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SPECIAL SECTION

CLIMATE CHANGE *and* HEALTH

THEME EDITOR: WILLIAM BINDER, MD

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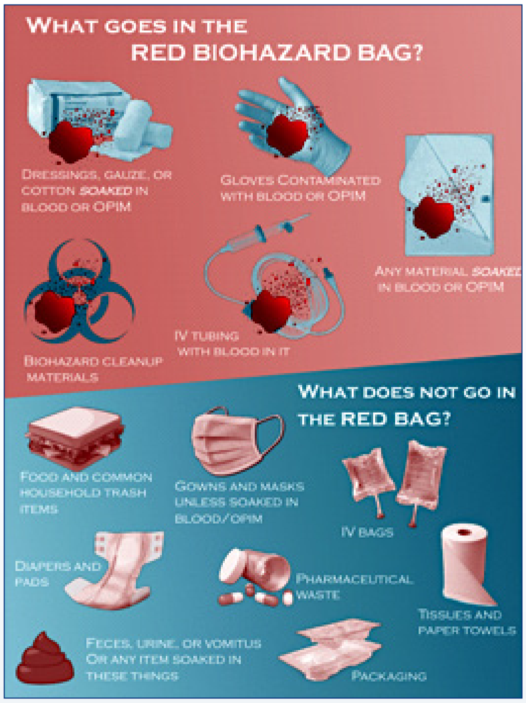
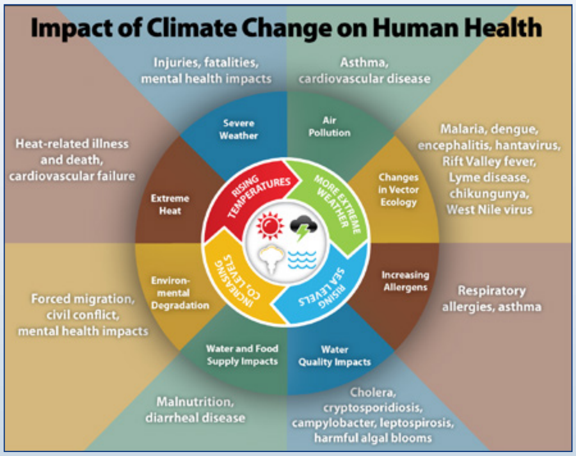
On the Cover:
The Fox Point Hurricane Barrier's three 40-ft gates can be closed in 30 minutes, preventing storm surges from inundating the low-lying areas of downtown Providence. The barrier was built 1960–1966, and in addition to the Providence River gates, consists of shore dikes with vehicular gates where roads pass through them, canal gates near the power station, and a pumping station.
[PHOTO BY ANDREW E. BINDER]

RHODE ISLAND MEDICAL JOURNAL





Climate Change and Health: A Special Edition of the *Rhode Island Medical Journal*

Examining the impacts of climate change on health, health care institutions, and mitigation strategies

WILLIAM BINDER, MD
THEME EDITOR

The impact of humans on climate has been recognized for centuries. Eighteenth-century Scottish Enlightenment philosopher David Hume postulated that the moderation of Europe's climate, in comparison to Roman times, was due to the gradual advance of cultivation in Europe. He further remarked, "Our northern colonies in America become more temperate, in proportion as the woods are felled…"[1]

While Hume could not cite rigorous data as a source for his opinion, scientists and philosophers continued to ponder the impact of humans on their environment. A century after Hume, Irish physicist John Tyndall ushered in the modern era of climate science in 1859 when he discovered the connection between atmospheric CO_2 and the greenhouse effect. By mid-20th century, 200 years after Hume, one scientist remarked, "Human beings are now carrying out a large-scale geophysical experiment of a kind which could not have happened in the past, nor be reproduced in the future. Within a few hundred years we are returning to the air and oceans the concentrated organic carbon stored over hundreds of millions of years."[2]

Data supporting the impact of humans on atmospheric warming continues to accumulate and this year's Nobel Prize in physics acknowledges the complex interaction between humans, climate, and weather. Rising seas, extreme weather events, and species extinction are no longer versions of apocalyptic science fiction but instead a harsh, modern reality with existential ramifications requiring mitigation and adaptation.

While some skeptics continue to doubt the incontrovertible data, the scientific, medical, and business communities, as well as the US military, have moved past reactionary arguments. In this special issue of the *Rhode Island Medical Journal* (RIMJ), we present an array of articles devoted to the impact of climate change on health in southern New England. Authors from throughout New England and representing multiple health systems, medical schools, universities, primary care practices, the United States Geological Survey, and the Rhode Island Department of Health have all contributed to this important edition of RIMJ.

NITIN S. DAMLE frames the issue by noting that extreme weather events and air pollution have precipitated increasing morbidity and mortality through heat waves, and increases in infectious and respiratory diseases. His commentary also alludes to the societal impact of climate change, as it can lead to food insecurity, mental health crises, and mass migration. The **RHODE ISLAND MEDICAL SOCIETY'S** consensus statement, signed in March 2020, endorses the perspective of multiple medical societies, and recognizes the impact of climate change on the health of every American.

EMILY WEBB et al., **NICHOLAS J. NASSIKAS** et al., and **KATELYN MORETTI** et al. offer supporting data on the impact of climate change on health in New England. **Webb** details the impact of extreme weather events such as hurricanes and floods – think Hurricanes Sandy, Katrina, and Ida – on electricity-dependent asthmatic patients in Massachusetts. Without electricity, asthmatic patients, as well as others requiring electrically dependent durable medical equipment, are at grave risk. **Nassikas** examines the consequences of pollution on asthma and reports on thousands of excess Emergency Department (ED) visits for summertime ozone-attributable asthma exacerbations across New England. **Moretti** reports on the straightforward association between higher temperatures and increasing Emergency Medical Services' (EMS), and de facto ED, utilization, suggesting that further research may help with planning and resource allocation during summer months. We are also fortunate to feature an article by **HOWARD S. GINSBERG** et al. from the US Geological Survey and the University of Rhode Island (URI) on the effects of climate change on tick-borne disease in Rhode Island and southern New England. The authors document the increasing incidence of Lyme, babesiosis and anaplasmosis in Rhode Island, and note that Lone star ticks, the Gulf Coast tick, and the introduced Asian longhorned tick have been spreading northward into our state. The **USGS/URI group** presents a balanced view, noting that climate change, as well as numerous other environmental and socioeconomic factors, may also contribute to the expanding range of ticks and tick-borne diseases.

The current issue of RIMJ also presents data on mitigation strategies designed to decrease hospital-based waste and reduce emissions. Previous reports suggest that the healthcare industry is responsible for 10% of greenhouse gases and two million tons of waste in the US annually.[3] **KATELYN MORETTI** et al. describe a waste mitigation project at Rhode Island Hospital that led to a 23% reduction in solid waste and significant reductions in greenhouse gas emissions. **KYLE DENISON MARTIN** et al. similarly performed a waste audit at Kent Hospital, noting the impact of the Covid-19 pandemic on waste and energy use in the ED. **Martin** et al. also provide an accompanying commentary regarding important takeaways of waste audits, offering ideas for an environmentally responsible pathway for large health systems.

Paraphrasing the axiom that all politics is local, it can be said that climate change education begins at a local and regional level. **RACHEL CALABRO** and **CAROLINE HOFFMAN** offer an introduction to the Rhode Island Department of Health's Climate Change and Health Program. As part of a US Centers for Disease Control and Prevention initiative, the program has partnered with community groups and state and local agencies to provide educational resources, fund projects fostering community resilience, and offer technical assistance. **CALEB DRESSER** et al. assess the extent of educational activity on a regional basis. In a first-of-its-kind study, they report on the scale of climate and health activities within educational institutions and professional societies in the New England region.

Rounding out this issue is a report by **JOSHUA BAUGH** et al. examining a large health system's sophisticated approach toward a vulnerability analysis, recognizing that previous analyses using historical data is inadequate in an era of rapid climate change and extreme weather events. This Harvard-wide review is a broadly applicable approach for other health systems and should be a model for other institutions moving forward. Recognizing the importance of Baugh's discussion, **ANDREW E. BINDER** et al. provide data and commentary on creating an accurate hazard analysis in order to mitigate the impact of future flooding on Providence's critical health care facilities.

We hope readers appreciate this edition of the RIMJ and that it piques an interest in what is arguably the most salient and pressing issue of our time.

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Climate Change and Human Health

NITIN S. DAMLE, MD, MS, MACP

In 2015, 186 countries signed the Paris climate agreement to limit global warming to "well below 2 degrees Celsius" and avoid the harmful impacts on human health. Integral to this goal was to reduce carbon emissions to near zero over the next several decades.

Unfortunately, carbon emissions have continued to rise, and the global average temperature has risen by 1.2 degrees Celsius, resulting in the five hottest years on record, all since 2015. The environmental impact is well documented and includes sea level rise, ocean acidification, ice melt, and loss of glacier mass. These changes have resulted in a 46% increase (since 1980) in extreme heat waves, flooding, droughts, forest fires, and intense weather events (hurricanes and cyclones).

The above weather events and air pollution lead to downstream consequences on human health. This article will focus on six health effects.

HEAT WAVES

The number and intensity of heat waves has increased significantly during the past 20 years. This burden is borne mostly by the elderly, children, those with cardiovascular and respiratory diseases, outside laborers, the homeless, and the poor. There has been a 53.7% increase in heat-related mortality for people over the age of 65. Heat waves and temperature rise increase the risk of myocardial infarction, stroke, and acute and chronic renal injury. Studies indicate for each day that the heat index is 95 degrees Fahrenheit (compared to 75 degrees F), emergency department visits increase by 6.6% over the following seven days, heat-related emergency department visits increase by 89% for seven days and death rates increase by 5.8% for each day.

Mitigation is essential and includes early warning systems and response plans, increased access to air conditioning, communication by clinical teams to reach vulnerable populations, and education about the risk of heat illness.

PARTICULATE MATTER AND RESPIRATORY DISEASES

The primary drivers of respiratory diseases are automobile, power plant emissions and forest fires. Measured particulate matter includes sulfates, nitrates, black carbon, and nitrous oxide.

Forty-three million people in the United States and 92% of the world live in areas in excess of the World Health Organization (WHO) particulate limit, and in 2019 there were eight million deaths worldwide attributable to air pollution.

Increased carbon dioxide production leads to increased growth of allergen-producing weeds, grasses, and trees with rain and floods leading to increased mold and fungal growth. The aeroallergen season has increased from 177 days in the 1970s to 190 days today and is projected to reach 214 days by mid-century. Allergy exacerbations lead to 11 million office visits per year at a cost of $11.2 billion per year and asthma and COPD exacerbations result in two million emergency department visits, 500,000 hospitalizations, and 3,600 deaths at a cost of $56 billion per year. Clinicians will need to educate patients about weather trends, knowledge about air pollution, early symptoms, and prevention.

VECTOR-BORNE AND WATER-BORNE DISEASES

The primary vectors in the United States are mosquitoes, sand flies, and ticks. There has been an increase in cases of dengue, Chikungunya, West Nile fever, Zika, and even malaria. The number of cases of Lyme disease has risen from 50,000 in the 1990s to over 400,000 in 2018 and is reported in most regions of the country.

Heavy rains and flooding lead to contamination of water systems, reservoirs, and surface water that increase risk for E. coli, Campylobacter, Leptospira, and Salmonella infection. Vibrio parahaemolyticus infection is a significant seafood-related public health concern. In addition, rates of parasitic infection have increased, in particular Cryptosporidium, Cyclospora, and Giardia Lamblia in contaminated drinking water and fresh produce. Globally, there are over one billion people that lack access to safe drinking water and 2.5 billion lack access to adequate sanitation, with an estimated five million deaths annually in children.

FOOD SECURITY

The food system involves a network of interactions with our physical and biological environments as food moves from production to consumption, or from "farm to table." There has been an increase in crop losses from fungi, bacteria, and viruses. There has been a decrease in food production by 2% per year in the face of a 14% per year increase in global demand, with a projected further decline of 6% in global wheat and 10% in global rice production for each one degree rise in temperature.

The nutrient content (protein, iron, and zinc) has decreased from 20% to 17% with an increase in carbon dioxide concentration from 385 parts per million (ppm) to 450 ppm between 2008 and 2020. Carbon dioxide production is 10 times greater for the consumption of beef, lamb, and pork versus more plant, fish, turkey, and chicken-based diets.

MENTAL HEALTH

The impact on mental health is well established. Forty-nine percent of Hurricane Katrina victims reported increased stress, anxiety, and depression and one in six have been diagnosed with post traumatic stress disorder. Studies show an increased rate of strained interpersonal relationships, substance use disorder, interpersonal aggression, violence, crime, and decreased community cohesion.

There also appears to be a relationship between increased temperature and the number of suicides, and people who meet criteria for mental illness are more vulnerable to the effects of climate change on physical as well as mental health. Much more research is necessary on the impact of climate change and prioritizing mental health benefits with mitigation efforts.

MASS MIGRATION

Extreme weather, sea-level rise, floods, food insecurity, and drought have forced two hundred million people in the world to migrate from their homes between 2008 and 2018. Modeling predicts that one billion people will need to migrate by the end of the century for these same reasons. Without climate change mitigation, this rate will significantly outpace other causes of migration, such as interstate conflict, failure of national governance, and unemployment or underemployment.

CONCLUSION

The effects of climate change have been predicted since the 1970s. There were non-binding agreements in 1979, 1989, and 1997 that did not succeed in slowing carbon dioxide emissions. It is time for the United States to rejoin and strengthen the Paris Agreement of 2015 and actively engage in setting standards at the upcoming UN Climate Change Conference (COP26) this month.

If the United States health sector were a country, it would be the fifth largest emitter on the planet, with $9 billion annually in energy costs. A 30% cut in healthcare greenhouse gas emissions by 2030 would prevent an estimated 4,130 premature deaths, 85,000 asthma attacks, four million respiratory symptom events, and 3,750 hospital visit incidents and save about $1.2 billion in medical costs.

As a physician you have the gravitas to make a significant impact on your community by raising awareness through talks in town halls and community gatherings, in addition to educating your colleagues and patients. You can lobby your local, state, and national representatives to make climate change and health a high priority issue and you can engage in climate-healthy habits, including plant-based diets, electric cars, energy-efficient homes and work environments.

I have painted a sobering outlook with one last opportunity to mitigate the effects of climate change. A recent report by the United Nations Intergovernmental Panel on Climate Change (IPCC) stated that it is possible to limit global warming to 1.5 degrees Celsius, but only with large-scale reductions of all greenhouse gases immediately. If countries move slowly, the Earth could warm by four degrees Celsius (7.2 degrees F) by the end of the century. Experts predict that such a rise would make the Earth uninhabitable. Therefore climate change is the existential threat of our time and now is the moment for all of us to educate and amplify our voices to protect future generations and the planet.

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Medical Society Consortium on Climate and Health Consensus Statement

Editor's note: *The following was adopted by the Rhode Island Medical Society in March 2020, along with Affiliates of the Medical Society Consortium on Climate and Health (medsocietiesforclimatehealth.org) regarding the health threats of climate change and the health benefits of solutions (decreasing fossil fuel use).*

We – the undersigned medical societies – support the international scientific consensus, as established in multiple national and international assessments, that the Earth is rapidly warming, and that human actions (especially burning of fossil fuels) are the primary causes. As established in the 2016 U.S. Climate and Health Assessment – The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment – the resulting changes in our climate are creating conditions that harm human health through extreme weather events, reduced air and water quality, increases in infectious and vector-borne diseases, and other mechanisms. While climate change threatens the health of every American, some people are more vulnerable and are most likely to be harmed, including: infants and children; pregnant women; older adults; people with disabilities; people with pre-existing or chronic medical conditions, including mental illnesses; people with low-income; and indigenous peoples, some other communities of color, and immigrants with limited English proficiency.

As medical professionals, many of our members know firsthand the harmful health effects of climate change on patients. We know that addressing climate change through reduction in fossil fuel use will lead to cleaner air and water, to immediate health benefits for Americans, and will help to limit global climate change.

We support educating the public and policymakers in government and industry about the harmful human health effects of global climate change, and about the immediate and long-term health benefits associated with reducing greenhouse gas emissions (i.e., heat-trapping pollution) and taking other preventive and protective measures that contribute to sustainability. We support actions by physicians and hospitals within their workplaces to adopt sustainable practices and reduce the carbon footprint of the health delivery system.

We recognize the importance of health professionals' involvement in policymaking at the local, state, national, and global level, and support efforts to implement comprehensive and economically sensitive approaches to limiting climate change to the fullest extent possible.

Our organizations are committed to working with officials at all levels to reduce emissions of heat-trapping pollution, and to work with health agencies to promote research on effective interventions and to strengthen the public health infrastructure with the aim of protecting human health from climate change.

Who's at Risk in a Changing Climate? Mapping Electricity-Dependent Patient Populations in a Coastal City

EMMA WEBB, BA; LAKSHMAN BALAJI, BDS, MPH; LARRY A. NATHANSON, MD;
SATCHIT BALSARI, MD, MPH; CALEB DRESSER, MD, MPH

ABSTRACT

BACKGROUND: Climate change is causing increasingly frequent extreme weather events. This pilot study demonstrates a GIS-based approach for assessing risk to electricity-dependent patients of a coastal academic medical center during future hurricanes.

METHODS: A single-center retrospective chart review was conducted and the spatial distribution of patients with prescriptions for nebulized medications was mapped. Census blocks at risk of flooding in future hurricanes were identified; summary statistics describing proportion of patients at risk are reported.

RESULTS: Out of a local population of 2,101 patients with prescriptions for nebulized medications in the preceding year, 521 (24.8%) were found to live in a hurricane flood zone.

CONCLUSIONS: Healthcare systems can assess risk to climate-vulnerable patient populations using publicly available data in combination with hospital medical records. The approach described here could be applied to a variety of environmental hazards and can inform institutional and individual disaster preparedness efforts.

KEYWORDS: electricity-dependent, mapping, nebulizer, hurricane, climate change, power outage

INTRODUCTION

Climate change, an aging and medically complex population, increasing technological dependence, and fragile public infrastructure present mounting challenges to the health of patients and the operation of healthcare systems.[1-3] Health risks from heat waves, hurricanes, flooding, fires, and other hazards are already increasing as result of anthropogenic climate change.[4] This is of particular concern because an increasing number of patients are reliant on medical devices and a stable supply of electricity, which can be compromised by climate-related hazards and infrastructure failures.[5-7]

The use of Durable Medical Equipment (DME) has been rising in the United States with the growing prevalence of non-communicable diseases and an aging population.[8-10] As of 2016, over 2.5 million Medicare patients were dependent on electrically-powered DME (EDME) including ventilators, oxygen concentrators, and home hemodialysis machines.[11] During power outages, EDME-dependent patients (EDPs) may experience device failure or problems continuing their care in the community and may seek assistance at hospitals.[2,12-14] Many of the patients facing this situation are elderly, have multiple chronic comorbidities, are on multiple medications, or are physically disabled,[15,16] putting them at elevated risk of immediate or long-term health harm from EDME dysfunction.

Sea level rise, hurricanes, severe storms, wildfires, and heat waves are expected to intensify as a result of climate change and are a substantial threat to power grid stability and access to electricity.[17,18,19] The frequency of power outages in the US has risen in recent decades because of an increase in the incidence of weather-related outages; severe weather was responsible for 80% of major outages between 2003 and 2012.[3] Extreme weather can cause power grid disruptions in a variety of many ways, ranging from the flooding of low-lying electrical infrastructure that occurred during Hurricane Sandy[7] to increases in demand for electricity in combination with reduced power plant efficiency and production capacity, as seen during heat waves in Southern California.[5,6,20] Power companies also sometimes initiate Public Safety Power Shutoffs, preemptively turning off power in an effort to reduce risk of wildfire ignition during hot, dry, and windy conditions.[21]

As increasing numbers of patients become dependent on electricity for their healthcare, the value of proactive patient engagement and institutional preparedness for disaster-related threats to the electricity supply will increase, particularly in areas at high risk of outages and with high numbers of EDPs. Information on this population and the hazards it faces are crucial to these initiatives, and efforts to map EDPs at national, state, and municipal levels using insurance claims data, medical record searches, and geographic information systems (GIS) are ongoing.[1,11,22-24] The most comprehensive existing tool is the Department of Health and Human Services emPOWER system, which maps EDME users at the zip code level based on Medicare claims and can provide address-level information to EMS agencies seeking to reach specific patients during a disaster.[11] However, the tool does not provide information about where patients obtain healthcare, excludes patients covered under other insurance providers or who have no insurance, and does not allow for disaggregated analysis at the municipal or institutional level.[11,24]

In this article we present a complementary, locally actionable approach that utilizes retrospective medical records review in combination with publicly available hazard data to assess the vulnerability of institution-specific EDP populations to climate-related natural hazards. For purposes of this pilot study, we focused on home nebulizers as a representative EDME and hurricane-related coastal flooding as a representative climate-related hazard.

METHODS

This study consisted of a retrospective chart review followed by spatial aggregation, mapping, and analysis of presumed nebulizer users in relation to publicly available data describing hurricane inundation zones. Nebulizers were selected as the representative EDME because they are commonly used, use can be inferred from prescription information, and device failure can contribute to adverse clinical sequelae. Inundation zones were chosen because of the strong relationship between flooding and electrical outages which has been demonstrated in recent hurricane events.[3,6,7]

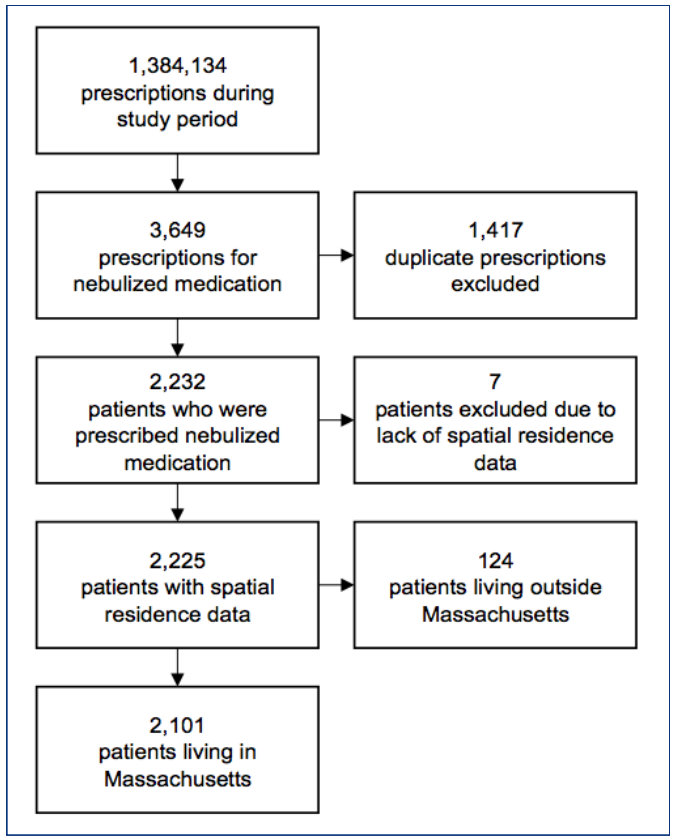
All medical records in the hospital online medical record (OMR) were queried for the presence of prescriptions for nebulized medications within the preceding year (10/25/2019 to 10/25/2020). Duplicate records from patients with multiple prescriptions within the time period were removed. Home addresses were converted to spatial coordinates via an application programming interface (API), and records were then aggregated to the level of census blocks to create the de-identified dataset used for this analysis. Hurricane Surge Inundation Zone data from the U.S. Army Corps of Engineers was obtained from MassGIS and overlaid with the frequency maps of nebulizer users.[25] A clip function was used to restrict the block-level nebulizer frequency maps to areas of overlap with hurricane inundation zones and quantify the population of patients with recent prescriptions for nebulized medication who would be exposed to storm surge inundation during a hurricane of a given Saffir-Simpson category. Attribute tables were exported and the sum and proportion of the total nebulizer population at risk and the increase in number and percent of patients expected with each increase in hurricane category were computed. Maps of nebulizer prescription frequency were created using 2010 US Census geographic data and are shown at the census tract level to protect patient anonymity.

Conversion of addresses to geo-coordinates was performed via the Google Maps API implemented in the ggmap package in R v3.6.1.[26,27] Spatial analysis and mapping was performed in ArcMap[28]; summary statistics were computed in MS Excel.[29] This study was reviewed and determined to be exempt by the BIDMC Institutional Review Board.

RESULTS

A total of 1,384,134 prescription entries for 185,906 patients were screened, from which a list of 3,649 nebulizer prescriptions was compiled. Of these, 1,417 duplicates (e.g. multiple prescriptions for the same patient during the study timeframe) were excluded, leaving 2,232 unique patient records. Seven records could not be successfully geocoded and were removed from the dataset, leaving 2,225 records representing presumed nebulizer users, from which the 2,101 patients residing in Massachusetts were included in the analysis of local vulnerability to hurricane inundation, as summarized in **Figure 1**.

Figure 1. Medical records screening and inclusion process. All records are from a single medical center during the period 10/25/2019 to 10/25/2020.



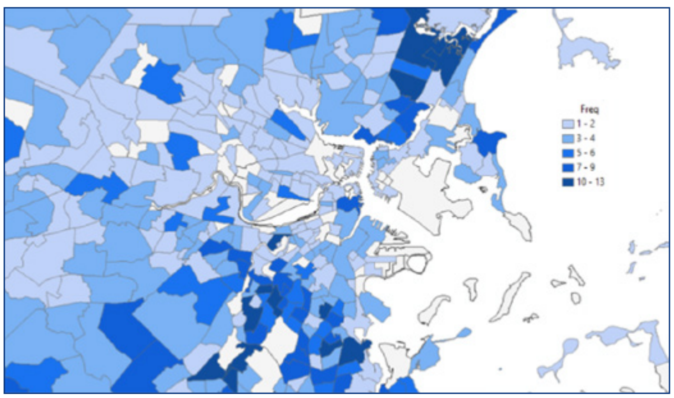
A total of 30 different medications were prescribed, including albuterol sulfate (1,237 patients), ipratropium-albuterol (372), budesonide (332), and other medications or combinations of medications (284). Most patients resided in Massachusetts (2,101), followed by New Hampshire (45), Maine (16), Rhode Island (14), and other states (49). Within Massachusetts, 730 lived in Suffolk County, 512 in Middlesex County, and 859 in other counties. See **Table 1**.

Within Massachusetts, 1,886 census blocks in 794 census tracts contained at least 1 presumed nebulizer user. All census tracts containing more than 10 patients were located in

Table 1. Study population characteristics, including locations of residence and nebulized prescriptions information.

	Number	Proportion (%)
Patients	2,225	100%
Prescription Type		
Albuterol	1,237	55.6 %
Ipratropium-Albuterol	372	16.7 %
Budesonide	332	14.5 %
Other / Combination	284	12.8 %
State of Residence		
Massachusetts	2,101	94.4 %
New Hampshire	45	2.0 %
Maine	16	0.7 %
Rhode Island	14	0.6 %
Other	49	2.2 %

Figure 2. Distribution of presumed nebulizer users in and around Boston, MA. Darker coloration corresponds to a larger number of presumed nebulizer users residing within the census tract.



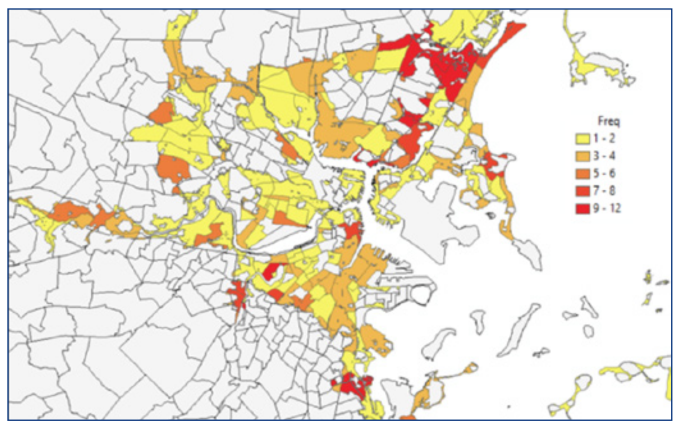
Dorchester, Saugus, and Revere. The spatial distribution of nebulizer users at the census tract level is shown in **Figure 2**.

At the block level, 521 presumed nebulizer users resided in census blocks that overlapped with hurricane flood zones. This population represents 24.8% of patients who received care at the study site during the study timeframe, were nebulizer users, and lived in Massachusetts. Subsets of this population living in each hurricane inundation zone were computed; stratified results are presented in **Table 2**. A total of 186 presumed nebulizer users (8.9%) reside in a zone that would flood in a Category 1 hurricane, and 372 (17.7%) reside in a zone that would flood in a Category 2 hurricane; the population of interest at risk of inundation in a Category 2 storm is approximately twice that at risk in a Category 1 storm. The spatial distribution of nebulizer users living in locations at risk of hurricane-related flooding is shown in **Figure 3**; data is presented at the census tract level to preserve anonymity.

Table 2. Population of presumed nebulizer users who received care at the study site during the study period and are at risk of inundation of their dwelling location in Category 1 through Category 4 hurricanes.

	Category 1 zone	Category 2 zone	Category 3 zone	Category 4 zone
Presumed nebulizer users at risk of flooding in this zone (n)	186	372	456	521
Proportion of Massachusetts nebulizer users (n=2,101) at risk of flooding in a storm of this category (%)	8.9	17.7	21.7	24.8
Additional patients at risk relative to next lowest category hurricane (n)	-	186	84	65
Proportional increase in number of patients at risk relative to next lowest category hurricane (%)	-	100%	22.6%	14.3%

Figure 3. Distribution of presumed nebulizer users residing in hurricane inundation zones. Darker red indicates a larger number of presumed nebulizers who may be at risk of inundation during a major hurricane.



DISCUSSION

This pilot study demonstrates a simple, reproducible methodology for mapping climate-related risk to electricity-dependent patients. Our approach, which uses publicly available hazard data in combination with internal medical records data, is not technologically complex and, thanks to the widespread use of electronic medical records, could be implemented by many healthcare institutions.

Our results show that nearly one-quarter of Massachusetts nebulizer users who received care at the study site are living in census blocks at risk of flooding during hurricanes, and that the number at risk approximately doubles in a Category 2 hurricane in comparison to a Category 1 hurricane. At the institutional level, this suggests there could be an increase in respiratory presentations in the hours or days following a hurricane; such information can help guide preparedness efforts. In addition, awareness of this risk may help primary care providers, pulmonologists, and patients make preparations so that alternative breathing treatments, sources of electricity, or temporary accommodations are available in the event of a major storm.

It was also noteworthy that the highest densities of presumed nebulizer users at risk of inundation in this study were in Dorchester, Saugus, and Revere – communities with substantial minority, historically marginalized, or financially constrained populations that may face substantial barriers to climate change adaptation. Such communities may benefit from hospital outreach efforts including collaboration with local governments or civil society organizations on community-based interventions to address these and other health risks.

This pilot study demonstrates that individual healthcare organizations already possess or can access the data needed to perform basic evaluations of the risk to their high-vulnerability patient populations posed by climate-related natural hazards. Practical information on the hazard exposure of vulnerable populations can be obtained using freely available datasets and analytical tools in combination with medical records data. Improving electronic medical records utilization, open-source statistical and geographic information systems, and availability of free training on their use mean that simple analyses should be within the reach of many institutions. While true real-time translational data readiness for disaster response remains an urgent and complex challenge,[30] static pre-disaster risk assessments such as the pilot results presented here can be performed at the level of individual institutions. Availability of such information may enhance engagement with community resilience and climate change adaptation efforts and could be expanded to a wide range of patient populations, hazards, and infrastructure issues.

At the organizational level, this information could contribute to forecasting patient surges and anticipating acute care needs. For example, Emergency Department (ED) demand forecasting is often done hour-to-hour[31-34]; the information and methods outlined here could be extended to allow organizations to predict which locations could receive a higher volume of EDME-related ED arrivals based on proximity to high-risk areas and vulnerable populations during disaster events. Community resilience efforts may also benefit from information on the hazard exposure of specific high-risk patient populations; such work may help avoid ED crowding related to DME problems and exacerbations of chronic conditions during disasters, which can lead to operational challenges, delays in care, and increased ED length of stay.[35-38]

Information on exposure to climate-related hazards can also inform care in the outpatient setting. Outpatient providers may find such information useful when counseling patients on issues such as respiratory health, heat wave safety, and disaster preparedness. Home Health Care (HHC) presents another intervention opportunity[39]; HHC organizations are uniquely positioned to assist EDME users with disaster preparedness at home – for example, using the National Association for Homecare and Hospice Emergency Preparedness Checklist.[40]

Analyses of climate change hazards in relation to vulnerable populations will be of growing importance in coming decades. There is a particularly urgent need to develop methods to proactively identify populations at high risk during disaster-related electrical outages in order to reduce suffering, avoid long-term health impacts associated with device failure, anticipate and reduce ED surges, and ease strain on hospital systems. Healthcare institutions have a responsibility to prepare for anticipated hazards that can affect their ability to provide care, including the risk of patient surges during extreme events. Healthcare providers are uniquely positioned to counsel patients on preparedness for natural hazards as a means of protecting their health and advocate for measures to adapt to climate change and protect health in the community. Information on local climate-related risk profiles can help inform such conversations.

LIMITATIONS

The population in this analysis is limited to nebulizer users and does not include persons dependent on other forms of EDME, which may have different spatial distributions. This medical records review was limited to a single medical center, and provides information specific to the hospital under assessment, rather than a portrait of the region as a whole. Our analysis infers that inundation from a hurricane is a predictor of electrical outage based on a variety of case studies and other evidence,[3,6,7] but lack of recent hurricanes means the degree of this correlation in the study region is not definitively known. In addition, quantifying the population at risk on the basis of residence within an inundation zone may underestimate the true number at risk, as damage to electrical infrastructure within flood zones may result in power outages affecting non-inundated areas, as occurred in large parts of Manhattan following a transformer failure during Hurricane Sandy.[6,7] Finally, a variety of factors may affect whether inundation actually harms electricity-dependent patients, including locations and fortifications of power stations and transmission lines, availability of public sites at which power is available, such as libraries or community centers, and whether or not a household is on a priority power restoration list or executes a pre-disaster evacuation plan.

CONCLUSION

Extreme weather related to climate change and the use of electricity-dependent medical devices are intersecting issues that combine to increase the risk of adverse health outcomes resulting from weather-related electrical outages. This pilot study uses publicly available hazard data and internal medical records data to show that a quarter of study-site patients who use nebulizers reside in locations that are expected to be inundated during a major hurricane and may experience electrical outages. Our findings suggest preparedness opportunities at both the population and institutional levels. The methodology necessary to conduct this type of assessment is not complex and could be reproduced in other settings to assess a variety of hazards and patient populations.

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Asthma Exacerbations Attributable to Ozone Air Pollution in New England

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ABSTRACT

BACKGROUND: Ground-level ozone (O_3) is an air pollutant and known trigger for asthma exacerbation. We sought to estimate the number of summertime emergency department (ED) visits for asthma exacerbations attributable to ozone in each county in New England (Rhode Island, Massachusetts, Connecticut, New Hampshire, Maine, and Vermont) in 2010.

METHODS: We performed a health impact assessment using BenMAP. We used population and incidence rates in New England, daily maximum 8-hour O_3 levels, and a concentration-response function derived from the epidemiological literature to quantify ozone-attributable asthma ED visits.

RESULTS: We estimate that in 2010 there were 4,612 (95% CI 2192, 6866) excess ED visits for asthma exacerbation attributable to summertime ozone across New England. Rates of ozone-attributable asthma ED visits were highest in Connecticut and Massachusetts.

CONCLUSIONS: There was a substantial number of ozone-attributable asthma ED visits in New England in 2010 with geographic heterogeneity across states and counties.

KEYWORDS: climate change, ozone, asthma, emergency department visit

INTRODUCTION

Asthma affects 1.3 million people in the New England region of the United States.[1] Exposure to pollen, dust, infections, and air pollutants can exacerbate symptoms of the disease. One air pollutant – tropospheric ozone (O_3), or ground-level O_3 – is a well-described trigger for asthma exacerbations.[2] Tropospheric O_3 is formed by the reaction of nitrogen oxides and volatile organic compounds in the presence of sunlight and heat and, unlike stratospheric ozone, which provides protection from ultraviolet radiation from the sun, ground-level ozone is harmful to human health. Tropospheric O_3 concentrations tend to be highest during the summer months when temperatures are higher and sun exposure is prolonged. One study estimated that approximately 8–21% of asthma emergency room visits in the United States are associated with O_3 exposure,[3] although the incidence varies geographically. Although ozone is recognized as a contributor to unhealthy air and an important trigger of asthma exacerbations across New England,[4] the burden of ozone air pollution on asthma across all states in New England has not been established. Accordingly, we sought to estimate the burden of disease in terms of summertime emergency department (ED) visits for asthma exacerbations attributable to ozone in every county in Rhode Island, Massachusetts, Connecticut, New Hampshire, Maine, and Vermont in 2010.

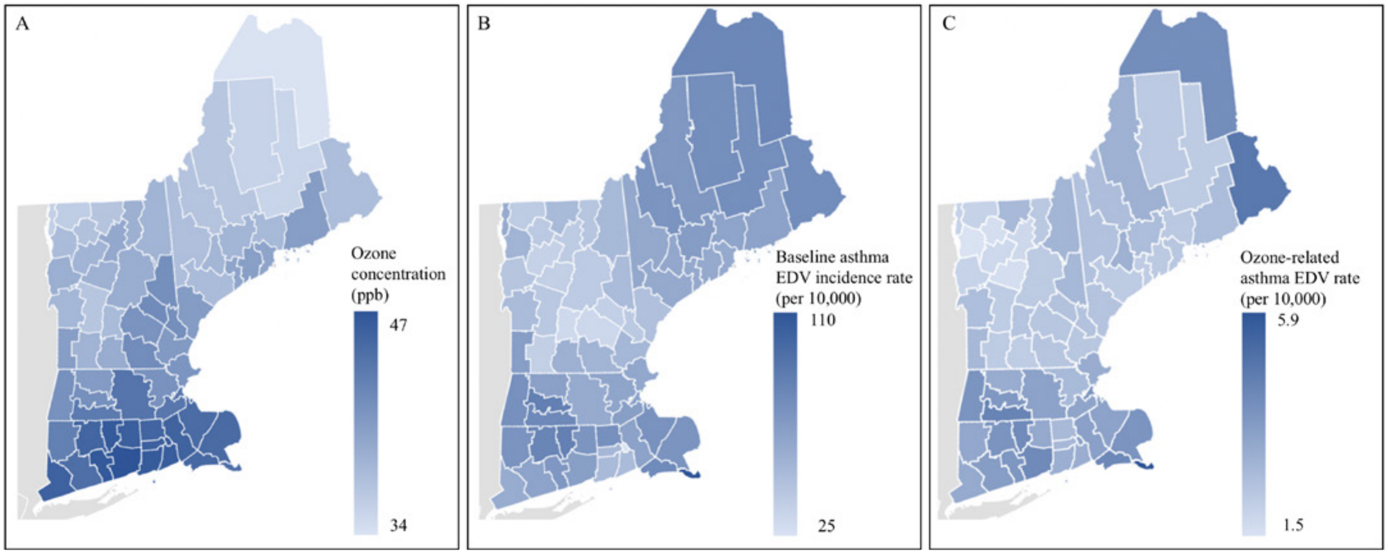
METHODOLOGY

We performed a health impact assessment to estimate the number of ozone-attributable asthma exacerbations in New England among all ages using the United States Environmental Protection Agency Benefits Mapping and Analysis Program (BenMAP), similar to prior studies.[5] This approach requires multiple data inputs including estimates of ozone concentrations, baseline incidence rates of asthma-related ED visits, population counts, and a defined concentration-response function providing estimates of the association between ozone and asthma exacerbation. Conditional on these inputs (described below), we then quantified ozone-attributable asthma exacerbation ED visits on a county-level as follows (Equation 1):

$$Y = Y_0 \cdot \left(1 - e^{-\beta \cdot \Delta O_3}\right) \cdot Pop$$

where Y is the number of ozone-attributable asthma exacerbation ED visits, Y_0 is the baseline incidence rate for asthma, ΔO_3 is the concentration of daily maximum 8-hour O_3, Pop is the population (age 0-99), and β is the risk coefficient on a natural log scale for asthma ED visits associated with daily O_3 exposure. County-level age-adjusted baseline incidence rates for asthma ED visits in 2010 are obtained from the National Environmental Public Health Tracking Network.[6-8] Daily maximum 8-hour ozone concentrations during the summertime, defined as May 1 to September 30, 2010 in New England are based on air pollution monitor stations within each state. BenMAP calculates an inverse-distance weighted average of nearby monitors to determine county-level ozone concentrations, an approach called the Voronoi Neighbor Averaging algorithm.[9] County-level population numbers are

Figure 1. Panel A: Average summertime (May 1–September 30), county-level ozone concentrations (parts per billion) in New England states in 2010.
Panel B: Age-adjusted baseline asthma emergency department visit (EDV) rates per 10,000 population in 2010 on a county-level.[8]
Panel C: Rates of ozone-attributable asthma ED visits per 10,000 people in New England counties in 2010.



based on the 2010 U.S. Census. The risk coefficient is based on the meta-analysis by Ji et al. (2011) that reports a 2.90% (95% CI 1.33, 4.50) increase in risk of ED visit for asthma exacerbation for every 10 part per billion (ppb) increase in daily maximum 8-hour O_3.[10]

RESULTS

In the New England states, warm season averages of daily maximum 8-hour O_3 concentrations between May and September 2010 ranged from 34–47 ppb and were highest in New London County and Middlesex County in Connecticut (**Figure 1**). Aroostook County in Maine had the lowest concentrations of O_3.

We estimate that in 2010 there were 4,612 (95% CI 2192, 6866) excess ED visits for asthma exacerbation attributable to summertime ozone exposure in New England. The average rate of excess asthma-related ED visits was 3.2 (95% CI 1.52, 4.75) per 10,000 population. Connecticut and Massachusetts had the highest rates of ozone-attributable asthma ED visits per 10,000 population, with 3.65 (95% CI 1.74, 5.41) and 3.40 (95% CI 1.62, 5.06) respectively, while Vermont had the lowest at 1.98 (95% CI: 0.94, 2.96) (**Figure 1**). Rates of ozone-attributable asthma ED visits per 10,000 population varied by county, ranging from 1.5 to 5.9 (**Table 1**). In terms of absolute numbers rather than rates, Massachusetts had the highest absolute number of ozone-attributable asthma ED visits on a state-level in 2010 and Vermont had the lowest at 2,226 (95% CI 1058, 3314) and 123 (95% CI 59, 185), respectively.

DISCUSSION

Ozone concentrations and the attributable asthma ED visits varied geographically across New England. The health effects of ozone on asthma vary in part due to differences in baseline asthma incidence rates between counties. Indeed, a few counties such as Washington County, Maine, have high rates of asthma ED visits at baseline that would contribute to relatively higher rates of ozone-related asthma ED visits despite relatively lower summertime ozone concentrations.

Table 1. Counties in New England with the highest and lowest rates of summertime ozone-attributable asthma ED visits in 2010.

Counties with highest number of ozone-attributable asthma ED visits		Counties with lowest number of ozone-attributable asthma ED visits	
County, State	**Asthma ED visit rate per 10,000 (95% CI)**	**County, State**	**Asthma ED visit rate per 10,000 (95% CI)**
Nantucket County, MA	5.89 (2.8,8.76)	Chittenden County, VT	1.49 (0.7,2.22)
Washington County, ME	4.79 (2.27,7.17)	Orange County, VT	1.61 (0.76,2.4)
Hampden County, MA	4.41 (2.1,6.57)	Lamoille County, VT	1.62 (0.76,2.41)
Dukes County, MA	4.27 (2.03,6.35)	Washington County, VT	1.8 (0.85,2.7)
New London County, CT	4.23 (2.02,6.28)	Caledonia County, VT	1.81 (0.86,2.7)
Tolland County, CT	4.17 (1.99,6.19)	Addison County, VT	1.97 (0.93,2.94)
Aroostook County, ME	4.11 (1.94,6.16)	Grand Isle County, VT	1.98 (0.94,2.96)
Somerset County, ME	3.0 (1.42,4.49)	Sagadahoc County, ME	2.16 (1.02,3.22)
Berkshire County, MA	3.92 (1.86,5.85)	Cheshire County, NH	2.17 (1.03,3.25)
Hartford County, CT	3.91 (1.86,5.81)	Windsor County, VT	2.18 (1.03,3.26)

Differences in ozone concentrations also explain the geographic heterogeneity of the health impacts on asthma and likely stem from the distribution of precursor emissions of nitrogen oxides and volatile organic compounds as well as sunlight and heat. While ozone concentrations in New England in 2010 were, on average, below the current Ozone National Ambient Air Quality Standard, set at 70ppb[11] there remained a substantial number of ED visits attributable to ozone. Prior studies have shown that reducing ozone concentrations below the national standard would lead to fewer deaths and fewer respiratory hospitalizations.[12]

In the future, climate change will have significant implications for asthma in New England, in part due to the influence of heat on ozone formation.[13] The Northeast is projected to have the fastest warming in the contiguous US, increasing 3°C by 2050 under some models.[14] There is also emerging evidence describing a synergistic effect of heat on air pollution and human health.[15] While our study estimates ozone-attributable asthma ED visits based on ozone concentrations in 2010, temperature increases in the future due to climate change will lead to more ozone formation while precursor emission levels are expected to decrease,[16] and may inform adaptation and mitigation strategies.

One of the strengths of this study is the spatial scale. We report ozone-attributable asthma ED visits on a state and county level. Understanding the local burden of ozone on asthma can provide useful information for policy-makers. Another strength is the use of local baseline incidence rates for asthma ED visits rather than applying a national or state level incidence rate to a county-level, since rates vary geographically.

There are multiple limitations to this study. Ozone concentrations are based on monitor station data, which are not always located in every county in this study and thus may not reflect the ozone concentrations on finer spatial resolutions. Similar to prior studies, we use an interpolation method within BenMAP to estimate ozone concentrations based on surrounding air pollution monitors.[17] Another limitation is the use of a single concentration-response function describing the relationship between ozone concentrations and asthma ED visits in all ages. Prior studies have reported differences based on sex and age in the concentration response relationship between ozone and asthma.[18]

Future work in this field would benefit from examining age-specific ozone-attributable ED visits for asthma exacerbation especially among vulnerable populations, such as children and elderly adults. Future research should also examine how mitigation strategies to address climate change affect ozone-attributable asthma ED visits.

CONCLUSIONS

Ozone air pollution is associated with thousands of asthma exacerbations requiring ED visit in New England. Rates of ozone-attributable asthma ED visits in New England varied by state and county in 2010, with the highest rates found in Connecticut and Massachusetts. These differences across space are likely due to a combination of varying demographic health characteristics and pollution levels, suggesting that efforts to reduce ozone-attributable ED visits should include improvements both to asthma treatments and air quality.

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Increased Temperatures Are Associated with Increased Utilization of Emergency Medical Services in Rhode Island

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ABSTRACT

BACKGROUND: Increasing temperatures negatively impact health and increases demands on healthcare systems. However, this has been poorly studied in Rhode Island (RI). Here we characterize the impact of heat on emergency medical services (EMS) utilization in RI.

METHODS: The Rhode Island National Emergency Services Information System V3 dataset was merged with data from the National Center for Environmental Information of the National Oceanic and Atmospheric Administration from the summers of 2018 and 2019. The outcome of daily mean EMS runs were compared against the exposure increasing daily temperatures, measured as daily maximum, minimum and daily average °F, using Poisson regressions. Patient characteristics were included across temperature models.

RESULTS: Increasing daily temperatures were associated with increasing EMS encounters. The adjusted incident rate ratio (IRR) for mean daily EMS encounters by increasing maximum daily temperature was 1.006 (95% CI 1.004–1.007, Table 3). This resulted in a projected 17.2% increase in EMS runs on days with a maximum temperature of 65°F compared to days with a maximum temperature of 95°F. The adjusted IRR for mean daily EMS encounters by the daily minimum temperature was 1.004 (1.003–1.006) and the adjusted IRR for the mean daily EMS encounters by the daily average temperature was 1.006 (1.005–1.008).

CONCLUSIONS: Increasing minimum, maximum, and average daily temperatures were associated with increasing EMS utilization across Rhode Island in the summers of 2018 and 2019. Further research into these trends may help with planning and resource allocation as summer temperatures continue to rise.

KEYWORDS: Heat, Emergency Medical Services, Rhode Island

INTRODUCTION

Heat detrimentally affects human health, leading to increased morbidity and mortality.[1] As carbon emissions continue to rise, the effects of heat on health will continue to worsen.[2] Specifically, increasing ambient temperature has been linked to worsened health outcomes, including hospitalizations and deaths across a range of disease-specific causes, including pure heat-related illness to cardiovascular, respiratory and renal disease.[3–6] Despite an international commitment to limiting global temperature rise to 2° Celsius as outlined in the Paris Climate Agreement, carbon emissions and temperatures continue to rise.[2] Over the last 20 years, heat-related deaths in patients 65 years or older have increased 53.7%. This resulted in 296,000 global heat deaths in 2018, 19,000 of which were in the United States.[2] Preparation and mitigation strategies for population health from climate change will require a clear understanding of the current climate change impacts on healthcare delivery.

Within the state of Rhode Island, only one study has explored the impact of heat on Emergency Department (ED) visits demonstrating increasing ED volume.[7] Logically, we expect this strain to increase across all aspects of the care continuum. However, no study has evaluated the impact of heat on EMS utilization across the state. Understanding changing demands in the summer may allow for improved planning and resource management as summers become hotter and longer. In this study, the correlation between increasing daily summer temperatures and emergency medical service utilization are described.

METHODS

Inclusion Criteria

All patient encounters with a Rhode Island agency emergency medical service (EMS) occurring in the state of Rhode Island between the months of June–August 2018 and 2019 were included for analysis.

Database Formation

The Rhode Island National Emergency Medical Services Information System (NEMSIS) V3 dataset was merged with the National Centers for Environmental Information of the National Oceanic and Atmospheric Administration (NOAA).[8] The NEMSIS V3 dataset is managed by the Center of Emergency Medical Services of the State of Rhode Island Department of Health and collects pertinent ambulance-run data for all agencies across the state of Rhode Island. It includes patient level data, including demographics, primary impression as well as the date, time and city of the encounter.

Duplicates were removed as defined by patient encounters that matched on date and time, age, race, gender, and complete address. Given that multiple EMS agencies may respond initially to the same call, a large number of duplicates were anticipated and observed. In addition, encounters not occurring within the state of Rhode Island were excluded. The NOAA database provides public access to the historical weather data and information in the United States. Daily maximum, minimum and average daily temperatures were extracted from the Providence, Theodore Francis Green State Airport weather station for dates of interest: June–August 2018 and June–August 2019 and merged by date with the NEMSIS dataset to provide temperature data on the date of each EMS call. Given possible effects of winter weather on EMS utilization, analysis was limited to months June–August. IRB approval was obtained through the RI Department of Health for access to the NEMSIS database.

Variable classifications

Patient-level data is ascertained from forms collected on each EMS run with each EMS agency responding completing a form. Demographic data extracted included: age, gender, race. Clinical data included: patient acuity and initial impression by EMS providers. Location information included: date and time of the response and address. The NOAA dataset contains no patient information and are available publicly. Age was categorized as <18 years, 18–65 and >65 years and race dichotomized as white versus non-white, consistent with previous heat research in Rhode Island.[7] Acuity was classified by EMS providers within the NEMSIS database as green, yellow, red or black (deceased) consistent with the Simple Triage and Rapid Treatment (START) triage method.[8] EMS primary impression were classified by physiologic system or topic including cardiac, renal, gastrointestinal disease, trauma.

Statistical Analysis

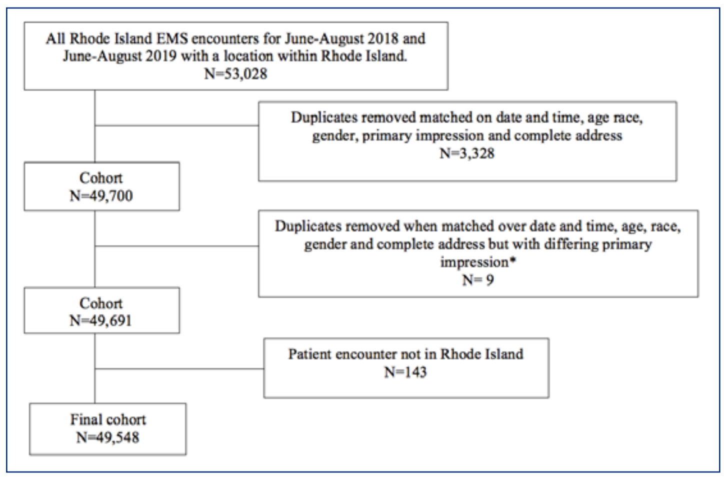
Given previous research demonstrating an increased mortality rate with maximum temperatures above 85°F in the state of Rhode Island,[7] cohort characteristics including year (2018 vs 2019), age, gender, race and acuity were compared with chi squared analysis dichotomized by encounters occurring on days with a maximum temperature below 85°F versus those occurring on days with a maximum temperature equal to or above 85°F. Mean EMS runs dichotomized by daily temperature at 85°F were compared with a two-sample t test.

The outcome of daily mean EMS runs was modeled against the exposure of increasing daily temperatures using Poisson regression. Variables for the model were chosen using forward selection and a Pr=0.2. Variables considered included: the city of the response, year, patient age, gender, acuity and EMS' first impression. Patient acuity, first impression and year were included in the maximum daily temperature model. Patient acuity, first impression, cohort year and age were included in the minimum daily temperature model and year and first impression were included in the average daily temperature model.

RESULTS

Within the NEMSIS database, 53,028 encounters were found for June–August 2018 and June–August 2019. After removal of duplicates and encounters not occurring within the state of Rhode Island, a final cohort of 49,548 EMS encounters remained (**Figure 1**). The majority (3,328) also matched on primary impression. Nine encounters had differing primary impressions (**Supplemental Table 1**).

Figure 1. Dataset creation with removal of duplicates from the EMS dataset. *For a list of the differing primary impressions see Supplemental table 1.



Supplemental table 1. Nine patients matched on date and time, age, race, gender and primary address with differing primary impressions. The encounter with impression 2 was removed from analysis.

Patient	Impression 1	Impression 2 (removed)
1	Traumatic injury	Injury of head
2	Injury of lower leg	Traumatic Injury, unspecified
3	Pain, unspecified	Injury of food
4	Fever	Missing
5	Injury of shoulder and upper arm	Injury of head
6	Injury of foot	Pain, unspecified
7	Injury of wrist, hand and fingers	Injury of lower back
8	Hypertension	Headache
9	Injury of neck	Injury of lower back.

Table 1. EMS response and patient characteristics for days below and above 85°F in Rhode Island, June–August 2018 and 2019.

	Maximum daily temperature < 85 °F N=28,168 (%)	Maximum daily temperature ≥ to 85 °F N=21,378 (%)	P value
Mean daily EMS runs	284.7 (95% CI 280.3–289.0)	300.7 (95% CI 295.9–305.5)	<0.0001
Year			
2018	12,782 (52.0)	11,788 (48.0)	<0.0001
2019	15,372 (61.6)	9,579 (38.4)	
Age			
<18	1,596 (5.7)	1,189 (5.6)	0.58
18-65	14,892 (52.9)	11,401 (53.4)	
>65	11,650 (41.4)	8,767 (41.1)	
Gender			
Male	13,253 (47.1)	10,188 (47.7)	0.33
Female	14,900 (52.9)	11,177 (52.3)	
Missing	10 (0.04)	10 (0.05)	
Race			
White	7,072 (25.1)	5,403 (25.3	0.22
Non-white	1,013 (3.6)	774 (3.6)	
Missing	20,083 (71.3)	15,201 (71.1)	
Acuity			
Green	14,789 (52.5)	11,309 (52.9)	0.30
Yellow	4,753 (16.9)	3,643 (17.0)	
Red	964 (3.4)	680 (3.2)	
Black	1 (0.0)	3 (0.01)	
Missing	7,661 (27.2)	5,743 (26.9)	
Top Five Primary Impressions			
Other	6,079	4,788	0.30
Cardiac	3,719	2,814	
Trauma	3,587	2,682	
Psychiatric	3,518	2,602	
Gastrointestinal	2,478	1,879	

Mean daily EMS runs were statistically higher on days with a maximum temperature above 85°F (285 vs. 300, p=<0.0001 **Table 1**). There was no statistical difference in patient characteristics: age, gender, race or acuity between those with an EMS encounter on days less than or greater than 85°F (**Table 1**).

The mean maximum, mean minimum and mean average daily temperatures between 2018 and 2019 were similar (**Table 2**). However, there were more days > 85°F in 2018 than 2019 (46% vs 37%) and a greater percentage of EMS runs on days that were over 85°F in 2018 versus 2019.

Increasing daily temperatures were associated with increasing EMS encounters for the state of Rhode Island in the summers of 2018 and 2019 (**Figure 2**). The adjusted incident rate ratio (IRR) for mean daily EMS encounters by increasing maximum daily temperature

Table 2. Daily temperature characteristics for the overall cohort and by year for June–August.

	Mean maximum daily temperature in °F (95% CI)	Mean average daily temperature in °F (95% CI)	Mean minimum daily temperature in °F (95% CI)
Overall	82.2 (81.2–83.3)	72.6 (71.7–73.5)	63.9 (62.9–64.9)
2018	82.9 (82.8–83.0)	73.1 (71.7–74.4)	64.4 (62.9–65.8)
2019	81.9 (80.4–83.3)	72.2 (71.0–73.4)	63.5 (62.3–64.8)

Figure 2. Mean daily EMS Responses by the maximum, minimum and average daily temperatures (°F) across the state of Rhode Island for June–August 2018 and 2019

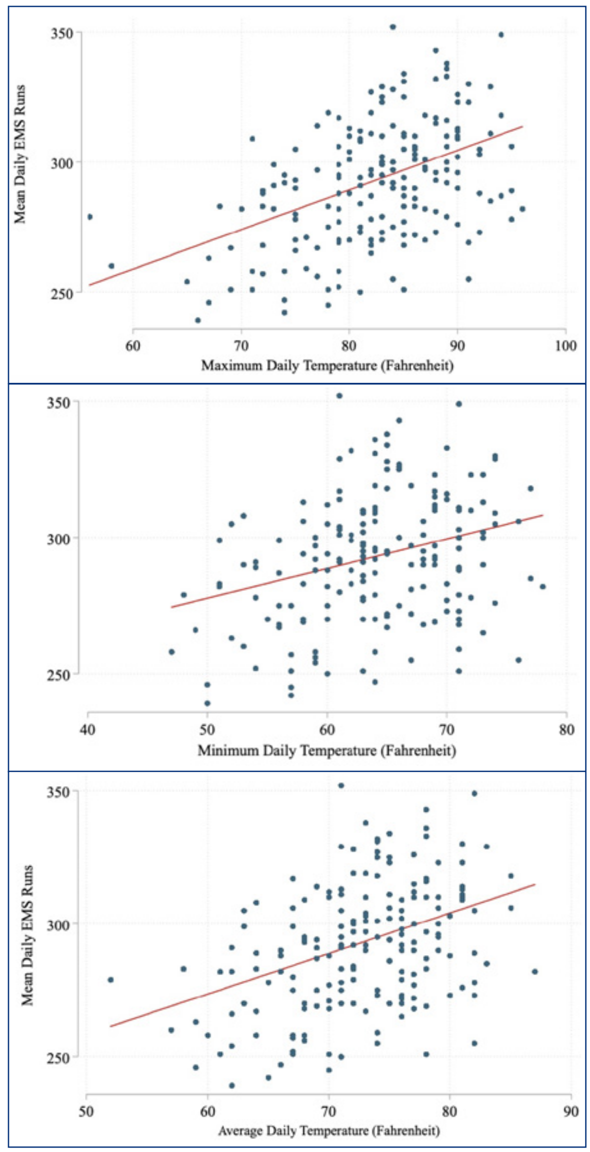


Table 3. Maximum daily temperature model controlled for patient acuity, first impression and year. Minimum daily temperature model controlled for patient acuity, first impression, year and age. Average daily temperature model controlled for year and first impression.

	Unadjusted Incident Rate Ratio Mean Daily EMS Encounters (95% CI)	Adjusted Incident Rate Ratio Mean Daily EMS Encounters (95% CI)
Maximum Daily Temperature	1.0053 (1.0052–1.0054)	1.006 (1.004–1.007)
Minimum Daily Temperature	1.0037 (1.0036–1.0038)	1.004 (1.003–1.006)
Average Daily Temperature	1.0053 (1.0052–1.0053)	1.006 (1.005–1.008)

was 1.006 (95% CI 1.004–1.007, **Table 3**). Thus, according to this model, we would expect an average of 250 EMS encounters on summer days with a maximum temperature of 65°F. While, on days with a maximum temperature of 95°F, we would expect an average call volume of 293, a 17.2% increase.

The adjusted IRR for mean daily EMS encounters by the daily minimum temperature was 1.004 (1.003–1.006) and the adjusted IRR for the mean daily EMS encounters by the daily average temperature was 1.006 (1.005–1.008).

CONCLUSIONS

Increasing minimum, maximum and average daily temperatures were associated with increasing EMS utilization across the state of Rhode Island in the summers of 2018 and 2019. Past literature has shown an association between increased ambient temperature and patient morbidity and mortality resulting in greater utilization and strain of the healthcare system.[5,9,10] In Rhode Island (RI), rising summer daily temperatures have been linked to worsened emergency department strain, with close to a 24% increase in Emergency Department (ED) visits.[7]

Heat has been associated with increased acute diseases as well as exacerbations of chronic illnesses. Specifically, heat has been associated with increased incidence of cardiac arrest,[6] subarachnoid hemorrhage,[11] acute kidney injury,[12] hyponatremia,[13] pulmonary arterial hypertension[14] and ischemic heart disease[15] to name a few. However, in this study, EMS' primary impression of the patient's illness did not change for days less than or greater than 85°F. In addition, the patients demographics including age, race acuity level did not change.

There was a greater percentage of patients seen on days over 85°F in 2018 than in 2019 most likely because there were more days over 85°F in 2018 as compared to 2019.

LIMITATIONS

Associations of EMS runs, heat and patient acuity or race were limited by large amounts of missing patient data. However, it is most likely missing at random and therefore represents a non-differential error. Thus, its impact on the association observed between heat and increasing EMS utilization is presumed to be minor. Given that heat impacts vulnerable populations disproportionately (SOURCE), vulnerable races may demonstrate a disproportionate increase in EMS utilization as temperature increases. However, data were insufficient to examine this relationship and future studies are needed to further examine this relationship. In addition, final hospital diagnosis was not available for patient encounters. The proxy of EMS' primary impression was used but may not fully capture the impacts on health outcomes in the population. Further research linking EMS records to hospital records including an evaluation of the final diagnosis would be beneficial.

Heat puts strains across all strata of emergency services, including EMS. As temperatures continue to rise, understanding the extent of increased demands may allow for appropriate staffing, early warning systems and increased public mitigation strategies such as cooling centers.

Additional heat considerations or measurements may also be important to examine. For example urban heat islands (UHIs) are areas of urbanization that, secondary to heat absorptive surfaces such as concrete and asphalt, result in surface temperatures above the average surface temperature in that geographic area.[16] Urban heat islands and heatwaves, neither examined in this study, have also been identified as exacerbating heat effects and may play in important role in the increased EMS usage during hot days seen here. Heatwave events, or prolonged periods of abnormally high temperatures, have resulted in specific negative health impacts including an increase in heat-related mortality rates[9] As our climate warms, heatwaves are increasing in frequency and associated morbidity is worsening.[2] In addition, UHIs are areas of urbanization that, secondary to heat absorptive surfaces such as concrete and asphalt, result in surface temperatures above the average surface temperature in that geographic area.[17] Patients living in UHIs are especially susceptible to heat waves and the deleterious health effects of increasing ambient temperatures.[16] Future research will further characterize EMS utilization during heatwaves and within UHIs. This understanding will better inform future preparedness and mitigation strategies.

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Potential Effects of Climate Change on Tick-borne Diseases in Rhode Island

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ABSTRACT

Human cases of tick-borne diseases have been increasing in the United States. In particular, the incidence of Lyme disease, the major vector-borne disease in Rhode Island, has risen, along with cases of babesiosis and anaplasmosis, all vectored by the blacklegged tick. These increases might relate, in part, to climate change, although other environmental changes in the northeastern U.S. (land use as it relates to habitat; vertebrate host populations for tick reproduction and enzootic cycling) also contribute. Lone star ticks, formerly southern in distribution, have been spreading northward, including expanded distributions in Rhode Island. Illnesses associated with this species include ehrlichiosis and alpha-gal syndrome, which are expected to increase. Ranges of other tick species have also been expanding in southern New England, including the Gulf Coast tick and the introduced Asian longhorned tick. These ticks can carry human pathogens, but the implications for human disease in Rhode Island are unclear.

KEYWORDS: ticks, climate change, Lyme disease, Babesiosis, Ehrlichiosis

INTRODUCTION

Ticks are major disease vectors in north temperate regions worldwide, transmitting a wide variety of pathogen types. Although mosquitoes are recognized as vectors of widespread tropical diseases such as malaria and dengue, they are responsible for far fewer cases of disease than ticks in North America. In Rhode Island, mosquitoes are responsible for an average of only about one human case of arboviral disease per year.[1] In contrast, annual cases of tickborne ailments in Rhode Island run into the thousands (https://health.ri.gov/data/diseases/). Climate change would be expected to result, overall, in a poleward shift in the distributions of tick-borne diseases.[2] However, numerous other environmental and socioeconomic factors that affect vector-borne disease transmission are also changing. This complicates direct predictions of climate change effects on future disease distribution patterns, and only a few examples have been demonstrated convincingly for tick-borne pathogens.[2] In this brief review we identify the major tick-borne diseases that currently occur in Rhode Island, describe the underlying transmission dynamics, and consider the likely effects of climate change. We also discuss tick species that have recently spread into the region and the pathogens they might bring with them.

MAJOR TICK-BORNE DISEASES IN RHODE ISLAND

The major tick disease vector in Rhode Island is the blacklegged tick (sometimes called the deer tick), *Ixodes scapularis*, which transmits the spirochete that causes Lyme disease. Several tick-borne pathogens cause human disease in Rhode Island, with Lyme disease being far the most common (**Table 1**). Reported cases of Lyme disease in the state are in the vicinity of 1,000 per year, but this is undoubtedly a substantial underestimate. A recent CDC estimate using insurance claims data indicates that the annual number of cases diagnosed in the US from 2010–2018 averaged about 476,000, compared to the average of only about 35,000 cases per year reported to the agency.[3]

The blacklegged tick is concentrated in woodlands with leaf litter and is most abundant in the southern portion of Rhode Island, but numbers fluctuate substantially from year

Table 1. Major tick-borne diseases in Rhode Island

Tick vector	Disease	Pathogen	Mean # cases per yr. (2015–2019)*
Blacklegged tick, deer tick (*Ixodes scapularis*)	Lyme disease	*Borrelia burgdorferi*	1,004.2
	Anaplasmosis	*Anaplasma phagocytophilum*	141.4
	Babesiosis	*Babesia microti*	165.8
	Powassan Encephalitis	Powassan virus, Deer tick virus	0.8
Lone star tick (*Amblyomma americanum*)	Ehrlichiosis	*Ehrlichia chaffeensis*, *E. ewingi*	57.0
American dog tick (*Dermacentor variabilis*)	Spotted Fever Group Rickettsiosis	*Rickettsia rickettsii*, *R.* spp.	6.0

* Data in Table 1 and Figure 1 from CDC (https://www.cdc.gov/nndss/data-statistics/infectious-tables/index.html)

to year such that dense populations extend throughout the state in some years.[4] In addition to Lyme disease, which is caused by a spirochete, the blacklegged tick is also the primary vector of the two other major tick-borne pathogens in Rhode Island, the rickettsia that causes anaplasmosis and the protozoan that causes babesiosis (**Table 1**). This tick can also transmit pathogens less commonly reported in Rhode Island, including Powassan encephalitis virus, and the relapsing fever spirochete *Borrelia miyamotoi*.[5]

Two other tick species are important vectors of human pathogens in Rhode Island, the lone star tick, *Amblyomma americanum*, which transmits the rickettsiae that cause ehrlichiosis and possibly those that cause Rocky Mountain Spotted Fever, and the American dog tick, *Dermacentor variabilis*, the primary vector of Rocky Mountain Spotted Fever (**Table 1**). These two tick species can also transmit the bacterium *Francisella tularensis*, which causes tularemia, but this pathogen is often transmitted via infectious fluids through handling or even breathing aerosols from infected animals rather than from tick bite. These diseases are far less common than some of those vectored by *I. scapularis*, but the distributions of these tick species are changing,[6] and effects of climate change are potentially important. Resources for identification of tick species, and information sources relevant to disease transmission and status in Rhode Island are readily available online (https://web.uri.edu/tickencounter/).

CLIMATE CHANGE AND TRANSMISSION PATTERNS OF TICK-BORNE PATHOGENS

Lyme disease, Anaplasmosis, Babesiosis

Rhode Island is near the center of the current geographic distribution of Lyme disease, and is likely to remain an epicenter of Lyme and other major tick-borne diseases in the foreseeable future. In the eastern and central U.S., Lyme disease is most common in the northern states, and relatively uncommon in the south (https://www.cdc.gov/lyme/datasurveillance/maps-recent.html). This pattern results primarily from latitudinal trends in host-seeking behavior and host associations of larval and nymphal ticks. Northern *I. scapularis* wait on leaves and twigs at the leaf litter surface and attach to passing hosts, while southern ticks remain below the litter surface when host-seeking.[7] Therefore, people frequently encounter northern ticks in their woodland habitats, but there is relatively little human exposure in the south.[8] Furthermore, northern larval and nymphal ticks feed primarily on small mammals such as rodents and shrews, which are excellent reservoirs for the Lyme spirochete, while southern ticks feed mostly on lizards, which are relatively poor reservoirs, so prevalence of spirochetal infection is much lower in southern than in northern ticks.[9] Some of these latitudinal differences might well be related to north-south climatic differences,[10] and so might be affected by climate change. Some modeling studies predict that climate change-related effects on factors such as tick development and phenology are likely to result in increases in Lyme disease incidence in the northeast,[11,12] as well as increased spread northward into Canada. Indeed, cases of Lyme disease have been increasing in the U.S., and northward spread into Canada has been documented.[13] However, predictions for changes in current endemic areas vary with model assumptions and local complexities,[14] so these effects remain uncertain for Rhode Island. Human cases of Lyme disease reported to the CDC have been increasing in Rhode Island (**Figure 1A**). Furthermore, evidence from various sources suggest that populations of *I. scapularis*, and human cases of associated diseases, have been increasing in the northeast,[6,15] and that these changes result, at least in part, from the effects of climate change.[2]

Epidemiological trends in cases of anaplasmosis and babesiosis are expected to be similar to those for Lyme disease, because they have the same tick vector species, *I. scapularis*, and the same primary reservoir species, the white-footed mouse (*Peromyscus leucopus*). As such, patterns of epizootiology are similar for these pathogens, except that transmission efficiency is apparently greater for *Borrelia burgdorferi* than for *Anaplasma phagocytophila*[16] or *Babesia microti*,[17] so infection prevalence of these pathogens in ticks is lower than that of Lyme spirochetes, and there are fewer human cases (**Figure 1B**). Thus, anaplasmosis and babesiosis are likely to remain important in Rhode Island,

Figure 1A.

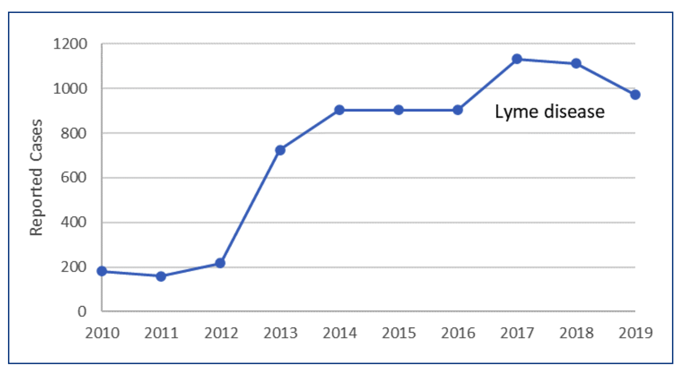
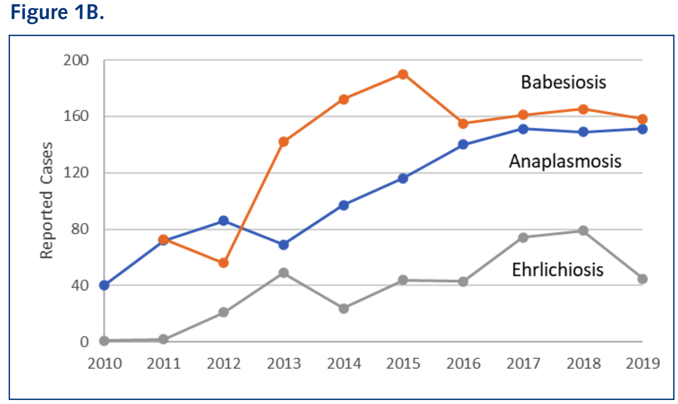


Figure 1B.



and though cases are expected to increase, they will likely remain less prevalent than Lyme disease.

Ehrlichiosis, alpha-gal syndrome

The lone star tick, *A. americanum*, is the vector of the rickettsiae that cause ehrlichiosis.[18] Growing evidence indicates that lone star tick bites are also responsible for alpha-gal syndrome (also called red meat allergy or tick bite meat allergy), an allergic response to the carbohydrate galactose-alpha-1,3-galactose, which is found in mammalian meat.[19] Populations of this tick species are spreading northward[20] and ehrlichiosis cases have been increasing in Rhode Island (https://health.ri.gov/data/diseases/Erlichiosis.pdf). Lone star ticks were formerly southern in distribution, with dense populations from central New Jersey and southward, but populations increased substantially on Long Island, NY, in the late 1980s and 1990s, and they are now established in Connecticut.[21] Climate change might contribute to the northward spread of this species, but increasing populations of its primary hosts, including white-tailed deer, coyotes, and wild turkeys, are also important.[20] This tick has previously been rare on the mainland of Rhode Island, although a dense population has existed on Prudence Island in Narragansett Bay, at least since 1990.[22] Populations have increased substantially since 2016 on Conanicut Island, and established populations (all three life stages) are now being detected at mainland sites, especially in coastal communities on both sides of Narragansett Bay and the south coast (TNM, personal observation). Thus, lone star ticks are spreading northward, likely related to changes in climate and in host distributions. Rhode Island is within the potential range of this species predicted by some models, but not others.[23] Given the recent local increases in *A. americanum* populations and the persistent population on Prudence Island, it is reasonable to expect increases in Rhode Island cases of ehrlichiosis and alpha-gal syndrome in the future.

Spotted fever group rickettsioses

The primary vector of *Rickettsia rickettsii*, etiologic agent of Rocky Mountain Spotted Fever (RMSF) in North America, is the American dog tick, *D. variabilis*, which is responsible for modest numbers of human cases in Rhode Island (**Table 1**). This species is distributed widely in the eastern U.S., and climate change might well result in larger populations in the northern U.S. and Canada.[6] Most RMSF cases currently occur in a band from the Carolinas to Oklahoma,[24] so climate change could result in greater numbers of cases in our area. This pathogen is maintained vertically in *D. variabilis* (passed from mother to offspring), and outbreaks tend to be focal, with local amplification presumably resulting from horizontal transmission by ticks among mammal hosts.[25]. However, these dynamics are poorly understood, so it is difficult to predict the likely effects of a changing climate on the epidemiology of RMSF.

Another spotted fever group rickettsia, *R. parkeri*, is transmitted by the Gulf Coast tick, *Amblyomma maculatum*. This tick was formerly found only in the southern states, but it has recently expanded its range into the mid-Atlantic region,[26] and an established population has recently been reported in Connecticut.[27] Human infection with *R. parkeri* has not yet been detected in Rhode Island, but given the northward range expansion of the vector, this possibility is worthy of attention in the future.

TICK SPECIES LIKELY TO SPREAD INTO RHODE ISLAND

Northward spread of two tick species has already been discussed: *A. americanum*, which is already present in Rhode Island and is likely to increase in the future, and *A. maculatum*, which has not yet been detected in the state, but which is spreading into the region. Both species present potential implications for human health, and their range expansion might be related, at least in part, to climate change.

A third tick species that was introduced into the United States, presumably from its native range in Asia, has recently appeared in the region, and the implications for human health are currently unclear. The Asian longhorned tick, *Haemaphysalis longicornis*, was first detected in North America in 2017. Examinations of earlier collections indicate that this species was present in the United States several years before that detection. It has now been detected in 16 states, and on dozens of animal species (https://www.aphis.usda.gov/animal_health/animal_diseases/tick/downloads/longhorned-tick-sitrep.pdf). Populations are known to exist on Block Island, and *H. longicornis* has recently been collected on the Rhode Island mainland (TNM, personal observation). The North American populations are parthenogenetic and can rapidly increase to high densities. This tick is known to vector numerous pathogens in Asia, including Severe Fever with Thrombocytopenia Syndrome (SFTS) virus,[28] and has become an introduced pest of cattle in Australia. It serves as a vector of the cattle pathogen *Theileria orientalis* Ikeda in Virginia.[29] To date, no human pathogens have been isolated from *H. longicornis* in the United States, except for one *B. burgdorferi* isolate from Pennsylvania.[30] Lab studies suggest that *H. longicornis* is not a competent vector of *B. burgdorferi*[31] or of *A. phagocytophilum*,[32] but that this tick species can acquire and transmit the RMSF pathogen *R. rickettsii*[33]. The potential role of this species as a vector of human pathogens in the U.S. remains unclear. Fortunately, this species does not readily bite humans, although cases of attachment to humans have been reported in the United States.[34] Rhode Island is within the predicted distribution of this species,[35] and populations are likely to increase in the future.

CONCLUSIONS

Incidence levels of tick-borne diseases generally respond to changes in environmental conditions such as habitat, vertebrate host populations, and climate, as well as to factors that influence tick encounter by people. Human cases of several tick-associated diseases in Rhode Island, Lyme disease chief among them, but also anaplasmosis, babesiosis, ehrlichiosis, and alpha-gal syndrome, are likely to increase in the future. Northward range expansions of some tick species into Rhode Island are likely, but the implications for human health are unclear.

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Wasting No Time: Implementation and the Climate Impact of a Solid Waste Stream Process Intervention in a Large Academic Emergency Department

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INTRODUCTION

Climate change is one of the most critical issues facing our planet, and healthcare systems play a major role in generating the greenhouse gases that lead to accelerated climate change.[1] In fact, healthcare is responsible for 10% of all greenhouse gas emission in the United States[2] and generates 4.3 million tons of waste annually.[3] Moreover, the emergence of the COVID-19 pandemic has created myriad challenges including the increased production of biomedical waste.[4]

Meaningful solutions to reduce the impact of human activity on climate change must include efforts by healthcare systems to reduce waste and decrease the production of greenhouse gases. In particular, biohazard waste, also known as regulated medical waste (RMW), requires autoclaving and shredding and results in up to fifteen times as much greenhouse gas equivalents emitted as compared to regular solid waste.[5,6] In addition, RMW processing is seven times more costly to healthcare systems as compared to regular solid waste processing.

RMW is typically defined as items saturated in blood or potentially infectious bodily fluids, sharps, and syringes and is generally collected in red biohazard bags and sharps containers. RMW comprises just a fraction of all waste produced within a medical system, yet idiosyncratic institutional practices (such as the sole use of red bags for all medical waste disposal) can adversely affect the environment at a disproportionate level. In order to mitigate this particular problem in the Emergency Department (ED) at Rhode Island Hospital (RIH), a multi-disciplinary departmental "Green Team" planned and implemented a pilot intervention, i.e., the introduction of a regular solid waste disposal "clear bag" option with accompanying educational efforts and materials on proper waste sorting.

Similar efforts have been successful in other healthcare settings: Inova Fairfax Hospital saved nearly $200,000 in annual waste disposal fees through better segregation of waste and a concerted effort to educate and engage staff;[7] a study by Garcia et al. reported a 2-million pound decrease in biohazard waste with a corresponding savings of $696,000 in annual costs through a similar hospital-wide initiative at Brookdale University Hospital and Medical Center.[8] However, we are not aware of initiatives that have been specific to the ED – this may be due to the positioning of the ED as a unique and high-risk environment with respect to waste disposal, given the nature of its clinical operations and associated challenges.

Figure 1. Regulated medical waste and tan regular solid waste bins.

In this context, the Green Team aimed to decrease its ED greenhouse gas footprint as well as operational costs by introducing new tan waste bins with clear bags for regular solid waste disposal (alongside the existing red waste bins and red bags for biohazard waste, **Figure 1**). In addition, educational materials were created and disseminated to ED staff by the Green Team to promote proper waste disposal one month prior to rollout of the project. In parallel with these processes, the team planned and conducted an objective analysis of the environmental impact and fiscal savings of this change within the ED. This manuscript describes the project's design, conduct, findings, and measured impact.

METHODS

Baseline Analysis

Green Team members met with institutional personnel, including environmental service staff to understand the existing waste stream processes. After meetings and direct observation, the project team conducted a baseline analysis by weighing the ED waste stream (comprising RMW and regular solid waste) over 7 days and then 14 days at two time points prior to implementation of the project's pilot intervention.

Education

To ensure that all ED technicians, nurses, advanced practice providers (APPs) and physicians understood proper disposal processes as well as the implications of correct waste disposal, the Green Team created educational materials for distribution. The Green Team developed posters to be placed on waste bins and in utility rooms, as well as slide shows with a brief overview of the planned intervention to display at education sessions. All materials were reviewed and approved by the institution's department of infection control. In-person education sessions were held at faculty meetings, resident conferences, APP meetings, and nursing and technician huddles; emails detailing the project were sent to all staff. Education sessions were also held with all environmental services staff who were briefed on waste disposal process updates as well as how to report RMW that was erroneously discarded in the regular solid waste stream (solid waste within the RMW stream was not reported). Instances of incorrect disposal of RMW were reported via an online reporting form for review by the Green Team and the institutional safety officer.

The multi-disciplinary composition of the Green Team facilitated staff buy-in and adherence to the new waste stream process. Dissemination of project goals and new waste disposal guidelines to staff began one month prior to implementation of the new process.

Project Solid Waste Stream Process Intervention

One month following the second baseline weighing, 105 tan bins with clear bags were added to ED patient rooms and areas (**Figure 1**). (Pre-existing tan bins which had been lined with red bags received clear bags.) Laminated signs reminding staff of appropriate waste disposal guidelines were affixed to the lids of the tan bins within patient rooms (**Figure 2**). A third ED waste stream weighing (for RMW only) was completed over a 3-week intervention period. (**Figure 3**)

Figure 2. Educational poster attached to tan bins placed in the ED for regular solid waste handling.

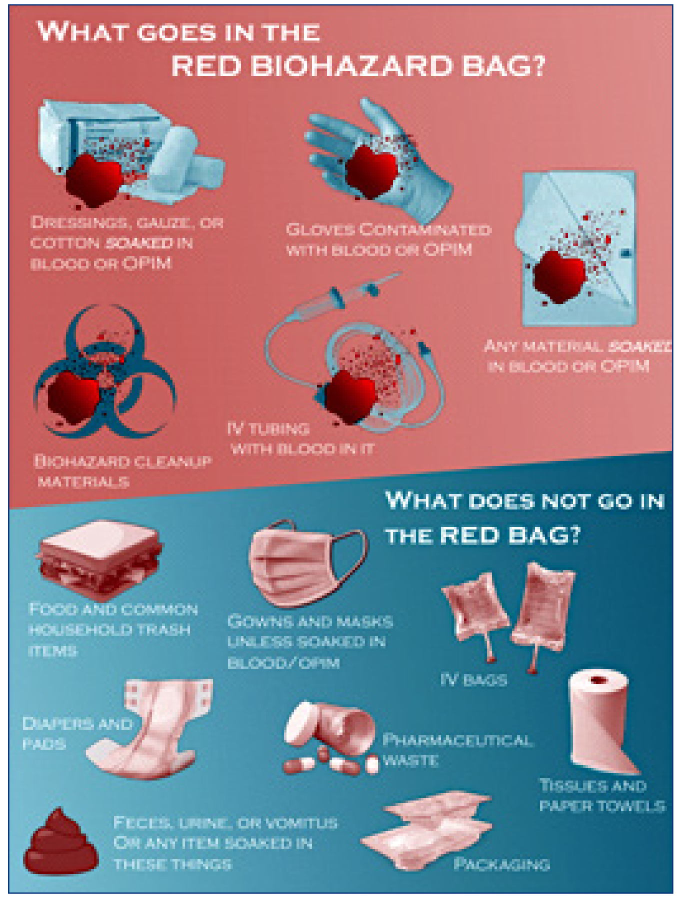
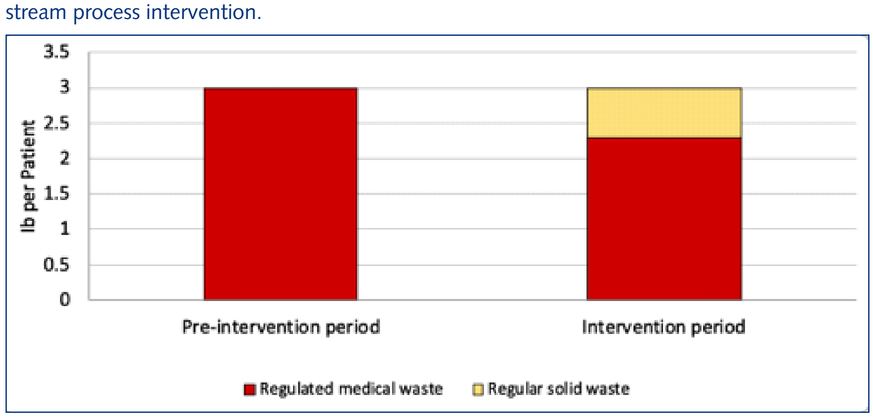


Figure 3. ED waste weights (lbs) per patient before and during introduction of a solid waste stream process intervention.



Data Analysis

Daily ED red bag weights for the pre-intervention period (RMW and regular solid waste) and for the intervention period (RMW only) were calculated with correction for ED census (patients who left prior to full medical evaluation were excluded from the census). Given that no interventions were implemented to change provider behaviors or institutional processes with respect to medical care and the resultant waste, the quantity of overall, total census-adjusted ED daily waste was presumed to remain the same, such that any red bag weight reductions in the intervention period were ascribed to the diversion of regular solid waste into the new clear bags and tan bins. A one-sided t-test was employed to compare the pre-intervention and intervention periods' red bag weights.

Greenhouse gas equivalents were calculated using the M+WasteCare Calculator.[5] The calculator used the amounts of pollutants in each step of the disposal process and converted them to carbon dioxide equivalents (greenhouse gas equivalents). Emissions factors were used for all calculations, including waste transportation to landfill and emissions associated with the landfill. The difference in greenhouse gas equivalent tons per year (TPY) for autoclaved RMW vs regular solid waste was calculated and applied to the observed and annual projected reductions (based on the

2020 ED census) in RMW production. RMW was classified as autoclaved on-site prior to being landfilled. Cost savings were estimated using the reduction in daily ED red bag waste weights between the two periods and with adjustment for accompanying increase in solid waste processing costs.

RESULTS

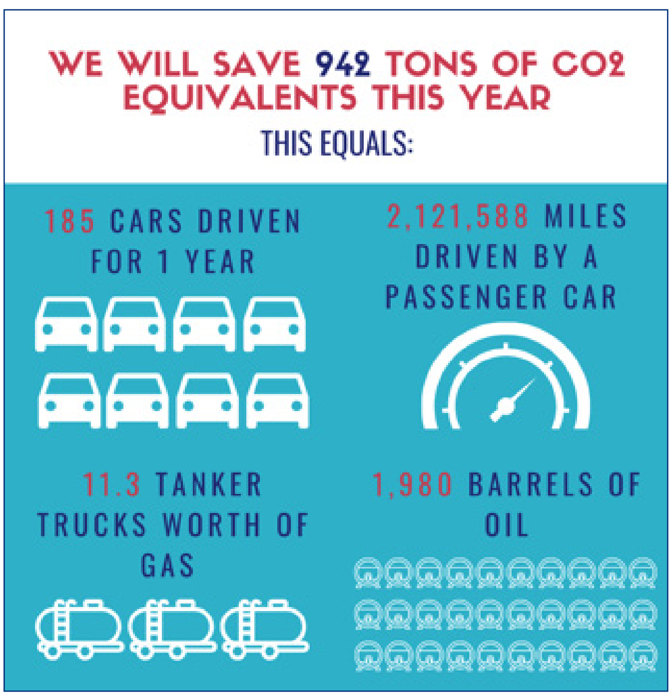
During the pre-intervention measurement periods, the average red bag waste produced per ED patient was 3.0 lbs (95% CI 2.5-3.5). Over the intervention period, the average red bag waste produced per ED patient was 2.3 lbs (95% CI 1.8-2.8, p=0.02), resulting in a net 0.7 lb reduction in biohazard waste per ED patient. Assuming no change in overall waste production per patient, regular solid waste constituted 23.3% of all waste generated during the intervention period. Using the 2020 ED census of 84,221 encounters, the projected annual RIH ED diversion of biohazard waste for 2021 will be 62,323 lbs (31.2 tons). The projected reduction in ED waste greenhouse gas equivalents is 942 TPY; the projected savings in ED waste processing costs is $11,841 per year. As of three months after the intervention period, there were no reported incidents of RMW within the regular solid waste stream.

DISCUSSION

Institution of a regular solid waste stream within a large academic ED resulted in significant reductions in greenhouse gas emissions. Projections indicate that in just the subsequent year, emissions prevented will be equivalent to over 2 million miles driven by a passenger car, 1,980 barrels of oil, or over 11 tanker trucks worth of gas (**Figures 4**).[10] Furthermore, the project's pilot intervention was found to be fiscally beneficial for the hospital system, with return on investment from start-up costs reached within nine months.

While the 23% reduction in actual RMW by the intervention represents a significant decrease for our ED, waste audits of other EDs suggest room for improvement. For example, a recent waste audit of a large academic ED in Boston demonstrated RMW was 10.7% total waste[9], and a similar audit of a community ED in Rhode Island found just 3% RMW. We expect greenhouse gas savings to improve over time with continued education and institutional adoption of eco-friendly waste disposal practices.

Figure 4. Educational poster distributed after institution of the solid waste stream process intervention to inform employees of the project's impact.



Limitations

Given the process by which hospital waste is measured at our institution, it was not possible to isolate and weigh only the regular solid waste component. Thus, calculations assumed the same total generation of waste on a per-patient basis. A formal waste audit was not performed to calculate the proportions of appropriate waste versus inappropriate waste within the RMW stream – a formal audit of the RMW stream in the future would allow for tailored education and further interventions to continue to reduce RMW generated.

Due to the architectural configuration and operational layout of the ED, certain patient care areas such as the 12-bed critical care patient space were not included in the project – there is significant healthcare waste produced in this area, and there exists the potential for substantial additional greenhouse gas reductions and cost savings. Future research will examine the amount and type of waste generated from this area as well as potential interventions to reduce impact.

The M+WasteCare calculator[5] uses known formulas for carbon and other pollutant generation from medical waste. Variables added to the calculator include distance to landfills, type and frequency of waste transport. There may be slight variations in the actual amount of greenhouse gases produced based on these variables. However, because the variables were constant across the measured periods, the impact of the intervention should not have been affected.

CONCLUSIONS

Proper sorting of RMW and regular solid waste within EDs represents a straightforward, economical, and impactful environmental intervention. While risk to the healthcare system exists in the form of waste misclassification, from this intervention, this appears to be minimal and outweighed by the advantages. In light of the COVID-19 pandemic and the related increase in biomedical waste, conscientious disposal practices will be even more important to the environmental sustainability of our healthcare systems.

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Trends in Waste Production at a Community Hospital during the COVID-19 Pandemic

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ABSTRACT

INTRODUCTION: As of September 2021, the COVID-19 pandemic has led to 42,500,000 cases and 680,000 deaths in the United States. In Rhode Island, there have been 170,000 cases and 2,820 deaths. Investigating resource utilization and waste production during disease outbreaks can inform efforts at disaster preparedness. The purpose of this study was to examine trends in waste production during the COVID-19 pandemic.

METHODS: This is a descriptive study examining trends in waste production during the COVID-19 pandemic. The study was conducted at a suburban community hospital in Rhode Island. Data was collected on regulated medical waste (RMW) and linen use from October 2019–July 2021. Adjusted patient days (APD) values were calculated using hospital census and revenue data. Total weight and weight/APD were calculated for each month of the study period. Data was then compared with overall COVID-19 cases and hospitalizations in Rhode Island. This data was gathered from the Rhode Island Department of Health (RIDOH) COVID Response Data Hub.

RESULTS: Regulated Medical Waste (RMW) by total weight was lowest in April 2020, when the hospital census and adjusted patient days (APD) were at their lowest. In contrast, linen use remained largely consistent with pre-pandemic levels during the initial months of the pandemic despite a decrease in hospital census. The highest linen weight/APD value (23.32 lbs/APD) was in April 2020. Both RMW and linen use (weight/APD) decreased during the study period. Linen use was highest during months with increased COVID-19 cases and hospitalizations.

CONCLUSIONS: This study examined trends in waste production at a community hospital during the COVID-19 pandemic. Linen use was highest during months of increased COVID-19 cases and hospitalizations, while RMW production decreased. There was a particular increase in linen use in April 2020, when the pandemic was in its initial phases.

KEYWORDS: COVID-19, waste, medical waste, pandemic, disaster preparedness

INTRODUCTION

As of September 2021, the COVID-19 pandemic has led to 42,500,000 cases and 680,000 deaths in the United States.[1] In Rhode Island, there have been 170,000 cases and 2,820 deaths.[2,3] Sophisticated hospital based patient care requires an enormous investment in resources, but results in waste production. Understanding how waste is produced can inform disaster preparedness efforts for future pandemics.

Most waste from the ED is considered municipal solid waste (MSW) and can be disposed in a landfill. It requires no additional treatment prior to transport. Disposal of regulated medical waste (RMW), which includes most bodily fluids such as blood and sputum suspected to carry infectious pathogens, may potentially increase when a new and unfamiliar disease emerges. The disposal of RMW requires strict adherence to specific procedures and, as such, is expensive and burdensome to the environment. Variables that affect the carbon footprint of waste production and removal include the type of waste, the method and site of disposal, and the means of conveyance.

The global response to waste production underscores the necessity of planning during a pandemic. In Romania, government-imposed restrictions on the disposal of waste from health care and designated quarantine facilities led to illegal dumping of medical waste.[4] In Indonesia, medical waste increased during the initial months of the pandemic; however, there was a lack of appropriate facilities for the disposal of this waste.[5]

Understanding trends in RMW during outbreaks of novel disease can guide preparation among health systems and government officials and can inform disaster preparedness efforts for future pandemics. As such, the purpose of this study was to examine trends in waste production at a suburban community hospital during the COVID-19 pandemic. Investigators focused particularly on RMW and linen use during the study period.

METHODS

This is a descriptive study examining trends in waste production during the COVID-19 pandemic. The study was conducted at a suburban community hospital in Rhode Island with 346 inpatient beds and an annual Emergency Department (ED) volume of approximately 70,000 patient encounters. The hospital has an Intensive Care Unit (ICU) and Progressive Care Unit (PRG) that provide services for critically ill patients. During the COVID-19 pandemic, the number of beds in these units varied based upon patient volume, infection control policies and care requirements. The hospital is home to several graduate medical training programs, including residencies in Family Medicine, Internal Medicine and Emergency Medicine.

Data was collected on regulated medical waste (RMW) and linen use from October 2019–June 2021. This time period was selected since it included six-months prior to the beginning of the COVID-19 pandemic. RMW and linen were selected as categories for analysis because of their pertinence to infectious control. RMW included all items placed in red biohazard bags. This did not include sharps. It did not include waste that could be categorized as RMW inappropriately placed in non-RMW containers. Linens included patient gowns and bedding as well as reusable isolation gowns. The hospital in this study utilizes reusable isolation gowns for patients who meet certain infection control criteria. These gowns are laundered after use and subsequently returned into circulation.

Environmental Services (EVS) gathers information on various categories of hospital waste, including sharps, linens, municipal solid waste (MSW), and RMW. These materials are weighed daily and recorded monthly. Adjusted patient days (APD) were calculated using hospital census and revenue data per criteria established by the Centers for Medicare & Medicaid Services (CMS). Weight per APD (lbs/APD) was then calculated for RMW and linens. These data points were plotted and compared to overall cases and hospitalization due to COVID-19 in Rhode Island. This information was gathered from the Rhode Island Department of Health (RIDOH) COVID Response Data Hub.

Figure 1. Total Weight (lbs) of Regulated Medical Waste (RMW) by Month

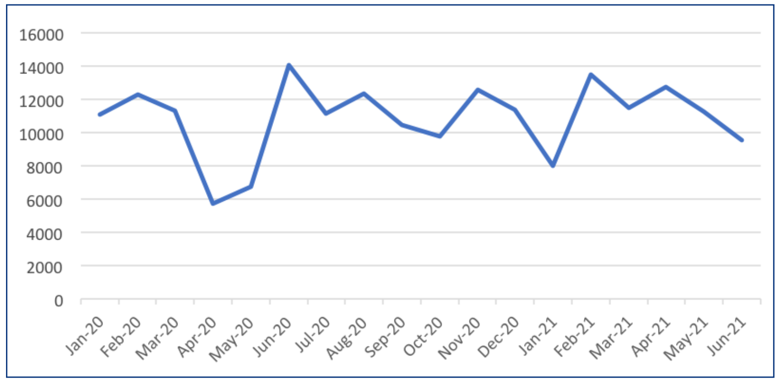


Figure 2. Adjusted Patient Days (APD) by Month

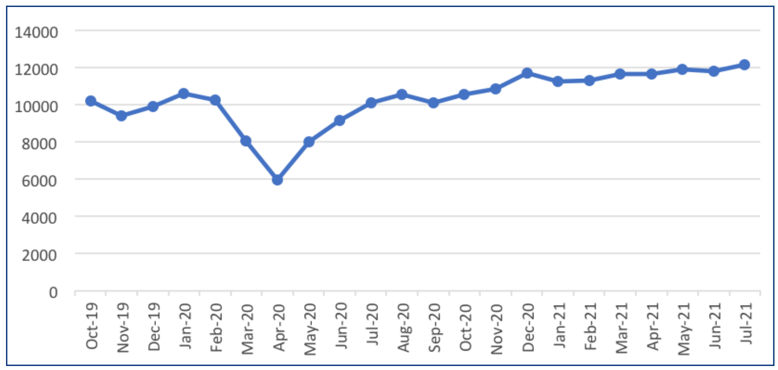
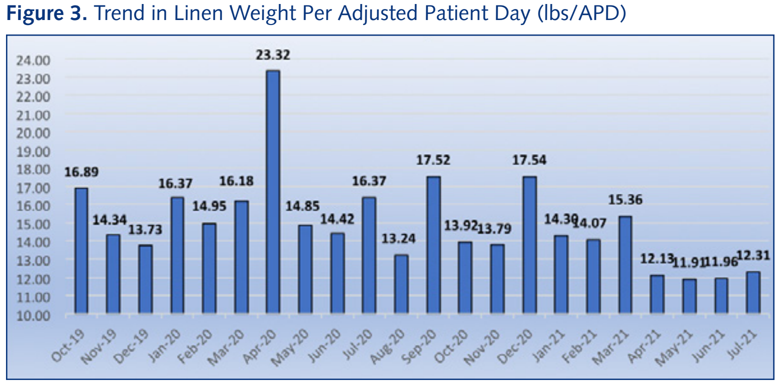


Figure 3. Trend in Linen Weight Per Adjusted Patient Day (lbs/APD)



RESULTS

RMW reached its lowest total weight (5,726 lbs) in April 2020 and highest total weight (14,052 lbs) in June 2020. RMW weight/APD hit its low in January 2021 (0.71 lbs/APD) and high in June 2020 (1.54 lbs/APD). The overall trend of RMW weight mirrored that of APD during the study period (**Figures 1 & 2**).

By total weight, RMW was at its lowest levels during April and May 2020 when the hospital census was lowest. In fact, RMW decreased by about 50% from pre-pandemic levels during these months. RMW increased as hospital volumes grew during the COVID-19 pandemic.

Linen reached its lowest total weight (119,078 lbs) in May 2020 and its highest total weight (205,563 lbs) in December 2020. Linen weight/APD hit a low (11.91 lbs/APD) in May 2021 and peaked (23.32 lbs/APD) in April 2020 (**Figure 3**).

When averaged over three-month periods from Oct 2019–June 2021, RMW weight per APD showed a steady decline while linen weight per APD increased during the period of April–June 2020 followed by a steady decline (**Table 1**).

Rhode Island has experienced several waves of COVID-19 infection, with total cases reaching their peak in April 2020, December 2020 and March 2021 (**Figure 4**). Hospitalizations due to COVID-19 reached their highest levels in April 2020, December 2020 and April 2021 (**Figure 5**). The largest number of patients hospitalized in the ICU was in April 2020.

Table 1. Average RMW and Linen Weight per APD (lbs/APD) by Three-Month Period

	RMW (lbs/APD)	Linen (lbs/APD)
Oct–Dec 2019	1.20	14.99
Jan–March 2020	1.21	15.83
April–June 2020	1.11	17.53
July–Sept 2020	1.10	15.71
Oct–Dec 2020	1.02	15.08
Jan–March 2021	0.96	14.57
April–June 2020	0.95	12.00

DISCUSSION

This study identified several trends in RMW and linen use during the COVID pandemic. RMW by total weight was lowest in April 2020, when the hospital census and adjusted patient days (APD) were at their lowest. In contrast, linen use remained largely consistent with pre-pandemic levels during the initial months of the pandemic despite a decrease in hospital census. This led to higher weight/APD values, including the highest linen weight/APD value (23.32 lbs/APD) in April 2020. However, linen use (weight/APD) decreased after this initial rise.

Linen use was highest during months with increased

Figure 4. Number of Daily New Positive Cases of COVID-19 in Rhode Island,[10] April 1, 2020–September 15, 2021.

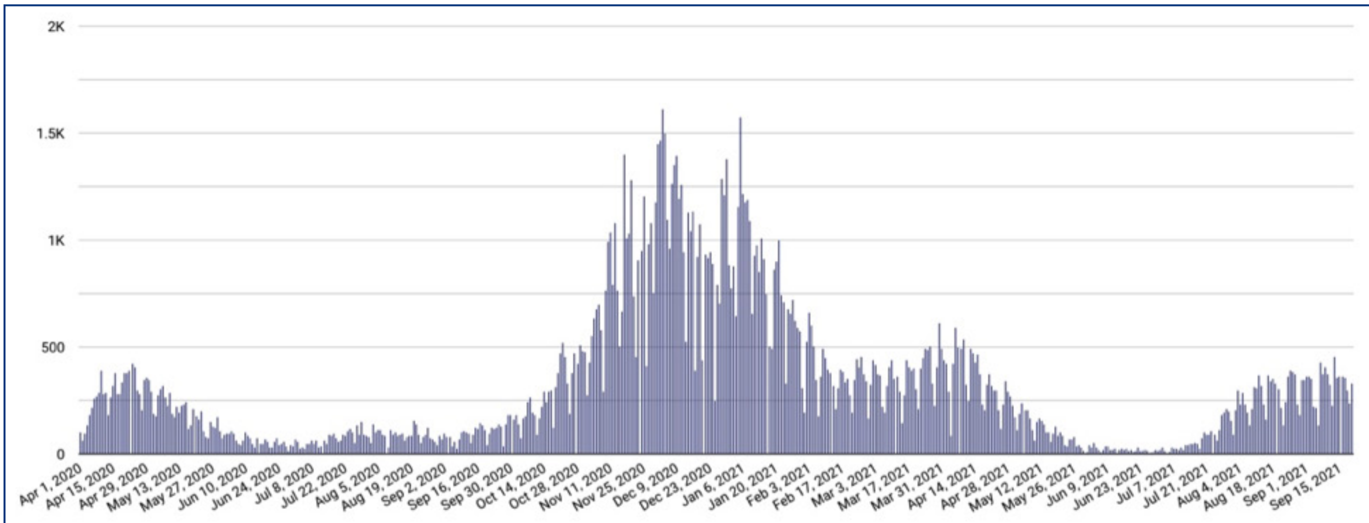
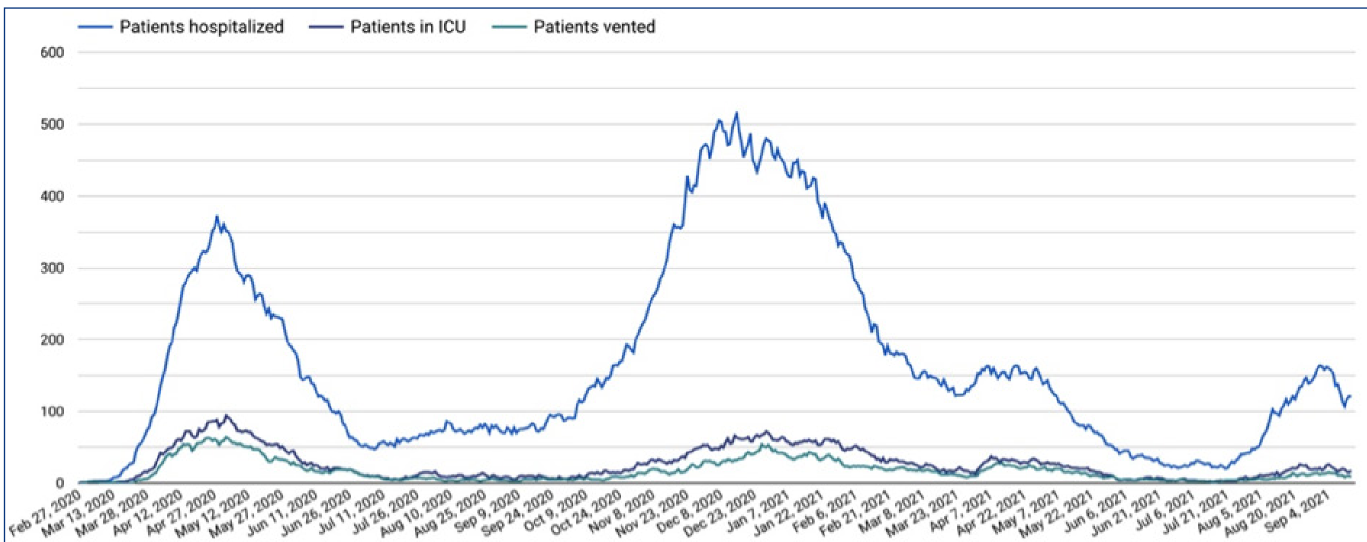


Figure 5. Number of Hospitalizations Due to COVID-19 in Rhode Island[11]



Notes: "Hospitalization refers to a patient that has both an entry in the Hospital Incident Reporting System (completed by a hospital staff member) and a lab-confirmed positive result for COVID-19. "People in the Intensive Care Unit (ICU)" is a subset of those who are hospitalized and represents the total number of hospitalized patients with COVID-19 who are currently in the ICU. "People currently vented" refers to those patients who are receiving oxygen from a ventilator to support breathing. These data are updated daily, Monday through Friday.
Source: RIDOH, SalesForce COVID-19 Case Dataset; RIDOH, Hospital Incident Reporting System

COVID-19 cases and hospitalizations. This is most pronounced in April 2020 at the beginning of the pandemic. This was also when ICU hospitalizations due to COVID-19 were at their highest level in Rhode Island. Overall linen use (by total weight) was highest in December 2020, when COVID-19 cases and hospitalizations reached their highest levels in Rhode Island.

Findings from this study are similar to those from other sites, including Wuhan, China, where the COVID-19 pandemic originated. During the initial phase of outbreak in Wuhan (January–April 2020), health care waste per 1,000 persons increased from 3.64 kg/day to 27.32 kg/day.[6] To accommodate this increase in waste production, disposal capacity in the region was increased from 50 tons/day to 280 tons/day. Researchers in Malaysia found that clinical waste (which includes any item potentially contaminated with infectious material) increased by 27% during the initial months of the COVID-19 pandemic.[7] This increase was mainly attributed to the disposal of PPE, such as gloves, facemasks and gowns. In Romania, waste from medical facilities peaked in the early months of the pandemic and then tapered over the following months.[5]

Several studies from Taiwan have examined waste use during 2003 SARS outbreak. A 2,000-bed hospital in northern Taiwan found that daily infectious waste generation tripled during the outbreak.[8] Interestingly, due to a decrease in hospital census, the mean daily overall waste production decreased 19.2%–25.3%. Taiwan saw an overall increase in infectious waste of about 4,000 tons (from 14,648 to 19,350 tons) following SARS.[9]

There are several limitations to this study, most notably that it was conducted at a single site. Data from this study came from a suburban community hospital in Rhode Island. Resource utilization might be different at a rural or urban hospital site. This is notably important in the case of COVID-19 since the pandemic affected different regions of the United States in very different ways. Some hospitals might have only had a few overall cases of disease, whereas others might have been overwhelmed to the point where they needed to transfer patients requiring ICU level-of-care to another facility. Hospital infection control policies likely also influenced resource utilization. A hospital that uses disposable gowns for PPE might have different patterns of use when compared to a hospital that uses reusable gowns. Another limitation of this study is aggregate data on COVID-19 hospitalizations on a state level was used for comparison. Hospital-level data and department-level data (particularly from the ED and ICU) would be more useful. Finally, a field hospital provided care to patients with mild-to-moderate cases of COVID-19 during the study period. Resource utilization at the field hospital was not included in this study.

This study examined the overall trends of RMW and linen use during the COVID-19 pandemic. The dramatic increase in linen use (weight/APD) during April 2020 is of particular interest. Several factors could have played a role in this occurrence, including infection control policies, staff compliance with isolation precautions, lack of knowledge of disease transmission, or fear amongst hospital employees of a new and unknown disease. Trends suggest that there may be an association with increased linen use and ICU hospitalizations. However, further investigation is needed to clarify this association. The gradual decrease in linen use (weight/APD) since April 2020 is also of interest. Are hospitals becoming more efficient with resource utilization or have staff developed noncompliance with infection control protocols as the COVID-19 pandemic drags on? Qualitative studies could provide insight. Overall, while this study highlighted trends that hint at correlation and causation, further research is needed to clarify these relationships.

CONCLUSION

This study examined trends in waste and resource utilization at a community hospital during the COVID-19 pandemic. While largely hypothesis-generating, it hints at several conclusions, including a relationship between linen use and ICU hospitalizations. Findings from this study can contribute to further understanding of resource utilization during outbreaks of disease and inform health system and government protocols for pandemic preparedness.

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Trash Talk in the ED: Takeaways from Waste Audits at New England Hospitals

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KEYWORDS: sustainability, environment, climate change & health, waste

Recent investigations at Kent Hospital, a suburban community hospital in Rhode Island, and Massachusetts General Hospital (MGH), a Level 1 trauma center, highlight the importance of health care waste.[1,2] These investigations involve a simple concept: sorting through trash can help identify ways to cut costs and reduce environmental impact.

The waste audits – both conducted in the Emergency Department (ED) – followed a similar protocol. Environmental Services staff collected waste from the ED for a 24-hour period. Waste was then sorted into various categories, including paper, plastic, food waste, glass, metal, electronic material and unused items. Most waste from the ED is considered municipal solid waste (MSW) and requires no additional treatment and can be disposed in a landfill. Regulated Medical Waste (RMW), on the other hand, requires specific protocols prior to disposal. It is expensive and often requires energy intensive processes such as autoclave sterilization or incineration.

Attention was given to whether Regulated Medical Waste (RMW) and sharps were appropriately disposed (i.e., in designated containers). Investigators also examined if non-RMW was inappropriately placed in RMW containers. All categories of waste were weighed and direct pollutant emissions were calculated using the M+ WasteCare Calculator.[3] The waste audits at the two facilities revealed some important takeaways:

(1) Inappropriate disposal of Regulated Medical Waste (RMW) is expensive and inefficient

While the amount of waste generated per-patient encounter was similar at Kent and MGH, estimated carbon emissions were 10 times higher at MGH. The difference in emissions was driven by differences in RMW. The waste audits identified 71.67 kg in RMW containers at MGH compared with 4.67 kg at Kent. Disposing of this waste accounted for 70% of overall waste emissions at MGH. This is because there are specific requirements for disposing of RMW that tend to be energy intensive. RMW needs to be rendered safe prior to disposal in a landfill. Hospitals can perform on-site sterilization or utilize a specialized hauling service to have waste processed off-site.

Only 15% of waste disposed in RMW containers at MGH met criteria for RMW. Eighty-five percent of material in RMW containers could have been transported to a landfill but, instead, was processed using the energy-intensive disposal methods reserved for RMW. Behavioral characteristics are partly responsible for inappropriate use of the RMW containers. Improvements in ED staff knowledge regarding RMW criteria and ED design simplifying RMW bin location could lead to more appropriate disposal.

(2) ED waste is filled with unused items

Audits at Kent and MGH demonstrated that unused items tossed in the garbage are a significant issue in the ED. More than 170 unused items were identified in the Kent audit, consisting of 5.2% of total waste. These items included unused boxes of gloves, surgical face masks, suture material and medications (**Table 1**). The audit at MGH identified 201 unused items, including 76 bundled and unused tourniquets. Both audits revealed resuscitation supplies still in storage packaging. Unused items tossed in the garbage are pure waste. There are monetary and environmental costs to producing these items, transporting them to the hospital and then disposing of them in a landfill.

It is unclear as to why there are so many unused items in ED waste. Infection control policies may play a role. Unused items may be considered "contaminated" if present in a room under isolation precautions. In addition, procedure kits often contain redundant or useless items, leading to the disposal of unused items. Evidence of unused resuscitation supplies in the Kent and MGH audits suggests that resuscitation scenarios are particularly prone to waste. There is likely also a behavioral component to the disposal of unused items. In a busy ED, it is easier to toss unused supplies into the garbage rather than placing them back in a drawer or supply closet.

Potential solutions for the problem of unused items include only bringing necessary supplies into the room when caring for patients on isolation precautions and designing "in-house" procedure kits with items pre-approved by ED staff. Kits for certain procedures (such as laceration repairs) could be sterilized in-house and then returned into circulation. ED administration could incentivize re-stocking of unused supplies. Specific ED staff could also be tasked with a re-stocking role. As with RMW disposal, ED design should

Table 1. A List of Unused Items Identified during the Kent ED Waste Audit

2 unopened boxes of non-sterile gloves
2 partially finished boxes of non-sterile gloves
3 unopened sets of sterile gloves
8 unopened female catheterization kits
6 unopened Yankauer suction handles
8 unopened suction tubing sets
1 unopened sterile drape
2 unopened 4x4 sponges
4 unused (and folded) adult diapers
7 unopened urine sample collection kits
13 unused bedpans
1 unopened Tegaderm
1 unopened C-collar
2 unused bags of IV fluids
12 unopened normal saline flushes
3 unopened IV catheters
10 unopened pairs of socks
1 partially finished box of procedural masks
2 sterile large cotton swap applicators
1 sterile solution bowl
4 unopened electrode sets
1 unused suction container
1 unopened ambu-bag
34 unopened alcohol prep pads
6 unopened small gauze packets
6 unopened ChloroPrep swab kits
1 unopened pill of Lorazepam
13 unused emesis basins
2 unopened Iodine prep pads
6 unused large pink irrigation containers
26 unused Castille soap towelettes
1 unused bag of IV antibiotics
Multiple unopened food items

also be taken into account. The layout of patient rooms and the ED should make it as easy as possible for staff to restock unused items instead of tossing them in the trash.

(3) How and where we process waste matters

Waste disposal sites and their proximity to the hospital are important to consider. Gunderson Health System in Wisconsin treats 90% of RMW through an in-house sterilization system powered by steam from the heating and cooling system at one of its buildings.[4,5] After sterilization, waste is transported just four miles to a waste-to-energy facility. Previously, waste was shipped to a landfill 1,250 miles away.

CONCLUSION

Waste audits can help make EDs and health systems more cost-efficient and environmentally friendly. While healthcare providers pledge *primum non nocere* – do no harm – pollutants and wasteful practices adversely affect our patients. We need to continue to examine hospital waste habits and embrace solutions that provide healthcare without harm.

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The Rhode Island Climate Change and Health Program: Building Knowledge and Community Resilience

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ABSTRACT

Climate change acts as a risk multiplier, meaning vulnerable populations bear a disproportionate burden of its effects. Improving climate resiliency is a key strategy to help the Rhode Island Department of Health meet its overarching goals of addressing the socio-economic and environmental determinants of health for all Rhode Islanders. The Climate Change and Health Program focuses on both the immediate health impacts of climate change and building resiliency. Part of the US Centers for Disease Control and Prevention's Climate Ready States and Cities Initiative, the Program has partnered with community groups and other state and local agencies to bring technical assistance, educational resources, and funding to support community resilience to the challenges presented by the already changing climate. Specific projects discussed include the extreme heat communications plan and outdoor worker campaign; community-driven resiliency projects in response to flooding and natural hazards, and improving resilience in senior citizen housing.

KEYWORDS: climate change, resilience, public health, extreme heat, climate mitigation

INTRODUCTION

Climate change, health, and equity are inherently intertwined.[1] The impact of race and socio-economic status on health has been evident in the disparate outcomes seen across populations during the COVID-19 pandemic.[2] These same communities bear a disproportionate burden of the effects of climate change.[1] Because climate change is a risk multiplier, improving climate resiliency is a key strategy to help the Rhode Island Department of Health (RIDOH) meet its overarching goals of addressing the socio-economic and environmental determinants of health for all Rhode Islanders, especially those from the most vulnerable demographics. As incidences of heatwaves and flooding increase, RIDOH focuses on addressing immediate health impacts and building resiliency among Rhode Islanders.[3]

MAKING RHODE ISLAND A CLIMATE READY STATE

The RIDOH Climate Change and Health Program began as part of the US Centers for Disease Control and Prevention's (CDC) Climate Ready States and Cities Initiative. This initiative is part of the CDC's efforts to train medical and public health professionals to better understand the impact of climate change on health.[4] The CDC provides resources for the professional community that include research papers, maps, and links to webinars from the American Public Health Association covering climate-related topics such as heart and lung health, children's health, mental health, and allergies and asthma.

Two notable data resources include the Heat and Health Tracker and localized climate change and health data. The Heat and Health Tracker is an online tool to help emergency and public health planners prepare for and respond to extreme heat events by providing local-level heat and health data.[5] Localized data for climate change and health, including future scenarios for heat and precipitation to the year 2099, can be found on the CDC's National Environmental Public Health Tracking Network portal.[6]

The Rhode Island Climate Change and Health Program began in 2013 and continues to focus on health effects from urban heat, flooding, severe weather and sea level rise, food and water borne diseases, vector-borne diseases, and poor air quality. (See **Figure 1** for more information about the health effects of climate change.) The program has partnered with community groups and other state and local agencies to bring technical assistance, educational resources, and funding to support community resilience to these challenges.

ADDRESSING EXTREME HEAT IN RHODE ISLAND

Extreme heat has become an increasing threat across Rhode Island as the average temperature has already risen three degrees in the last century.[3] During the climate normal period (1981 to 2010), there was an average of 9.3 days equal to or above 90 degrees Fahrenheit (F) in the Providence Metro Area each year.[7] There is variability in this number year-to-year. While there was an average of 11 such days each year from 2010 to 2014, there were 19 such days in 2021 (see **Figure 2**). It could increase to as many as 27 days at or above 90 degrees F per year by mid-century with slow action to reduce greenhouse gas emissions.[8]

Figure 1. Climate change causes a range of direct and indirect impacts on human health. This figure depicts the most significant climate change impacts (rising temperatures, more extreme weather, rising sea levels, and increasing carbon dioxide levels), their effect on exposures, and the subsequent health outcomes that can result from these changes. (US Centers for Disease Control and Prevention, 2021.)

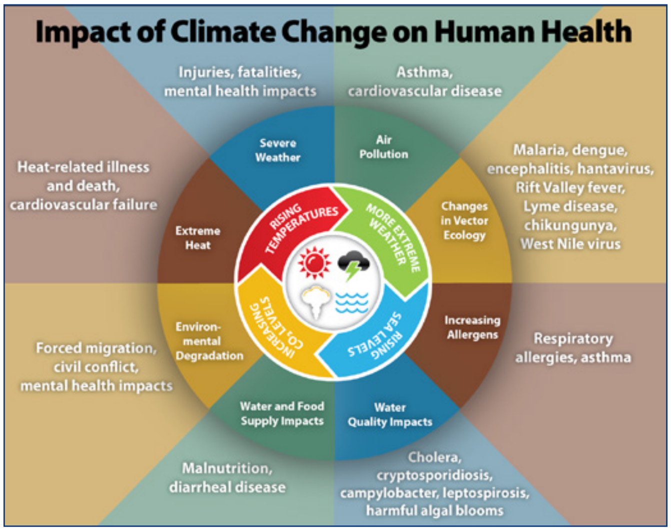
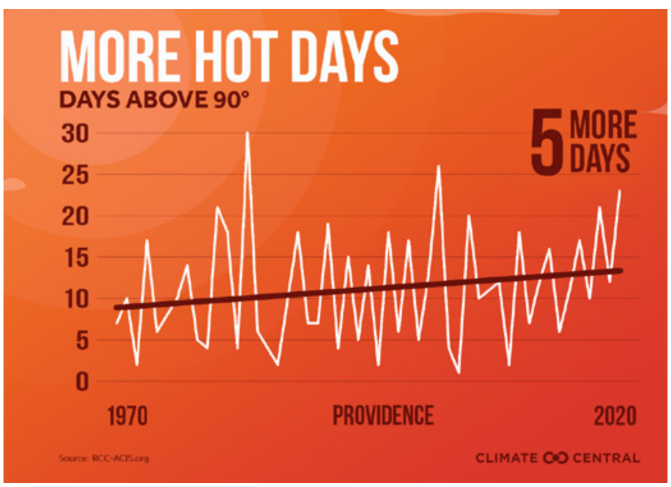


Figure 2. In the Providence Metro Area, there are an average of five more days per year above 90 degrees than there were in 1970. (Image provided by Climate Central.)



Extreme heat events are a leading cause of weather-related injury and can result in the worsening of existing illnesses. Extreme heat can cause increases in cardiovascular events leading to hospitalization.[9] When Rhode Island sees multiple days of temperatures above 80 degrees F, emergency room visits begin to rise.[10]

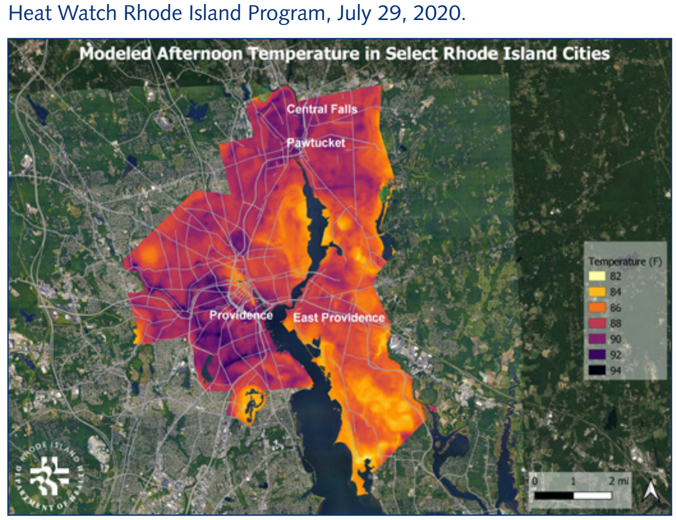
Alarmingly, a recent study shows that one quarter of the US population had heat-related symptoms during the summer 2020.[11] This was largely due to a lack of cooling resources and the social isolation that was part of the COVID-19 pandemic. The interaction between the two health crises expanded the scope and range of vulnerability to heat across the country. This research showed that when COVID-19 disrupted social networks, people were less able to seek comfort and suffered more from the symptoms of heat stress.

The effects of heat are not felt evenly across communities. Evidence shows that low-income communities with little tree cover and those that were formerly redlined are up to 12.6 degrees F hotter than surrounding neighborhoods.[12] Redlined areas are those that were coded as "high risk" by the Federal Housing Administration starting in the 1930s. Often based on race, these neighborhoods were denied government loans and services due to land use and other concerns. In Rhode Island, we see similar disparities across neighborhoods in Providence and surrounding urban areas, especially when it comes to heat and tree cover.

To create and implement more effective interventions, the neighborhoods and communities with the highest vulnerability and exposure need to be identified. Collaborating with researchers at CAPA Strategies, based at Portland State University, the Program in partnership with the Department of Environmental Management's Division of Forest Environment and American Forests mapped ambient air temperatures and humidity in Providence, Pawtucket, Central Falls, and East Providence in July 2020.[13] **See Figure 3.** The results showed that many Providence neighborhoods warmed by 10 degrees F more than others, indicating substantially higher exposure to heat. Many areas also stayed warm at night, maintaining temperatures above 70 degrees F and depriving residents of critically important time for the body to recover from heat stress experienced during the day.

To combat the effects of extreme heat in Rhode Island, the Program developed a heat communications plan and outreach for specific vulnerable populations. Implementation

Figure 3. Modeled afternoon temperatures in Providence, Pawtucket, Central Falls, and East Providence, based on data from CAPA Strategies Heat Watch Rhode Island Program, July 29, 2020.



of the extreme heat communications plan includes sending email notices to primary care providers before heat events and using social media to inform the public about heat safety and heat alerts issued by the National Weather Service. Other interventions have included trainings for outdoor workers about the dangers of heat exposure and a *Beat the Heat* campaign with both television and radio advertisements. Grants have been provided to local emergency management officials for portable misting stations; to the Providence Housing Authority and the Town of Barrington for educating seniors about the dangers of heat and natural disasters, and to youth groups for heat-related outreach campaigns.

COMMUNITY-DRIVEN RESILIENCE FRAMEWORK

One way that the Program works to build overall resilience in a community is by building up program supports and social networks. These networks help to create social cohesion and places for residents to turn during an emergency.[14,15] It is important to empower the communities most affected by climate change to design resiliency programs that address the realities of their lived experience. One way that RIDOH builds community support is through the Health Equity Zone (HEZ) initiative. The HEZ initiative is a place-based approach that brings communities together to address systemic changes at the local level. Each HEZ identifies the unique social, economic, and environmental factors that are preventing people from being as healthy as possible.[16]

The Climate Change and Health Program worked with HEZs in Providence, Pawtucket, Central Falls, and Newport to support community resilience to the effects of climate change. Through community workshops, the Program helped residents assess their strengths and vulnerabilities associated with climate change and identify strategies to reduce climate hazards. After the workshops, each team surveyed their own communities to identify strategies and develop a community-led intervention.

The HEZ in the Olneyville neighborhood of Providence chose to create a film about the historic 2010 floods. (The film is available to view at: https://vimeo.com/359888817/6c75fdddfe). The film aims to raise awareness of the dangers presented by the increasing frequency of natural disasters. It works to transform the threat of a major disaster into a tangible reality so that residents feel a greater sense of urgency regarding emergency preparation. The film was screened at multiple events and will continue to be used in schools and with community groups.

BUILDING RESILIENCE IN RESPONSE TO NATURAL GAS OUTAGE

During a gas outage in January 2019, National Grid was forced to shut down a portion of its gas distribution system to over 7,000 customers in Newport for more than one week. Evacuations forced people from their homes, and information was limited and inconsistent. This led to a feeling within the community that their needs were not being met by the established emergency management procedures and was fueled by underlying inequities that are often revealed in times of crisis.

During this time, the Newport HEZ became an important part of the effort to share information and reach vulnerable community members. The HEZ leaders realized that there was not a well-defined emergency response plan, nor was there the capacity locally to carry a plan out.

After the event, community conversations about climate change provided opportunities for residents to receive disaster-preparedness training and supplies and to establish relationships with public officials. Creating connections between agencies, officials, and communities increased cohesion and will hopefully lead, both directly and indirectly, to better health outcomes by ensuring that local needs are addressed and plans are in place before disaster strikes.

EMPOWERING COMMUNITY PARTNERS FOR RESILIENT CLIMATE MITIGATION

In Pawtucket and Central Falls, the nonprofit group Groundwork RI partnered with Southside Community Land Trust and Farm Fresh RI's Harvest Kitchen for a six-week summer youth program. These community partners employed and trained 24 youth on how to grow, process, and cook their own local produce. The youth also worked to engage residents and gather data regarding resilient climate mitigation strategies. By the end of the summer, they completed 25 green home assessments, planted 21 trees at Baldwin Elementary school in Pawtucket, installed nine raised garden beds at resident homes, and collaborated with the City of Pawtucket to install and deliver seven residential rain barrels to reduce flooding and utility bills.

IMPROVING EXTREME WEATHER RESILIENCY IN SENIOR HOUSING

Older adults are vulnerable to extreme weather because they often have limited mobility and must shelter in place. This is especially true for those who live in independent senior housing or assisted living. To help make these spaces more resilient to natural disasters and other emergencies such as power loss, the Program partnered with the Yale New Haven Health System Center for Emergency Preparedness and Disaster Response to support long-term care, assisted living, and independent living senior housing facilities in preparing for climate-related disasters through energy resiliency audits and the development of all-hazards emergency plans that emphasize sheltering in place. These important emergency preparedness actions reduce risk to senior citizens by limiting disruptions like power outages or flooding that can force the evacuation of medically vulnerable people. By increasing the overall emergency preparedness levels of the facilities that serve them and allowing them to shelter in place, seniors are safer. Resources from the project include a facility self-assessment tool, shelter-in-place plan templates, staff trainings, and webinars.[17]

PROGRAM RESOURCES AND WEBSITE

Resources are available from the Program for a variety of topics, including extreme heat, air quality, and climate literacy. Partnerships with other RIDOH programs such as the Center for Acute and Infectious Disease Epidemiology have allowed the development of educational tools related to vector-borne diseases like Lyme disease, Eastern equine encephalitis (EEE), and West Nile virus, along with emerging diseases like Zika virus. Links to our reports, brochures, and videos are available on the Program webpage.

The Program has also focused on providing resources to help teachers bring environmental health and climate change into their classrooms. Partnering with school nurse teachers, the two programs have provided thousands of copies of the *Tick Workbook for Kids* to classrooms across the state.

CONCLUSION

The effects of the changing climate in Rhode Island are far-reaching in terms of the scope of the systems impacted, types of impacts, and people who are impacted. At RIDOH, we are continuing these efforts and remain committed to supporting climate change mitigation strategies, preparing for the human health effects, and working closely with community partners to help improve the resilience of all Rhode Islanders.

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Climate Change and Health in New England: A Review of Training and Policy Initiatives at Health Education Institutions and Professional Societies

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ABSTRACT

BACKGROUND: There has been increasing interest in climate change among healthcare professionals, but it is unclear to what extent resources on this topic are available to students and clinicians in New England.

METHODS: Structured review of publicly available information regarding climate change and health activity at schools of medicine, public health, and physician assistant studies and in state medical and physician assistant societies in New England.

RESULTS: Of 39 programs reviewed, 18 (46%) had at least one climate-related initiative. Six universities accounted for 87% of climate change and health initiatives in the region. Three out of 12 state professional associations had committees or position statements addressing climate change.

CONCLUSION: There is substantial activity related to climate change and health in New England, but it is concentrated in a small number of locations. Opportunities exist to improve access to education on this topic and increase involvement of health professional associations.

KEYWORDS: climate change, health education, organized medicine, physician assistant, public health

INTRODUCTION

Climate change is a threat to health in New England. Climate-related hazards include heat, extreme rainfall, flooding, vector-borne disease, hurricanes, and sea level rise.[1] Rising awareness of climate change has been accompanied by increased recognition of its implications for patients and healthcare institutions.[2]

The past decade has seen increasing engagement with climate change issues in the regional healthcare community. Multiple academic institutions host centers working at the intersection of human health, healthcare, and climate change.[3,4,5] There have also been efforts to address healthcare-related greenhouse gas emissions[6,7] and medical waste,[8] improve resilience to climate health hazards,[9] and communicate climate change and health issues to clinicians, policymakers and the general public.[2,3]

There is increasing interest in curricula, courses, and training programs on climate change and health education.[10,11,12,13] Medical Students for a Sustainable Future, a student-driven organization founded in 2019, advocates for action and education on climate change and health; in the two years since its creation, it has expanded to 105 medical schools, including chapters in five of the six New England states.[14] New England now has free online climate and health courses,[15,16] a physician fellowship in Climate and Human Health,[17] and a steady stream of lectures and symposia on the topic.[18,19]

However, many health care workers remain unaware of how healthcare systems contribute to climate change and how climate change threatens their patients and healthcare institutions, or have difficulty engaging with this issue.[20,21] While it is clear that study of the intersection of climate change and health is increasingly prioritized at major academic centers in the region, it is less clear how available resources on this topic are to the bulk of students and practicing clinicians in the region.

The purpose of this review was to assess the extent of climate and health activities including educational offerings and policy statements at medical, physician assistant, and public health education institutions and within health professional societies in the New England region.

METHODS

This was a structured review of publicly available material describing educational offerings, academic centers, student organizations or committees, and position statements from educational institutions offering graduate degrees in medicine, public health, and physician assistant studies, state medical societies, and state physician assistant societies in New England. All institutions granting graduate degrees in Medicine, Public Health, or Physician Assistant Studies within the six New England states (Maine, New Hampshire, Vermont, Massachusetts, Connecticut, Rhode Island) were included. State medical associations and physician assistant associations for each of the six New England states were also included. Lists of institutions were obtained from the Association of American Medical Colleges (AAMC), the American Association of Colleges of Osteopathic Medicine (AACOM), the Accreditation Review Commission on Education for the Physician Assistant (ARC-PA), the Physician

Assistant Education Association (PAEA), and the Council on Education for Public Health (CEPH).

Due to the wide variety of website designs and online platforms, ascertainment of the presence of publicly available information on items of interest could not be performed reliably via institutional website navigation. Instead, a methodology employing standardized search terms was implemented via internet search engine. Search terms consisted of "[Name of Institution]" + "climate" + "class" OR "course" OR "elective" OR "center" OR "curriculum" OR "statement" OR "student organization" OR "student group" for educational institutions, and "[Name of Association]" + "climate" + "committee" OR "position" OR "statement" OR "policy" for state associations. The first 30 results were reviewed for relevance to these climate and health activity areas. For educational institutions, activity areas included the following categories: an elective course in climate change and health, the inclusion of climate change topics in the core curriculum, an institutionally-recognized student organization focused on climate change, a center focused on climate change and health, and the existence of an institutional position statement on climate change and health. For associations, activity areas included the existence of a committee or sub-committee focused on climate change and health and the existence of a formal position statement or other policy statement regarding climate change.

Results were tabulated, and summary statistics regarding specific areas of activity, institutional subsets, and geographic regions were computed. All searches were performed in the standard public Google search engine, and reflect the top results displayed via Google search engine prioritization as of July 2021.[22] Analysis was performed in R v3.1.0.[23] All materials reviewed in this study were publicly available and were accessed remotely via public-facing websites. This study was exempt from IRB review as it did not involve human subjects research.

RESULTS

A total of 51 separate institutions or associations were included in the analysis. These consisted of 11 institutions offering degrees in medicine, 13 institutions offering graduate degrees in public health, and 15 institutions offering degrees in physician assistant studies within the six New England states, as well as 6 state medical associations and 6 state physician assistant associations (**Table 1**).

Of the 39 degree granting institutions, 18 (46%) had at least one climate change and health initiative, 9 (23%) had two or more, and 21 (54%) had none. Institutions with education or advocacy activities related to climate change and human health were located in Massachusetts (n=8), Connecticut (n=5), New Hampshire (n=3) and Rhode Island (n=2), principally in coastal cities (**Figure 1**).

Table 1. Climate and health activities at educational programs in New England

	Medical Schools	Physician Assistant Programs	Public Health Programs
Elective	2	0	4
Position Statement	0	1	1
Core Curriculum	1	0	4
Student Group	7	1	4
Center	2	2	2
None of the Above	3	12	6
Total Programs	**11**	**15**	**13**

Figure 1. Climate Change and Health Initiatives in New England

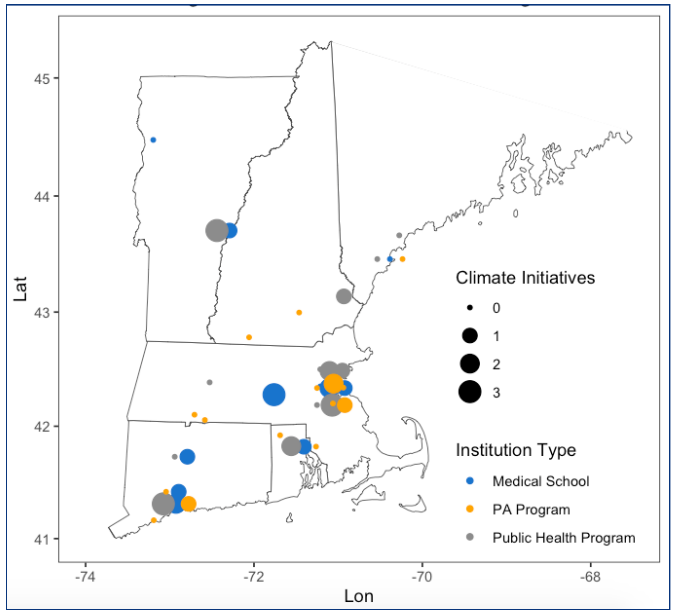

Figure 2. Climate Change and Health Initiatives at Educational Institutions

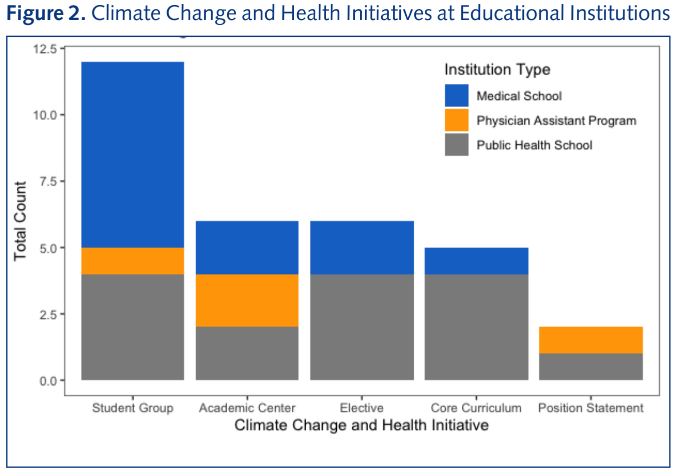

Table 2. Climate and health initiatives at educational programs in New England

Institution	Degree Program	Climate Change and Health Initiatives
Boston University School of Medicine	Medicine	The Climate Action Group, a student, staff, and faculty organization engaged in "environmental advocacy through a variety of climate initiatives including climate change education for health professionals, improving campus sustainability and reducing the University's use of nonrenewable energy, and exploring the role of climate change in impacting human health and wellbeing."
Frank H. Netter MD School of Medicine at Quinnipiac University	Medicine	Human Health and Climate Change medical student group.
Geisel School of Medicine at Dartmouth	Medicine	Chapter of Medical Student for a Sustainable Future whose goal is to "integrate climate change competencies into the medical education curriculum."
Harvard Medical School	Medicine	In addition to an active student group, an academic center focused on climate change and health activities hosts workshops and training programs, a physician fellowship that includes research and public communication, and courses on climate change and health. Additional climate and health initiatives at the university level and at individual teaching hospitals exist but did not meet inclusion criteria. A course on climate change and health is known to the authors but was not identified via structured search methodology.
The Warren Alpert Medical School of Brown University	Medicine	Students can take an elective on Climate Change and Health that provides "an overview of the wide-ranging health impacts of climate change as well as the impact of healthcare on the environment."
UMass Chan Medical School	Medicine	A chapter of Medical Students for a Sustainable Future is active. Students created a Climate Change and Medicine elective. The core curriculum is being updated to include climate change topics.
University of Connecticut School of Medicine	Medicine	Active student group; Medical Students for a Sustainable Future has been active on sustainability at UConn Health organization meetings
Yale School of Medicine	Medicine	There is an active student group, and students have access to an academic center on climate change and health that houses a wide range of initiatives including courses, a student associate program, and a certificate program in climate and health.
Boston University	Physician Assistant	The Climate Action Group, a student, staff, and faculty organization engaged in "environmental advocacy through a variety of climate initiatives including climate change education for health professionals, improving campus sustainability and reducing the University's use of nonrenewable energy, and exploring the role of climate change in impacting human health and wellbeing."
MGH Institute of Health Professions	Physician Assistant	Students have access to a Center for Climate Change, Climate Justice, and Health; the core curriculum may include climate change in future years. Official Institute materials describe climate change as "a threat to the health of individuals, families, communities, and populations worldwide."
Yale School of Medicine	Physician Assistant	Students have access to an academic center on climate change and health that houses a wide range of initiatives including courses, a student associate program, and a certificate program in climate and health.
Boston University School of Public Health	Public Health	In addition to student involvement in the Climate Action Group (above), the BU School of Public Health offers an MS in Climate and Health, a Program on Climate and Health, a climate change elective course, and includes climate change topics in the core curriculum.
Brown University School of Public Health	Public Health	Students have the opportunity to take an elective titled "Climate Change and Human Health", which is also a substantial content area in other courses and faculty research. The School of Public Health urges "policy action to mitigate the negative health impacts of climate change."
Dartmouth Geisel School of Medicine MPH Program	Public Health	A course on "Public Health Impacts of Climate Change" is included in the second-year curriculum and student organization is active on climate change issues.
Harvard T.H. Chan School of Public Health	Public Health	An academic center focused on climate change and health activities hosts workshops and training programs, a physician fellowship that include research and public communication, and courses on climate change and health. There is also organized student activity. Additional climate and health initiatives at the university level did not meet inclusion criteria. A course on climate change and health is known to the authors but was not identified via structured search methodology.
Simmons University Public Health Program	Public Health	Core curriculum includes climate change topics as part of an Environmental Health & Justice course.
University of New Hampshire	Public Health	Curriculum includes a Climate Change and Health course that teaches "an environmental epidemiology framework for analyzing the direct and indirect impacts of climate variability to public health as well as appropriate public policies."
Yale School of Public Health	Public Health	A degree concentration in climate change and health is offered. There is an active student group, and students have access to an academic center on climate change and health that houses a wide range of initiatives including courses, a student associate program, and a certificate program in climate and health.

Table 3. Number of climate and health activities aggregated by academic affiliation of educational institutions.

Institutional Academic Affiliation	Total Climate and Health Activities
Yale University	6
Harvard University	6
Boston University	5
Dartmouth	4
University of Massachusetts	3
Brown University	3
All Others	4

A total of 31 climate change and health initiatives were identified, of which 12 (39%) were student groups, 6 (19%) were electives, 6 (19%) were climate change and health centers, 5 (16%) involved inclusion of climate change in the core curriculum, and 2 (6%) were position statements (**Figure 2**). These initiatives are summarized in **Table 2**. A total of 27 (87%) of the climate change and health initiatives were located at sites affiliated with one of six large research universities (Harvard University, Yale University, Boston University, Dartmouth, the University of Massachusetts, and Brown University), each of which hosted at least three initiatives; the remaining 4 initiatives were located at Simmons University, the University of New Hampshire, Quinnipiac, and the University of Connecticut (**Table 3**).

Climate change and health initiatives varied substantially across the programs reviewed. At several sites, the sole on-campus offering was a chapter of Medical Students for a Sustainable Future[14] or another student organization; these were typically set up by students with limited institutional support and were focused on advocacy including requests for inclusion of climate change topics in the core or elective curriculum. In some cases, these efforts were successful; for example, at the UMass Chan Medical School, students recruited external lecturers to create an elective in Climate Change and Medicine,[24] and efforts to include climate change in the core curriculum are ongoing.[25] Academic centers dedicated to climate change and human health tended to offer a range of activities that included research programs, CME courses, elective courses, fellowships in Climate and Human Health for physicians, and a range of climate change and health policy and advocacy material.[3-5,15-17,19]

Of the 12 state-level medical and physician assistant associations reviewed, three medical associations (Maine, Massachusetts, and Vermont) had position statements regarding climate change. Two statements included language on the implications of climate change for the health of patient populations, one called for reductions in greenhouse gas emissions, and one called for investment in climate change adaptation as a means to protect health. All three position statements were issued in 2017 or later. Two state medical associations (Maine and Massachusetts) had committees whose goals included addressing climate change issues.

DISCUSSION

This review describes climate change and health activity in a set of health education institutions and professional societies in New England. The burgeoning number of educational offerings, their uneven distribution, and the lack of public action from most regional medical and physician assistant societies are of significance to educators, students, advocates, and policymakers.

Climate change and health has clearly gained attention as an educational topic and object of organized student and professional activity. While this subject was largely absent from discussion outside specialist circles for many years, nearly half of the educational institutions assessed in this review now host some form of climate change and health education or advocacy activity, and the past four years have witnessed the first statements on climate change from medical societies in the region.

However, most climate change and health activity identified in this review was concentrated at large research universities; the majority of medical, public health, and physician assistant education institutions in the region do not publicly describe any climate-related activities. The concentration of initiatives at coastal, urban institutions may impede clinicians and students in rural or interior locations from accessing these resources and presents an important opportunity for growth. Climate change will have substantial effects on health throughout New England during the decades in which clinicians who are being trained today can expect to practice,[1] and it is important that opportunities for climate change education and action reach clinicians training and practicing in communities throughout the region.

Students, faculty, and administrators interested in implementing climate change and health curricula or other offerings at their institutions now have access to a wide variety of materials to support their efforts. Organizations including Medical Students for a Sustainable Future,[26] Healthcare Without Harm,[27] several academic centers,[3,4] and the Medical Society Consortium on Climate and Health[28] offer model curricula, educational content, templates for action, networking opportunities, remote courses, and other resources. Recent academic work provides needs assessments, guidelines on program design, and case studies of climate change and health education and advocacy in action.[2,11-13,29-32] For residents, fellows, and practicing clinicians, resources ranging from career planning tools[33] to federal guidance on the specific health impacts of climate change are also available.[1,34]

There are abundant opportunities for professional societies to increase their engagement; only three of the twelve professional societies reviewed were active on climate change issues. Policy statements can provide an authoritative voice in support of climate and health education, climate smart healthcare systems, and climate resilient communities. Affiliation with national organizations such as the Medical Society Consortium on Climate and Health is another avenue for action – one that the medical societies in Vermont, Rhode Island, and Massachusetts have already taken.[35]

While uneven, the overall trajectory of climate change and health activity in New England is one of rapid expansion and improving capabilities. In the brief period since completion of data collection for this review, a new regional fellowship program focused on climate and health advocacy has become available.[36] In addition, the climate and health activity of nursing programs, hospitals, and other organizations that were not reviewed in this study is substantial; examples include the Nurse's Climate Challenge,[37] hospital programs,[38] state government programs,[39,40] the launch of the *Journal of Climate Change and Health*[41], the inclusion of the climate crisis as key topic area in the *New England Journal of Medicine*,[42] and special issues of regional publications focused on climate change.[43,44] While many of these initiatives are associated with large research universities that are already active in this area, they provide a model for future engagement with this issue throughout New England.

Students, trainees, and healthcare professionals now have access to an increasing variety of education and policy materials related to climate change and health. As New Englanders face escalating health risks from hurricanes, extreme rainfall, heat waves, vector-borne disease, sea level rise, and other hazards, it is important that these education and policy resources be extended to benefit health professionals and patients throughout the region.

LIMITATIONS

As a review of publicly available material rather than a survey of educators and administrators, our methodology assesses information that is accessible to the general public and intentionally mimics the approach students, prospective students, and healthcare workers may take when seeking information on offerings at their institutions, but also has several limitations. All information was gathered from public internet sources, and as such may have missed initiatives that were not described on the internet or were behind firewalls, password protection, or other barriers. Some relevant programs may not have been prioritized by search engines using our search criteria; the term "environment" was not used in structured searches as it led to a large number of results unrelated to climate change. As searches were restricted to health education institutions, some potentially relevant initiatives did not meet inclusion criteria. As a result, initiatives including an elective course on climate change and health,[15] a chapter of Medical Students for a Sustainable Future,[14] and a university-level center working on environmental issues including health impacts of climate change[45] were not identified by structured searches or included in our analysis.

CONCLUSION

Climate change threatens patients, healthcare systems, and future clinicians. This review reveals uneven access to education and policy guidance on the subject of climate change and health; while some academic centers have many climate-related initiatives, the majority of the institutions reviewed do not publicly describe any offerings at all, and only a quarter of the medical and physician assistant associations reviewed are publicly engaged with this issue. Health professionals, administrators, and students have an opportunity to make education on this topic more accessible and to advocate for climate change action through state medical and physician assistant associations.

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Beyond the Hazard Vulnerability Analysis: Preparing Health Systems for Climate Change

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ABSTRACT

INTRODUCTION: Climate change is heightening both long-term adverse risks to human health and the immediate-term risk of injuries and illness following climate-related disaster events that are becoming more frequent and severe. In addition to its direct health effects, climate change poses new threats to the nation's health care infrastructure – with potential to negatively impact healthcare capacity amidst increasing demand – through risks of flooding, wind damage, heat stress, power outages, and other physical harm to facilities. The typical Hazard Vulnerability Analyses conducted annually by hospitals use historical data to assess risks; these analyses are likely now inadequate for future preparation due to the impact of climate change. This article describes one approach to how healthcare leaders can better assess both near-term and long-term risks due to climate change, to mitigate against unprecedented but foreseeable threats.

METHODS: In our large health system in the US Northeast, a process was undertaken to gather updated data and expert projections to forecast threats faced by each of our facilities in different climate-related disaster scenarios. Hazards examined in our setting included precipitation-based and coastal flooding events, heat waves, and high wind events, in addition to seismic events. Probabilities of occurrence and extents of different hazards were projected for the near term (2030) and the long term (2070). We then performed detailed vulnerability analyses for each facility with the predicted amount of rainfall, storm surge, heat stress, and windspeed, in collaboration with leaders at each facility. This was followed by a process to understand what would be needed to mitigate each vulnerability along with the associated costs. Ultimately, a cost/benefit analysis was performed – incorporating the relative likelihood and impact of different scenarios – to decide which improvement projects to embark on immediately, and what to defer and/or incorporate into future building plans.

RESULTS: In our system, all facilities were vulnerable to the effects of increased temperatures, and multiple hospitals were noted to be vulnerable to extreme precipitation, storm surge, and high winds. Specific damaging scenarios identified included flooding of basements and building infrastructure spaces, water entry through windows during high winds, and overheating of power systems during heat waves. Potential solutions included improved power redundancy for cooling systems, enhancements to roof and window systems, and the acquisition of deployable flood barriers. We identified four categories for prioritization of action based on projected impact: 1) priorities in need of urgent mitigation, 2) priorities in need of investigative study for medium-term mitigation, 3) priorities for planned capital improvement projects, and 4) priorities to integrate into new facility construction.

DISCUSSION: While the specific risks and vulnerabilities for each facility will differ according to its location and structural features, the approach we describe is broadly applicable. By forecasting specific risks, diagnosing vulnerabilities, developing potential solutions, and using a risk/benefit approach to decision making, hospitals can work toward protecting facilities and patients in the face of potential climate related natural disasters in an economically sound manner.

KEYWORDS: climate change, climate resilience, disaster medicine, hazard analysis, emergency preparedness

INTRODUCTION

Due to climate change, the frequency and intensity of dangerous weather patterns and natural disasters are known to be increasing throughout the world. These trends pose significant threats to human health both in the immediate and long term. The impact of climate-related changes on patient health include both direct injury and illness from discrete events such as hurricanes and fires, as well as exacerbation of chronic conditions like asthma and heart disease from increased levels of atmospheric carbon and higher average temperatures.[1] In addition to the increased demand on healthcare services that these trends will bring, there is another particularly difficult challenge for hospitals and other care facilities: at precisely the moment a weather event makes more patients ill or injured, that event may also directly interfere with the ability of healthcare facilities to function effectively.

This is, of course, the focus of most hospital-based emergency preparedness initiatives and the rationale behind standard Hazard Vulnerability Analyses (HVA). The problem is, in the era of climate change, HVAs based on historical data often underestimate the true level of risk for healthcare facilities. For example, hospitals in New York had, in fact, built flood barriers as part of their preparedness plans for extreme precipitation prior to 2012; yet, the flood depths produced by Hurricane Sandy were higher than those planned for and unfortunately overwhelmed these physical barriers, necessitating the evacuation of multiple facilities and resulting in extensive damage.[2] Similarly, multiple hospitals in Louisiana very recently required evacuation due to damage from high winds and precipitation during Hurricane Ida, a particularly challenging task amidst the power grid failures resulting from the storms.[3] These types of events are harmful to patient care, harrowing for staff, and ultimately very expensive for the facilities involved.

The unprecedented weather patterns created by climate change require a new approach to emergency preparedness for healthcare systems, as risks previously thought impossible are likely to become reality in coming years. Yet, each healthcare entity cannot reasonably prepare for every possible extreme scenario; the cost would be overwhelming and would compromise other important hospital missions. An approach is therefore needed that accounts for the rapid pace of climate change and prepares facilities appropriately without bankrupting health systems. In this article, we describe the strategy that our large health system in the US Northeast undertook to increase the climate change resilience of our facilities.

METHODS

Setting

Our large integrated health system is located in New England in the United States, and includes facilities in urban, suburban, rural, and island locations. There are 10 individual hospitals in our system along with many other associated facilities, including rehabilitation centers, administrative buildings, and research complexes. Some of the hospitals are high volume quaternary care academic centers, while others are relatively small community hospitals with limited numbers of service lines. In total, our process included resilience analyses for over 30 individual buildings across the system.

Climate Projections

Our first step involved an assessment of climate change projections for each of our locations over short-term and longer-term time horizons (for the years 2030 and 2070, respectively). To do this, we engaged a consultant group with climate change expertise and leveraged recent city and state level reports on projected changes in weather patterns over time. For our locations, we focused on three climate-related threats: 1) Extreme heat (higher temperatures and prolonged duration) 2) flooding (due to storm surge and/or high precipitation), and 3) high winds (likely in the setting of severe storms). We also decided to include a seismic assessment, although this is not known to be climate related. Fire and drought were not included as likely threats in our location, but these would certainly be necessary to plan for in other parts of the US.

For heat projections, we used a report commissioned by the city of Cambridge, Massachusetts with extrapolations for our various locations. To assess flood risk, we created probabilistic and consequence-based flood maps for each location. Probabilistic flood maps showed us flood extents and depths for 100-year and 500-year storms at our two future time horizons. Probabilistic maps were useful in assessing risk tolerance; for example, we might tolerate flooding that extended into a parking lot but not a building or we might tolerate a 5% annual chance of flooding in a garage but not a 1% annual chance of flooding in a clinical building. Consequence-based flood maps modeled worst-case scenario storms, which provided insight into the maximum level of protection our health system might need, or if that wasn't feasible, what kind of emergency preparedness plans we needed. This modeling was possible through use of the Boston-Harbor Flood Risk Model, commissioned by the Massachusetts Department of Transportation.[4]

Previous studies predict that wind speeds are expected to increase 5% for each 1 degree increase in sea surface temperature.[5] Applying this principle to climatology and storm surge models, high level estimates of potential wind speed increases through 2070 were prepared. These projections were compared with the wind speed design criteria specified by the Massachusetts Building Code for the location and use at the time of construction.

To evaluate seismic risk, we used historical building codes for each of the facilities evaluated, assuming that each building had been constructed with only the seismic resiliency required by local code for its primary use. The probability of earthquakes was calculated based on historic data and an understanding of the geological conditions which help to predict epicenters, drivers, and propagation of seismic events.

Ultimately, we produced a series of scenarios categorized by likelihood and projected consequence, which could subsequently be applied to each facility.

Vulnerability Analysis

Next, we sought to examine the potential impact of various climate scenarios on each of our facilities, to discover vulnerabilities to different types and levels of threat. To do this, members of our project team met with structural engineers, facility managers, research, operations, and emergency preparedness leaders, as well as clinical leaders from every site. At these meetings, these local leaders were given the projections for various levels of heat, flooding, wind speed, and seismic disturbance, and asked to assess the potential consequences of each for their respective areas of responsibility. At each site, the following specific structural/systems features were explicitly discussed:

Main grid power, emergency power, natural gas, medical gasses, fuel oil, HVAC system, potable water, non-potable water, storm water removal, waste water removal, medical waste, information technology, communications, among others.

In addition, the following operational functions were also each discussed:

Patient transfers, staff availability, on-site accommodations for staff, capacity for patient surges, medical supply chain, lab and pharmacy operations, and food and nutrition availability, among others.

Multiple conversations occurred with each set of local leaders to quantify potential disruptions to each of these functions due to the various projected climate threats. Ultimately, a comprehensive list of vulnerabilities for all sites was generated, organized by likelihood of an event and the potential consequences of that event based on our models. Consequences from a vulnerability were organized into three categories: Major, Severe, and Catastrophic (See **Table 1** for definitions of these criteria by facility type).

Table 1. Facility Damage Assessment Criteria

	Major	Severe	Catastrophic
Outpatient clinical operations	Interruption of clinical activities for 1 week or less OR inability to provide essential services	Interruption of clinical activities for 1 month or less	Interruption of clinical activities for greater than 1 month OR complete loss of an outpatient care site
Inpatient clinical operations	Evacuation or closure of some major inpatient care areas (but not the whole facility) for < 3 days	Evacuation or closure of some major inpatient care areas (but not the whole facility) for < 14 days	Evacuation of all inpatient care areas OR closure of some major inpatient care areas for > 14 days
Research operations	Evacuation or closure of major research labs/ areas (but not all research areas) for < 3 days	Evacuation or closure of major research labs/ areas (but not all research areas) for < 14 days OR loss of unique animals, cell lines, specimens, data, etc	Evacuation of all research areas OR complete loss of a research facility
Support services/ areas	Damage or destruction of a support area that will cause moderate impact to facility operations	Damage or destruction of a support area that will cause major impact to facility operations	Damage or destruction of a support area that will cause severe impact to facility operations

Developing Interventions

Once a comprehensive list of vulnerabilities was created, we then worked with a team of facility engineers along with operational and emergency preparedness leaders to develop plans for what would be needed to reduce or eliminate each vulnerability. Some solutions involved structural changes, while others involved primarily operational changes. Common interventions included moving equipment from a basement to a location higher in the building and installing cooling mechanisms for backup power systems. These projects ranged widely in complexity and estimated cost. Through this process, an exhaustive list of over 300 potential projects was generated, with a description of the work requirements and estimated costs for each.

Assessing Interventions

The list of potential interventions was far too long and expensive for every project to be carried out in the near term, so a prioritization scheme was needed. Elements of the scoring system included whether failure to fix an issue would create a regulatory violation, which type of clinical area would be affected (e.g. emergency departments and operating rooms vs. outpatient clinic spaces), and how severe the disruption would be to local operations. Weighed against the costs of each project, the team chose to prioritize interventions into four categories:

1) Immediate priorities for urgent mitigation
2) Projects in need of investigative study for medium-term mitigation
3) Priorities for planned capital improvement projects
4) Priorities for integration into new facility construction

This rational blended approach facilitated a plan that would increase preparedness in the short term while also ensuring that climate resiliency would improve over time – in line with increasing levels of threat over time – as new construction projects were undertaken across the system. Where physical plant improvements were not feasible or would be delayed for later phases of implementation, emergency preparedness and operational leaders were tasked with developing emergency plans for the relevant climate-driven events.

RESULTS

Our systematic approach to risk assessment and intervention development identified over 300 potential vulnerabilities in our health system, with a range of consequences from moderate to catastrophic. We identified that climate change adjusted projections for heat, flooding, and wind would all strain our current facilities if improvements were not undertaken. See **Table 2** for examples.

Table 2. Examples of vulnerabilities created by each type of climate-related disaster in our settings, along with potential solutions in the near and longer terms.

Threats	Examples of Vulnerabilities	Examples of Solutions
Heat Waves	- Lack of cooling for back-up power sources - Lack of back-up power for cooling mechanisms - Potential regional brownouts - Potential need for hospital as shelter for the community	- Adding chillers to emergency power - Creating street connections for supplemental emergency power & chillers - Energy efficiency initiatives to reduce burden on power sources, in current and future facilities
Flooding	- Critical infrastructure interruptions (transit, energy, telecom) - Supply chain disruptions - Personal impact to workforce - Loss of critical services on lower levels (utilities, pharmacy, food services) - Water contamination	- Business continuity planning - Flood barriers - Utility hardening - Storm water management systems - Advocate and partner for public utility improvements - Incorporate flood projections into new building designs/relocations
High Winds	- Hazards from slate and ballasted roofs - Wind-driven rain entering through windows, under cladding and roofs - Equipment blowing off roofs	- Roofing repairs and replacements - Wind resiliency improvements to current facades - Stronger equipment tie-downs - New facilities built to codes of areas with higher wind speeds

Nearly all facilities faced vulnerabilities amidst projected extended heat waves, particularly during summer months when a majority of days could be expected to exceed 90-degree temperatures by 2070. The most common problem encountered was how to keep buildings cool if local power systems or the grid were to fail, as most buildings did not have emergency power for cooling. Most buildings also faced vulnerabilities if wind speeds were to increase markedly, with particular risks to older slate and ballasted roofs. In addition, some equipment on building exteriors was deemed at risk due to inadequate strength of tie-downs, and many buildings faced risk of wind-driven water entry through windows and under roofs.

Flooding was also projected to be a major risk for many sites. Flooding on-site could directly damage critical services on buildings' lower levels including utilities, pharmacy, food services, and water supply. Flooding of surrounding areas could disrupt critical infrastructure (e.g. local transit, energy lines, and telecommunications), and interrupt usual supply chain routes. Such flooding could also impede the ability of staff to come to work (and return home). Most facilities were not fully prepared for the flood depths that could occur in future climate-adjusted models.

Some of the more immediate interventions undertaken in response to these vulnerabilities included adding chillers to emergency power, creating connections to the street for accessing supplemental emergency power, replacing roofs and windows, increasing wind resiliency of existing structures, strengthening equipment tie-downs, creating higher flood barriers, improving storm water management systems, and hardening of utilities against water damage. Longer-term interventions included considering flood projections into new building site choices, incorporating wind resilience into new building plans far beyond local code requirements, and advocating for improvements to local public utility infrastructure.

DISCUSSION

In this article, we present a systematic approach to assessing healthcare system vulnerabilities and prioritizing preparedness interventions in the setting of increasingly severe weather events resulting from climate change. Utilizing climate projections that largely already existed for our local area, we were able to create realistic scenarios for what each of our facilities could expect in coming years, and plan for levels of threat that would not be accounted for by usual Hazard Vulnerability Analyses based on historical data. Some of the projections were startling and resulted in construction principles we would otherwise have never employed; one of our Massachusetts hospitals now has a building enclosure, roof, and walls designed to the building code for wind levels in Miami, for example. Without a clear-eyed assessment of climate change scenarios, our healthcare systems risk more events like those seen in Hurricanes Katrina and Sandy. However, by using data often already available, health systems can plan for these types of severe events and become better prepared for when they occur more frequently in coming decades.

A key feature of our strategy was the blending of short- and long-term projections with a mix of time horizons for improvements. Not all projects could feasibly be completed immediately, but not all needed to be; some could safely wait a decade or two based on climate projections. This allowed many strategies to be built into future construction plans, which is more cost effective than renovating current structures. Plans created now can therefore help to ensure increased climate resiliency for many decades.

One important lesson from our experience was the need to engage local leaders across disciplines at each facility. Assembling climate projections and flood maps can be done in a conference room or behind a desk, but the vulnerability analysis cannot. Without engaging the people who understand the structure and operational processes of each facility in depth, a vulnerability analysis cannot effectively reveal the most pertinent issues to be addressed. In addition, involving local leaders – including CFOs – helps to ensure buy-in for projects once improvement possibilities are identified.

While our analysis focused only on facility structures and day-to-day operations, there are certainly broader impacts of climate change that hospitals should consider moving forward. One major challenge will involve accommodating increasing healthcare demand due to the impact of climate change on patients. Others have discussed how both discrete weather events and overall climate trends are likely to increase the burden of both acute injury and vector-borne illness as well as many chronic diseases.[1] Many American hospitals already lack reserve capacity and struggle with overcrowding on a daily basis; future health system design must account for yet further increases in the number of patients requiring care in coming decades.[6]

Another important consideration is the impact of climate change on facilities beyond traditional hospitals. In our setting, we included research facilities as medical research is core to the mission of our health system; with extra-cold freezers and other unique needs, protecting research capability can necessitate additional types of strategies. We also assessed rehabilitation centers, and future work at local and broader levels should include skilled nursing and long-term care facilities. If these types of facilities are rendered unsafe during a disaster, their residents will end up in hospitals, only further stressing the healthcare system. For example, Florida hospitals received many patients during Hurricane Irma in 2017 after cooling systems in nursing homes failed.[7] Helping to ensure that lower level of care settings have preparedness plans can help alleviate burdens on hospitals at times of great stress.

CONCLUSION

The potential impacts of climate change on our hospitals and health systems are daunting but must be faced head-on to ensure that patients can receive life-saving care when they need it most. While the specific risks and vulnerabilities for each hospital will differ according to location and structural features, the rational blended approach we describe here is broadly applicable. By forecasting specific risks, diagnosing vulnerabilities, developing potential solutions, and using a risk/benefit approach to decision making, hospitals can work toward protecting themselves and their patients in the face of potential climate-related natural disasters in an economically sound manner.

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Providence's Vulnerability to Floods: Impacts of Sea Level Rise, Stronger Storms, and Heavier Rainfall

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KEYWORDS: climate change, climate resilience, disaster medicine, hazard analysis, emergency preparedness, flooding

INTRODUCTION

The City of Providence, RI, and its healthcare infrastructure face growing risks from climate change. Environmental stressors including higher temperatures and atmospheric changes increase pressure on the existing social-environmental system. In a 2019 report, the Providence Emergency Management Agency (PEMA) and Local Hazard Mitigation Committee (LHMC) identified flood-related hazards as a major risk to Providence's built and natural environments and community health.[1] Hazard Vulnerability Analyses, (HVAs), conducted annually as part of each acute care hospitals' emergency preparedness, also consider the impact of flooding, hurricanes, and winter storms in their danger assessments.

Providence is located on the lowland shore of the northern fringe of Narragansett Bay, a coastal estuary environment with a 4-foot tidal range.[2] The city area also includes four river systems that are tidally affected. Providence's northern region is drained by the Moshassuck River, and the western-central region is drained by the Woonasquatucket River. Their confluence at downtown's Waterplace Park forms the tidal Providence River, which flows southward to join the Seekonk River at the head of Narragansett Bay. The city's coastal floodplain from the port area along Allens Avenue and river floodplains through the downtown Fox Point Hurricane Barrier (FPHB) and up the Moshassuck and Woonasquatucket River corridors, face risk of hazards related to inland, riverine, tidal, and storm-surge flooding.[2]

Since the establishment of the Providence Colony in 1636, centuries of industrial and residential development have modified the coastal landscape. Dense urbanization, river engineering, and waterfront barriers replaced the region's salt marshes, swamps, and river floodplains with impervious surface cover (>37% of the city), which has decreased the city's ability to infiltrate excess water into soil.[2,3] This development pattern has compounded the magnitude and frequency of flooding events, especially urban flooding caused by stormwater runoff.[2]

The causes of flooding are multifactorial. Global surface temperatures have risen over the past 150 years, with a rapid change since 1970, due to increasing atmospheric concentrations of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_20), and fluorinated gases.[4] Warming is certain to continue until at least mid-century under even the most aggressive emissions reduction scenarios, with significantly different temperature ranges beyond 2050, depending on the emissions path.[4] Together with changing physical conditions, three major climatic impact drivers (CIDs) – rising sea levels, intensifying storms, and increasing precipitation rates – increase the likelihood of hazardous flooding in Providence.[2]

RISING SEA LEVELS

Thermal expansion of oceans, mass loss from glaciers and ice sheets, and transfer of water from terrestrial aquifers to the ocean have led to a global mean sea level (GMSL) rise of 7.9 inches between 1901–2018.[4] Rhode Island's tide gauges have risen even higher.[5,6,7] Observations from the National Oceanic and Atmospheric Administration's (NOAA) Providence Tidal Station show that Relative Sea Level (RSL) rose 9 inches from 1938-2020, a higher rate than the global average due, in part, to local land subsidence and ocean circulation.[5,6] The rate will likely accelerate non-linearly through the 21st century. Under a high emissions scenario, Narragansett Bay's RSL is projected to rise an additional 3.7 inches by 2030, 8.3 inches by 2040, 13.8 inches by 2050, 2.5 feet by 2070, and 4 feet by 2100, according to the United States Army Corps of Engineers (USACE) and NOAA.[6] The rising high tide level will cause the city's coastal floodplain to encroach inland toward downtown, expanding the area prone to flood events.

STORM INTENSITY

The Northeast is experiencing intensification of tropical cyclones and extratropical storms due to warmer sea surface temperatures and the poleward shift of North Atlantic storm tracks.[2,4,8] These storms temporarily raise sea level – called 'storm surge' – due to several factors, including changes in atmospheric pressure, high winds and wave activity that push water up against a coastline. According to storm modelers at the University of Rhode Island, Narragansett Bay's funnel-like shape further amplifies the height of a storm surge as it moves up the bay.[2] Examples of storm surges in Narragansett Bay include the Great New England Hurricane of 1938 (Category 3), Hurricane Carol (1954, Category 3), Hurricane Diane (1955, Category 1), Hurricane Bob (1991, Category 2), Superstorm Sandy (2012), and Tropical Storm Henri (2021). More intense coastal storms coupled with a significant rise in the RSL will generate greater storm surges surpassing historical benchmarks and extending further inland. Importantly, a future storm-driven 1-in-20 year flood on top of a two-foot SLR will have the same water level and depth as today's 100-year flood.[7]

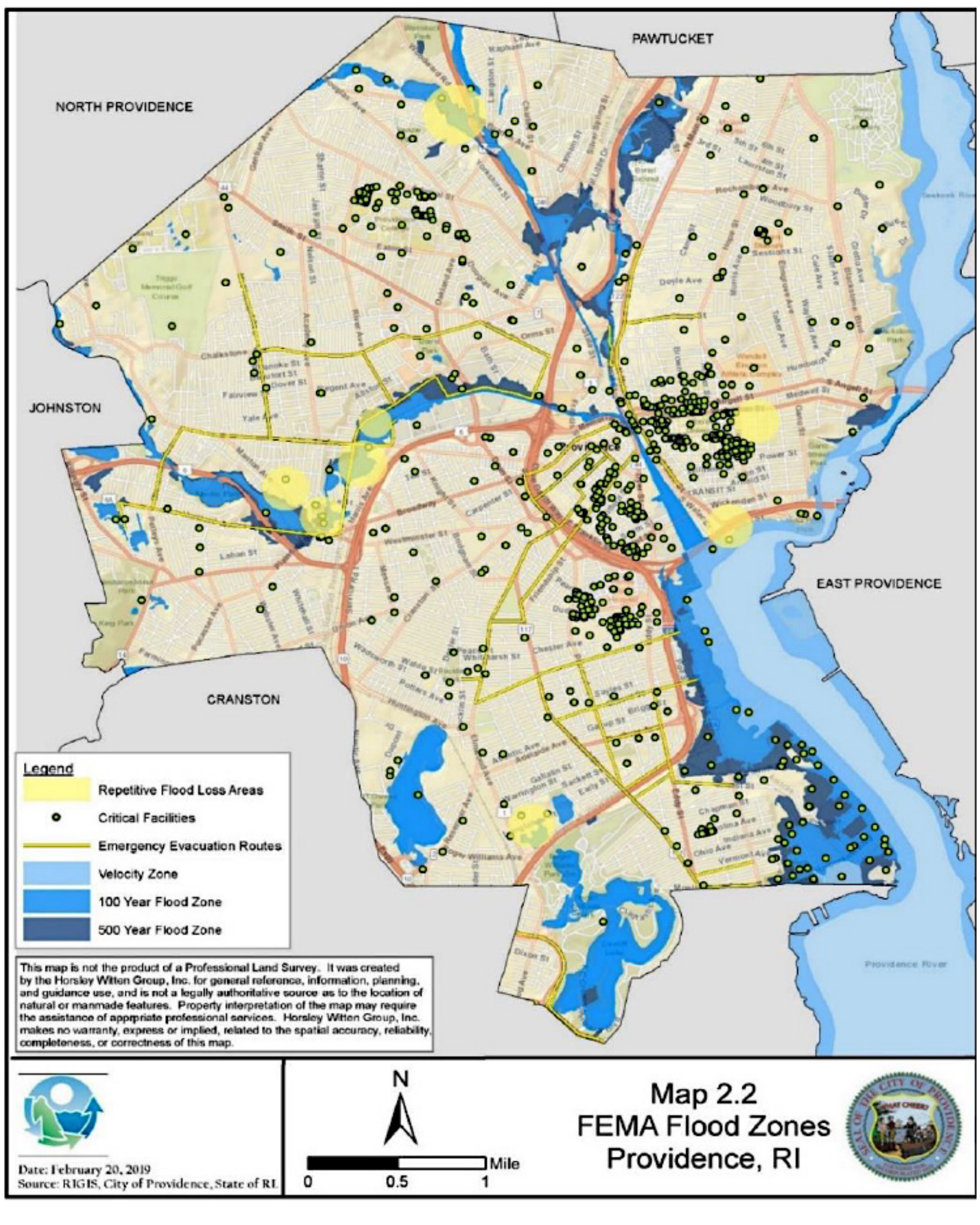
IMPACT ON PROVIDENCE

Taken together, the climatic impact drivers make sections of Providence vulnerable as seen in the flood map (see **Figure 1**).[1] Even one additional foot of sea level rise, predicted by mid-century, would multiply the impact of flooding, and thereby affect numerous facilities in an expanded flood zone. Critically affected infrastructural assets include commercial and industrial port facilities, drinking water supply systems, wastewater treatment plants and stormwater systems, along with roadways, the FPHB, and some residential neighborhoods. Healthcare facilities located south of the FPHB, near the port area, are particularly vulnerable to inundation or access disruption. These include Hasbro Children's Hospital, Rhode Island Hospital, and Women & Infants Hospital,

PRECIPITATION RATES

The warming atmosphere causes higher evaporation rates, which increase humidity, rainfall totals, and frequency of rainfall events. Many regions of the contiguous United States have experienced this trend since the 1950s, but it is most pronounced in the Northeast.[5,8] From 1895 to 2011, average annual precipitation in the Northeast increased 10%, and since 1958 extremely heavy precipitation increased 70%.[9] In Rhode Island, the number of heavy downpours (downpour = top 1% heaviest rain events) has increased 104% since 1950, a higher increase than in any other state.[10] This year's July was Rhode Island's third wettest July on record with 7.12 inches of rainfall, nearly double the historical average.[11] Only July of 1916 and 2009 were wetter, with 9.09 and 10.32 inches of rainfall respectively.[11] By the end of the century, the number of 24-hour events per year that produce at least 1 inch of precipitation is projected to increase in all emissions scenarios.[4,10] This rainfall trend presents risk of inland and urban flooding which may be compounded by simultaneous coastal flood events and overwhelmed drainage system infrastructure.

Figure 1. FEMA Flood Zones in Providence, RI.



as well as several smaller facilities.[1] PEMA's 2019 assessment of flood-related hazards show that these three hospitals/healthcare facilities would be significantly impacted by the storm surge of a Category 1 hurricane, while numerous additional facilities would be devastated by a Category 3 hurricane storm surge.[1,2] As seen in Hurricanes Katrina and Harvey, flooding and associated storm winds and rain can also cause havoc from above by damaging protective structures such as roofing, and damage hospitals outside the flood zone. Destruction of critical hospital infrastructure, including generators, HVAC systems, water supply, and the medical supply chain can lead to additional downstream emergencies.[12,13]

CONCLUSION

The risk of flooding in Providence will become more severe in the coming decades. HVAs are constructed using historical data, but as Baugh et al. emphasize, we live in an era of climate change, making past data unreliable in estimating an accurate level of risk for Providence's critical healthcare facilities.[14] Coalitions including the Providence Resilience Partnership (PRP) have emphasized the need for a predictive flood model incorporating climate change, land-cover types, hurricane barrier dynamics, and diverse stakeholder needs, but a common resilience strategy does not yet exist.[2] It is important that the city of Providence, the Rhode Island Sea Grant, the RI Department of Health, RI Emergency Management Agency (RIEMA) and the city's hospitals develop a plan based on future projections, as the natural hazard of flooding poses a significant risk of harm to the city, its hospitals, and the frontline communities they serve.

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A Case of Heat Stroke in the Era of Climate Change

FRED VARONE, MD; WILLIAM BINDER, MD

From the Case Records of the Alpert Medical School Residency in Emergency Medicine

DR. FRED VARONE: Today's patient is an elderly male of unknown age (later found out to be 68 years old) who was brought into the Emergency Department (ED) by Emergency Medical Services (EMS) after being found unresponsive in a park. The patient was fully dressed and wearing a coat, lying face down, despite outside temperatures hovering at 99°F and > 90% humidity.

Initial vital signs were notable for a systolic blood pressure of 70 mm Hg, pulse 130s, and a rectal temperature of 43.3°C (110°F). The patient was noted to be unresponsive to painful stimuli and his skin was dry and warm to touch. Pupils were 3 millimeters bilaterally and sluggishly reactive. His cardiac exam revealed tachycardia with a regular rhythm. Breath sounds were clear although he was noted to have sonorous respirations.

The patient was given a bolus of crystalloid IV fluids and push dose phenylephrine for hypotension. He was intubated for airway protection via rapid sequence intubation using ketamine and rocuronium.

DR. AMY MATSON: What laboratory and imaging studies were obtained?

DR. VARONE: Notable labs are seen in **Table 1.** The patient's laboratory abnormalities are not unusual in heat stroke. Rhabdomyolysis and injury to the kidneys and liver are often noted by elevations in the creatinine phosphokinase (CPK), creatinine and liver function tests. Thrombocytopenia is also common. Troponin is frequently elevated as well, reflecting a type 2 myocardial infarction.[1,2,3,4,5]

Table 1. Heat Stroke Criteria

Lab	Initial presentation	Day 1 of hospitalization	Day 3 of hospitalization
Hemoglobin/Hematocrit	10.9/33	11.8/34	
Platelets	64 x 10^9/L	21 x 10^9/L	74 x 10^9/L
Creatinine	1.80 mg/dl	2.51 mg/dl	5.43 mg/dl
Troponin I	0.166 ng/ml	68.194 ng/ml	65.271 ng/ml
AST/ALT	125/36 IU/L	4,060/354 IU/L	949/302 IU/L
CPK	243 IU/L	6,638 IU/L	4,555 IU/L
Lactate	9.3 mEQ/L	4.6 mEQ/L	

There are no specific findings on radiographic imaging suggestive of heat stroke. When acute lung injury and ARDS are suspected, chest X-ray will show the typical bilateral infiltrates. In our patient, a chest X-ray after intubation showed the endotracheal tube in good position and no acute cardiopulmonary abnormalities. CT imaging of the brain and cervical spine without IV contrast was unremarkable for acute changes. CT imaging of the abdomen and pelvis with intravenous contrast revealed diffuse thickening of bowel loops with enhancing walls concerning for bowel ischemia, as well as bibasilar airspace disease.

DR. JOSEPH LAURO: With a temperature of 110°F, this patient has heat stroke. Is it unusual for a temperature to rise so high without exertion? Can you review the different types of heat stroke?

DR. VARONE: Heat-related illness exists on a spectrum of disease severity, with heat stroke being the most severe manifestation. Other classifications for heat-related illnesses include heat stress, heat injury, heat exhaustion, heat syncope, and heat cramps. The loss of fluid and salt in sweat can lead to muscle cramping and intravascular volume depletion leading to syncope. Heat exhaustion can be considered the precursor to heat stroke, with symptoms such as headache, dizziness, nausea, weakness, and a temperature that is typically between 36 and 40°C. While these are all readily reversible clinical conditions with cooling and hydration, they can progress into organ failure if untreated, leading to the syndrome of heat stroke.

Our patient has heat stroke, classically defined as high environmental heat exposure combined with CNS dysfunction and elevated core body temperature > 40°C (104°F).[6] Additional definitions have been proposed which do not include temperature criteria (See **Table 2**).[7]

Heat stroke can be divided into classic heat stroke (CHS) and exertional heat stroke (EHS). CHS occurs more often in vulnerable populations, such as the elderly, as their ability to compensate is often impaired by comorbidities and medications. EHS, on the other hand, occurs in

Table 2. Comparison of different criteria for diagnosis of heat stroke

All definitions	• High Environmental Heat Exposure
Bouchama	• Core temperature > 40°C • CNS effects (coma, delirium, seizures)
JAAM	• CNS symptoms (Japan Coma Scale score of ≥ 2, cerebellar symptoms, convulsions seizures) • Hepatic or renal dysfunction • DIC by JAAM criteria
JAAM-HS-WG	• GCS ≤ 14 • JAAM DIC score ≥ 4 • Creatinine or bilirubin sym 1.2 mg/dl

Glasgow Coma Scale, Japanese Association of Acute Medicine (JAAM), Japanese Association of Acute Medicine heat stroke committee working group (JAAM-HS-WG)

young, healthy individuals during strenuous physical activities (athletes, military personnel).[7,8] Temperatures can rise substantially in both forms of heat stroke.

In patients with heat-related illness, heat loss is mediated by several different mechanisms. These include radiation, conduction, convection, and evaporation. In cool temperatures, the majority of body heat (55%–65%) is lost by radiation, or the emission of energy from the skin. Convection occurs through the transfer of heat from the body to a gas (air), while conduction occurs by the transfer of heat between two surfaces with different temperatures. In warm temperatures, evaporation is the primary means to dissipate heat, but it has limited efficacy when humidity rises above 60%.[1] Unfortunately, our patient was unable to dissipate heat due to his clothing and the high heat index (a combination of air temperature and relative humidity).

DR. ELIZABETH SUTTON: This patient's temperature reached 110°F. Is that usually survivable? What happens to the patient's organs?

DR. VARONE: While organ systems may start to exhibit dysfunction at 40°C (104°F), higher temperatures are survivable, and patients may have temperatures up to 43.3°C (109.9°F) and survive with good neurologic outcome.[9] Some studies suggest that time to cooling may be more important than maximum temperature.[3,10,11]

The cause of an elevated temperature is important. Fever is created when pyrogens (such as bacterial endotoxins or cytokines produced from cell damage) act on the hypothalamus to increase the natural temperature set point through increased prostaglandin production.[7]

In heat stroke, however, temperatures rise without an adjustment in the hypothalamic set point. In heat injury, cell membrane physiology is disrupted, leading to endothelial and organ cell death.[2,12,13,] Proteins start to denature around 40°C, leading to enzyme disruption, mitochondrial failure, and loss of oxidative phosphorylation. In response to injury, cells produce heat-shock proteins, which are protective against heat, hypoxia, and ischemia, but these quickly can become overwhelmed in severe heat stroke.[1] The end result is cell death across multiple systems.[14]

The impact of hyperthermia on organ systems is significant. In the CNS, thermal injury can lead to cellular denaturing, neuronal death, and excitotoxicity. Cytokine release and resultant vascular damage, as well as local ischemia and systemic changes in blood flow can result in cognitive impairment, seizures, and cerebral injury.[15]

Gastrointestinal tract physiology is altered by hyperthermia and contributes to mortality. To dissipate heat, blood flow shunts from the GI tract to the skin, resulting in bowel ischemia, mucosal barrier disruption, and bacterial translocation. Bacteremia, circulating endotoxin and sepsis can ensue.[1,3,13] Additional inflammatory mediators, including IL-1 and IL-6, are released from injured cells, causing a systemic inflammatory syndrome response (SIRS).[1,7] Vascular endothelial cells also sustain damage, which can lead to a consumptive coagulopathy and systemic microthrombi.[2,13]

Other organ systems are impacted. Myocardial infarction has been reported in up to 7% of admitted heat stroke patients.[4] Multi-organ dysfunction and systemic manifestations including disseminated intravascular coagulation, rhabdomyolysis, hepatic necrosis, and acute kidney injury have all been reported.[5,16]

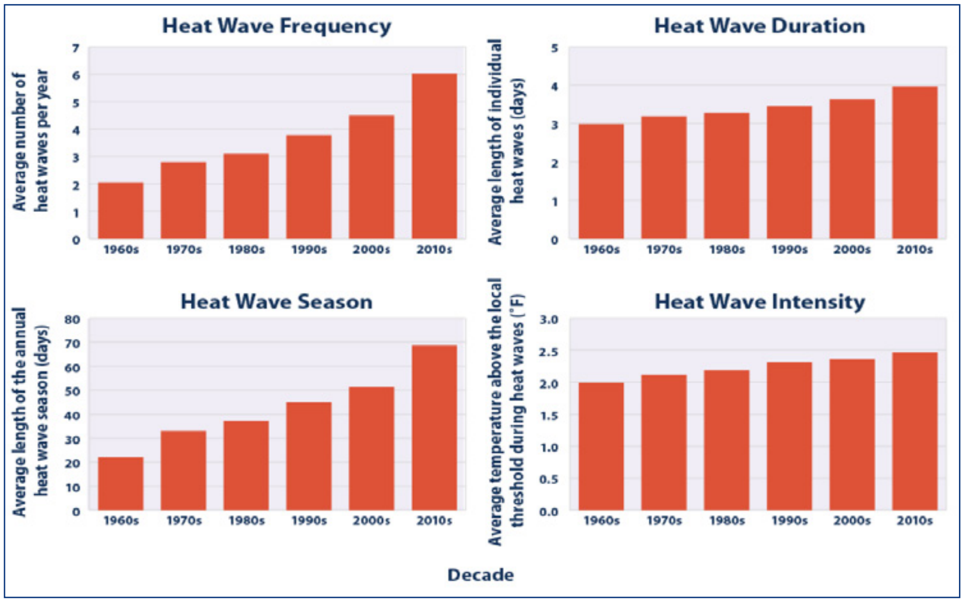
DR. OTIS WARREN: Are heat-related illness occurring with greater frequency?

DR. WILLIAM BINDER: There has been an increase in the frequency of extreme heat events (EHEs) over the last several decades. Data analyzed between 1961 and 2019 for 50 metropolitan areas in the US shows an increase in heat wave frequency, duration, intensity, and an increase in the length of the heat wave season (see **Figure 1**).[17]

Heat related mortality has risen concordantly. While it is reported that approximately 700 individuals die annually in the US due to heat, it is felt that this number is grossly underestimated as comorbid diseases are often reported as a primary cause of death, thereby concealing environmental heat's role.[1,18] The recent Lancet countdown on health and climate change suggests that in 2018, 19,000 deaths in the US were related to high environmental temperatures.[19] Underscoring this, our patient's problem list and discharge summary in the electronic health record acknowledges NSTEMI, encephalopathy, and acute kidney injury, but makes no mention of heat stroke.

While data on heat-related mortality in Rhode Island is not available, average temperatures have risen over the past several decades. Between 1981–2010 there were an average of 9 days ≥ 90°F in the Providence Metro area; this number increased between 2010 to 2014, and in 2021 there were 19 days ≥ 90°F. Rising summer daily temperatures have been linked to increased EMS utilization and ED visits.[20,21]

Figure 1. Heat-wave frequency, duration, intensity, and length of season between 1961–2019 for 50 metropolitan areas in the US.



Rapid cooling is the mainstay of treatment for heat stroke and improved outcomes are related to early recognition and treatment.[6,8,10,11,12] Patients should be cooled at a rate of 0.1–0.2°C per minute until evidence of clinical improvement, with careful attention paid to preventing overcooling.[6,26] While there is no specific temperature goal and the patient's clinical picture should guide cooling, some studies have used specific temperature cutoffs to prevent overcooling (38–39°C).[6,10] Techniques used for cooling in the ED include cold packs and ice (conduction), and evaporative cooling using cold water and fans. Cold-water immersion, frequently used in the pre-hospital setting for patients with EHS, is often impractical in the ED and potentially harmful in older patients with CHS requiring monitoring. Invasive methods for cooling include bladder, gastric and peritoneal lavage, and cardiopulmonary bypass methods such as ECMO-based cooling.[26]

Our patient received intravenous fluids, cold packs and ice, and evaporative cooling with fans. His temperature decreased to 39°C within 45 minutes of arrival to the ED.

Of note, antipyretics have no utility in hyperthermia due to environmental exposure, and some studies suggest they may be harmful in heat-related injury.[26]

DR. VARONE: Anthropogenic climate change from increasing urbanization has resulted in heat islands, areas where the average temperature is higher than surrounding areas. Developed cities tend to have higher day and nighttime temperatures due to increased heat production, replacement of vegetation by concrete and other manmade materials, and disruption of natural airflow by large buildings, streets, and city geometry.[22] Higher evening temperatures prevent humans from recovering from daytime heat exposure and injury. Analysis of the 2003 Paris heat wave shows a clear association between increased nighttime surface temperature in heat islands and risk of death, particularly in elderly people.[22]

While cities only make up around 2% of the Earth's surface, they are responsible for 75% of the world's emissions.[23] In 2007 there were 19 cities with 10 million or more inhabitants; by 2018 there were 33 "mega-cities." Increasing urbanization will lead to more heat islands and more heat-related illness, particularly in developing countries where populations and urbanization are still accelerating.[23,24]

DR. CATHERINE CUMMINGS: What was your management of this patient with hyperthermia?

DR. VARONE: Rectal temperatures should be checked in patients with suspected heat stroke. External measurements have been shown to correlate poorly with rectal temperature and underestimate the degree of hyperthermia.[8,11] In one study of collapsed marathon runners, only two of 17 collapsed runners with true hyperthermia (rectal temperature ≥ 39.4°C) were identified correctly by temporal measurement.[25]

DR. NICK MUSISCA: What happened to this patient?

DR. VARONE: After intubation, orogastric and rectal tubes were placed. His ED course was complicated by runs of atrial fibrillation with rapid ventricular response, and cardioversion was attempted but was unsuccessful. His rate decreased with fluid administration and temperature control. He received benzodiazepines, to prevent shivering and agitation, piperacillin-tazobactam for ischemic bowel, and anti-epileptic medications (AEDs).

The patient was admitted to the medical intensive care unit and multiple medical services were consulted. Continuous electroencephalography was performed for 24 hours, and the patient did not demonstrate seizure activity. On hospital day 4 he was extubated, although he was confused and encephalopathic. On hospital day 10 he was able to provide health care workers his name, and social work was able to locate his daughter. She reported a history of chronic alcohol abuse and dementia - known risk factors for heat stroke. The patient improved to his baseline and was discharged to a skilled nursing facility on hospital day 19.

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Image 1. Swedish icebreaker Oden.

Frozen Obsession documentary follows URI team studying climate change in the Arctic

MARY KORR
RIMJ MANAGING EDITOR

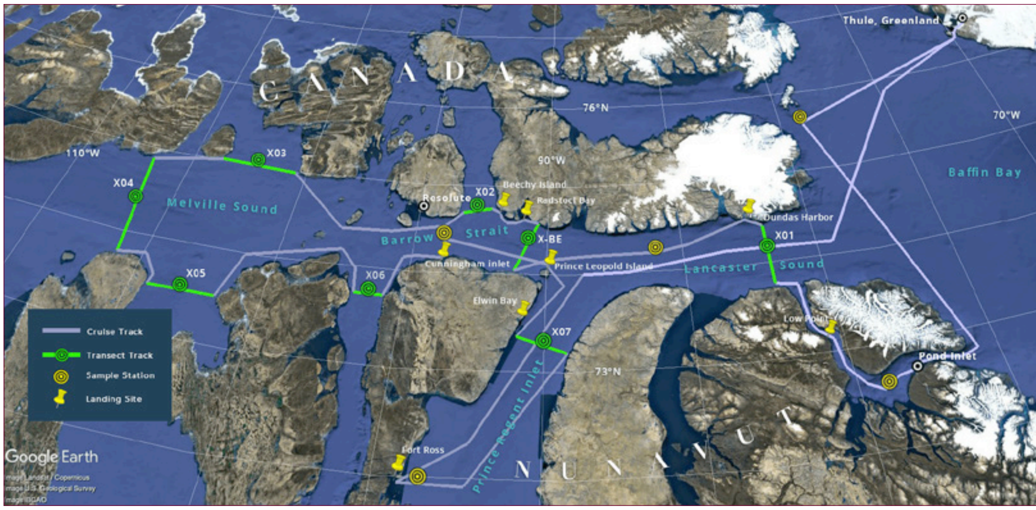
Frozen Obsession captures a once-pristine Polar ecosystem eroding at an alarming and accelerating rate. The PBS documentary by Emmy Award-winning filmmaker **DAVID CLARK** chronicles the Northwest Passage Project (NPP) expedition studying the effects of climate change in the Canadian Arctic. A team at the University of Rhode Island (URI) Graduate School of Oceanography (GSO) and its Inner Space Center, an international research and education hub, developed the project.

Aboard the Swedish icebreaker *Oden*, (**Image 1**), the expedition departed from the U.S. Thule Air Base in Greenland in July 2019, on a 2,000-mile voyage through the Northwest Passage (**Figure 1**). During a pre-release viewing of the film, followed by a ZOOM panel discussion, planners and participants shared their experiences during the 18-day mission.

URI Associate Professor of Oceanography **BRICE LOOSE, PhD**, the project's chief scientist, described the Arctic as "a melting pot. The old Arctic is disappearing. I feel like we are watching a tragedy unfolding." He noted the dramatic shifts in the climate record. "Humans were not on the planet the last time there was a major change in the climactic pattern like the one we are experiencing today. Previously it has been over the course of several thousand to a hundred thousand years. What we are seeing today is a profound change because of the speed with which it is unfolding. It is not even a matter of decades now, but years."

Loose described the NPP research as "basic science, data collection. It was an opportunity to peer into a complex system and start to understand it for the first time." Clark's documentary offers fascinating glimpses into this; one scene depicts Loose and a small group helicoptered to sea ice floes, where they drilled into six-foot thick ice to collect core samples (**Image 2**). What they found was disturbing – plastics of different types, sizes and colors. "There was so much plastic that you could look at it with your naked

Figure 1. Map of the Northwest Passage Project Expedition.



Q&A with oceanographer Brice Loose, PhD, NPP project lead scientist

MARY KORR
RIMJ MANAGING EDITOR

Q. What kind of routine medical screenings were done for the pre-COVID Northwest Passage Project (NPP) and what is taking place now on research expeditions?

A. Participants have to go through a fairly rigorous medical screening with certification from their physician and dentist that the likelihood of needing emergent care is low within the next 3-6 months. People are sometimes disqualified for heart and eye conditions, for example.

Q. Was the medical team on the ship from New England?

A. Typically, the medical personnel are employed by the ship operator. In this case, the Swedish Polar Research Secretariat had a staff physician aboard.

Q. It did not sound like there were any medical emergencies, but if there were, would a patient be helicoptered out?

A. Yes, the helicopters are critical in this respect. They can rapidly transfer someone to a town with a hospital or with airline service to larger towns. In the Northwest Passage, we were often less than one day away from a community that was accessible by helicopter. These townships are serviced by two Canadian airlines, so the field setting was not as remote as it can be.

Q. Are there research findings from the Project you would like to highlight?

A. For NPP, the other results are preliminary and still in progress, but we see the influence of terrestrial glaciers affecting the distribution of plankton and microbes, and potentially even the production and degradation of greenhouse gases. Despite the extended daylight, we found very little exchange of nutrients between land and sea. That, combined with the enhanced freshwater on top of seawater, meant that very little plant nutrient was available in the surface ocean to fuel plankton growth by primary production. In these respects, extended summer melt is really transforming the region.

I'd also like to make you aware of the **MOSAiC project: https://mosaic-expedition.org**. In total there were four URI members who participated in MOSAiC during the course of the year-long drift. We had some serious logistical hurdles to transfer personnel during the spring crew changes, but a protocol was developed so that COVID never made it out to the vessel.

Q. Is there follow-up research to the NPP taking place in the Canadian Arctic?

A. We are in collaboration with Canadian Dept. of Fisheries and Wildlife that have long-term monitoring in this area. Their work is ongoing. One of our graduate students has been journeying to the Canadian Arctic and the NWP almost every summer for several years. ❖

eye and see all of the beads, fibers and filaments just sitting there in the bottom of the containers," Loose said.

Previous European research has shown the trajectory of plastics, determining it lofts through air masses, descends on Arctic islands, and flows with ocean currents. Some of the sea ice collected during the 2019 expedition is believed to have started in the Central Arctic, moved east through the Nares Strait by Greenland, and then into the Northwest Passage's Lancaster Sound.

Analyses into the data collected during the NPP project is ongoing; for example, identifying the state of weathering on the ice samples and trying to determine the degradation of the plastics, and potentially tracing its source to the manufacturer.

"It is important for people everywhere on Earth to see and understand how this region affects all of us," said NPP principal investigator and project director **GAIL SCOWCROFT**. "The region's meltwater, water circulation, and exchange of greenhouse gases between the ocean and the

Image 2. Dr. Brice Loose, at right, chief expedition scientist with the Northwest Passage Project and research team collecting samples from ice cores in the Arctic.

[COURTESY NORTHWEST PASSAGE PROJECT/ CAMERA: DUNCAN CLARK]

Image 3, 4. Polar bear and iceberg in the Canadian Arctic waters.
[COURTESY OF THE NORTHWEST PASSAGE PROJECT.]

atmosphere are causing wide-scale environmental and climatic changes, which increasingly affects people and wildlife diversity around the world." (**Images 3, 4**)

However, she pointed to encouraging signs, with the United States rejoining the Paris climate agreement this year, and also stressed the urgency for individuals to act. "We can, as citizens, reduce our own carbon footprint and encourage our governments to move towards a zero-emissions economy."

On the voyage, GSO microbiology graduate student **JACOB STROCK** supervised the observation and collection of plankton samples, "to understand what is in the water and how susceptible these 'small but mighty' microscopic organisms might be to climate change. Many small organisms can have a large effect. What impact will it have on the Arctic as a whole?" he pondered during the panel discussion.

Filmmaker Clark said he hoped the film's takeaway for viewers would be to "believe the science, and see that climate change is real. We look to the next generation of young scientists and decision-makers; they are the ones who are going to save us."

Frozen Obsession also explores the maritime history of the Northwest Passage, and the history and effects of climate change on indigenous populations. The latter perspective was compelling, given by student participant **MIA OTOKIAK**, Inuit scientist and community liaison.

The NPP was supported with major funding from the U.S. National Science Foundation and additional support from the Heising-Simons Foundation.

For further information on the project and how to view the documentary, visit https://northwestpassageproject.org.