COVID-19 Containment Ship Model: A Case Study for Pacific Island Response

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Abstract

The Republic of the Marshall Islands, American Samoa, the Federated States of Micronesia, and the Republic of Palau have been without any COVID-19 community transmission since the beginning of the global pandemic. The Commonwealth of the Northern Mariana Islands has experienced modest community transmission, and Guam has had significant COVID-19 community transmission and morbidity. Although several of these United States Affiliated Pacific Island jurisdictions made difficult strategic choices to prevent the spread of COVID-19 which have been largely successful, the built environment and the population density in the urban areas of the Pacific remain inherently conducive to rapid COVID-19 transmission. Rapid transmission could result in devastating health and economic consequences in the absence of continued vigilance and long-term strategic measures. The unique COVID-19 vulnerability of islands in the Pacific can be modeled through examination of recent outbreaks onboard several United States Naval ships and other marine vessels. The environmental characteristics that pose challenges to infection control on an isolated naval ship are analogous to the environmental characteristics of these Pacific island communities. Considering a collection of case studies of COVID-19 transmission on ships and applying to Pacific Island environments, provides a heuristic, easily accessible epidemiologic framework to identify methods for interventions that are practical and reliable towards COVID-19 containment, prevention, and control. Using accessible evidence based public health policies, infection risk can be decreased with the objective of maintaining in-country health and social stability. These case studies have also been examined for their relevance to current discussions of health care infrastructure and policy in the Pacific Islands, especially that of vaccination and repatriation of citizens marooned in other countries. The need for aggressive preparation on the parts of territories and nations not yet heavily exposed to the virus is critical to avoid a rapid "burn-through" of disease across the islands, which would likely result in catastrophic consequences.

Keywords

SARS-CoV-2, COVID-19, Pacific, Oceania, Repatriation, Vaccination

Abbreviations

AS = American Samoa
CDC = Centers for Disease Control and Prevention
CNMI = Commonwealth of the Northern Marianas Islands
COFA = Compact of Free Association
COVID-19 = coronavirus disease 2019
FSM = Federated States of Micronesia
GDP = gross domestic product
GU = Guam
RMI = Republic of Marshall Islands
ROP = Republic of Palau
SARS-CoV-2 = severe acute respiratory syndrome coronavirus 2
USAPI = The US Affiliated Pacific Islands
WHO = World Health Organization (WHO)

Introduction

The US Affiliated Pacific Islands (USAPI) is made up of 3 US territories and 3 sovereign island nations. The US territories include American Samoa (AS), the Commonwealth of the Northern Marianas Islands (CNMI), and Guam (GU). The 3 sovereign nations, which are politically linked to the US by the Compacts of Free Association agreement (COFA), include the Republic of Palau (ROP), Federated States of Micronesia (FSM), and the Republic of the Marshall Islands (RMI). The USAPI are separated by the Pacific Ocean from other large land masses by thousands of miles; these isolated islands, with relatively small populations, are largely sustained by larger Western economies. Through aggressive quarantining measures, the majority of USAPI, including the RMI, AS, FSM, and ROP, have proactively managed to avoid widespread coronavirus disease 2019 (COVID-19) outbreaks since the beginning of the pandemic.[1,2] This aggressive quarantine approach can be described as a bubble containment strategy, where communities remain in complete social isolation. Despite the effectiveness of this strategy, most remote island communities cannot sustain bubble containment; strategies are needed to emerge from isolation to ensure both economic and social recovery.

In the context of COVID-19, the social and environmental characteristics that pose challenges to densely populated naval ships are similar to characteristics found in the Pacific islands. A viewpoint article published in June 2020[7] described the epidemiology of COVID-19 infections aboard US Navy ships, and described how COVID-19 transmission in Pacific Island nations may be analogous to transmission on large ships. Through a review of the evolution of the COVID-19 epidemiology and interventions in the USAPI since June 2020, this manuscript formalizes this viewpoint and describes a model for public health interventions to prevent and control the spread of COVID-19 in settings similar to the characteristics of an isolated ship. The COVID -19 Containment Ship Model consists of 3 approaches that include (1) a term referred to as a "burn-through" approach, represented by the conscious or unconscious decision to allow the virus to spread, or "burn through" through a population; (2) a reactive crisis management strategy, where the focus is to mitigate on-board community viral transmission; and (3) an aggressive prevention, detection, containment, and response plan that employs very strict prevention and control protocols.

An analysis of deployed US naval ship outbreaks on the USS Ronald Reagan, USS Kidd, and USS Theodore Roosevelt, as well as the outbreak onboard the civilian Diamond Princess cruise ship, illustrates how the virus could rapidly spread in an unprepared island community. Based on the similarities shared by Pacific Islands and the environmental characteristics of largely populated ships, the COVID-19 Containment Ship Model may provide remote Pacific Islands a basis which can guide the development of public health policies and evidence-based interventions in future pandemics. Lessons from the model can be accessed and applied by public health, policy, and community leaders, to prevent and contain COVID-19 transmission in Pacific Island environments.

Table 1. Per Capita Total Health Expenditure Health and Population Census for USAPI Compared to the USA[3,4]

Affiliated Jurisdiction	Per Capita Total Health Expenditure (2018)	Total Population Census	Year Census Was Taken
CNMI	$261	53 883	2010
FSM	$414	102 843	2010
RMI	$677	53 158	2011
AS	$692	55 519	2010
GU	$1990	159 358	2010
ROP	$2012	17 661	2015
USA	$10 637	308 745 538	2010

Methods

The COVID -19 Containment Ship Model was informed and developed by authors who have worked extensively with the COVID-19 prevention and control efforts. Six of the authors are citizens of the USAPI, and have been an integral part of the teams dedicated to managing COVID-19 in AS, the RMI, GU, the FSM, and with the migrants from these USAPI in Hawai‘i.

Referenced within this manuscript, data to develop the ship framework was taken from COVID-19 reports which were published in scientific journals, newspaper articles, public naval reports, and conversations with medical officers working on naval vessels. The epidemiology of the COVID-19 pandemic in the Pacific was pulled together from World Health Organization (WHO) Expanded Situational Reports (Situational Reports), the USAPI COVID-19 epidemiologist, and work with the teams assigned to manage the pandemic in the USAPI and in Hawai‘i.

Results

The health care infrastructure of each USAPI jurisdiction varies widely in scope and technology as well as per capita expenditures for health. All share a common need for tertiary medical procedures, and advanced specialty medical care is often obtained in Hawai‘i, the Philippines, or Taiwan. The Indigenous Pacific Islanders from the USAPI have disproportionate rates of non-communicable diseases including atherosclerotic heart disease, type 2 diabetes mellitus, and cancers. Population density in the urban island centers also affects the quality of available healthcare to surrounding communities. In the RMI, Ebeye Island is the most densely populated island in the Pacific with 10 000 people living on about one-eighth of a square mile, and the capitol Majuro atoll supports about 20 000 inhabitants living on about half of the atoll's total 3.7 square miles. Guam has about 795 people per square mile. The population and the health care per capita expenditures for each affiliated jurisdiction are listed in Table 1 for comparison. The lower health care per capita expenditures in the USAPI compared to those of the US highlight a financial limitation that hinders the development of robust secondary and tertiary health care facilities.[3,4]

During the COVID-19 pandemic, the spread of the disease across the USAPI has varied. The CNMI has had modest community transmission while GU has had significant COVID-19 community transmission, morbidity, and mortality.[1,2] However, through aggressive quarantining measures, the majority of the USAPI , including the RMI, AS, FSM, and ROP have proactively managed to avoid a widespread COVID-19 outbreak[1,2] since the beginning of the pandemic. These 4 affiliated jurisdictions took the most aggressive actions by implementing a bubble containment approach. In this strategy, communities remain in complete social isolation, with strict implementation of aggressive quarantine measures. Given the limited health care infrastructure, geographic isolation, and economies, which are very dependent on a large amount of global commerce, the strategic decision by community leaders to remain in isolation has been difficult, but necessary and effective. Looking forward to potential outcomes by examining what can occur following this containment period is critical to ensuring the health and safety of the vulnerable, while also maintaining optimism for future endeavors to revitalize the economic and communal support systems.

Three different approaches to COVID-19 containment with varying levels of preparation are described to exemplify the possible outcomes of each intervention: burn-through; reactive crisis management; and aggressive prevention, detection, containment, and response plan. These approaches can be used to explain how the outbreaks spread or were contained onboard the Diamond Princess cruise ship, the USS Roosevelt, the USS Reagan, and the USS Kidd. Figure 1 summarizes these approaches.

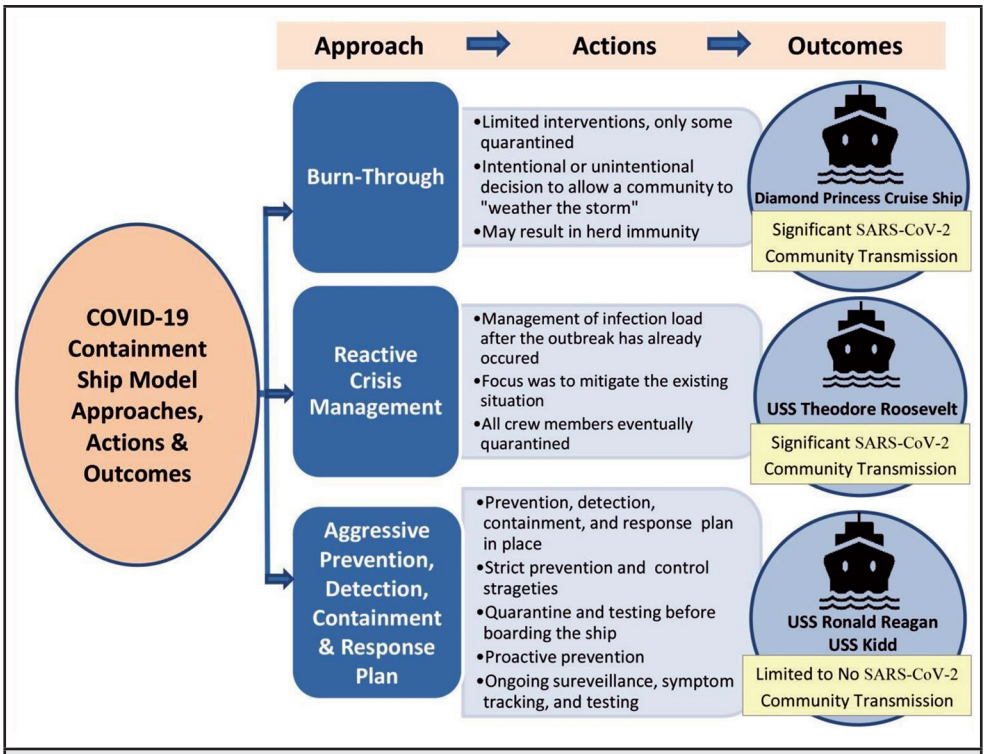

Figure 1. COVID-19 Containment Ship Model Approaches, Actions and Outcomes

Burn-through Approach

The strategy with the most limited interventions can be referred to as the burn-through approach, represented by the conscious or unconscious decision to allow the virus to spread through a population. This is best exemplified by the COVID-19 outbreak onboard the Diamond Princess cruise ship.

The first official case onboard the Diamond Princess was confirmed on February 1, 2020; the vessel anchored in Yokohama Harbor, Japan on February 3, 2020.[8] There were 2 infected passengers who had contracted severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) in late January 2020 who had been suspected of transmitting the virus to other passengers and crew members before pulling in to port. Quarantine measures implemented on February 5 slowed the spread, although crewmembers were expected to continue to operate the cruise ship as normal.[9] The levels of infection were found to be most prevalent in persons ages 70-79.[10] By February 22, 18 days after anchoring in port, there were more than 700 cases of infection reported out of 3711 individuals onboard, a 19.2% infection rate.[8] The Centers for Disease Control and Prevention (CDC) Investigative Report found the transmission among crew members was more common among those who worked in the areas of food service.[8]

Sweden, as another example, also gained notoriety in the early months of the pandemic with its burn-through strategy. Sweden mandated very few lockdown measures, specifically with the intention that enough infections would eventually produce sufficient herd immunity to protect the population.[12] The approach has since shifted to stricter quarantine measures after recording an exponential increase in infections, once again demonstrating the potential consequences of this strategy.[11]

Reactive Crisis Management Approach

News of the outbreak onboard the USS Theodore Roosevelt made international headlines as the first major US Naval vessel to be incapacitated by the COVID-19 virus.[5] The $4.5 billion, Nimitz-class, nuclear aircraft carrier with 5000 sailors was forced to remain docked in GU for over a month. This major incident was subjected to numerous inquiries since the outbreak was first reported in late March 2020, including an investigative report released by the CDC in June of 2020.[3] Since the outbreak onboard the USS Roosevelt, more than 190 other Naval vessels have experienced COVID-19 outbreaks, each with varying degrees of severity.[6]

The USS Roosevelt employed a reactive crisis management approach, with a focus on mitigating on-board community viral transmission.[13,15,22] The aircraft carrier was forced to dock in GU on March 27 in order to address the COVID-19 transmission onboard as soon as the first on-board cases were reported. The US Navy had not yet developed a comprehensive plan to address viral spread, although it had been quarantining traveling sailors in a limited capacity.[13,14] More than 4000 sailors were

taken ashore for quarantine, however widespread infection had already been established. Unlike the Diamond Princess, the quarantine implemented by the USS Roosevelt in GU applied to all crewmembers.[5] Approximately 1273 cases of infection in the 5000 sailors were recorded.[15] Antibody testing of the crew in April found that more than two-thirds of the sample of USS Roosevelt sailors were sero-positive with COVID-19 antibodies, indicating that the proportion of infected sailors was likely much larger than the 25% (1273/5000) cases that were initially reported.[5] With this approach there also was a high level of community transmission of COVID-19.

Aggressive Prevention, Detection, Containment, and Response Plan

A third approach is exemplified by the outbreaks onboard the USS Kidd and the USS Reagan, which each utilized an aggressive prevention, detection, rapid containment, and response plan. The time between the USS Roosevelt and USS Kidd COVID-19 outbreaks allowed the US Navy some time to develop a strategy for COVID-19. The first cluster of 18 cases onboard the USS Kidd was reported on April 24, 2020, nearly a month after the outbreak onboard the USS Roosevelt.[16] Reports about the USS Kidd ceased after 78 cases, and the vessel was deployed back to sea soon after, though the exact number of infections was not publicly reported. In the case of the USS Reagan, the sister aircraft carrier of the USS Roosevelt, there were only 2 reported cases of SARS-CoV-2 infection after deployment in May 2020.[17] The USS Kidd and USS Reagan both employed very strict prevention and control strategies. Crews faced strict quarantine before boarding and infections were tracked through rapid testing and symptom checking while on board before an outbreak could occur. Proactive prevention measures included restricted activities between crewmembers, disease surveillance after boarding, and rapid isolation and quarantine measures of crew members off the ships in the case of infection.[5] With this approach there was markedly lower community transmission of COVID-19 compared to the approach used on the USS Theodore Roosevelt.

Transmission Rate

As shown in Figure 2, the rate of transmission as a function of time supports an association between a ship's response and the rate of cases of SARS-CoV-2 infection. The solid lines reflect the timeline in which the US Navy and news sources continued to report new cases as they occurred and were confirmed.[18-26] Due to a policy released by the Pentagon in the spring, the US Navy subsequently halted further reports on vessels affected by SARS-CoV-2 outbreaks; therefore, the final toll of COVID-19 cases is not known. A best-fit line was derived based on the trend leading up to the point cases stopped being reported. The acute and rapid rate of the viral spread can be appreciated through the slope of the respective curves, which terminates at the final number of cases that were reported by the US Navy.

Discussion

COVID 19 Quarantine and Testing

There are several key areas of interest relevant to the discussion of COVID-19 interventions. This information is valuable to communities where living and working conditions are dense, are geographically isolated, community members have limited medical resources, and are prone to poor outcomes from COVID-19 due to prevalent chronic health conditions. In the case of remote Pacific Islands, the effects of rapid spread of infectious disease may be far-reaching and overwhelming as illustrated by prior tuberculosis, syphilis, dengue fever, and measles outbreaks in the Pacific.

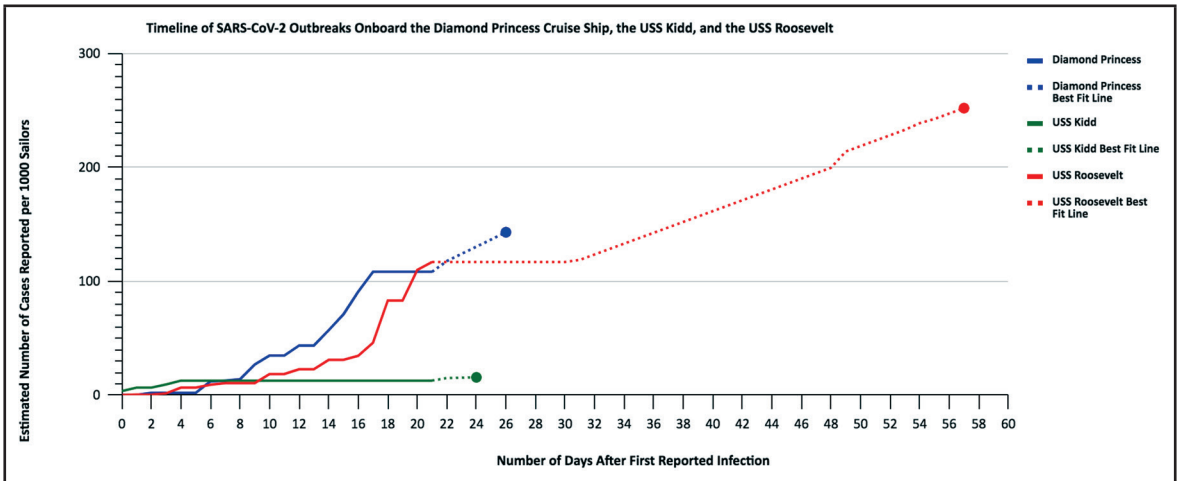

Figure 2. SARS-CoV-2 transmission rate exemplified by the reported cases of three Naval Outbreaks[18-26]

The US Navy's strategy in mitigating SARS-CoV-2 transmission placed an emphasis on streamlined communication between officers and crewmembers. Sailors were expected to follow an established protocol to report symptoms, and a COVID-19 response team was appointed onboard both the USS Reagan and the USS Kidd to address potential cases of infection and quarantine. Rapid transmission risk factors included close interdependence between crew members that is critical to maintaining ship function, the crews' limited space in sleeping quarters, and communal dining and shared restroom facilities for many crew members. For the fleet, surrounding ships referred to 1 point of contact on the carrier, whose responsibility was to ensure that proper resources were made available in the case of an emergency or air evacuation.[27]

The ability of the USS Roosevelt to situate sailors into living quarters off the ship in GU required collaboration with local communities and officials. This practice was subsequently implemented by other ships experiencing outbreaks while in port. Another US Navy vessel, the USS Tripoli, was docked in its homeport of San Diego when an onboard outbreak occurred. Immediately after the third case, 630 sailors were taken off the ship in order to decrease the density of living quarters.[18] Ships that could not immediately offload sailors in port had designated areas for quarantining potentially infectious crewmembers, each equipped with a nearby shower facility and access to meals. Navy spokeswoman Lt. Emily Wilkin recommended that sailors alternate head to foot orientation when bunking, and frequently change bed linens to avoid contamination.[6]

Utility and Application for Pacific Island Nations

Pacific island urban areas have similarities to ships with respect to the nature of the social, natural, and built environment. Naval ships deployed out to sea are geographically isolated by miles of ocean, in which access to medical resources and food can be limited by distance. Although there are medical crews onboard, the proportion of medical officers to sailors is about 1:100, and medical officers often are expected to serve in multiple capacities depending on the medical needs of the vessel. Infectious outbreaks present significant transmission risk onboard a marine vessel, given the environment of high density and limited capacity for social distancing.[27]

Similarly, many island homes support multi-generation extended families. Islands have limited living space, and like ship sleeping quarters, are tight with shared restroom facilities between many individuals. Meals are prepared and shared by many, and the frequent gathering and fellowship of community members remains an integral component of the culture. As is the case in military culture, the social structure of many Pacific Island communities is centered on community and collaborative communication through a chain of command, which speaks to an island asset for COVID-19 managment.[27] However, the hospital and health care infrastructure on these islands frequently lacks robust advanced medical and intensive care support, all of which contribute to greater risk for poor health outcomes within the Pacific Island environment.

COVID-19 Prevention and Control Vigilance

As the COVID-19 pandemic progresses, the response adopted by Pacific Island governments, public health sectors, and individuals are intertwined with understanding the roles, limitations, and timing of evidence-based behavioral, screening, treatment, and vaccination strategies. The application and access to these strategies within varying Pacific socioeconomic, cultural, geographic, and built environments may differ widely. There is currently no effective treatment for COVID-19. Vaccines are available, and new information about the nature of COVID-19 and its variants is evolving daily. As severe outbreaks are still occurring globally, vigilance will be aided by an understanding of the factors contributing to transmission, so as to employ effective and practical measures in the Pacific island environments, utilizing what is available while not becoming overly-dependent on advanced medical technology for COVID-19 prevention and control.

The Pacific Island lockdowns in AS, RMI, FSM and ROP during the first 11 months of the pandemic implemented a ban on any incoming travelers from outside of the country including their own citizens. Traditional leaders have also taken active roles in island communities as exemplified by traditional chiefs in the RMI who have taken the firm position that quarantining foreign arrivals during the pandemic in the densely populated capital of Majuro would not be allowed. All repatriation quarantine efforts are carried out for 14 days in Hawai‘i prior to departure to the RMI. This is followed by another 14 days on the US military Base in Kwajalein atoll in the RMI. Those who pass the requirements of quarantine at both sites can then be brought to Majuro.[28,29,30] Collaboration between the government-run medical systems with the community leaders is facilitated by this shared public health model.

The lessons learned from the outbreaks onboard naval ships helps to provide a comprehensive understanding of virus transmission in dense and isolated environments, and also provides a working model for situations in which standard strategies for COVID-19 control are of limited utility, for example, a significant community outbreak in an isolated island community. Looking forward, building upon COVID-19 interventions that have already been implemented by community and public health leaders in the Pacific Islands with a focused prioritization of long-term COVID-19 strategies is essential. Disseminating these best practices will be critical as efforts to repatriate and vaccinate community members continue.

Repatriation

Pacific Island repatriation efforts allow the return of island citizens stranded abroad since the start of the pandemic due to island lockdowns. Long and unexpected stays away from home have raised concerns that stranded island residents may exhaust their financial resources before the opportunity to return home becomes available, making active repatriation a necessary and prudent course of action.

One of the first indications of a SARS-CoV-2 presence on a Pacific Island that had been under lockdown was the report of a person with COVID-19 who repatriated to the Solomon Islands in early October.[28] This Pacific Island recognized the need for extremely strict repatriation efforts. During the last week of October 2020, the RMI officially began repatriation efforts, beginning with 27 residents of the estimated 300 residents awaiting return.[29] Of the first 27 residents repatriated, 3 tested positive for SARS-CoV-2 upon arrival in the Marshall Islands in spite of the strict quarantine protocol. CDC epidemiologists determined that these 3 cases were not active infections and were a result of the nature of COVID-19 testing, demonstrating the difficulty of strategic repatriation.[30] A third cohort of 51 Marshall Islands residents has recently been successfully repatriated.

The ROP and AS have also instituted repatriation efforts beginning in September 2020. The AS repatriation effort was designed to return nearly 3000 American Samoans home over a period of 6 months. The process for each country has involved a strictly monitored 14-day single hotel quarantine in Hawai‘i or Guam with COVID -19 screening at the beginning and end of the off-island quarantine, followed by another on-island 14 day quarantine and additional testing upon arrival. Transportation to the airports and through security is closely monitored and supervised.

All repatriation efforts must be handled with precision, given that the Pacific Islands are prone to significant increased rates of morbidity and mortality from rapid infection of COVID-19. There have been several studies focused on the non-communicable disease burden in many Pacific island nations.[27,28] Among others, obesity, cancer and heart disease are some of the chronic conditions listed by the CDC as factors that may increase the severity of a SARS-CoV-2 infection.[31] Infection rates in Pacific Island communities have indicated disproportionate overrepresentation in communities throughout the state of Hawai‘i and the continental United States, including Washington, Arkansas, and Oregon.[32,33,34]

Vaccination

As of March 1, 2021, there have been 3 vaccines authorized for emergency use in the United States, those manufactured by the Pfizer-BioNtech, Moderna, and Johnson & Johnson companies.[35] Logistical factors of production, storage, and distribution indicate that widespread inoculation may still be a distant ideal for some of the islands. In addition to the larger urbanized islands, the Pacific is home to many smaller island communities located hundreds of miles from these urban islands, some of which do not have access to electricity and are difficult to reach by boat or plane. Vaccination in these distant and isolated islands will be an ongoing challenge. Tight mitigation strategies must be maintained with strict repatriation quarantine and testing requirements, a continued travel lock down, and community COVID-19 education, while pressing forward with systematic vaccination efforts. At the time of this publication the island nation of Palau has vaccinated nearly all of its eligible citizens. A strong Ministry of Health and public health system, coupled with a close-knit, well connected community has supported this success.

Limitations

This model has several limitations. First, limitations to the accuracy of COVID-19 testing in the ship environment during rapid transmission should be considered. Rapid identification of infected individuals is difficult because of the asymptomatic carrier state, poor testing sensitivity in the early phases of an individual's infection and the relatively long turnaround times for the lab results preclude rapid decision making for triage. Asymptomatic transmission of the virus presented a major challenge to containing outbreaks onboard the Diamond Princess, and the USS Roosevelt. Of the 712 people infected on the Diamond Princess cruise ship, about half tested positive without showing symptoms of SARS-CoV-2. Although they were asymptomatic,18.5% of participants in the CDC investigation onboard the USS Roosevelt tested positive for SARS-CoV-2 .[27]

A second limitation are the differences in the age and health profile of the individuals on naval ships compared to that of Island citizens. The health outcomes related COVID-19 in large-scale island community transmission events would likely have greater morbidity and mortality rates.

Finally, while navy ships and remote Pacific Islands have similarities in their isolation, the financial resources available to the US Navy far outstrip the gross domestic product (GDP) of any of the Pacific Island Nations or jurisdictions. The ability to mobilize resources in response to public health emergencies is a limiting aspect of the model. Remote islands do not have the option to move all their citizens to another location to start anew. The prevention aspects must be done effectively at the outset in Island nations.

Conclusion

The examination of SARS-CoV-2 outbreaks onboard the US Naval vessels have yielded valuable information relevant to developing a model for prevention of infectious disease transmission in the Pacific Islands. Despite the many health care challenges facing the communities in Oceania, with the

proper public health interventions, government commitment, and community mobilization, prevention and containment of outbreaks (regardless of the availability of a vaccine) and effective medical treatment is feasible. The need for aggressive prevention, detection, containment, and response plans on the part of affiliated jurisdictions which have not yet been exposed to the virus, is critical to avoid a burn-through, especially in communities that do not have high vaccine coverage. In the event that the COVID-19 variants become more widespread, or vaccine boosters are required, these preparation and containment steps will become increasingly important. The degree and timing of interventions will likely be a determining factor in transmission rates, as demonstrated by the varying degrees of intervention within the US Naval aircraft carrier outbreaks.

The crucial elements learned from the ship case studies include aggressive prevention, detection, containment, and response planning efforts. This includes the screening and quarantine of individuals before they board the ships, monitoring those on board through viral testing, especially those who develop symptoms, and aggressive containment, which includes isolation and quarantine of those who are infected or exposed. Once significant community transmission has taken hold in the densely populated ship community, masking and social distancing had limited value without appropriate isolation and quarantine strategies

Although this article focused on COVID-19 in the USAPI, evaluating the outbreaks on board the US Naval vessels and the Diamond Princess cruise ship can provide insights for island nations in the Pacific to inform strategies that foster self-agency and the ability to act to prevent and control COVID-19 within their own context with the available technology at hand. Without proper preparation, a lower-income island community with limited medical or financial resources can be just as vulnerable to a SARS-CoV-2 outbreak as a highly equipped aircraft carrier such as the USS Roosevelt. By learning from such case studies, nations can strategize accordingly to best utilize characteristics that are unique to each community.

Conflict of Interest

None of the authors identify a conflict of interest.

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