government Printing Office (2022). Fees for Sanitation Inspection of Cruise Ships. *Federal Register*. *87*(230), 73767-73768.

Table 3: Comparison of Point Distribution in VSP Operations Manuals-2000, 2005, 2011

Category	Point Totals by Inspection Category		
	2000	2005	2011
Medical	5	5	5
Potable Water	21	21	18
Recreational Water	4	4	5
Food Safety	64	64	62
Environmental Health	6	6	8
Knowledge	---	---	2
Total	100	100	100

Note. The Environmental Health category includes Integrated Pest Management (IPM), Child Activity Center, Housekeeping, and Ventilation. The knowledge category was formally introduced in the 2011 VSP Operations Manual.

Table 4: GII.4 Variant Strains, Years of Circulation, Epidemic Season, and Other Names

Norovirus strain	Gen Bank accession number †	Years of circulation	Increase in number of outbreaks in the USA	Other names used in literature
Bristol	X75716	1987-1994	None	Lordsdale, Camberwell, and MD145-12
95/96-US	AJ004864‡	1995-2002	1995-1996	Grimsby
Henry	EU310927	2000–2002	None	
Farmington Hills	AY485642‡	2002–2004	2002–2003	2002 variant
Hunter	AY883096‡	2003–2006	None	2004 variant
Asia	AB220921	2004–2006	None	Chiba, Sakai, Asia_2003
Yerseke	EF126963	2006-2008	2006-2007	Laurens, 2006a variant
Osaka	AB279553	2005-2007	None	
Den Haag	EF126965‡	2006-2009	2006-2007	Minerva, 2006b variant
New Orleans	GU445325	2009-present	None	
Sydney	JX459908	2012-present	None	

Notes. †Gen Bank accession number of the first submitted capsid sequence of this variant. ‡Pandemic strains.
Source: Pringle, K., Lopman, B., Vega, E., Vinje, J, Parashar, U. D., & Hall, A. J. (2015). Noroviruses: epidemiology, immunity and prospects for prevention. *Future Microbiology*, *10*(1), 53-67 (Table 2). https://doi.org/10.2217/FMB.14.102.

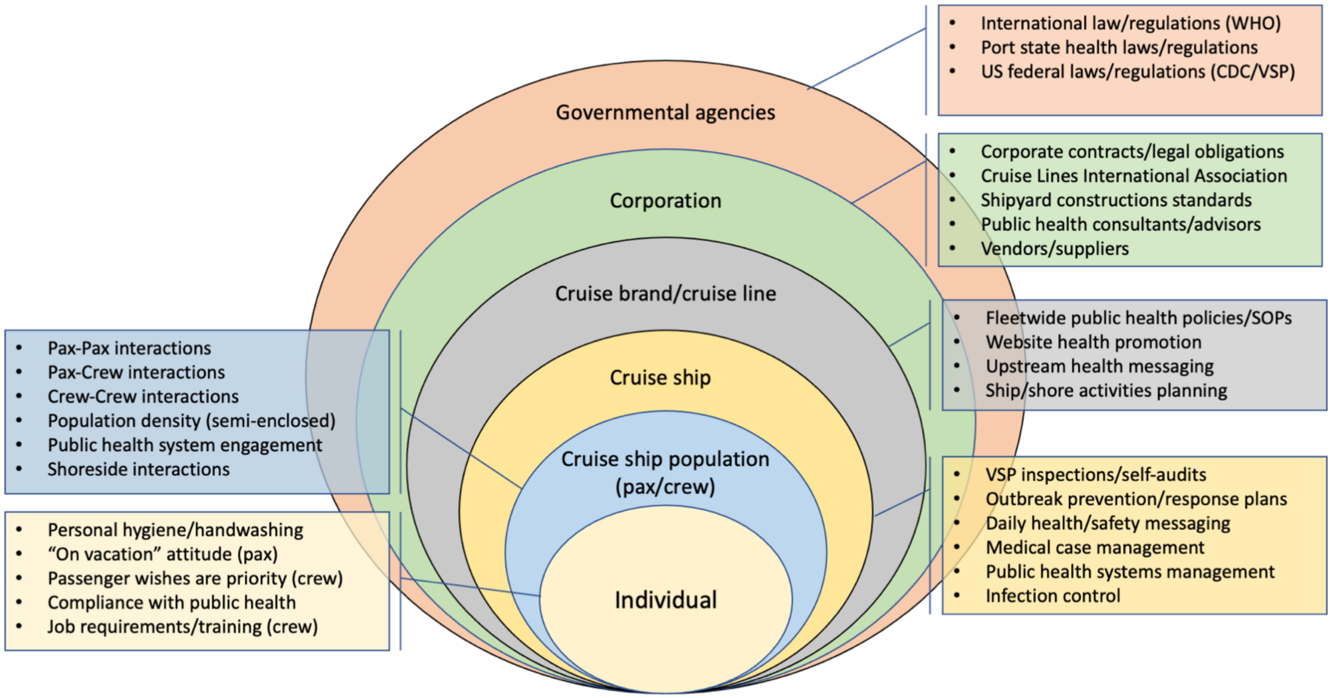

Figure 1: Social-Ecological Model (SEM) and Public Health Policy Development Adapted to the Cruise Ship Environment

CHAPTER 3: AN ASSESSMENT OF THE ASSOCIATION BETWEEN VSP OPERATIONS INSPECTION OUTCOMES, CRUISE SHIP CHARACTERISTICS, AND ACUTE GASTROENTERITIS INCIDENCE[1]

[1] Vaughan, G. To be submitted to the *Journal of Environmental Health*.

Abstract

Since its establishment in 1975, the Vessel Sanitation Program (VSP) has conducted sanitation inspections on passenger cruise ships visiting U.S. ports following international travel. Their operations inspection program is the foundation for evaluating cruise ship compliance with recognized and accepted maritime public health standards, including policies developed through the collaboration of the U.S. federal government and cruise industry, reflected in manual revisions. Initially, cruise ships were inspected based on communicable disease surveillance reports submitted by the master of cruise ships before arrival into the U.S.; today, cruise ships operating within U.S. jurisdiction are routinely inspected twice a year. The purpose of sanitation inspections is to 1) determine if shipboard sanitation and public health practices are sufficient to prevent the introduction, transmission, and spread of communicable diseases into the U.S. from cruise ships, and 2) to identify communicable disease risks associated with foodborne and waterborne vehicles and their associated transmission to passengers and crew. Inspection findings and reports help cruise companies manage public health risks to their fleet assets and establish effective policies and prevention strategies to minimize communicable disease transmission and risks of outbreaks. The primary goal is to prevent communicable disease outbreaks aboard passenger cruise ships that could lead to the introduction, transmission, and spread of communicable disease pathogens into the U.S. and receiving port communities.

This manuscript examines the association between cruise ship operations inspections and the control of acute gastroenteritis (AGE) incidence and outbreaks aboard passenger cruise ships. Additionally, the relationship between inspection outcomes and selected cruise ship and inspection characteristics was assessed to determine the nature of their association. Finally, this study tests the relationship between inspection score and public health outcomes (enteric disease

incidence and outbreaks), controlling for cruise ship and inspection characteristics. Understanding the relationships between inspection scores and public health outcomes is important for evidence-based VSP and cruise industry public health policy development and shipboard standard operating procedures, as the VSP-cruise industry collaboration seeks continuous improvement in public health standards and practices.

Introduction

VSP Operations Inspections

Environmental health officers of the VSP conduct twice-yearly unannounced inspections on all cruise ships carrying ≥13 or more passengers with a foreign itinerary, making port calls in the United States (CDC, 2018b, Forward, p. ii). The authority to conduct environmental health (sanitation) inspections is detailed in 42 CFR Section 71.41 General Provisions, Foreign Quarantine - Requirements Upon Arrival at US Ports: Sanitary Inspections. This regulation authorizes the VSP to conduct unannounced environmental health (sanitation) inspections to determine the presence of pests, contaminated food or water, and other unsanitary conditions that may lead to the introduction, transmission, or spread of communicable diseases into the United States from cruise ships (US Department of Health and Human Services [DHHS], 2003).

Elements of the operation inspections are grounded in recognized public health standards essential to the prevention of food and waterborne disease and outbreaks on cruise ships, including relevant chapters and sections of the *WHO Guide to Ship Sanitation* (World Health Organization [WHO], 2011) and the *FDA Model Food Code* (Food and Drug Administration, 2017). The VSP publishes requirements for cruise ships in the VSP Operations Manual, first published in 1989 and used for over ten years before its update in 2000 (CDC, 2000). This revised operations manual provided expanded requirements for food safety practices, improved

AGE reporting, and updated swimming pools and whirlpool spa management, and expanded the reportable case definition (Cramer et al., 2008). The VSP continuously reviews the contents of its operations manual and revises it every three-to-five years to include important changes in public health practice, advances in food safety and potable water practice, and significant technology improvements (CDC, 2018b). Additional operations manual revisions were published in 2005, 2011, and 2018 (CDC, 2018b). The VSP Operations Manual, considered the maritime industry public health standard for North America, has been adopted, at least in part, by most maritime public health programs worldwide.

The VSP operations inspection assesses the cruise ship staff's compliance with recognized environmental health and sanitation standards detailed in the VSP Operations Manual that prevent and control acute gastroenteritis (AGE) incidence aboard cruise ships. Specific shipboard programs evaluated during an operations inspection include AGE medical case management and reporting, potable and recreational water, food safety, integrated pest management (IPM), housekeeping and infection control, child activity center, and heating, ventilation, and air conditioning systems.

Cruise ships are graded on a 100-point scale, with a score ≥86 considered satisfactory. In general, while lower inspection scores are associated with an overall lower level of sanitation, no definitive research has linked them to an elevated risk of AGE. VSP staff record all findings identified during an operations inspection on an inspection summary sheet, scored using a risk-based weighting where critical violations may result in a three-to-five-point deduction. Critical violations, associated with outbreaks of infectious diseases, mostly involve gastrointestinal illnesses where food and water (both potable and recreational) are known to be the vehicles of spread. Non-critical violations may result in a one- or two-point deduction, based on frequency, severity, and/or whether they represent repeat violations from the previous inspection. Cruise ships failing an operations inspection must undergo an unannounced reinspection, usually conducted within a month, provided the cruise ship remains in U.S. jurisdiction (CDC 2018b; CDC, 2019). All findings listed in the operations inspection report must be corrected. The VSP has established procedures for cruise lines to submit a post-inspection report of corrective action, including a corrective action statement and a management monitoring plan.

Depending on the version of the operations manual, 80-85 of the 100 points are associated with food safety and potable water systems management, a focus consistent with VSP's historical emphasis on food- and water-related illnesses. Appendices B, C, and D present the operations inspection score sheets for 2000, 2005, and 2011 VSP Operations Manuals, published between 2001 and 2019. Table 3 lists the major categories of the operations inspections with the assigned point deductions.

Vessel Sanitation Program Inspection Reporting System (VSPIRS)

The VSP maintains its operations inspection data in the VSP Inspection Reporting System (VSPIRS), a database held at the CDC. The VSPIRS contains operations inspections data, including ship name and parent cruise line, the number of passengers and crew on board at the time, inspection date, the U.S. port where the inspection was conducted, the type of inspection (periodic, reinspection, other), and the name(s) of the VSP inspector(s). Additionally, the database contains the inspection score, the point deductions by category and violation, and a medical record review of the AGE cases for passengers and crew for the five voyages previous to inspection date.

The VSP provides operations inspection information to the general public through a portal on its website. Individuals seeking cruise ship information, including scores, inspection reports, and cruise-line-submitted corrective action statements, can search the portal for any cruise ship operating within the U.S. This information is used by public health professionals and the traveling public to determine the public health and safety of cruise ship travel; the latter group usually focuses on the inspection score as the primary public health metric. Therefore, it is essential to determine whether operations inspection scores are genuinely informative.

VSP Maritime Illness and Database Reporting System (MIDRS)

Federal foreign quarantine regulations in 42 CFR § 71.4(c) authorize the VSP to conduct syndromic surveillance of AGE for passenger cruise ships entering U.S. jurisdiction from foreign countries. The master of cruise ships carrying 13 or more passengers with an international itinerary and making port calls in the U.S. must submit at least one voyage report for each voyage, or segment in the case of segmented cruises. The report contains the cumulative total of all passenger and crew AGE cases seeking medical care and meeting the reportable AGE case definition (including zero cases). With a few exceptions, the initial report is submitted 24-36 hours before arrival at the first U.S. port. When additional AGE cases occur between submission of the initial report and a four-hour threshold before arrival at the first U.S. port, at least one updated report of the cumulative case count is required. VSP also mandates additional special reports when the cumulative AGE passenger/crew attack rate is $\geq 2.0\%$ and when the outbreak threshold of 3% has been reached. Regardless of report type, each report submission includes the cruise ship name, voyage number, embarkation and disembarkation dates and locations, the total number of passengers and crew, and the number of passengers and crew that reported AGE symptoms to the medical center and met the reportable AGE case definition. All voyage-specific AGE incidence reports are collected and maintained in the Maritime Illness and Database and Reporting System (MIDRS) held at the CDC.

Since 2000, the reportable AGE case has been defined as a passenger or crew member reporting to the ship's medical center with the following signs and symptoms: 1) diarrhea (three or more loose stools in 24 hours) or 2) vomiting and at least one additional symptom, including diarrhea, blood in stool, abdominal cramps, headache, myalgia, or fever defined as a temperature ≥ 100.4°F (≥38°C). The reportable AGE case definition was used as the reporting standard throughout the study. The VSP defines an AGE outbreak as when ≥3.0% of passengers or crew members report AGE symptoms to the medical center during a voyage or voyage segment.

Research Aims

The VSP inspection program and monitoring of AGE incidence aboard cruise ships through syndromic surveillance activities are critical to VSP operations and essential to establishing basic criteria for cruise ship public health programs. Effective inspection programs are hypothesized to reduce adverse public health outcomes such as the incidence of reportable AGE illness and the frequency of outbreak occurrences. However, no extant study has worked to empirically determine the validity of this hypothesis by examining the alignment of inspection criteria and the predominant enteric disease threats aboard passenger cruise ships.

This manuscript aims to determine the relationships between 1) operations inspection scores, cruise ship characteristics, and inspection region and 2) operations inspection scores and AGE incidence and outbreaks. Such findings are essential to providing evidence-based information on the status of cruise ship public health, as established by inspection outcomes, that may inform decision-making for the VSP, its cruise industry partners, and the traveling public.

Research Questions and Hypotheses

1. Are cruise ship characteristics and region of inspection associated with operations inspection outcomes?

2. Is there a relationship between operations inspection scores and AGE incidence or outbreaks on passenger cruise ships?

Research Methods

This study used data from VSP operations inspection scores (maintained in the VSPIRS) and AGE incidence reports (maintained in MIDRS databases) within the period of January 1, 2001, to December 31, 2019, to examine associations between 1) operations inspection outcomes and selected cruise ship and inspection characteristics and 2) operations inspections and AGE incidence, including outbreaks. All periodic inspection scores with inspection dates during the study timeframe were included in the analysis; however, reinspections following a failed operations inspection were excluded, since they were not considered independent inspections.

Inspection scores were based on cruise ship staff performance compared with applicable VSP Operations Manuals requirements. Three versions of the VSP Operations Manuals were in force during the study period. Cruise ships inspected between 2001 and 2005 were evaluated for compliance with public health requirements based on the 2000 VSP Operations Manual, whereas cruise ships inspected between 2005-2011 and 2011-2018 were evaluated based on the requirements in the 2005 and 2011 VSP Operations Manuals, respectively.

AGE reports for cruise ships with voyages 3-21 days in length and carrying ≥100 passengers were included for the same period. The range of voyage lengths was selected to minimize underreporting of AGE cases for voyages less than three days and voyages longer than 21 days, which are likely incomplete (Cramer et al., 2003; Cramer et al., 2006; Freeland et al., 2016). Additionally, cruise ships carrying fewer than 100 passengers may feature AGE incidence rates that easily exceed the VSP's outbreak threshold of 3.0%, subsequently misclassifying voyages as having outbreaks and overinflating outbreak statistics.

Outcome Measures

The outcome variables included AGE incidence and inspection scores. Baseline AGE incidence occurs with <3.0% reportable AGE cases in either passenger or crew on a voyage, or voyage segment for longer voyages. An AGE elevation was defined as a voyage where ≥2.0% and <3.0% reportable AGE cases were reported on a segment, while AGE outbreaks were defined as AGE incidence ≥3.0%. The VSP AGE outbreak definition was based partly on a study by Merson and colleagues (1975b) examining 2,445 medical logs from 38 vessels, finding gastrointestinal illness incidence rates ≤ 1% on 92% of voyages and ≥5.0% on 2% of voyages. A multivariable binary logistic regression model was developed to examine the overall association between background AGE incidence and operations inspection outcomes (pass/fail), controlling for potential confounding or effects modifying variables.

To determine whether periodic inspection scores were associated with AGE elevations or outbreaks, the VSPIRS and MIDRS datasets were merged using cruise ship and periodic inspection unique identifiers to create a single dataset for multivariable linear and multivariable logistic regression analyses. AGE incidence rates were dichotomized based on the VSP threshold of ≥2% reportable AGE cases for voyages or voyage segments in either passenger or crew subpopulations (AGE elevation or outbreak ≥2.0% reportable AGE cases; otherwise, background AGE incidence). To compare findings with recent VSP published reports, AGE incidence data for 2001-2019 were analyzed using each cruise ship's most recently submitted MIDRS report (Freeland et al., 2016; Jenkins et al., 2021). The primary independent variable for this manuscript was periodic operations inspection scores.

Univariate analyses were conducted of operations inspection scores and cruise ship characteristics, including the size of the ship (gross registered tonnage [GRT]), the age of the vessel at the date of inspection (in years and categorized), fleet size (categorized), and the port region of inspection. Medians and interquartile ranges (IQR) were used to characterize continuous variables such as inspection scores, inspection year, and cruise ship age (in years). For dichotomous variables, continuous measures were compared using the Wilcoxon rank-sum test. Frequencies and percentiles were used to characterize categorical variables such as cruise ship size (gross registered tonnage categories), inspection regions, ship's age at inspection, and mean fleet size. Bivariate analyses were conducted to test for an association between inspection outcome (pass/fail) and selected cruise ship characteristics and inspection region. Trend analyses were conducted using Cochrane-Armitage trend tests. Cruise ships without periodic operations inspections were excluded from the analyses.

MIDRS reports meeting the inclusion criteria were analyzed using the most recently submitted report for each voyage. AGE incidence rates per 100,000 travel days were calculated for passenger and crew subpopulations (where applicable). AGE outbreak rates were calculated per 1,000 voyages to help compare findings with previously published reports. Cruise ships with domestic-only itineraries were excluded from the study, because they do not fall under the authority of the VSP. Relative risks were calculated (incidence rate failed inspections/incidence rate passed inspections) and compared to assess the risk of illness on passed and failed inspections. Reinspections were excluded from this analysis since they were not considered independent of the failed inspection.

To determine whether cruise ship characteristics and region of operations inspection were associated with inspection scores, a multivariable linear regression model was used to examine periodic inspection scores as a function of ship size (GRT), ship age at inspection, fleet size, and region of inspection. The independent variables selected for analysis were found to be statistically significant in other studies (Cramer et al., 2003; Cramer et al., 2008). Visual examination (e.g., charts) and postestimation testing was conducted to determine compliance with basic regression assumptions, including linearity and multicollinearity tests.

A multivariable binary logistic regression model was specified to examine the relationship between operations inspection outcomes (pass/fail), selected ship characteristics, and inspection region. A second multivariable logistic regression model was specified to assess the relationship between AGE elevations and outbreaks and operations inspection scores, controlling for selected cruise ship characteristics linked with operations inspection outcomes in previous studies (Cramer et al., 2003; Cramer et al., 2008) and theoretical considerations regarding communicable disease transmission in the shipboard environment. An AGE elevation was defined as a voyage or voyage segment with an AGE incidence (attack) rate of ≥2.0% and <3.0%; and an AGE outbreak was classified as any voyage or voyage segment with an AGE incidence (attack) rate ≥3.0% in passenger or crew subpopulations. Independent variables included in the model were ship size (gross registered tonnage [GRT]), ship age at the time of inspection, fleet size, and inspection region. The model aimed to determine whether operations inspection scores were associated with AGE outbreaks over the study period.

This study, which used de-identified data for cruise ships and cruise lines, was not considered human subjects research by the University of Georgia Institutional Review Board (IRB). Informed consent was not required, as the MIDRS database does not capture passenger or crew identifying information, and the VSPIRS database contains data on cruise ships and inspection information rather than people. All statistical analyses were performed using Stata SE, version 17.0 (Stata Corporation, College Station, Texas).

Data Analysis and Results

Descriptive Analysis of VSP Operations Inspections

Between 2001 and 2019, the VSP conducted 4,685 operations inspections on 333 unique cruise ships representing 88 cruise lines. The number of operations inspections conducted each year of the study period varied from 160 in 2019 and 287 in 2004. Operations inspections were categorized as 1) periodic (n=4,598; 98.1%) or 2) reinspections (n=87; 1.9%). For all inspections types (including reinspections), statistical significance was observed for inspection outcome (pass/fail) for inspection year (Pearson $X^2(18)=49.62$; $p<0.001$), ship size (GRT categories) (Pearson X^2 $(4)=160.91$; $p<0.001$), ship age categories (Pearson $X^2(4)=91.75$; $p<0.001$), mean fleet size categories (Pearson $X^2(4)=100.33$; $p<0.001$), and inspection region (Pearson $X^2(7)=16.78$; $p=0.019$). Reinspections following failed periodic inspections were excluded from further analysis since they were not considered independent inspections.

For the study period, VSP Environmental Health Officers (EHOs) conducted 4,597 periodic operations inspections on 2,709 cruise ships (including repeated cruise ships). The number of unique cruise ships inspected annually ranged from 127 in 2001 to 154 in 2004 and 2015. The annual periodic operations inspections ranged from 156 in 2019 to 282 in 2004. Cruise ships received passing inspection scores during 4,459 (97.0%) periodic inspections, while 138 (3.0%) received failing scores (<86%) during periodic inspections. The median periodic inspection scores improved significantly, from 94% in 2001 to 98% in 2009-2011 (Kruskal-Wallis H =287(18)), $p<0.001$. In comparison with the initial year of the study (2001), cruise ships were less likely to fail periodic inspections for all years except 2013 (*RR*=1.18; CI: 0.51 – 2.80) and 2017 (*RR*=1.21; CI: 0.54 – 2.80), though the relative risks were not statistically significant. Table 5 at the end of this chapter summarizes cruise ship inspection outcomes and the relative risk of failing operations inspections compared to 2001, the reference year. Statistical associations were observed between periodic inspection outcomes for cruise ship size (GRT) (Pearson $X^2(4)=148.24$; $p<0.001$), ship age at the time of inspection (Wilcoxon rank-sum: Z=7.66; p<0.0001), ship age category (Pearson $X^2(4)=87.41$; $p<0.001$), mean fleet size (Pearson $X^2(4)=99.71$; $p<0.001$), and inspection region (Pearson $X^2(4)=99.71$; $p=0.031$). Table 6 summarizes periodic inspection outcomes, selected ship characteristics, and inspection region.

Results of the Multivariable Linear Regression Models

A multivariable linear regression model was fitted for periodic operations inspection score as a function of fleet size (categorized), GRT category, ship age at the date of inspection (categorized), and inspection region (categorized). The model used factor variable notation for the independent variables, with the highest frequencies for categories serving as the reference group. The model was statistically significant (n= 4,576; F [91, 4,556] = 29.59; p<0.0001), indicating a significant improvement in model fit over the intercept-only model ($R^2=0.1409$). A comparison of inspection scores by fleet size (reference: ≤5 ships) found slightly higher inspection scores for ships in the 6-10, 11-15, and 16-20 groups; however, only the 11-15 ship category had statistically significant higher inspection scores ($t=2.89$; $p<0.004$), controlling for ship size, ship age at inspection, and inspection region. The largest fleet size group (>20 ships) had significantly lower inspection scores compared to the reference group ($t=-3.90$; p <0.001).

For cruise ship size based on GRT categories, the extra-small to medium (≤30,000 GRT) ($t=-10.97$; $p<0.001$), large (30,001-60,000 GRT) ($t=-7.52$; $p<0.001$), and super-mega groups (≥140,001 GRT) ($t=-3.76$; $p<0.001$) had significantly lower inspection scores when compared to the extra-large reference group. The mega group ($t=0.21$; $p=0.837$) had slightly higher inspection scores but were not statistically significant. For ship age groups, lower inspection scores were observed for all groups compared to the ≤7-year reference group; however, the 8-12 year group (t=-0.67; p=0.503) was not statistically significant. Statistical significance was observed for the 13–18-year group (t=-4.03; p<0.001), the 19–30-year group (t=-5.00; p<0.001), and the >30-year group (t=-4.59; p<0.001).

Except for Hawaii, there was no statistical significance among inspection regions compared to the Southeast inspection region (reference group). Statistically significant lower inspection scores (t=-2.95; p=0.003) were found for the Hawaii inspection region compared to the Southeast reference group. Table 7 displays the output for the multivariable linear regression for operations inspection scores.

Multivariable linear regression models were specified separately for passenger and crew populations to determine whether an association existed between mean AGE incidence (attack) rates and periodic inspection scores. The dependent variables for both models were the mean attack rate (as percentages) for the respective population, and the primary independent variable was periodic inspection scores, controlling for cruise ship age at the inspection (in years), voyage length (in days), fleet size, and inspection region. No association was observed between the mean passenger attack rate and periodic inspection score (t=0.80; p=0.425). For crewmembers, an association was observed between the mean attack rate and periodic inspection score, with crewmembers having a lower mean attack rate (t=-2.17; p=0.03).

Results of the Multivariable Binary Logistic Regression Models

A multivariable binary logistic regression model was fitted on periodic inspection outcomes (pass/fail) as the dependent variable, as a function of fleet size (categorized), ship size based on gross registered tonnage (GRT) category, ship age at the date of inspection (categorized), and inspection region (categorized) for periodic inspections, and were statistically significant (n=4,570; Likelihood Ratio $X^2(18)$ =156.54; p<0.0001), indicating a significant improvement in model fit over the intercept-only model. The model explained about 13% of observed differences between periodic inspection outcomes as a function of the independent variables included in the model (McFadden's pseudo R^2 =0.1321). A comparison of inspection outcome by fleet size (reference group: ≤7 ships) found higher odds of passing operations inspections for ships in the 6-10 (*OR*=1.16; *Z* =0.26; *p*=0.798), 11-15 (*OR*=3.46; Z =3.31; *p*=0.001), and 16-20 (*OR*=2.87; *Z* =1.73; *p*=0.003) groups, controlling for ship size, ship age at inspection, and inspection region; however, the 6-10 and 16-20 groups were not statistically significant. Cruise ships in the >20 fleet size group had lower odds of passing inspection but were not statistically significant.

It was expected that fleet size would generally improve operations inspection outcomes due to more significant resources to conduct self-audits. Cruise lines with larger fleet sizes usually have dedicated shipboard environmental officers responsible for environmental compliance and environmental health programs, including oversight of VSP operations inspections. Furthermore, these cruise lines also employ corporate-level teams of public health professionals to oversee compliance with VSP inspection programs and to develop public health and operational standard operating procedures for shipboard staff. However, cruise ships in the larger fleet groups tend to have multiple food outlets with complex food operations, several recreation water systems, and more intricate potable water systems evaluated during operations inspections. As such, it is possible that they do not score significantly better on VSP inspections due to the likelihood of more findings with subsequent point deductions.

For ship size based on GRT categories, the extra-small to medium (≤30,000 GRT) (*OR*=0.22; *Z*=-4.25; *p* <0.001), large (*OR*=0.35; *Z*=-3.25; *p* = 0.001), and super-mega (≥140,001

GRT) group ships (*OR*=0.53; *Z*=-0.80; *p*=0.424) had lower odds of passing operations inspections compared to the extra-large (60,001-120,000 GRT) reference group; however, the super mega ship group was not statistically significant. The mega group (120,001-140,000 GRT) (*OR*=1.02; *Z*=0.03; *p*=0.979) had higher odds of passing operations inspection but was not statistically significant.

The odds of passing operations inspections for ship age groups were the same for ships 8-12 years compared to the ≤7 years and were not statistically significant (*OR*=1.00; *Z*=0.01; *p*=0.992). All other ship age groups had lower odds of passing operations inspection; however, only the 19-30 years group was found to be statistically significant (*OR*=0.44; *Z*=-2.45; *p*=0.014). Older cruise ships are more likely to be subject to point deductions due to older equipment and facilities that are harder to maintain and more difficult to clean. Additionally, it is postulated that some cruise companies may assign younger, inexperienced staff to older ships while more experienced staff may be assigned to newer ones. Defects in operational standards by inexperienced staff can lose points for significant procedural violations, especially for critical inspection items.

The Hawaii inspection region was found to have statistically significant lower odds of passing operations inspections (*OR*=0.34; *Z*=-2.83; p=0.005) compared to the southeast inspection region (reference group). Lower odds of passing operations were also observed for northeast (*OR*=0.95; *Z*=-0.14; *p*=0.886) and northwest (*OR*=0.92; *Z*=-0.32; *p*=0.748) regions but were not statistically significant. A plausible explanation for these findings is that operations inspections conducted at distant or remote ports where inspections are infrequently performed may make cruise ship staff less prepared for VSP inspections. Table 8 provides the output for the multivariable logistic regression for operations inspection outcomes.

To determine whether an association existed between AGE outcome and inspection score, multivariable binary logistic regression models were separately specified for AGE elevations and outbreaks and inspection score for passenger and crew populations. The dependent variable was AGE elevation or outbreak described earlier (coded as 1 for an AGE elevation or outbreak voyage). The primary independent variable of interest was the periodic inspection score, controlling for cruise ship size (GRT), ship age at the time of inspection (in years), voyage length (in days), fleet size, and inspection region. Both models were statistically significant (Passenger Wald X^2 (14) =283.47; p<0.0001; Crew Wald X^2 (18) = 599.38; p<0.0001). The association between AGE outcome and periodic inspection scores was not statistically significant for passengers (*OR*=1.02; p=0.492 or crew (*OR*=0.95; p=0.147) models, controlling for other independent variables in the model. This finding indicated no statistical association between AGE elevation or outbreaks and periodic inspection scores, consistent with a previous study conducted by the VSP (Cramer et al., 2006).

Discussion

Cruise ships continue to demonstrate effective public health programs, as demonstrated during bi-annual periodic operations inspections conducted by the VSP. Operations inspection scores improved from a median score of 94% in 2001 to a high of 98% in 2009-2011. This trend is likely attributable to newer cruise ships with technological improvements to public health systems and enhanced shipboard public health practices over the study period.

The VSP operations inspection program's point distribution is weighted heavily toward controlling risk factors for enteric pathogens transmission through exposure to contaminated food and water. Technological advancements in potable water production allow modern cruise ships to produce volumes of potable water at sea, precluding the need to purchase, or “bunker,” drinking water from questionable shoreside water sources. Improvements in automation and monitoring systems allow the ship's engineering personnel to control complex potable water storage, distribution, and halogenation dosing systems, providing safer drinking water. Cruise ships serve a plethora of food items at various service times and durations in buffet service areas where the cold- and hot-holding of potentially hazardous food can be challenging. However, improvements in food safety systems and practices, including training in active managerial control and Hazard Analysis Critical Control Points (HACCP) and using time only as a public health control, are possibly essential factors in reducing critical food safety violations and the risk of foodborne illness outbreaks. These changes in potable water and food safety practices are considered significant factors in reducing the risk of point deductions for critical violations in these areas. The observed decline in operations inspection scores from 2009-2011 is likely due to emphasis on specific inspection categories by VSP environmental health inspectors based on periodic internal reviews of operational inspection findings.

Federal government oversight of cruise industry operations has been a necessary component driving improvements in public health aboard passenger cruise ships. Trust in federal government oversight by the traveling public and transparency of cruise ship public health are essential aspects of VSP operations. The review of operations inspection results, including the scores, is the primary method by which passengers self-assess public health risks associated with cruise ship travel before booking a cruise.

However, inspection results and scores alone may not provide enough information to determine the risk of acquiring enteric diseases. Currently, most enteric disease transmission aboard cruise ships is thought to be linked to person-to-person transmission of enteric pathogens such as noroviruses, where infection control procedures appear to be the most relevant AGE prevention strategies. However, the weighting of infection control-related findings is anticipated to have little effect on inspection outcomes, since they account for a relatively small proportion of point totals. Moreover, significant breaches in infection control protocols resulting in increased AGE incidence may occur when the ship is outside U.S. jurisdiction, since operations inspections occur only when the ships operate in U.S. waters. Additionally, operation inspections typically occur between voyages during "turnaround," when infection control protocols tend to be at their highest levels.

Limitations

Several limitations have been identified in this study. First, the current operations inspection model is heavily weighted toward foodborne and waterborne disease risk factors, while present-day enteric disease threats appear to align more with infection control strategies. This imbalance in point distribution makes an evaluation of enteric disease risk based on inspection scores of limited value for pathogens transmitted via person-to-person and environmental contact.

Secondly, AGE incidence data used to analyze public health outcomes were based on syndromic surveillance of reported AGE cases aboard cruise ships. The non-specific symptoms associated with enteric illnesses can also result from non-infectious causes, making it challenging to determine the cause of illness for specific cases. Therefore, since laboratory confirmation of illness was not conducted, it is likely that an unknown proportion of AGE cases were associated with noninfectious causes, such as vomiting caused by seasickness and ear infection in children and diarrhea associated with irritable bowel syndrome. Moreover, cruise ships with reportable AGE cases occurring after arrival at the first U.S. port are not required to submit additional AGE reports unless cumulative cases reach the special reporting threshold (≥2.0%).

Thirdly, since the VSP does not require cruise ships to submit an end-of-voyage report, it is likely that reported AGE cases underestimate actual AGE incidence, which may vary across all demographic groups. Moreover, this underestimates the number of reported AGE outbreaks since outbreaks are defined by a cumulative AGE incidence ≥3.0%. It is also possible that people with underlying medical conditions are more likely to report AGE illness to the cruise ship's medical center.

Summary

The analyses and findings in this manuscript examined 19 years of data on operations inspection scores and AGE incidence, including outbreaks on passenger cruise ships. Environmental health (sanitation) inspections, integral to shipboard public health programs, include the VSP operations inspection, which aims to identify and correct risky practices, educate personnel on the findings, and recommend safe practices (Jones & Grimm, 2008). These inspections examine facilities, processes, products (e.g., food, potable water), systems, and associated records comparing observations to a specific set of standards and are essential to managing risk factors associated with adverse public health outcomes (Mouchtouri et al., 2010; Barnes et al., 2022).

The periodic operations inspections approach focuses on preventive rather than reactive measures (Barnes et al., 2022). However, it is important to note that the risk of AGE illness and outbreaks for specific violations are likely pathogen-specific (Lee & Hedberg, 2016). This is particularly relevant for programs that conduct evaluations of multiple areas of public health importance during the same inspection, such as the areas covered during a periodic shipboard operations inspection.

A fundamental question is whether operations inspection scores are a good indicator of acute gastroenteritis incidence on cruise ships. Previous studies on cruise ship sanitation inspection reported that improved sanitation scores were associated with declining AGE outbreaks (Dannenberg et al., 1982; Koo et al., 1996; Cramer et al., 2008). However, Cramer and colleagues (2006) found that acute gastroenteritis incidence on cruise ships increased from 2001 to 2004, despite good performance on sanitation inspections. In a recent study of operations inspection scores and AGE outbreaks, Taylor (2018) found no significant difference between pre-outbreak inspection scores and inspections not followed by an AGE outbreak. These findings suggest that operations inspection scores are not a good predictor of acute gastroenteritis incidence on cruise ships.

Notably, however, Cramer led a 2008 study that found that median operations inspection scores from cruise ship environmental sanitation inspections steadily improved over 15 years, from 94% in 2001 to 98% in later years, indicating improved compliance with *VSP Operations Manual* requirements. Fluctuations in the median periodic inspection score are likely due to increased emphasis on specific violations deemed by VSP to be important to public health. While operations inspections are unannounced, evidence suggests some cruise ship staff maintain a preparation-adherence-relaxation cycle, in which intense preparation immediately before an anticipated inspection is followed by a brief period of adherence to public health standards before relaxing into less stringent compliance. These cycles are likely to occur approximately every six months, or when the cruise ship returns to U.S. jurisdiction, and can lead to artificially inflated operations inspection scores. This can be problematic if compliance with public health standards is less than optimal, placing passengers and crew at risk and vulnerable to enteric diseases, particularly when cruise ships travel in international waters outside the jurisdiction of maritime public health agencies.

To ensure a high level of compliance with public health requirements, an organizational culture must be present that values public health as an integral part of daily operations and vital to the survival of the business entity. Establishing and maintaining such a culture goes beyond policy statements touting quality improvement: it must be demonstrated through leadership actions that fully support continuous quality improvement efforts. Quality improvement in public health must be a deliberate, defined, and ongoing process that achieves measurable improvements in public health outcomes (Riley et al., 2010). Effective execution of such initiatives requires a strong commitment from all levels of the organization, including shipboard and corporate executive leadership (Riley et al., 2010), and may optimize disease surveillance, public health emergency response, health promotion, policy advocacy, and research, leading to improved health outcomes (Mando & Saleh, 2014).

The VSP inspection program's transparent publication of inspection results is crucial to maintaining credibility with the general and traveling public. Complete inspection reports, including all findings, recommendations, scores, and corrective action statement by the respective cruise lines, are published on the VSP website and readily accessible to persons interested in public health status on a selected cruise ship. This service allows people interested in cruise ship travel to evaluate the status of cruise ships inspected by the VSP before deciding to cruise. Positive inspection outcomes provide a source of reassurance that the shipboard environment meets or exceeds current maritime public health standards. Published inspection reports can be an essential source of information, allowing cruise travelers to make informed decisions about which cruise ship to select based partly on recent and past inspection scores and published AGE outbreak summaries. Conversely, poor performance on operations inspections or repeated AGE outbreaks can result in revenue loss and poor public image, thereby serving as strong motivation to maintain high public health standards.

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Table 5: Summary of Cruise Ship Periodic Inspections and the Relative Risk of Failure, 2001-2019

Year	No. of cruise ships inspected	No. of periodic inspections	No. of failed periodic inspections n (%)	Overall median inspection score*	Relative risk of failing an inspection (95% CI)
2001	127	231	12 (5.19)	94	1.00 (Reference)
2002	138	231	9 (3.90)	95	0.75 (0.27 – 1.94)
2003	153	276	9 (3.26)	95	0.63 (0.23 – 1.62)
2004	154	282	10 (3.55)	95	0.68 (0.26 – 1.72
2005	144	260	6 (2.31)	96	0.44 (0.13 – 1.28)
2006	144	272	8 (2.94)	96	0.57 (0.20 – 1.51)
2007	143	240	4 (1.67)	97	0.32 (0.75 – 1.06)
2008	145	252	3 (1.19)	97	0.23 (0.04 – 0.85)
2009	135	234	3 (1.28)	98	0.25 (0.04 – 0.91)
2010	138	236	1 (0.42)	98	0.08 (0.02 – 0.56)
2011	140	244	3 (1.23)	98	0.24 (0.04 – 0.88)
2012	148	238	7 (2.94)	97	0.57 (0.19 – 1.56)
2013	136	228	14 (6.14)	96	1.18 (0.51 – 2.80)
2014	144	246	12 (4.88)	96	0.94 (0.39 – 2.29)

Year	No. of cruise ships inspected	No. of periodic inspections	No. of failed periodic inspections n (%)	Overall median inspection score*	Relative risk of failing an inspection (95% CI)
2015	154	269	5 (1.86)	96	0.36 (0.99 – 1.09)
2016	146	237	4 (1.69)	96	0.32 (0.76 – 1.07)
2017	149	255	16 (6.27)	95	1.21 (0.54 – 2.80)
2018	138	211	7 (3.32)	95	0.64 (0.21 – 1.76)
2019	133	156	5 (3.21)	96	0.62 (0.17 – 1.89)
Total	2,709	4,597	138 (3.00)	96	

*Kruskal-Wallis H =287.5; *d.f*=18; p = 0.0001 (with ties)
[a] Excludes inspections that follow failed inspections (Categorized as reinspections)
[b] Unadjusted

Table 6: Summary of Cruise Ship Characteristics and Inspection Region and Periodic Operations Inspection Status, Vessel Sanitation Program, 2001-2019 (N=4,597)

Cruise Ship Characteristics and Inspection Region	Passed inspection n=4,459 (%)	Failed inspections n=138 (%)	*p*-value*
Ship size (gross registered tonnage)			0.001
Extra small, small, and medium (≤30,000)	827 (91.88)	81 (8.92)	
Large (30,001-60,000)	720 (96.51)	26 (3.49)	
Extra-large (60,001-120,000)	2,402 (98.93)	26 (1.07)	

Cruise Ship Characteristics and Inspection Region	Passed inspection n=4,459 (%)	Failed inspections n=138 (%)	*p*-value*
Mega (120,001-140,000)	322 (99.08)	3 (0.92)	
Super mega (>140,001)	188 (98.95)	2 (1.05)	
Ship age (in years) at inspection[b]			0.001
≤7	1,284 (98.47)	20 (1.53)	
8-12	1,141 (98.45)	18 (1.55)	
13-18	1,085 (97.66)	26 (2.34)	
19-30	704 (93.62)	48 (6.38)	
>30	226 (90.40)	24 (9.60)	
Fleet size			0.001
≤5	1,552 (93.72)	104 (6.28)	
6-10	293 (98.65)	4 (1.35)	
11-15	1,225 (99.27)	9 (0.73)	
16-20	624 (99.36)	4 (0.64)	
>20	765 (97.83)	17 (2.17)	
Inspection region			0.03

Cruise Ship Characteristics and Inspection Region	Passed inspection n=4,459 (%)	Failed inspections n=138 (%)	*p*-value*
California	357 (98.89)	4 (1.11)	
Caribbean Islands	658 (96.34)	25 (3.66)	
Hawaiian Islands	148 (93.67)	10 (6.33)	
Northeastern United States	550 (96.32)	21 (3.68)	
Northwestern United States	631 (96.34)	24 (3.66)	
Southern United States	270 (97.47)	7 (2.53)	
Southeastern United States	1,839 (97.51)	47 (2.49)	
Not in the United States (NUS)	6 (100.00)	0 (0.00)	

Note. Twenty-one (21) periodic operations inspections were excluded for ship age at the inspection category due to missing ship age values. * Significance based on Pearson Chi-square statistic.

Table 7: Multivariable Linear Regression Model of Periodic Inspection Scores and Cruise Ship Characteristics and Inspection Region

DV: Inspection Score	Coefficient	*p*-value	95% Confidence Interval	
Fleet size (Reference: ≤5 ships)				
6-10	0.05	0.847	-0.4377	0.5335

DV: Inspection Score	Coefficient	*p*-value	95% Confidence Interval	
11-15	0.51	0.004	0.1640	0.8546
16-20	0.11	0.611	-0.3073	0.5227
>20	-0.82	0.000	-1.2409	-0.4106
GRT*category (Reference: Extra-large ships (60,001-120,000))				
Extra small to medium (≤30,000)	-3.39	0.000	-3.9961	-2.7844
Large (30,001-60,000)	-1.32	0.000	-1.6658	-0.9771
Mega (60,001-120,000)	0.05	0.837	-0.3974	0.4905
Super mega (>140,001)	-1.12	0.000	-1.7108	-0.5383
Ship age category (Reference: ≤7 years)				
8-12	-0.11	0.503	-0.4313	0.2118
13-18	-0.71	0.000	-1.0622	-0.3673
19-30	-1.24	0.000	-1.7232	-0.7518
>30	-2.37	0.000	-3.3777	-1.3546

DV: Inspection Score	Coefficient	*p*-value	95% Confidence Interval	
Inspection region (Reference: Southeast region)**				
Not in the U.S. (NUS)	-0.56	0.487	-2.1494	1.0247
California	-0.02	0.913	-0.4143	0.3706
Caribbean	-0.07	0.743	-0.4709	0.3359
Hawaii	-1.21	0.003	-2.0161	-0.4063
Northeast	-0.33	0.137	-0.7694	0.1056
Northwest	-0.24	0.300	-0.6922	0.2132
South	-0.50	0.051	-0.9980	0.0030

Note. *Gross Registered Tonnage (GRT) is the maritime industry standard for ship size. **Northwest (WA, OR, AK): ADK, AKU, ANC, AOR, ATT, BAK, BWA, COR, DHA, EFC, FHW, GLB, HAK, HNS, HOM, IAK, JNU, KIS, KOD, KTN, MET, NOM, PAN, POR, PTB, SEA, SGY, SIT, SWD, VDZ, WAI, WRG, WTR, YAK; Hawaiian Islands, Guam, American Samoa, Saipan: GUA, HIL, HNL, KAH, KAU, KON, LAH, MAU, PAS, SAI, SAM; California: ACA, CAT, LAX, LBC, MCA, SAC, SBC, SDC, SFO, SPC; South (all ports on Gulf of Mexico, excluding FL): BRT, CCT, FTP, FTX, GAL, GMS, HOU, MAL, NOL, PAT, PIT; Northeast (all states north of and including NC): ABN, AMD, ANY, AVA, BAL, BAR, BAT, BNJ, BNY, BOO, BOS, BUF, CHI, CLY, CMA, CME, COH, DET, DMN, EME, ERI, GMA, GNY, HOL, JOL, KNY, MAC, MAR, MCI, MIL, MVY, NOR, NRI, NYC, OGS, OMA, OSW, PEJ, PHL, PHM, PME, PNH, PNY, PRI, PVM, RCK, RHI, RNY, SMA, SMI, STP, SYN, TCM, TNY, TRA, WDE, WNC, WPN, WRI, WVA, WYN, YRK; Southeast (all ports in FL, GA, and SC): CHA, JAX, KWE, MAN, MIA, NPF, PBF, PCF, PEN, PEV, SAV, SFL, SPF, TAM, VBF, WPB; Caribbean Islands: FPR, ISC, MAY, NYA, PPR, SJO, SJU, STC, STT.

Table 8: Multivariable Binary Logistic Regression Model of Periodic Inspection Outcomes by Cruise Ship Characteristics

DV: Inspection Score (Pass=1)	Odds Ratio	*p*-value	95% Confidence Interval	
Fleet size (Reference: ≤5 ships)				
6-10	1.16	0.798	0.3786	3.5367
11-15	3.46	0.001	1.6603	7.1982
16-20	2.87	0.083	0.8707	9.4431
>20	0.73	0.400	0.3474	1.5251
GRT* category (Reference: Extra-large ships (60,000-120,000))				
Extra small to medium (≤30,000)	0.22	0.000	0.1068	0.4385
Large (30,001-60,000)	0.35	0.001	0.1879	0.6603
Mega (120,001-140,000)	1.02	0.979	0.2676	3.8727
Super mega (>140,001)	0.53	0.424	0.1099	2.5321
Ship age category (Reference: ≤7 years)				
8-12	1.00	0.992	0.5175	1.9456

DV: Inspection Score (Pass=1)	Odds Ratio	*p*-value	95% Confidence Interval	
13-18	0.82	0.545	0.4279	1.5656
19-30	0.44	0.014	0.2313	0.8501
>30	0.47	0.052	0.2220	1.0076
Inspection region** (Reference: Southeast region)				
California	1.83	0.257	0.6449	5.1754
Caribbean	1.03	0.902	0.6027	1.7751
Hawaii	0.34	0.005	0.1581	0.7158
Northeast	0.96	0.886	0.5501	1.6761
Northwest	0.96	0.748	0.5344	1.5687
South	1.06	0.896	0.4425	2.5398

Note. *Gross Registered Tonnage (GRT) is the maritime industry standard for ship size. **Northwest (WA, OR, AK): ADK, AKU, ANC, AOR, ATT, BAK, BWA, COR, DHA, EFC, FHW, GLB, HAK, HNS, HOM, IAK, JNU, KIS, KOD, KTN, MET, NOM, PAN, POR, PTB, SEA, SGY, SIT, SWD, VDZ, WAI, WRG, WTR, YAK; Hawaiian Islands, Guam, American Samoa, Saipan: GUA, HIL, HNL, KAH, KAU, KON, LAH, MAU, PAS, SAI, SAM; California: ACA, CAT, LAX, LBC, MCA, SAC, SBC, SDC, SFO, SPC; South (all ports on Gulf of Mexico, excluding FL): BRT, CCT, FTP, FTX, GAL, GMS, HOU, MAL, NOL, PAT, PIT; Northeast (all states north of and including NC): ABN, AMD, ANY, AVA, BAL, BAR, BAT, BNJ, BNY, BOO, BOS, BUF, CHI, CLY, CMA, CME, COH, DET, DMN, EME, ERI, GMA, GNY, HOL, JOL, KNY, MAC, MAR, MCI, MIL, MVY, NOR, NRI, NYC, OGS, OMA, OSW, PEJ, PHL, PHM, PME, PNH, PNY, PRI, PVM, RCK, RHI, RNY, SMA, SMI, STP, SYN, TCM, TNY, TRA, WDE, WNC, WPN, WRI, WVA, WYN, YRK; Southeast (all ports in FL, GA, and SC): CHA, JAX, KWE, MAN, MIA, NPF, PBF, PCF, PEN, PEV, SAV, SFL, SPF, TAM, VBF, WPB; Caribbean Islands: FPR, ISC, MAY, NYA, PPR, SJO, SJU, STC, STT

CHAPTER 4: AN ASSESSMENT OF PUBLIC HEALTH POLICY AND THE MANAGEMENT OF ACUTE GASTROENTERITIS INCIDENCE AMONG PASSENGERS AND CREW[2]

[2] Vaughan, G. To be submitted to the *Journal of Environmental Health*.

Abstract

Developing strong public health policies and practices consistent with the cruise ship environment and adaptable to changing environmental threats that increase the risk of enteric disease morbidity and outbreaks is important to positive public health outcomes. Since 1975, the VSP has required cruise ships with international itineraries carrying 13 or more passengers to submit communicable disease reports of the number of reported cases of enteric diseases meeting the current reportable case definition. This syndromic surveillance system allows the VSP staff to rapidly respond to public health threats, provide technical assistance and support to their cruise industry partners, examine cruise industry disease trends, and create public health policy to reduce enteric disease morbidity and outbreaks among passengers and crew associated with cruise ship travel. In addition, the data gathered through the syndromic surveillance activity has been important to refining existing policies and programs that allow the VSP to meet its statutory obligations to prevent the introduction, transmission, and spread of enteric disease pathogens into the U.S. through its marine port communities.

This manuscript examines and quantifies the impact of public health policy, as detailed in the 2005 and 2011 Vessel Sanitation Program (VSP) Operations Manuals, on acute gastroenteritis (AGE) incidence between January 1, 2001 and December 31, 2019. The VSP operations manuals are considered the industry standard for maritime public health in North America and have been adopted in whole or in part as the policy basis of many international maritime public health agencies. Moreover, the cruise industry incorporates the basic requirements of the operations manuals as the foundation of the public health standard operating procedures (SOPs), customized to meet the operational needs of their respective fleets.

Therefore, it is essential that these policies are effective in controlling current public health threats.

Introduction

Public Health Policy Development within the Cruise Industry

Policy development for cruise ships is a joint venture between the VSP and its cruise industry and other partners. Federal statutes authorize the VSP to assist the cruise industry in developing public health policy to prevent the introduction, transmission and spread of communicable diseases into the U.S. from cruise ships with international itineraries (42 USC § 264 Quarantine and Inspection Regulations to Control Communicable Diseases). Since 1989, this collaborative effort has produced a series of operations manuals (2000, 2005, 2011, and 2018) that serve as the foundation of public health policy in the cruise industry, addressing crucial public health issues at the time of publication. These manuals were developed through negotiation with each cruise line, representative shipyards, international maritime public health agencies, and several consulting groups and maritime organizations. Each successive manual revision built upon the requirements of its predecessor, incorporating advances in medical case management and disease reporting, food safety practices, potable/recreational water systems management, integrated pest management (IPM), housekeeping and infection control, child activity centers, and heating, ventilation, and air conditioning systems (HVAC) including decorative fountains, misting systems, humidifiers, and showers.

The requirements in the operations manual apply to all cruise ships within its jurisdiction regardless of size or complexity. However, each cruise line may amend the criteria to meet the needs of individual ships or the fleet through standard operating procedures (SOPs). Cruise line SOPs may add additional requirements, provided they are at least as protective and do not violate operations manual requirements. Cruise ship compliance with the operations manual requirements is assessed during unannounced, biannual operations inspections conducted by VSP Environmental Health Officers (EHOs) (Centers for Disease Control, 2019).

The 2005 and 2011 VSP Operations Manuals were the first documents to strategically address AGE outbreaks on cruise ships caused by emerging enteric pathogens, driven almost exclusively by noroviruses. These enteric pathogens presented a unique challenge, as the primary transmission modes were person-to-person spread and fomite transmission instead of food or potable water. In response to the new public health challenge, the 2005 VSP Operations Manual required the cruise industry to develop written Outbreak Prevention and Response Plans (OPRPs) specific to their fleet operations. OPRPs were developed by leveraging risk assessment strategies that identified shortcomings in current cruise ship responses, making necessary adjustments to prevent AGE outbreak occurrence while improving AGE outbreak response actions. Central to the OPRP were requirements for establishing 1) an incident command structure, 2) enhanced cleaning and disinfection strategies, including using U..S EPA (or equivalent) registered chemical disinfectants or chemical disinfectants demonstrating efficacy against norovirus surrogates, and 3) the necessity for continuous cleaning and disinfection until the AGE case levels decreased to less than 2%. Furthermore, the VSP developed an industry-specific webpage that outlined essential content for inclusion in the OPRP, standardizing basic plan elements across the cruise industry.

In addition to establishing OPRP requirements, the 2005 *Operations Manual* introduced strict isolation of crew AGE cases and monitoring of their close contacts. This operation manual version also supported shipboard medical personnel to encourage self-isolation of passenger AGE cases for 24 hours after symptom resolution. In support of new operations manual requirements, the VSP developed training modules for enhanced outbreak management and response strategies for middle managers as a component of its training seminar program held six times per year.

While the revisions and additions in the 2011 VSP Operations Manual primarily focused on improving recreational water facilities (RWFs) management, there were further refinements in outbreak prevention, control, and response strategies, including enhanced hand hygiene for passengers. During the period this manual was in force, the cruise industry leveraged lessons learned to improve outbreak prevention and response plans (OPRPs) and the deployment of chemical disinfectants for enhanced infection control procedures.

The requirements embodied in the 2005 and 2011 VSP Operations Manuals formed the foundation for controlling enteric pathogens transmitted by means other than food and potable water. The preponderance of norovirus outbreaks necessitated these requirements, as norovirus outbreaks on cruise ships were purported to be transmitted through person-to-person spread or contact with contaminated environmental surfaces.

Vessel Sanitation Program Syndromic Surveillance Reporting

Since 1975, the Vessel Sanitation Program (VSP) has received syndromic surveillance reports for diarrheal disease (1975-2000) and acute gastroenteritis (AGE) (2000 - current) from passenger cruise ships entering the U.S. from foreign ports of call. Federal regulations require the master of cruise ships carrying 13 or more passengers and making U.S. port calls following travel from foreign ports to make periodic voyage reports for each voyage or voyage segment. During a voyage, the master must submit at least one AGE report to the VSP, even if the passenger and crew case counts are zero. In the event of additional AGE cases, the master may be required to submit updated cumulative AGE reports during predetermined times in the voyage.

These diarrheal disease/AGE reports aim to monitor enteric disease illness aboard cruise ships and allow the VSP to provide technical assistance and support or to conduct environmental health and sanitation inspections or outbreak investigations as needed. More recently, AGE reports have been used in research on cruise ship operations to assess trends in AGE incidence, guide public health policy development, and inform infectious disease prevention strategies to improve the health of passengers and crew aboard cruise ships.

Research Aims

This manuscript aims to determine the impact of policy implemented in the 2005 and 2011 VSP Operations Manuals on AGE incidence and outbreaks. From 2001 to 2019, most AGE outbreaks confirmed noroviruses as the etiologic agent and were typically associated with person-to-person transmission in the cruise ship environment (Widdowson et al., 2004; Iskabaeva et al., 2005; Cramer et al., 2006; Wikswo et al., 2011; Freeland et al., 2016; Jenkins et al., 2021). Moreover, low infectious dose and environmental stability allow it to propagate efficiently in settings where many people congregate and interact in confined areas. The results of this manuscript should inform federal authorities and cruise industry partners regarding the effectiveness of public health policy and infection control strategies in controlling these emerging enteric pathogens.

Research Questions and Hypotheses

1. Are cruise industry policies promulgated in the 2005 and 2011 VSP Operations Manuals effectively controlling AGE incidence?

2. Are cruise industry policies promulgated in the 2005 and 2011 VSP Operations Manuals effectively controlling the frequency and magnitude of AGE outbreaks?

Effective public health policy and infection control strategies are hypothesized to reduce adverse public health outcomes, including the trend in AGE incidence among passengers and crew and the frequency and magnitude of AGE outbreaks. Additionally, if the policies are robust and evidence-based, it is hypothesized that the programs will manage norovirus variants and pandemic strains that are anticipated to occur in the future.

Research Methods

The current study examined voyage-level AGE incidence reports from cruise ships maintained in the MIDRS database to 1) ascertain whether AGE incidence declined between January 1, 2001 and December 31, 2019 and 2) assess the effects of the interventions introduced in the 2005 and 2011 VSP Operations Manual on AGE incidence over this period. The selection criteria for AGE incidence reports were restricted to voyages 3-21 days in length and cruise ships carrying ≥100 passengers. The range of voyage lengths was selected to minimize underreporting of AGE cases for voyages less than three and longer than 21 days, which are likely to be incomplete (Freeland et al., 2016). Additionally, for cruise ships transporting less than 100 passengers, AGE incidence rates can easily exceed the VSP's outbreak threshold of 3.0% with few AGE cases, subsequently misclassifying voyage outbreaks and overinflating AGE outbreak metrics. Voyage embarkation dates between January 1, 2001 and December 31, 2019 were included in the analyses. Since the VSP MIDRS requires multiple reports for some voyages (and case counts are cumulative for a given voyage), the most recent report for each voyage was selected, based on date and time of submission, as reported by MIDRS. For voyages without a voyage identifier, one was created by combining cruise ship ID and embarkation date. It was assumed that a voyage could have only one embarkation date and that all cruise ship identifiers were unique. Voyage lengths were calculated by subtracting embarkation dates from disembarkation dates as reported in the most recent MIDRS report. Aggregate AGE incidence rates per 100,000 travel days were calculated using the following formula provided by in an earlier study (Cramer et al., 2006):

((Total reported passenger or crew cases)/(Total passengers or crew on board x total number of days of the voyage)) x 100,000 travel days.

AGE incidence rates were calculated separately for passenger and crew populations and independently for each year of the study. Baseline AGE incidence rates were based on voyages with less than 3% of passengers (or crew). Outbreak-associated AGE incidence rates for passengers or crew were calculated using the following formula for voyages with an AGE incidence ≥ 3% (Cramer et al., 2006):

((outbreak-associated passenger or crew cases)/(Total passengers or crew onboard x number of days of the voyage during an outbreak voyage)) x 100,000 travel days

Cruise ships with domestic-only itineraries did not fall under VSP jurisdiction and were excluded from the study. Cruise ships on domestic voyages operate under the jurisdiction of the U.S. Food and Drug Administration; therefore, illness reports are not received by the VSP.

The dataset was inspected for reporting errors since MIDRS reports were submitted through various methods, including the email receiver, MIIDRS web portal, and manual entries by VSP administrative staff. Error-checking was done before removing reports outside the study entry criteria to avoid inadvertently excluding relevant reports. The email receiver reporting system is based on a template without error-checking, while the web interface data entry method incorporates basic error-checking before MIDRS report submission, allowing the cruise ship data entrant to make corrections and resubmit reports. The dataset was inspected for outliers using histograms, spike plots, descriptive statistics, and manual reviews. Outliers in voyage lengths were evaluated by comparing embarkation, next port, and disembarkation dates (user-generated) to the dates and times of submission to MIDRS (system-generated) to determine the most appropriate dates, where possible. Additionally, embarkation and disembarkation dates were compared to identify reversed date entries and incorrect year values and used to calculate voyage length (in days), a variable important to this investigation. MIDRS reports were also inspected for reversal of passenger and crew totals by comparing suspect reports to the maximum passenger and crew capacities maintained in the VSP Inspection Reporting System (VSPIRS). To reduce the introduction of bias into the analyses, extreme values that could not be resolved were deleted before further analysis. Common reasons for edits and corrections were reversed embarkation and disembarkation dates and incorrect year, especially when the voyage length spanned more than a single year (e.g., voyages at the end of a year), reversed passenger and crew totals, and extreme passenger and crew totals. Once the errors in the dataset were corrected, the most recent MIDRS report with the maximum reported AGE cases for passengers and crew was maintained.

Univariate analysis was conducted using frequencies, percentiles, and graphs (e.g., histograms) to visually inspect the dataset for characteristics of dependent and independent variables, including distributions and extreme values (e.g., outliers). Analyses included pairwise correlation coefficients, skewness and kurtosis tests, and tests for normality and multicollinearity. Bivariate analysis was conducted using crosstabulations with measures of association, including Pearson’s Chi-squared test, Fisher’s exact test (small cell counts), Cramer's V, and Kendall's Taub as appropriate. The threshold for hypothesis testing and statistical significance was set at an alpha level of 0.05.

Regression Model Specifications

AGE incidence proportion (attack rate) was evaluated for this study using multivariable longitudinal and time series data analysis techniques to determine overall trends in AGE incidence and outbreaks. Longitudinal data analysis allows for controlling unobserved variables, such as differences in business practices across cruise lines or cruise ships, accounting for individual heterogeneity (HKT Consultant, 2022). This approach allowed for the simultaneous examination of individual cruise ships and group-level variation. Examining voyage-level longitudinal data also helped minimize the estimation bias often observed in aggregated group-level data (HKT Consultant, 2022).

Multivariable regression models for longitudinal/panel data were fitted to voyage-level MIDRS AGE incidence proportion report data (percentage of passengers or crew ill during individual voyages) to understand trends in AGE incidence proportion, controlling for the effects of confounding variables. Independent variables included in the models were embarkation year, mean fleet size, ship age (in years), space-passenger ratio, passenger-crew ratio, gross registered tonnage (GRT) categories, voyage length (in days), and next U.S. port region following AGE report submission. Before specifying longitudinal regression models, OLS regression models were specified using the independent variables described above, and post-estimation diagnostic tests were run for normality (Jarque Bera Test, Shapiro-Wilks test, and Shapiro-Francia test), multicollinearity (Variance Inflation Test and Pearson's correlation coefficients), and heteroskedasticity tests of standard errors (Breusch-Pagan and White Tests). Fixed effects (time-invariant variables are not estimated) and random effect models (time-invariant variables are estimated) were specified to address unobserved individual-level heterogeneity within and between cruise ships. The fixed-effects approach assumes the unobserved individual-specific effects are correlated with the independent variables, whereas the random-effects approach assumes the unobserved individual-specific effects are uncorrelated with the independent variables (HKT Consultant, 2022). Fixed-effects and random-effects models were fitted to the data, with the most efficient model determined using the Durbin-Wu-Hausman (DWH) specification test (Hausman, 1978). The Breusch-Pagan Lagrange Multiplier (LM) test (Breusch & Pagan, 1980) was used to determine the appropriateness of the random effects model compared to the pooled OLS model for this research project.

To estimate the AGE incidence proportion by year, Poisson regression models were specified for the passenger (or crew) reported AGE cases as the dependent variable and embarkation year as the single independent variable. The log of total passengers (or crew) for each voyage was used as the offset variable. The model used voyage-level data to explain the passenger and crew acute gastroenteritis incidence proportions (AGE attack rates). For these models, the independent variable was the embarkation year of each voyage. Because of heteroskedastic standard errors, the Huber/White/sandwich VCE estimator was used to calculate the standard errors estimated by the respective models (StataCorp, 2021). Akaike Information Criteria (AIC) and Bayesian Information Criteria (BIC) were used as objective criteria to determine the best model fit.

Since many voyages reported no reportable AGE cases for passenger and crew populations, binary multivariable logistic regression models were used to compare voyages with no passenger or crew AGE cases to voyages reporting one or more AGE cases in passenger or crew populations. The dependent variable was dichotomized for whether AGE cases were reported for passengers or crew (AGE cases reported =1; otherwise=0), with all independent variables included in each model. Similarly, multivariable logistic regression models were specified for voyages reporting AGE elevations or outbreaks compared to voyages without AGE outbreaks (AGE elevation or outbreaks=1; No AGE elevation or outbreaks =0). Binary multivariable logistic regression models were also specified for voyages reporting either elevations or outbreaks for passenger and crew populations independently, like the models specified for the absence or presence of reported AGE cases. These models aimed to explain the relationship between reported AGE elevations or outbreaks controlling for selected cruise ship characteristics.

A stepwise variable selection procedure was used for the longitudinal models to determine the most appropriate independent variables from a list of plausible variables identified in previous studies of cruise ships, theoretical considerations regarding communicable disease transmission aboard passenger cruise ships, or variables deemed important for face validity. The goal was to determine the best model approach and construct parsimonious models that included the fewest explanatory variables for AGE incidence. The set criterion used to determine variables for inclusion in the model was based on the absolute value of the t-statistic and associated p-value. The models aimed to explain the variability in acute gastroenteritis incidence proportion using voyage-level data. The multivariable regression models used the Huber/White/sandwich VCE estimator to calculate the coefficients estimated by the respective models (StataCorp, 2021). Akaike Information Criteria (AIC) and Bayesian Information Criteria (BIC) were used as objective criteria to determine the most parsimonious model that best fit the data while avoiding overfitting.

Interrupted Time Series Analysis

An interrupted time series (ITS) analysis was also conducted to determine the impact of the policy interventions on passenger and crew AGE incidence. The interrupted time series design is considered a robust quasi-experimental approach for evaluating pre- and post-intervention periods for single-group studies and is recognized as a primary research design (Linden, 2017; Cochrane Effective Practice and Organization of Care [EPOC] Group, 2019). To analyze the effectiveness of policy interventions on AGE incidence and outbreaks, intervention periods were set to 2005 for the first intervention period and to 2011 for the second intervention period. The impact of the 2011 *VSP Operations Manual* intervention was compared with the 2005 *VSP Operations Manual* intervention. The dependent variable was AGE incidence, measured as the aggregate incidence rate for cruise ships under U.S. jurisdiction during the study period. AGE incidence rates were calculated separately for passengers and crew. Additionally, AGE incidence proportions (e.g., attack rates) were analyzed for passengers and crew populations independently aggregated for each cruise ship. Each year was based on AGE incidence as reported in MIDRS reports, consistent with prior VSP-published research (Freeland et al., 2016; Jenkins et al., 2021). Throughout the study period, AGE case definition and AGE incidence were consistently defined, enabling valid comparisons across time.

The analysis for aggregated AGE incidence per 100,000 travel days for all cruise ships used the -itsa- command developed by Ariel Linden to estimate the effect of the VSP policy interventions introduced in 2005 and 2011 (Linden, 2015). The -itsa- command was selected because it allows for assessing the intervention effects for a single group with multiple interventions. The interrupted time series regression for two interventions assumes the following functional form:

$$Y_i = \beta_0 + \beta_1 T_t + \beta_2 X_{1t} + \beta_3 X_{1t} T_{1t} + \beta_4 X_{2t} + \beta_5 X_{2t} T_{2t} + \epsilon_t \qquad (1)$$

where:

Y_i is the aggregated outcome variable measured at time point *t*, T_t is the time since the beginning of the study, X_t is the dummy variable for the intervention (coded 0 for preintervention and 1 as postintervention), and $X_t T_t$ is an interaction term (Linden, 2017a). The intercept (β_0) represents the initial level of the outcome variable, and the slope or trend before the introduction of the intervention is represented by β_1. The change in the outcome variable immediately following the introduction of the intervention is indicated by β_2. The differences between preintervention and postintervention slopes of the outcome variable are represented by β_3. In this equation, X_{2t} and $X_{2t}T_{2t}$ are variables representing the second intervention period of the study (2011 Operations Manual), and β_4 indicates the change in the outcome level that occurs in the period immediately following the introduction of the second intervention (Linden, 2017). The β_5 coefficient reports the difference between the outcome variable's first and second intervention slopes (Linden, 2017a). The program estimates Newey-West standard errors for coefficients produced through ordinary least-squares (OLS) regression and provides a comprehensive set of post-estimation commands, including individual trend lines, comparisons of multiple interventions, and comparisons with counterfactual outcomes (Linden, 2017a).

The ITSA program for longitudinal/panel data analysis (-xtitsa- program) was used to analyze AGE incidence proportion (as attack rates in percentages) for passengers and crew for each cruise line and cruise ship (Linden, 2021). Like the -itsa- command, the -xtitsa- command accommodates multiple intervention periods (Linden, 2021). The interrupted time series regression for two intervention periods assumes the following formula:

$$Y_{ti} = \beta_0 + \beta_1 T_{ti} + \beta_2 X_{ti} + \beta_3 X_{ti} T_{ti} + \beta_4 X_{ti} + \beta_5 X_{ti} T_{ti} + \epsilon_{ti} \qquad (2)$$

Where Y_{ti} represents the outcome variable (AGE incidence) measured at equally spaced time point *t* for each individual-level i, T_{ti} is the time since the beginning of the study, X_{ti} is the intervention variable coded as 0 for the pre-intervention period and 1 for the post-intervention period, and $X_{ti}T_{ti}$ is an interaction term (Linden, 2021). The intercept (β_0) is the initial level of the outcome variable, and the slope or trend before the introduction of the intervention is represented by β_1; the change in the outcome variable immediately following the introduction of the intervention is indicated by β_2. The differences between preintervention and postintervention slopes of the outcome variable are represented by β_3. An immediate effect of the intervention is determined by significant p-values in β_2, while significant p-values indicate an intervention effect over time in β_3. The Huber-White sandwich (robust) variance estimator was used for these interrupted time series analysis models.

The -xtitsa- command was reported to be a wrapper for Stata -xtgee- command, used to fit longitudinal/panel data models incorporating generalized estimation equations (GEE) (Linden, 2021). This command provided options for selecting the appropriate family and link functions based on the underlying distribution of the outcome variable. Additionally, all post-estimation tests in -xtgee- were available following -xtitsa- model specifications. The -actest- command (Baum & Schaffer, 2013) was used following model specification to perform the Cumby-Huizinga general specification test to assess autocorrelation in time series data (Baum & Schaffer, 2013). Models were adjusted based on the Cumby-Huizinga general specification test results as needed. This analysis utilized a single-group technique, since all cruise ships must comply with the interventions according to federal policy; therefore, a suitable control group was unavailable.

Multivariable linear regression models were specified for passenger and crew attack rates, respectively. For each regression model, post-estimation tests were conducted to determine whether violations in regression assumptions were present, and adjustments in functional form and inclusion of robust standard errors were included as needed. The final models were estimated, controlling for known confounders, including the presence of circulating, pandemic norovirus strains, ship size (in gross registered tonnage, or GRT), fleet size, voyage length (days), and next port of arrival following the most recent AGE report submission. Additionally, two proxy measures for density and passenger-crew interactions (space-to-passenger ratio and passenger-crew ratio, respectively) were included as potential confounders. The space-to-passenger ratio was calculated by dividing the gross registered tonnage (GRT) by the number of passengers onboard during each voyage. The larger the number, the less dense the passenger population (e.g., the more space per passenger). To the author's knowledge, no previous studies have investigated this metric using MIDRS AGE case data. The passenger-crew ratio was calculated by dividing the total number of passengers by the total crew for each voyage. Theoretically, the higher the number, the more potential passenger interaction with the crew, particularly in service-related engagements. However, this ratio is considered crude, as it includes crew members without consistent passenger interaction, such as engineering and navigational staff.

The analyses in this manuscript were conducted using de-identified data for cruise ships and cruise lines. The University of Georgia Institutional Review Board (IRB) determined that the study was not considered human subjects research. Informed consent was not required for reported AGE cases, since the MIDRS does not collect passenger or crew identifying information. All statistical analyses were performed using Stata/SE, version 17.0 (Stata Corporation, College Station, Texas).

Outcome Measures

The primary outcome measures were AGE incidence, defined as AGE incidence rates per 100,00 travel days for passengers and crew. Additionally, baseline AGE cases (e.g., non-outbreak-associated AGE cases) were defined for voyages with <3.0% AGE incidence in either passenger or crew subpopulations, while AGE outbreak-related cases were defined for voyages with AGE incidence ≥3.0% of reported AGE cases (Merson et al., 1975b). A subset of analyses dichotomized AGE incidence by AGE elevations and outbreak voyages where AGE elevations and outbreaks were defined as a voyage or voyage segment with AGE incidence ≥2.0%. To compare findings with recent VSP published reports, AGE incidence data for 2001-2019 were analyzed using each cruise ship's most recently submitted MIDRS report (Freeland et al., 2016; Jenkins et al., 2021). AGE incidence rates per 100,000 travel days were calculated for passenger and crew subpopulations. AGE outbreak rates were calculated per 1,000 voyages to compare findings with previously published reports.

Data Analysis and Results

Descriptive Data Analysis

Between January 1, 2001, and December 31, 2019, 339 cruise ships (representing 85 cruise lines) submitted 145,523 AGE reports to MIDRS, for all voyage lengths and ship sizes. Annually, MIDRS report submissions ranged from 4,851 in 2001 to 9,382 in 2014. The distribution of the 145,523 AGE reports by report type were 91,552 (62.9%) 24-hour reports, 51,870 (35.6%) 4-hour update reports, and 2,102 (1.4%) special reports. Most AGE reports (93,820 [64.5%]) were submitted through the VSP email receiver component. By comparison, 44,584 (30.6%) AGE reports were submitted through the MIDRS web interface, with the remaining 7,119 (4.9%) AGE reports manually entered by VSP administrative support staff. For all voyage reports, 1,207 (0.8%) were AGE outbreak reports for passengers, and 260 (0.2%) were AGE outbreak reports for the crew. AGE reports were also categorized by gross registered tonnage (GRT), a measure of cruise ship size, with the most frequent AGE reports (n=96,060 [66.0%]) submitted by the shipboard staff of extra-large vessels. AGE reports were also categorized by voyage lengths, with 68,191 of 137,581 (49.6%) voyages between 8 and 10 days in length. Following data editing and removal of outlier MIDRS AGE reports, 145,189 reports remained. For certain voyages, the VSP required multiple reports, requiring the removal of duplicates and resulting in 86,303 AGE reports for all voyages, regardless of length or passenger count. A total of 416 (0.48%) voyages were classified as outbreak voyages for passengers based on VSP outbreak criteria, while 82 (0.10%) voyages met the outbreak criteria for crewmembers.

MIDRS AGE reports (N=74,047) were included in the analyses for voyages 3-21 days in duration and carrying ≥ 100 passengers. Due to the study inclusion criteria, AGE reports excluded 9,263 voyages less than three days in duration, 807 voyages longer than 21 days, and 1,037 voyages carrying fewer than 100 passengers at the start of the voyage. Cruise ships in the extra-large category (60,001-120,000 GRT) submitted 52,975 (71.5%) unique AGE reports for each voyage by cruise ship size, while extra small-to-medium category cruise ships (≤30,000 GRT) reported the smallest number of AGE reports at 2,394 (3.2%) for each voyage. AGE reports characterized by voyage lengths indicated cruise ships with voyage lengths between 6-7 days submitted the largest unique number of reports (34,258, 46.3%), and cruise ships with voyage lengths between 15-21 days submitted the fewest unique AGE reports (n=2,031 [2.7%]). The Southeast, the location of most cruise line headquarters, was the most frequently reporting

U.S. port region (n=38,855 [52.5%]). By contrast, the reporting region with the fewest AGE reports was the Hawaiian Islands (n=573, [0.8%]). For cruise ships with voyages terminating outside the United States, 149 (0.2%) unique AGE reports were submitted at the last U.S. port.

Table 9, at the end of this chapter, summarizes AGE reports by passenger and crew mean and standard deviation of AGE incidence rates per 100,000 travel days by the categories described above. AGE incidence rates appeared to be somewhat consistent across all passenger/crew categories, with lower incidence rates for crew members than passengers. The median voyage length was seven days for cruise ships considered in this study.

Voyage frequency by embarkation date ranged from 2,958 (4.0%) in 2001 to 4,530 (6.1%) in 2019. The distribution of reported passenger AGE cases ranged from 6,190 (2001) to 22,382 (2007), and the mean number of reported passenger AGE cases by embarkation year was 17,178 (sd=3,243.6). These MIDRS AGE reports contained 323,437 AGE cases for passengers, of which 36,405 were AGE outbreak-related cases. For crew members, 112,691 AGE cases were reported during the study period, and 1,652 were AGE outbreak-related cases. Reported crew AGE cases ranged from 3,733 (2001) to 7,330 (2004). The mean number of reported crew AGE cases by embarkation year was 5,944 (sd=867.3). Acute gastroenteritis incidence rates per 100,000 travel days varied over the study period for passenger and crew populations, ranging from 17.2 (2001) to 42.7 (2006) (mean=27.4; sd=6.4) for passengers and 15.1 (2019) to 33.8 (2005) (mean=24.6; sd=5.7) for crew. The rates of acute gastroenteritis per 100,000 travel days increased from 17.2 for passengers in 2001 to a high of 42.7 in 2006 (median:26.5), which then declined to a low of 18.5 per 100,000 travel days in 2019. A linear regression model for passenger incidence rate and embarkation year indicated that the decrease was statistically significant (t=-187.44; $p<0.000$). The initial acute gastroenteritis rate for crewmembers was

25.4, peaking at 33.8 in 2006, then decreasing to 15.1 in 2019 (median: 24.15). A linear regression model for crew incidence rate and embarkation year indicated the decrease was statistically significant (*t*=--454.44; p<0.000) In 2006-2007, two novel pandemic strains of noroviruses (GII.4 Yerseke and GII.4 Den Haag) emerged driving AGE incidence and outbreaks for both populations.

During the study period, 344 acute gastroenteritis outbreak voyages were recorded for passengers, and 54 acute gastroenteritis outbreak voyages were recorded for crewmembers for voyages 3-21 days in length, carrying 100 or more passengers. Similar to the trends in AGE incidence rates per 100,000 travel days for passengers and crew, the passenger AGE outbreak rates per 1,000 voyages peaked in 2006 at 11.12 per 1,000 voyages. The Cochran-Armitage test for trends of the frequency of passenger AGE outbreaks was significant (z=-4.40; p<0.0001), indicating a decrease in AGE outbreaks for passengers over the study period. The AGE outbreak rate per 1,000 voyages for crewmembers crested at 2.34 per 1,000 voyages in 2003. The Cochran-Armitage test for trends for the frequency of AGE outbreaks among crewmembers was significant, demonstrating a decrease in AGE outbreaks over the study period (*z*=-4.87; p<0.0001). In 2002, a novel strain of noroviruses emerged (GII.4 Farmington Hills) and likely influenced passenger and crew AGE outbreaks during that year. Table 9 summarizes AGE cases, incidence rates per 100,000 travel days, AGE outbreak frequency and rates per 1,000 voyages, and the number of background and outbreak-related cases by year for passengers and crew populations. Figures 2-6 are charts of the trends of the AGE incidence rates per 100,000 travel days for passengers and crew, AGE outbreaks per 1,000 voyages for passengers and crew, and AGE outbreak-related cases for passengers and crew, respectively. Table 12 summarizes the frequency and rate of AGE outbreaks per 1,000 voyages for cruise ship size, voyage length, and regional port of arrival.

The highest frequencies and rates for outbreak voyages and illness were associated with epidemic and pandemic strains of noroviruses reported circulating in 2002, 2004, 2006-2007, 2009, and 2012 (Widdowson et al., 2004; Blanton et al., 2006; Pringle et al., 2015). A statistical association was found for the presence of circulating epidemic or pandemic strain(s) and reported shipboard AGE outbreaks in years where norovirus epidemic or pandemic strains were circulating for passengers (Pearson χ^2 (1) = 39.94, $p < 0.001$) and crew populations (Pearson χ^2 (1) = 19.90, $p < 0.001$). Of the AGE outbreak voyages involving passengers, 197 of 344 (57.3%) occurred when norovirus epidemic or pandemic strains were circulating. A similar pattern was observed for crewmembers, where 38 of 54 AGE outbreak voyages (70.4%) occurred during years when norovirus epidemic or pandemic strains were in circulation. Furthermore, the distribution of passenger AGE outbreaks indicated that most occurred during the earlier months (Jan-May) and later months (Oct-Dec) for passengers (Pearson χ^2(11) = 78.23, p< 0.001) and crew populations (Pearson χ^2 (11) = 21.41, p=0.029).

Bivariate analysis of categorical variables with AGE outbreak voyages for passenger and crew populations indicated statistically significant associations for ship size (passengers: Pearson χ^2 (4) = 86.20, p<0.001; crew: Pearson χ^2 (4) = 67.46, p<0.001), voyage length (passengers: Pearson χ^2 (4) = 979.48, p<0.001; crew: Pearson χ^2 (4) = 110.94, p<0.001), and next U.S. port region for passengers only ((passengers: Pearson χ^2 (7) =144.44, p<0.001). The extra-large ship size group reported 217 of 344 (63.1%) AGE outbreaks voyages. For the 344 AGE outbreak voyages, 149 (43.3%) were reported in the southeast region, where 38,855 of 74,047 (52.5%)

AGE reports were submitted to the VSP. The next U.S. port region was not statistically significant for crew AGE outbreaks (Pearson χ^2 (7) = 7.8, p=0.350).

An investigation of the relationship between AGE outbreak voyages and the presence of epidemic or pandemic norovirus strains in circulation reveals that, over the study period, 43,856 (59.6%) AGE reports with no passenger AGE outbreaks occurred in the absence of circulating epidemic or pandemic norovirus strains, whereas 29,847 (40.5%) of AGE reports without an AGE outbreak occurred in the presence of circulating norovirus strains. Of the 344 passenger AGE outbreak voyages, 197 (57.3%) occurred when epidemic or pandemic norovirus strains were circulating, and 147 (42.7%) passenger AGE outbreak voyages occurred without epidemic or pandemic norovirus strains in circulation. The association between the presence of norovirus strains and passenger AGE outbreak voyages was statistically significant (Pearson χ^2(1) =39.9; $p<0.001$). For crew members, 16 of 54 (29.6%) crew AGE outbreak voyages occurred without circulating epidemic or pandemic norovirus strains, whereas 38 of 54 (70.4%) crew AGE outbreaks occurred in the presence of circulating epidemic or pandemic norovirus strains. As with passengers, the association was statistically significant (Pearson χ^2(1) 19.8; $p<0.001$).

Selected cruise ship characteristics and AGE reporting regions were used to analyze acute gastroenteritis (AGE) incidence rates per 100,000 travel days. For ship size (gross registered tonnage), mean passenger AGE incidence rates ranged from 23.2 for the super-mega group to 28.6 for the large group. Similarly, crew AGE incidence rates ranged from 20.0 for the super-mega group to 27.1 for the large group. AGE incidence rate by voyage length (in days) was consistent across all voyage length groups and varied between 26.8 (15-21 days) to 27.8 (11-14 days). Overall, crew AGE incidence rates were lower than passenger AGE rates for all voyage length categories, varying between 23.8 (15-21 days) and 24.9 (6-7 days) for the study period.

Following the AGE report submission, mean passenger AGE incidence rates by the next U.S. port region varied between 27.2 (Southeast Region) and 29.2 (Hawaii Region). For crewmembers, AGE incidence rates ranged from 24.2 (Northeast Region) to 27.5 (Hawaii Region). Following the peak in AGE incidence in 2006-2007, there was a steady decline in AGE incidence per 100,000 travel days for passengers and crew (see Figure 2).

Regression Diagnostic Test Results

An ordinary least squares (OLS) model with passenger attack rates (%) as the dependent variable was specified, and included candidate independent variables fleet size, ship age (in years), space-to-passenger ratio (a proxy for density), passenger-to-crew ratio (a proxy for passenger-crew interactions), gross registered tonnage (ship size), next U.S. port region, and voyage length (in days). Correlation coefficient tests were below 0.5, suggesting the absence of multicollinearity among continuous independent variables. On post-estimation of the variance inflation factor (vif), all continuous independent variables were well below 10. Post-estimation diagnostic testing indicated evidence of heteroskedasticity of standard errors (White's test p <0.0001 and Breusch-Pagan/Cook-Weisberg test p <0.0001). White's test also indicated statistical significance for skewness (p <0.0001) and kurtosis (p =0.0001). Similarly post-estimation diagnostic tests for crew attack rates indicated the variance inflation factor (vif); all continuous independent variables were well below 10. Post-estimation diagnostic testing also indicated evidence of heteroskedasticity of standard errors (White's test p <0.0001 and Breusch-Pagan/Cook-Weisberg test p <0.0001). White's test also indicated statistical significance for skewness (p <0.0001) and kurtosis (p =0.0112). The Shapiro-Wilk W test for normality for passenger and crew attack rates (modeled separately), embarkation year, mean fleet size, ship age, space-to-passenger ratio, passenger-to-crew ratio, and residuals were not normally distributed ($p < 0.00001$). Except for GRT category (t=1.87; p =0.062), all independent variables were statistically significant: embarkation year (t=-13.77; p <0.001), ship age (t=4.11; p <0.001) space-to-passenger ratio (t=-7.84; p<0.001), and passenger-to-crew ratio (t=-4.33; p<0.001), next port region (t=5.59; p<0.001), and voyage length category (t=63.01; p<0.001). Since the diagnostics tests of passenger and crew attack rates indicated the presence of heteroskedastic standard errors, robust standard errors were used for the final regression models.

The Breusch-Pagan LaGrange Multiplier test for random effects indicated that the pooled OLS model was preferred to the random-effects regression model ($X^2(15)$ =1,052; p <0.0001). The Hausman specification test comparing fixed-effects and random-effects models indicated that the fixed-effects model provided a better model fit for the passenger data ($X^2(15)$ =86.32; p <0.0001). The Hausman specifications test results indicated that the fixed-effects model provided the best model fit for passenger and crew attack rates; however, the random-effects model was selected when it was deemed important to evaluate time-invariant independent variables.

Longitudinal Data Analysis

The longitudinal multivariable linear regression model for passenger attack rate (the dependent variable), ship characteristics, and port region following AGE report submission found positive statistical differences for all embarkation years except for 2019 (compared to the 2001 reference year), controlling for fleet size, gross registered tonnage (ship size), ship age, space-to-passenger and passenger-to-crew ratios, next U.S. port, and voyage length. The significance levels corresponded to embarkation years in which shoreside communities reported circulating epidemic and pandemic strains of noroviruses. Fleet size categories, compared to >20 cruise ships (reference), were statistically significant, except for the <6 ships category. The latter was inversely associated with passenger AGE attack rates but not statistically significant (Z=-

0.23; p=0.820). Cruise ship size, as determined by gross registered tonnage categories (reference=extra-large category), was not statistically significant for the extra-small to medium (Z=0.95; p=0.343), large (Z=0.96; p=0.336), or super mega category (Z=-1.89; p=0.058). The mega cruise ship category had statistically significantly lower passenger attack rates (Z=-2.73; p=0.006) than the reference category (extra-large cruise ships). Cruise ship age (in years) was inversely associated with passenger attack rates but was not statistically significant (Z=-1.47; p=0.141). The space-to-passenger ratio had statistically lower passenger attack rates (*Z*=-4.69; p<0.001), controlling for other independent variables. The passenger-to-crew ratio was also inversely associated with passenger attack rates; however, it was not statistically significant (*Z*=-1.25 *p*=0.210). A comparison of the next U.S. port following the AGE report submission to the Southeast region reference category was statistically significant for Caribbean (Z=-4.59; p<0.001); Hawaii (Z=-7.19; p<0.001), Northeast (Z=-5.33; p<0.001) and Northwest (Z=-8.42; p<0.001), with lower passenger AGE attack rates. California (Z=0.89; p=0.0.376) and South (Z=1.79; p=0.074) regions have slightly higher passenger attack rates than to the Southeast region but were not statistically significant. Cruise ships with the next port outside the United States reported slightly higher passenger attack rates than the Southeast region; however, the association was not statistically significant (*Z*=1.70; *p*=0.88). Significantly higher passenger AGE attack rates were observed for voyage length categories 8-10 days (*Z*=6.82; *p*<0.001), 11-14 days (*Z*=10.91, *p*<0.001), and 15-21 days (*Z*=11.25; *p*<0.001), compared to the reference category of 6-7 days. Passenger attack rates were significantly lower for voyages 3-5 days (*Z*=-12.44; *p*<0.001) than for voyages 6-7 days in length. Increasing passenger attack rate patterns appeared to be associated with increasing voyage lengths.

Higher crew AGE attack rates by embarkation year were observed, with significantly higher attack rates between 2002-2007 compared to the 2001 reference year. After 2007, crew attack rates did not vary significantly from 2001; While 2009, 2011, and 2015-2019 featured rates slightly lower than 2001, the differences were not statistically significant. All fleet size categories had lower crew attack rates than the >20 reference category. Cruise ship size (gross registered tonnage categories) all showed lower crew attack rates than the extra-large reference category; however, only the mega category was statistically significant ($Z=-2.21$; $p=0.027$). An inverse association was observed for ship age ($Z=-1.98$; $p=0.047$), with newer cruise ships reporting lower crew attack rates. An inverse association was also observed between the space-to-passenger ratio ($Z=-1.57$; $p=0.117$); however, the association was not statistically significant. A positive association between the passenger-to-crew ratio ($Z=1.63$; $p=0.103$) and crew AGE attack rates indicating greater contact between passengers and crew likely contributed to higher crew AGE attack rates, although the association was not statistically significant. For the next U.S. port following the AGE report submission, crew attack rates were significantly lower for the Caribbean region ($Z=-2.30$; $p=0.022$), Hawaii region ($Z=-4.62$; $p<0.001$), Northeast region ($Z=-4.93$; $p<0.001$) and Northwest region ($Z=-10.13$; $p<0.001$) compared to the Southeast region reference category. Slightly higher crew attack rates were noted for the next U.S. port outside the United States ($Z=0.10$; $p=0.917$) and California region ($t=0.08$; $p=0.938$) but were not statistically significant. As with passenger attack rates by voyage length, crew attack rates increased with longer voyage lengths and were significantly higher for 8-10 days ($Z=5.08$; $p<0.001$), 11-14 days ($Z=12.47$; $p<0.001$), and 15-21 days ($t=15.05$; $p<0.001$) compared to voyages 6-7 days in length. Voyages 3-5 days in length had significantly lower crew attack rates

(*Z*=-9.30; *p*<0.001) than voyages 6-7 days in length. Table 13 summarizes the regression output for the multivariable linear regression models for passengers and crew.

Multivariable binary logistic regression models for voyages reporting AGE elevations and outbreaks for passengers and crew complement the multivariable linear regression analyses described above. These analyses provide critical insights into the patterns observed in voyage-level data and inform VSP's daily operations and policy strategies. The VSP defines an elevation as a voyage or voyage segment reporting ≥ 2.0% AGE cases in either passenger or crew populations, representing the initial action threshold for follow-up and response. An AGE outbreak, defined as a voyage or voyage segment in which reported AGE cases make up ≥ 3.0% of either passenger or crew populations, is VSP's action threshold for conducting onboard outbreak investigations.

The odds of a voyage or voyage segment reaching the elevation or outbreak thresholds within the passenger population were significantly higher during 2002-2013, compared with the 2001 embarkation year and controlling for confounding variables in the model. This period corresponds to the emergence of novel epidemic and pandemic strains of noroviruses in shoreside communities. The highest odds ratios were observed in 2006 (*OR*=5.79; *Z*=4.58; *p*<0.001), 2007 (*OR*=3.82; *Z*=3.77; *p*<0.001), 2008 (*OR*=4.07; *Z*=3.49; p<0.001), 2009 (*OR*=3.52; *Z*=3.06; *p*=0.002); 2010 (*OR*=3.64; *Z*=3.14; *p*=0.002), and 2012 (*OR*=4.04; *Z*=3.35; *p*=0.001). Between 2014 to 2018, the odds ratios were higher than for the 2001 embarkation year; however, they were not statistically significant. In 2019, the odds of a voyage reaching the elevation or outbreak threshold were lower than in 2001, indicating a return to pre-pandemic norovirus AGE levels among passengers. A comparison of fleet size categories to the >20 reference category reported higher odds ratios for the <6 (*OR*=2.63; *Z*=3.44; *p*=0.001), 6-10

(*OR*=2.80; *Z*=4.10; *p*<0.001); 11-15 (*OR*=3.16; *Z*=5.42; *p*<0.001), and 16-20 (*OR*=1.88; *Z*=2.89; *p*=0.004) categories. Ship age represented slightly higher odds of a passenger elevation or outbreak on a voyage or voyage segment (*OR*=1.02, *Z*=2.15; *p*=0.032), controlling for confounders. The space-to-passenger ratio indicated lower odds of an elevation or outbreak voyage; however, it was not statistically significant (*OR*=0.996; *Z*=-1.03; *p*=0.302). The passenger-to-crew ratio had a slightly higher odds ratio, which was not statistically significant (*OR*=1.04; *Z*=0.29; *p*=0.772). Cruise ship size (gross registered tonnage) did not demonstrate a significant pattern in terms of increased odds of reaching the elevation or outbreak threshold for passengers, with no significant difference when GRT categories were compared with the extra-large reference category, controlling for confounders. Except for the Hawaii region (*OR*=0.46; *Z*=-2.43; *p*=0.015) and the next port outside the United States (NUS) (*OR*=10.01; *Z*=6.30; *p*<0.001), the next U.S port did not impact the odds of a passenger elevation or outbreak voyage to a statistically significant level when compared with the Southeast region reference category. The significant odds ratio for the "not in the U.S.," or NUS, category is likely influenced by the small number of voyages within the category, as indicated by the large confidence interval. All voyage length categories had statistically significant odds ratios for passenger elevation or outbreak voyages compared to the 6–7 voyage length reference category. The 3–5-day voyages had significantly lower odds of passenger elevation or outbreak voyages (*OR*=0.22; *Z*=-6.09; *p*<0.001), while higher odds ratios were observed for voyage categories 8-10 (*OR*=2.83; *Z*=7.85; *p*<0.001), 11-14 (*OR*=5.2; *Z*=11.90; *p*<0.001), and 15-21 (*OR*=11.27; *Z*=15.01; *p*<0.001).

Higher crew odds ratios were typically lower across the years of the study than that of passengers, with significant odds of a crew elevation or outbreak voyage associated with 2002 (*OR*=3.99; *Z*=2.77; *p*=0.005) compared to the 2001 reference year. For fleet size categories, higher odds for a crew elevation or outbreak voyage were identified for the <6 fleet size category (*OR*=2.72, *Z*=2.17; *p*=0.30) than for the >20 reference category. There was no statistically significant association with ship age or the space-to-passenger ratio for crew elevation or outbreak voyages. A higher odds ratio was identified for the passenger-to-crew ratio (*OR*=1.21; *Z*=3.17; *p*=0.002) and is likely associated with crew contact with passengers during routine operations. For GRT categories, no statistically significant differences were observed for the odds of crew elevation or outbreak voyages (compared to the extra-large ship size). Overall, small differences were observed for the next U.S. port region compared to the Southeast region. A slightly lower odds for crew elevation or outbreak voyages was observed for the Northeast region (*OR*=0.41, *Z*=-2.03; *p*=0.042), which was statistically significant. For voyage length categories, higher odds for crew elevation or outbreaks were found for 8-10 (*OR*=3.75, *Z*=4.08; *p*<0.001); 11-14 (*OR*=6.70; *Z*=5.89; *p*<0.001) and 15-21 (*OR*=21.43; *Z*=8.34, *p*<0.001) days, compared to the 6-7 day reference category. Table 13 presents the multivariable logistic regression for passengers and crew AGE elevation or outbreak voyages.

Poisson Regression Models

To examine trends in AGE attack rates by embarkation year, Poisson regression models were fitted for passenger and crew AGE cases (the dependent variable) with total passengers and total crew as offsets, respectively (e.g., modeled as AGE attack rates for the respective populations) and embarkation year (the independent variable). The 2001 embarkation year was set as the reference year. Incidence rate ratios for passenger AGE attack rates were higher for all years between 2002-2015. For embarkation years 2016-2019, the incidence rate ratios were similar to the 2001 reference year but were not statistically significant. For passengers, the highest incidence rate ratios occurred in 2006 and 2007 (*IRR*=2.37; *Z*=8.02; p<0.001 and

IRR=2.06; Z=6.07; *p*<0.001, respectively), corresponding to the embarkation years immediately following the peak of AGE outbreaks on cruise ships. For crew members, AGE attack rates were higher than the 2001 reference year for embarkation years 2002-2007 and, except for 2007, were statistically significant. For crew members, the highest incidence rate ratios were observed for 2003 (*IRR*=1.32; *Z*=3.28; p=0.001) and 2006 (*IRR*=1.30; *Z*=3.75; *p*<0.001). During these years, pandemic strains of noroviruses were detected in shoreside and shipboard populations and likely influenced the higher crew attack rates. Between 2008-2019, crew AGE attack rates were lower than 2001, with significantly lower attack rates observed in 2009, 2011-2013, and 2015-2019. Crew member attack rates appear to have decreased more rapidly than passenger attack rates and are likely attributed to greater control by shipboard supervisory staff over crew members than passengers. Table 14 summarizes the Poisson regression models for passengers and crew.

Interrupted Time Series Analysis for Passenger and Crew Populations

The interrupted time series model for passenger AGE incidence rates per 100,000 travel days for all cruise ships (n=305) operating within the United States for all or part of the study period indicated a starting incidence rate of 20.5 and appeared to have increased significantly, by 4.93, prior to the first intervention (*p*<0.001; CI = [2.4936 – 7.3676]). During the first year of the 2005 policy intervention, the passenger AGE incidence rate decreased by 1.97 but was not statistically significant *(p*=0.561; CI = [-9.1087 – 5.1698]). The trend of the passenger AGE incidence rate following the 2005 *VSP Operations Manual* implementation decreased by 6.84 and was statistically significant (*p*<0.001; CI = [-10.3916 - -3.2912]). The postintervention linear trend estimated a 1.91 reduction in AGE incidence rate following implementation of the 2005 *VSP Operations Manual*, which was statistically significant (*p*<0.040; CI=[-3.7177 - -0.1039]).

During the first year of the 2011 policy intervention, the AGE incidence rate increased by 1.79 over the 2005 policy intervention; however, the increase was not statistically significant (*p*=0.524; CI=[-4.1215 – 7.7108]). The trend of the passenger was slightly higher (0.62) compared to the 2005 policy intervention but was not statistically significant (*p*=0.480; CI = -1.2180 – 2.4561]). The postintervention linear trend for the 2011 *VSP Operations Manual* intervention estimated a -1.29 reduction in AGE incidence rates and was statistically significant (*p*<0.001; CI = [-1.5862 - -0.9972]). Table 18 provides the regression table output of the interrupted time series analysis of passenger AGE incidence rates per 100,000 travel days. Figure 5 represents the trends in AGE incidence rates for passengers.

The interrupted time series model for crew AGE incidence rate per 100,000 travel days indicated a starting incidence rate was 27.37, and, prior to the first intervention, increased by 2.02 but was not statistically significant (*p*=0.064; CI = [-0.1355 – 4.1681]). During the first year following the 2005 intervention, the crew incidence rate declined by -1.68, which was not statistically significant (*p*=0.568; CI=[-7.8679 – 4.5110]). The crew AGE incidence rate trend decreased by -4.35, which was significant *(p*=0.002; CI = [-6.7489 - -1.9535]). The postintervention linear trend estimated a significant reduction in AGE incidence rates of -2.33 (*p*<0.001; CI = -3.3926 - -1.2772]).

During the first year of the 2011 policy intervention, the AGE incidence rate for crew increased by 5.21 compared to the 2005 policy intervention, which was not significant (*p*=0.052; -0.0479 – 10.4735]). The trend in AGE incidence increased by 1.20 and was statistically significant (*p*=0.043; CI = [0.0464 – 2.3488]). The postintervention linear trend for the 2011 *VSP Operations Manual* estimated a reduction in AGE incidence rates of -1.14, which was statistically significant (*p*<0.001; CI = [-1.5919 - -0.6828]). Table 19 provides the regression table output of the interrupted time series analysis of crew AGE incidence rates per 100,000 travel days. Figure 6 charts trends in AGE incidence rates for crew members.

The interrupted time series model of the mean passenger AGE attack rates, with a starting level of 0.34%, appears to have increased slightly, by 0.003%, each embarkation year, but the increase was not statistically significant (*p*=0.258; CI = [-0.0022 - 0.008]). During the first year of the first intervention, there was a slight decline in the mean passenger AGE attack rate (-0.0248), but it was not statistically significant (*p*=0.626; CI= [-0.0224 – 0.0748]). The trend in the mean passenger AGE attack rate immediately following the 2005 *VSP Operations Manual* implementation decreased by -0.006% per year, which was not statistically significant (*p*=0.509; CI = [-0.0236 – 0.0117]). The postintervention trend estimated a -0.003% decline in the mean passenger AGE attack rate following the implementation of the 2005 *VSP Operations Manual*, which was not statistically significant (*p*=0.719; CI = [-0.0192 – 0.00132]).

During the first year of the implementation of the 2011 *VSP Operations Manual,* there was a slight increase (0.0007%) in the mean passenger AGE attack rate, which was not statistically significant (*p*=0.986; CI = [-0.0797 – 0.0812]). The trend in the mean passenger AGE attack rate after implementing the 2011 *VSP Operations Manual* decreased by -0.01%; however, the decrease was not statistically significant (*p*=0.274; CI = [-0.0282 – 0.0080]). The postintervention linear trend following the implementation of the 2011 *VSP Operations Manual* indicated a -0.0131% decrease in the mean passenger AGE attack rate, which was statistically significant (*p* <0.001; CI = [-0.200 - -0.0061]). Table 18 is the regression table for cruise ship mean passenger AGE attack rate by embarkation year, displayed graphically in Figure 7.

The interrupted time series model of the mean crew AGE attack rate had an initial level of 0.21% and increased slightly for each embarkation year; however, the increase was not statistically significant (*p*=0.431; CI = [-0.0015 – 0.0035]). Following the initial implementation of the 2005 *VSP Operations Manual*, a slight decrease in mean crew AGE attack rate (-0.006%) was observed but was not significant (*p*=0.609; CI [-0.0299 – 0.01752]). A significant decrease in mean crew AGE attack rates (-0.009%) occurred each year following policy implementation (*p*=0.018; CI [-0.0171 - -0.0016]). During the first year following the implementation of the 2011 *VSP Operations Manual*, the mean crew AGE attack rate increased by 0.0263%, likely due to the presence of circulating pandemic strains of norovirus, but the increase was not statistically significant (*p*=0.062; CI = [-0.0013 – 0.0540]). The trend increased slightly (0.0009%) compared to the 2005 policy intervention, although the increase was not statistically significant (p=0.820; CI = -0.0066 – 0.0084). The postintervention linear trend for the 2011 policy intervention showed a decrease in mean crew AGE attack rates which was statistically significant (p<0.001; CI = -0.0104 - -0.0045). Table 19 presents the full regression for cruise ship mean crew AGE attack rate by embarkation year, displayed visually in Figure 8.

The trend in mean AGE attack rates for passengers and crew demonstrated an overall downward slope in reference to the VSP policy interventions. However, the postintervention linear trends in the decrease in mean AGE attack rates for crew members were significant following both policy interventions. The mean passenger AGE attack rates decreased significantly only after the 2011 *VSP Operations Manual* implementation.

Discussion

Major successes in controlling public health risks on cruise ships involved improving food safety and potable and recreational water systems management. Improved equipment design in food preparation and storage areas allowed better hot and cold-holding practices, reduced cross-contamination potential, and enhanced sanitation practices. In addition, adopting food safety practices, such as prohibiting bare-hand contact with ready-to-eat foods and using time only as a public health control for potentially hazardous foods (PHFs), significantly reduced foodborne illness associated with bacterial enteric pathogens.

Cruise lines also reduced risks dramatically through potable and recreational water systems improvements. Strict equipment maintenance and operation requirements, including audible and visual alarms for proper halogenation throughout the systems, strategic bunkering and production practices, improved filtration systems, periodic bacterial testing to monitor for contamination, and cross-connection control programs, prevented the contamination of potable and recreational water systems with chemicals and pathogenic organisms from non-potable sources.

These enhancements to critical public health systems have been essential in reducing the risks of acute gastroenteritis and other communicable diseases associated with bacterial pathogens. However, viral enteric pathogens have replaced bacterial pathogens as the primary threats to public health, via changes in the cruise ship environment, pathogen characteristics, and travel to port communities with a high prevalence of enteric pathogens.

This study proposed that public health policies and the resulting standard operating procedures (SOPs) developed through the VSP-cruise industry partnership effectively controlled public health risks associated with bacterial and viral enteric pathogens, reducing AGE incidence and outbreaks. This research performed longitudinal data analysis of AGE incidence, and the impact of two VSP-cruise industry public health policy interventions upon that incidence for passenger and crew populations, for cruise ships with voyage embarkation dates between January 1, 2001, and December 31, 2019.

The results indicate a significant overall decline in AGE incidence and outbreaks. Public health policy interventions and improvements in shipboard environmental health and sanitation practices, outlined in the 2005 and 2011 *VSP Operations Manuals,* appear to have been instrumental in this decline, stabilizing AGE incidence rates and outbreaks since 2013-2014. Lessons learned during the study period, general best practices, and new technologies informed these policies, leading to the creation and maintenance of high standards for food safety, potable and recreational water systems management, and overall environmental sanitation, all critical factors for protecting the public health of the traveling public and crew (Centers for Disease Control and Prevention, 2005, p.1; Centers for Disease Control and Prevention, 2011, p.1).

However, declines in AGE incidence and outbreaks should be interpreted with caution, and may be partly due to the absence of pandemic strains of noroviruses after the emergence of GII.4 Sydney in 2012. Novel norovirus strains strongly influence AGE outcomes on passenger cruise ships, as demonstrated in 2002, 2004, 2006, 2009, and 2012, with the emergence of pandemic norovirus strains. Therefore, it will be important to observe cruise ship responses to emerging enteric pathogens in the future and to adjust public health strategies for their control. Nevertheless, robust, evidence-based public health policies, programs and practices should effectively manage enteric disease risks in the future.

The VSP/cruise industry collaboration adopted a multi-pronged disease control approach based on the available science. Outbreak prevention and management are purported to rely on sound infection control principles, including restricting exposure to symptomatic persons, proper hand hygiene, and thorough environmental decontamination with effective cleaning and disinfection protocols (Hall, et al., 2011; Barclay et al., 2014). Therefore, the 2005 and 2011 policy updates included requirements for the exclusion and isolation of symptomatic passengers and crew, improved hand hygiene, written Outbreak Prevention and Response Plans (OPRPs), and environmental disinfection with effective chemical disinfectants.

Hand Hygiene Programs

Effective hand hygiene is essential in interrupting human norovirus transmission (Hall et al., 2011; Escudero-Abraca et al., 2020). However, the efficacy of alcohol-based hand sanitizers was unclear, and thought to depend on product formulation, contact time, and evaluation methods (Hall et al., 2011; Steinmann et al., 2012). Some investigators reported that alcohol-based hand sanitizers showed poor efficacy against non-enveloped viruses, such as noroviruses, indicating that handwashing with soap and water was the preferred intervention to prevent viral transmission (Liu et al., 2010; Tuladhar et al., 2015). During the early years of this study, cruise lines deployed alcohol-based hand sanitizer stations at strategic locations throughout cruise ships, especially during AGE case elevations above normal and outbreaks. Public health messaging on the importance of proper hand hygiene was also delivered, in daily public service content on closed-circuit television systems, announcements by cruise ship leadership, daily shipboard newsletters, and before large gatherings and performances. During periods of elevated AGE cases and outbreaks, cruise ship staff often supplied personal hand sanitizers in passenger staterooms, with an accompanying "pillow letter" describing the importance of hand hygiene in controlling enteric pathogen transmission.

AGE Case Management and Monitoring of Asymptomatic Close Contacts

The 2000 *VSP Operations Manual* did not include guidance for medical case management for reported acute gastroenteritis (AGE) or the monitoring of close contacts (Centers for Disease Control and Prevention, 2000). However, in 2002, noroviruses played a significant role in rising AGE incidence and outbreaks on land and cruise ships (Widdowson et al., 2004). In 2005, the VSP introduced requirements for isolating symptomatic AGE cases and primary contacts of crew and passengers (Centers for Disease Control and Prevention, 2005, pp. 29-30). This section of the *Operations Manual* included guidance on 1) minimum crew isolation periods for food and non-food employees and recommended self-isolation for passengers (crew members who handle food and unwrapped single-use and single service items are isolated for longer periods of time because of a greater risk of transmitted foodborne pathogens, including noroviruses), 2) monitoring immediate close contacts of reported AGE cases, including periodic verbal interviews, 3) provision of hygiene and handwashing fact sheets, and 4) immediate reporting of symptoms of diarrhea or vomiting (Centers for Disease Control and Prevention, 2005, pp. 29-30). The 2011 revision clarified and expanded these requirements, codifying written return-to-work authorizations by medical department personnel, symptom documentation, and indications for verbal interviews of asymptomatic immediate close contacts of reported crew AGE cases. These medical case management requirements are evaluated during each VSP operations inspection. The most recent version of the *VSP Operations Manual* also requires the supervisor to 1) assess food items prepared or served by a symptomatic food employee and take and document appropriate actions (e.g., discard food items handled by the food employee and contact those served food by him or her), and 2) review reported passenger or crew AGE cases following the employee symptom onset to determine if they are epidemiologically related to other AGE cases within a time period of concern (Centers for Disease Control and Prevention, 2018, p. 41).

Enhancements to Cleaning and Disinfection Strategies

Chemical disinfection is an essential intervention in controlling norovirus transmission. Norovirus environmental contamination is extremely difficult to control due to the low infectious dose (Teunis et al., 2008; Teunis et al., 2020), high shedding rate of up to 100 million virus particles per gram of vomitus and stool (Atmar et al., 2008), and environmental stability of the pathogen (Hall et al., 2011; Barclay et al., 2014). Research indicates enhanced cleaning and disinfection strategies, including increased frequency of cleaning and disinfection of frequently touched surfaces with effective chemical disinfectants, is required to prevent or control norovirus transmission (Heijne et al., 2009; Park et al., 2011). In response to rising AGE cases and norovirus outbreaks, the VSP instituted the requirement for continuous cleaning and disinfection of all public areas aboard cruise ships when the cumulative proportion of cases among passengers or crew was ≥2.0% (CDC, 2005, p. 137). Passenger staterooms housing symptomatic AGE cases were cleaned and disinfected last in the housekeeping sequence, or by a separate team of specially trained crew, to prevent cross-contamination between ill and well staterooms. Additionally, the cleaning and disinfection sequence inside all staterooms required cleaning heavily soiled areas last (e.g., bathrooms) or cleaning and disinfecting with separate teams for these areas.

For public vomiting or diarrhea incidents (PVIs/PDIs), most cruise ships deployed specially trained rapid response teams called “Hit Squads,” equipped with appropriate personal protective equipment (PPE) and chemical disinfectant systems, to minimize risk of exposure and reduce transmission of enteric pathogens. Response data and outcomes were documented in a PVI/PDI Log, developed by a cruise line, in case follow-up was required. Additionally, public areas were fogged with hydrogen peroxide-based disinfectants, which is believed to be an appropriate strategy for controlling norovirus contamination (Montazeri et al., 2017).

Before 2009, the primary disinfectant used on cruise ships to control enteric pathogens was chlorine solutions in concentrations between 1,000 and 5,000 parts per million (ppm).

While this substance is effective for hard, non-porous surfaces, it may be corrosive and incompatible with numerous soft, porous surfaces and furnishings found aboard cruise ships, such as colored fabrics. To disinfect these surfaces, cruise ship staff used a variety of chemical disinfectants with active ingredients such as accelerated hydrogen peroxide, quaternary ammonia, and peroxymonosulfate. However, little scientific data was available to advise on the appropriate formulations, surface compatibility, required concentrations, and contact times of these compounds to inactivate human noroviruses or recognized surrogates. The VSP required cruise lines to provide data and information confirming the efficacy of disinfectants against human norovirus or calicivirus surrogates. Some cruise lines collaborated with independent researchers to conduct studies and provide the required information.

In 2009, the U.S. Environmental Protection Agency published *List G: Antimicrobial Products Registered with EPA for Claims Against Norovirus (Feline calicivirus)*, providing users with a list of effective disinfectants against human noroviruses (Environmental Protection Agency [EPA], 2009). The searchable database provides users with important details on listed products, including the EPA registration number, active ingredient(s), product name, company, required contact time, formulation type, and surface types for product application. To be registered and listed as effective against human noroviruses, the product must demonstrate a 4-log reduction of feline calicivirus (FCV) within 10 minutes (EPA, 2018). As of December 7, 2022, the U.S. EPA lists 355 chemical disinfection products for hospitals, institutions, and residential use (EPA, 2022). The publication of *List G* provided a much-needed evidence-based resource that resulted in the standardization of chemical disinfectant use for norovirus control across the cruise industry.

Written Outbreak Prevention and Response Plans (OPRPs)

The VSP required each cruise line to develop written Outbreak Prevention and Response Plans (OPRP) to facilitate industry-wide preparation for eventual AGE elevations and outbreaks. The OPRP was to include standard operating procedures and policies to address increasing reported AGE cases aboard cruise ships. Each plan was required to contain, at a minimum, the following content (Centers for Disease Control and Prevention, 2005, pp. 137-138):

- Response duties and responsibilities for each department and its staff, including establishing an Outbreak Management Team (OMT)
- Steps in outbreak management and control
- A graduated approach based on response triggers in response to increasing reported AGE cases or unexplained increases in reports of public vomiting/diarrhea events, room service requests, meal or excursion cancellations, missed paid events, or other similar reports.
- Disinfectant products or systems used, including surface application, concentrations, and contact times. The disinfectants must demonstrate efficacy against human noroviruses or an acceptable calicivirus surrogate.
- Procedures to protect passengers and crew from exposure to chemical disinfectants, including providing Material Safety Data Sheets (MSDSs), personal protective equipment for the crew, and health and safety procedures to minimize respiratory and dermal exposures to both passengers and crew.
- Procedures for informing passengers and crew of the outbreak, including notification of passengers embarking on the cruise ship on the following voyage or voyage segment after an outbreak voyage.

- Procedures for returning the cruise ship to normal operations following an outbreak (e.g., Turnaround Plan)

During AGE outbreaks, detailed turnaround plans described procedures to minimize exposure between newly embarking passengers and crew members, a plausible risk factor for transmission (Verhoef et al., 2008). Following the introduction of norovirus infection in a closed or semi-closed environment, AGE outbreaks can occur through person-to-person transmission (Lopman et al., 2003). Additionally, the VSP recommended that cruise lines coordinate response efforts with port authorities to ensure all public areas, including terminals and transportation vehicles under their control, were properly cleaned and disinfected according to terminal protocols.

In addition to VSP mandates, cruise lines also instituted specific standard operating procedures (SOPs) geared to their fleet operational requirements. For example, some cruise lines opted to serve meals for the initial days of the voyage while monitoring AGE cases; if relatively few AGE cases are reported, the ship's leaders, in consultation with corporate officials, may authorize the start of self-service buffet operations. The cruise lines also maintain policies on AGE cases identified during the pre-boarding process, whether those self-reported via health questionnaires or obvious through apparent symptoms. Shipboard monitoring of passenger isolation and disembarkation of noncompliant AGE cases were also disease control strategies incorporated in cruise line policies and SOPs.

Federal government oversight of cruise industry operations is crucial in driving improvements in public health aboard passenger cruise ships. Since the establishment of the VSP in 1975, its partnership with the cruise industry has led to the continuous improvement of public health policies that minimize the risk of AGE among passengers and crew. The 2005 and 2011 *VSP Operations Manual* publications provided essential guidance on managing AGE incidence caused by emerging pathogens such as noroviruses, which are the most common cause of AGE outbreaks aboard passenger cruise ships and extremely difficult to control.

With the subsequent publication of the 2018 *VSP Operations Manual* (CDC, 2018) and additional improvements to cruise line standard operating procedures (SOPs), the VSP and cruise industry partners have an opportunity to discern the cumulative effects of these changes on AGE health outcomes in the future. The frequency and magnitude of these health outcomes should become apparent when challenged with emerging enteric pathogens or changes in environmental conditions or circumstances. The VSP should continue monitoring and surveillance activities to evaluate the effectiveness of policy and program interventions and collaborate with cruise industry partners on recommended improvements.

Limitations

Several limitations are observed in this study. First, AGE incidence data was based on syndromic surveillance of reported AGE cases aboard cruise ships. In the absence of laboratory confirmation of the etiologic agent of infection for each AGE case, some unknown proportion of AGE cases may result from noninfectious causes (e.g., seasickness, ear infection in children, or chronic conditions such as irritable bowel syndrome). Furthermore, cruise ships with additional reportable AGE cases after arrival at the first U.S. port are not required to submit an updated report for the remainder of the voyage unless cumulative cases reach the special reporting threshold (≥2.0%). Consequently, reportable AGE cases evaluated in the ship's medical center after arrival in the U.S. are not reported to the VSP if the percentage of reportable cases does not reach the special reporting threshold. Secondly, the VSP does not require an end-of-voyage report of AGE cases, which likely underestimates actual AGE incidence; this differential may vary across demographic. Moreover, this underestimates the number of reported AGE outbreaks, which are defined by a cumulative AGE incidence ≥3.0%. Third, except for those reaching VSP special reporting thresholds, voyages over 15 days are required only to report AGE cases within 15 days before arrival at the first U.S. port. Fourth, reported AGE cases may represent more severe cases requiring medical attention, whereas people without underlying medical conditions or with mild symptoms may choose to wait for symptoms to resolve on their own without medical attention or may take over-the-counter medication purchased shoreside.

In addition, while prior investigations of AGE outbreaks indicate that risk factors likely vary by itinerary type (e.g., repositioning voyage, South American voyage, Panama Canal voyage), this field is not included in VSP's AGE reporting requirements. For example, the second most common etiologic agent identified in cruise ship-associated AGE outbreaks is reported to be enterotoxigenic *E. coli*, frequently associated with ports of call on South American itineraries (Freeland et al., 2016). Exposure to this pathogen has been linked to shore excursions and other shoreside activities at specific ports of call, specifically with the consumption of contaminated drinking water. Consequently, including this field in MIDRS may elicit important information regarding AGE incidence patterns and inform public health policy and risk mitigation strategies, such as robust public health messaging when visiting ports with an elevated risk of enteric pathogen exposure. The ongoing systematic collection, analysis, and interpretation of quantitative data are important for developing and implementing effective public health policies and programs (Jacobs et al., 2012).

Summary

This study examined 19 years of AGE incidence and outbreak data for passenger cruise ships, to determine the impact of the industry's public health policies. The study period began with the change in the reportable AGE case definition, necessitated by increasing norovirus outbreaks, and ended with the CDC-mandated COVID-19 lockdown of the cruise industry. Collaborations between the VSP and cruise industry partners are the cornerstone of public health policy development and shipboard disease prevention and control programs. The interrupted time series analysis (ITSA) study design was innovative in evaluating policy modifications on AGE public health outcomes. A comprehensive understanding of the effectiveness of public health policy interventions and resulting program implementation is vital in responding to changing infectious disease threats, including the emergence of novel strains of noroviruses that spread rapidly in susceptible populations. Timely adjustments in public health policy and procedures may be required to protect the traveling public and crew aboard passenger cruise ships and evaluated periodically to determine their effectiveness following implementation.

Factors postulated to have contributed to the decrease in AGE incidence, as well as the frequency and magnitude of AGE outbreaks, included improvements in shipboard housekeeping and infection control (e.g., continuous cleaning and disinfection, fogging with effective chemical disinfectants, and enhanced housekeeping procedures), improved training for shipboard response personnel regarding their duties and responsibilities, the use of chemical disinfectants registered by the U.S. EPA for noroviruses (EPA, 2009), strict medical case management and monitoring of asymptomatic cabin mates and close immediate contacts, and enhancements to AGE outbreak management and response strategies, including written protocols. At the request of the VSP, the cruise industry began to develop public health messages to inform passengers and crew of elevated AGE case incidence and outbreaks. Frequent and transparent health communications with the traveling public and shoreside communities became integral to risk reduction and outbreak management strategies.

Recommendations for Improved MIDRS Reporting

The VSP and cruise industry partners should consider reviewing the syndromic surveillance system (MIDRS) to determine whether current reporting standards require modification or inclusion of additional data elements necessary for evidence-based policy development. For example, such elements as voyage type may reveal AGE incidence and outbreak risk factors associated with cruise ship location or shoreside activities.

Additionally, this investigator recommends that an end-of-voyage AGE report be the primary requirement for the complete assessment of AGE incidence, possibly replacing the current 24-hour report requirement and eliminating the 4-hour update report requirement. According to the number of AGE reports submitted 2001-2019, dropping the 4-hour reporting requirement would reduce the reporting burden on cruise ship staff by approximately 36%. The 4-hour update report was created to provide the VSP an opportunity to board a cruise ship to conduct a sanitation inspection or outbreak investigation upon reports of significant diarrheal disease or AGE cases. During VSP's early existence, VSP staff were located at or near U.S. maritime ports. However, with the exceptions of the Port of Miami, Florida, and Port Everglades in Fort Lauderdale, Florida, VSP personnel are no longer stationed in port areas and do not respond to AGE cases below the special reporting threshold, until incidence exceeds endemic levels of 3% in passenger or crew populations. Additionally, consideration should be given to removing the 15-day reporting option, since it leads to biased case ascertainment between routine and special reporting requirements, and codifying the special reporting requirements, as they are not currently a part of the federal foreign quarantine regulations. However, the investigator does not recommend including numerical thresholds in the federal rules, allowing flexibility to modify current thresholds based on evolving evidence. Any changes in reporting requirements will require modification of the foreign quarantine regulations through a “notice of proposed rulemaking” process (42 CFR Part 71).

As the VSP continues to move towards evidence-based public health, these recommended modifications to its syndromic surveillance system should help to fulfill its mission. In principle, evidence-based public health leverages the systematic use of data and information systems, program-planning frameworks, and community inputs to develop policies and programs based on the best available scientific evidence (Brownson et al., 2009). The unique operations of cruise ships requires evidence specific to this environment and the risks associated with cruise ship travel. While MIDRS was developed for public health action, it could offer a more robust system, for information dissemination and sharing with cruise industry partners and international public health authorities, through professional publications and reports.

The evidence-based decision-making process within the cruise industry should integrate the best available research evidence, public health expertise, other related resources, and the characteristics, needs, values, and preferences of those affected by the programs and interventions (Jacobs et al., 2012). Some public health decisions will be influenced by the cruise ship environment and organizational context. While risk factors associated with enteric diseases are similar across settings, maritime operations present unique characteristics and require special considerations when developing public health policy. Additionally, exposure periods for the traveling public and crew members are usually shorter than in shoreside environments but longer than that of other forms of transportation, such as air travel.

Finally, the VSP should fully consider cruise industry partner concerns regarding implementing evidence-based public health policies and programs. Glanz and Bishop (2010) state that public health interventions are most likely effective when they include an ecological perspective. Figure 9, a model by Satterfield and colleagues (2009), describes the domains that influence evidence-based decision-making. The social-ecological model broadly conceptualizes health and provides a framework that considers relevant intrapersonal characteristics of individuals and their interactions (interpersonal) within the broader context of their social, organizational, and physical environments (Fielding et al., 2010; National Institutes of Health [NIH], 2011).

When developing maritime public health policy, the VSP-cruise industry collaboration should consider the elements of this model, as it will provide a more complete discussion on the need for evidence-based public health policies and programs. Engaging industry partners and stakeholders in assessment and decision-making, the systematic use of data and information systems, utilizing the best peer-reviewed quantitative and qualitative evidence, applying a program planning framework that is frequently based on health behavior theory, and conducting sound policy and program evaluations are key elements of evidence-based public health (Jacobs et al., 2012). This framework suggests that cruise industry public health interventions and programs focus not just on the individuals at risk of enteric diseases on cruise ships but also on the interpersonal, organizational, and environmental factors that influence the health behaviors of passengers and crew (Glanz & Bishop, 2010). Understanding the interrelationship between these factors is important in shaping public health strategies, including public health messaging, for influencing positive health behaviors for shipboard populations. Therefore, a supportive shipboard environment conducive to health-promoting behaviors, such as frequent handwashing and avoiding risky behaviors while ashore, are essential in mitigating public health risks in the cruise ship and shoreside environments. Given population interactions with public health systems and their influence on public health outcomes, these principles should also be properly considered in cruise ship planning, design, and construction.

Table 9: Acute Gastroenteritis Mean Incidence Rate Per 100,000 Travel Days for Passengers and Crew by Selected Cruise Ship and Voyage Characteristics, Maritime Illness Database and Reporting System, 2001-2019 (N=74,047)

Characteristic	AGE reports n, (%)	Mean Incidence Rate per 100,000 Travel Days	
		Passenger Rate (sd)	Crew Rate (sd)
Gross Registered Tonnage (GRT)			
Extra small to medium (≤30,000)	2,394 (3.2)	28.0 (6.5)	25.9 (6.0)
Large (30,001-60,000)	7,763 (10.5)	28.6 (7.0)	27.1 (5.7)
Extra-large (60,001-120,000)	52,975 (71.5)	27.8 (6.4)	24.8 (5.5)
Mega (120,001-140,000)	6,899 (9.3)	25.4 (5.9)	22.4 (5.4)
Super mega (≥140,001)	4,016 (5.4)	23.2 (4.7)	20.0 (4.0)
Voyage Length (days)			
3-5	2,688 (36.0)	27.1 (6.4)	24.2 (5.5)
6-7	34,258 (46.3)	27.6 (6.4)	24.9 (5.7)
8-10	6,888 (9.3)	27.5 (6.6)	24.4 (5.8)
11-14	4,182 (5.7)	27.8 (6.6)	24.7 (5.8)
15-21	2,031 (2.7)	26.8 (6.4)	23.8 (5.6)
Reporting Region (next U.S. port)*			

Characteristic	AGE reports n, (%)	Mean Incidence Rate per 100,000 Travel Days	
		Passenger Rate (sd)	Crew Rate (sd)
California	8,111 (11.0)	28.1 (6.7)	25.0 (5.7)
Caribbean Islands	5,068 (6.8)	27.8 (6.5)	25.7 (5.6)
Hawaiian Islands	573 (0.8)	29.2 (5.1)	27.5 (5.7)
Northeastern	7,098 (9.6)	27.3 (6.4)	24.2 (5.6)
Northwestern	7,189 (9.7)	27.5 (6.6)	24.6 (5.7)
Southern	7,004 (9.5)	27.3 (6.4)	24.3 (5.9)
Southeastern	38,855 (52.5)	27.2 (6.4)	24.3 (5.6)
Not in the United States (NUS)	149 (0.2)	29.9 (5.7)	30.6 (3.2)

Note. Gross Registered Tonnage (GRT) is the maritime industry standard for ship size. * Northwest (WA, OR, AK): ADK, AKU, ANC, AOR, ATT, BAK, BWA, COR, DHA, EFC, FHW, GLB, HAK, HNS, HOM, IAK, JNU, KIS, KOD, KTN, MET, NOM, PAN, POR, PTB, SEA, SGY, SIT, SWD, VDZ, WAI, WRG, WTR, YAK; Hawaiian Islands, Guam, American Samoa, Saipan: GUA, HIL, HNL, KAH, KAU, KON, LAH, MAU, PAS, SAI, SAM; California: ACA, CAT, LAX, LBC, MCA, SAC, SBC, SDC, SFO, SPC; South (all ports on Gulf of Mexico, excluding FL): BRT, CCT, FTP, FTX, GAL, GMS, HOU, MAL, NOL, PAT, PIT; Northeast (all states north of and including NC): ABN, AMD, ANY, AVA, BAL, BAR, BAT, BNJ, BNY, BOO, BOS, BUF, CHI, CLY, CMA, CME, COH, DET, DMN, EME, ERI, GMA, GNY, HOL, JOL, KNY, MAC, MAR, MCI, MIL, MVY, NOR, NRI, NYC, OGS, OMA, OSW, PEJ, PHL, PHM, PME, PNH, PNY, PRI, PVM, RCK, RHI, RNY, SMA, SMI, STP, SYN, TCM, TNY, TRA, WDE, WNC, WPN, WRI, WVA, WYN, YRK; Southeast (all ports in FL, GA, and SC): CHA, JAX, KWE, MAN, MIA, NPF, PBF, PCF, PEN, PEV, SAV, SFL, SPF, TAM, VBF, WPB; Caribbean Islands: FPR, ISC, MAY, NYA, PPR, SJO, SJU, STC, STT.

Table 10: Acute Gastroenteritis Among Passengers on Cruise Ships, Maritime Illness Database and Reporting System, Vessel Sanitation Program, 2001-2019

Characteristic	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Number of voyages	2,958	3,539	3,842	4,114	3,229	3,508	4,113	3,892	3,782	3,943	3,970	3,917	3,802	4,248	4,094	3,932	4,185	4,449	4,530
Total cases	6,190	13,562	15,911	18,702	15,423	22,310	22,382	18,731	15,223	19,962	17,797	20,326	16,373	19,163	17,771	16,523	15,573	15,592	15,923
Background cases	6,063	11,410	14,160	16,390	13,801	18,157	19,333	16,599	13,391	17,089	16,059	16,971	14,365	17,023	16,302	15,305	14,446	15,039	15,109
AGE outbreak cases	127	2,152	1,751	2,312	1,622	4,153	3,049	2,132	1,832	2,873	1,738	3,355	2,008	2,140	1,469	1,218	1,107	553	814
Number of AGE outbreaks	2	19	20	27	17	39	29	21	19	20	16	27	18	15	14	13	11	9	8
Mean AGE outbreak size	63.5	113.3	87.6	85.6	95.4	106.5	105.1	101.5	96.4	143.7	108.6	124.3	111.6	142.7	104.9	93.7	100.6	61.4	101.8
AGE outbreak rate*	0.68	5.37	5.21	6.56	5.26	11.12	7.05	5.40	5.02	5.07	4.03	6.89	4.73	3.53	3.42	3.31	2.63	2.02	1.77
AGE incidence rate**																			

Year																		
2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
17.2	29.8	31.6	33.0	32.9	42.7	36.9	31.9	26.0	30.5	26.5	29.9	24.4	26.0	24.3	22.8	20.0	18.6	18.5

Note. * Acute gastroenteritis outbreak rate per 1,000 voyages. ** Acute gastroenteritis incidence rate per 100,000 travel days.

Table 11: Acute Gastroenteritis Among Crewmembers on Cruise Ships, Maritime Illness Database and Reporting System, Vessel Sanitation Program, 2001-2019

	Year																		
	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Characteristic																			
Number of voyages																			
	2,958	3,539	3,842	4,114	3,229	3,508	4,113	3,892	3,782	3,943	3,970	3,917	3,802	4,248	4,094	3,932	4,185	4,449	4,530
Total crew cases																			
	3,733	5,826	6,830	7,330	6,260	7,091	6,982	5,791	5,220	6,142	5,949	6,149	5,946	7,130	5,799	5,439	5,170	5,049	4,855
Background cases																			
	3,689	5,633	6,578	7,126	6,135	6,857	6,913	5,760	5,145	6,070	5,920	6,082	5,924	6,969	5,790	5,428	5,170	5,030	4,820
AGE outbreak cases																			
	44	193	252	204	125	234	69	31	75	72	29	67	22	161	9	11	0	19	35
Number of AGE outbreaks																			
	1	8	9	6	4	4	3	2	3	3	1	1	1	4	1	1	0	1	1

	Year																		
	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Characteristic																			
Mean AGE outbreak size																			
	44.0	24.1	28.0	34.0	31.3	58.5	23.0	15.5	25.0	24.0	29.0	67.0	22.0	40.3	9.0	11.0	0.0	19.0	35.0
AGE outbreak rate*																			
	0.34	2.26	2.34	1.46	1.24	1.14	0.73	0.51	0.79	0.76	0.25	0.26	0.26	0.94	0.24	0.25	0.00	0.22	0.22
AGE incidence rate**																			
	25.4	31.6	32.9	31.7	33.0	33.8	28.9	24.8	22.8	24.1	22.8	23.4	23.0	25.1	20.8	19.8	17.6	16.1	15.1

Note. * Acute gastroenteritis (AGE) outbreak rate per 1,000 voyages. ** Acute gastroenteritis (AGE) incidence rate per 100,000 travel days.

Table 12: Number and Rate of Acute Gastroenteritis Outbreaks* per 1,000 Voyages Among Passengers and Crew by Cruise Ship Size, Voyage Length and Regional Port of Arrival – Maritime Illness Database and Reporting System, Vessel Sanitation Program, 2001-

		Passengers		Crew	
Characteristic	Number of voyages	n	Rate per 1,000	n	Rate per 1,000
GRT category					
Extra small to medium (≤30,000)	2,394	20	8.4	7	2.9
Large (30,001 – 60,000)	7,763	83	10.7	21	2.7

Extra-large (60,001 – 120,000)	52,975	217	4.1	24	0.5
Mega (120,001 – 140,000)	6.899	14	2.0	1	0.1
Super mega (≥140,001)	4,016	10	2.5	1	0.2
Voyage length (days)					
3-5	26,688	18	0.7	13	0.5
6-7	34,258	95	2.8	12	0.4
8-10	6,888	64	9.3	7	1.0
11-14	4,182	80	19.1	9	2.2
15-21	2,031	87	42.8	13	6.4
Regional port of arrival/disembarkation**					
California	8,111	67	8.3	9	1.1
Caribbean Islands	5,068	18	3.6	1	0.2
Hawaiian Islands	573	4	7.0	0	0.0
Northeast	7,098	44	6.2	2	0.3
Northwest	7,189	38	5.3	6	0.8
South	7,004	15	2.1	8	1.1
Southeast	38,855	149	3.8	28	0.7

Not in the U.S. (NUS)	149	9	60.4	0	0.0

Note. *An acute gastroenteritis (AGE) outbreak is defined as reportable AGE cases ≥3.0 percent in either passengers or crew on a voyage or voyage segment. ** Northwest (WA, OR, AK): ADK, AKU, ANC, AOR, ATT, BAK, BWA, COR, DHA, EFC, FHW, GLB, HAK, HNS, HOM, IAK, JNU, KIS, KOD, KTN, MET, NOM, PAN, POR, PTB, SEA, SGY, SIT, SWD, VDZ, WAI, WRG, WTR, YAK; Hawaiian Islands, Guam, American Samoa, Saipan: GUA, HIL, HNL, KAH, KAU, KON, LAH, MAU, PAS, SAI, SAM; California: ACA, CAT, LAX, LBC, MCA, SAC, SBC, SDC, SFO, SPC; South (all ports on Gulf of Mexico, excluding FL): BRT, CCT, FTP, FTX, GAL, GMS, HOU, MAL, NOL, PAT, PIT; Northeast (all states north of and including NC): ABN, AMD, ANY, AVA, BAL, BAR, BAT, BNJ, BNY, BOO, BOS, BUF, CHI, CLY, CMA, CME, COH, DET, DMN, EME, ERI, GMA, GNY, HOL, JOL, KNY, MAC, MAR, MCI, MIL, MVY, NOR, NRI, NYC, OGS, OMA, OSW, PEJ, PHL, PHM, PME, PNH, PNY, PRI, PVM, RCK, RHI, RNY, SMA, SMI, STP, SYN, TCM, TNY, TRA, WDE, WNC, WPN, WRI, WVA, WYN, YRK; Southeast (all ports in FL, GA, and SC): CHA, JAX, KWE, MAN, MIA, NPF, PBF, PCF, PEN, PEV, SAV, SFL, SPF, TAM, VBF, WPB; Caribbean Islands: FPR, ISC, MAY, NYA, PPR, SJO, SJU, STC, STT.

Table 13: Multivariable Linear Regression Model for Passenger and Crew Attack Rates and Selected Independent Variables, Maritime Illness Database and Reporting System, Vessel Sanitation Program, 2001-2019.

	Model 1: Passengers				Model 2: Crew			
	Coefficient	*p*-value	95% Confidence Interval		Coefficient	*p*-value	95% Confidence Interval	
Embarkation year (Reference year: 2001)								
2002	0.8523	0.000	0.0563	0.1141	0.0473	0.000	0.0289	0.0657
2003	0.1073	0.000	0.0756	0.1361	0.0589	0.000	0.0320	0.0858
2004	0.1102	0.000	0.0772	0.1432	0.0530	0.000	0.0284	0.0777
2005	0.1063	0.000	0.0703	0.1406	0.0581	0.000	0.0291	0.0872
2006	0.1671	0.000	0.1235	0.2106	0.0626	0.000	0.0367	0.0884
2007	0.1480	0.000	0.1064	0.1895	0.0336	0.005	0.0991	0.0572
2008	0.1180	0.000	0.0763	0.1596	0.0076	0.551	-0.0173	0.0325

	Model 1: Passengers				Model 2: Crew			
	Coefficient	*p*-value	95% Confidence Interval		Coefficient	*p*-value	95% Confidence Interval	
2009	0.0927	0.000	0.0444	0.1410	-0.0043	0.759	-0.0315	0.0230
2010	0.1230	0.000	0.0654	0.1806	0.0076	0.600	-0.0208	0.0359
2011	0.1027	0.000	0.0487	0.1566	0.0023	0.887	-0.0319	0.0272
2012	0.1278	0.000	0.0675	0.1881	0.0027	0.987	-0.0318	0.0324
2013	0.1031	0.001	0.0396	0.1424	0.0065	0.705	-0.0273	0.0404
2014	0.1134	0.001	0.0447	0.1821	0.0165	0.367	-0.0194	0.0525
2015	0.1065	0.004	0.0342	0.1787	-0.0107	0.571	-0.0479	0.0264
2016	0.1028	0.008	0.0272	0.1783	-0.0137	0.489	-0.0526	0.0251
2017	0.0845	0.033	0.0069	0.1648	-0.0266	0.193	-0.0666	0.0134
2018	0.0845	0.048	0.0009	0.1682	-0.0309	0.145	-0.0725	0.0107
2019	0.0835	0.062	-0.0406	0.1710	-0.0360	0.101	-0.0790	0.0070
Fleet size (Reference: >20)								
<6	0.3602	0.338	-0.0377	0.1097	-0.0584	0.004	-0.9084	-0.0184
6-10	0.0366	0.130	-0.0108	0.0841	-0.0951	0.000	-0.1240	-0.0662
11-15	0.0988	0.000	0.0609	0.1368	-0.0492	0.000	-0.0758	-0.0226
16-20	0.0343	0.005	0.0102	0.0584	-0.0559	0.000	-0.0792	-0.0326

	Model 1: Passengers				Model 2: Crew			
	Coefficient	*p*-value	95% Confidence Interval		Coefficient	*p*-value	95% Confidence Interval	
Gross registered tonnage (Reference: Extra-large)								
Extra small to medium	0.0766	0.343	-0.0816	0.2348	-0.0461	0.189	-0.1150	0.0227
Large	0.0383	0.336	-0.0396	0.1162	-0.0026	0.895	-0.0409	0.0357
Mega	-0.0767	0.006	-0.1319	-0.0216	-0.3860	0.027	-0.07278	-0.0044
Super mega	-0.0755	0.058	-0.1537	0.0027	-0.0192	0.376	-0.0617	0.0233
Ship age (in years)								
	-0.0037	0.141	-0.0087	0.0012	-0.0023	0.047	-0.0045	-0.0003
Space-to-passenger ratio								
	-0.0006	0.000	-0.0008	-0.0003	-0.0001	0.117	-0.0003	0.0000
Passenger-to-crew ratio								
	-0.0139	0.210	-0.0357	0.0078	0.0193	0.103	-0.0039	0.0425
Next U.S. port* (Reference: Southeast region)								
Not in the US (NUS)	0.2338	0.088	-0.0350	0.5025	0.0030	0.917	-0.0543	0.0604
California	0.0128	0.376	-0.0155	0.0411	0.0010	0.938	-0.0243	0.0263

	Model 1: Passengers				Model 2: Crew			
	Coefficient	*p*-value	95% Confidence Interval		Coefficient	*p*-value	95% Confidence Interval	
Caribbean	-0.0672	0.000	-0.0959	-0.0385	-0.0300	0.022	-0.0552	-0.0044
Hawaii	-0.2416	0.000	-0.3074	-0.1757	-0.1215	0.000	-0.1730	-0.0700
Northeast	-0.1093	0.000	-0.1495	-0.0691	-0.0525	0.000	-0.0734	-0.0316
Northwest	-0.1600	0.000	-0.1973	-0.1228	-0.0926	0.000	-0.1105	-0.0747
South	0.0233	0.074	-0.0023	0.0489	0.0107	0.464	-0.0179	0.0393
Voyage length (in days) (Reference: 6-7 days)								
3-5	-0.1013	0.000	-0.1172	-0.0849	-0.0818	0.000	-0.0990	-0.0645
8-10	0.0986	0.000	0.0703	0.1270	0.0420	0.000	0.0258	0.0581
11-14	0.2596	0.000	0.2129	0.3062	0.1116	0.000	0.0940	0.0129
15-21	0.5500	0.000	0.4541	0.6459	0.2660	0.000	0.2313	0.3006

Notes. N= 74,047 voyages 3-21 days in length; 305 groups (cruise ships). Results are based on separate passenger and crew random effects models with robust standard errors. Passenger Wald chi-square test (40 d.f.) = 958.51; p<0.0001. Crew Wald chi-square test (40 d.f.) = 850.27; p<0.0001. * Northwest (WA, OR, AK): ADK, AKU, ANC, AOR, ATT, BAK, BWA, COR, DHA, EFC, FHW, GLB, HAK, HNS, HOM, IAK, JNU, KIS, KOD, KTN, MET, NOM, PAN, POR, PTB, SEA, SGY, SIT, SWD, VDZ, WAI, WRG, WTR, YAK; Hawaiian Islands, Guam, American Samoa, Saipan: GUA, HIL, HNL, KAH, KAU, KON, LAH, MAU, PAS, SAI, SAM; California: ACA, CAT, LAX, LBC, MCA, SAC, SBC, SDC, SFO, SPC; South (all ports on Gulf of Mexico, excluding FL): BRT, CCT, FTP, FTX, GAL, GMS, HOU, MAL, NOL, PAT, PIT; Northeast (all states north of and including NC): ABN, AMD, ANY, AVA, BAL, BAR, BAT, BNJ, BNY, BOO, BOS, BUF, CHI, CLY, CMA, CME, COH, DET, DMN, EME, ERI, GMA, GNY, HOL, JOL, KNY, MAC, MAR, MCI, MIL, MVY, NOR, NRI, NYC, OGS, OMA, OSW, PEJ, PHL, PHM, PME, PNH, PNY, PRI, PVM, RCK, RHI, RNY, SMA, SMI, STP, SYN, TCM, TNY, TRA, WDE, WNC, WPN, WRI, WVA, WYN, YRK; Southeast (all ports in FL, GA, and SC): CHA, JAX, KWE, MAN, MIA, NPF, PBF, PCF, PEN, PEV, SAV, SFL, SPF, TAM, VBF, WPB; Caribbean Islands: FPR, ISC, MAY, NYA, PPR, SJO, SJU, STC, STT.

Table 14: Poisson Regression Model of Passenger and Crew Acute Gastroenteritis Attack Rates by Embarkation Year, Maritime Illness Database and Reporting System, Vessel Sanitation Program, 2001-2019.

	Model 1: Passengers				Model 2: Crew			
	IRR**	*p*-value	95% Confidence Interval		IRR**	*p*-value	95% Confidence Interval	
Embarkation year (2001 reference year)								
2002	1.67	0.000	1.4309	1.9607	1.25	0.000	1.1351	1.3773
2003	1.82	0.000	1.5326	2.1557	1.32	0.001	1.1177	1.5535
2004	1.87	0.000	1.5600	2.2524	1.28	0.001	1.1045	1.4854
2005	1.80	0.000	1.4795	2.1924	1.28	0.002	1.0964	1.5050
2006	2.37	0.000	1.9203	2.9288	1.30	0.000	1.1352	1.4977
2007	2.06	0.000	1.6649	2.5384	1.08	0.258	0.9445	1.2374
2008	1.78	0.000	1.4314	2.2036	0.91	0.183	0.7973	1.0442
2009	1.47	0.002	1.1508	1.8692	0.82	0.019	0.6916	0.9671

	Model 1: Passengers				Model 2: Crew			
			95% Confidence				95% Confidence	
	IRR**	*p*-value	Interval		IRR**	*p*-value	Interval	
2010	1.69	0.000	1.3155	2.1793	0.87	0.075	0.7476	1.0140
2011	1.51	0.002	1.1700	1.9461	0.81	0.022	0.6843	0.9703
2012	1.72	0.000	1.3077	2.2517	0.81	0.022	0.6754	0.9694
2013	1.42	0.009	1.0891	1.8425	0.79	0.012	0.6618	0.9508
2014	1.49	0.005	1.1282	1.9564	0.85	0.090	0.7043	1.0258
2015	1.37	0.020	1.0517	1.7896	0.70	0.000	0.5731	0.8506
2016	1.28	0.064	0.9856	1.6663	0.66	0.000	0.5407	0.8104
2017	1.12	0.417	0.8530	1.4673	0.58	0.000	0.4536	0.7297
2018	1.04	0.754	0.7997	1.3616	0.53	0.000	0.4306	0.6612
2019	1.02	0.904	0.7727	1.3386	0.50	0.000	0.4010	0.6133

Notes. * Percentage of reportable acute gastroenteritis cases recorded by the cruise ship medical center for each voyage or voyage segment for passengers or crew. ** Incidence rate ratio. N=74,047 voyages reported from 305 cruise ships.

Table 15: Multivariable Logistic Regression Analysis of Acute Gastroenteritis Elevations and Outbreaks for Passengers and Crew (N=74,047 voyages), Maritime Illness Database and Reporting System, Vessel Sanitation Program, 2001-2019.

	Model 1: Passengers				Model 2: Crew			
	Odds ratio	*p*-value	95% Confidence Interval		Odds Ratio	*p*-value	95% Confidence Interval	
Embarkation year (Reference: 2001)								
2002	3.22	0.003	1.4942	6.9488	3.98	0.006	1.4954	10.5807
2003	3.07	0.004	1.4449	6.5044	2.91	0.068	0.9223	9.1570
2004	3.28	0.004	1.4769	7.2793	1.89	0.289	0.5816	6.1609
2005	2.72	0.010	1.2732	5.8072	1.94	0.237	0.6480	5.7818
2006	5.79	0.000	2.7321	12.2795	1.70	0.394	0.5033	5.7257
2007	3.82	0.000	1.9042	7.6549	0.91	0.859	0.3424	2.4432
2008	4.07	0.000	1.8516	8.9449	1.46	0.529	0.4471	4.7928
2009	3.52	0.002	1.5718	7.8941	0.81	0.754	0.2206	2.9891
2010	3.65	0.002	1.6244	8.1907	1.25	0.724	0.3649	4.2730
2011	3.18	0.005	1.4155	7.1358	0.15	0.085	0.0168	1.300
2012	4.04	0.001	1.7834	9.1409	0.67	0.625	0.1302	3.4023
2013	2.47	0.037	1.0581	5.7551	0.63	0.520	0.1500	2.6082
2014	2.04	0.117	0.8360	4.9844	0.87	0.850	0.2180	3.5084

	Model 1: Passengers				Model 2: Crew			
	Odds ratio	*p*-value	95% Confidence Interval		Odds Ratio	*p*-value	95% Confidence Interval	
2015	2.51	0.032	1.0822	5.8286	0.27	0.145	0.04584	1.5739
2016	2.68	0.023	1.1455	6.2571	0.67	0.572	0.1710	2.6547
2017	1.27	0.629	0.4836	3.3293	0.12	0.057	0.0132	1.0687
2018	1.33	0.536	0.5423	3.2447	0.11	0.054	0.0122	1.0359
2019	0.89	0.823	0.3356	2.3809	0.17	0.103	0.0214	1.4231
Fleet size (Reference: >20)								
<6	2.63	0.001	1.5147	4.5551	2.72	0.030	1.0995	6.7352
6-10	2.80	0.000	1.7129	4.5921	1.01	0.835	0.4446	2.7270
11-15	3.16	0.000	2.0826	4.7845	0.99	0.989	0.4427	2.2333
16-20	1.88	0.004	1.2255	2.8835	0.42	0.044	0.1840	0.97813
Ship age (in years)								
	1.02	0.032	1.0018	1.0403	1.01	0.445	0.9787	1.0503
Space-to-passenger ratio								
	1.00	0.302	0.9874	1.0039	1.00	0.673	0.9921	1.0051
Passenger-to-crew ratio								
	1.04	0.772	0.8045	1.3403	1.21	0.002	1.0759	1.3639

	Model 1: Passengers				Model 2: Crew			
	Odds ratio	*p*-value	95% Confidence Interval		Odds Ratio	*p*-value	95% Confidence Interval	
Gross registered tonnage (GRT) category (Extra-large: reference)								
Extra small								
to medium	0.51	0.063	0.2474	1.0380	0.66	0.433	0.2331	1.8676
Large	1.20	0.338	0.8254	1.7485	1.20	0.573	0.6341	2.2789
Mega	0.68	0.112	0.4062	1.1000	0.46	0.276	0.1109	1.8744
Super mega	0.80	0.492	0.4317	1.4977	1.60	0.551	0.3400	7.5624
Next US port region* (Reference: Southeast region)								
NUS	10.09	0.000	4.9163	20.7020	1.66	0.578	0.2808	9.7431
California	1.00	0.871	0.7355	1.2972	0.85	0.583	0.4756	1.5191
Caribbean	0.81	0.327	0.5306	1.2350	0.37	0.051	0.1347	1.0032
Hawaii	0.46	0.015	0.2413	0.8596	0.26	0.192	0.0344	1.9698
Northeast	0.85	0.339	0.6140	1.1827	0.41	0.042	0.1735	0.970
Northwest	1.13	0.453	0.5184	1.5709	1.00	0.991	0.5395	1.8403
South	1.39	0.209	0.8315	2.3261	1.34	0.429	0.6460	2.7969
Voyage length (days) (Reference: 6-7 days)								
3-5	0.22	0.000	0.1371	0.3610	0.93	0.850	0.4530	1.9207

	Model 1: Passengers				Model 2: Crew			
	Odds ratio	*p*-value	95% Confidence Interval		Odds Ratio	*p*-value	95% Confidence Interval	
8-10	2.83	0.000	2.1838	3.6727	3.75	0.000	1.9879	7.0768
11-14	5.34	0.000	4.0556	7.0433	6.70	0.000	3.5580	12.6346
15-21	11.27	0.000	8.2148	15.4635	21.43	0.000	10.4312	44.0461

Note. An AGE elevation is defined as an attack rate of ≥2.0% and <3.0% in either passenger or crew population. An AGE outbreak is an attack rate of ≥3.0 percent in either passenger or crew population. Passenger Wald chi-square test: (40 d.f.) 903.02; p<0.0001; N=74,047; groups (cruise ships) = 305. Crew Wald chi-square test (37 d.f.): 459.50; p<0.0001; N=74,047; groups (cruise ships) = 305) . * Northwest (WA, OR, AK): ADK, AKU, ANC, AOR, ATT, BAK, BWA, COR, DHA, EFC, FHW, GLB, HAK, HNS, HOM, IAK, JNU, KIS, KOD, KTN, MET, NOM, PAN, POR, PTB, SEA, SGY, SIT, SWD, VDZ, WAI, WRG, WTR, YAK; Hawaiian Islands, Guam, American Samoa, Saipan: GUA, HIL, HNL, KAH, KAU, KON, LAH, MAU, PAS, SAI, SAM; California: ACA, CAT, LAX, LBC, MCA, SAC, SBC, SDC, SFO, SPC; South (all ports on Gulf of Mexico, excluding FL): BRT, CCT, FTP, FTX, GAL, GMS, HOU, MAL, NOL, PAT, PIT; Northeast (all states north of and including NC): ABN, AMD, ANY, AVA, BAL, BAR, BAT, BNJ, BNY, BOO, BOS, BUF, CHI, CLY, CMA, CME, COH, DET, DMN, EME, ERI, GMA, GNY, HOL, JOL, KNY, MAC, MAR, MCI, MIL, MVY, NOR, NRI, NYC, OGS, OMA, OSW, PEJ, PHL, PHM, PME, PNH, PNY, PRI, PVM, RCK, RHI, RNY, SMA, SMI, STP, SYN, TCM, TNY, TRA, WDE, WNC, WPN, WRI, WVA, WYN, YRK; Southeast (all ports in FL, GA, and SC): CHA, JAX, KWE, MAN, MIA, NPF, PBF, PCF, PEN, PEV, SAV, SFL, SPF, TAM, VBF, WPB; Caribbean Islands: FPR, ISC, MAY, NYA, PPR, SJO, SJU, STC, STT.

Table 16: Aggregate Interrupted Time Series Analysis for Passenger Incidence Rates*, All Cruise Ships, Maritime Illness Database and Reporting System, Vessel Sanitation Program, 2001-2019.

Passenger Incidence rate	Coefficient	*p*-value	95% Confidence Interval	
_t	4.93	0.001	2.4936	7.3676
_x2005	-1.97	0.561	-9.1087	5.1698
_x_t2005	-6.84	0.001	-10.3916	-3.2912

Passenger Incidence rate	Coefficient	*p*-value	95% Confidence Interval	
_x2011	1.79	0.524	-4.1215	7.7108
_x_t2011	0.62	0.480	-1.2180	2.4561
_cons	20.51	0.000	16.0601	24.9764

Note: * Acute gastroenteritis (AGE) incidence rate per 100,000 travel days. Regression analysis with Newey-West standard errors lag(3).

Postintervention Linear Trend: 2005

Linear Trend	Coefficient	*p*-value	95% Confidence Interval	
Treated	-1.91	0.040	-3.7177	-0.1039

Postintervention Linear Trend: 2011

Linear Trend	Coefficient	*p*-value	95% Confidence Interval	
Treated	-1.29	0.000	-1.5862	-0.9972

Note. Number of observations = 19.

Table 17: Aggregate Interrupted Time Series Analysis for Crew Acute Gastroenteritis Incidence Rates*, All Cruise Ships, Maritime Illness Database and Reporting System, Vessel Sanitation Program, 2001-2019.

Crew Incidence Rate	Coefficient	*p*-value	95% Confidence Interval	
_t	2.02	0.064	-0.1355	4.1681

Crew Incidence Rate	Coefficient	*p*-value	95% Confidence Interval	
_x2005	-1.68	0.568	-7.8679	4.5110
_x_t2005	-4.35	0.002	-6.7489	-1.9535
_x2011	5.21	0.052	-0.0479	10.4735
_x_t2011	1.20	0.043	0.0464	2.3488
_cons	27.37	0.000	23.0040	31.7282

Note. *Acute gastroenteritis (AGE) incidence rate per 100,000 travel days. Regression with Newey-West standard errors, lag(0).

Postintervention Linear Trend: 2005

Linear Trend	Coefficient	*p*-value	95% Confidence Interval	
Treated	-2.33	0.000	-3.3926	-1.2772

Postintervention Linear Trend: 2011

Linear Trend	Coefficient	*p*-value	95% Confidence Interval	
Treated	-1.14	0.000	-1.5919	-0.6828

Note: Number of observations=19

Table 18: Interrupted Time Series Analysis of Mean Passenger Attack Rates, Maritime Illness Database and Reporting System, Vessel Sanitation Program, 2001-2019.

Mean Attack Rate (%)	Coefficient	*p*-value	95% Confidence Interval	
_t	0.00297	0.258	-0.0022	0.0081
___x2005	-0.0248	0.626	-0.0124	0.0748
_x_t2005	-0.0059	0.509	-0.0236	0.0117
_x2011	0.0007	0.986	-0.0797	0.0812
_x_t2011	-0.0101	0.274	-0.0282	0.0080
_cons	0.3421	0.000	0.2430	0.4412

Postintervention Linear Trend: 2005

Linear Trend	Coefficient	*p*-value	95% Confidence Interval	
Treated	-0.0030	0.719	-0.0192	0.0132

Postintervention Linear Trend: 2005

Linear Trend	Coefficient	*p*-value	95% Confidence Interval	
Treated	-0.0131	0.000	-0.200	-0.0061

Table 19: Interrupted Time Series Analysis of Mean Crew Attack Rates, Maritime Illness Database and Reporting System, Vessel Sanitation Program, 2001-2019

Mean Attack Rate (%)	Coefficient	*p*-value	95% Confidence Interval	
_t	0.0010	0.431	-0.0015	0.0035
_x2005	-0.0062	0.609	-0.0299	0.01752
_x_t2005	-0.0093	0.018	-0.0171	-0.0016
_x2011	0.0263	0.062	-0.0013	0.0540
_x_t2011	0.0009	0.820	-0.0066	0.0084
_cons	0.2135	0.000	0.1859	0.2411

Postintervention Linear Trend: 2005

Linear Trend	Coefficient	*p*-value	95% Confidence Interval	
Treated	-0.0083	0.020	-0.0153	-0.0013

Postintervention Linear Trend: 2011

Linear Trend	Coefficient	*p*-value	95% Confidence Interval	
Treated	-0.0074	0.000	-0.0104	-0.0045

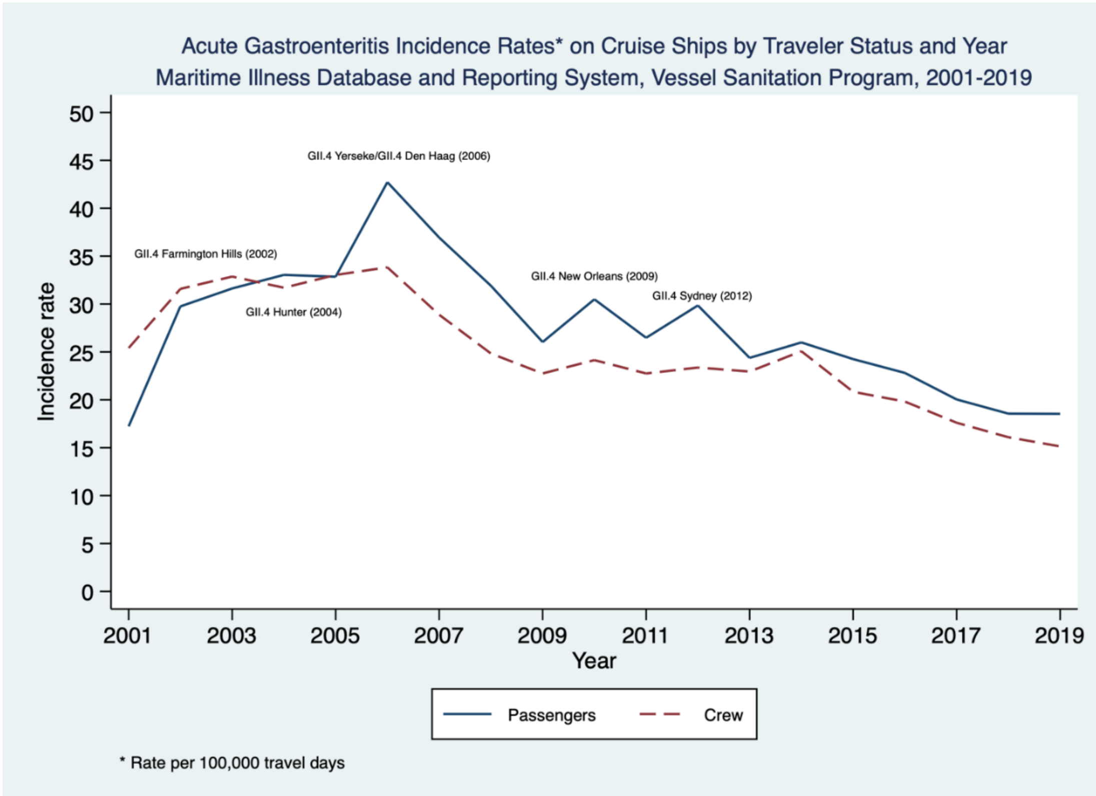

Figure 2: Acute Gastroenteritis Incidence Rate by Status and Year

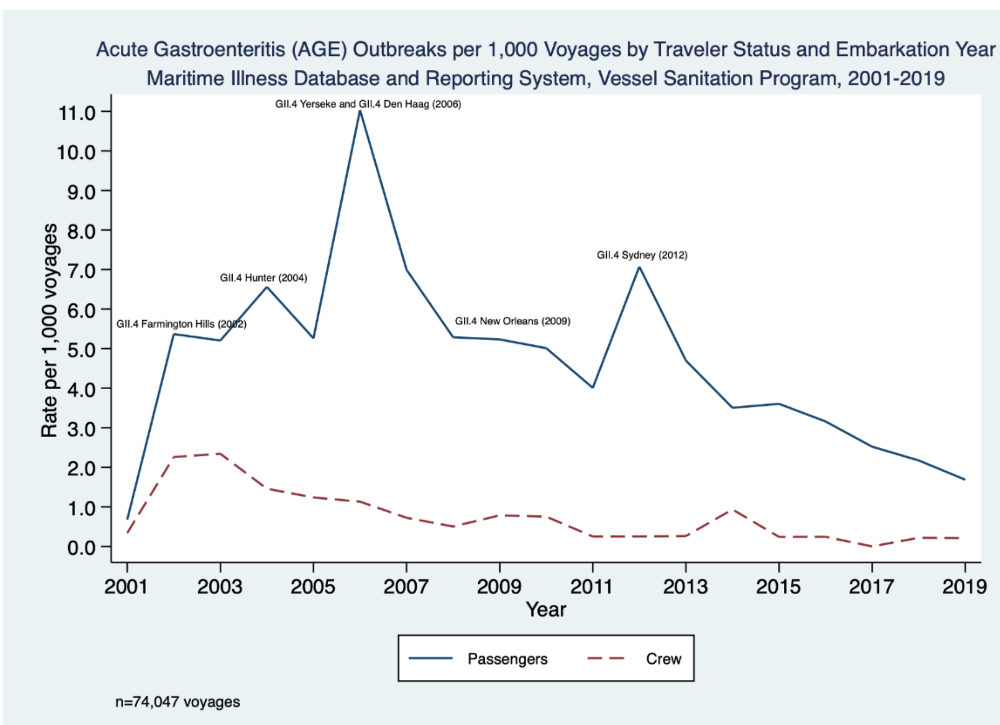

Figure 3: Acute Gastroenteritis Outbreaks Per 1,000 Voyages

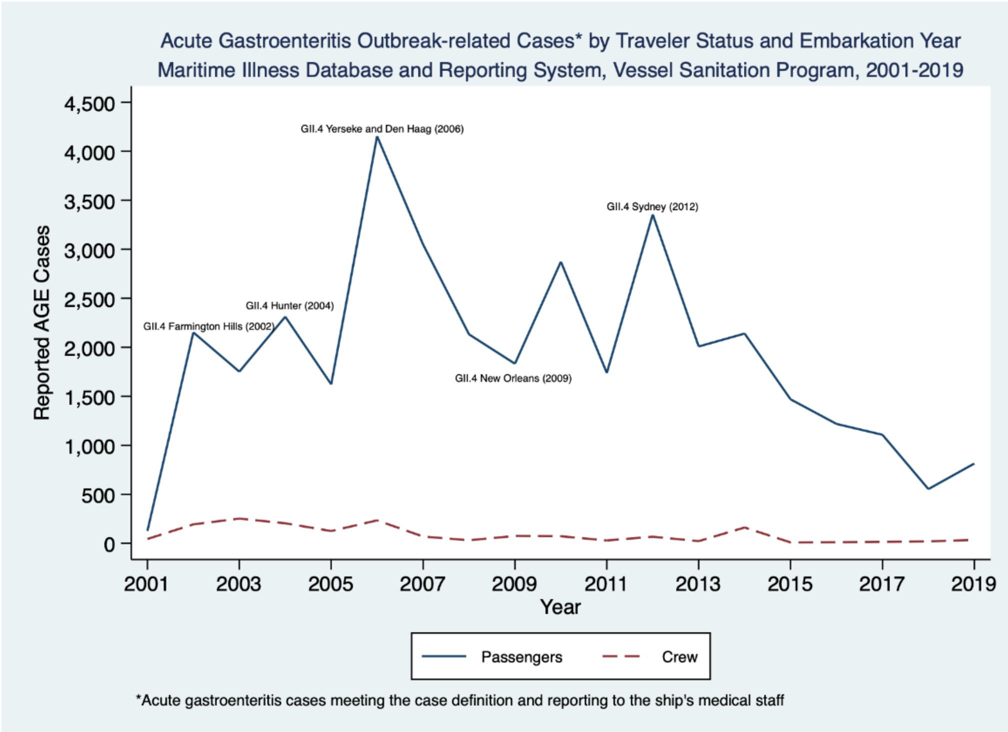

Figure 4: Acute Gastroenteritis Outbreak-related Cases by Traveler Status and Embarkation Year

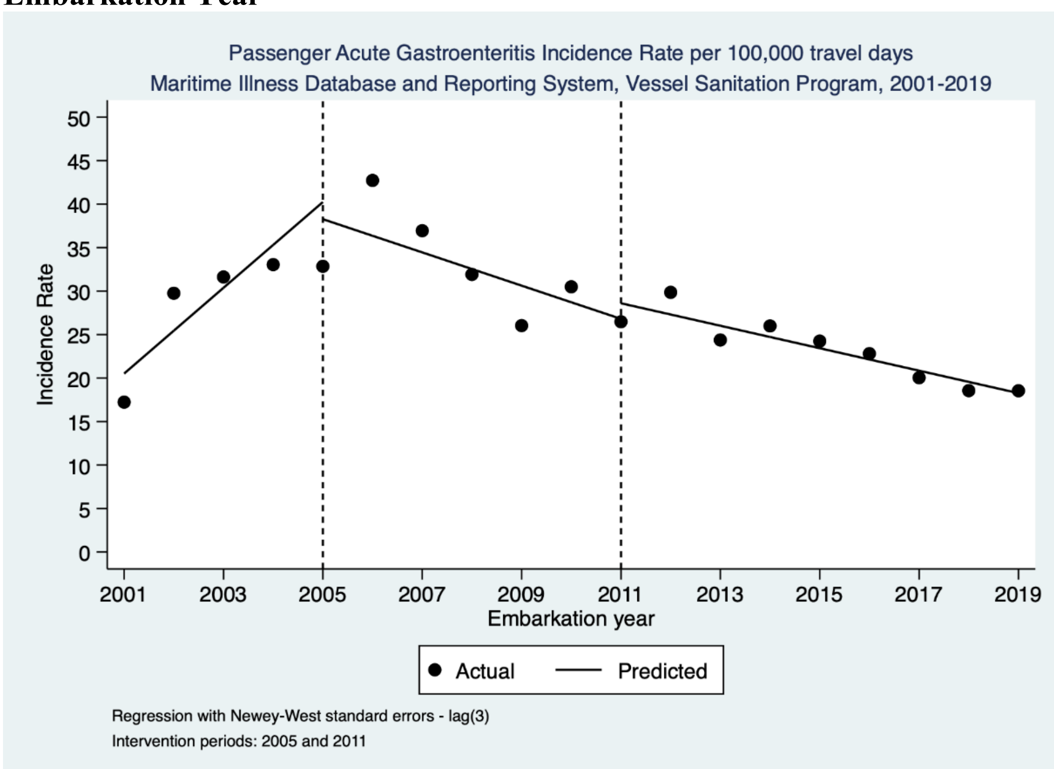

Figure 5: Passenger Acute Gastroenteritis Incidence Rate per 100,000 travel days

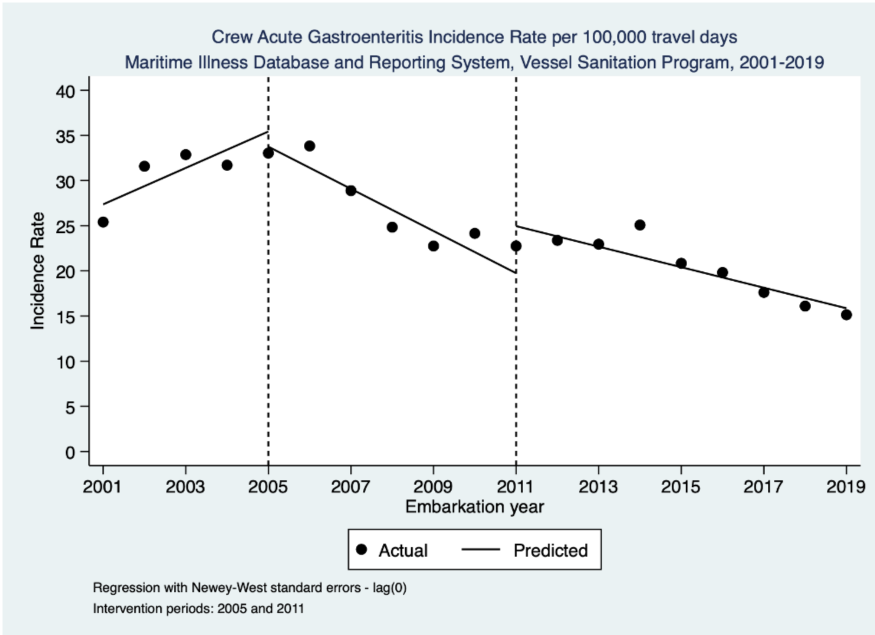

Figure 6: Crew Acute Gastroenteritis Incidence Rate per 100,000 *T*ravel *D*ays

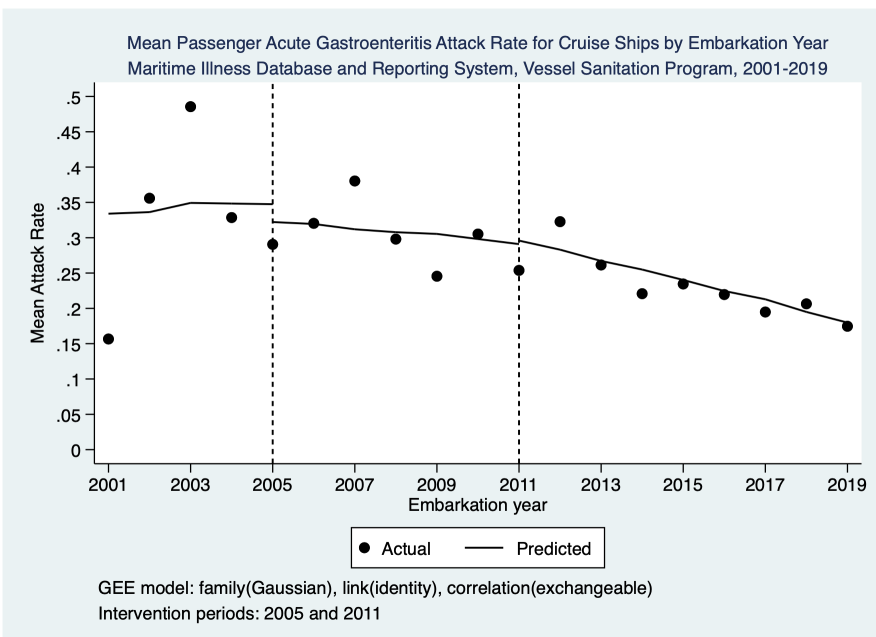

Figure 7: Mean Passenger Acute Gastroenteritis Attack Rate

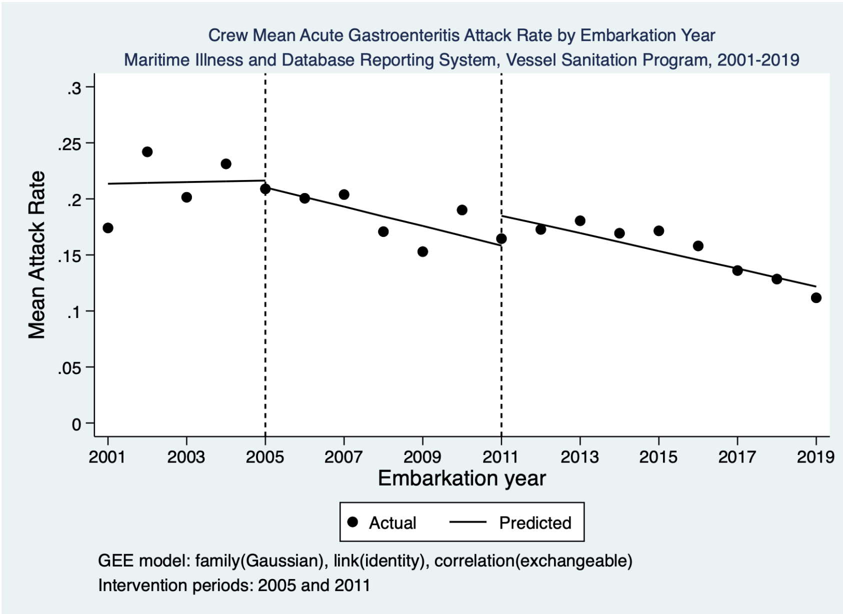

Figure 8: Mean Crew Acute Gastroenteritis Attack Rate

Figure 9: Domains Influencing Evidence-Based Health Decisionmaking

Note. Adapted from: Toward a transdisciplinary model of evidence-based practice. Satterfield, J. M., Spring, B., Brownson, R. C., Mullen, E. J., Newhouse, R. P., Walker, B. B., & Whitlock, E. P. (2009). *The Milbank Quarterly*, *87*(2), 368-390.

CHAPTER 5: DISCUSSION AND CONCLUSION

During the study period, the VSP and cruise industry partners continually updated strategies for risk mitigation of enteric pathogens, including those transmitted through person-to-person spread. Each revision of the *VSP Operations Manual* introduced new requirements, reflecting scientific research that identified improved methods for food and (potable and recreational) water protection, disinfection (in particular, technological advancements in the efficient and safe application of disinfectants, including fogging), the strategic placement of passenger handwashing stations at buffets and self-service food outlets, and public health messaging to encourage health-protective behaviors among passengers and crew.

A high level of cruise ship compliance with public health requirements continued throughout the study, with median operations inspection scores consistently in the upper 90s. Moreover, the requirement for written Outbreak Prevention and Response Plans (OPRPs), and subsequent refinements based on internal risk assessments and lessons learned, contributed to better public health outcomes, through 1) improved guidance on crew member outbreak response roles and responsibilities, 2) expanded housekeeping and infection control strategies, including targeted cleaning and disinfectant protocols for noroviruses, and 3) strict medical case management with monitoring of close contacts of crew AGE cases. The results of this study demonstrate that overall AGE outbreak voyages decreased over time (for voyages 3-21 days long), from a peak of 39 in 2006 to eight in 2019; further, this drop may be attributed, in part, to improved AGE outbreak prevention and response policies, procedures, and practices.

During the study period, the cruise industry used new construction and renovations as opportunities to install plumbed handwashing stations in strategic areas, such as buffets. The

2018 *VSP Operations Manual* mandated this hand hygiene intervention for all cruise ships with keel laid dates (i.e., the date on which the foundational steel beam, or keel, is installed, signaling the start of the ship-building process) of June 1, 2018 or later, requiring one handwashing station (per 100-passenger seating) at each entry to the main buffet areas and self-service stations (CDC, 2018, p. 146). Additionally, better health messaging provided a greater awareness of the need for frequent hand hygiene among passengers and crew, both onboard and during shore excursions. Hand sanitizer stations with formulations effective against common shipboard pathogens placed throughout public areas presented an alternative, albeit less effective, way to sanitize hands, thereby reducing pathogen transfer among passengers, crew, and environmental surfaces. Additionally, all passengers and crew ashore at ports of call were advised to use alcohol-based hand sanitizers when handwashing with soap and water was unavailable.

During the norovirus pandemics of the 2000s, the cruise industry sought assistance from the scientific community to ascertain the most effective chemical disinfectants (other than high-concentration chlorine solutions) against human noroviruses and other enteric pathogens. These chemical disinfectants were required to be compatible with various hard (non-porous) and soft (porous) surfaces (e.g., soft furnishings) most likely to be contaminated with noroviruses. The VSP requires cruise ship operators to use chemical disinfectants with demonstrated efficacy against human norovirus or a recognized surrogate, such as feline calicivirus (FCV) or murine norovirus (MNV). In 2009, the U.S. EPA published *List G: EPA's Registered Antimicrobial Products Effective Against Norovirus* (EPA, 2009), which lists all antimicrobial products with demonstrated efficacy against human noroviruses and is the primary resource for the selection of chemical disinfectants. Moreover, strategically placing chemical disinfectant wipes in public areas such as game tables, libraries, casinos, and lounges encourages passenger involvement in reducing the environmental burden and potential exposure to infectious disease pathogens.

Although AGE incidence and outbreaks have decreased substantially over the study period, preventable AGE outbreaks continue. The VSP must continue active monitoring of AGE incidence and, with the cooperation of cruise industry partners, revise policies and procedures based on evidence to provide maximum protection for passengers, crew, and the populations of receiving shoreside communities. Critical factors that may influence communicable disease transmission aboard cruise ships include the prevalence of communicable diseases at home ports and receiving ports of call, the mode of transmission of pathogens, the design and construction of cruise ships, the medical and public health support on cruise ships, characteristics of cruise ship tourism aboard ship and at receiving ports, and constant public health messaging to passengers and crew (Li et al., 2021). Future policy and program interventions should include reviewing these aspects of communicable diseases on cruise ships to reduce public health risks and ameliorate adverse public health outcomes.

Recommendations for Future Research

During the early 2000s, industry-wide trends of building larger cruise ships with more advanced public health systems, diverse onboard activities, and unique itinerary offerings to new ports of call may have resulted in unintended consequences, including increased enteric disease risks. The impact of these enteric disease threats may go unrecognized without a robust surveillance system and a focused, evidence-based research program that informs public health policy development, program evaluation, and standard operating procedures and practices.

Since 1975, the VSP has conducted syndromic surveillance of enteric diseases aboard passenger cruise ships; this surveillance initiates response actions, including environmental sanitation inspections and AGE outbreaks investigations. While the reporting methods have changed, the required data elements have not been updated to reflect the changing landscape of the cruise industry or the operations of the VSP. During their early years of operation, VSP staffed teams at or near port cities, from which they could conduct sanitation inspections or outbreaks investigation in response to reported cases of enteric disease based on 24-hour and 4-hour update reports. However, apart from major cruise ports in south Florida, VSP staff are no longer stationed in port cities.

Moreover, responses to enteric disease reports are limited to those in which AGE cases reach the 2% and/or 3% thresholds in either passenger or crew subpopulations. In addition, routine reports, which do not cover the entire voyage, may miss reportable cases. This potential underreporting is particularly evident on voyages in which cruise ships enter the United States from a foreign port early in the itinerary and make port calls at domestic port cities for the remainder. Given current VSP operations and logistics, it is recommended that VSP consider instituting an end-of-voyage report (or segment report for longer voyages) to replace the 24-hour and 4-hour update reporting requirements. Additionally, the VSP should consider removing the 15-day requirement (possibly created based on the incubation period and duration of illness for bacterial enteric pathogens and hepatitis A) and include all reportable AGE cases for the entire voyage or voyage segment.

Further, the special reporting requirements currently outlined in the *VSP Operations Manuals* should be codified and authorized within federal foreign quarantine regulations (42 CFR Part 71). However, such language should exclude specific thresholds (such as 2% and 3% reporting) to ease the process of modifying these requirements based on emerging research, though the *VSP Operations Manual* should publish these thresholds with each revision. These modifications could lead to improved AGE reporting, decreased reporting burdens for cruise ship medical staff, reduced odds for lost points on operations inspections due to errors in MIDRS reporting, and improved data quality for VSP research and data-driven policy development.

The VSP and cruise industry partners should also consider reviewing the current MIDRS reporting requirements and make necessary adjustments and additions to allow for improved disease risk assessment associated with different itineraries. Though AGE outbreak investigation reports have determined that certain etiologic agents cause elevations in AGE incidence in select geographic areas and appear to be associated with specific shore excursions, no current data element describes the type of itinerary that may be linked to these risk factors.

Additionally, the VSP should augment the MIDRS dataset with additional information regarding support at the corporate and cruise ship level, to determine its effect on reducing AGE incidence and outbreaks and promoting other public health outcomes of interest. For example, larger cruise lines tend to have more resources available to support fleet assets, including more corporate-level public health staff, the use of independent public health consultants, assigned shipboard sanitation officers, and standard operating procedures that determine the frequency of internal public health inspections and mandated corrective actions, which likely to lead to better operations inspection and public health outcomes. However, this investigator is aware of no systematic evaluation of the contribution of public health support functions. Such a study would require specific data elements collected through surveys administered to corporate medical and public health leadership or during operations inspections, such as the frequency of internal inspections, the number of public health support staff at corporate and ship levels, budgets dedicated to public health projects and programs, and the use of independent public health consultants in support of public health. These data could be maintained with inspection data in the VSPIRS and leveraged in future research projects.

The VSP should continue to monitor enteric disease trends through the MIDRS syndromic surveillance system, as pathogen threats will continue aboard passenger cruise ships. Etiologic agents such as noroviruses will continue to evolve and infect naive populations, causing serious health outcomes for some highly susceptible people in the traveling populations. Consequently, it continues to be important to periodically evaluate whether public health interventions are effective in minimizing disease risks. Employing evidence-based approaches to public health prevention can help garner cruise industry consensus on future proposed changes to policy, programs, and practices.

Additionally, etiologic agents and associated risk factors implicated in AGE outbreaks should be assessed separately from overall AGE incidence and trends. Rapid data and information collection are necessary to terminate the outbreak and foster transparency in outbreak reporting. VSP's historical effort to capture AGE outbreak data to better understand dynamics and improve tracking and reporting included the design of the EpiModule Project, a platform to support VSP staff in collecting, analyzing, and disseminating AGE outbreak data and information to organizations with a need-to-know. However, the project remains incomplete due to technical and data collection issues; this investigator maintains its importance to managing AGE outbreaks and associated data, generating hypotheses, and guiding future research efforts. Meanwhile, data alignment and compatibility with the Acute Gastroenteritis Surveillance Log ("AGE Log") required for each voyage or voyage segment or with shipboard electronic medical record systems will be required for efficient data capture. Cruise industry support and compliance will require full system integration; however, the resulting collaboration can benefit both VSP and its cruise industry partners.

These findings also suggest the need for a review of the error-checking capabilities for MIDRS. Several cruise ships reported voyage lengths of one day. While some cruise ships, such as international ferries, have such short itineraries, others that typically sail on longer voyages (e.g., 7 days) listed one-day voyages, likely due to reporting errors confusing embarkation, disembarkation, and next-port dates. Additionally, some reports were submitted on or before the embarkation date; since these discrepancies could not be resolved, these data were lost to the study. While VSP conducts spot checks of recent voyage reports, detecting these data entry errors would be difficult without a periodic database review. A MIDRS report can be recalled within 96 hours of submission if the submitter realizes it includes errors (CDC, 2018b). After 96 hours, corrected MIDRS reports can be entered by the VSP Systems Analyst, including edits and overwriting existing reports (Personal communications, LCDR Amy L. Freeland, Deputy Chief, Vessel Sanitation Program, September 10, 2022). However, reporting errors persist. A periodic review (e.g., an annual report) may assist in identifying report anomalies and common reporting errors. An alert or flag during report submission may also reduce reporting errors. Collaboration and support with cruise industry partners will be required to improve MIDRS data quality and may be facilitated via a letter to the cruise industry and through discussions at the annual public meeting. As a final option, VSP inspectors may deduct points for substantial violations of the reporting requirements.

Merson and colleagues (1975b) provided the basis for the VSP definition of a diarrheal disease outbreak aboard passenger cruise ships. The investigators reviewed 2,445 shipboard medical logs of 38 vessels, finding that, on 92% of the voyages, the recorded gastrointestinal illness incidence was 1% or less, and on 2% of voyages, it was 5% or more. Moreover, the investigators administered questionnaires to all passengers (ill and non-ill) on nine voyages, finding gastrointestinal illness incidence to be at least four times as high as that recorded in the medical logs. The strength of the evidence suggested that most gastrointestinal illnesses were likely linked to unsafe food-handling practices and water system management, indicating possible foodborne and waterborne transmission. Considering the myriad of developments in cruise ship operations, changes in primary etiologic agents, and new predominant mode of transmission since 1975, the VSP and cruise industry partners should revisit the current 3% AGE outbreak threshold, conducting primary research using MIDRS syndromic surveillance data, AGE outbreak investigation reports, and relevant cruise industry data to validate or modify as needed.

Moreover, an opportunity exists to determine baseline AGE incidence for passenger and crew subpopulations more accurately, which could drive changes in public health policy, procedures, and practices. For example, defining accurate endemic disease levels can better inform VSP and cruise industry response actions, preventing progression to AGE outbreak thresholds. Current VSP response action is initiated at the 2% threshold; at this point, VSP staff increase monitoring through daily reports and direct communications with corporate medical and public health staff. However, shipboard response actions by the VSP typically wait until AGE incidence exceeds the 3% outbreak threshold, which may be problematic in certain AGE outbreaks featuring person-to-person transmission and environmental contamination. With the rapid passenger growth aboard modern passenger cruise ships, delayed response actions could result in preventable morbidity.

The logistical aspects of shipboard response also call for further consideration. Since cruise ship travel involves movement to different ports of call, early decisions to conduct onboard AGE outbreak investigations can eliminate some logistical challenges, potentially leading to more frequent shipboard responses and better public health outcomes. Shipboard outbreak investigations that administer hypothesis-testing questionnaires continue to be essential to estimating true AGE incidence, by comparing reported AGE cases to those that do not seek care at the ship's medical center. Equally important is identifying the relative contributions of foodborne, waterborne, and person-to-person transmission and leveraging the evidence to inform outbreak prevention and control strategies.

A critical aspect of AGE outbreak prevention and control on modern cruise ships is housekeeping and infection control strategies. Before 2012, the cruise industry faced significant challenges to infection control, due to the limited evidence on the effectiveness of chemical disinfectants against human noroviruses. The most frequent chemical surface disinfectant involved high chlorine solution concentrations (e.g., 1,000 mg/l). While evidence suggested that a high chlorine concentration solution was effective in inactivating norovirus, its application was limited to hard, non-porous environmental surfaces that could tolerate chemical disinfection. Noroviruses are reported to persist on most environmental surfaces, remaining infectious for extended periods and resulting in prolonged outbreak duration (Kotwal & Cannon, 2014). In addition, these enteric pathogens are known to be transferred efficiently person-to-person and via contaminated hands, food, water, and environmental surfaces (Kotwal & Cannon, 2014). In 2009, the U.S. Environmental Protection Agency published the first list of approved disinfectants (*List G*) with demonstrated efficacy against human norovirus surrogates (EPA, 2009). The approved disinfectant list has been updated periodically to include additional chemical disinfectants, providing the cruise industry with good evidence regarding the effectiveness of chemical disinfectants (EPA, 2021). Effective application of chemical disinfectants, including timing and frequency of applications, concentration and contact times, and prompt implementation of infection control protocols, are important factors in AGE outbreak prevention and control. While cruise lines maintain disparate policies and strategies for housekeeping and infection control, no available studies compare and contrast these approaches. Therefore, comparative studies on infection control strategies and AGE incidence may provide important information for strengthening public health programs. Since the cruise ship environment presents unique challenges to enteric disease control, robust, evidence-based infection control programs are necessary. The VSP, in collaboration with cruise industry partners and CDC Viral Gastroenteritis Laboratory, should consider conducting primary research to determine the most effective infection control strategies. This research should also focus on evaluating the persistence of noroviruses on cruise ships during endemic voyages and persistence across voyages following significant AGE case elevations and outbreaks.

Recent trends in cruise shipbuilding or renovation include improvements in hand hygiene facilities. Several cruise ships installed plumbed handwashing stations in high-traffic areas, such as passenger and crew buffets, replacing hand sanitizer stations. This intervention, fundamental to enteric and respiratory pathogen control, is central to improving shipboard public health. One line of future research, therefore, may compare enteric and respiratory disease incidence before and after handwashing station installation. A second study design may compare cruise ships with installed handwashing stations to cruise ships of the same class without, possibly providing evidence to compel the installation of plumbed handwashing stations at additional locations in public areas. Where installing a handwashing station is impractical, a hand sanitizer station may be an appropriate alternative. Important public areas where the staging of hand sanitizer stations may be beneficial include theaters, clubs, lounges, libraries, gift shops, casinos, transportation vehicles, tenders, and gangways. Several cruise lines have already installed hand sanitizer stations throughout their fleet of cruise ships; however, it is not universal.

Public health messaging and education on proper hand hygiene are paramount to infectious disease control programs. In a review of passenger surveys from three cruise ship AGE outbreaks caused by noroviruses, Neri and colleagues (2008) found that passenger AGE cases were less likely to believe handwashing or hand sanitizer use were effective means to prevent enteric pathogen spread. A similar study aboard a cruise ship (Chimonas et al., 2008) concluded that behavioral factors may have been as important in reducing the risk of widespread transmission of norovirus as environmental health practices. Therefore, a potential area for future research may involve studies on the traveling public's knowledge, attitudes, and practices to understand behavioral risk factors for contracting infectious diseases of importance in the shipboard environment. Passenger-perceived barriers, to reporting their illness to the ship's medical center or participating in self-isolation and incentives, might influence reporting and compliance behaviors. Thus, it is recommended that stakeholders utilize brief paper-based or electronic survey tools to collect passenger responses to selected questions on knowledge, attitudes, and practices prior to disembarkation, since passenger responses would drop precipitously following departure from the ship.

Impact of SARS-CoV-2/COVID-19 Pandemic on Shipboard Communicable Disease Control

In the aftermath of several major SARS-CoV-2/COVID-19 outbreaks aboard cruise ships worldwide, including the *Diamond Princess* (Japan) and the *Grand Princess* (Oakland, CA), the cruise industry announced a 30-day pause of operations on March 13, 2020 (CLIA, 2020b). A 30-day No-Sail Order (NSO), issued by CDC, followed on March 14, 2020, for cruise ships carrying 250 or more passengers traveling in U.S. jurisdiction (CDC, 2020b). The purpose was to halt the introduction, transmission, and spread of SARS-CoV-2 into the United States and to develop interim guidelines to mitigate SARS-CoV-2 transmission. The March 14th NSO was extended in April 2020, as COVID-19 outbreaks continued on cruise ships sailing internationally, and then three more times, to provide cruise lines time to develop response plans (CDC 2020c; CDC 2020d: CDC 2020e). Following the NSO extensions, the CDC established the Framework Conditional Sailing Order (CSO), procedures in preparation for a phased return to safe operations in the United States and the development of public health guidelines (CDC 2020f). On July 18, 2022, the CDC COVID-19 Program for Cruise Ships was discontinued and replaced by guidelines for mitigating and managing COVID-19 on cruise ships (CDC, 2022).

The SARS-CoV-2 pandemic brought about substantive changes to cruise ship operations and infectious disease control, including upgraded ventilation systems with high-efficiency filters and UV light disinfection to combat common respiratory pathogens such as coronaviruses, rhinoviruses, and influenza virus. Furthermore, at least one cruise line began experimenting with ultraviolet-C (UV-C) disinfection robots to augment environmental cleaning and disinfection procedures for public areas. UV-C robot technology has been increasingly deployed in hospitals, airports, and shopping malls (Fueszl et al., 2021). Park and colleagues (2015) examined the efficacy of UV-C irradiation against hepatitis A virus (HAV) and murine norovirus (MNV-1) on an experimentally contaminated stainless-steel surface, reporting antiviral effects on both MNV-1 and HAV and concluding that low doses of UV-C light may be effective in inactivating human noroviruses on food contact surfaces. Noroviruses are known to persist, remaining infectious on a variety of environmental surfaces for up to 28 days (Kim et al., 2014); while UV-C robot technology is considered promising for surface disinfection (Diab-El Schahawi et al., 2021), it should complement, not replace, manual cleaning and disinfection protocols. Additional technical development and clinical trials are required to establish the efficacy and effectiveness of this novel approach to cruise ship infection control. The VSP and cruise industry partners should investigate whether UV-C technology is a practical and cost-effective solution for some shipboard infection control applications.

During the study period, major cruise lines employed shipboard Sanitation Officers (SO) and positioned land-based public health officers at their corporate offices, to ensure compliance with *VSP Operations Manual* requirements and maritime environmental protection laws. However, during the SARS-CoV2/COVID-19 pandemic, cruise lines upgraded the SO positions to Public Health Officers (PHOs) with expanded public health roles and responsibilities, including oversight of public health standards associated with respiratory diseases. Most PHOs have several years of shipboard experience and training, which allows them to identify violations of public health and environmental protection standards and take prompt corrective actions during voyages. These assigned PHOs can theoretically become extensions of international maritime public health agencies, providing oversight when cruise ships are within and between jurisdictions. As such, these positions, if properly trained, resourced, and authorized to initiate prompt corrective action in partnership with ship leadership, can be integral to ensuring daily compliance with federal public health requirements and corporate policy, reducing the risk of negative public health outcomes. The shipboard and shoreside command structures should maintain a strong and resilient public health mission engrained in all cruise ship operations.

Finally, multiple recent studies show that nonpharmaceutical interventions such as physical distancing, mask mandates, increased handwashing, and alcohol-based hand sanitizers leveraged during the SARS-CoV-2/COVID-19 pandemic appear to have reduced the burden of several infectious diseases. Fukuda and colleagues (2021) reported decreased hospitalizations among children in Japan for common respiratory and enteric diseases (including noroviruses), attributing the reductions to the non-pharmaceutical interventions (NPIs) introduced during the pandemic. A second study (Ahn et al., 2021) also observed sharp reductions in illness rates for several viral infectious diseases, including norovirus (a 40% drop over two years). A mathematical modeling study, using laboratory reports conducted in England, estimated a 47-79% reduction of norovirus during the pandemic period (Ondrikova et al., 2021). Another (O'Reilly et al., 2021) reported that COVID-19 NPIs may have introduced unintended consequences of increased susceptibility to norovirus infection at the community level and the possibility of increased norovirus incidence following the return to pre-pandemic conditions. Similarly, there were fewer AGE outbreaks on cruise ships during this time period (zero in 2020, and one in 2021). As the cruise industry returned to normal operations, AGE outbreaks also returned, with four outbreaks in 2022 and seven in the first three months of 2023. The VSP should continue to monitor MIDRS reports for increasing AGE incidence as the cruise industry returns to pre-pandemic operations, recommending strategies for early interventions to minimize the resurgence of AGE outbreaks on cruise ships.

Currently, the cruise industry has not decided whether to continue to apply most public health strategies implemented for SARS/CoV-2 control as cruise ships return to normal operations and the full complement of passengers and crew. Respiratory diseases such as SARS-CoV-2 and influenza continue to be of concern on cruise ships. Anecdotal evidence suggests that

NPIs instituted to control SARS-CoV-2 transmission significantly reduced reported enteric and respiratory pathogen-associated cases on cruise ships operating internationally. However, when SARS-CoV-2/COVID-19 interventions, such as social distancing and mask mandates, are no longer enforced, the traveling public will likely revert to previous behaviors, with subsequent increases in pathogen transmission. The VSP and cruise industry partners should identify effective interventions against enteric pathogen transmission and consider recommendations and permanent adoption of selected interventions.

Prioritized Recommendations for Future Research and VSP Program Improvements

Based on the findings and observations of this study, the following are prioritized recommendations for future research and programs improvements for the Vessel Sanitation Program and cruise industry partners. The first recommendation is to update the Maritime Illness Database and Reporting System (MIDRS) reporting requirements and strengthen error-checking prior to accepting AGE reports into the MIDRS. Complete and accurate reporting is essential for evidence-based decision-making, and the MIDRS database serves as the primary method for tracking AGE incidence on passenger cruise ships. Specific recommended modifications and enhancements should, at a minimum:

- require an end-of-voyage report to replace the 24-hour and 4-hour reports, for more complete AGE reports
- eliminate the 15-day report option to reduce bias in AGE reports for voyages longer than 15 days
- add a report requirement for voyage type for each MIDRS AGE report to allow for assessments of public health risks for specific itineraries and geographic locations

- codify the Special Report operations requirements in the next revisions of the Foreign Quarantine Regulations (42 CFR Part 71). It is not recommended VSP include threshold values directly in the regulations, but a general statement would allow VSP to update thresholds in the current *VSP Operations Manuals* and future revisions.

Closely linked to the MIDRS AGE reports is the need to review the current AGE outbreak threshold, which was established based on a study conducted in 1970s. Changes in the cruise industry and current VSP field operations require a review of the AGE outbreak threshold to determine if it accurately reflects outbreak conditions on cruise ships with the capacity to carry much larger passenger and crew populations. This is essential because the AGE outbreak threshold determines likely VSP actions for conducting AGE outbreak investigations.

VSP should consider updating the EpiModule Project as part of the ongoing CDC data modernization project to provide efficient access to AGE outbreak data and information and to facilitate prompt reporting of AGE outbreak information to cruise industry partners, public health authorities, the traveling public, and others with a need to know.

This investigator also recommends that VSP collaborate with appropriate CDC laboratories for the planning and execution of a future study examining the effectiveness of chemical disinfectants and application strategies for controlling enteric pathogens on cruise ships. The study may also include non-chemical-based disinfectant strategies, such as UV-C light disinfection used by some cruise lines. The results of such a study should provide useful information on the efficacy of disinfectant strategies to cruise industry partners.

Finally, since hand hygiene is critical to communicable disease control, a study comparing different hand hygiene strategies should considered. Protocols may include comparisons of public health outcomes 1) across different hand hygiene formulations, 2) between cruise ships with dedicated handwash stations at buffets and those without, and 3) before and after instituting dedicated handwash stations, as an intervention, on the same cruise ship. Any of these approaches should provide important information for developing future public health policies for managing communicable diseases of all types in the cruise ship environment.

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APPENDIX A: VSP ACUTE GASTROENTERITIS LOG

Note: The Header/Banner section of the AGE Surveillance Log must be completed for EVERY voyage, even if the case counts are zero for both passenger and crew. Even if there is an underlying illness, there may be justification in reporting the patient as reportable. This should be based on sound clinical judgment and based on medical practice. Enter "none" if there is no underlying illness.

Vessel Name		Date From		Total No. of Pax.		Total No. of Crew	
Voyage Number		Date To		Reportable Total No. of Pax Ill		Reportable Total No. of Crew Ill	

Patie	Report to Medical				Age	Sex	Pax o	Cabin	Pax N	Crew	Illness Onset		Diarr hea Episo		Vomi ting Episo	Fever		Abdo mina l Cram	Head ache	Myal gia	Speci men Requ este	Speci men Recei ved	Anti diarr heal	Repo rtabl e	Underlying Illness Specify
	Date	Time	Last Name	First Name							Date	Time	#	Blood Y/N	#	Y/N	°F	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	

APPENDIX B: 2000 VSP OPERATIONS MANUAL SCORE SHEET

CDC
CENTERS FOR DISEASE CONTROL AND PREVENTION

VESSEL SANITATION INSPECTION REPORT

Vessel Name	Inspection Date		Port	Results Presented To	Score:
Cruise Line	No. Pax	No. Crew	Inspection Type	Inspected by	

Item No.	Point Value	Description (**Bold** = Critical Item)
DISEASE REPORTING		
01	**4**	**Disease reporting**
02	1	Medical logs maintenance
POTABLE WATER		
03	**5**	**Bunker / production source; Halogen residual**
04	**5**	**Distribution system halogen residual**
05	**5**	**Distibution system halogen analyzer calibrated**
06	2	Halogen analyzer chart recorder maintenance, operation, records; Micro sampling, records
07	**3**	**System protection cross-connections, backflow; Disinfection**
08	1	Filling hoses, caps, connections, procedures; Sample records, valves; System construction, maintenance
SWIMMING POOLS, SPAS		
09	**3**	**Swimming pools / spas halogen residuals**
10	1	Swimming pools / spas maintenance, safety equipment
FOOD SAFETY		
PERSONNEL		
11	**5**	**Food handlers infections, communicable diseases**
12	**4**	**Hands washed; Hygienic practices**
13	**3**	**Management, knowledge, monitoring**
14	1	Outer clothing clean; Jewelry, hair, hand sanitizers
FOOD		
15	**5**	**Food source, sound condition; Food re-service**
16	**5**	**Potentially hazardous food temperatures**
17	2	Temperature practices; Thawing
18	**3**	**Cross-contamination**
19	2	Food protection; Original containers; labeling; In-use food dispensing, preparation utensils

MEDICAL LOG REVIEW

Cruise - Start / End / Port / PAX / ILL / CREW / ILL

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Item No.	Point Value	Description (**Bold** = Critical Item)
EQUIPMENT		
20	2	PHF temperature maintenance facilities; Food-contact surfaces; Food TMD's
21	1	Nonfood-contact surfaces; Ambient TMD's
22	2	Warewashing facilities; TMD's; Test kits
23	2	Pre-wash; Wash and rinse **solutions**
24	**3**	**Sanitizing rinse**
25	1	Wiping cloths / chef's towels
26	**3**	**Food-contact surfaces equipment / utensils clean; Safe materials**
27	1	Non-food contact surfaces equipment / utensils clean
28	2	Equipment / utensil / linen / single / service storage handling dispensing; Cleaning frequency
TOILET AND HANDWASHING FACILITIES		
29	**3**	**Facilities convenient, accessible, design, installation**
30	1	Hand cleanser, sanitary towels, waste receptacles, handwash signs; Maintenance
TOXIC SUBSTANCES		
31	**5**	**Toxic items**
FACILITIES		
32	1	Solid waste containers
33	1	Decks / bulkheads / deckheads
34	1	Plumbing fixtures / supply lines / drain lines / drains
35	2	Liquid waste disposal
36	1	Lighting
37	1	Rooms / equipment venting
38	1	Unnecessary articles, cleaning equipment; Unauthorized personnel
ENVIRONMENTAL HEALTH		
39	**3**	**IPM program effective; Approved pesticide application**
40	1	IPM procedures; Outer openings protection
41	2	Housekeeping; Child-Activity Centers

Comments:

APPENDIX C: 2005 VSP OPERATIONS MANUAL SCORE SHEET

CDC
SAFER • HEALTHIER • PEOPLE™

VESSEL SANITATION INSPECTION REPORT

Vessel Name		Inspection Date	Port	Results Presented to	Score:
Cruise Line	No. Pax.	No. Crew	Inspection Type	Inspected by	

Item No.	Point Value	Description (**Bold** = Critical Item)
DISEASE REPORTING		
01	**4**	**Disease reporting**
02	1	Medical logs maintenance
POTABLE WATER		
03	**5**	**Bunker / production source; Halogen residual**
04	**5**	**Distribution system halogen residual**
05	**5**	**Distribution system halogen analyzer calibrated**
06	2	Halogen analyzer chart recorder maintenance, operation, records; Micro sampling, records
07	**3**	**System protection cross-connections, backflow; Disinfection**
08	1	Filling hoses, caps, connections, procedures; Sample records, valves; System construction, maintenance
SWIMMING POOLS, SPAS		
09	**3**	**Swimming pools / spas halogen residuals**
10	1	Swimming pools / spas maintenance, safety equipment
FOOD SAFETY		
PERSONNEL		
11	**5**	**Food handlers infections, communicable diseases**
12	**4**	**Hands washed; Hygienic practices**
13	**3**	**Management, knowledge, monitoring**
14	1	Outer clothing clean; Jewelry, hair, hand sanitizers
FOOD		
15	**5**	**Food source, sound condition; Food re-service**
16	**5**	**Potentially hazardous food temperatures**
17	2	Temperature practices; Thawing
18	**3**	**Cross-contamination**
19	2	Food protection; Original containers; labeling; In-use food dispensing, preparation utensils

MEDICAL LOG REVIEW

Cruise – Start / End / Port / PAX / ILL / CREW / ILL

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Item No.	Point Value	Description (**Bold** = Critical Item)
EQUIPMENT		
20	2	PHF temperature maintenance facilities; Food-contact surfaces; Food TMD's
21	1	Nonfood-contact surfaces; Ambient TMD's
22	2	Warewashing facilities; TMD's; Test kits
23	2	Pre-wash; Wash and rinse solutions
24	**3**	**Sanitizing rinse**
25	1	Wiping cloths / chef's towels
26	**3**	**Food-contact surfaces equipment / utensils clean; Safe materials**
27	1	Non-food contact surfaces equipment / utensils clean
28	2	Equipment / utensil / linen / single / service storage handling dispensing ; Cleaning frequency
TOILET AND HANDWASHING FACILITIES		
29	**3**	**Facilities convenient, accessible, design, installation**
30	1	Hand cleanser, sanitary towels, waste receptacles. Handwashing signs; Maintenance
TOXIC SUBSTANCES		
31	**5**	**Toxic Items**
FACILITIES		
32	1	Solid waste containers
33	1	Decks / bulkheads / deckheads
34	1	Plumbing fixtures / supply lines / drain lines / drains
35	2	Liquid waste disposal
36	1	Lighting
37	1	Rooms / equipment venting
38	1	Unnecessary articles, cleaning equipment; Unauthorized personnel
ENVIRONMENTAL HEALTH		
39	**3**	**IPM program effective; Approved pesticide application**
40	1	IPM procedures; Outer openings protection
41	2	Housekeeping; Child-Activity Centers

Comments:

APPENDIX D: 2011 VSP OPERATIONS MANUAL SCORE SHEET

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U.S. PUBLIC HEALTH SERVICE 1798

VESSEL SANITATION INSPECTION REPORT

Vessel Name	Inspection Date		Port	Results Presented to	Score:
Cruise Line	No. Pax.	No. Crew	Inspection Type	Inspected by	

Item No. / Point Value / Description **Bold** = Critical Item

Item No.	Point Value	Description
DISEASE REPORTING		
01	**4**	**Disease reporting**
02	1	Medical logs maintenance
POTABLE WATER		
03	**5**	**Bunker / production source; Halogen residual**
04	**5**	**Distribution system halogen residual**
05	2	Distribution system halogen analyzer calibrated
06	2	Halogen analyzer chart recorder maintenance, operation, records; Micro sampling, records
07	**3**	**System protection cross-connections, backflow; Disinfection**
08	1	Filling hoses, caps, connections, procedures; Sample records, valves; System construction, maintenance
RECREATIONAL WATER FACILITIES		
09	**3**	**RWF halogen residuals**
10	2	RWF maintenance, safety equipment
FOOD SAFETY		
PERSONNEL		
11	**5**	**Food handlers infections, communicable diseases**
12	**4**	**Hands washed; Hygienic practices**
13	**3**	**Management, knowledge, monitoring**
14	1	Outer clothing clean; Jewelry, hair, hand sanitizers
FOOD		
15	**5**	**Food source, sound condition; Food reservice**
16	**5**	**Potentially hazardous food temperatures**
17	2	Temperature practices; Thawing
18	**3**	**Cross-contamination**
19	2	Food protection; Original containers; labeling; In-use food dispensing, preparation utensils

MEDICAL LOG REVIEW

Cruise – Start / End / Port / PAX / ILL / CREW / ILL

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Item No. / Point Value / Description **Bold** = Critical Item

Item No.	Point Value	Description
EQUIPMENT		
20	2	PHF temperature maintenance facilities; Food-contact surfaces; Food TMDs
21	1	Nonfood-contact surfaces; Ambient TMDs
22	2	Warewashing facilities; TMDs; Test kits
23	2	Prewash; Wash and rinse solutions
24	**3**	**Sanitizing rinse**
25	1	Wiping cloths / chef's towels
26	**3**	**Food-contact surfaces equipment / utensils clean; Safe materials**
27	1	Nonfood-contact surfaces equipment / utensils clean
28	2	Equipment / utensil / linen / single / service storage handling dispensing; Cleaning frequency
TOILET AND HANDWASHING FACILITIES		
29	**3**	**Facilities convenient, accessible, design, installation**
30	1	Hand cleanser, sanitary towels, waste receptacles. Handwashing signs; Maintenance
TOXIC SUBSTANCES		
31	**3**	**Toxic Items**
FACILITIES		
32	1	Solid waste containers
33	1	Decks / bulkheads / deckheads
34	1	Plumbing fixtures / supply lines / drain lines / drains
35	2	Liquid waste disposal
36	1	Lighting
37	1	Rooms / equipment venting
38	1	Unnecessary articles, cleaning equipment; Unauthorized personnel
ENVIRONMENTAL HEALTH		
39	**3**	**IPM program effective; Approved pesticide application**
40	1	IPM procedures; Outer openings protection
41	2	Housekeeping
42	1	Child activty centers
43	1	Ventilation
KNOWLEDGE		
44	2	Person in charge, Knowledge