EXPLORING THE CORRELATION BETWEEN CLIMATE CHANGE AND INFLUENZA ACTIVITY IN THE NORTHEAST UNITED STATES, 2003-2023

by

Emily M. Posadas, MPH, MCHES

Liberty University

A Dissertation Presented in Partial Fulfillment

Of the Requirements for the Degree

Doctor of Philosophy

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ABSTRACT

The influenza virus is influenced by a myriad of complex interactions with human and environmental factors, with changing climate patterns having significant effects on the health status of a population. This study investigates the correlation between climate change and influenza activity in the northeast United States from 2003 to 2023, providing insight and understanding into the interaction between the two variables. The anthropogenic factors that have contributed to climate change are recognized, and circulating seasonal and avian influenza viruses are discussed within the context of climate change. The investigation of the correlation between climate change and influenza activity across this region relies on undertaking a Pearson's correlation coefficient analysis between climate variables and influenza case-counts, as well as analyzing longitudinal, retrospective climatic time series data from the National Oceanic and Atmospheric Association. Influenza data, from the 20-year timespan, was collected from state public health departments across the northeast United States, as well as from the Centers for Disease Control and Prevention's Flu View site. This data was analyzed against climate factors to determine if a correlation exists. A correlation (Pearson's $r = .327$, $p = 0.05$) between climate change and influenza activity was found for this region. Furthermore, the One Health approach was used as a framework to promote further research and interdisciplinary collaboration and to encourage greater influenza surveillance and public health policies aimed at establishing a more climate-resilient region.

Keywords: Climate change, influenza activity, avian influenza, seasonal influenza, One Health, surveillance, policy, climate resilience

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Dedication

To my beautiful children, Junior and Logan: I hope this body of work will inspire you to seek great things in life. Thank you for the love and patience you have selflessly given throughout this process. Especially to my loving husband, Jesse, without whom none of this hard work would have come to fruition. You and our children are my rocks, my life, my enthusiasm.

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List of Abbreviations

Avian Influenza Virus (AIV)

Autoregressive Integrated Moving Average (ARIMA)

Centers for Disease Control and Prevention (CDC)

Cumulated Index to Nursing and Allied Health Literature (CINHAL)

Deoxyribonucleic Acid (DNA)

El Niño Southern Oscillation (ENSO)

Elton B. Stephens Company (EBSCO)

Environmental Protection Agency (EPA)

Goose Guangdong Virus (Gs/GD)

Hemagglutinin (HA)

Highly Pathogenic Avian Influenza (HPAI)

Influenza-like Illness (ILI)

Institutional Review Board (IRB)

Locally Estimated Scatterplot Smoothing (LOESS)

Low Pathogenic Avian Influenza (LPAI)

National Oceanic and Atmospheric Administration (NOAA)

Neuraminidase (NA)

Ribonucleic Acid (RNA)

United States (US)

United States Department of Agriculture (USDA)

World Health Organization (WHO)

CHAPTER 1: INTRODUCTION

Overview

There is increasing evidence suggesting that influenza activity is affected by changing global climate patterns (Lane et al., 2022). The purpose of this chapter is to introduce climate change with regard to influenza activity in the northeastern United States. Climate change is described as the "long-term change in the average weather patterns that have come to define Earth's climate" (NASA, 2023). These changes can encompass alterations in temperature, precipitation, and weather patterns, and are often attributed to natural processes, but have recently been increased by human, or anthropogenic, activities. Anthropogenic activities trap warming gases such as carbon dioxide and methane into Earth's atmosphere and heat the surface of the planet. This heating can disrupt already fragile weather patterns, causing polar ice caps to melt, leading to acidification of oceans, and exacerbating the rise in sea levels (Cao et al., 2023; Macias et al., 2021; Morin et al., 2018). While there is some evidence linking influenza activity to climate change, a more thorough investigation into the two factors is warranted before scientists can definitively conclude whether the two variables are indeed intertwined (Lane et al., 2022).

Background

Researchers maintain that climate change principally stems from anthropogenic activities and emissions of greenhouse gases (Aune et al., 2021; Cao et al., 2023; Dennis & Fisher, 2018; Wu et al., 2020). The correlation between climate change and influenza activity is increasingly recognized as a topic of great importance, bearing significant implications for public health. This acknowledgement is supported by evidence indicating the adverse impact of a shifting climate on human health over the last fifty years. (Hochman et al., 2020; Lane et al., 2022). Changes in climate patterns have been observed globally over the past few decades, impacting various ecological systems, causing vectors to migrate to new regions with favorable climate profiles, creating extreme weather events that drive human migration patterns, and increasing exposure to respiratory infections, such as influenza (Lane et al., 2022; Hochman et al., 2020).

Climate change has been disrupting life on a global scale, causing extreme drought in some places and flooding events in others; stressing food and ecologic systems; and contributing to infectious diseases such as diarrheal, vector-borne, and respiratory illnesses (Lane et al., 2022). The research shows that climate change creates opportunity for respiratory pathogens to change their seasonal patterns (Aune et al., 2021; Geier et al., 2018; Liu et al., 2020; Suntronwong et al., 2020). This is important in the case of the influenza viruses, as they are highly mutagenic, seasonal, and climate sensitive (Hochman et al., 2021; Zhang et al., 2020). According to Hochman and colleagues (2021), climate change over the past 50 years has had an impact on human health, primarily due to the alteration of epidemiological factors related to climate sensitive pathogens, such as influenza.

Influenza poses a significant threat to public health; it has the potential to cause severe morbidity and mortality to include deconditioning, and complications of the respiratory, cardiovascular, neurological, renal, and endocrine systems, and death (Hochman et al., 2021; Macias et al., 2021). In addition, there have been four major pandemics since the great influenza pandemic of 1918, denoting the hazardous nature of the virus (Brussow, 2022; Nickol & Kindrachuk, 2019; Yamaji et al., 2020). Climate change has been associated with an increase in transmissibility of infectious diseases, which are climate-sensitive in nature, such as malaria, dengue, influenza, and diarrheal diseases, to name a few (Zhang et al., 2020; Flahault et al., 2016).

Influenza, a non-vector borne disease, has also experienced changes in transmissibility, which are thought to be related to changing climate patterns (Chong et al., 2020; Hochman et al., 2021; Zhang et al., 2020). This investigation aims to explore the relationship between climate change and influenza activity in the northeastern United States, from 2003 to 2023, in the hopes of adding to an increasing body of evidence on the effect that climate change has on influenza transmissibility, incidence, and virulence. The dynamic and complex interactions between the two variables will be analyzed, discussed, and presented herein. Moreover, this project will present original findings that demonstrate whether a relationship between changing climate patterns and influenza activity exists in this region, and will provide an in-depth analysis along with empirical evidence to support. In addition, this study will also provide an evidence-based predictive model, which will forecast the impact of climate change on influenza rates over a separate 25-year timespan. The predictive approach can contribute to more proactive public health planning and surveillance efforts, helping the northeastern region of the United States adapt to changing climatic conditions and minimize the health risks associated with influenza disease (Viboud & Vespignani, 2019).

Climate Change Overview

The expansion of scholarly literature on the topic of climate change has emerged as a subject of high significance (Callaghan et al., 2020). According to Semenza and coauthors (2021), climate change is a threat to health security, adversely adding to the burden of infectious diseases across the globe. Climate change refers to the long-term alterations in Earth's climatic patterns, which are predominantly driven by anthropogenic activities like fossil fuel burning, deforestation, and increased carbon dioxide, methane, nitrogen dioxide, and other greenhouse gas emissions into the atmosphere (Adamo et al., 2022). Greenhouse gas emissions trap heat into the Earth's atmosphere and result in higher surface temperatures (Adamo et al., 2022). The Industrial Revolution marks the period when carbon emissions were accelerated, initiating a trajectory of rising global temperatures (Adamo et al., 2022). The Swedish scientist Svante Arrhenius discovered the relationship between carbon dioxide gas emissions and rising atmospheric temperatures in 1896, and espoused the theory that increased fossil fuel burning played a major role in increased global surface temperatures since the beginning of the Industrial Revolution (Adamo et al., 2022).

During the 1950s and 60s, the emergence of enhanced atmospheric equipment and testing procedures confirmed Svante Arrhenius's theory, finding that fossil fuel emissions were rising annually (Adamo et al., 2022). In 1958, Dr. Charles D. Keeling found carbon dioxide emissions at the Mauna Loa Observatory to be at 315 ppm, and growing annually (Adamo et al., 2022). The rapid rise in temperatures since the 1960s is directly associated with the use of fossil fuels in the transportation and power industries (Adamo et al., 2022). Carbon dioxide gas emissions did not increase more than 30 ppm during the previous 1,000-year period but published research in 2020 found a rise of 30 ppm since the year 2000 (Adamo et al., 2022). The accuracy of Dr. Keeling's research provides the scientific association between fossil fuel emissions and global climate change patterns that is needed to prove the relationship (Adamo et al., 2022). The graph of Dr. Keeling's data from the Mauna Loa Observatory is known as the Keeling curve and is published by the National Oceanic and Atmospheric Administration (Adamo et al., 2022). The Keeling curve shows a jagged red line which represents the natural changes in climate (Adamo et al., 2022). It shows a larger increase over time, which is associated with anthropogenic climate change caused primarily by fossil fuel burning (Adamo et al., 2022).

Influenza Activity Overview

Although climate patterns have been found to change over time, influenza activity also changes, albeit more abruptly from one season to the next. Influenza epidemics across the United States account for approximately 12,000 to 56,000 deaths each year (Baltrusaitis et al., 2019). The large variation in the number of influenza deaths depends on several factors such as socioenvironmental determinants, climatological influences, vaccination rates, and the high mutation rates the virus undergoes each season (Baltrusaitis et al., 2019; Boddington et al., 2021; Lee et al., 2019). The emergence of new seasonal strains is due to influenza's ability to rapidly mutate (Dharmapalan, 2020; Lee et al., 2019). Vaccines are most effective if antigenic matching of the vaccine corresponds to that of the circulating viral strains (Dharmapalan, 2020; Lee et al., 2019).

Across the United States, influenza activity spans from fall to early spring, with its peak emerging in the winter months (Dharmapalan, 2020; Lee et al., 2019; Zanobini et al., 2022). The predominant strains, and severity thereof, can vary from one season to the next, impacting hospitalizations, morbidity, and mortality rates (Zanobini et al., 2022). Moreover, the regular seasonal dynamics may vary with the emergence of novel pandemic influenza viruses (Lee et al., 2019; Zanobini et al., 2022). Thus, while vaccination is the most effective strategy for seasonal influenza prevention and symptom mitigation, novel influenza viruses may lead to reduced vaccine effectiveness, as witnessed during the pandemic of 2009 (Lee et al., 2019; Zanobini et al., 2022). Influenza surveillance systems, such as the Centers for Disease Control and Prevention's FluView site, monitor the transmission cycles of influenza and provide data on currently circulating strains and vaccine effectiveness (CDC, 2023). In an effort to minimize the impact that influenza activity has on populations, more comprehensive surveillance methods must be enacted, as well as more research aimed at enhancing influenza preparedness and response during outbreaks, epidemics, and pandemics (Zanobini et al., 2021).

Avian Influenza Overview

While seasonal influenza poses annual challenges, the scope of the influenza viruses extends beyond human borders. Research into avian influenza and the impact global climate change patterns have on its distribution and transmission can give researchers more information on avian influenza viruses (AIV) that increase the risk for pandemic influenza strains among bird and human hosts (Morin et al., 2018). Like seasonal influenza A and B viruses, avian influenza viruses contain eight segmented negative-sense RNA strands (Youk et al., 2023). The AIVs belong to the genus *Alphainfluenzavirus* in the *Orthomyxoviridae* family and can be classified as low pathogenic avian influenza (LPAI) or highly pathogenic avian influenza (HPAI), depending on the severity of the disease it causes among bird species (Youk et al., 2023). In the past, HPAI developed in poultry, after introduction of LPAI from marine bird species (Youk et al., 2023). HPAI is not usually widely sustained in marine bird species, but the A/goose/Guangdong/1/96 (Gs/GD) H5 lineage of HPAI has caused great mortality across poultry and wild bird populations in the past decades (Youk et al., 2023).

Migratory birds, which travel across the Atlantic, can potentially carry a novel strain of AIV across continents (Morin et al., 2018; Youk et al., 2023). As observed in 1996, the H5 Gs/Gd lineage has evolved in domestic poultry, with spillover into migratory bird species (Youk et al., 2023). The recurring transmission of this viral lineage from domestic poultry to wild waterfowl species led to four instances of intercontinental transmission of HPAI into European and African nations, through the wild birds' natural migratory patterns (Lee et al., 2021; Youk et al., 2023). Further intercontinental transmission of the H5 viral lineage caused the first outbreak of its kind in North America in 2014-2015; between 2016-2017, this lineage also affected Europe, Africa, and Asia (Youk et al., 2023). The 2014-2015 epizootic imported a "fully Eurasian (EA) H5N8" virus from Asia to North America across the Bering Strait into Alaska (Youk et al., 2023). Viral reassortments quickly emerged and the H5N2 virus became the predominant strain affecting over 50 million birds across the United States, before its elimination in poultry in June 2015 (Youk et al., 2023). Therefore, it is important to understand the unique characteristics of avian influenza to be able to determine what roles shifting migration patterns of avian species play in the transmission of the virus from migratory birds to human hosts.

Interaction between Climate Change and Influenza Activity

Multiple studies have found an interaction between changing climate patterns and an increase in influenza activity (Arikawa et al., 2019; Brattig et al., 2019; Chong et al., 2019; Lane et al., 2022; Zheng et al., 2020). Zheng and colleagues (2020) espoused the idea that climatic factors affect the survival of viruses and are linked to influenza epidemics. Similarly, Cano Cevallos and co-authors (2019) found a significant relationship between influenza activity and climatological patterns. Further, Brattig et al. (2021) found an exponential surge in avian H5N1 viruses in southeast Asia, which is statistically attributed to increased warming of the region. The current change in climate patterns has created environmental conditions favorable to increased influenza activity across many parts of the world (Lane et al., 2022; Brattig et al., 2021). The interaction between climate change and influenza activity can also be attributed to human-made factors, as well as the changes found in seasonal weather patterns which affect the transmission cycle of influenza (Chae et al., 2018; Lane et al., 2022).

Anthropogenic factors have led to an increase in atmospheric greenhouse gasses and subsequent increased global surface temperatures, which have been associated with an increase in influenza activity (Adamo et al., 2022; Lane et al., 2022; Semenza et al., 2022). Predictive modeling shows that increases in the intensity and frequency of extreme heat, extreme cold, heavy precipitation, increased humidity, and extreme droughts will continue, placing human health under threat from infectious diseases, including influenza (Chae et al., 2018; Semenza et al., 2022). A warmer and unpredictable climate can extend the duration of influenza seasons, as temperature and humidity play a large role in increased incidence of influenza in temperate regions (Semenza et al., 2022). Moreover, a changing climate increases the risk of severe flooding events, which can result in large numbers of people crowding together in confined quarters when their homes are lost, thus increasing the risk of influenza and other respiratory disease transmission (Semenza et al., 2022). The intersectionality of changing climate patterns and influenza activity underscores the importance of climate resilience and better infectious disease surveillance strategies to mitigate public health risks posed by influenza activity in a changing climate (Harrington et al., 2021).

Need for this Study

Human health and disease states are closely linked to changing climate patterns, such as increased temperatures in some regions, decreased temperatures in other regions, increased precipitation rates, and more frequent and intense severe storm events (Macias et al., 2021; Ghazali et al., 2018; Khan et al., 2019; Lagendijk et al., 2022; Lim et al., 2022; Lane et al., 2022). In addition to ecological and environmental catastrophes, changing climatic patterns (as mentioned above) can lead to increased transmission of respiratory viruses (Macias et al., 2021). This is of great concern globally, because infectious respiratory diseases, such as influenza, have the potential to become pandemic in nature, as witnessed several times over the past century (Jester et al., 2020; Monto & Fukude, 2020). Warmer temperatures in some regions, cooler temperatures in other regions, increasing precipitation, and greater humidity have created environmental conditions favorable to the transmission of influenza (Chong et al., 2020; Liu et al., 2020).

The northeast United States lacks comprehensive regional research on the correlation between climate change and influenza activity. Overall inquiry on the two variables requires increased interdisciplinary scientific collaboration: ecologists, biologists, climatologists, meteorologists, health scientists, and a wide assortment of medical and public health scientists must come together and undertake interdisciplinary research on the impact climate change has on influenza activity (Watts et al., 2018). The transmission of influenza depends, among many factors, on the virus's survival and ability to reproduce in various ambient conditions (Liu et al., 2020). The literature shows that influenza thrives in colder, more moist air, making its transmission more efficient in winter seasons (Liu et al., 2020). Interestingly, the winter of 2017-2018 was a warmer winter in the northern hemisphere but showed higher rates of morbidity and mortality in the United States than any influenza epidemic in the past several decades (Hochman et al., 2021; Liu et al., 2020). A more robust body of research is needed to help identify whether the relationship between climate change and increasing influenza activity exists, and if so, how the scientific community can come together to build climate and disease resilience and help combat another influenza pandemic from occurring.

Climate-related hazards, such as extreme heat, drought, and intense flooding, account for 90% of natural disasters across the globe (Sillmann et al., 2021). As people become displaced due to natural disasters, they may congregate in close quarters, thus facilitating the transmission of respiratory diseases such as influenza (Ghazali et al., 2018). The effects of changing climate patterns on natural disasters create increased humanitarian crises that raise the risk for displaced populations to contract viral respiratory infections, such as influenza and influenza-like illnesses (Ghazali et al., 2018). Displacements may also harbor potential for mutagenesis of circulating viruses to occur, thereby increasing the risk of antigenic shift of influenza strains, creating a novel virus to which humans have no immunity (Ghazali et al., 2018; Sillmann et al., 2021). As climate change becomes more unstable and subjects the planet to more extreme weather events, its role in engaging the next pandemic increases (Canavan, 2019; Liu et al., 2020). It is imperative that we study this relationship to gain more knowledge, add to the existing literature, and affect change.

In addition to the antigenic drift that occurs from one year to the next with seasonal influenza, a changing climate affects changes in bird migration patterns (Hall et al., 2020). Migratory birds' increased interactions with humans, other mammals, and other species of potentially infected birds may lead to mutations in avian influenza that can cross the zoonotic barrier and infect humans (Hall et al., 2020). The interaction between bird species and other mammalian species can provoke an antigenic shift in the virus, which is a more severe genetic assortment that is sudden and significant, resulting in a new virus with a novel hemagglutinin (HA) or neuraminidase (NA) subtype (Heymann, 2022). In the case of a novel virus, there is little to no human immunity, creating the potential for a pandemic event.

In birds, avian influenza can be of the highly pathogenic type (HPAI), or the low pathogenic type (LPAI) (Chung et al., 2022; Grant et al., 2022). Highly pathogenic avian influenza is contagious among bird species, may jump the zoonotic barrier, and is characterized by a high degree of virulence and mortality among bird populations (Grant et al., 2022). HPAI was introduced to Europe in 2005 and has since become more prevalent in wild and domestic bird species across the continent (Grant et al., 2022). In addition, HPAI has caused outbreaks in Europe among birds since 2016 (Gass et al., 2023). This is concerning for the northeast United States, as potentially infected bird species migrate across the Atlantic and can infect both migratory and resident (non-migratory) birds that dwell in the region (Gass et al., 2023). More surveillance of bird species migrating from Europe to the northeast United States must be undertaken to help curb the possibility of avian transmission from birds to other mammals and a potential pandemic event.

Problem Statement

The problem addressed through this dissertation is the relationship between climate change and an increase in influenza activity in the northeastern United States (Aune et al., 2021; Geier et al., 2018; Lane et al., 2022; Marlon et al., 2017). The significance of uncovering this relationship is twofold: first, it gives other researchers a foundation from which to base future research; second, it may aid the development of stronger influenza and climate surveillance programs and policies. Furthermore, uncovering the intersectionality between the two variables in this region of the United States will add to the literature; the current body of evidence in this area requires further research (Aune et al., 2021). This is a region with a high population density; what Karmalkar et al. (2019) refer to as one of the most densely populated regions of the United States, with over 20% of the population residing in the area. Therefore, it is important to address whether there is indeed a relationship between climate change and influenza activity in this region, to help mitigate risks posed by the two variables and protect this zone from climate and influenza-related disasters (Karmalkar et al., 2019).

The problem also impacts the population in this region and beyond, as a changing climate can cause the influenza virus to undergo a major genetic reassortment which can evade the immune response, giving rise to a potential pandemic event (Gass et al., 2023; Blagodatski et al., 2021). Lane and colleagues (2022) suggest global climate change patterns impact the incidence of influenza and also espoused the idea that there is insufficient evidence to determine how climate change impacts the virus's entire transmission cycle. Additionally, Liu et al. (2020) wrote that there is a potential link between the seasonality of influenza and that of climate, but that the risk of a shift in influenza activity in a changing climate has not been found. Therefore, further investigation of the relationship between climate change and influenza activity in the northeast United States is warranted.

Purpose of the Study

The purpose of this quantitative study is to observe, describe, and analyze the correlation between climate change and influenza rates in the northeastern United States, to improve the scientific understanding of the relationship between the two variables. The questions this study will attempt to answer are as follows: "Is there a correlation between climate change and influenza activity in the northeast United States?" and: "Has a correlation between climate change and influenza activity been found in the northeast United States between the years of 2003 and 2023?" The research indicates that climate is associated with disease outbreaks (Chong et al., 2019; Watts et al., 2018; Arikawa et al., 2019; Khan et al., 2019; Zheng et al., 2021); this dissertation also aims to develop and test a predictive model that informs on climate-related patterns and the potential for influenza outbreaks in this region over the next 120 years.

Significance of the Study

This proposed study will contribute to the current body of knowledge and analyze the link between climate change and influenza activity. The aim is to ensure a more robust understanding of how climate change affects influenza incidence. This is a significant public health issue that is critical in ensuring professionals in this specific region of the United States deliver an appropriate and accelerated response to the issues of climate change and influenza activity (Watts et al., 2018). A goal of this current research is to create a predictive model to forecast whether the impact of changing climate patterns will continue to affect influenza rates in another 50-year interval; this may aid in developing stronger influenza surveillance programs and more proactive public health policies (Viboud & Vespignani, 2019). As of this writing, there have been no current studies found that report on a correlation between climate change and influenza activity in the northeast region of the United States between 2003 and 2023. Additional research is needed in this area to help the scientific community gain a better understanding of this correlation, if one exists, and to build a more interdisciplinary record of evidence on the impact that a changing climate has on influenza infections in the human population. There is a gap in the literature on this topic; this research aims to fill the gap, in the hopes of contributing to more effective policies targeting climate change and stronger influenza surveillance and preparedness programs.

Research Questions and Hypotheses

Several research questions were created for the analysis of this study, exploring the correlation between climate change and influenza activity in the northeast United States over a 20-year period, between 2003-2023. The purpose of research questions is to provide guidance, structure, and a focal point for the research (Joyner et al., 2018). Research questions define the scope and direction of this dissertation and give the committee a clear idea of what the investigation will entail (Joyner et al., 2018; Novosel, 2022). The research questions stated herein align with the overarching objective of the dissertation and will ensure the study remains focused on the questions being investigated (Joyner et al., 2018; Novosel, 2022).

Research hypotheses are specific, testable predictions about the study's expected outcomes (Joyner et al., 2018; Novosel, 2022). The hypotheses articulate the expected outcomes of the research based on the existing body of knowledge (Joyner et al., 2018; Novosel, 2022). Additionally, research hypotheses include the direction that the expected relationship of the study variables will take and provide a statistical basis for testing the research questions (Joyner et al., 2018; Novosel, 2022). A framework for data analysis is provided by the hypotheses, as well as a layer of scientific rigor, since they are subject to empirical testing and allow for the validation or rejection of the proposed ideas (Joyner et al., 2018). Indeed, both the research questions and hypotheses provide a roadmap for this dissertation's research processes.

Research Questions

This study will be designed to answer the following questions:

RQ1. Is there evidence of a correlation between climate change and an increase in influenza activity in the northeast United States?

RQ2. What roles do shifting migration patterns of avian species play in the transmission of avian influenza viruses from their natural reservoirs to human hosts in a changing climate?

RQ3. To what extent do changing climate patterns in the northeast United States influence the seasonality and geographic distribution of influenza outbreaks in this region?

Research Hypotheses

Based on this dissertation's research questions, and the data found in the existing literature on this topic, this study serves the following null hypotheses:

$RH_0$1. Between the years 2003 – 2023, no evidence exists of a statistically significant correlation between changing climate patterns in the northeast United States and the subsequent increase in the frequency and severity of influenza outbreaks in this region during the same period, indicating a no impact between the two variables.

$RH_0$2. Changing climate patterns do not make transmission of avian influenza from its natural reservoir to human hosts more likely to occur and are not due to altered migration patterns and increased human interaction with wild and domestic birds.

$RH_0$3. Within the defined timeframe, shifting climate patterns in the northeast United States, characterized by rising average temperatures and altered precipitation trends, have not been found to influence the seasonality and geographic distribution of influenza outbreaks throughout the northeast United States.

Methodology Overview

A quantitative research approach is used to determine whether a statistically significant correlation exists between climate change and increased influenza activity in the northeastern United States. This research aims to determine whether there is a measurable relationship between climate change and influenza activity in this region between the years 2003 – 2023, that is unlikely to have occurred by random chance. As much of the recent, available literature shows, there is a relationship between climate change and an increase in respiratory infections, such as influenza, across the entire United States and much of the world (Khan et al., 2019; Lagendijk et al., 2022; Lim et al., 2022; Lane et al., 2022), but little is known whether there is a significant relationship in the northeast United States, specifically. This study will investigate the correlation between the two variables in that specific region. A Pearson's correlation test will be undertaken, to determine whether there is a strong, linear relationship between a changing climate and increased influenza activity in the northeast United States (Wu et al., 2020).

In addition to the Pearson's correlation coefficient, time series analyses will be utilized, to help visually capture long-term climate trends and their potential impact on influenza activity over the two-decade span of this investigation (Wu et al., 2020). This statistical analysis will be used to test the effectiveness of the predictive model that will be built to forecast influenza outbreaks related to changing climate patterns in the northeast region over the next 20 years. A two-decade time span was selected because, according to Grothe and co-authors (2020) and Abram et al. (2021), a multidecadal time span is best to determine whether climate change has indeed been occurring. Further, the El Niño Southern Oscillation (ENSO) phenomenon has shown the greatest rate of warming, from 1970 through 2020, than observed since the preindustrial age (Grothe et al., 2020). Chapter three will further discuss the research design, procedures, and data analysis features of this study.

Methodological Considerations

This investigation into the relationship between climate change and influenza activity in the northeastern United States between 2003 – 2023 requires careful selection of the methodological approaches undertaken to ensure reliable findings (Wu et al., 2020). Therefore, while a Pearson's correlation coefficient will be used to determine if there is a statistically significant relationship between climate change and influenza activity, this study will also determine if there is a strong linear relationship between the two variables over time, utilizing a time series analysis (Guo et al., 2019; Wu et al., 2020). Methodological considerations to keep in mind when analyzing climate data are average changes in temperatures, humidity, precipitation, and wind speed, and how those factors relate to influenza activity (Guo et al., 2019; Peci et al., 2019). Through careful analysis of climate and epidemiological factors, and the use of both the Pearson's correlation coefficient and time series analysis as statistical measures, this study can provide valuable insights into the relationship between climate change and influenza activity in the northeast United States in the chosen time frame.

Definition of Terms

Climate Change

The long-term change in average weather patterns that define Earth's local, regional, and global climates (NASA, 2023).

El Niño Southern Oscillation (ENSO)

A climate phenomenon, comprised of three states (El Niño, La Niña, and Neutral), and characterized by periodic warming and cooling of sea surface temperatures in the central and eastern equatorial Pacific Ocean. This phenomenon influences global weather patterns, impacts temperature and precipitation distribution, and can lead to extreme climate events in various regions across the world (NOAA, 2023; Grothe et al., 2019).

El Niño

The periodic warming of the ocean surface (or sea surface temperatures) in the central and eastern tropical Pacific Ocean. This phenomenon influences global weather patterns (NOAA, 2023; Grothe et al., 2019).

La Niña

The periodic cooling of sea surface temperatures in the central and eastern tropical Pacific Ocean. This phenomenon influences global weather patterns, opposite from, El Niño (NOAA, 2023; Grothe et al., 2019).

Influenza

A contagious respiratory illness caused by the influenza viruses (A, B, and C) that infect the nose, throat, and lungs (CDC, 2022).

Epidemic

An outbreak that is transmitted among a large geographical region (Grennan, 2019).

Outbreak

A sudden, greater than expected, increase in the number of people with an illness (Grennan, 2019).

Pandemic

An outbreak that spreads over a larger geographic area, into multiple countries, or across the world (Grennan, 2019).

Avian Influenza

The disease caused by infection with avian (bird) influenza Type A viruses. These viruses do not usually infect humans; however, sporadic infections have occurred across the world (CDC, 2023).

Highly Pathogenic Avian Influenza (HPAI)

Avian influenza caused by subtypes of Type A (H5 and H7) influenza which causes serious illness in birds that is easily transmissible, and results in high morbidity in multiple species of birds. Some HPAI strains may infect humans, threatening public health (Gass et al., 2023; PAHO, ND).

Low Pathogenic Avian Influenza (LPAI)

Avian influenza, caused by subtypes of Type A influenza, which does not cause serious illness in birds (Youk et al., 2023).

Pearson's Correlation Coefficient

A standardized measure of the strength of the relationship between two given variables. It can take any value from -1 to +1; the higher the value, the stronger the relationship (Field, 2018).

Time series analysis

This statistical analysis involves analyzing the patterns, trends, and fluctuations within datasets collected or recorded over time. It uses the principle of continuity and the underlying structure of temporal data to help researchers make predictions from the observed time-dependent factors. It has a high short-term prediction accuracy (Field, 2018; Wu et al., 2020).

National Oceanic and Atmospheric Administration (NOAA)

A federal agency within the United States Department of Commerce that focuses on the conditions of the oceans, major waterways, and the atmosphere (NOAA, 2023).

Centers for Disease Control and Prevention (CDC)

A federal agency under the Department of Health and Human Services that is the prominent national public health institute of the United States (CDC, 2023).

Limitations/Delimitations of the Study

Due to the magnitude of this study, and the amount of retrospective climate and influenza data that will need to be gathered and analyzed from various sources in the northeast United States, not all data may be generalizable to the entire population of the United States. Further, data for climate research is difficult to access, requiring more time for data gathering and analysis. Additionally, complete public health data on influenza rates over the period from 2003 to 2023 in the northeast region of the United States, from Pennsylvania through Maine, is also difficult to access from one database alone, and will need to be accessed from several state and local public health departments. Furthermore, only about 50% of influenza cases require medical intervention, making reporting of all influenza infections difficult to attain (Heymann, 2022). In addition, seasonal influenza is such a common illness that health scientists can only estimate its incidence (Tokars et al., 2018; Lo et al., 2017; Gordon & Reingold, 2018). Moreover, data on the relationship between climate change and influenza activity in the northeastern United States is limited. Much of the data on this correlation comes from articles which look at the entire country, certain districts, or different regions of the world, not only the northeast region of the US (Lane et al., 2022; Aune et al., 2021; Carter-Templeton et al., 2022; Caini et al., 2018; Arikawa et al., 2019; Zheng et al., 2021).

Another limitation that can occur is bias in the data (Mahmoud et al., 2023). Because some influenza cases may not be immediately reported, or reported at all, they may or may not show up in surveillance systems (Mahmoud et al., 2023). Reporting bias and selective reporting bias may exist, as researchers may be more likely to report only statistically significant findings or only severe influenza cases may be reported, giving rise to test-positivity measure bias (Mahmoud et al., 2023). To limit such biases from occurring, this research must include a comprehensive literature review and carefully examine several studies' methodologies (Mahmoud et al., 2023).

A delimitation of this study is that all of the information gathered, from peer-reviewed articles, to national, state, and local climate and public health data, is found online and on reputable scholarly or government organizations and databases, which are easily accessible through Liberty University's extensive library program or through a secure search engine.

Assumptions

Because all the peer-reviewed articles gathered for this research project were gathered from the PubMed, ProQuest, CINHAL, or the digital Summons site, provided by the Jerry Falwell Library at Liberty University, it is assumed that they were written with credible, reliable evidence. Similarly, since all the climatological data that will be gathered come from credible governmental websites, such as the NOAA and EPA, it is assumed all the evidence is correct. Finally, the evidence analyzed on influenza activity in the northeast United States comes from either national or local databases, such as the Centers for Disease Control and Prevention, the World Health Organization's FluNet site, and state public health departments; it is assumed that the information gathered is also credible and reliable. The primary assumptions made for this investigation are that historical climate and influenza data are accurate, consistent, and reliable, and that the peer-reviewed literature analyzed is also reliable and accurate.

Research Organization

The body of research for this project will be organized chronologically, utilizing a temporal pattern to analyze climate patterns and influenza trends. Moreover, Liberty University offers students use of the RefWorks database, which is where the peer-reviewed references on climate change and influenza for this study are organized. In addition, a working annotated bibliography is kept on an Excel spreadsheet, housed in the cloud, facilitating access to needed references for this research. All articles used for this research project are downloaded and kept in file folders on the cloud. Each file folder is labeled according to the overarching topics of the articles housed within. The file folders are labeled “Influenza,” “Climate change,” “Influenza and climate change,” “Northeast United States,” “Framework,” and “Methods.” This organization provides for easier access to certain articles, should they be required for review. Moreover, separate folders for climate data accessed from the National Oceanic and Atmospheric Association (NOAA) and the Centers for Disease Control and Prevention (CDC) websites are included in the organizational management system for this investigation.

Chapter Summary

A primary motivator for environmental and public health regulations is the protection of human health (Amukawa-Mensah et al., 2017). Such regulations are designed to mitigate the negative impacts of pollution and prevent disease transmission related to environmental factors (Neira et al., 2023). Policies aimed at reducing greenhouse gas emissions may directly impact climate change. By mitigating these impacts, environmental and public health policies can benefit human health by reducing the frequency and severity of extreme weather events over time, which can impact influenza outbreaks, epidemics, and pandemics (David & Lee, 2019). As such, this investigation can add to the body of academic knowledge, encourage more research in the areas of public health, environmental health, and health science, and help promote and advance policies aimed at reducing current changing climate patterns and preventing future influenza outbreaks, epidemics, and pandemics.

CHAPTER TWO: REVIEW OF THE LITERATURE

Overview

In this section of the investigation on the relationship between climate change and influenza activity in the northeastern United States, a survey of the existing, current research is presented. This section discusses past studies conducted that investigate the correlation between changing climatic conditions and influenza activity, addressing the many factors that contribute to the intersectionality of climate change, environmental health, public health, and the health sciences. Historical data, past influenza pandemics, and scholarly interpretations are explored in this section, with the goal of establishing the context and theoretical frameworks that will be used in the dissertation. The overarching themes of climate change, influenza dynamics, and the factors that contribute to the relationship between the two variables in the northeastern United States, will be discussed. Finally, a summary of the literature review and recommendations for future research will be established.

Related Literature

Climate Change and Influenza: Northeast United States

A substantial amount of literature has been published on the effects that climate change has on the influenza viruses (Goodwins et al., 2019; Dennis & Fisher, 2018; Lane et al., 2021; Caini et al., 2018). Goodwins and colleagues (2019) suspect that changing climate patterns affect the timing and severity of influenza activity. For example, it is theorized that increasing rainfall and humidity may result in an increase in influenza incidence (Dennis & Fisher, 2018). The types of environmental conditions that are associated with increased influenza outbreaks are “cold-dry” and “humid-rainy” (Park et al., 2020). There is also a greater risk of influenza incidence with humidity higher than 70% and with humidity lower than 40%. Therefore, should climate patterns shift and become colder and drier, or more humid and rainier, the risk of influenza incidence increases (Park et al., 2020).

Climate change can influence influenza activity in the northeastern United States through various mechanisms, such as altering the temperature and precipitation patterns which allow for more favorable conditions for the influenza virus to thrive (Karmalkar et al., 2019; Thompson et al., 2022). Because the northeast United States is one of the fastest warming regions of the United States, there is potential for a shift in influenza rates across the region (Mayo & Lin, 2022; Karmalkar et al., 2019; Thompson et al., 2022). The warming effects of climate change, as well as shifts in extreme weather events, may also affect the survival and transmission of viruses such as the influenza virus (Thompson et al., 2022; Ghazali et al., 2018). The negative effects of an increase in pathogens, witnessed due to changing climate patterns, carry with them important implications for human health (Thompson et al., 2022). Altered climatic patterns can also influence certain ecological factors, such as bird migration, which can lead to an increase in influenza activity in this region of the United States (Gass et al., 2023; Karmalkar et al., 2019).

Dennis and Fisher (2018) note that severe weather events are key factors in increased influenza rates. In some regions, increased precipitation and higher humidity are correlated with greater influenza activity (Dennis & Fisher, 2018; Lane et al., 2021; Park et al., 2020). In other regions, colder temperatures and lower humidity are linked with increased influenza activity (Park et al., 2020). However, there has been very little published literature on changing climate patterns and influenza activity in the northeast United States. While climate change does not directly cause influenza, it influences several factors that are related to the transmission and prevalence of the virus (Lane et al., 2022; Park et al., 2020; Dave & Lee, 2019). This literature review will analyze the most recent literature on climate change and its relationship to influenza activity, to inform on these intertwined phenomena.

Influenza

Influenza is an acute respiratory infection caused by viruses that circulate across the world (Goodwins et al., 2019; Uyeki et al., 2022). The disease has a mean incubation period of between one to two days, with a range of one to four days; viral shedding takes place a day prior to symptom onset and can last between three to five days in adults, and for several weeks in children and the immune compromised (Dharmapalan, 2020). Symptoms often include fever, respiratory issues, cough, sore throat, body aches, and fatigue (Dharmapalan, 2020). Currently, there are four identified influenza viruses: influenza A to D (Uyeki et al., 2022). Seasonal influenza is the disease that circulates in humans, mutates seasonally, and is comprised of the influenza A or B group of viruses (Uyeki et al., 2022). Influenza is characterized by its constant mutation, as well as its ability to cause mild to severe illness, contributing to significant morbidity and mortality in the most severe cases (Dharmapalan, 2020; Goodwins et al., 2019). While vaccines exist to help combat seasonal influenza outbreaks and epidemics, they are most highly effective if antigenic matching of the vaccines mirror the strains in current circulation (Dharmapalan, 2020). However, vaccination against seasonal influenza remains the predominant mode of prevention against infection and is recommended for all people aged six months and older (Boddington et al., 2021; Dharmapalan, 2020).

Influenza is part of the *Orthomyxoviridae* family and contains a negative-sense RNA genome (Uyeki et al., 2022). Influenza A and B contain eight viral ribonucleic acid (RNA) segments translated into 12 viral proteins (Uyeki et al., 2022). It contains a lipid bilayer envelope, that is host-derived, in which the hemagglutinin (HA) and neuraminidase (NA) glycoproteins are embedded (Heymann, 2022; Sederdahl & Williams, 2020). Types A and B cause seasonal epidemics across the globe (Uyeki et al., 2022). Influenza Type C primarily causes cold-like symptoms in children under two years of age, with some instances of lower respiratory infection (Sederdahl & Williams, 2020). Type C differs from Types A and B in that it contains seven viral RNA segments that are translated into nine viral proteins (Sederdahl & Williams, 2020). Influenza A strains infect avian as well as mammalian species and have caused past pandemics. Influenza B strains primarily infect humans, and influenza C strains infect humans and other mammals (Uyeki et al., 2022). There is a fourth type of influenza, type D, but it is unclear whether this type causes disease in humans. Influenza D antibodies have been isolated in the blood of those working closely with cattle (Uyeki et al., 2022).

In addition to seasonal influenza, which infects humans, avian influenza is a separate disease, made up of the influenza A group of viruses, which primarily infects birds and other mammals (Dharmapalan, 2020; Uyeki et al., 2022). As avian influenza is primarily zoonotic in nature, the threat of emergence of human illness caused by this set of influenza viruses poses pandemic hazards (Guo et al., 2022; Uyeki et al., 2022). This group of influenza viruses mainly infects birds, such as poultry, waterfowl, and marine birds, but can also cross the species barrier and infect other mammals, such as pigs (Uyeki et al., 2022). Avian influenza is a group of viruses to be closely surveilled, as there has been a sharp increase in the number of human cases infected with avian influenza A worldwide since 2016 and carries with it the potential to cause a pandemic with a novel avian influenza strain (Cheng et al., 2018; Guo et al., 2022).

Avian influenza A contains 16 hemagglutinin (H1 – H16) subtypes and nine neuraminidase (N1 – N9) subtypes that are enzootic to avian species but can cross the species barrier to infect other mammals (Uyeki et al., 2022). The elevated error rate in RNA-dependent

RNA polymerases and the reassortment of RNA segments during co-infections with other influenza viruses contribute to the evolutionary potential of influenza A, to include avian influenza viruses (Uyeki et al., 2022). This mutative process aids in viral circulation among hosts, leading to the rapid selection of influenza A viruses with enhanced survivability (Uyeki et al., 2022). Epidemiological data shows that avian influenza A is not easily transmissible between their avian reservoirs and human hosts, but increased direct contact with infected birds can lead to human transmission (Pusch & Suarez, 2018; WHO, 2023). Therefore, it is important to control its spread, due to its pandemic potential and high mutation rate.

Seasonal Influenza

Influenza is a contagious viral infection, with a distribution that is predominantly seasonal in nature (David & Lee, 2019). It is primarily airborne, transmitted mainly through respiratory droplets, and causes between 300,000 to 650,000 deaths, and between 3 to 5 million severe illnesses per year across the world (Heymann, 2022; Yuan et al., 2021). Influenza causes a respiratory disease that is attributed to severe morbidity and mortality, particularly in vulnerable populations, such as the elderly, young children, and the immunocompromised (Grohskopf et al., 2022). Most who contract influenza recover without complications, however, depending on the virulence of the circulating strains, and the immunity of those infected, influenza can be a serious disease. The timing, intensity, and severity of seasonal influenza cannot be predicted; therefore, outbreak surveillance is an important aspect in determining the intensity of current circulating influenza strains (Grohskopf et al., 2022).

In temperate regions across the globe, seasonal influenza peaks during late winter through early spring (Geier et al., 2018; Uyeki et al., 2022). Influenza Types A and B account for most of the seasonal influenza strains found across the world and demonstrate the ability to mutate over time (Heymann, 2022; Liu et al., 2020). In certain regions, such as in sub-tropical China, influenza A peaks in the winter months, while influenza B carries on to the spring months (Liu et al., 2020). One study found that influenza A has two annual peaks: one in the winter/spring months, and an uncertain peak in the summer (Liu et al., 2020). Global travel and increased indoor crowding attribute to transmission of seasonal influenza, as it is highly contagious and primarily spreads through infected respiratory droplet transmission (Liu et al., 2020). The virus can also circulate via fomite transmission, that is, when viral particles contaminate the surface of an object, and a person touches the contaminated object then his or her facial membranes.

In tropical regions, influenza viruses typically circulate year-round, and do not follow the seasonal patterns displayed in the Northern and Southern Hemispheres (Zanobini et al., 2022). Typical seasonal patterns of influenza occur during the winter months, with fewer cases occurring during the summer (Yuan et al., 2021). In tropical and sub-tropical climates, influenza causes multiple epidemics per year and displays unpredictability in the intensity of its outbreaks (Yuan et al., 2021). While humidity is high year-round in the tropics, influenza peaks during the rainy seasons, when humidity is at its highest (Yuan et al., 2021; Zanobini et al., 2022). Determining virus circulation patterns are factors in deciding when the best time to distribute the influenza vaccine will be (Zanobini et al., 2022). Strategic deployment of the influenza vaccine is a key element in helping to deter the transmission and severity of the virus. Predominant virus strains, population immunity, and vaccine effectiveness are fundamental in determining the impact of seasonal influenza each year. (Grohskopf et al., 2022; Wiggins et al., 2021). Changes in influenza activity across tropical regions can relate to the northeast United States through several interconnected factors such as global travel, migration of bird species, and human behavior (Dave & Lee, 2019; Lane et al., 2022). Human movement can lead to the introduction of novel influenza strains to new global regions; therefore, changes in influenza activity in tropical regions may have indirect, but significant implications for the northeast United States due to the interconnectedness of the world through travel, trade, environmental factors, and population immunity (Dave & Lee, 2019).

As established in the literature (Grohskopf et al., 2022; Wiggins et al., 2021; Zanobini et al., 2021), seasonal influenza can significantly impact public health. Organizations such as the Centers for Disease Control and Prevention and the World Health Organization monitor influenza activity to determine the severity of each season. Moreover, while seasonal influenza is a significant public health concern, there are other types of influenza that are of additional interest and should not be ignored in the context of the relationship between climate change and influenza activity. One such type of influenza that may have the ability to jump the species barrier and carries the potential to become pandemic influenza is avian influenza A (Canavan, 2019; Cheng et al., 2018). Therefore, it is of extreme importance that global climate patterns are monitored, as migratory wild bird species may flock to new areas with favorable climates and increase global transmission of the virus among birds and other mammalian species, creating a potential for a novel pandemic influenza shift (Canavan, 2019; Gass et al., 2023; Hall et al., 2020).

Vaccination

Vaccination against seasonal influenza strains is fundamental to preventing influenza disease and the complications that may arise from infection (Zanobini et al., 2022). Distributing the seasonal influenza vaccine is crucial to protecting public health, as it limits the burden influenza poses across populations. The influenza vaccines currently in use across the United

States include inactivated, recombinant, and live-attenuated formulations (Wiggins et al., 2021). Inactivated egg-based vaccines are recommended for those over six months of age, whereas inactivated cell-based vaccines are recommended for those over four years old (Wiggins et al., 2021). Recombinant vaccines are approved for adults aged 18 and older. Live-attenuated influenza vaccines are available for those ages two to 49 years, with no underlying high-risk health conditions (Wiggins et al., 2021). For persons in the 65 and older age groups, high-dose vaccines and those containing adjuvants are recommended, to promote stronger immune responses (Wiggins et al., 2021).

The influenza vaccines available throughout the world are safe, effective, and have the potential to prevent extreme morbidity and mortality (Fadlyana et al., 2023). Each year, the World Health Organization recommends that vaccines be composed of the circulating strains found based on global influenza surveillance (Fadlyana et al., 2023). The available seasonal influenza vaccines can be trivalent vaccines or quadrivalent vaccines (Fadlyana et al., 2023; Allen & Ross, 2021). Trivalent influenza vaccines consist of two influenza A strains, H1N1 and H3N2, and one influenza B strain (Allen & Ross, 2021; Fadlyana et al., 2023). Quadrivalent vaccines consist of two influenza A strains and two influenza B strains and have been licensed for use in the United States since 2012 (Fadlyana et al., 2023; Tisa et al., 2016). Influenza A and influenza B virus subtypes normally co-circulate and pose threats to human health (Allen & Ross, 2021). Seasonal vaccine strains are chosen by predicting prevalent or emerging strains of influenza viruses through information gained from global surveillance programs (Allen & Ross, 2021). Seasonal influenza vaccination is crucial, especially during times of observed changes in global climate patterns, as it helps mitigate the impact of shifting environmental conditions on the transmission of influenza viruses (Zhang et al., 2021; Zheng et al., 2021; Chow et al., 2019).

The best influenza prevention method is through seasonal influenza vaccination (Chow et al., 2019). Although seasonal protection varies from one year to the next, the vaccine stimulates the immune system to build increased antibody responses against the virus and reduce the risk of infection, or, if infected, decreases the duration and severity of illness (Wiggins et al., 2021). The timing and intensity of seasonal influenza outbreaks may vary from one season to the next. While some seasonal influenza vaccines offer suboptimal protection against symptomatic infection, they are the most optimal line of defense in reducing influenza associated morbidity and mortality (Baylor et al., 2022).

Factors such as predominant circulating strains, vaccine efficacy, and population immunity determine the impact of each influenza season (Grohskopf et al., 2022). Between each of the influenza seasons beginning in 2010 and ending in 2016, influenza vaccination prevented approximately 1.6 to 6.7 million illnesses and 3,000 to 10,000 deaths per season. Similarly, during the extreme 2017-2018 influenza season, vaccination prevented 7.1 million illnesses and approximately 8,000 deaths (Grohskopf et al., 2022). Vaccination against seasonal influenza is critical because it helps reduce overall disease burden, prevents some transmission from occurring, and reduces potential genetic mutations that may arise (Lee et al., 2019). By minimizing the impact of seasonal influenza, the risk of a more severe strain emerging can be mitigated, lessening the risk of a pandemic from emerging (Wang et al., 2019).

In synthesizing the literature on seasonal influenza vaccination, its connection to climate change in the northeast United States, and its relevance to emerging pandemics, a comprehensive understanding of the importance of vaccination for all persons from the ages of six months and onward emerges (Wang et al., 2019, Lee et al., 2019, Allen & Ross, 2021; Fadlyana et al., 2023). Studies consistently underscore the importance of influenza vaccination as a preventive measure, especially in an age where climate is rapidly changing in the northeast United States (Karmalkar et al., 2019; Lane et al., 2022; Marlon et al., 2017). Climate change can influence influenza patterns, making vaccination a critical tool in mitigating the pandemic potential of novel strains (Lane et al., 2022; Wang et al., 2019; Ghazali et al., 2018). The literature converges on the idea that proactive vaccination strategies play a vital role in addressing the intersection of influenza activity, climate change, and the emergence of influenza pandemics, emphasizing the need for adaptive public health measures in a changing environmental landscape across the northeast United States (Hasan et al., 2023; Nardell et al., 2020; Lane et al., 2022; Karmalkar et al., 2019).

Just as there is a seasonal influenza vaccine for humans to help protect against severe morbidity and mortality during influenza season, there are also vaccines developed against highly pathogenic avian influenza (HPAI) for use in poultry (Nielsen et al., 2023). As HPAI has been routinely identified in migratory waterfowl, the risk of transmission to poultry in certain regions is thereby increased (Nielsen et al., 2023). In the European Union, there is one vaccine authorized for use in poultry, but it is not fully effective in stopping viral transmission (Nielsen et al., 2023). In the United States, there are two vaccines available for poultry and wild bird vaccination. The first of the vaccines is based on plasmid DNA technology (called ExactVac) and the other vaccine is based on RNA particle technology (called RP-H5 vaccine manufactured) (Nielsen et al., 2023). Both vaccines hold an emergency use authorization (EUA) from the United States Department of Agriculture (USDA) for use in chickens and turkeys, however, the RNA vaccine is the only one that can be utilized in turkeys (Nielsen et al., 2023). The vaccines used in birds are for clinical protection against avian influenza and for reduction of viral shedding (Nielsen et al., 2023).

Vaccinating poultry is critical as an avian influenza prevention strategy (Nielsen et al., 2023). Vaccination helps build immunity to the virus, reduces morbidity and mortality associated with HPAI, and curbs transmission among other birds (Nielsen et al., 2023). By implementing vaccine strategies, the spread of HPAI among poultry populations can be reduced and minimizes risk of transmission to humans (Nielsen et al., 2023). Vaccination not only protects the poultry industry, but also serves as a preventive measure to mitigate potential outbreaks that may have severe consequences to animal and human health (Hasan et al., 2023; Nielsen et al., 2023).

It is important that public health efforts in the northeast United States be aimed at seasonal and pandemic influenza preparedness and response. This is a highly populous region, with diverse ecosystems which carry the potential for harboring influenza viruses that can undergo genetic reassortment and cross the species barrier (Karmalkar et al., 2019). Preparedness for seasonal influenza enhances the overall readiness for a pandemic event. Surveillance, early detection, vaccination efforts, and communication between public health officials and the general population are essential efforts to help contain influenza outbreaks that have the potential to become epidemics, or in a worst-case scenario, contain viral strains that harbor pandemic potential (Harrington et al., 2021; Yamaji et al., 2020). In the case of avian influenza A, following the introduction of the virus into North America from Europe and Asia, the virus (H5N1 strain) quickly spread throughout different geographic regions across the United States (Gass et al., 2023).

Avian Influenza

The predominant natural reservoir for influenza A viruses is wild birds (Ariyama et al., 2023; El-Shesheny et al., 2022; Hall et al., 2020). The virus typically replicates in the respiratory and intestinal tracts of birds and is shed in the environment where other hosts can become infected (Yamaji et al., 2020). Viruses from the marine bird reservoir may infect other avian species, including domestic poultry and waterfowl. These species can then transmit avian influenza to mammalian hosts, creating opportunities for genetic reassortment which can have pandemic potential (Yamaji et al., 2020). According to Yamaji et al. (2020), highly pathogenic avian influenza A viruses have mutated through genetic reassortment with other avian influenza viruses enzootic to different regions, resulting in regional epizootics in poultry, which increases the risk for human transmission. The pandemic potential of these viruses is uncertain but must not be ignored, especially due to the possibility of inter-species and human-to-human transmission (Dennis & Fisher, 2018; Yamaji et al., 2020).

In 2014, a strain of highly pathogenic avian influenza emerged in Southeast Asia, which expanded to Europe, North America, and Africa, and caused numerous outbreaks with high mortality among wild and domestic birds (Gass et al., 2023). This virulent form of avian influenza belongs to viruses of clade 2.3.4.4 (H5Nx), that share a common ancestry with A/Goose/Guangdong/1/1996 (H5N1) (Gs/GD), which was first detected in China in 1996. This clade frequently reassorts with other highly pathogenic avian influenza viruses and has been found in a variety of avian species (Gass et al., 2023). Following this viral clade's emergence, it migrated with wild marine birds across the Pacific Ocean and ventured into North America, initiating outbreaks in wild and domestic birds (Gass et al., 2023). This strain was first documented passing via the Atlantic route in 2021, where it infected and decimated birds in Canada and the United States. The introduction of this group of avian influenza viruses via this route raises questions as to how viral movement across the Atlantic occurred (Gass et al., 2023).

Ecological, anthropogenic, and environmental drivers of host avian movement have been investigated as possible factors propelling different bird migratory patterns and introducing the virus into North America via a novel route (Gass et al., 2023). The findings suggest increased viral spread across bird species throughout the United States may be related to the immune naivety of those species in the US versus in avian species from Europe (Gass et al., 2023). While an increase of H5Nx influenza A transmission was found from European to American bird species, a decrease in transmission within American bird species was exhibited. Additionally, this research found that as temperatures in a region increased, there was tendency for the migration of the H5Nx virus to decrease (Gass et al., 2023). This finding implies that higher temperatures affect the behavior and transmission patterns of this viral clade (Gass et al., 2023). More research needs to be conducted in this area to determine if increased temperature is associated with decreased survival of avian influenza.

Avian influenza continues to emerge in humans (Guo et al., 2022; Wang et al., 2020; Yamaji et al., 2020). Therefore, its continued surveillance is critical for the early detection of outbreaks, monitoring of viral strains, and implementation of timely interventions (Guo et al., 2022; Wang et al., 2020). Utilizing a more proactive approach to the surveillance of avian influenza can prevent its potential transmission to humans (Guo et al., 2022). In addition, economic losses as well as viral transmission from birds to humans in the poultry industry can be mitigated if surveillance shows an increase in avian influenza in the region, and protective measures are employed to slow transmission of the virus (Yamaji et al., 2020). Adopting effective avian influenza surveillance programs can also contribute to global public health by facilitating the development of effective vaccines and control strategies to limit viral spread (Yamaji et al., 2020).

In addition to surveillance in domestic birds and poultry, increased surveillance in aquatic birds is also essential to limit the spread of avian influenza, as these birds, especially wild waterfowl and shorebirds, serve as natural reservoirs for the viruses (Ariyama et al., 2023; El-Shesheny et al., 2022; Wang et al., 2000). Monitoring these birds' populations can help scientists detect the prevalence and genetic diversity of avian influenza. Early identification of potential outbreaks in aquatic birds allows for immediate response measures, helping to prevent viral spread to domestic poultry and reducing transmission risk to humans (Wang et al., 2020). According to Wang and colleagues (2020), there is evidence of increased accumulated mutations in several avian influenza A genomes, increasing their evolutionary capacity and ability to cause epidemics or pandemics in domestic poultry, and other mammals, including humans.

There are multiple genomes of avian influenza A viruses (Guo et al., 2022; Yamaji et al., 2020). Human health is threatened by several avian influenza strains such as H5N1, H5N2, H5N6, H5N8, H7N9, H10N3, and H10N8 (Guo et al., 2022; Yamaji et al., 2020). Avian influenza A viruses are known for their genetic diversity, with various subtypes and strains circulating among several bird species (Guo et al., 2022; Gass et al., 2023; Wang et al., 2020; Yamaji et al., 2020). The diversity of avian influenza A genomes contributes to the ongoing evolution of the virus, posing challenges to surveillance, prevention, and control efforts (Guo et al., 2022; Yamaji et al., 2020). Transmission of avian influenza viruses has been reported in various countries, with some human infections being reported, which are attributed to viral transfer from wild birds to poultry, then from poultry to humans (Wang et al., 2020).

One of the countries where highly pathogenic avian influenza A (HPAI) has been found in wild birds is Chile (Ariyama et al., 2023). This virus, of the strain H5N1, clade 2.3.4.4b, emerged in the country in December 2022; genome analysis suggests that there have been several introductions of HPAI across South America (Ariyama et al., 2023). Viruses of this clade are being increasingly transmitted globally, with spread across Europe, Asia, Africa, and North

America in 2021 (Ariyama et al., 2023; El-Shesheny et al., 2022). In 2022, the virus was detected in South America, first being reported in Columbia, later in Peru, Ecuador, and Venezuela, before being reported in Chile (Ariyama et al., 2023). Shortly after its detection in wild birds, this virus was detected in domestic poultry in South America and across other world regions (Ariyama et al., 2023; El-Shesheny et al., 2022). This clade of HPAI has high mortality rates among domestic and wild avian species (Ariyama et al., 2023). Furthermore, the viruses in this clade have infected many non-avian species, to include humans (Ariyama et al., 2023). In an effort to control the HPAI viral outbreaks, approximately 131 million domestic birds were culled worldwide, in 2022, due to exposure or infection with these viruses (Ariyama et al., 2023). This group of avian influenza viruses pose public health threats and threats to food security, due to the infection and subsequent culling of an important food source (Ariyama et al., 2023).

According to El-Shesheny et al. (2022), pathogens originating from non-human animal reservoirs frequently lead to pandemics that affect human populations. This is also the case with avian influenza viruses. HPAIs can disseminate across diverse hosts, traversing species barriers, to generate novel influenza A virus strains (Ariyama et al., 2023; El-Shesheny et al., 2022). The H5Nx lineage of HPAI viruses, belonging to the phylogenetic clade 2.3.4.4, has sparked widespread global outbreaks, evolving into eight separate subclades (2.3.4.4a to 2.3.4.4h) (El-Shesheny et al., 2022; Tian et al., 2023). Throughout 2020 and 2021, the 2.3.4.4b subclade of H5N1 HPAI viruses extended their presence to numerous countries across Europe, Africa, Asia, and the Americas (Ariyama et al., 2023; El-Shesheny et al., 2022). Notably, infections were reported in both wild and captive mammals and in humans (El-Shesheny et al., 2022). These findings underscore the importance of surveillance efforts and monitoring of the avian influenza viruses, particularly those with pandemic potential which can cross the human-animal species barriers (Ariyama et al., 2023; El-Shesheny et al., 2022).

Interestingly, in December 2022, the HPAI H5N1 strain belonging to clade 2.3.4b was found in a domestic cat in France (Briand et al., 2023). The cat, residing with a human family in proximity to a duck farm, contracted a virus closely related to the one affecting the ducks (Briand et al., 2023). The influenza symptoms the cat displayed were apathy, mild hyperthermia, pronounced neurologic symptoms, and respiratory dyspnea (Briand et al., 2023). Four days after symptom onset, the cat was humanely euthanized (Briand et al., 2023). Sinonasal, tracheal, and anal cultures were performed and analyzed post-mortem, which were confirmed to be infected with HPAI H5N1 clade 2.3.4.4b (Briand et al., 2023). Further genetic analyses of the HPAI H5N1 genome revealed that the virus was directly related to other viral sequences identified in the same area in the weeks preceding the cat's death (Briand et al., 2023). Moreover, the HPAI H5N1 virus isolates from the duck farm only showed two nucleotide differences, from 13,507, compared to the cat's virus (Briand et al., 2023). The mutations stemmed from the "E627K mutation in polymerase basic protein 2 and E26G mutation in nonstructural protein 2" found in the deceased cat's samples (Briand et al., 2023, p. 1696). According to Briand et al. (2023), the E627k mutation is a primary marker of avian influenza adaptation to mammalian hosts and may play a role in viral adaptation to changes in temperature (Briand et al., 2023).

In summary, the understanding of avian influenza transmission requires a comprehension of its connections to human health, climate change, and the variety of interactions found among the virus and wild and marine birds, domestic poultry, and human beings (Hasan et al., 2023; Morin et al., 2018; Yamaji et al., 2020). The role climate change plays in the increased transmission of avian influenza increases the challenges posed by this virus and emphasizes the urgency of addressing changing environmental factors that help to propagate the disease (Morin et al., 2018; Yamji et al., 2020). Additionally, the pivotal role of wild and marine birds as viral reservoirs accentuates the need for effective surveillance and preventive measures to curb viral spread to domestic birds, poultry, lower mammals, and ultimately humans (Ariyama et al., 2023; Briand et al., 2023; El-Shesheny et al., 2022; Yamaji et al., 2020). Furthermore, the ability of avian influenza to breach the species barrier highlights the need for continual research and vigilant monitoring to safeguard public health against potential zoonotic threats (Ariyama et al., 2023; Briand et al., 2023; Yamaji et al., 2020). This comprehensive approach is essential for devising strategies that not only curb current risks of avian influenza transmission, but also anticipate and counter future challenges posed by this virus, which carries pandemic potential (Hasan et al., 2023; Yamaji et al., 2020).

Past Influenza Pandemics

Influenza A was the cause of the four influenza pandemics that occurred between 1918 and 2009 (Harrington et al., 2021). The pandemic of 1918 was caused by a novel H1N1 influenza A virus; the pandemic of 1957 was caused by an H2N2 strain (predominantly with 1918 and avian reassortment); the 1968 pandemic derived from the H3N2 strain (with 1918, 1957, and avian reassortment); and the 2009 pandemic emerged from an H1N1 subtype with avian, human, and swine genomic reassortment (Harrington et al., 2021; Jester et al., 2020). According to Nickol and Kindrachuk (2019), all of the influenza pandemics occurring after the 1918 "Spanish Flu" were caused by its descendants. The 1918 influenza pandemic was one of the deadliest in recorded history, causing an estimated 50 to 100 million deaths across the world. Interestingly, the 1918 H1N1 strain made a re-emergence in 1977 and is thought to have been brought about by a "man-made event" (Nickol & Kindrachuk, 2019).

Through the early 1950s, the influenza A (H1N1) virus was the predominant circulating strain, until it was replaced in 1957 by the pandemic influenza A (H2N2) virus. The H2N2 virus displayed significantly less mortality than its 1918 H1N1 counterpart (Brussow, 2022). This virus held three new genetically reassorted segments from an avian lineage but contained five segments of H1N1 1918 lineage (Brussow, 2022). This novel pandemic influenza virus was dubbed the "Asian Flu" and caused over 1 million fatalities worldwide (Brussow, 2022; Nickol & Kindrachuk, 2019). It circulated in humans until it was replaced in 1968 by a novel influenza A (H3N2) virus (Brussow, 2022).

The H3N2 virus originated in Hong Kong and caused the "Hong Kong Flu" pandemic from 1968 to 1969 (Brussow, 2022). It resulted in approximately 1 million fatalities and had a greater impact on those under the age of 65 years (Brussow, 2022; Nickol & Kindrachuk, 2019). This pandemic virus descended from the H2N2 strain and maintained five gene segments of the 1918 H1N1 lineage, one gene segment from the 1957 H2N2 virus, and two gene segments of avian origin (Brussow, 2022; Harrington et al., 2021). H3N2 influenza viruses circulated across the human population exclusively until the unexpected re-emergence of the H1N1 virus in 1977 (Brussow, 2022).

Typically, influenza strains evolve and replace each other over time, making the 1977 re-emergence of this H1N1 strain a rare event (Nickol & Kindrachuk, 2019). The strain's sudden reintroduction is subject of debate among researchers. Nickol and Kindrachuk (2019) refer to its re-circulation as a "man-made event," suggesting it escaped from a laboratory or was accidentally reintroduced from a previous sample, as it showed a great similarity to a 1950 "reference virus." Researchers hypothesize that this strain could not have been retained in an animal reservoir for 27 years without having undergone genetic reassortment (Brussow, 2022;

Nickol & Kindrachuk, 2019). The 1977 strain primarily affected individuals under the age of 24, perhaps because they had no previous immunity to similar past strains (Brussow, 2022). This strain's re-emergence was a unique event and speaks to the unpredictability of the influenza viruses. It details the importance of ongoing surveillance for the detection of and response to influenza viruses which may display pandemic potential.

Since its reintroduction into the human population, the H1N1 virus cocirculates with the H3N2 virus, causing the seasonal influenza epidemics experienced today (Brussow, 2022). However, in 2009, an H1N1 virus caused a pandemic that originated in Mexico and is known as the "Swine Flu" (Brussow, 2022). This virus was characterized by severe pneumonia and high morbidity. It contains genes from avian viruses, human H3N2 virus genes, and genes from swine influenza viruses (Brussow, 2022; Nickol & Kindrachuk, 2019). It is estimated that between 150,000 and 570,000 people died from this virus in 2009 (Brussow, 2022). According to Harrington and colleagues (2021), host diversity and multiple reassortments were the causal factors for the 2009 H1N1 pandemic, which produced a novel virus that was highly transmissible among humans.

Climate Change

Climate in the northeast United States is primarily continental, with some regions that display a more temperate climate. Continental climate regions are characterized by "warm to cool summers and cold winters" (NOAA, ND). This climate zone can sustain snowstorms, high winds, and cold temperatures (NOAA, ND). The temperate climate region displays warm, humid summers and mild winters (NOAA, ND). Climate patterns in the northeastern United States show several significant trends. Temperatures in the region, stretching from West Virginia to Maine, have been on the rise. Over the past century, annual temperatures in the northeast United

States have increased by about 1.1 degrees Celsius and precipitation has increased by more than 10% (Marlon et al., 2017). Along with a rise in average temperatures, the number of extremely hot days has surged, particularly in the summer months (Marlon et al., 2017). There has been an observable loss of ice cover during the winter months over Lake Superior, which has caused surface water temperatures to increase by about 2.5 degrees Celsius (Marlon et al., 2017). According to Blagrave and Sharma (2023), lakes are valuable indicators of climate change patterns, as the freshwater necessitates temperatures below 0 degrees Celsius to freeze.

Furthermore, in Maine, ice-out dates, which are the days when the winter ice first melts, have arrived sooner each spring, providing evidence of warming over the last century (Marlon et al., 2017). Marlon and colleagues (2017) found that lake ice has broken up earlier each spring, by about "0.6 days per decade^{-1}," between the years of 1884 through 2008. Additionally, since 1937, Sebago Lake in Maine has increasingly experienced incomplete freezing (Marlon et al., 2017). In New England, warming is more rapid in the southern states versus the northern states, but the increasing trends in temperature and precipitation are expected to continue over the next decades (Marlon et al., 2017). The northeast region of the United States has experienced an increase in its total annual precipitation, resulting in more intense and frequent rainfall events, leading to flooding in some areas. Snowfall variability has been observed in this region, affecting snowmobile trails, winter sports, recreation, transportation, and other resources (Marlon et al., 2017; Blagrave & Sharma, 2023). The risk of seasonal drought in summer and autumn months is expected to continue, due to increasing temperatures and earlier snowmelt (NOAA, ND).

Coastal areas of the northeast United States are affected by rising sea levels. Sea level rise is related to greater vulnerability to storm surges (Mayo & Lin, 2022). The northeast is the region with the fastest observed warming in the United States, and because of its high population density (comprised of about 20% of the US population), it is vulnerable to flooding caused by storms and rising sea levels (Mayo & Lin, 2022; Karmalkar et al., 2019). In the coming decades, increased precipitation is predicted to continue, along with extreme flooding and storm surge events (Karmalkar et al., 2019; Mayo & Lin, 2022). Between 2000 and 2013, climate change has been attributed to five hurricanes that affected the northeast US coastline. By the end of this century, it is predicted that the volume of coastal flooding could increase by 36%. Furthermore, the area of flooding events could increase by 25%, due to storm surges (Mayo & Lin, 2022). By increasing the region's adaptation and climate resilience efforts, as well as implementing climate action plans, many communities in the northeast US can become better prepared to mitigate and survive climate-related events.

The northeast US has seen the greatest increase in precipitation of all regions in the United States (NOAA, ND). Between 1958 and 2010, this region experienced a 70% increase in precipitation, and this trend is expected to increase throughout this century. Moreover, longer, more frequent, and more intense heatwaves are projected to increase in the northeast US this century, which can have a profound negative impact on local ecosystems, vulnerable populations, infrastructure, and agriculture in the region (Bronnimann et al., 2019; Karmalkar et al., 2019; NOAA, ND). Human and natural resources are becoming threatened by warming temperatures, increasing precipitation, and increasing ocean temperatures (NOAA, ND). The Gulf of Maine is experiencing a significant increase in warming ocean temperatures, which is affecting its marine life (NOAA, 2023). In addition, changing climate patterns are affecting the coastline of the northeast region in the United States. The coastline from Virginia to Cape Cod, Massachusetts is encountering the greatest rise in sea level across the globe, between 2 and 3.7 mm per year, which is "more than three times the global average" (NOAA, 2023). Indeed, due to the changes in climate documented and experienced across the northeastern region of the United States, it is necessary to build climate resilience in this region and to address any threats to human health that may arise due to changing climate patterns.

Global climate events also influence the climatic patterns in the northeast United States. The El Niño and La Niña phenomena are part of a larger climate phenomenon known as the El Niño Southern Oscillation (ENSO), which includes a warmer phase (El Niño) and a colder phase (La Niña). These occur irregularly, every two to seven years (Grothe et al., 2019; Flahault et al., 2016). Due to shifts in temperatures, precipitation patterns, and humidity, the ENSO phenomenon has been associated with an increase in communicable diseases, including influenza (Flahault et al., 2016). The El Niño and La Niña phenomena are also associated with infectious disease epidemics (Flahault et al., 2016).

La Niña, a cooling oscillation cycle associated with cooler temperatures of the Pacific Ocean, is also linked to past influenza pandemics of the twentieth century (Flahault et al., 2016). There is a strong statistical correlation between the La Niña phenomenon and influenza outbreaks across Europe and the United States (Flahault et al., 2016). Further, Flahault and colleagues (2016) found a relationship between the size and severity of influenza outbreaks and the La Niña phenomenon in France and the United States. The outbreaks on each continent varied by about a half-week, suggesting that there is an intercontinental correlation that is due to climatic events (Flahault et al., 2016). This is suggestive of a strong correlation between the capacity and intensity of influenza epidemics across Europe and the United States, and the La Niña cold oscillation phenomenon (Flahault et al., 2016). According to the literature, the La Niña phenomenon occurs every three to five years, but is predicted to occur more frequently and intensely, due to global climate change patterns (Flahault et al., 2016).

Similarly, the El Niño phenomenon can influence influenza activity through changes in surface temperatures across the Pacific Ocean, leading to warmer atmospheric circulation patterns, increased temperatures, and higher humidity, which are correlated with greater transmission of the influenza virus (Flahault et al., 2016; Park et al., 2020). It is hypothesized that if the El Niño events continue to increase, there will be an increased risk of outbreaks of infectious diseases, to include influenza (Flahault et al., 2016). Therefore, it is imperative that greater surveillance measures, as well as increased recognition of long-term trends, impacts and changing climate patterns are utilized to guide future public health strategies and preparedness efforts (Viboud & Vespignani, 2019).

Theoretical Frameworks

Overview

The theoretical frameworks discussed throughout this dissertation provide a structured foundation for the research processes (Joyner et al., 2018). The frameworks selected will guide the research, provide an understanding and analysis of the complex relationship between climate change and influenza activity, and prepare a basis for data collection and analysis (Joyner et al., 2018). Additionally, they will help to establish a connection between the published literature on the topic and the study being undertaken, and provide bases for hypotheses formulation (Joyner et al., 2018). The two selected theoretical frameworks that this study will follow are the One Health approach and work by Zivin and Neidell (2013), which advocates for environmental regulation for the protection of human health (Zhang et al., 2022; Zinsstag et al., 2018). Grounding this study in established frameworks will provide a more robust association between the existing knowledge base and this study's findings (Joyner et al., 2018).

One Health Approach

One framework that has been put in place to mitigate the correlation between climate change and human diseases such as influenza is the One Health approach. This concept recognizes the intersectionality between human health, zoonoses, and environmental health (Zinsstag et al., 2018). It stipulates that climatic changes can impact ecosystems, alter the migration of disease vectors (such as marine birds or estuary waterfowl), and affect animal reservoirs of zoonotic diseases. Such changes may influence the risk of disease transmission to humans (Zinsstag et al., 2018; Zhang et al., 2022). Scientists utilize the One Health framework to study how climate change may lead to the emergence of zoonoses that can cross the species barrier and infect humans; avian influenza A is one such disease that requires attention, for its potential to infect other mammalian species, including humans (Zinsstag et al., 2018; Zhang et al., 2022).

The One Health approach is effective for understanding the link between climate change and influenza activity as it helps the scientific community recognize the large role that human, animal, and environmental health play in achieving healthier societies (Hasan et al., 2023; Zinsstag et al., 2018; Zhang et al., 2022). Through consideration of the above factors together, the One Health approach provides a holistic perspective on the ways that climate change impacts the determinants and distribution of influenza across populations (Hasan et al., 2023). This approach benefits the health science and public health communities by imparting a deeper understanding of environmental factors that lead to greater disease states, aid in better preparedness, and provide for more coordinated response strategies (Hasan et al., 2023). Additionally, the One Health approach helps to explore the role that extreme meteorological events play in infectious disease systems and pathogen transmission to humans (Coalson et al., 2021; Naguib et al., 2019).

Understanding the One Health approach as a theoretical framework for this dissertation on the correlation between climate change and influenza activity is critical because it showcases the complex relationships that occur between human health, animal health, and environmental health (Hasan et al., 2023; Naguib et al., 2019; Zinsstag et al., 2018). Changing climate patterns can influence each of the above components, leading to shifts in disease rates caused by influenza activity. By adopting a One Health perspective, the scientific community can better understand the relationship between climate change and influenza (Naguib et al., 2019; Zinsstag et al., 2018; Zhang et al., 2022). This approach can lead to the development of more comprehensive strategies aimed at mitigating and adapting to the impacts that a changing environment has on influenza activity (Naguib et al., 2019; Zinsstag et al., 2018; Zhang et al., 2022). The goal is to gain enough insight to curtail emerging influenza epidemics and the threat of another pandemic (Naguib et al., 2019; Zinsstag et al., 2018; Zhang et al., 2022).

Considering the interactions between climate, animals, humans, and ecosystems, researchers can better understand and address the health impacts caused by climate change. The One Health Framework promotes interdisciplinary collaboration among environmental scientists, ecologists, public health professionals, health scientists, and veterinary scientists, among others, to assess and help mitigate the risks associated with climate change and human health (Zinsstag et al., 2018; Zhang et al., 2022). Utilizing this framework to analyze the correlation between climate change and influenza activity may help toward disease mitigation and public health preparedness efforts. In a densely populated area, such as the northeast US, this approach can be useful in reducing the number of deaths and hospitalizations associated with the influenza virus, as well as reducing its pandemic potential, in the case of an antigenic shift.

As a theoretical framework, the One Health approach helps explore the relationship between climate change and influenza activity by considering environmental factors which may be connected to the relationship (Hasan et al., 2023; Naguib et al., 2019; Zinsstag et al., 2018; Zhang et al., 2022). Utilizing this framework allows for researchers to analyze changes in ecosystems, weather patterns, long-term climatic changes, and animal-to-human interactions (Hasan et al., 2023; Morin et al., 2018). By integrating data from widely diverse scientific fields, such as climatology, meteorology, ecology, and public health, this approach facilitates a more comprehensive understanding of how climate change may influence influenza activity in the northeast United States (Zinsstag et al., 2018; Zhang et al., 2022). The One Health perspective allows for the identification of potential links between climate change and influenza activity and contributes to a more accurate assessment of the interactions involved between environmental, zoonotic, and human factors that play a role in increased influenza activity across regions (Hasan et al., 2023; Morin et al., 2018; Zinsstag et al., 2018; Zhang et al., 2022).

The Environmental Regulation and Protection of Human Health Approach

A second theoretical framework is used by Amukawa-Mensah and colleagues (2017) and follows the work of Zivin and Neidell (2013), which posits that climate change has effects on human health. This framework postulates that a primary motivation for national and international leaders is that environmental regulations are needed for the protection of human health and should include regulations to mitigate climate change (Amukawa-Mensah et al., 2017; Zivin & Neidell, 2013). Under this framework, environmental regulations must be designed to mitigate the negative impacts of pollution and greenhouse gas emissions that can harm human, environmental, and planetary health. Regulations should aim to ensure clean air and water, and reduce exposure to harmful chemicals, and prevent the transmission of diseases related to environmental factors (Amukawa-Mensah et al., 2017; Zivin & Neidell, 2013).

Further, the economic welfare of producers and consumers may be significantly affected by environmental regulations (Zivin & Neidell, 2013). Producers of goods may face higher costs for emissions or compliance, but such regulations may be drivers for innovation, creating new markets for environmentally friendly products (Zivin & Neidell, 2013). Consumers benefit from healthier environments, which can translate to reduced healthcare costs, and greater access to environmentally friendly products (Zivin & Neidell, 2013). This can be a challenge for policymakers, as balancing environmental protection with economic interests can pose legal and political issues but will be beneficial for human health in the long-term. Environmental regulations targeted at reducing greenhouse gas emissions address climate change and help protect human and environmental health (Amukawa-Mensah et al., 2017; Zivin & Neidell, 2013).

By addressing climate change, policy makers can put into action environmental and public health policies that can benefit human health (Zivin & Neidell, 2013). Such policies can be beneficial by reducing the frequency and severity of extreme weather events, reducing sea-level rise, and reducing zoonoses and inter-species transmission of viruses. All of these factors can impact influenza outbreaks and mitigate the spread of novel strains which can have pandemic potential. Indeed, environmental policies can have a critical role in addressing changing climate patterns and influenza activity by promoting clean energy and improving air quality. Finally, controlling disease vectors, such as migrating birds, and their exposure to other bird or mammalian species that they normally do not encounter, contribute to a comprehensive approach to protecting human health in an era of climate change.

Indeed, recognizing the interconnected systems involved between human, animal, and environmental health enhances our theoretical understanding of the intricate relationship between climate change and influenza activity, and can help determine which policies should be put into place to help support human and environmental health (Amukawa-Mensah et al., 2017; Hasan et al., 2023; Morin et al., 2018; Naguib et al., 2019). In addition, these approaches provide a holistic lens from which to examine the multifaceted impacts of climate change on influenza activity, acknowledging the interdependence of socio-biological factors such as policy makers, animal health, environmental health, and human health (Zivin & Neidell, 2013; Zinsstag et al., 2018; Zhang et al., 2022). By integrating data from such diverse fields, researchers are provided with a more comprehensive understanding of the relationship between climate change and influenza activity, to include avian influenza (Hasan et al., 2023; Morin et al., 2018; Naguib et al., 2019). Informed by the theoretical frameworks herein, strategies can be developed to address the impact of climate change on influenza viruses (Amukawa-Mensah et al., 2017; Zivin & Neidell, 2013; Zinsstag et al., 2018; Zhang et al., 2022).

Theoretical Frameworks Summary

Understanding how the environment is connected to animal health and the role that it plays in human health can inform the development of greater surveillance and preventive public health measures that consider the context of human, environmental, and animal health, and minimize the risk of influenza outbreaks and epidemics (Hasan et al., 2023; Naguib et al., 2019; Morin et al., 2018). The interdisciplinary nature of the theoretical frameworks followed in this dissertation encourages collaboration between experts from various fields, as well as policymakers, fostering a united effort to adapt to the changing environmental and health-related dynamics influenced by changing climate patterns (Hasan et al., 2023; Zinsstag et al., 2018; Zhang et al., 2022). Employing the One Health approach not only facilitates comprehension of the interactions between the environment and human health, but also provides insights into the significant impact of avian influenza on environmental, animal, and human health and disease states (Hasan et al., 2023; Naguib et al., 2019; Morin et al., 2018).

Utilizing a policy and economic approach, in addition to the One Health approach, to climate change and the protection of human health, as demonstrated by Zivin and Neidell (2013), not only advances the theoretical understanding of the correlation between changing climate patterns and influenza activity, but also leads to more pragmatic policies and solutions that can be effective, collaborative, and considerate of the broader impacts that climate change has on the influenza viruses, public and economic policies, and ultimately, human health (Zinsstag et al., 2018; Zhang et al., 2022; Amukawa-Mensah et al., 2017; Zivin & Neidell, 2013). By framing this study within the already established theoretical frameworks mentioned above, a more comprehensive and integrated understanding of the relationship between climate change and influenza activity will be demonstrated.

Chapter Summary

While there is a substantial body of literature dedicated to climate change and its relationship to the influenza virus, there is little literature of the relationship between climate change and influenza activity in the northeast United States. This field becomes even more narrow when looking at the 20-year timeframe of 2003 through 2023. More research is needed to determine how climate change can influence influenza activity in a primarily continental climate zone such as the northeast United States and inform public health professionals on best practices for the protection of human health (Bronnimann et al., 2019; Lane et al., 2022; Liu et al., 2020). There is ongoing research into the correlation between climate change and influenza (Lane et al., 2022). Avian influenza A is another factor to consider when conducting research of this magnitude, as there is currently no effective human vaccine against this group of influenza strains (Chen et al., 2019). Current seasonal influenza vaccines are our primary prevention methods to help reduce the severity and duration of seasonal influenza but may not be of much service if there is an extreme antigenic shift and a novel influenza strain of avian origin appears.

Several studies have suggested links between climate factors such as temperature and humidity in the transmission of influenza; this is a complex relationship that researchers are currently attempting to understand, and additional research is needed in this field for a more thorough understanding of this relationship (Dave & Lee, 2019). It is of critical note that several factors, to include population density, vaccination, and viral mutagenicity, play significant roles in influenza activity (Karmalkar et al., 2019; Dave & Lee, 2019). In addition, more investigation into climate adaptation and its role in curbing influenza activity could be beneficial, not only for this region of the US, but for the entire nation and perhaps on a more global scale. Further research is required to establish clear correlations and determine whether a relationship was truly established between climate change and influenza activity in the northeast United States between 2003 to 2023.

CHAPTER THREE: METHODOLOGY

Overview

This quantitative study will utilize an observational and retrospective research design to determine if a relationship between climate change and influenza activity in the northeast United States between the years 2003 – 2023 exists. Furthermore, in building a predictive model to forecast whether the relationship between climate change and influenza activity will continue over the next 120-year timeframe (2024-2144), it can encourage leaders to strengthen influenza surveillance programs and policies aimed at reducing climate change. This chapter will describe the methods used for this study. The research design will be discussed first, followed by a presentation of the primary research question and additional questions that will direct the study. Research hypotheses will also be presented and discussed. Moreover, data gathering procedures will be specified. The researcher's role in this project will be to gather 20 years' worth of climate data from the northeast region of the United States as well as 20 years' worth of influenza data from the same region and to analyze and discuss whether a statistically significant relationship between the two datasets exists. A Pearson's correlation coefficient will be used to determine if there is a significant relationship between the two variables (Wu et al., 2020). The purpose and importance of the research will be summarized, and recommendations for future research will be given. This research methodology will include a comprehensive framework for conducting the study, analyzing the available data, and determining conclusions about the relationship between climate change and influenza activity in the northeast United States.

Research Design

The aim of this study is to investigate any potential relationship between changing climatic indicators and influenza activity in this region, across the 20-year timeframe. To achieve this objective, a comprehensive research design that involves multiple key components will be employed. The first component that will be analyzed is the study period and geographic scope of the study (Morin et al., 2018). This research will encompass a two-decade time frame, focusing on climate and influenza data spanning from 2003 to 2023, allowing for capture of short-term fluctuations and longer-term trends within and between the datasets. The geographic scope of this study will cover the northeast region of the United States, spanning from Pennsylvania through Maine, ensuring a representative sample of diverse climatic and geographic conditions (NOAA, 2023). The statistical analysis will aim to employ techniques that examine the relationship between climate change and influenza rates. A Pearson's correlation analysis will be conducted to identify potential patterns, trends, and statistically significant associations, as well as a time series analysis to extract insights about the relationship between potential changing climate patterns and influenza activity and make predictions about future trends (Field, 2018; Wu et al., 2020).

According to Sürücü and Maslakci (2020), it is essential to develop a conceptual model, which includes the identified variables to be studied. The problem must be identified, then data must be collected and analyzed to determine a conclusion. Finally, the conceptual model that was developed must be tested (Sürücü & Maslakci, 2020). This investigation will do just that. The variables of climate change and influenza activity have been identified, the region and time frame for the study have been delineated, and the statistical tests that will be run have been selected. This research design will also rely on two frameworks that have been shown in the literature to be effective when conducting a study on climate change and infectious diseases (Zinsstag et al., 2018; Zhang et al., 2022; Zivin & Neidell, 2013). A scholarly contribution to the understanding of the interactions between climate change and influenza activity will be made by employing a research design that outlines a geographical and temporal scope; valid and accurate data collection methods; statistical analyses that identify relationships, patterns, and trends; and adheres to ethical guidelines and standards.

Research Questions

To gain a deeper understanding about the complexities of the relationship between climate change and influenza activity in the northeast United Sates between 2003 to 2023, it is imperative to formulate precise and focused research questions that will guide this investigation. These research questions serve as the compass for this study, directing efforts toward uncovering insights and contributing to the existing body of knowledge in this intersection of the health sciences. In this section, carefully crafted research questions are presented, which pinpoint the core issues being analyzed and reflect the overarching research objectives. By addressing the following research questions, critical aspects of the relationship between climate change and influenza rates in the northeast United States are uncovered, ultimately contributing to a more in-depth understanding of this complicated subject matter. This study is designed to answer the following questions:

RQ1. Is there evidence of a correlation between climate change and an increase in influenza activity in the northeast United States?

RQ2. What roles do shifting migration patterns of avian species play in the transmission of avian influenza viruses from their natural reservoirs to human hosts in a changing climate?

RQ3. To what extent do changing climate patterns in the northeast United States influence the seasonality and geographic distribution of influenza outbreaks in this region?

The first research question aims to uncover a relationship between climate change and influenza activity in the northeastern United States. Work toward answering this question will be conducted through use of statistical analyses, particularly the Pearson's correlation and time series modeling (Wu et al., 2020). The second question intends to uncover the role of changing migration patterns of bird species in influenza transmission from its natural avian reservoirs to human hosts. An investigation of whether changing climate patterns have a function in this phenomenon will also be undertaken. Lastly, the third research question proposes to unveil the extent to which climate change in the northeastern United States influences the transmission of influenza across the region. An analysis and examination of a changing climate and extreme weather events, and their correlation with increased influenza transmission and susceptibility will be conducted.

Indeed, the research questions outlined in this section form the foundation for this investigation. The relationship between climate change and influenza activity is complicated, and there is not much research published about their relationship in this region of the United States (Lane et al., 2022; Marlon et al., 2017). The carefully designed research questions discuss the complexities of this phenomenon and may shed some light into how changing climate patterns influence the seasonality and geographic distribution of influenza outbreaks. Addressing these questions may not only enhance our understanding of the implications of climate change on public health, but also provide valuable insights for policymakers, health professionals, and researchers striving to mitigate the impact of influenza in a rapidly changing world. The ensuing chapters will delve into the methods, data analyses, and findings that will help answer these questions and contribute to the ever-evolving study on the intersection of climate change and infectious disease dynamics.

Research Hypotheses

In addition to the research questions posed above, the formulation of null hypotheses has been completed. This process is essential in determining whether the relationship between an independent variable and a dependent variable, in this case, climate change and influenza activity in the northeast region of the United States exists (Barroga & Matanguihan, 2022; Novosel, 2022). By positing that no significant association exists between climate change and influenza activity, these hypotheses serve as critical benchmarks for scientific inquiry (Barroga & Matanguihan, 2022; Novosel, 2022). Through rigorous research and statistical analysis, any rejection or acceptance of the null hypotheses provides valuable insights into the dynamics of climate and influenza interactions. Furthermore, the null hypothesis framework fosters methodological clarity, guiding the selection of appropriate research methods and analytical techniques to assess the hypothesized relationships (Barroga & Matanguihan, 2022; Novosel, 2022). The examination of null hypotheses contributes to a comprehensive understanding of the correlation between climate change and influenza activity and will help to inform evidence-based strategies for public health interventions and climate adaptation in the region (Barroga & Matanguihan, 2022; Novosel, 2022). This study will either reject or accept the following null hypotheses:

$H_0$1. There is no evidence of a correlation between climate change and an increase in influenza activity in the northeast United States.

$H_0$2. Changing climate patterns do not make transmission of avian influenza from its natural reservoir to human hosts more likely to occur, due to altered migration patterns and increased human interaction with wild birds.

$H_0$3. Changing climate patterns in the northeast United States do not significantly impact the seasonality and geographic distribution of influenza outbreaks in this region.

Indeed, the testing of null hypotheses serves vital roles in the pursuit of scientific inquiry and helps guide researchers toward deeper insights and valid conclusions regarding the complicated correlation between climate change and influenza activity in the northeast United States.

Population and Setting

For this project, the population examined is that of the northeast United States, spanning from the mid-Atlantic region (Pennsylvania, New Jersey, and New York), through New England (Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont), between the years 2003-2023. This study explores the relationship between climate change and influenza activity across the region during the specified timeframe. This region, characterized by its diverse climate patterns, ranging from humid subtropical to continental, serves as an ideal setting for investigating the impacts of climate variability on influenza incidence and public health dynamics (NOAA, n.d.; Marlon et al., 2022; CDC, 2023). With its densely populated urban centers, such as New York City and Boston, and extensive rural landscapes, such as that of Vermont and New Hampshire, the region offers a microcosm of environmental and demographic factors that influence disease transmission patterns (CDC.gov, 2023; New York.gov, 2024;

Mass.gov, 2024; New Hampshire.gov, 2024). According to the NOAA, over the twenty-year timeframe specified, climate change has manifested through warming in temperature an increase in precipitation patterns, and extreme weather events, thereby potentially exerting profound influences on infectious disease dynamics, to include influenza (NOAA, n.d.; Lane et al., 2022). By studying this temporal span, this project aims to uncover any potential relationship between climatic shifts and influenza activity, offering critical insights into climate's implications on public health in this region.

In addition to seasonal influenza, avian influenza trends were analyzed and pulled from the USDA's website (aphis.usda.gov) and relationships with average temperature and precipitation rates for the northeast region were evaluated.

Finally, based off the information gathered from seasonal influenza and climate data, an autoregressive integrated moving average (ARIMA) predictive model was built, which is used to understand past influenza and climate relationships as well as to predict future influenza cases, given current climate data for the region (Field, 2018). This type of time series predictive model will be helpful for future research looking at the relationship between influenza activity and climate change over the course of the next 25 and 120 years, respectively (Chae et al., 2018; Soebiyanto et al., 2010).

Procedures

This study employed a comprehensive analysis of retrospective climate and public health data of the northeast United States for the period between 2003 and 2023. The relationship between climate change and influenza activity in this region has been carefully analyzed. Historical climate data was pulled from the National Oceanic and Atmospheric Association, and influenza data was gathered from the Centers for Disease Control and Prevention's Flu View website, as well as from state public health departments across the northeast region. Utilizing a rigorous retrospective research design, temperature patterns and precipitation levels will be examined, along with the relevant public health data. The public health data will focus on influenza or influenza-like illness case-counts in the study's time frame, as well as its geographical spread. Influenza-like illness case counts will be used in cases where influenza rates are not available. A detailed timeline of climate variations and influenza activity will be constructed, enabling a thorough exploration of the variables' correlation over the two-decade time span. By employing a Pearson's correlation coefficient analysis, as well as a time-series analysis, valuable insights into the interactions between climatic shifts and the prevalence of influenza and influenza-like illness will be uncovered, as these statistical tests evaluate the strength of the linear relationship between the two continuous variables (Wu et al., 2020). This study will significantly contribute to the understanding of this crucial public health issue.

Institutional Review Board (IRB) approval was gained by Liberty University's Research Ethics Office, through the Cayuse platform. A detailed proposal was submitted outlining this project's objectives, methods, and the timeframe and region that was to be analyzed. Because this study does not utilize human participants for research and is analyzing climate patterns and influenza or influenza-like illness case counts, permission to continue the study was granted, by Liberty University's Research Ethics Office, within two days of submission. The original submission was looking at 50 years of influenza and climate data between 1970 to 2020; however, because influenza is not a reportable illness in all states, 20 years of influenza data, going as far back as 2003, was as much as could be gathered. An amendment question to the IRB committee was submitted, with new timeframe of 2003-2023, versus the previous time frame of

1970-2020. Because this research project does not involve human subjects research, no official amendment to the IRB was needed.

Once IRB approval was granted, the NOAA's website was searched, and their Climate-at-a-Glance tool was found (https://www.ncei.noaa.gov/access/monitoring/climate-at-a-glance/). The "region" tab at the top of the website was used to find their regional time series data gathering site (https://www.ncei.noaa.gov/access/monitoring/climate-at-a-glance/regional/time-series). The parameters in the drop-down menus were then selected based off the information needed for this project and will be explained in more detail in the data collection section of this paper. In addition to gathering climate data for the region, state public health departments were emailed and asked to provide influenza case counts, by respiratory season, going as far back as possible. The state public health departments of Pennsylvania, New Jersey, New York, Massachusetts, New Hampshire, Vermont, Connecticut, and Rhode Island were contacted, via their official email address which were found on their respective websites. Epidemiologists from Pennsylvania, Massachusetts, New Hampshire, Connecticut, and Rhode Island responded and sent Excel spreadsheets with the requested data. Case counts from New Jersey and New York were gathered from their respective public health department websites (nj.gov/health, 2024; health.ny.gov, 2024).

Data Collection

A search of several websites and the published literature was conducted to collect and analyze influenza and influenza-like illness data. Of note, the Centers for Disease Control and Prevention maintains a database of limited historical influenza data for the United States and can be found through the CDC's FluView website; it can be accessed through (https://www.cdc.gov/flu/weekly/index.htm). This site provides access to weekly influenza surveillance reports and includes some retrospective influenza data. Furthermore, the CDC's Flu View Interactive website provides historical data by influenza season, surveillance area, and provides charts and a map to help researchers better visualize the distribution of influenza and influenza-like illness across a region. The website can be found at (https://gis.cdc.gov/grasp/fluview/fluportaldashboard.html). Data on influenza incidence, prevalence, and surveillance in the northeastern United States was collected and analyzed from the above-mentioned websites.

The data search for peer-reviewed articles was conducted using the Summons database found under Liberty University's Jerry Falwell Library, the PubMed database, along with other search engines such as ProQuest, EBSCO Host, and Google Scholar (Liberty University, 2024; Google Scholar, 2024; PubMed, 2024). Both ProQuest and EBSCO Host were accessed through Liberty University's Jerry Falwell Library (Liberty University, 2024).

Moreover, public health data was collected from several states across the region. The states from which public health data was gathered were chosen because they represent diverse population densities, socioeconomic backgrounds, and geographical locations. State public health departments were contacted, data requests were emailed to those state health departments who required them, and influenza case-counts or influenza-like illness (ILI) case counts were later returned, via email. The following were states where influenza or ILI data was collected: Pennsylvania, New Jersey, New York, Connecticut, Rhode Island, Massachusetts, and Maine. The states above were chosen to ensure a mix of urban, suburban, and rural areas to gain a comprehensive overview on influenza activity across several geographic locations throughout the northeast United States.

It is important to note that influenza is not a reportable illness across all States. Some States, such as Rhode Island, only gather data from visits to sentinel providers that were due to ILI (Rhode Island Department of Health, 2024). For the purposes of this project, ILI is defined as an illness presenting with a fever of ≥ 100°F (37.8°C) and cough or sore throat (Chow et al., 2020; CDC, 2023). According to Chow and colleagues (2020), those patients who fulfill the CDC's ILI case definition are six times more likely to have an influenza infection than those not meeting the criteria. For the purposes of this project, those state public health departments who sent case counts using ILI criteria will be counted as influenza cases. Rhode Island was the only state that sent ILI data for this project, all other states contacted sent confirmed influenza case counts.

Sampling

The sampling protocol for climate change in this study involved gathering retrospective climate data from the NOAA's Climate-at-a-Glance website (2024), filtered by region and time frame. The region filter includes the northeast region of the United States and the timeframe chosen is the following—start year: 2003, end year: 2023. Additionally, the climate parameters chosen were average temperature and a 12-month timescale, beginning from February of one year through January of the following year. The base period was chosen to be displayed between the years 2003 to 2023. Trendlines were chosen to be displayed to show a per decade trend in temperature. In this case, there was a +0.09°F increase in warming per decade for the two decades chosen (NOAA, 2024). Furthermore, a smoothed time series filter was chosen with the locally estimated scatterplot smoothing (LOESS) as the smoothing method for the series of data (NOAA, 2024). The LOESS curve was chosen because it considers that no assumptions are made about the structure of the underlying data (Cleveland, 1979). Moreover, the LOESS is an effective method to use when there are outliers in the data (Cleveland, 1979).

In addition to filtering the time scale parameter by a 12-month timeframe, a second regional time series graph was generated, looking at a monthly time scale versus an annual time scale, beginning in February of each year. The second time series graph found that the trend of warming in the northeast region of the United States was at a rate of a +2.4°F increase per decade (NOAA, 2024).

The sampling protocol for influenza activity in the northeast United States involved emailing all the state public health departments in the region and gathering their seasonal influenza case-counts, by respiratory season. Respiratory season runs from 1 October of one year through 31 March of the following year. Of note, in years where there is more widespread activity in the spring months, the respiratory season can be extended by the Centers for Disease Control and Prevention (CDC, 2023). Influenza data was received from Pennsylvania, New Jersey, New York, Massachusetts, Connecticut, Vermont, and Maine. New Hampshire was excluded, as the information sent was in percentages, not actual case counts. Vermont data was excluded, as data was only available for a five-year period, from 2018-2023. No data was available on the entire 20-year timeframe requested, as seasonal influenza is not a reportable disease in that state unless it is a novel strain (Healthvermont.gov, 2024). A Pearson's correlation analysis was run on all the public health department data above, and all were highly correlated, a with Pearson's R of between .8 and .9 for all influenza data collected. This is indicative of a statistically significant correlation between all states in the region and their respective rates of influenza and influenza-like activity (Field, 2018).

Furthermore, influenza case counts were gathered from the CDC's Flu View Website (2024), for the short time span of 1997 through 2002. This five-year data set was used to compare against climate data during that timeframe, and as an outside sample for the test-retest reliability method. The test-retest reliability method is a measure of reliability that details the results of two datasets and can be correlated to evaluate the reliability of the tests being used (Field, 2018).

In addition to influenza data collected from the CDC website, the academic literature was reviewed and articles that discussed a relationship between climate and influenza were analyzed. Articles written about climate change in the northeast United States and climate change and its implications on influenza activity were analyzed (Lane et al., 2022; Lim et al., 2022; Liu A et al., 2020; Liu H et al., 2020; Marlon et al., 2017). Datasets on climatic data for the northeastern region of the United States were collected and analyzed and the information found therein was compared to the information gathered from the peer-reviewed literature. The NOAA's Climate-at-a-Glance tool provides information on the climate change patterns by region, state, or county, and can be found at https://www.ncei.noaa.gov/access/monitoring/climate-at-a-glance/regional/mapping.

Academic research databases such as PubMed, Google Scholar, Liberty University's Jerry Falwell Library, ProQuest, EBSCO Host, and CINHAL were utilized to access peer-reviewed articles and studies that included retrospective influenza and climate data for the northeastern United States. Data on the relationship between influenza and climate was gathered to analyze a global perspective on this parallel, and was used to support assertions, recommendations, interpretations, and conclusions for this investigation.

For data on avian influenza (AIV), both the CDC's website (https://www.cdc.gov/flu/avianflu/data-map-wild-birds.html) and the USDA's Animal and Plant Health Inspection Service (https://www.aphis.usda.gov/animal_health/data-csv/hpai-wild-birds.csv) were utilized to find AIV cases in both wild birds and domestic poultry (CDC, 2024; USDA, 2024). Avian influenza data on domestic poultry flocks were gathered and correlations between climate data and AIV data were run. As AIV data sets involving wild birds could not be separated by year, domestic poultry cases were analyzed using statistical correlation methods. However, a map with total case counts of AIV found in wild birds for the northeast US during the timeframe of January 1, 2022, through January 1, 2024, has been added to this paper's Appendix B.

Data Analysis

The approach for data analysis in this investigation involved data gathering, organization, management, and analysis using a qualitative approach. The Statistical Package for the Social Sciences (SPSS) and the online-based Intellectus Statistics ® software packages were employed. Utilizing these software tools, statistical analyses to examine the datasets gathered from the NOAA, CDC, and other public health departments over the specified timeframe were conducted and cross-referenced. Descriptive statistics, such as mean, median, mode, variance, and standard deviation were employed to summarize the climate and influenza variables, providing an overview of the patterns observed. To explore the potential relationship between climate change and influenza rates in this specified region, Pearson's correlation coefficient tests were undertaken to assess the strength and direction of the associations between climate change indicators and influenza activity metrics. Additionally, a time series analysis was employed to discern long-term climate trends and seasonal patterns that are indicative of climate change factors and an increase or decrease in influenza activity (Field, 2018; NOAA, 2024).

Sample and Variables

For this dissertation, the study focuses on analyzing the correlation between climate change and influenza activity in the northeast United States, spanning the time period from 2003 to 2023. The selection of this timeline enables the capture of long-term climate trends and their potential impact on public health across the two decades sampled. The sample encompasses a diverse range of data sources, including meteorological records from the National Oceanic and Atmospheric Administration, public health databases from the Centers for Disease Control and Prevention's website, and influenza surveillance systems from across the northeast region of the US. The sample, comprising datapoints from the northeast region, provides the foundation for this analysis.

The climatic variables analyzed include climate factors, including temperature abnormalities, precipitation patterns, and humidity levels (NOAA, 2023). The influenza factors to be analyzed will include influenza incidence, outbreak severity, and geographical distribution (CDC, 2022). Climate change is this study's independent variable and influenza activity is the dependent variable. Through meticulous analysis of these variables, patterns and correlations were assessed, shedding light on the interrelationship between climate change and influenza activity in this specific geographic region of the United States, within the specified timeframe. The purpose of this project is to determine whether there is a correlation between climate change and influenza activity in this region, and to build a predictive model that can help forecast influenza outbreaks due to climate-related patterns over the next 25 and 120 years.

Informed Consent

As this study does not utilize human subjects, informed consent is not required. No one person's specific data was analyzed, rather, this investigation examines retrospective climate and public health data to determine whether a relationship exists between the two. This research relies on publicly available data from reputable sources. Therefore, ethical concerns regarding data privacy and informed consent are not applicable.

Validity

Ensuring the validity and reliability of the findings is paramount to the integrity of this research. In a quantitative research study, validity refers to the extent to which a measurement accurately reflects the concept it is intended to assess (Field, 2018). It is the degree to which a statistical test measures what it claims to measure (Field, 2018). Validity is a key aspect of research because it ensures the findings and conclusions drawn from the study will apply to current situations (Field, 2018). The steps that have been taken to ensure validity in this research study are ensuring the theoretical framework is evidence-based; ensuring that the literature review conducted is thorough and that the studies analyzed apply to the phenomena being tested; and ensuring the study's measurements of climate change variables are comparable with established climate data sources and measurements (Libarkin et al., 2018).

Additionally, this study ensures that measurements of influenza activity come from reliable public health databases and sources. This study must show a correlation between the data gathered and established data sources, which indicates criterion-related validity (Libarkin et al., 2018). Further, construct validity will be ensured using statistical methods such as Pearson's correlation coefficient and time series analysis, to confirm the variables being tested are related

(Libarkin et al., 2018; Field, 2018). Through rigorous analysis of the above-mentioned aspects of validity, the validity of this quantitative research study is established and the relationship between climate change and influenza activity in the northeast United States is accurately represented.

Reliability

Ensuring reliability in a quantitative research study investigating the relationship between climate change and influenza activity involves demonstrating the research methods yield consistent results (Field, 2018). Some steps used to measure reliability include consistent measurement techniques, utilization of reliable instruments, test-retest reliability, and appropriate statistical analysis methods (Field, 2018). Consistent measurement techniques ensure that the methods used to measure climate variables, such as temperature and precipitation, and influenza variables (incidence and outbreak severity), remain constant throughout the study. Changes in methodology partway through the study can introduce uncertainty and variability (Yoe, 2019). The use of reliable instruments to gather data is also an aspect paramount to ensuring reliability in a study. Using established and reliable meteorological sources (such as the NOAA's databases) ensure reliability of data obtained. Similarly, utilizing data from reputable public health sources, such as the CDC's databases and publications and those of state public health departments also ensures reliability of data obtained.

The use of a test-retest reliability analysis is another way the data will be analyzed for reliability. This test will be conducted by administering the same statistical techniques used on the entire dataset, to a smaller data set at differing points in time (outside of the study period of 2003 – 2023). The timeframe used for the test-retest reliability method was taken from the years 1997 – 2022. Score calculation was undertaken to determine the correlation between the scores.

This will assess the stability of the measurements over time (Field, 2018). Finally, the statistical methods discussed earlier will provide numerical indicators to help determine whether a statistically significant relationship exists between climate change and influenza activity in the northeast United States. The data has undergone rigorous analysis, to include data grouping, validation, and standardization to ensure quality, validity, and reliability. The data will also be visually presented in line graphs and tables, later in this manuscript, to enhance the clarity of results to the readers. Through careful analyses of the data's validity and reliability, a solid relationship between climate change and influenza activity may be established, while ensuring the consistency and stability of the results.

Data Interpretation

Interpretation of the results will involve analyzing the Pearson's correlation coefficient and time-series analysis values. For the Pearson's correlation test, the numerical values given (from -1 through 0 to +1) signify the strength of the correlation or relationship between the two variables (Field, 2018). The strength and direction of the linear relationships have also been measured. A positive correlation of the Pearson's test indicates a positive correlation between climate change and influenza activity (Field, 2018).

For the time-series analysis, outliers and sudden shifts in climate and influenza rates have been analyzed, trends have been determined, and the information will be summarized later in this manuscript (Field, 2018). The time series analysis shows whether long-term trends exist between seasonal patterns in climate and influenza rates. Through visual representation of the data over the decades, patterns can be identified. Such patterns can include increasing or decreasing temperatures, changes in precipitation, and increases or decreases in influenza rates over the time span analyzed.

Together, the Pearson's correlation coefficient and the time-series analysis will provide an understanding of the dynamic relationship between climatic variables and influenza rates, if they exist. The Pearson's test offers insight into the degree of association, while the time series analysis can allow for the visualization of temporal patterns, enabling a comprehensive interpretation of the datasets and help make predictions about future trends (Field, 2018).

Data Reporting

In this investigation on climate change and its relationship to influenza activity in the northeast US between 2003 to 2023, ethical data reporting is paramount. All findings, evidence, and conclusions have been honestly reported. Ethical guidelines were stringently adhered to, plagiarism was strictly avoided, and authorship has been truthfully reported. Transparency has been maintained throughout the research process; all methods, procedures, data collection, and analytical techniques have been clearly documented and made available for committee review, promoting accountability and integrity of the research.

Assumptions

When conducting a research study on climate change and its relationship to influenza activity in this specific region of the US, some assumptions can be made. First, there is an assumption that climate change indicators, such as rising temperatures and altered precipitation patterns have a significant impact on environmental factors that influence the transmission of influenza viruses. Second, it can be assumed that historical influenza data gathered from reliable surveillance systems and organizations (such as the CDC and state public health departments) accurately represent the prevalence, incidence, and severity of influenza over the years. Another assumption is that human behavior and public health interventions, such as vaccination campaigns, remain consistent over time, but may vary based on social, economic, or political factors. Further, it is assumed that the relationship between climate change and influenza activity is linear, can be accurately assessed through quantitative methods, and may miss potential nonlinear relationships. It is also assumed that the relationship between climate change and influenza activity is static and remains constant over time. Moreover, it is assumed that all the peer-reviewed literature analyzed on this topic was written with credible, reliable evidence. Finally, other assumptions made for this investigation are that historical climate and influenza data are accurate, consistent, and reliable, and grant researchers correct information on retrospective climate and public health trends.

Limitations

Conducting a study on climate change and influenza activity in the northeast US over a two-decade time span is a complex project and comes with inherent limitations. One significant limitation is the availability and reliability of historical climate and public health data. There may be gaps, inconsistencies, or variations in data collection methods over time. This presents a challenge in establishing long-term trends or relationships among the datasets. Additionally, this is a large region with a great population density, making reporting of influenza cases difficult to attain. According to Heymann (2022), only about 50% of all influenza cases are reported across the United States. Finally, regional variations in climate and influenza strains complicate the project, creating a challenge to generalize findings to the entire region (Gass, 2022).

Chapter Summary

In summary, the methodology that has been followed for this investigation is quantitative in nature. This study investigates the relationship between changing climate patterns and influenza activity in the northeast United States over a twenty-year time span (2003-2023). The aim is to review retrospective climate data for the region, as well as historical influenza incidence records for the same period and utilize statistical models to determine the nature of the relationship between the two. The statistical tests that will be employed are the Pearson's correlation coefficient, as well as time-series models, to identify correlations and trends, considering factors such as temperature variations, precipitation rates, and climatic shifts. As there is a gap in the scholarly literature on the relationship between climate change and influenza rates in this exact region, this study will attempt to add to the knowledge base on this topic, providing valuable insights into the interaction between climate change and influenza activity in the northeast United States.

The literature has shown a correlation between changing climate patterns and an uptick in influenza activity. Both seasonal and avian influenza rates have been investigated, as well as changes in climatic factors, such as temperature and precipitation. While this relationship is not fully understood, what researchers do know is that it relies on several interrelated factors, such as seasonal variation, changes in climate patterns, human behavioral factors, animal migratory patterns, and public health measures. There are some potential links between climate change and the transmission of influenza, but more research into these interactions is needed to study these interactions to better understand how climate change may affect influenza transmission patterns. Although temperature, humidity, precipitation, and animal migratory patterns have been linked to influenza activity, other factors such as population density, vaccination rates, and viral mutagenicity may also significantly contribute to increasing influenza rates. This investigation intends to establish a correlation between these factors, should they exist. The result can be increased public health preparedness and strengthened responses to influenza outbreaks, epidemics, and pandemics, and the enacting of environmental policies that focus on climate change mitigation and resilience.

CHAPTER FOUR: FINDINGS

Overview

This results section will convey the findings of the study on the correlation between climate change and influenza activity in the northeast United States from 2003 to 2023. Statistical analyses, Pearson's correlations, and time series analyses between climate variables and influenza activity will be presented herein. The time series analyses on average temperatures and precipitation, generated by the NOAA, will be found in the Appendix A of this dissertation. This section will highlight any significant relationships observed and will provide insights into the potential impact of climate change on influenza activity across the northeast United States. Patterns, trends, and relationships identified in the data and their implications on public health, epidemiological research, and the health sciences will also be discussed.

The relationship between climate change and influenza activity has become an increasingly critical area of study in public health, epidemiology, ecology, and across the health sciences (Lane et al., 2022). This dissertation investigates the complexities of the relationship between climate change and influenza activity in the northeastern United States across a two-decade span, from 2003 through 2023. Focusing on both seasonal and avian influenza, this research examines the interconnectedness between climatic factors and the incidence and prevalence of the influenza viruses. Through the careful examination of the correlation between climate variables and influenza activity, this study aims to contribute valuable insights into the dynamics driving infectious disease patterns amidst a changing climate.

The purpose of this quantitative correlational study was to determine if there is a relationship between changing climate patterns and influenza activity across the northeast United States. A retrospective observational design was used to gather climate data from this region as well as data on seasonal influenza and avian influenza. Historical data on temperature, precipitation, and seasonal and avian influenza case counts were analyzed to identify associations, trends, or relationships. The retrospective observational design of this quantitative correlational study will help to draw conclusions about the variables of interest (De Sanctis et al., 2022). Retrospective observational studies are often used in public health, epidemiology, and the health sciences to investigate the relationships between exposures and outcomes over time (De Sanctis et al., 2022).

Research Questions

RQ1. Is there evidence of a correlation between climate change and an increase in influenza activity in the northeast United States?

RQ2. What roles do shifting migration patterns of avian species play in the transmission of avian influenza viruses from their natural reservoirs to human hosts in a changing climate?

RQ3. To what extent do changing climate patterns in the northeast United States influence the seasonality and geographic distribution of influenza outbreaks in this region?

Null Hypotheses

$H_0$1. There is no evidence of a correlation between climate change and an increase in influenza activity in the northeast United States.

$H_0$2. Changing climate patterns do not make transmission of avian influenza from its natural reservoir to human hosts more likely to occur, due to altered migration patterns and increased human interaction with wild birds.

$H_0$3. Changing climate patterns in the northeast United States do not significantly impact the seasonality and geographic distribution of influenza outbreaks in this region.

Descriptive Statistics

The descriptive statistics presented herein provide a comprehensive summary of the data collected on climate change and influenza activity in the northeast United States. These statistics include measures of central tendency to include mean, median, frequency, and variability, such as standard deviation, range and variance, which offer a foundational understanding of the data distribution (Field, 2018). Through these summaries, the descriptive statistics provide a clear and concise depiction of the patterns and trends found within and between the datasets, facilitating a preliminary assessment of the relationship between climatic variables and influenza activity. The inclusion of descriptive statistics is critical as it helps researchers to identify anomalies, outliers, or underlying distributions that may influence the interpretation of the correlation analysis, thereby ensuring a data-informed analytical process (Cohen, 1988; Field, 2018). Table 1 depicts the descriptive statistics for average temperatures found in the northeast United States between the years 2003 through 2023 and reported influenza cases during that same time period. Figure 1 shows the distribution curve of reported seasonal influenza cases, and Figure 2 shows the average temperatures found in the northeast United States from February of one year through January of the following year over the 20-year timespan.

Table 1

Descriptive Statistics of Average Temperatures and Reported Influenza Cases

Descriptive Statistics

	N	Range	Minimum	Maximum	Mean	Std. Deviation	Variance	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
Reported Cases	20	680719	7538	688257	128092.90	157251.002	2.473E+10	2.597	.512	8.370	.992
Average Temps Feb to Jan	20	3.9	45.5	49.4	47.560	1.1505	1.324	-.202	.512	-.982	.992
Valid N (listwise)	20										

Figure 1

Reported Influenza Cases February through January

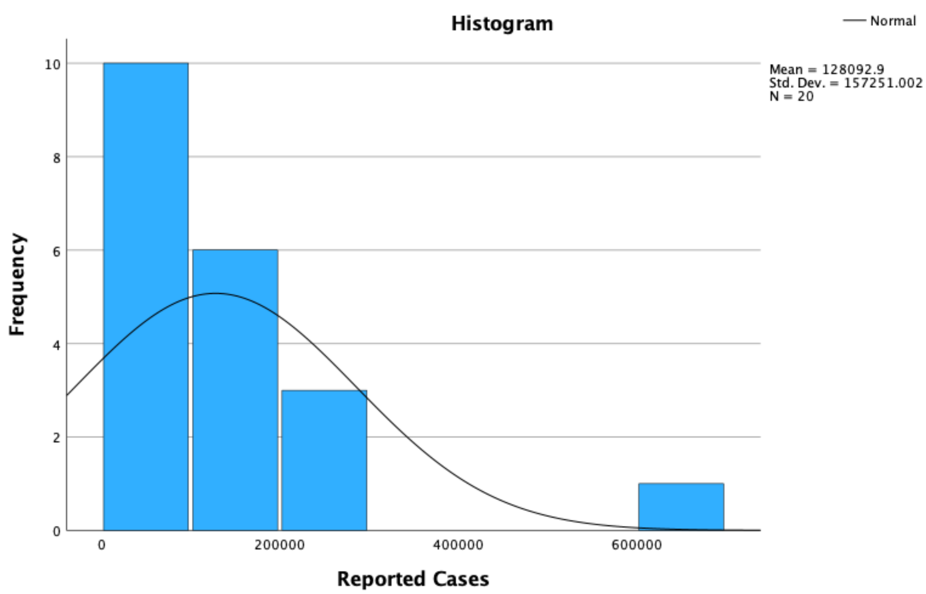
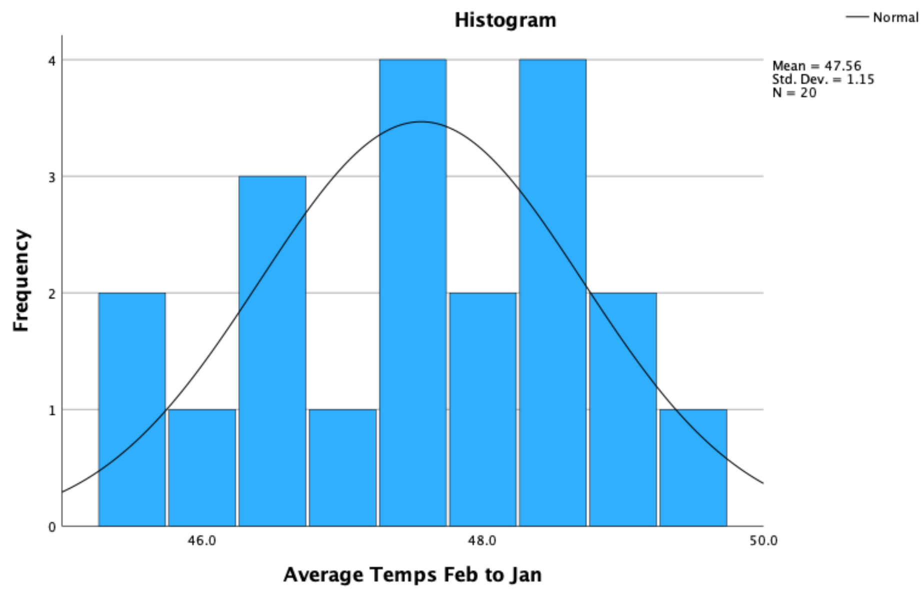


Figure 2

Average Temperatures February through January



Results

Hypotheses

The examination of potential correlations between climate change and the prevalence of influenza activity across the northeast United States represents a crucial inquiry within the health sciences. Through rigorous data analysis of climate and influenza datasets, spanning the two-decade timeframe of 2003 through 2023, patterns and associations between climate variables and influenza incidence in this region were uncovered. The following paragraphs set the stage for a comprehensive exploration of the findings, shedding light on the relationship between climate and infectious disease patterns within this geographical context.

Research Question 1

This study sought to address, first, the following research question:

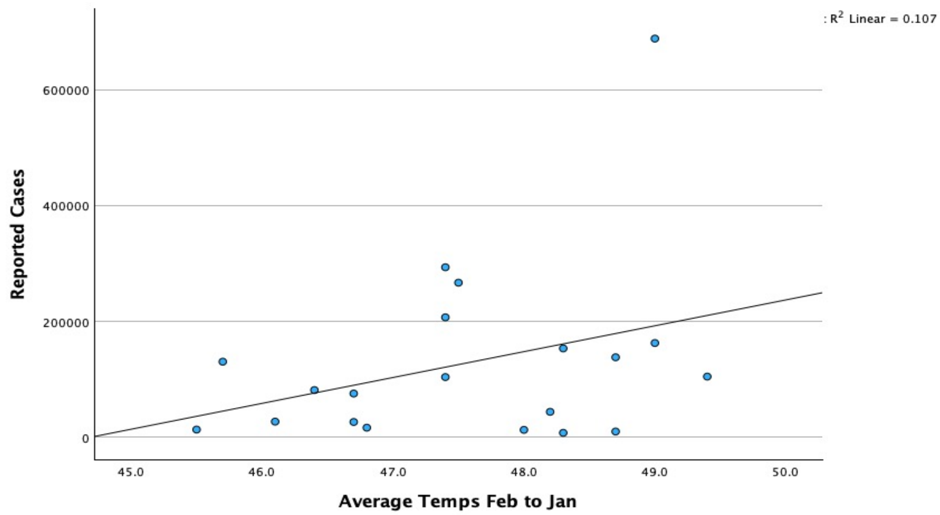
RQ1. *Is there evidence of a correlation between climate change and an increase in influenza activity across the northeastern United States?*

A calculation of a Pearson's correlation coefficient was undertaken, to analyze the potential relationship between climate change and influenza activity in the northeast United States. This widely recognized measure of a relationship between two variables allowed for quantification of the strength and direction of any observed correlations between climate variables and influenza incidence (Field, 2018). The analysis was conducted between climate factors (*Average Temps Feb to Jan*) and reported influenza cases or ILI (*Reported Cases*). This statistical approach not only provided valuable insights into the nature of the relationship under investigation but also facilitated the identification of potential trends or patterns that may inform future research endeavors across the health sciences and a strengthening of public health interventions and policies (Field, 2018; Langendijk et al., 2022). Cohen's standard was used to evaluate the strength of the relationship, where coefficients between .10 and .29 represent an insubstantial effect size, coefficients between .30 and .49 represent a moderate effect size, and coefficients above .50 indicate a substantial, statistically significant, effect size (Cohen, 1988).

Assumptions. A Pearson's correlation requires a linear relationship between each pair of variables (Conover & Iman, 1981). This assumption is violated if the scatterplot shows curvature (Conover & Iman, 1981). Figure 3 presents the scatterplot of the correlation. A regression line has been added to assist with interpretation of the scatterplot.

Figure 3

Scatterplots with the Regression Line added for Average Temps Feb to Jan and Reported Cases



Pearson's Correlation Coefficient. The result of the correlation was examined based on an alpha value of 0.05. The Pearson's correlation coefficient (r) between the variables is .327 ($p < 0.05$, 95% CI [-0.144, .667], n = 20), and indicates a moderately significant positive correlation. This result explains approximately 33% of the variation in the dependent variable, labeled *Reported Cases*. Consequently, a moderately significant correlation was found between the datasets of reported influenza cases and average annual temperatures. Table 2 and Table 3 present the results of the correlation.

Table 2

Pearson's Correlation Coefficient Showing the Relationship between Average Temperatures and Reported Influenza Cases

Correlations

		Reported Cases	Average Temps Feb to Jan
Reported Cases	Pearson Correlation	1	.327
	Sig. (2-tailed)		.160
	N	20	20
Average Temps Feb to Jan	Pearson Correlation	.327	1
	Sig. (2-tailed)	.160	
	N	20	20

Table 3

Confidence Intervals Table Showing the Results of the Pearson's Correlation Coefficient and its Associated Confidence Intervals

Confidence Intervals

	Pearson Correlation	Sig. (2-tailed)	95% Confidence Intervals (2-tailed)[a]	
			Lower	Upper
Reported Cases - Average Temps Feb to Jan	.327	.160	-.144	.667

a. Estimation is based on Fisher's r-to-z transformation with bias adjustment.

Because there is a moderately positive effect size in the correlation between the climatic factor of average temperatures and reported influenza cases during this 20-year timespan, this study rejects the null hypothesis ($p = 0.05 < 0.160$). Additionally, the Pearson's r value of .327 indicates a slight positive correlation between climate change and influenza activity in the northeast United States. This correlation suggests that there is a moderate linear relationship between the two variables analyzed.

Research Question 2

The second research question is as follows:

RQ2. *What roles do shifting migration patterns of avian species play in the transmission of avian influenza viruses from their natural reservoirs to human hosts in a changing climate?*

Shifting migration patterns of avian species can potentially impact the transmission of avian influenza viruses to human hosts in several ways, due to changing climate patterns (Gass et al., 2023). Changes in climate can alter the timing and routes of bird migrations, creating potential contacts between migratory birds and domestic poultry, other mammalian species, or human populations (Gass et al., 2023; Hill et al., 2022; Lycett et al., 2016). Furthermore, changes in habitat due to climate changes may force birds to migrate to new areas, potentially introducing novel influenza viruses to previously unaffected regions (Hill et al., 2022; Lycett et al., 2016). Moreover, alterations in climate conditions can affect the behavior and health of migratory birds, potentially making them more susceptible to carrying and transmitting HPAI viruses (Blagodatski et al., 2021; Hill et al., 2022). Indeed, understanding and monitoring these shifting migration patterns is critical for early detection and prevention efforts against avian influenza transmission to humans.

Domestic birds facilitated the gradual but continuous spread of HPAI (H5), while wild birds such as swans, geese, and ducks contributed to quick but sporadic dispersal through distinct pathways (Blagodatski et al., 2021; Gass et al., 2023; Hill et al., 2022). Through careful analysis of virus-host connecting mechanisms, there is potential to improve and strengthen surveillance and outbreak prediction (Hill et al., 2022).

A Pearson's correlation analysis was conducted among three variables: average monthly temperatures, average precipitation, and size of affected flocks (axes titled *Avg_Monthly_Temp, Avg_Precip,* and *Flock_Size*). As in Research Question 1, Cohen's standard was used to evaluate the strength of the relationships (Cohen, 1988).

Assumptions. A Pearson's correlation requires a linear relationship between each pair of variables (Conover & Iman, 1981). This assumption is violated if curvature exists in the scatterplot. Figure 4 and Figure 5 present the scatterplots of the correlations. A regression line has been added for ease of interpretation.

Figure 4

Scatterplots with the Regression Line added for Avg_Monthly_Temp and Avg_Precip (left), Avg_Monthly_Temp and Flock_Size (right)

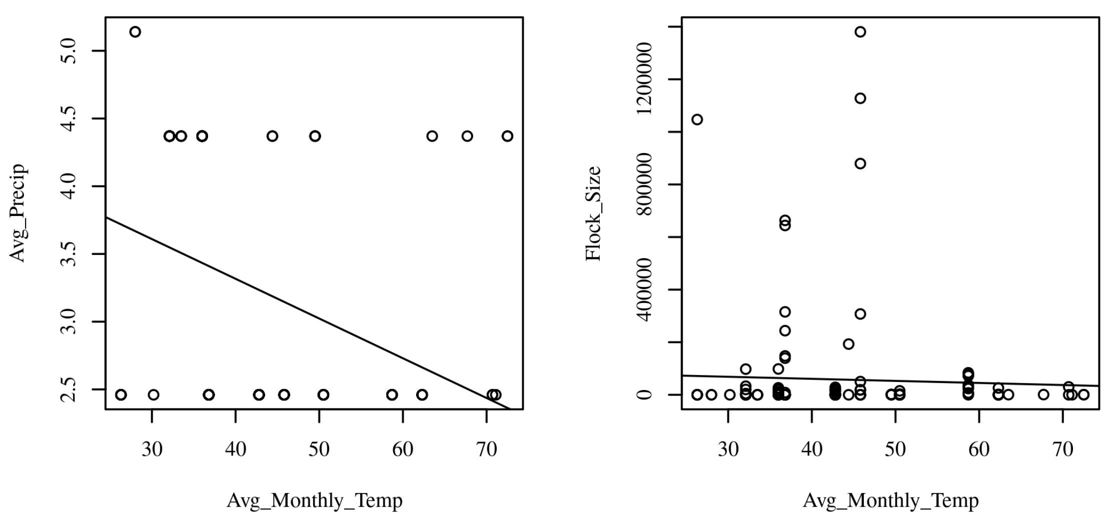
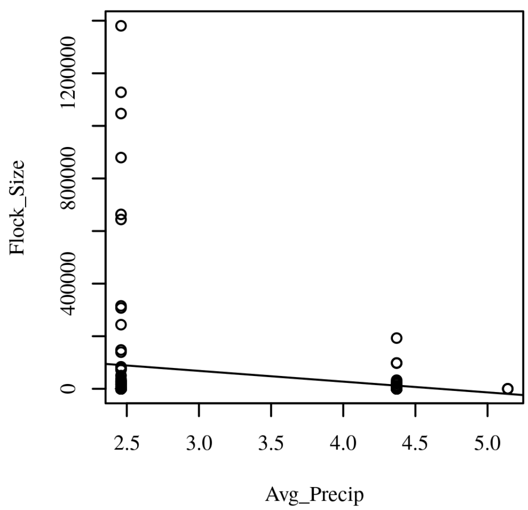


Figure 5

Scatterplots with the Regression Line added for Avg_Precip and Flock_Size



A significant negative correlation was observed between the average monthly temperatures and average precipitation, with a correlation of -.34, indicating a moderate effect size, or correlation (*p* < .001, 95% CI = [-.48, -.19]). This suggests that as average monthly temperatures increase, average precipitation tends to decrease in the northeast United States. A significant negative correlation was observed between average precipitation and avian influenza incidence, with a correlation of -.19 (*p* = .047, 95% CI = [-.35, -.03]). This suggests that as average precipitation increases, the number of affected flocks tends to decrease. A 2008 article written by Fang and colleagues found the same phenomenon (Fang et al., 2008). Because the p-values are less than the correlation coefficients in both instances, this study rejects the null hypothesis.

No other significant correlations were found. Table 4 and Table 5 present the results of the correlations. It is of importance to note, that although a statistically significant negative correlation was found between average precipitation and affected flocks, and average temperatures and average precipitation, it is essential to recognize that correlation does not imply causation. Other factors can influence a decrease in avian influenza rates among domestic bird flocks, such as environmental conditions, bird behavior, contact with wild bird species, and the disease transmission dynamics of certain viral clades (Fang et al., 2008; Gass et al., 2023; Hill et al., 2022). Further research and analysis are necessary to determine the causal mechanisms underlying these correlations.

Table 4

Pearson's Correlation Matrix Among Avg_Monthly_Temp, Avg_Precip, and Flock_Size

Variable	1	2	3
1. Avg_Monthly_Temp	-		
2. Avg_Precip	-.34*	-	
3. Flock_Size	-.04	-.19*	-

Note. *p

Table 5

Pearson's Correlation Results Among Avg_Monthly_Temp, Avg_Precip, and Flock_Size

Combination	*r*	95.00% CI	*n*	*p*
Avg_Monthly_Temp-Avg_Precip	-.34*	[-.48, -.19]	140	< .001
Avg_Monthly_Temp-Flock_Size	-.04	[-.21, .12]	140	.615
Avg_Precip-Flock_Size	-.19*	[-.35, -.03]	140	.047

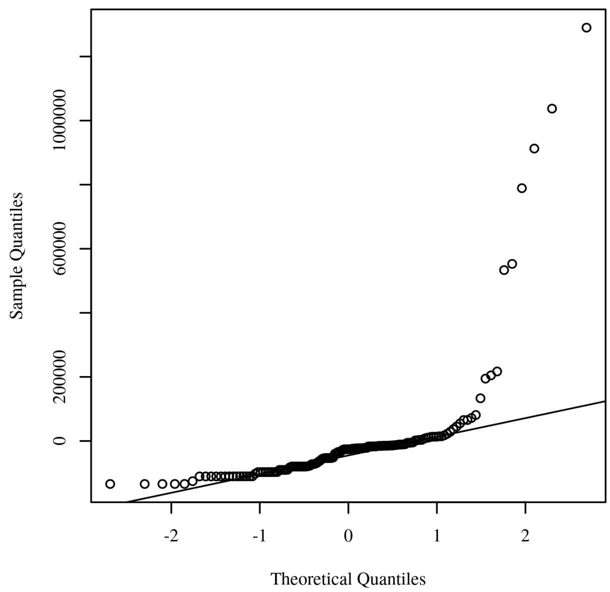
Note. *p*-values adjusted using the Holm correction.

Linear Regression Analysis. In addition to a Pearson's correlation coefficient analysis, a linear regression analysis was undertaken to assess the relationship between the three variables of average monthly temperatures, average precipitation, and the flock sizes of domestic poultry that were affected by Avian influenza during the years 2022 and 2023. A linear regression analysis tests the strength and direction of the linear association between the three variables mentioned above. The aim of this analysis is to understand how changes on one variable are associated with changes in another variable, allowing for inferences to be made about the relationship (Field, 2018).

Assumptions. By plotting the quantiles of the model residuals against those of the Chi-square distribution (also called a Q-Q scatterplot), the assumption of normality was assessed (DeCarlo, 1997). Figure 6 presents the Q-Q scatterplot for the regression model. The normally distributed data appears as a straight line in the Q-Q scatterplot.

Figure 6

Q-Q Scatterplot for Normality of the Residuals for the Regression Model



The results of the linear regression model were significant, $F(2,137) = 3.60$, $p = .030$, $R^2 = .05$, indicating that approximately 5% of the variance of avian influenza in the data analyzed (*Flock_Size*) is explainable by changes in average temperatures and average precipitation (*Avg_Monthly_Temp* and *Avg_Precip*). Average monthly temperatures did not significantly predict incidence of avian influenza, $B = -2{,}249.16$, $t(137) = -1.39$, $p = .168$. Based on this sample, a one-unit increase in average monthly temperature does not have a significant effect on avian influenza incidence. Average precipitation, however, significantly predicted avian influenza incidence, $B = -49{,}890.30$, $t(137) = -2.63$, $p = .009$. This indicates that on average, a one-unit increase of precipitation will decrease the value of avian influenza by 49,890.30 units (Field, 2018; Intellectus, 2024; Fang, 2008). Table 6 summarizes the results of the regression model.

Table 6

Results for Linear Regression with Avg_Monthly_Temp and Avg_Precip Predicting Flock_Size

Variable	*B*	*SE*	95.00% CI	β	*t*	*p*
(Intercept)	316,121.77	108,491.68	[101,586.94, 530,656.61]	0.00	2.91	.004
Avg_Monthly_Temp	-2,249.16	1,622.76	[-5,458.05, 959.74]	- 0.12	- 1.39	.168
Avg_Precip	-49,890.30	18,937.85	[-87,338.59, - 12,442.00]	- 0.23	- 2.63	.009

Note. Results: $F(2,137) = 3.60$, $p = .030$, $R^2 = .05$

Unstandardized Regression Equation: Flock_Size = 316,121.77 - 2,249.16*Avg_Monthly_Temp - 49,890.30*Avg_Precip

Research Question 3

Building on the previous research questions, the third research question examines the extent to which climate change has influenced the seasonality and distribution of influenza outbreaks in the northeast United States. The question reads as follows:

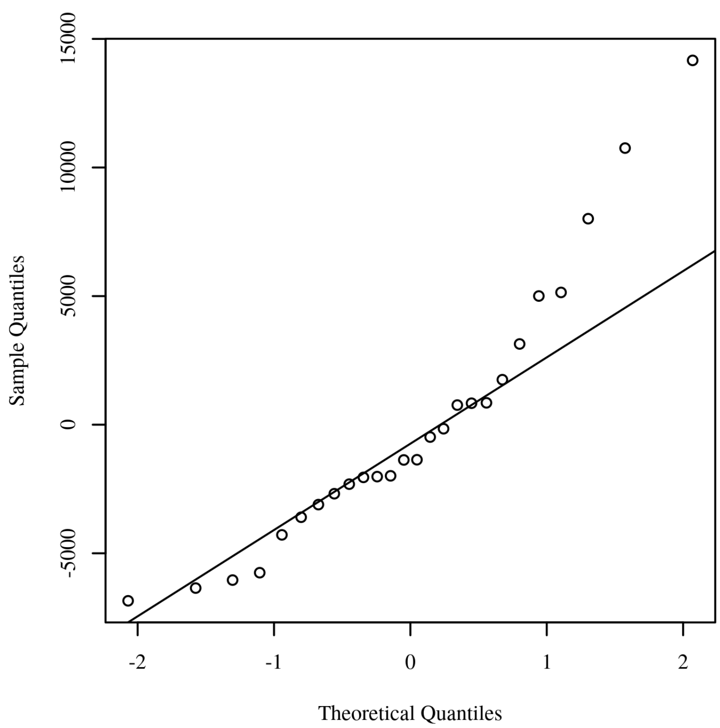
RQ3. *To what extent do changing climate patterns in the northeast United States influence the seasonality and geographic distribution of influenza outbreaks in this region?*

To measure this research question, a linear regression analysis was conducted to model the relationship between the climate variables of average temperatures and precipitation as independent variables and influenza or ILI case-counts as dependent variables, for the time frame of 2003 to 2023. This type of statistical analysis helps to quantify the extent to which changes in climate patterns predict variations in the seasonality and geographic distribution of influenza activity in this region.

Assumptions. As with the previous research questions, the assumption of normality for this research question was assessed. A Q-Q scatterplot was generated to assess normality. Figure 7 depicts the Q-Q scatterplot of the model residuals.

Figure 7

Q-Q Scatterplot for Normality of the Residuals for the Regression Model



Results. The results of the linear regression model were not significant, $F(2,23) = 1.21$, $p = .317$, $R^2 = .10$, indicating average temperatures and precipitation did not account for a significant proportion of variation in the total reported cases of influenza in the northeast United States. Because the overall model was not significant, the individual predictors were not further analyzed. Since the p-value is greater than the test statistic, this study fails to reject the null hypothesis. Table 7 summarizes the results of the regression model.

Table 7

Results for Linear Regression with Average_Temp_Feb_to_Jan and Precipitation_in_Inches Predicting Total

Variable	*B*	*SE*	95.00% CI	β	*t*	*p*
(Intercept)	67,176.64	47,900.14	[-31,912.36, 166,265.64]	0.00	1.40	.174
Average_Temp_Feb_to_Jan	-1,368.72	957.01	[-3,348.44, 611.00]	-0.29	-1.43	.166
Precipitation_in_inches	91.05	221.20	[-366.55, 548.65]	0.08	0.41	.684

Note. Results: $F(2,23) = 1.21$, $p = .317$, $R^2 = .10$

Unstandardized Regression Equation: Total = 67,176.64 - 1,368.72*Average_Temp_Feb_to_Jan + 91.05*Precipitation_in_Inches

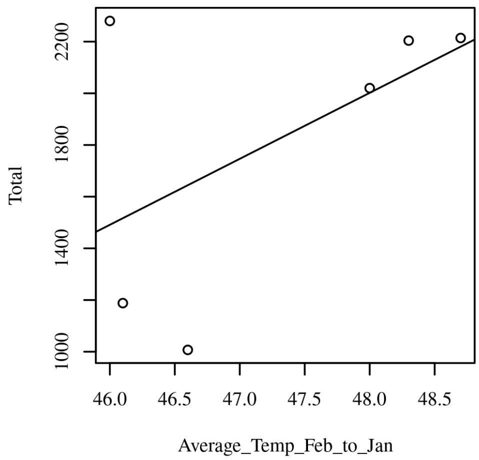
Test-Retest Reliability Analysis

In addition to analyzing the data generated from the Pearson's correlation coefficient and time series analyses on climate and influenza data, a test-retest reliability analysis was undertaken. Conducting a test-retest reliability analysis is important to ascertain the validity of the findings (Field, 2018). By analyzing a small sample size of climate and influenza data for the five years prior to the 20-year sample originally analyzed, the consistency of the temporal measurements can be assessed (Field, 2018; Lange & Dewitte, 2021). Furthermore, this analysis helps to inform whether the observed correlation persists across multiple points in time or if there is fluctuation in the data. This analysis helps to mitigate the impact of random variations in measurement errors and provides greater confidence in the reliability of the correlation findings. Moreover, by evaluating the five-year time frame using the test-retest reliability method, any systematic biases or confounding factors that may affect the observed correlation between climate change and influenza activity can be identified and addressed (Lange & Dewitte, 2021). Overall, integrating a test-retest reliability analysis strengthens the credibility of the correlation analysis and enhances the scientific rigor of the study, enabling more accurate interpretations and better-informed decision-making regarding public health interventions and climate change mitigation strategies in the northeastern United States (Lange & Dewitte, 2021).

A Pearson's correlation analysis was conducted between the average temperatures (labeled *Average_Temp_Feb_to_Jan*) found in the northeast United States and reported influenza cases (labeled *Total*) between the years 1998 and 2002. Cohen's standard was used to evaluate the relationship, as was used in the research questions' analyses (Cohen, 1988). Figure 8 presents the correlation's scatterplot.

Figure 8

Scatterplots with the Regression Line added for Average_Temp_Feb_to_Jan and Total



The result of the correlation was examined based on an alpha value of .05. The correlation in the pair of variables analyzed found a high degree of significance, with a Pearson's correlation coefficient of .534 ($r = .534$, 95% CI [-.49, .94], $n = 6$) (Field, 2018; Intellectus, 2024). Table 8 and Table 9 present the results of the correlation.

Table 8

Pearson's Correlation Matrix Between Average_Temp_Feb_to_Jan and Total

Variable	1	2
1. Average_Temp_Feb_to_Jan	-	
2. Total	.534*	-

Note. $^{*}p$

Table 9

Pearson's Correlation Results between Average_Temp_Feb_to_Jan and Total

Combination	*r*	95.00% CI	*n*	*p*
Average_Temp_Feb_to_Jan-Total	.534*	[-.49, .94]	6	.275

Therefore, in the five years preceding the study period, there is a correlation between changing climate patterns and an increase in influenza activity in the northeast United States. When looking at the two scores of data (r = .534 for the small sample and r = .327 for the test sample), and at their levels of significance (.275 for the small sample and .160 for the large sample), there was a significant correlation of 1. This is indicative of the two samples being highly correlated, and that the tests undertaken are highly reliable (Field, 2018). Table 10 and Table 11 show the Pearson's correlation coefficient table between the small and large datasets. Table 12 indicates the descriptive statistics between the small and large datasets.

Table 10

Pearson's Correlation Results between Small Sample and Test Sample

Correlations

		Pearson's R	Sig
Pearson's R	Pearson Correlation	1	1.000**
	Sig. (2-tailed)		.
	N	2	2
Sig	Pearson Correlation	1.000**	1
	Sig. (2-tailed)	.	
	N	2	2

**. Correlation is significant at the 0.01 level (2-tailed).

Table 11

Pearson's Correlation Results between Small Sample and Test Sample with Sum of Squares and Covariance Included

Correlations

		Pearson's R	Sig
Pearson's R	Pearson Correlation	1	1.000**
	Sig. (2-tailed)		.
	Sum of Squares and Cross-products	.021	.012
	Covariance	.021	.012
	N	2	2
Sig	Pearson Correlation	1.000**	1
	Sig. (2-tailed)	.	
	Sum of Squares and Cross-products	.012	.007
	Covariance	.012	.007
	N	2	2

**. Correlation is significant at the 0.01 level (2-tailed).

Table 12

Descriptive Statistics of the Pearson's Correlation Results between Small Sample and Test Sample

Descriptive Statistics

	Mean	Std. Deviation	N
Pearson's R	.43050	.146371	2
Sig	.21750	.081317	2

Predictive Model

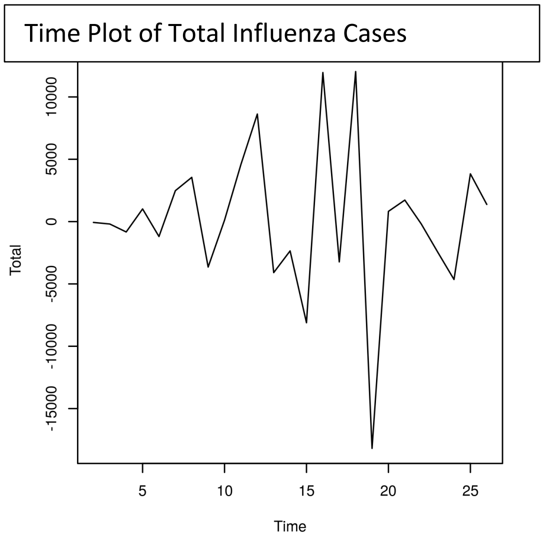
As the results of the Pearson's correlations and time series analyses have been discussed for all research questions involved, the attention of the preceding paragraphs will now turn to the predictive model. An ARIMA time series analysis was conducted to forecast future values over time for the total number of reported influenza cases based on annual average temperatures and precipitation. An autoregressive integrated moving average, or ARIMA, is a model used in statistics and economics to measure events that may occur over a period of time (Cohen, 1988; Field, 2018; Intellectus, 2024). In this project, the model is used to understand past data and predict future outcomes of influenza, given the warming temperatures and increased precipitation found in the northeast United States over the past several decades (Marlon et al., 2017; NOAA, 2024).

Assumptions

Outliers were assumed and determined by using a LOESS curve, which fits a line to the scale variable over time. The residuals of the LOESS curve were then examined using upper and lower bounds to determine the outliers. There were no data points outside the upper and lower bounds of the residuals, indicating no outliers were present in the data. Additionally, the assumption of stationarity was assessed by creating a time plot for the scale variable, influenza incidence (labeled *Total* in the graph), after differencing (Hyndman & Athanasopoulos, 2018; Intellectus, 2024). In statistics, stationarity in a time series analysis means that the statistical properties of generating a time series do not change over time (Field, 2018; Hyndman & Athanasopoulos, 2018; Intellectus, 2024). For the assumption of stationarity to be met, there should not be any trends, such as increasing or decreasing in the time plot, or seasonality, such as changes that occur at set intervals (Hyndman & Athanasopoulos, 2018; Intellectus, 2024). Strong trends or seasonality can cause the results of the ARIMA model to be unreliable. Figure 9 presents the time plot for predicted cases of influenza, given the changes currently seen in climate between the years 2003-2023 (Intellectus, 2024).

Figure 9

Time Plot of Total Influenza Cases to Assess Stationarity (25-Year Predictive Model)



Additionally, a 120-year predictive model was run using SPSS software (SPSS, 2023). In this model, the expected number of influenza cases are shown to rise with time, if the climate in the northeast United States continues at its current rate of change. Model covariates were added to estimate the effects of each variable on the time series. In this model, average temperatures significantly predicted influenza incidence after differencing, $B = -2,301.82$, $t(24) = -4.04$, $p < .001$, indicating that on average, a one-unit increase in average temperatures will increase the value of reported cases (*Number*), after differencing (Intellectus, 2024). Table 13 shows the descriptive statistics in the SPSS model. Figure 10 depicts the 120-year predictive model generated by SPSS software (SPSS, 2023).

Table 13

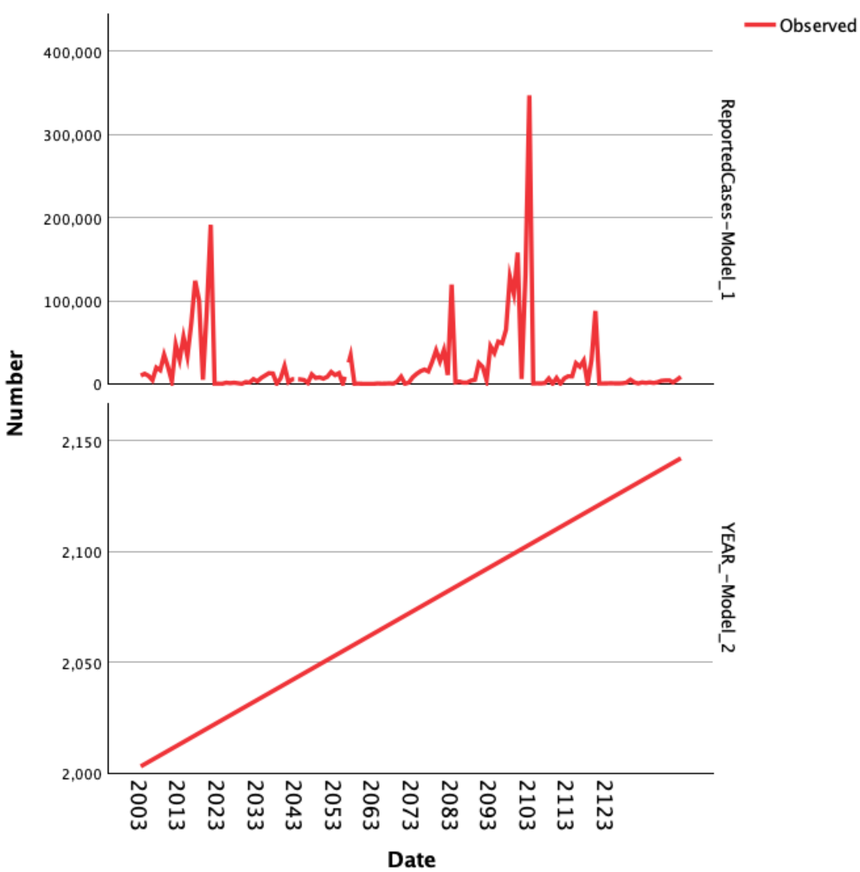
Model Statistics

Model Statistics

Model	Number of Predictors	Model Fit statistics	Ljung-Box Q(18)			Number of Outliers
		Stationary R-squared	Statistics	DF	Sig.	
Reported Cases-Model_1	0	.279	9.601	14	.791	<.001
YEAR, not periodic-Model_2	0	.	.	0	.	<.001

Figure 10

120-Year Predictive Model



Chapter Summary

In summary, this chapter discusses the findings regarding the relationship between climate change and influenza activity in the northeast United States between the years 2003-2023. Each research question was presented, and the results of the statistical tests undertaken were discussed. While there was not a large effect size in the first research question, which looks at the correlation between climate change and influenza activity in the region during the specified time frame, there was a moderate effect size, which shows some correlation between the two variables. Similarly, there was a statistically significant negative impact in the second research question, which delved into the relationship between avian influenza and changing climate patterns in the region, showing that the higher the precipitation rates, the lower the incidence of avian influenza. Fang and colleagues (2008) also found a similar correlation in their 2008 article. Lastly, the third research question explored the extent to which changing climate patterns in the northeast United States influenced the seasonality and geographic distribution of influenza outbreaks in this region. The statistical tests run for this question showed no statistical significance.

Finally, a predictive model was built forecasting what future influenza trends may look like, based on current climate trends and reported influenza activity. The development of this model may be useful for public health planning and policymaking, enabling proactive measures to be decided upon in order to mitigate future influenza outbreaks, particularly those that may evolve into influenza pandemics. This predictive model would be useful as it provides valuable insights into future influenza trends given current climatic shifts, aiding healthcare systems in preparing for potential increases in influenza cases and informing public health interventions to better analyze the impact climate change has on influenza disease transmission.

CHAPTER FIVE: CONCLUSIONS

Overview

This final chapter will synthesize the findings of this research, shedding light on the relationship between climate change and influenza activity in the northeast United States. The preceding paragraphs will discuss the context with which the conclusions were drawn, the implications for future public health policy regarding climate change and infectious diseases, and recommendations for future research. The discussion on drawn conclusions is broken down by research questions, followed by recommendations for educational initiatives. Additionally, the limitations and implications of this study are discussed, as are recommendations for future research and public health, health science, and ecological policy.

Discussion

The purpose of this study is to investigate the potential impact, if any, on changing climate patterns and influenza activity across the northeast United States. The aim is to provide a more comprehensive understanding of how climate change influences influenza activity, thereby helping to shape public health policy and create greater resilience against climate change and infectious diseases, to include influenza, across the region. This research highlights the crucial need for adaptive public health, ecological, biological, and health science strategies which address the challenges posed by climate change and influenza activity across the northeast United States (Fang et al., 2008; Gass et al., 2023; Lam et al., 2020; Youk, et al., 2023). The need for future research will be explored, emphasizing the importance of undertaking further study on this topic. In so doing, the quality of life for residents in the area can be enhanced, and a future influenza pandemic can hopefully be either prevented or reduced in severity.

Research Question 1

This question examines whether a relationship exists between climate change and increased influenza activity across the northeast United States. It reads as follows:

Is there evidence of a correlation between climate change and an increase in influenza activity in the northeast United States?

This study found a moderate correlation between climate change and influenza activity across the northeast United States between the years 2003-2023. The data analyzed was generated from the NOAA's Climate at a Glance website, as well as from the public health departments across the region. As seen from the literature search, Lam et al. (2020) found that influenza antigenic shifts were not predicted by the climate variables of temperature and humidity. These authors did find that the two-week timeframes preceding state-level influenza epidemics across the United States demonstrated low temperatures or absolute humidities than in the weeks preceding the outbreaks (Lam et al., 2020). Additionally, Chen and colleagues (2024), found that the correlation between influenza activity temperature was marked by a sudden increase in cases, when the temperature dropped below 13 degrees Celsius. Zheng and coworkers (2021) discovered a slight increase in influenza activity with increase in relative humidity and decreasing temperatures. Additionally, these researchers also found a positive correlation between an increase in influenza activity and an increase in air pollution, particularly with increases in nitrogen dioxide levels (Zheng et al., 2021). Finally, Lane et al. (2022) found increasing evidence that climate change affects the incidence of influenza activity. According to these researchers, 93 published articles were found that showed an association with influenza activity and climatological factors (Lane et al., 2022). Therefore, from examination of the literature and this dissertation's findings of a moderate correlation between climate patterns and influenza activity in the northeast United States, such associations need to be further examined to determine if influenza incidence is indeed related to an increase in precipitation, humidity, and average temperatures.

Research Question 2

The second research question of this dissertation examines whether shifting migration patterns of avian species influence the transmission of avian influenza. It reads as follows:

> *What roles do shifting migration patterns of avian species play in the transmission of avian influenza viruses from their natural reservoirs to human hosts in a changing climate?*

In the context of a changing climate, the results of this investigation reveal a significant negative correlation between precipitation levels and avian influenza transmission. Conversely, the study found no significant association between temperature fluctuations and avian influenza spread, indicating that temperature shifts alone do not directly influence avian influenza transmission dynamics (Lam et al., 2020; Lee et al., 2021; Youk et al., 2023). However, previous research studies have found that the highly pathogenic form of avian influenza stems from wild bird migration, which is facilitated through changing climate patterns (Gass et al., 2023; Fang et al., 2008; Hill et al., 2022). Alterations in temperature, precipitation, and seasonal cycles affect the availability of food and habitats, prompting wild birds to adjust their migration timing, routes, and destinations (Gass et al., 2023; Hill et al., 2022). Such changes can lead to shifts in migratory schedules, extended migratory ranges, and new stopover sites, which may impact avian influenza transmission rates (Gass et al., 2023; Hill et al., 2022; Fang et al., 2008). Additional studies are recommended to determine whether climate-induced shifting migration patterns of wild birds do indeed contribute to an increase in the transmission of avian influenza from its avian reservoir to human hosts.

Between 2003 through 2008, highly pathogenic avian influenza outbreaks led to the deaths of millions of domestic poultry, over 10-thousand wild birds, and over 370 laboratory-confirmed infections in humans, with over 230 human fatalities (Fang et al., 2008). The 2009 influenza pandemic stemmed from a highly pathogenic avian influenza strain which reassorted with a swine influenza strain and then eventually crossed the species barrier to infect humans on a global scale (Blagodatski et al., 2021; Harrington et al. 2021). Close human and bird interaction carries with it a risk for cross-species transmission of highly pathogenic avian influenza viruses (Fang et al., 2008; Blagodatski et al., 2021; Harrington et al., 2021). Therefore, in times of rapid shifting climate patterns, with varying bird migratory routes, scientists must be cautious as these shifts can lead to new interactions between migratory birds, domestic poultry, other mammals, and humans (Gass et al., 2023; Fang et al., 2008; Hill et al., 2022). Such interactions can lead to new viral reassortments that may have pandemic potential (Harrington et al., 2021). As birds alter their migration routes and migratory timing in response to climate change, they may transmit avian influenza to other regions, increasing the risk of outbreaks or viral reassortment among different species, which may carry pandemic potential (Gass et al., 2023; Fang et al., 2008). Further research on the role of shifting migration patterns of avian species in the human transmission of avian influenza, especially in the context of climate change, is essential to enhance our understanding of this issue.

Research Question 3

This question examines the extent that changing climate patterns in the northeast United States influences the distribution of influenza across the region. It is reads as follows:

To what extent do changing climate patterns in the northeast United States influence the seasonality and geographic distribution of influenza outbreaks in this region?

The investigation undertaken for the research question above explores the correlations between shifting temperature and precipitation trends and the timing and distribution of influenza activity across the region. The aim is to uncover how variation in climate affects influenza activity across the Northeast. Although this study found no statistically significant correlation between changing climate patterns in the northeast United States and the seasonality and geographic distribution of influenza activity across the region, the climate impacts on human health warrant further investigation (Lane et al., 2022). More research is needed to better understand the potential direct and indirect effects and trends that may emerge involving climate change and influenza activity (Lane et al., 2022; Zhang et al., 2021; Zheng et al., 2021).

Serman et al. (2021) found, that across the northeast region of the United States, there was a slight increase of influenza activity at higher humidity versus lower humidity. These researchers also found that the Northeast (as defined by NOAA standards) had a lower increase in influenza cases than the rest of the country at lower humidity values (Serman et al., 2021). The climatological factors most studied in relation to influenza activity are temperature, precipitation and humidity (Lane et al., 2022). This dissertation focuses on the factors of temperature and precipitation and found no correlation between those climate factors and the seasonality and distribution of influenza activity in the study region. In addition, Marlon et al. (2017) found that, since the 1950s, the temperature in the Northeast increased by about 1.1^{o}C, and precipitation increased by approximately 12 cm over the past century. Furthermore, Liu and colleagues (2020) concluded that an increase in influenza activity can be attributed to strong and rapid variations in weather patterns. Moreover, recent climate model predictions indicate that significant quick weather fluctuations in the fall months can lead to increased influenza activity in the months following, especially in densely populated northern mid-latitudes (Liu et al., 2020). Therefore, while this dissertation found no statistically significant evidence of climate factors impacting the seasonality and distribution of influenza across the Northeast, some studies have identified such impacts, highlighting the need for further research in this area (Lane et al., 2022; Liu et al., 2020; Serman et al., 2021).

Educational Initiatives

As previously established, the health and sustainability of environments, animals, and human beings are all interconnected (Zhang et al., 2022; Zinsstag et al., 2018; Spodie et al., 2021). The relationships between climate change, ecosystem sustainability, disease emergence, and human health are well documented, and it is imperative for interdisciplinary teams of professionals in ecology, biology, the health sciences, the animal sciences, and public policy to converge and bring about a holistic understanding of how all of the above systems interconnect and impact human health, particularly in terms of the influenza viruses (Lane et al., 2022; Spodie et al., 2021). Such initiatives, such as continuing education opportunities, conferences, or symposia, may lead to more effective and informed decision making on how to best mitigate the impact that a severe influenza season may have on a particular region (Gordon & Reingold, 2018; Niera et al., 2023).

Spodie and colleagues (2021) coined the term “ecosystem health” to describe the conviction that health is enhanced if individuals positively change the ways in which they interact with their environments. Therefore, to effect positive change across ecosystems, animal health, and human health, an interdisciplinary approach must be undertaken. Such approaches include professional training programs or continuing education programs aimed at embracing and implementing such principles as interdisciplinary research, ecologic sustainability, and promotion of optimal health and vaccine uptake (Spodie et al., 2021; Baylor & Goodman, 2022). According to Spodie et al. (2021), there is a shortage of professionals trained in the ecosystem health sciences. Thus, implementing training opportunities such as conferences, symposia, webinars, and continuing professional education activities can lead to ecologists, biologists, animal scientists, health scientists, and public health professionals gaining additional expertise in agriculture, renewable natural resources, and environmental sciences, and may help to fill in the gaps that are needed to help advise policy makers on the ways in which all aspects of ecological, biological, and animal sciences interact and affect human health. In so doing, these experts may find ways to improve influenza surveillance programs, enhance environmental health, and hopefully, mitigate the severity of future influenza outbreaks.

Educating multidisciplinary groups of professionals whose aims are to enhance environmental, animal, and human health can promote their respective fields of study while simultaneously benefitting societies in terms of improving health, enhancing public health strategies, and increasing preventative measures to help safeguard environmental and human health (Spodie et al., 2021). Knowledge of the relationships in various interdisciplinary fields may aid in designing public health strategies that address root causes of health issues, instead of merely treating symptoms (Spodie et al., 2021; Zhang et al., 2022; Zinsstag et al., 2018). In addition, educating health professionals about the connections found among environmental, biological, animal, and human health promotes preventive measures, and may help in potentially reducing the incidence and severity of climate-related health issues, for example, influenza outbreaks, epidemics, or a novel pandemic event (Spodie et al., 2021; Zhang et al., 2022; Zinsstag et al., 2018).

Educational initiatives in cross-disciplinary fields focusing on environmental and human health may also aid in creating climate and disease adaptation and resilience. Professionals equipped with the knowledge of the One Health approach, for example, can better prepare for and respond to health challenges posed by climate change, thereby improving community or regional resilience (Spodie et al., 2021; Zhang et al., 2022; Zinsstag et al., 2018). Increased policy advocacy can also be a positive consequence of educational initiative implementation. Informed health professionals can advocate for policies that mitigate climate change, and improve influenza disease surveillance and their impacts on health, influencing legislative and regulatory actions that help promote human, animal, and environmental health (Niera et al., 2023; Rahman et al., 2021; Spodie et al., 2021).

Indeed, creating educational initiatives that communicate the relationship between climate change, public health, the health sciences, ecology, animal science, biology, and human health is crucial for health science professionals' understanding of the important role the environment plays in the safeguarding of human health (Spodie et al., 2021; Zhang et al., 2022; Zinsstag et al., 2018). Such initiatives equip professionals with a holistic understanding of how environmental changes impact public health. By highlighting the interconnectedness between these multidisciplinary fields, educational initiatives can foster a more comprehensive approach to health surveillance that considers environmental determinants of health (Spodie et al., 2021). Gaining this knowledge is essential for developing effective strategies that mitigate and help humans and environments adapt to climate-related health challenges (Spodie et al., 2021; Zhang et al., 2022; Zinsstag et al., 2018). Moreover, well-informed health professionals are better able to advocate for policies that protect both human and ecological health, leading to more sustainable health outcomes and promote climate-resilient communities (Spodie et al., 2021; Zhang et al., 2022; Zinsstag et al., 2018).

Implications

This study explores the correlation between climate change and influenza activity in the northeast United States and highlights the need for an interdisciplinary approach in further studies of this topic across the health sciences. By discussing the findings herein, and sharing the correlations found regarding the interactions between climate variables and influenza activity, this research contributes to the existing body of knowledge, emphasizing the importance of integrating environmental data into public health strategies and health science research (Watts et al., 2018). A greater understanding of this topic can guide the development of more effective influenza surveillance and intervention programs, ultimately improving public health outcomes and resilience in an era of rapidly changing climate patterns (Rahman et al., 2021).

Rahman et al. (2021) espouse the idea that in spite of the connections found between climate shifts and infectious diseases, there is a gap in merging the climate-based surveillance systems and public health policy practices, informed by the health sciences, to better prevent the disease burden that influenza places on populations in times of changing climate. Indeed, while this study found a moderate correlation between shifting climate patterns and influenza activities, this presents an opportunity for further research on the topic, to help strengthen influenza surveillance programs across the region, and to put stronger environmental and public health policies in place that will help build better climate resilience (Niera et al., 2023; Rahman et al., 2021). Consequently, efforts which focus on climate monitoring and influenza control may help with early detection of outbreaks, improved public health preparedness, and the development of targeted intervention strategies to mitigate influenza's impact in the context of a changing climate.

These are times where the climate landscape is changing (Marlon et al., 2017). With changes in global and regional climate patterns, more opportunities for greater variation in influenza activity arises. Furthermore, changing migration patterns of marine birds and other waterfowl have been found, which further increase the risk of avian influenza crossing the zoonotic barrier and eventually infecting human beings, creating a potential pandemic scenario (Gass et al., 2023; Guo et al., 2021). Educating health science and environmental health professionals on the connections between the changing climate landscapes and the potential for a more virulent strain of seasonal or avian influenza emerging may help promote preventive measures and may reduce the incidence of climate-related influenza outbreaks, epidemics, or even a pandemic event (Gass et al., 2023; Guo et al., 2021; Lane et al., 2022; Spodie et al., 2021).

Limitations

The greatest limitation of this study is the barrier of gathering influenza data, primarily because influenza is not a reportable disease in all States, and secondly, because many influenza cases go unreported (Gordon & Reingold, 2018; Heymann, 2022; Lo et al., 2017; Tokars et al., 2018). Tokars and coworkers (2018) state that seasonal influenza is so widespread that scientists can only estimate its incidence. Given that only a percentage of influenza cases are reported each season, gathering influenza case counts from public health departments comes with the limitation of potentially underestimating the true incidence of the disease (Gordon & Reingold, 2018; Heymann, 2022; Lo et al., 2017; Tokars et al., 2018).

The percentage of reported influenza incidence presents a limitation in this study as it can lead to an incomplete dataset, affecting the accuracy and reliability of the study's findings. With only a percentage of actual cases being recorded, the true magnitude of influenza activity may be underestimated, obscuring the true relationship between climate change and influenza disease patterns (Lo et al., 2017; Tokars et al., 2018). To mitigate these impacts, the research should account for underreporting by using statistical methods to estimate the true incidence of influenza activity (Tokars et al., 2018). Additionally, other sources, such as hospital records, laboratory confirmed data, syndromic surveillance, and sentinel surveillance methods should be used to supplement reported influenza case counts (Tokars et al., 2018). Acknowledging this limitation is important for results interpretation and emphasizes the need for improved influenza surveillance and reporting systems in future research (Gordon & Reingold, 2018; Lo et al., 2017; Tokars et al., 2018).

Threats to Validity

Some threats to internal validity in a study such as this include selection bias, confounding variables, and measurement errors (Libarkin et al., 2018; Suruku & Maslakci, 2020). Selection, or sample, bias occurs if the study sample is not representative of the broader population (Suruku & Maslakci, 2020). This type of bias can occur if the sample group is dissimilar to the predominant population in its features or if the sample is low and does not sufficiently represent the population, both of which may lead to skewed results (Suruku & Maslakci, 2020). This study is generalizable across the northeast United States; however, due to population dynamics and socioeconomic levels found across this region, the results may not be generalizable to other regions of the United States.

Confounding variables (such as access to healthcare and vaccination rates) may influence the observed relationship between climate change and influenza activity, creating difficulty in insolating the true impact of either the climate variables or influenza variables alone. Therefore, test validation should be undertaken to support the interpretation of the results and minimize confounding variability in the tests (Libarkin et al., 2018). Measurement errors can occur if there are inaccuracies in climate data collection or if influenza case reporting is inconsistent or incomplete (Libarkin et al., 2018; Suruku & Maslakci, 2020). In this study, a measurement error may arise from inconsistent influenza case reporting among both individual cases, and state public health departments.

Indeed, threats to internal validity exist in all studies, and must be mitigated to ensure a solid cause and effect relationship which is free from the influence of confounding variables and biases (Libarkin et al., 2018; Suruku & Maslakci, 2020). High internal validity means that the results of the study are well conducted, and it is accurate in its results (Libarkin et al., 2018).

Some threats to external validity in this study include issues related to generalizability to the population. This is compromised if the study sample does not accurately represent the population (Suruku & Maslakci, 2020). The barrier of gathering the most accurate influenza data in this study represents a threat to external validity. However, the research included data from the entire region, sent to the primary investigator from state public health departments or taken directly from the state public health department websites; therefore, the threat to external validity was minimized.

Recommendations for Future Research

To advance the understanding of the correlation between climate change and influenza activity across the northeast United States, several recommendations for research are proposed. The following lists the recommendations, in detail, below:

1. Development and testing of novel instrumentation and methodologies to gather empirical evidence on exposure-response functions involving changing climate patterns and influenza outcomes (Niera et al., 2023).
2. Exploration of theoretical constructs, such as the One Health framework, to help assess the effects of climate change on ecological determinants of health, and the interactions between environmental, animal, and human health factors (Niera et al., 2023; Zhang et al., 2022; Zinsstag et al., 2018).
3. Expanding longitudinal studies and incorporating climate models and influenza models to help clarify causal relationships and evaluating the interactions between climate adaptation and influenza mitigation strategies (Niera et al., 2023; Zhang et al., 2022; Zinsstag et al., 2018).
4. Assessing effects of long-term exposure to changing climate patterns in the context of both avian and seasonal influenza activity; this would require interdisciplinary efforts between climatologists, epidemiologists, veterinary scientists, ecologists, biologists, and health scientists to encourage and foster a holistic understanding of the impacts that climate change has on influenza dynamics in the region (Niera et al. 2023; Gass et al., 2022; Zhang et al., 2022; Zinsstag et al., 2018).

In addition to the recommendations listed above, studies should include diverse populations across several different socioeconomic age, and ethnic groups to ensure comprehensive data and insights on climate change and influenza prevention (Niera et al., 2023; Rahman et al., 2021). Such data could be utilized produce better predictive models of climate change and influenza activity (Niera et al., 2023). The effects of environmental variables on influenza transmission (to include avian or other mammalian vectors' migration patterns) and viral genetic variability and the effects of climate change on the distribution of the virus and its reservoirs must also be evaluated (Niera et al., 2023). For such strategies to be most effective, policies aimed at reducing environmental diseases and comprehensive climate-based disease surveillance strategies should be initiated (Niera et al., 2023; Rahman et al., 2021).

Some policy suggestions to help mitigate the impact that climate change has on the influenza virus include the following:

1. Integrate policy frameworks. Develop policies that address both climate adaptation and infectious disease mitigation strategies to ensure each issue is addressed in strategic plans and policies and regulations (Niera et al., 2023; Rahman et al., 2021).
2. Move toward large reductions in greenhouse gas emissions. Provide financial incentives for initiatives that include promoting green infrastructure and renewable energy with climate-resilient features. This is imperative to protecting human health from future climate change (Niera et al., 2023; Zinsstag et al., 2018).
3. Promote the One Health framework and cross-sector collaboration. Including various areas such as agricultural, ecologic, and the health sciences can create unified strategies aimed at addressing climate change mitigation and may help reduce the impact that infectious diseases, such as influenza, have on populations (Niera et al.,

2023; Rahman et al., 2021). Encouraging the One Health approach into policy can help promote studies that include investigation of the interconnectedness of environmental, animal, and human health (Niera et al., 2023; Zhang et al., 2021; Zinsstag et al., 2018).

In addition to the policy recommendations above, a recommendation for a multidisciplinary approach to educational initiatives on climate change and its link to influenza activity is advised. Universities can incorporate courses into their environmental health, biological sciences, health sciences, and public health curricula to further educate aspiring professionals in the field (Spodie et al., 2021). Moreover, certifying agencies which provide professional certifications can encourage their members to attend conferences, symposia, webinars for credit, or take continuing education courses on climate change and its impacts on influenza and other climate-sensitive pathogens. According to Spodie and coworkers (2021), academia must address emerging educational demands and workforce needs, necessitating improved cross-disciplinary skills, and fostering enhanced reliance on effective, diverse, and multi-disciplinary teams. In doing so, collaborations across different fields can be fostered, which may lead to innovative solutions that address complex issues such as climate change and its impact on influenza activity in the northeast United States.

Conclusion

In conclusion, this dissertation has demonstrated that the relationship between climate change and influenza activity in the northeast United States is one of great complexities and has demonstrated a moderate correlation between average temperatures in the region and influenza incidence. These findings emphasize the urgency of integrating climate discussions into public health policies and strategic planning and highlight the need for adaptive strategies to diminish the impacts of climate variability on human and environmental health. Additionally, the need for greater course development, more training opportunities, and new educational demands in this complex, multidisciplinary field has been discussed. Despite this study's limitations, such as potential influenza inaccuracies and confounding variables, the results provide a crucial foundation for future research. Further studies should expand on this work by incorporating diverse populations, enhancing data collection methods, and exploring additional environmental factors that can attribute an increase in influenza incidence. Ultimately, understanding the intersectionality between climate change and influenza activity is essential for developing effective public health polices, responses, enhanced surveillance of influenza, and safeguarding communities in an era of changing climate patterns.

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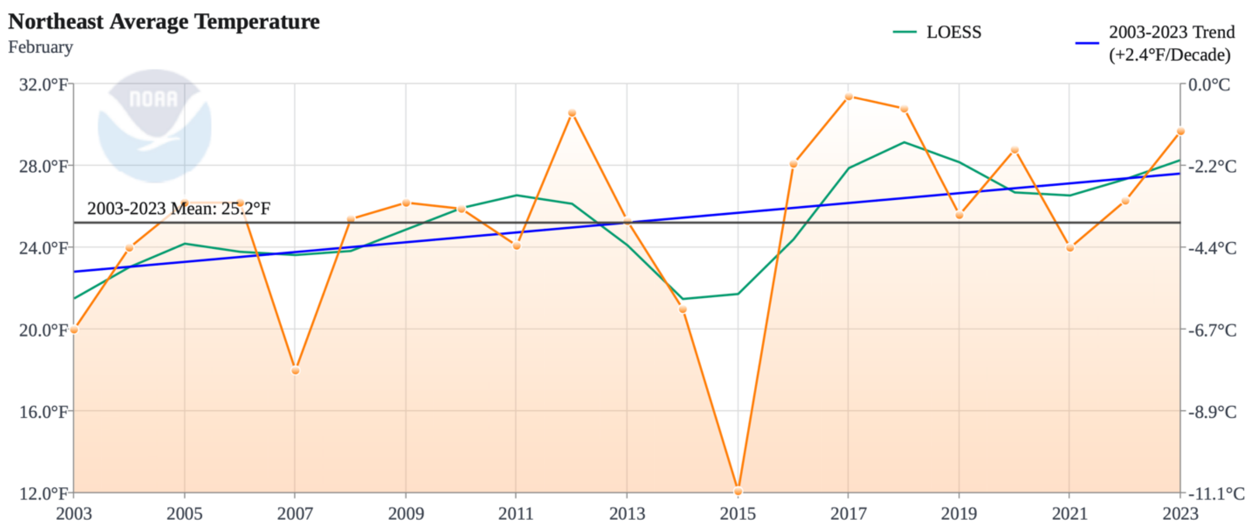
APPENDICES

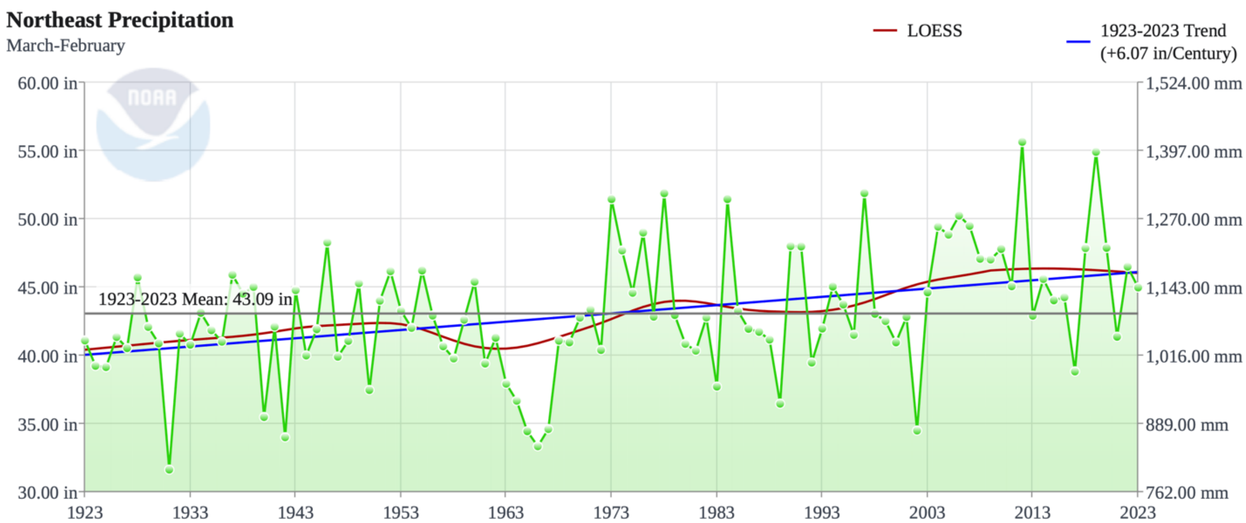
APPENDIX A

Northeast Average Temperature (NOAA, 2024)



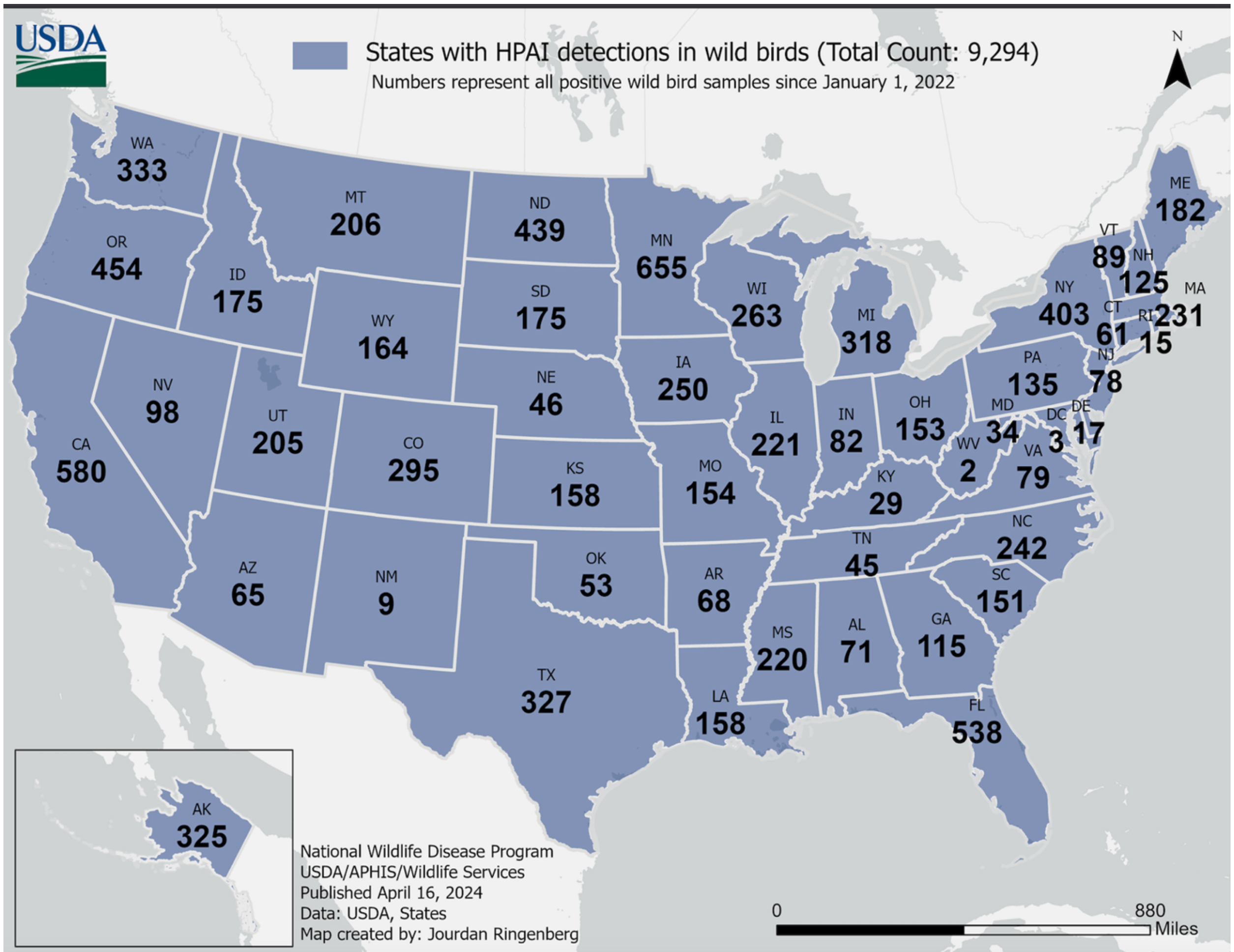
APPENDIX B

Northeast Average Precipitation (NOAA, 2024)



APPENDIX C

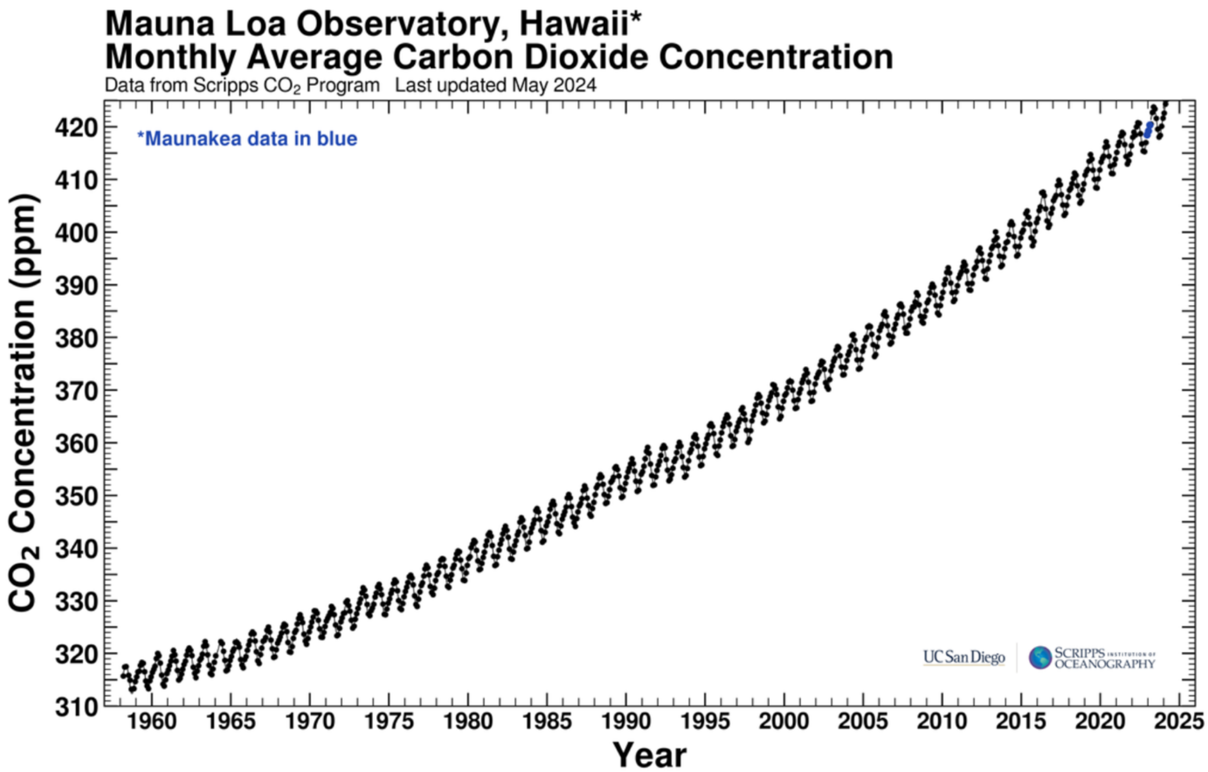
HPAI in Wild Birds Map (USDA, 2024)



APPENDIX D

Keeling Curve Depicting Increase of CO_2 Concentration in PPM from 1958 through 2024

(Scripps Institution of Oceanography, 2024)



APPENDIX E

IRB APPROVAL

Date: 1-15-2024

IRB #: IRB-FY23-24-653
Title: Exploring the correlation between climate change and influenza activity in the northeast United States, 1970 - 2020
Creation Date: 10-18-2023
End Date:
Status: Approved
Principal Investigator: Emily Posadas
Review Board: Research Ethics Office
Sponsor:

Study History

Submission Type Initial	Review Type Exempt	Decision No Human Subjects Research

Key Study Contacts

Member Matthew Ingle	Role Co-Principal Investigator	Contact [redacted]
Member Emily Posadas	Role Principal Investigator	Contact
Member Emily Posadas	Role Primary Contact	Contact

APPENDIX F

IRB AMENDMENT FOR STUDY TIME SPAN

From: Posadas, Emily [redacted]
Sent: Friday, April 19, 2024 10:11 AM
To: IRB, IRB <IRB@liberty.edu>
Cc: Ingle, Matthew E [redacted]
Subject: Re: Cayuse IRB Access

Good morning,

I am a PhD candidate currently wrapping up my Dissertation II course (HSCI 988). I received IRB approval for my dissertation study on October 18, 2023. As my project has developed, I realized that I am not able to collect retrospective influenza data going as far back as 1970, for the northeast United States. I can, however, collect data going as far back as 2003. Therefore, the title of my dissertation will change from: "Exploring the correlation between climate change and influenza activity in the northeast United States, 1970-2020" to "Exploring the correlation between climate change and influenza activity in the northeast United States, 2003-2023."

Because I am eliminating 33 years of potential influenza and climate data and because the title of my dissertation has changed to reflect that, is there anything that I need to do with respect to an IRB amendment? I am not using human subjects nor am I using personally identifiable information; I am only using average temperatures and precipitation for the climate data, and influenza case-counts (raw numbers) for influenza data.

I appreciate your time and advise.

Respectfully,

APPENDIX G

IRB RESPONSE

From: **IRB, IRB** IRB@liberty.edu
Subject: RE: Cayuse IRB Access
Date: April 19, 2024 at 5:06 PM
To: Posadas, Emily [redacted]
Cc: Ingle, Matthew E mingle3@liberty.edu, IRB, IRB IRB@liberty.edu

Good morning, Emily,

Thank you for your email! Since your study was approved as "No Human Subjects' Research," there are no further steps you need to take with the IRB. We hope this information is helpful. Thank you!

Sincerely,

Emily J. Brubaker
Research Coordinator
Office of Research Ethics

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